7.4 Surface Water Hydrology

This Section includes the characterization of stream flow in the creeks and rivers in the vicinity of the Minago Project, including prediction of the magnitude and frequency of occurrence of peak flows (floods) and low flows. Surface water hydrology integrates information on climate (rainfall and snowfall data) (Section 7.1: Climate) and groundwater hydrogeology (Section 7.6: Groundwater), as well as the effects of processes such as snowmelt and evaporation. Understanding the range of natural variability of surface water hydrology is important for project design and for understanding the sensitivity of stream and lake ecosystems to potential project effects.

Potential project effects on hydrologic conditions are evaluated and remediation and mitigation measures are described. The significance and likelihood of residual project and cumulative effects is characterized along with recommended monitoring programs and adaptive management measures. This section describes the effects of routine project activities on hydrology. Effects associated with accidents and malfunctions are discussed in Section 8: Accidents and Malfunctions.

The scope of the surface water assessment, baseline conditions and the estimated impact of the project are detailed in the following sections. Hydrologic processes relevant to the Minago Project are summarized in Appendix 7.4 for readers unfamiliar with this topic.

Introduction to Hydrometric Assessments

The primary hydrologic issue associated with the Minago Project will be how it will affect the flow regimes in Oakley Creek, William River, and Minago River. The Minago Project Site is located within the Nelson River sub-basin, which drains northeast into the southern end of the Hudson Bay (Figures 7.4-1 and 7.4-2). The Minago River and Hargrave River catchments, surrounding the Minago Project Site, occur within the Nelson River sub-basin. The William River and Oakley Creek catchments at or surrounding the Minago Project Site, occur within the Lake Winnipeg sub-basin, which flows northward into the Nelson River sub-basin.

The footprint of the mine and surface facilities will be considerable and will consume some of the wetland and correspondingly reduce its reservoir capacity while increasing the intensity of flood events. Mine development and operation will also involve pumping of significant quantities of groundwater to surface and this will further increase flows in the streams draining the development area.

To assess and quantify the impact of the project on the hydrology of the adjacent streams, a baseline hydrologic study was undertaken to determine the long-term climatic and hydrometric characteristics of the area encompassing the proposed Minago Project development. Water quality sampling was initiated in the project area in 2006, while climate and hydrometric data collection started in 2007.

LEGEND:

N W E S

URS

MAJOR WATERSHEDS SURROUNDING THE MINAGO PROJECT SITE

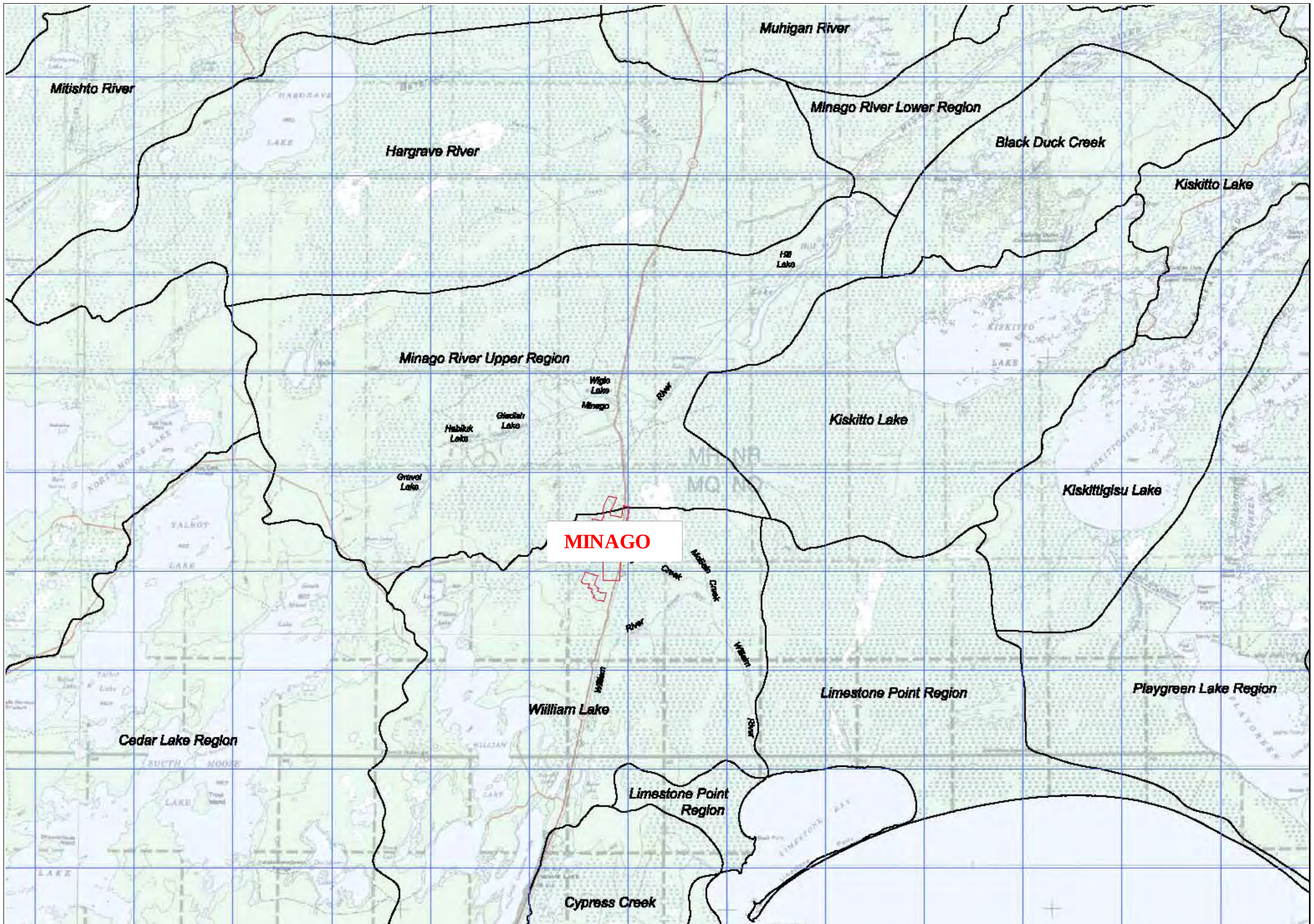
Environmental Baseline Studies
Minago Project, Northern Manitoba

