Figure 2.4-2b

Geology of the Madrid Deposit Area Legend

ERM

Proterozoic

Lamprophyre (minette) dyke; pre-dates 1267 Ma

Goulburn Supergroup - Burnside Formation (ca. 1.9 Ga); alluvial siliciclastic rocks dominated by quartzite, sandstone, conglomerate, and siltstone with minor gabbro/diabase sills and dykes

Diabase dykes and sills; various ages
- Franklin diabase (ca. 723 Ma)
- Mackenzie diabase (ca. 1,267 Ma)
- Brichta diabase (ca. 2.2 - 2.1 Ga)
- unsubdivided diabase dykes

Archean

"Late"mafic intrusive rocks. Subdivisions indicated by suffix: a = gabbro; d = diorite; f = feldspar-phyric; h = hornblende-phyric; l = locally xenolithic; m = magnetite-bearing; y = amygdaloidal/vesicular

Xenolithic mafic intrusions. Subdivisions indicated by suffix: a = gabbro; d = diorite; h = hornblende-phyric; b =fine-to-medium-grained dyke; w ="Wog Suite"(variably magneticfine-grained diorite, commonly with epidote +/- hematite) & similar rocks

Gabbro or diorite with demonstrable or inferred"B-type"geochemical affinity (Al203/TiO2 = 5.5 - 11); enhanced magnetism common

"Late"granitoids - multiphase, foliation typiclly moderate to absent. Subdivisions indicated by suffix: a = granite; b = granodiorite; c = tonalite; d = monzonite and quartz monzonite; e = monzodiorite and quartz monzodiorite; h = diorite and quartz diorite; p = porphyritic; q = quartz-phyric; f = feldspar-phyric; m = magnetite-bearing; l = xenolithic; t = with extensive supracrustal rafts (transitional zone)

Syenite and allied alkaline rocks; quartz-undersaturated; generally massive & unfoliated; uncertain age (may be Proterozoic)

"Early"granitoids - multiphase, commonly well foliated. Subdivisions indicated by suffix: a = granite; b = granodiorite; c = tonalite; d = monzonite and quartz monzonite; e = monzodiorite and quartz monzodiorite; h = diorite and quartz diorite; p = porphyritic; q = quartz-phyric; f = feldspar-phyric; m = magnetite-bearing; l = xenolithic; t = with extensive supracrustal rafts; l =fine-grained rock of possible extrusive origin

Mafic granitoids dominated by diorite and quartz diorite, with lesser tonalite, trondjhemite and granodiorite; enhanced magnetism common

Migmatite suite: heterogeneous, variably foliated tonalite, granodiorite and quartz diorite, with abundant amphibolite zones; migmatitic and gneissic textures common; in part, paragneiss

Ultramafic intrusions ("early"= 7u or"late"= 10u). Subdivisions indicated by suffix: u = composition not specified; o = pyroxenite; h = anorthosite; r = peridotite; m = magnetite-bearing

"Early"mafic intrusive rocks (mainly synvolcanic). Subdivisions indicated by suffix: a = gabro; b = leucogabbro; c = melanogabbro; d = diorite; m = magnetite-bearing; h = anorthosite; u = ultramafic components; r = peridotite; o = pyroxenite; f = feldspar-phyric; g = with feldspar glomerocrysts; t = mixed amphibolite, gabbro & granitoids; l = xenolithic; l =fine-grained rock of possible extrusive origin

Gabbro or diorite with demonstrable or inferred"C-type"geochemical affinity (Al203/TiO2>11)

Gabbro or diorite with demonstrable or inferred"B-type"geochemical affinity (Al203/TiO2 = 5.5 - 11); enhanced magnetism common

Gabbro or diorite with demonstrable or inferred"A-type"geochemical affinity (Al203/TiO2< 5.5); enhanced magnetism common

"Late"sedimentary rocks - primarily offluvial or shallow marine facies (post volcanic)
- Conglomerate; suffix o = polymictic
- Argillite - arenite series; subdivisions indicated by suffix: a = argillite; b = siltstone; c = arenite; d = conglomerate; l = lithic arenite; f = feldspathic arenite; q = quartzose arenite
- Primary carbonate rocks: dolostone, dololutite, dolostone-siltstone rhythimites, carbonaceous siliciclastic rocks, limestone/marble

"Early sedimentary rocks of the wacke-mudstone facies (primarily syn- to post-volcanic; commonly turbiditic). Subdivisions indicated by suffix: a = argillite; b = siltstone; c = wacke/arenite; d = conglomerate; g = iron formation; f = feldspathic wacke; q = quartzose wacke; m = magnetite- bearing; s = metasedimentary schist; v = volcanic sandstone and conglomerate; t = with extensive granitoid intrusions

Primary carbonate rocks: dolostone, dololutite, dolostone-siltstone rhythmites, carbonaceous siliciclastic rocks, limestone/marble

Volcanogenic sedimentary rocks: transitional or interlayered resedimented dacitic volcaniclastic rocks and wacke-mudstone sequences. Subdivisions indicated by suffix: a = argillite; b = siltstone; c = wacke; d = conglomerate; o = polymictic; l = lithic wacke

Felsic (rhyolitic) volcanic rocks. Subdivisions indicated by suffix: a =flow; b = tuff; c = lapillistone; d = breccia; e = amphibolite metamorphic facies; f = feldspar-phyric; j = sandstone to conglomerate; o = heterolthic fragmental rock; q = quartz-phyric; s = quartz-sericite schist; y = amygdaloidal/vesicular; n = thin-bedded; t = with extensive granitoid intrusions; l = transitional to hypabyssal intrusive rocks

Dacitic to rhyodacitic volcanic rocks/ Subdivisons indicated by suffix: a =flow; b = tuff; c = lapillistone; d = breccia; e = amphibolite metamorphic facies; f = feldspar-phyric; j = sandstone to conglomerate; o = heterolithic framental rock; q = quartz-phyric; s = quartz-sericite schist; y = amygdaloidal/vesicular; n = thin-bedded; t = with extensive granitoid intrusions; l = transitional to hypabyssal intrusive rocks

Andesitic volcanic rocks - (may include some bleached mafic volcanic rocks). Subdivisions indicated by suffix: a = massiveflow; p = pillowedflow; b = tuff c = lapillistone; d = breccia; e = hornblende-bearing (amphibolite facies); f = feldspar-phyric; g = with interflow iron formation; j = with interflow sedimentary rocks; m = magnetite +/- ilmenite bearing; s = chloritic schist; v = variolitic; y = amygdaloidal/vesicular