VICTORY NICKEL INC.

DATE:	PROJECT NO.:	DRAWN BY:	REVISION NO.:	DRAWING NO.:
March 2008	39548827	TS	0	

Source: adapted from URS, 2008a

Figure 7.4-1 Regional Hydrological Setting near the Minago Project



Source: adapted from URS, 2008f

Figure 7.4-2 Regional Hydrological Setting near the Minago Project

7.4.1 Scope of Hydrometric Assessment Program

In May 2006, Victory Nickel Inc. initiated a hydrometric monitoring program for the assessment of water quality within local watercourses. Pressure transducers have also been in operation at these stations since July 2007, for the assessment of water levels and streamflow.

Wardrop commenced the surface water hydrology program for the Victory Nickel Minago Project Site (the "Site") in August 2006, which was continued by URS Canada Inc. in 2007 with a widened scope (Wardrop, 2007; URS, 2008a). Starting in September 2007, KR Design Inc. collaborated with URS and VNI and continued hydrological assessements in 2008. In 2008, Golder Associates compiled a comprehensive database of available climatic and hydrologic characteristics for the Minago Project and derived representative hydrometric characteristics for the project area (Golder Associates, 2009).

The objectives of the hydrological assessment program were to:

- establish pre-mining hydrologic baseline conditions for the Minago Project Area;
- provide hydrologic baseline data required to complete an Environmental Impact Assessment of the Minago Project under the Manitoba *Environmental Assessment Act*;
- provide hydrologic baseline data required to complete bankable Feasibility Study on the Minago Project; and
- provide hydrologic baseline data for water quality modeling, engineering design, water management and determining impacts to aquatic resources.

7.4.1.1 Scope of Hydrometric Assessments conducted in 2006

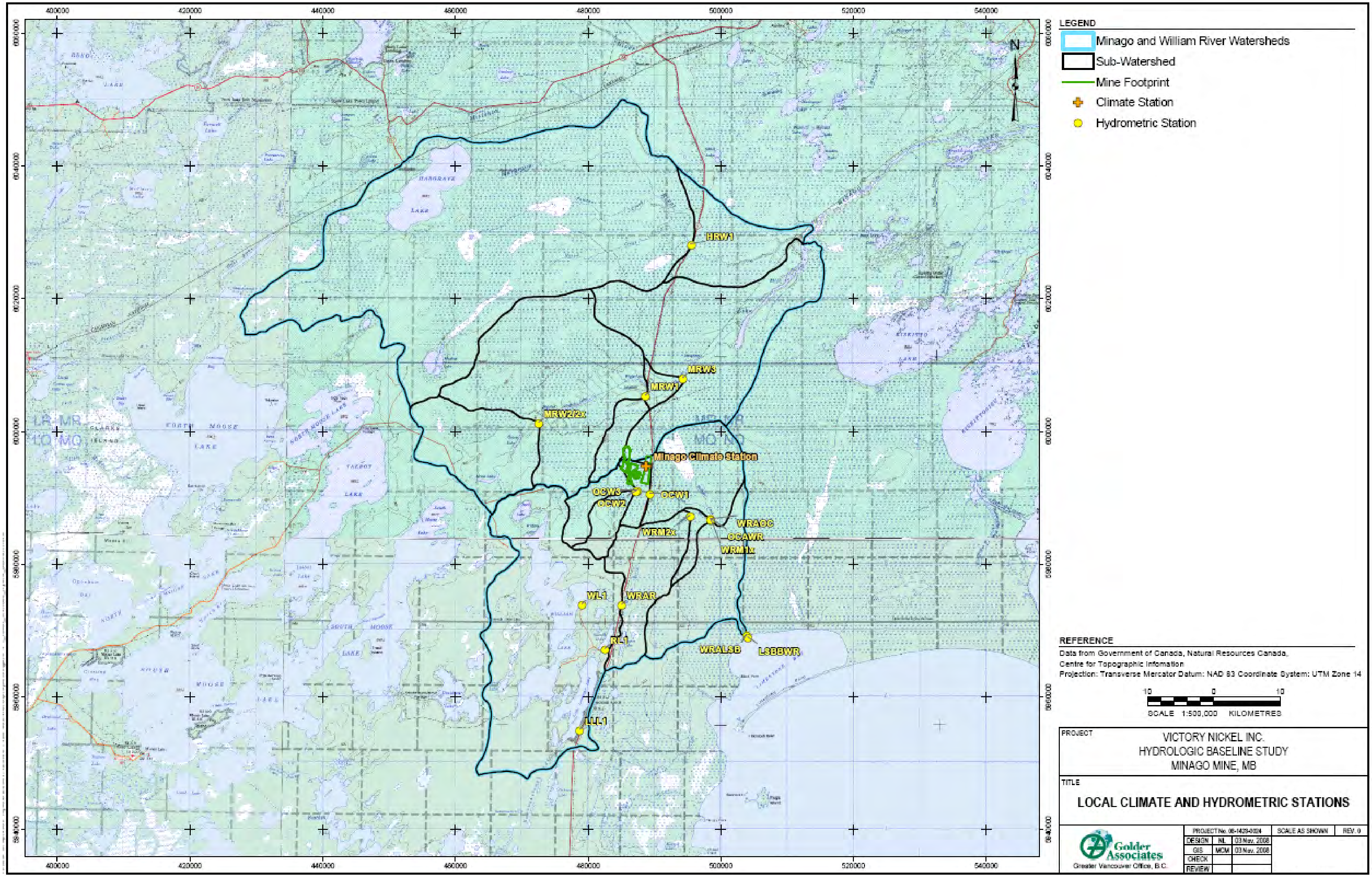
Wardrop collected streamflow data at OCW-1 on Oakley Creek and at MRW-1 on the Minago River once per month from August to October 2006 (Table 7.4-1, Figure 7.4-3). OCW-1 is located on the westside of Highway 6 and receives drainage from Oakley Creek and the ditches along Highway 6. Sampling station MRW-1 was established on the Minago River at the Highway 6 crossing, approximately 15 km north of Oakley Creek. Detailed field methods and streamflow records are given in Appendix 7.4. A detailed description of the watersheds and sampling locations is also provided in Appendix 7.4