Mafic to intermediate volcaniclastic rocks. Subdivisions indicated by suffix: a = argillaceous zones; b = tuff; c = lapillistone; d = breccia; e = amphibolite metamorphic facies; m = magnetite-ilmenite bearing; o = heterolithic fragmental rock; q = quartz-crystal bearing

Mafic volcanic rocks - primarily of tholeiitic basalt to basaltic andesite composition. Subdivisions for all subsets of Unit 1 indicated by suffix: a = massiveflow; p = pillowedflow; b = tuff; c = lapillistone; d = breccia; e = hornblende-bearing (amphibolite facies); f = feldspar-phyric; g = with interflow iron formation; j = with interflow sedimentary rocks; m = magnetite +/- ilmenite bearing; s = chloritic schist; v = variolitic; y = amygdaloidal/vesicular; x = spinifex textured; u = ultramafic composition locally; t = with extensive granitoid intrusions; l = transitional to hypabyssal intrusions. May include abundant synvolcanic gabbro. Primarily with "C-type"geochemistry (Al203/TiO2 > 11), but locally with intercalations of"B-type" and"A-type"tholeiites
- Broad area dominated by varioliticflows
- Fine-grained ultramafic rocks of presumed extrusive origin; pillows and varioles locally recognizable
- Interflow sedimentary rocks of mappable thickness: chert, jasper, iron formation, argillite, arenite
- Hornblende-bearing volcanic rocks (amphibolite or"transition zone"metamorphic conditions); primary structures commonly obscured; locally"layered"or thinly laminated
- Transitional zone with abundant granitoid intrusions

Fe- andTi- enriched tholeiites ("B-Type") and associated gabbro; commonly magnetite-bearing;Al203/TiO2 = 5.5 - 11

Fe- andTi- enriched andAl-depleted tholeiites ("A-Type") and associated gabbro; commonly magnetite-bearing;Al203/TiO2 < 5.5

Deformation Zone: complex cataclastic and alteration zone hosting Madrid group of deposits (syn-volcanic?)

Source: Newmont, 2012.

North of the Madrid Deformation Zone, the Wolverine volcanic suite is composed of a series of coalesced variolitic pillowed flows and subordinate flow breccia. The suite exhibits weak to moderate strain and is overprinted by a predominantly chlorite-calcite alteration assemblage. The suite may also be locally unstrained to strongly strained and intensely (sericite-dolomite) altered (TMAC 2013).

As mentioned earlier, the Madrid Deformation Zone is an east-west trending to north-south trending corridor of intense strain and alteration. The Madrid Deformation Zone represents the contact between the Wolverine and Patch groups near the western shore of Patch Lake and through the east-west oriented valley between Windy and Patch lakes. Four lithologies have been truncated and entrained in this high strain-alteration zone: the Wolverine volcanic rocks, Wolverine porphyry, quartz-feldspar phyric porphyry, argillaceous sedimentary rocks, and Patch Group A-type volcanic rocks (TMAC 2013).

The volcanic rocks of the Madrid Deformation Zone are defined as strongly foliated (schistose) with domains of dolomite and millimetre-wide bands of sericite that define the foliation. Within the Madrid Deformation Zone, the Wolverine porphyry occurs as salmon pink to beige coloured segregations, which are also affected by and demonstrate the pervasive foliation (TMAC 2013).

The Patch Group volcanic suite is composed of a series of flows which grade from aphanitic, massive basal flows exhibiting poorly formed, small rubble pillows to flow top breccias, capped by argillaceous interflow sediments. Gabbroic intrusive phases are rarely present, and where present, are found near the bottom of flows. Some of the flows to the east are variolitic and their occurrence is correlated with that of ultramafics and “melanocratic” basalts (TMAC 2013).

Patch Group volcanics are characteristically A-type volcanic rocks with rare horizons of Btype. At Suluk, variolitic phases are olivine green, fine grained, chloritized basalt with discontinuous variolitic texture. Variolites are ovoid to round and are typically less than a few centimetres in size but generally larger than varioles seen in the Wolverine basalts (TMAC 2013).

2.4.3 Mineralization of Madrid Area

The gold mineralization within Madrid trend includes the Naartok West, Naartok East, Rand Suluk, and Patch 14 zones. These zones consist of quartz-carbonate stockwork veining, which overprints dolomite-sericite-albitepyrite altered mafic volcanic rocks of the Patch Group. The gold mineralization is characterized by multi-stage brecciation and alteration with at least two separate gold mineralization events. Gold occurs within north-northeast, east, southeast, and north-northwest trending brecciated and carbonate altered zones and is associated with disseminated pyrite which has replaced brecciated mafic fragments.

The Patch 14 zone, which is the focus of the Madrid South Bulk Sample, is located adjacent to the Madrid Deformation Zone approximately four kilometres south of the Suluk zone. Gold mineralization is hosted within a zone of moderately to strongly carbonate-sericite altered mafic volcanic rocks and narrow intermediate porphyry dykes (Wolverine porphyry dykes). This moderately to intensely strained zone is wedged between two wider (±20 m), thick dykes of porphyry. Mineralization occurs as visible gold and disseminated pyrite hosted within massive bull quartz and quartz-carbonate veins. At least three sub-parallel veins have been identified which exhibit a north-south strike and steep (80°) dip to the west.

The West Vein is the most significant structure at Patch 14 and has been traced discontinuously along strike for 400 m. However, the mineralized portion has only about a 100 m strike extent. The East Vein extends for approximately 80 m along strike but has much less vertical extent. Mineralization is open down a steep southerly plunge (about 70°) and along strike at the depth. Drilling to a depth of 300 m below the bottom of Patch Lake has intersected multiple veins and gold mineralization. The main quartz lenses appear to be steep, southerly plunging bodies that appear to be open at depth.

2.4.4 Geochemical Characterization

SRK (2009) contains complete details pertaining to geochemical characterization of the Doris-Windy All-Weather Road Quarries confirming the suitability of these quarries for use in construction.

A geochemical characterization program for proposed Quarry G and H was conducted in summer 2010 (SRK 2014). Using a backpack-type drill, for each quarry, the program consisted of obtaining shallow drill core samples across the strike of the geology, with the objective of examining geochemical variability according to lithology and/or sample location. For Quarry H, two drillholes were located in overburden to determine the recessive geology. A total of 36 samples were analyzed for elemental analysis by aqua regia digestion with ICP finish and acid-base accounting (ABA) parameters, including paste pH, total sulphur, sulphate sulphur, total inorganic carbon (TIC) and modified NP. Based on this geochemical characterization program, the material from Quarry G and H was considered to have a low potential for ARD generation based on NP/AP ratios and low sulphur content. Accordingly, materials from these quarries are suitable to be used as construction material for the road and infrastructure associated with the Madrid Advanced Exploration Program.