Table 7.4-1 Coordinates of 2006 Streamflow Monitoring Locations

Monitoring Station	NAD 83 Northing (m)	NAD 83 Easting (m)
OCW-1	5990528	489238
MRW-1	6005275	488684

7.4.1.2 Scope of Hydrometric Assessments conducted in 2007 and 2008

URS conducted monthly hydrologic monitoring on Minago River, William River, Oakley Creek and Hargrave River between May and October 2007 (Table 7.4-2, Figure 7.4-3). Monitoring sites



Source: Golder Associates, 2009

Figure 7.4-3 Local Climate and Hydrometric Stations

Table 7.4-2 Local Hydrometric Stations

Drainage Network	Station [1]	Description	Watershed Surface Area (km^2)	Northing	Easting	Period of Record for the Transducer
Hargrave River	HRW1	Hargrave at Highway 6	1,512	6028072	495606	23-Jul-07 to 1-Nov-07, 9-May-08 to 6-Aug-08
Minago River	MRW1	Minago at Highway 6 (Alloway Lake outlet)	716	6005277	488671	15-Aug-07 to 4-Nov-07, 8-May-08 to 3-Aug-08
	MRW2/2x	Minago upstream of Habiluk Lake	214	6001166	472571	15-Aug-07 to 4-Nov-07, 9-May-08 to 6-Aug-08
	MRW3	Minago downstream of Highway 6, near power line cut	785	6007895	494274	No transducer installed
Oakley Creek [2]	OCW1	Oakley downstream of Highway 6	123	5990510	489322	27-Jul-07 to 4-Nov-07, 10-May-08 to 17-Aug-08
	OCW2	Oakley near mine site	92.6	5990961	487463	23-Jul-07 to 30-Nov-07, 11-May-08 to 16-Aug-08
	OCW3	Tributary to Oakley Creek	42.9	5990892	487230	No transducer installed
	OCAWR	Oakley upstream of confluence with William River	303	5986744	498457	17-Oct-07 to 5-Nov-07, 8-May-08 to 3-Aug-08
William River	WRW1x	William downstream of confluence with Oakley Creek	1,139	5986554	498523	23-Jul-07 to 4-Nov-07, 8-May-08 to 18-May-08, 3-Aug-08 to 14-Aug-08
	WRW2x	William upstream of station WRAOC	815	5987162	495416	23-Jul-07 to 15-Sep-07
	WRAOC	William upstream of confluence with Oakley Creek	836	5986647	498452	Broken transducer; new one installed in Aug 08
	WRAR	William at Highway 6	654	5973791	485078	Installed in Aug-08
	LLL1	Little Limestone Lake (at end of road)	Lake	5954922	478725	No transducer installed
	RL1	Russell Lake	Lake	5967117	482571	No transducer installed
	WL1	William Lake at end of access road	Lake	5973831	479083	No transducer installed
	WRALSB	William River Above Limestone Bay	Lake	5969206	503935	No transducer installed
	LSBBWR	Limestone Bay Below William River	Lake	5968889	504092	No transducer installed

Source: Golder Associates, 2009

1. The hydrometric data were obtained from Victory Nickel (2008)
2. The Oakley Creek drainage network is within that of William River.

were established on Minago River and Oakley Creek above and below proposed project area. The sites were selected to develop baseline hydrologic conditions upstream and downstream of the Project site (URS, 2008a). KR Design Inc. continued hydrologic monitoring on Minago River, William River, Oakley Creek and Hargrave River in May and August 2008. A detailed description of the watersheds and sampling locations is provided in Appendix 7.4. Field methods and streamflow results for the 2007 and 2008 assessments are also provided in Appendix 7.4.

On the Minago River, one site (MRW1) was located at the Highway 6 Bridge and another site (MRW2) was located several kilometres upstream near Habiluk Lake. MRW2 was relocated approximately 100 metres downstream in October 2007 because a beaver dam had been constructed just downstream of MRW2. This new monitoring location on Minago River was called MRW2x.

On Oakley Creek, one monitoring site (OCW1) was located approximately 100 metres downstream from the Highway 6 culverts, one site (OCW2) was located several kilometres upstream from the Highway 6 crossing, one site (OCW3) was located approximately 250 m upstream of OCW2, and another site (OCAWR) was located immediately upstream of the Oakley Creek and William River confluence. OCAWR was established in October, 2007. On William River, one site (WRW1X) was located approximately 100 metres downstream from the Oakley Creek/William River confluence and one site (WRW2X) was located several kilometres upstream from the confluence. A third monitoring site (WRAOC) was established in October 2007 immediately upstream from the Oakley Creek/William River confluence. In addition, streamflow was assessed just west of Highway 6 on William River (at William River at Road), starting in May 2008. On Hargrave River, one site (HRW1) was located at the Highway 6 Bridge.

7.4.2 Geographic Characteristics

The topography in the Minago and William River watersheds varies between elevation 210 and 300 m. The watersheds are located within the Mid-Boreal Lowland eco-region (Wiken, 1986). This eco-region is a relatively flat, low-lying area with extensive wetlands covering approximately half the area. Underlain by flat-lying, limestone bedrock, the project site area is covered almost entirely by a glacial and lacustrine overburden of fine material, and extensive peat deposits (Wiken, 1986; Betcher et al., 1995). The cold and poorly drained fens and bogs are covered with tamarack and black spruce. The mixed deciduous and coniferous forest in the other half of the area is characterized by medium to tall, closed stands of trembling aspen and balsam poplar with white and black spruce, and balsam fir occurring in late successional stages.

The Mid-Boreal Lowland eco-region is replaced to the north and east of the watersheds by the Hayes River Upland eco-region (Wiken, 1986). Standing vegetation in this region consists predominantly of dense medium to tall black spruce and jack pine with some paper birch. The shrub layer is dominated by ericaceous shrubs, willow, and alder. The ground cover consists of mosses and lichens, low ericaceous shrubs, and some herbs.

The Minago Project Area lies within the Localized Permafrost Zone (Zoltai, 1995). There, permafrost occurs as small, isolated lenses in peat. The hydrological impacts of their thawing have been proven to have no significant effect on bog hydrology (Thibault and Payette, 2009). Moreover, Thibault and Payette (2009) have shown that over the last 50 years, the southern limit of permafrost distribution has moved significantly towards the north.

Nowadays, it is therefore unlikely to observe permafrost in the Minago area. Hydrometric Data Inventory.