2.4.5 Seismicity

The Project is located in the lowest category seismic hazard zone of Canada in accordance with the 2010 National Building Code of Canada (National Research Council Canada 2011); the Project area is thus considered relatively stable and not prone to earthquakes. Descriptions relative to seismic hazard that follow pertain primarily to design purposes and project-related risks associated with seismicity hazards.

The seismic hazard, which is considered relatively low for this Project, is described by spectral-acceleration (Sa) values at periods of 0.2, 0.5, 1.0 and 2.0 seconds. Spectral acceleration is a measure of ground motion that takes into account the sustained shaking energy at a particular period. This is a better measure of potential damage than the peak measures used by the 1995 code; however, Peak Ground Acceleration (PGA) still needs to be used for foundation design.

Site specific ground motion probability values provided in Table 2.4-1 are expressed in terms of probable exceedance, that is the likelihood of a given horizontal acceleration or velocity being exceeded during a particular period. The probability used is 0.000404 per annum, equivalent to a 2% probability of exceedance over 50 years. This means that over a 50-year period there is a 2% chance of an earthquake causing ground motion greater than the given expected value (SRK 2011b).

Table 2.4-1. Project Specific Seismic Hazard Values

Spectral Acceleration (Sa; s)	Ground Motion (*g*)
Sa (0.2)	0.095
Sa (0.5)	0.057
Sa (1.0)	0.026
Sa (2.0)	0.008
PGA	0.036

Note:
1 g (acceleration due to Earth's gravity, equivalent to g-force) = 9.81 m/s^2

2.4.6 Permafrost and Permafrost-related Features

Permafrost characteristics are discussed in (SRK 2011b) and are summarized below.

Surficial geotechnical investigations across the entire Hope Bay Belt confirm that the site is within the region of continuous permafrost. Thermistor strings were installed during site investigations in 1997, 2004, and 2008. Regular temperature measurements obtained from these thermistor strings have been used to characterise subsurface temperature and permafrost conditions.

Mean near-surface ground temperatures are approximately -8°C, with seasonal variability. The active layer is generally less than 1 m thick in morainal sediments, but is expected to vary considerably with surficial geology and may be as much as 5 m deep in coarse sediments such as glaciofluvials.

Thermistor string records indicate the depth of zero amplitude (i.e., the point at which there is no discernable change in temperature) is approximately 10 m below grade. Based on data from deep (200 m) thermistors, the basal permafrost depth is estimated to be greater than 500 m (SRK 2009). A basal cryopeg layer, where flowing groundwater is present at temperatures below 0°C, is expected to be present in the deep permafrost due to the measured salinity of the groundwater (discussed further in Section 2.4.8).

Taliks (unfrozen ground in the otherwise continuous permafrost) are expected to be present beneath current and pre-existing surface water features. Open taliks (talik connected with ground surface) are expected beneath existing lakes with depths greater than two-thirds of the mean annual lake ice thickness. More extensive open taliks are expected to be present beneath larger lakes. Closed taliks (bounded by permafrost on all sides) are expected to be present beneath ancient surface water bodies that have not sustained significant surface water for more than two years. Through taliks (connected with ground surface and the unfrozen ground beneath the permafrost) are expected to be present beneath existing very large lakes.

Patterned ground, usually consisting of surface drainage rills, masks the underlying soils. Small, frost-heaved clay-silt polygons are very common. Linear frost cracks are noted in raised marine spit deposits. Ice wedge polygons are common in muskegs. There is also evidence of naturally degrading permafrost in the Project area. Permafrost degradation can also be attributed to past human activity such as exploration drilling and transportation corridors (Thurber Engineering Ltd. 2003).

2.4.7 Groundwater

In general, groundwater flow in the Hope Bay Belt region is controlled by topography, the distribution of hydraulic conductivity, and permafrost extents. From a regional perspective, topography slopes gently towards the ocean in the north, with local variability. The regional groundwater flow direction is inferred to be roughly south to north, aligned with regional topography (HBML 2011).

The presence of liquid groundwater is controlled by the extents of subsurface freezing conditions (permafrost). As discussed in Section 2.4-6, permafrost is continuous from approximately 1 m below surface to approximately 500 m, except where taliks are present. *Open taliks* exist beneath surface water bodies whereas *through taliks* exist beneath very large surface water bodies. Flowing groundwater does not exist within the permafrost, except where salinity depresses its freezing temperature. Thus, flowing groundwater is present in pore spaces in the active layer (summer only), in taliks, beneath the permafrost, and in cryopegs (liquid groundwater within the permafrost exhibiting a freezing temperature below 0°C).

Groundwater quantity and quality characterization for the Doris, Madrid and Boston areas were completed as part of a combined geotechnical and hydrogeological study. These included installation of three Westbay monitoring systems in 2010 (Doris North, Doris Central, Boston), and down-hole packer testing (including 39 at the Madrid South deposit).

The measured range of hydraulic conductivity in the bedrock at the Madrid South area is 2.7×10^{-9} m/s to 5.5×10^{-9} m/s with a mean value of 3.3×10^{-9} m/s. Hydrogeological field investigations have not yet been conducted at Madrid North, though results are expected to be similar to those at Madrid South due to the similar geologic and permafrost conditions.

Groundwater in the active layer only flows during months with thawed surface conditions (generally June to September).

Groundwater beneath the permafrost moves under hydraulic gradients dictated by lakes overlying through taliks. Hydraulic conductivity is expected to be low, as indicated by packer testing. Pore pressure measured beneath the permafrost indicates a piezometric surface close to ground surface, indicating the permafrost behaves as a confining unit (HBML 2011).

All of the bedrock lithologies within the Hope Bay Belt region appear to have very low primary porosity, indicating that hydraulic conductivity is controlled by the presence and nature of joint sets and fault zones. Lithology is interpreted to exert indirect control on hydraulic conductivity by affecting the presence and/or characteristics of fractures or structures. Available data indicates a tendency for hydraulic conductivity to decrease with depth (HBML 2011).

2.4.8 Groundwater Quality

Groundwater within the Madrid Advanced Exploration Program area has been identified as saline, with a salinity (total dissolved solids) content similar to seawater (Roscoe Postle Associates Inc. 2013).