7.4.3 Hydrometric Data Inventory

7.4.3.1 Local Data

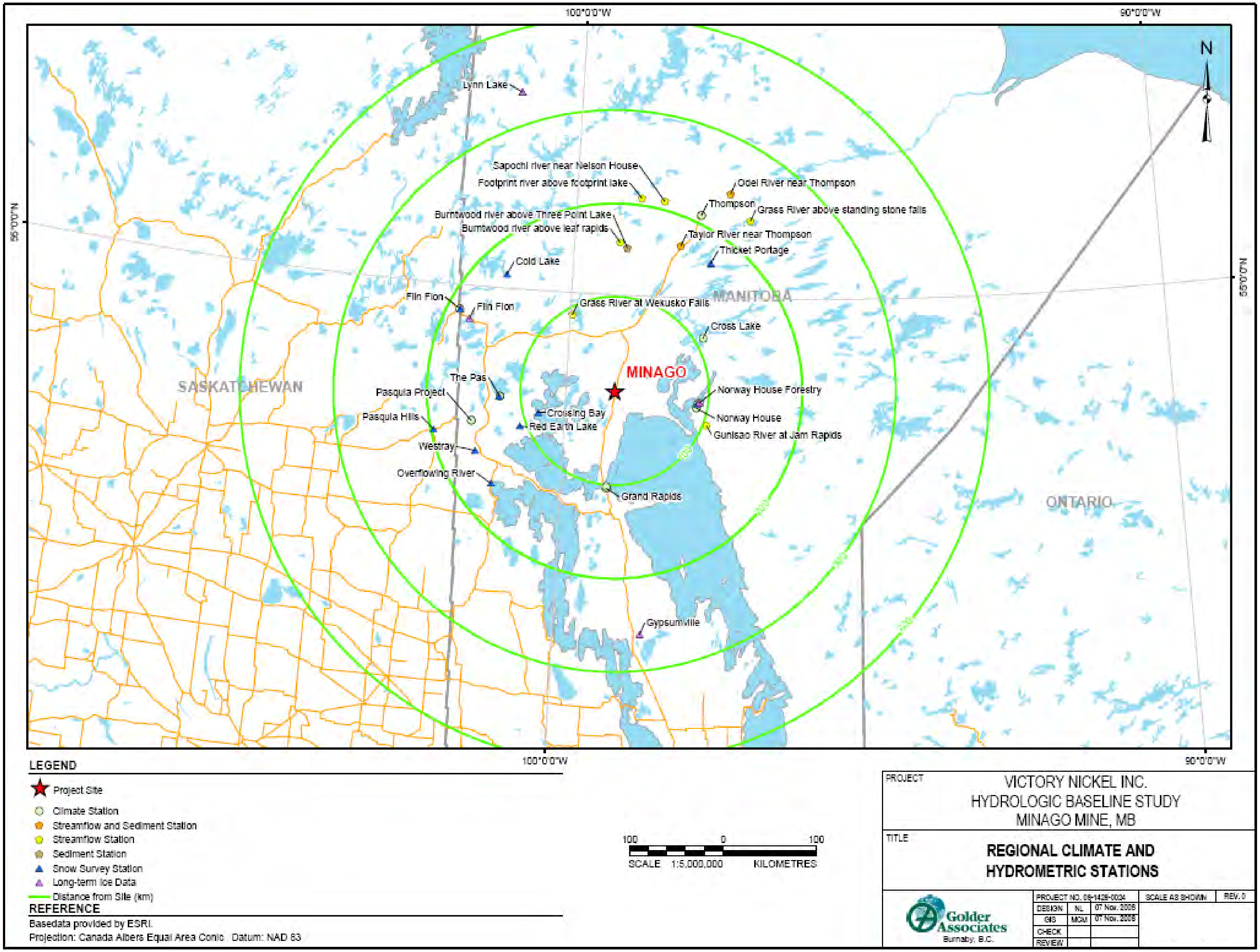
The collection of water quality samples has been undertaken on behalf of Victory Nickel by Wardrop Engineering in 2006, URS in 2007, and KR Design Inc. The monitoring network for the collection of climate and water level observations has provided data since July 2007. Figure 7.4-3 illustrates the station locations for the Victory Nickel's monitoring network. The sub-sections below detail the inventory of hydrometric data available from this monitoring network.

The local hydrometric monitoring program includes stations for the observation of in-stream water level and for the collection of water quality samples (Table 7.4-2 and Figure 7.4-3). Hydrometric stations equipped with a pressure transducer (i.e., HRW1, MRW1, MRW2/2x, OCW1, OCW2, OCAWR, WRW1x, WRW2x, WRAOC and WRAR) are those where water level can be determined within the period of record. The expanded version of the abbreviated hydrometric station names listed above are provided in Table 7.4-2. Measurements from the transducers were available from a period as early as late July 2007 up to as late as early November 2007, and from as early as May 2008 up to as late as mid August 2008. The transducers were not in operation during the 2007/08 winter period.

Water quality samples were collected at the hydrometric stations listed in Table 7.4-2. The analysis of the samples included the determination of total suspended solid (TSS) concentrations. Sampling typically occurred during spring summer and fall, and the last samples available for this study are those of the spring of 2008. One sample only was collected at Little Limestone Lake (LLL1) and Russell Lake (RL1) in September 2007, William River above Limestone Bay (WRALSB) and Limestone Bay below William River (LSBBWR) in October 2007, and William Lake (WL1) in May 2008. The surface water quality program is presented and discussed in Section 7.5.

7.4.3.2 Regional Data

Regional temperature and precipitation data are available from seven climate stations located in northern Manitoba. Regional evaporation estimates, relative humidity, wind and radiation are also respectively available at one or more of these stations (Figure 7.4-4). Regional precipitation data may be supplemented by a national database of snow survey and snow water equivalent information that is current up to 2004.



Source: Golder Associates, 2009

Figure 7.4-4 Regional Climate and Hydrometric Stations

Data from eight regional hydrometric stations are available from Water Survey of Canada (Table 7.4-3). River and lake ice information was available from the Canadian Ice Database (Table 7.4-4). Data from three regional sediment sampling stations (Table 7.4-5) was used to complete the database for the Minago Project.

7.4.3.2.1 Streamflow and Water Level

The Water Survey of Canada (WSC) branch of Environment Canada maintains a network of streamflow monitoring stations that record daily flows and flood peak discharges. Table 7.4-3 shows long-term WSC stations near the Minago Project with periods of record greater than ten years (EC 2008d), operating year-round, and with watersheds near the regional climate stations. The locations of these stations are shown in Figure 7.4-4.

7.4.3.2.2 Ice Regime

The Canadian Ice Database (CID; Lenormand et al., 2002) compiles observations of ice-cover duration and thickness for various sizes of water bodies and watercourses. Main data contributors include the Meteorological Service of Canada, the Canadian Ice Service, and provincial and territorial governments. The CID was used to identify available ice data in the Minago region. A total of 8 stations with long-term ice records within this region are listed in Table 7.4-4.