Groundwater chemistry within the Madrid Advanced Exploration Program area is inferred to be similar to that of the Doris Lower area, due to similarity in geologic and permafrost controls. The deep groundwater samples expected to best represent with groundwater conditions at Madrid were collected at well 10WBW001 in Doris Central (Zone 1), the deepest sampling port at a depth of 485 m below surface (SRK 2011a).

The groundwater collected from the deepest zone at the Doris Central Westbay (Table 2.4-2) can be characterized as follows:

- calcium, sodium, and chloride were the dominant ions;
- the groundwater may be regarded as saline, with a TDS of 41,000 mg/L;
- the majority of total metals had concentrations below detection limits; and
- detected trace metals included cobalt, copper, iron, manganese, molybdenum, nickel, and zinc.

Table 2.4-2. Summary of Groundwater Quality Data for Doris Central Westbay Zone 1

Parameter	Unit	10WBW001-Zone1 (548 m) 6-Apr-2011
pH	pH	7.1
Total Dissolved Solids	mg/L	41,000
Alkalinity (as $CaCO_3$)	mg/L	2.7
Chloride (Cl)	mg/L	19,000
Sulfate (SO_4)	mg/L	940
Bicarbonate (HCO_3)	mg/L	-

(continued)

Table 2.4-2. Summary of Groundwater Quality Data for Doris Central Westbay Zone 1 (completed)

Parameter	Unit	10WBW001-Zone1 (548 m) 6-Apr-2011
Dissolved Metals		
Aluminum (Al)	mg/L	<0.005
Arsenic (As)	mg/L	<0.002
Cadmium (Cd)	mg/L	<0.00005
Calcium (Ca)	mg/L	4,800
Chromium (Cr)	mg/L	<0.0005
Cobalt (Co)	mg/L	0.000059
Copper (Cu)	mg/L	0.00083
Iron (Fe)	mg/L	0.034
Lead (Pb)	mg/L	<0.0003
Magnesium (Mg)	mg/L	71
Manganese (Mn)	mg/L	0.73
Mercury (Hg)	mg/L	<0.00001
Molybdenum (Mo)	mg/L	0.011
Nickel (Ni)	mg/L	0.0016
Potassium (K)	mg/L	39
Selenium (Se)	mg/L	<0.002
Sodium (Na)	mg/L	7,000
Zinc (Zn)	mg/L	0.16

2.5 SURFACE WATER

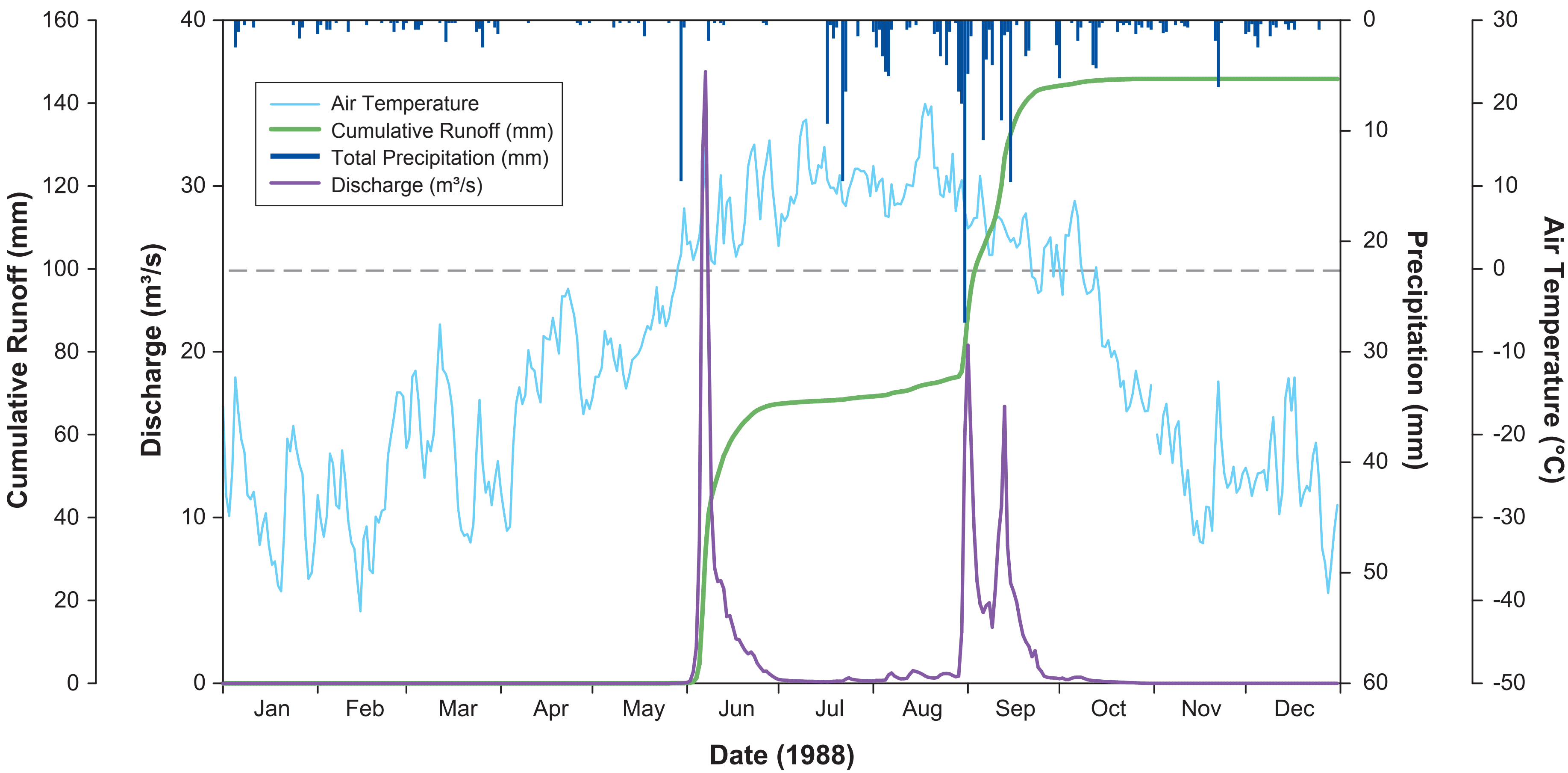
2.5.1 Hydrology

2.5.1.1 Regional Hydrologic Regime

Hydrometeorologic data from a typical Arctic nival stream (Atitok Creek near Dismal Lake, Water Survey of Canada station 10PC002) and weather station (Kugluktuk A, Meteorological Service of Canada station 2300902) are displayed on Figure 2.5-1. The monitoring station at Atitok Creek is located approximately 440 km west-southwest of the Madrid Area. Although the Atitok Creek station is a substantial distance from the Madrid project area, the two sites are influenced by similar climate, and their watersheds have physiographic similarities which result in comparable hydrologic regimes. Also, at 270 km^2 Atitok Creek is a relatively small watershed by WSC standards, making its hydrologic regime similar to the regime in Madrid project area watersheds.