7.4.3.2.3 Suspended Sediment

Suspended sediment observations in Manitoba have been typically made at locations in the southern parts of the province or on very large rivers (e.g., the Saskatchewan River), and therefore, are not likely to provide data that are representative of conditions in the region of the proposed project site. Table 7.4-5 lists the sediment data stations with relatively small watersheds that are located near the Minago Project.

7.4.4 Hydrometric Results

7.4.4.1 Local Results

7.4.4.1.1 Streamflow and Water Level

The available local hydrometric data includes pressure, staff gauge and streamflow measurements for HRW1, MRW1, MRW2/2x, OCW1, OCW2, OCAWR and WRW1x. Pressure transducers were only recently installed at WRAOC and WRAR, and therefore no water level or streamflow were available for the hydrological assessment. As well, no concurrent pressure and staff gauge measurements were available to determine water levels or streamflow at WRW2x.

Table 7.4-3 Regional Streamflow Stations

Station Name [1]	Station ID	Distance from Site (km)	Latitude North	Longitude West	Drainage Area (km^2)	Period of Record	Years of Record
Sapochi River near Nelson House	005TG006	200 km to the North	55°54'	98°29'	391	1993-2007	15
Footprint River above Footprint Lake	005TF002	200 km to the North	55°56'	98°53'	643	1978-2007	30
Taylor River near Thompson	005TG002	180 km to the North East	55°29'	98°11'	886	1970-2007	38
Grass River at Wekusko Falls	005TB002	100 km to the North	54°47'	99°58'	3,260	1957-2007	51
Gunisao River at Jam Rapids	005UA003	100 km to the East	53°47'	97°40'	4,800	1971-2007	37
Burntwood River above Leaf Rapids	005TE002	160 km to the North	55°30'	99°13'	5,810	1985-2007	23
Odei River near Thompson	005TG003	250 km to the North East	56°00'	97°21'	6,110	1979-2007	29
Grass River above Standing Stone Falls	005TD001	240 km to the North East	55°45'	97°00'	15,400	1959-2007	49

1. Source: Golder Associates, 2009 (Secondary source: Water Survey Branch of Environment Canada (EC, 2008d)).

Table 7.4-4 Regional Long-Term Ice Data Stations

Station Name [1]	Water Body / Watercourse	Station Identification	Distance from Site (km)	Latitude North	Longitude West	Period of Record	Years of Record
Flin Flon	Schist Lake	FUBU-171	200 km to the North West	54°41'	101°41'	1956-1983	28
Norway House Forestry	Little Playgreen Lake	FUBU-354	90 km to the East	54°00'	97°48'	1956-1998	43
Norway House Forestry	Playgreen Lake	FUBU-356	90 km to the East	54°00'	97°48'	1986-1996	11
Norway House Forestry	Nelson River	FUBU-355	90 km to the East	54°00'	97°48'	1957-1962	6
Lynn Lake	Eldon Lake	FUBU-300	340 km to the North	56°52'	101°05'	1969-1994	26
Lynn Lake	Lynn Lake	FUBU-301	340 km to the North	56°52'	101°05'	1969-1985	17
Lynn Lake	West Lynn Lake	FUBU-302	340 km to the North	56°52'	101°05'	1987-1994	8
Gypsumville	Portage Bay	FUBU-231	270 km to the South	51°46'	98°38'	1969-1986	18

1. Source: Golder Associates, 2009 (Secondary source: Canadian Ice Database (Lenormand et al., 2002)).

Table 7.4-5 Sediment Data Stations

Station Name [1]	Station ID	Distance from Site (km)	Latitude North	Longitude West	Drainage Area (km^2)	Period of Record	Number of Years Available
Taylor River near Thompson	05TG002	180 km to the North East	55°29'	98°11'	886	1971-1979	7
Odei River near Thompson	05TG003	250 km to the North East	55°59'	97°21'	6,110	1979-1987	4
Burntwood river above Three Point Lake	05TE001	160 km to the North	55°27'	99°06'	6,670	1977-1983	6

1. Source: Golder Associates, 2009 (Secondary source: Water Survey Branch of Environment Canada (EC, 2008e)).

The steps used to derive water level and streamflow from the pressure measurement were:

- Establishment of a relationship between the pressure measurements and stream water levels based on water elevations measured from the reference staff gauge located at the site; and
- Establishment of a relationship between water elevations measured from the staff gauge and manual streamflow measurements made at the site.

The relationships determined for HRW1, MRW1, MRW2/2x, OCW1, OCW2, OCAWR and WRW1x are given in Appendix 7.4. These relationships were based on the observed water levels and streamflows at the stations. Confidence in the results of these relationships is greater within the ranges of the observations at the stations than outside these ranges. Water levels referenced to the staff gauge and corresponding streamflows at these stations are also graphed in Appendix 7.4. The graphs in Appendix 7.4 show the maximum observed water level and streamflow at the stations. A summary of derived streamflow characteristics for the period of record are provided in Table 7.4-6.

The record of pressure transducer measurements at the local hydrometric stations was limited to two periods: July to November 2007 and May to August 2008. Table 7.4-6 gives a summary of the streamflow characteristics for each of these periods. Based on the air temperature recorded from the regional stations, high streamflow levels recorded in early May 2008 are likely the result of the onset of the freshet. Streamflow variations for the other recorded months are attributed to rainfall runoff.