Rivers in the Hope Bay belt area have stream flow typical of the Arctic nival regime (Church 1974). The long and severe Arctic winter, and brief time when air temperatures are above freezing, limit surface water activity to a short period. Surface water flow typically begins in late May or early June, and rapidly rises to peak annual flow by early- to mid-June. Snow that accumulated over the long winter is usually the dominant contributor of water to stream flow on an annual basis. Shortly after air temperature rises above freezing, the snow melts rapidly.

Figure 2.5-1
A Typical Example of Discharge and Runoff in an Arctic Nival River (Atitok Creek near Dismal Lake, 1988), with Air Temperature and Precipitation



After the snowmelt-fed freshet, stream flow steadily decreases to a summertime minimum, which typically occurs in August. Due to the presence of permafrost, there is limited groundwater supply to smaller streams; however, there may be interaction between groundwater systems and larger rivers and/or lakes through taliks. Autumn rain events often augment stream flow (Figure 2.5-1). Although snowmelt is typically responsible for the majority of runoff in most years, this may not be the case in exceptionally rainy seasons. In October, air temperature normally dips below freezing, precipitation begins to fall as snow, and stream flow ceases for the winter except in rivers with very large watersheds. Based on the results of hydrometric monitoring in the Project area, all monitored streams freeze solid in the winter with the exception of the Koignuk River, which retains under-ice liquid water in isolated pools separated by frozen sections of the river (Rescan 2009b, 2011i). However, no under-ice flow has been measured in the Koignuk River.

Lakes are common in the region. Runoff is stored in lakes and gradually released, attenuating hydrologic events that would otherwise cause a rapid response in stream flows, such as the nival peak flood and responses to precipitation events. Evaporation from lake surfaces is more efficient than evaporation from tundra, so runoff is generally lower in watersheds with extensive open water.

2.5.1.2 Watersheds in the Project Area

The northern portion of the Hope Bay Belt (Doris and Madrid areas) consists of two main watersheds: Windy-Glenn (48 km^2) and Doris-Roberts (194 km^2). Both of these watersheds drain north into Roberts Bay (Figure 2.5-2). A topographic drainage divide separates the Windy-Glenn watershed from the Koignuk River watershed (2,937 km^2; not pictured), which encompasses the southern portion of the belt (Boston area) and drains into Hope Bay to the west of Roberts Bay. The Madrid South bulk sample site and the Doris North Project are located in the Doris-Roberts watershed, whereas the Madrid North bulk sample site is located in the in the Windy-Glenn watershed.

2.5.1.3 Hydrometric Monitoring in the Project Area

Numerous hydrometric stations have been installed and operated throughout the Hope Bay Belt since the mid-1990s. Multiple years of data are available for many of the major lake drainage outlets within the Doris and Madrid areas. Hydrometric monitoring in the belt began in 1993 at several sites where stream flow and water levels were manually measured. Automated hydrometric monitoring began in 1996 and has continued to the present, although the size of the monitoring network has varied over time to accommodate changes in project scope.

Hydrometric monitoring in the Madrid Area has included lake level monitoring at Wolverine, Patch, and Windy lakes, and discharge measurements at the lake outlets. Monitoring stations Wolverine Hydro, Patch Hydro, and Windy Hydro are pictured in Figure 2.5-3 and summarized in Table 2.5-1. Monitoring was initiated in 2006 at all three lakes and continued until 2011 at Wolverine and Patch lakes. Monitoring at Windy Lake has continued to the present; the most recent data available are from 2013. Baseline results from 2009 to present are summarized below. Data prior to 2009 are included in the *Doris Project Area 2008 Hydrology Baseline Update Report* (Golder 2009c).

Streams in the Madrid Area generally have low gradients and low bank slopes. Lakes may drain through channelized, permanent outlet streams (e.g., Patch Lake and Windy Lake outflows, pictured respectively in Plates 2.5-1 and 2.5-2) or undefined, dispersed, and ephemeral drainages (e.g., Wolverine Lake, pictured in Plate 2.5-3). In defined channels, substrate is generally composed of sand, gravel, and cobbles.

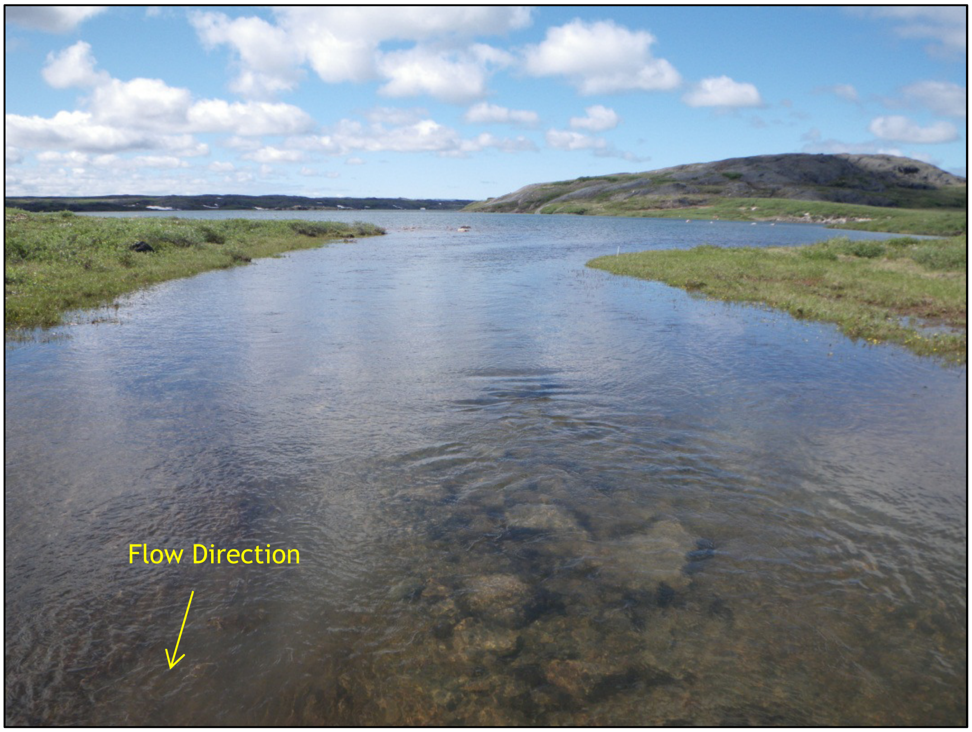


Plate 2.5-1. Patch Lake Outflow Stream. View is upstream (west) towards the lake. Channel width is approximately 10 metres. Photo taken August 23, 2011.