Long-term characterization of flow cannot be determined from this comparatively short period of record. Furthermore, confidence in the derived water level and streamflow at the local hydrometric stations are compounded by the following factors (Golder Associates, 2009):

- During high flow events, water in the Minago River could potentially be conveyed by two channels (i.e., the Wigle and Alloway Lake outlets at Highway 6). The MRW1 station monitors flow for only one of these channels (Alloway Lake outlet).

Table 7.4-6 Streamflow Characteristics at Local Stations for 2007 and 2008

Station [1]	Watershed Area (km^2)	Flow from July to November 2007 (m^3/s)			Flow from May to August 2008 (m^3/s)		
		Minimum	Median	Maximum	Minimum	Median	Maximum
HRW1	1512	0.20	3.24	6.22	0.17	4.54	9.35
MWR1	716	0.058	1.54	6.70	0.27	1.71	5.79
MWR2/2x [2]	214	0.68	1.08	1.77	0.51	0.77	2.01
OCW1	123	0.28	0.61	1.14	0.24	0.54	1.42
OCW2	93	0.30	0.52	0.92	0.002	0.38	0.92
OCAWR [3]	303	1.12	1.71	1.90	0.13	1.20	7.09
WRW1x [4]	1139	2.15	5.05	6.50	1.92	5.74	7.29

1. Data source: Golder Associates, 2009 (Secondary source: Victory Nickel (2008)).
2. Monitoring at MRW2/2x could have been impacted by a beaver dam.
3. In 2007, streamflows were only available from October 17 to November 5 at OCAWR.
4. In 2008, streamflows were only available from May 8 to 18 and from August 3 to 15 at WRW1x.

- A beaver dam was observed after the installation of station MRW2. This station was eventually moved to a location downstream (i.e., MRW2x) of the beaver dam water impoundment. The impoundment has impacted pressure measurements at the original location.
- The stream at OCW2 has a very wide floodplain. High flows would likely be underestimated based on the staff gauge/streamflow relationship that was developed for that station.
- Station OCW1 is located roughly 100 m downstream from a culvert that conveys the water from Oakley Creek across Highway 6. Natural flows as a result of high rainfall events could be underestimated if water is stored or diverted upstream of that culvert.

Golder Associates recommended mitigation measures, which could include monitoring flow on the second channel of Minago River at Highway 6 (Wigle outlet) or moving station MRW1 upstream the split channels, and relocating stations OCW1 and OCW2 (Golder Associates, 2009).

7.4.4.1.2 Suspended Sediment

Analytical results from the water quality sampling program conducted by Victory Nickel (2008) for the Minago Project included the quantification of total suspended solids (TSS). The analytical results for TSS are summarized in Table 7.4-7 for each hydrometric station assuming that TSS is composed entirely of suspended sediment.

Measured TSS concentrations in the Minago River and upper reaches of Oakley Creek (OCW1, OCW2, and OCW3) were markedly lower than those in the Hargrave and William Rivers.

Table 7.4-7 Observed Total Suspended Solids at Local Stations between 2006 and 2008

Station [1]	Sampling Period	Sample Count		TSS (mg/L) [2]		
		Total	Below Detection Limits	Min	Median	Max
HRW1	May-Oct 2007; March and Aug 2008	8	0	8.0	28.5	42.0
MRW1	May-Oct 2006-2007; March and Aug 2008	14	4	1.0	<3.0	5.0
MRW2/2x	May-Oct 2007; May 2008	7	1	<3.0	4.0	12.5
MRW3	May-Oct 2007; May 2008	7	3	<3.0	3.0	5.7
OCW1	May-Oct 2006-2007; May 2008	14	10	<1.0	<3.0	23.0
OCW2	May-Oct 2006-2007; May 2008	13	8	<1.0	<3.0	11.0
OCW3	May-Oct 2006-2007; May 2008	13	11	<1.0	2.0	<3.0
OCWAR	Oct 2007 and May 2008	2	0	3.5	26.8	50
WRW1x	May-Oct 2007; May 2008	7	0	5.9	18.9	57.5
WRW2x	May-Sep 2007	5	0	6.9	29.9	65.0
WRAOC	Oct 2007 and May 2008	2	0	6.5	20.0	33.5
WRAR	May 2008 [3]	0	0	-	-	-
LLL1	Sep 2007	1	0	9.2	9.2	9.2
RL1	Sep 2007	1	0	14.2	14.2	14.2
WL1	May 2008	1	1	<3.0	<3.0	<3.0
WRALSB	Oct 2007	1	0	7.5	7.5	7.5
LBBWR	Oct 2007	1	0	6.5	6.5	6.5

1. Data source: Golder Associates, 2009 (Secondary source: Victory Nickel (2008)).
2. The < sign indicates a value below analytical detection limits. The detection limit for TSS was 1 mg/L for 2006 samples and 3 mg/L for 2007 and 2008 samples.
3. A water quality sample was taken at WRAR; however no analytical result for TSS was available.

7.4.5 Hydrometric Characteristics

This section summarizes the anticipated hydrologic processes occurring at the Minago project site, and within the Close Study Area (Figure 7.1-1) and Extended Study Area (Figure 7.1-2). The following components are addressed:

- Ice regime and snow on the ground;
- Surface water runoff;
- Peak and low flows; and
- Sediment yield.