Plate 2.5-2. Windy Lake Outflow Stream. View is upstream (south) towards the lake. Channel width is approximately 1 metre. Photo taken September 8, 2013.

Figure 2.5-2

Main Watersheds in the Doris and Madrid Areas

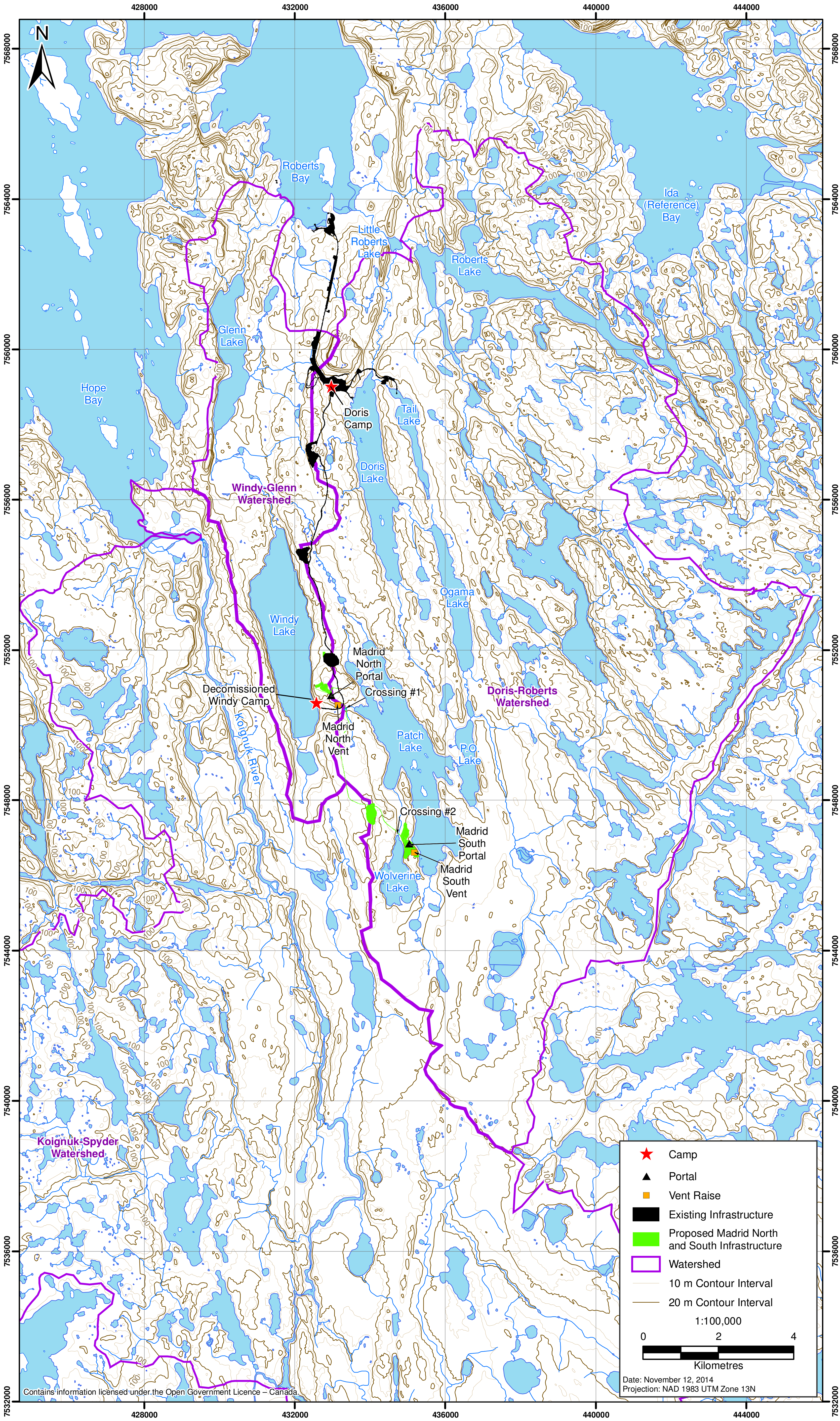


Figure 2.5-3

Hydrometric Monitoring Stations in the Madrid Area

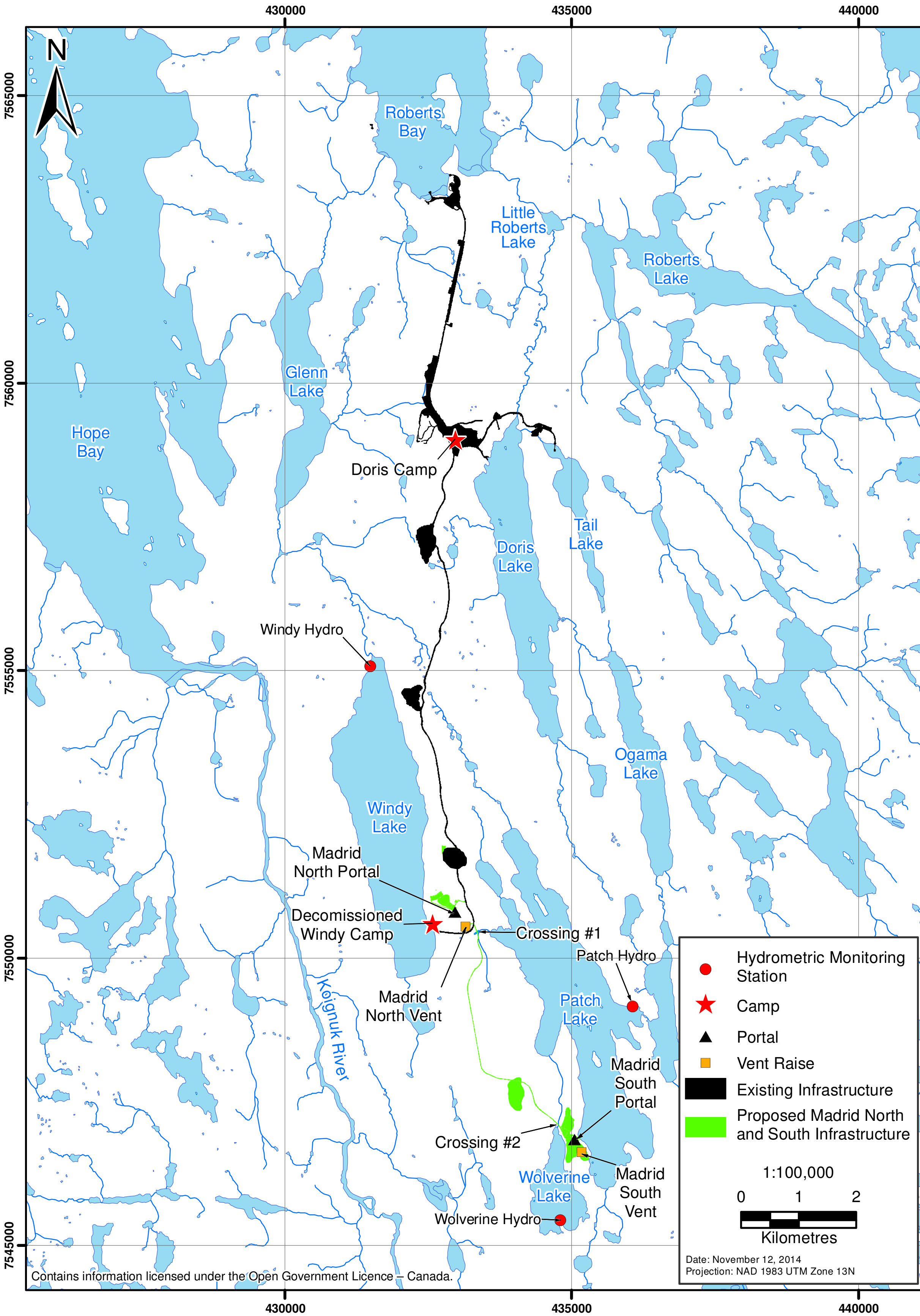


Table 2.5-1. Station and Watershed Information for Automated Hydrometric Monitoring Stations in the Madrid Advanced Exploration Program Area, 2006 to 2013

Station	UTM Coordinates		Drainage Area (km^2)	Lake Area (km^2)	Years of Automated Data Collection
	Easting	Northing			
Wolverine Hydro	434,802	7,545,443	3.0	1.0	2006-2011
Patch Hydro	436,062	7,549,169	32.0	5.7	2006-2011
Windy Hydro	431,481	7,555,089	14.1	5.3	2006-2013

Note: Data from 2006-2008 are available in Golder 2009c.

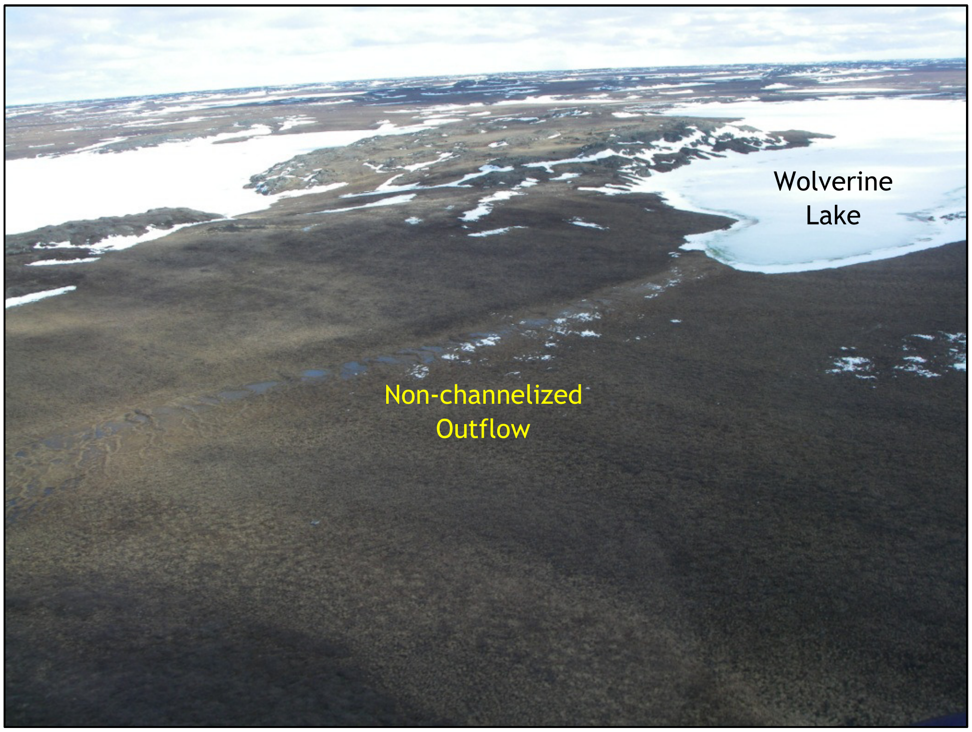


Plate 2.5-3. Southeast side of Wolverine Lake. View is northwest. Note non-channelized water in marsh-like outflow area of lake. Photo taken June 12, 2009.

Prior to construction of the bulk samples and all-weather road, further studies will be undertaken to determine the channel morphology of streams potentially affected by the bulk samples (e.g., roads or other infrastructure). These studies will adhere to methodology and standards of the *British Columbia Channel Assessment Procedure* (BC MOF and BC MFLNRO 1996) or similar guidelines.

During the 2009 to 2011 monitoring period, surface flows were not measured at Wolverine Hydro because no defined outlet channel existed. Negligible amounts of dispersed flow were observed over relatively wide areas with marsh-like features on the north and southeast ends of Wolverine Lake (Plate 2.5-3).

Table 2.5-1 summarizes selected hydrometric indices for the Windy Hydro and Patch Hydro monitoring stations. The streams freeze to the bed in winter; therefore, annual low flows are assumed to be zero. Open water season lake level fluctuation at Wolverine, Patch, and Windy lakes was generally 0.2 to 0.3 m (Tables 2.5-2 and 2.5-3).

Table 2.5-2. Selected Hydrometric Indices for Patch Lake and Windy Lake Outflow Streams (2009 to 2013)

Hydrometric Station	2009	2010	2011	2012	2013	Min	Mean	Max
Observed Total Runoff (mm) [a]								
Patch Hydro	85	88	123	n/d	n/d	85	99	123
Windy Hydro	141	197	143	112	42	42	127	197
Annual Total Runoff (mm) [b]								
Patch Hydro	95	98	175	n/d	n/d	95	123	175
Windy Hydro	168	222	152	118	43	43	141	222
Observed Mean Discharge (m^3/s) [a]								
Patch Hydro	0.32	0.30	0.48	n/d	n/d	0.30	0.37	0.48
Windy Hydro	0.23	0.30	0.26	0.22	0.07	0.07	0.22	0.30
Annual Mean Discharge (m^3/s) [b]								
Patch Hydro	0.10	0.22	0.42	n/d	n/d	0.10	0.25	0.42
Windy Hydro	0.07	0.22	0.19	0.05	0.02	0.02	0.11	0.22
Daily Peak Flow (m^3/s)								
Patch Hydro	0.51	0.55	2.51	n/d	n/d	0.51	1.19	2.51
Windy Hydro	0.34	0.46	0.64	0.36	0.12	0.12	0.38	0.64
Observed Low Flow (m^3/s) [a]								
Patch Hydro	0.17	0.14	0.13	n/d	n/d	0.13	0.15	0.17
Windy Hydro	0.15	0.16	0.11	0.06	0.02	0.02	0.10	0.16

Notes: Site-specific periods of record for historic data are presented in baseline and compliance reports (Rescan 2009b, 2011d, 2011i, 2012d, 2012b; ERM Rescan 2014b).
n/d = No data; the Patch Hydro monitoring station was not active in 2012 and 2013.
[a] *Statistics from the open water season are calculated from recorded values during the periods of station operation.*
[b] *Annual values include estimated data for periods when stations were demobilized over winter.*

Table 2.5-3. Recorded Ranges of Seasonal Lake Levels for 2009 to 2013 Open-water Seasons

	Water Level Change (m)							
Lake	**2009**	**2010**	**2011**	**2012**	**2013**	**Min**	**Mean**	**Max**
Wolverine	0.25	0.24	0.26	n/d	n/d	0.24	0.25	0.26
Patch	0.18	0.30	0.44	n/d	n/d	0.18	0.31	0.44
Windy	0.23	0.10	0.24	0.18	0.10	0.10	0.17	0.24

Notes: Site-specific periods of record for historic data are presented in published baseline and compliance reports (Rescan 2009b, 2011d, 2011i, 2012d, 2012b; ERM Rescan 2014b).
n/d = No data; Wolverine and Patch lake levels were not monitored in 2012 and 2013.

2.5.2 Bathymetry and Limnology

2.5.2.1 Bathymetry

Between 1993 and 2007, systematic bathymetric surveys were conducted across the Hope Bay Belt (HBML 2011). Wolverine, Patch, and Windy lakes are the three major waterbodies in the Madrid Area; all lakes were surveyed for bathymetry in 2006 (Golder 2006a). Physical properties of the lakes measured by the 2006 bathymetric surveys are provided in Table 2.5-4.

Table 2.5-4. Physical Properties of Wolverine, Patch, and Windy Lakes, 2006

Lake	Lake Area (km^2)	Volume (m^3)	Maximum Depth (m)	Mean Depth (m)	Fetch (m)	Maximum Width (m)	Shoreline Length (m)
Wolverine Lake	1.0	2.1×10^6	4.7	2.1	1,875	980	6,146
Patch Lake	5.7	23.6×10^6	15.1	4.1	6,470	1,175	23,013
Windy Lake	5.3	59.1×10^6	21.2	n/a	n/a	n/a	n/a

Notes: Data for Wolverine and Patch lakes from Golder (Golder 2006a, 2009c).
Data for Windy Lake from Golder (2006b) and Rescan (2013).
n/a = data not available

Wolverine Lake (Figure 2.5-4), the southernmost of the major lakes in the Madrid Area, is located to the southwest of Patch Lake (Figure 2.5-5). Wolverine Lake is relatively small and shallow, with a maximum depth of approximately 4.7 m and an area of 1.0 km^2 (Table 2.5-4). Wolverine Lake drains into Patch Lake via a non-channelized, marshy area (Plate 1.2-6). Measurable flow has only been observed in the Wolverine Lake outflow during spring snow melt or heavy rain events (Golder 2009e); (Rescan 2012d). Patch Lake (Figure 2.5-5) is both deeper and larger than Wolverine Lake. The Patch Lake outflow is short (<200 m), and is located on the east shore, where it empties directly into P.O. Lake. Windy Lake is the largest of the three lakes by volume and is also the deepest reaching depths upwards of 21.2 m (Table 2.5-4; Figure 2.5-6).

2.5.2.2 Limnology

Physical limnology characteristics are available for Madrid Area lakes from 1995 to 1998, 2007, 2009, and 2010 (Table 1.1-1; Figure 2.5-7). Physical profiles were collected during the ice-covered season and/or the open-water season. A comprehensive baseline sampling program was conducted in the Madrid Area in 2009 (Rescan 2010f, 2011g).

Profiles of winter dissolved oxygen concentrations and temperatures were typical of ice-covered Arctic lakes. In April/May 2009, the ice cover was approximately 2 m thick on all lakes, and water temperatures were coldest just below the ice (0.2 to 0.8°C). In deep lakes, temperature gradually warmed with depth to maximum temperatures of approximately 2°C near the water-sediment interface. Dissolved oxygen concentrations were highest near the water-ice interface, averaging 13.0 mg/L, and gradually declined with depth. Bottom waters in some lakes (e.g., Ogama and Wolverine lakes) were nearly anoxic (≤ 1 mg/L dissolved oxygen; Rescan 2010f, 2011g).

Profiles of dissolved oxygen concentrations and temperatures during the open-water season were also typical of Arctic lakes. The lakes in the area mix fully at least two times per year: during ice breakup in the spring and during periods of high winds and low temperatures in the autumn just prior to freeze-up. In addition, the lakes around the Madrid Area are shallow enough to become fully mixed during the summer, depending on wind and temperature conditions. In August 2009, even the deepest lakes surveyed tended to be well mixed or weakly stratified. Water temperatures ranged from 8°C to 13°C. Dissolved oxygen concentrations were generally saturated to super-saturated, and remained relatively constant throughout the water column (Rescan 2010f, 2011g).

The Canadian Council of Ministers of the Environment (CCME) has established guideline oxygen concentrations for the protection of (cold-water) aquatic life of 9.5 mg/L for early life stages and 6.5 mg/L for other life stages (CCME 1999). Most lakes had dissolved oxygen concentrations above these guidelines in the upper portions of the water column; however, bottom water concentrations were below guidelines in Wolverine, Ogama, and Windy lakes in the winter and in Patch Lake in the summer. Oxygen concentrations in Wolverine Lake were consistently lower than 6.5 mg/L throughout the water column during winter under-ice sampling.