7.4.5.1 Ice Regime and Snow on the Ground

The Canadian Ice Database (CID) was used to compile available ice data for lakes and rivers located between Latitudes 51 and 56 degrees north, and between Longitude 97 and 101 degrees west. An analysis of the data was conducted to provide a basis for estimating the following parameters in the vicinity of the Minago Project:

- Average maximum ice thickness;
- Average date for the first occurrence of permanent ice;
- Average date of complete freeze over;
- Average date of the first occurrence of ice deterioration; and
- Average date for water to be clear of ice.

Table 7.4-8 summarizes the available regional data. Mean ice thickness varies within a narrow range between 0.8 and 0.9 m, with only the northernmost stations (West Lynn Lake) having an ice smaller than the lower range value (0.8). The first occurrence of ice may be as early as mid-October; however, a complete freeze over is not observed until the end of October or early November. Deterioration of the ice cover is observed by late April and likely coincides with the freshet.

Similarly, the snow on the ground information from Environment Canada stations at Flin Flon, Norway House, Pasquia Project, The Pas and Thompson indicate that the snowpack becomes completely depleted by April 17 on average at these locations. The depletion can occur as early as March 1 or as late as May 9. Snow on the ground can vary significantly spatially, and therefore snow on the ground in a given area can be anticipated past the date of complete depletion at the climate stations.

Based on long-term air temperature data (Table 7.1-8), ice cover characteristics (Table 7.4-8) and snow on the ground depletion information, three distinct periods can be identified:

Table 7.4-8 Regional Ice Cover Characteristics

Station Name [1]		Waterbody	Available Period of Record	Mean Maximum Ice Thickness (m)	Mean First Date of Occurrence of Permanent Ice [2]	Mean Date of Complete Freeze Over [2]	Mean First Date of Occurrence of Ice Deterioration	Mean Date for Water to be Clear of Ice
1	Flin Flon	Schist Lake	1956-1983	0.8	04-Nov	09-Nov	26-Apr	10-May
2	Norway House Forestry	Little Playgreen Lake	1956-1998	0.9	30-Oct	04-Nov	23-Apr	08-May
		Playgreen Lake	1986-1996	0.8	-	03-Nov	23-Apr	13-May
		Nelson River	1957-1962	0.9	-	-	22-Apr	02-May
3	Lynn Lake	Eldon Lake	1969-1994	0.8	15-Oct	25-Oct	01-May	16-May
		Lynn Lake	1969-1985	0.9	13-Oct	23-Oct	28-Apr	15-May
		West Lynn Lake	1987-1994	0.6	24-Oct	28-Oct	08-May	15-May
4	Gypsumville	Portage Bay	1969-1986	0.9	02-Nov	14-Nov	18-Apr	06-May
Range of variation				**0.6 to 0.9**	**13-Oct to 04-Nov**	**23-Oct to 09-Nov**	**22-Apr to 08-May**	**02-May to 15-May**

1. Data source: Golder Associates, 2009 (Secondary source : Lenormand et al. (2002)).
2. Insufficient or no data available denoted by a – symbol.

- April to May: when the deterioration of the ice cover and the depletion of the snowpack is observed. This is the freshet period where rainfall and snowmelt produce surface runoff.
- June to October: when no winter processes such as ice cover or snowpack developments are observed. Surface runoff is generated from rain events only.
- November to March: when winter processes such as ice cover or snowpack developments are observed. Surface runoff is reduced during that period.

7.4.5.2 Annual Surface Water Runoff

The hydrometric stations listed in Table 7.4-3 were used in a regional analysis of annual runoff potential in the vicinity of the proposed project site. Table 7.4-9 provides the calculated seasonal runoff depths for each of these stations from April to May, June to October, November to March, and on an annual basis. Runoff is calculated by dividing the total streamflow observed

Table 7.4-9 Mean Annual Water Yield at Regional Stations

Station Name [1]	Watershed	Mean Streamflow (m^3/s)				Watershed Runoff (mm)				Percent of Annual Runoff (%)		
	Area (km^2)	Apr-May	Jun-Oct	Nov-Mar	Annual	Apr-May	Jun-Oct	Nov-Mar	Annual	Apr-May	Jun-Oct	Nov-Mar
Sapochi River near Nelson House	391	4.7	2.8	0.5	2.2	63	95	18	176	36	54	10
Taylor River near Thompson	886	8.6	6.4	1.6	4.8	51	96	24	171	30	56	14
Odei River near Thompson	6,110	60.4	46.1	10.1	33.6	52	100	22	173	30	57	12
Grass River at Wekusko Falls	3,260	10.2	13.6	9.2	11.2	16	55	37	108	15	51	34
Grass River above Standing Stone Falls	15,400	43.1	88.0	51.5	65.4	15	76	44	134	11	56	33
Footprint River above Footprint Lake	643	4.2	3.8	2.0	3.1	34	78	42	154	22	51	27
Gunisao River at Jam Rapids	4,800	27.8	22.8	8.6	17.8	31	63	24	117	26	54	20
Burntwood River above Leaf Rapids	5,810	35.1	31.1	9.0	22.6	32	71	20	123	26	58	16

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008d)).

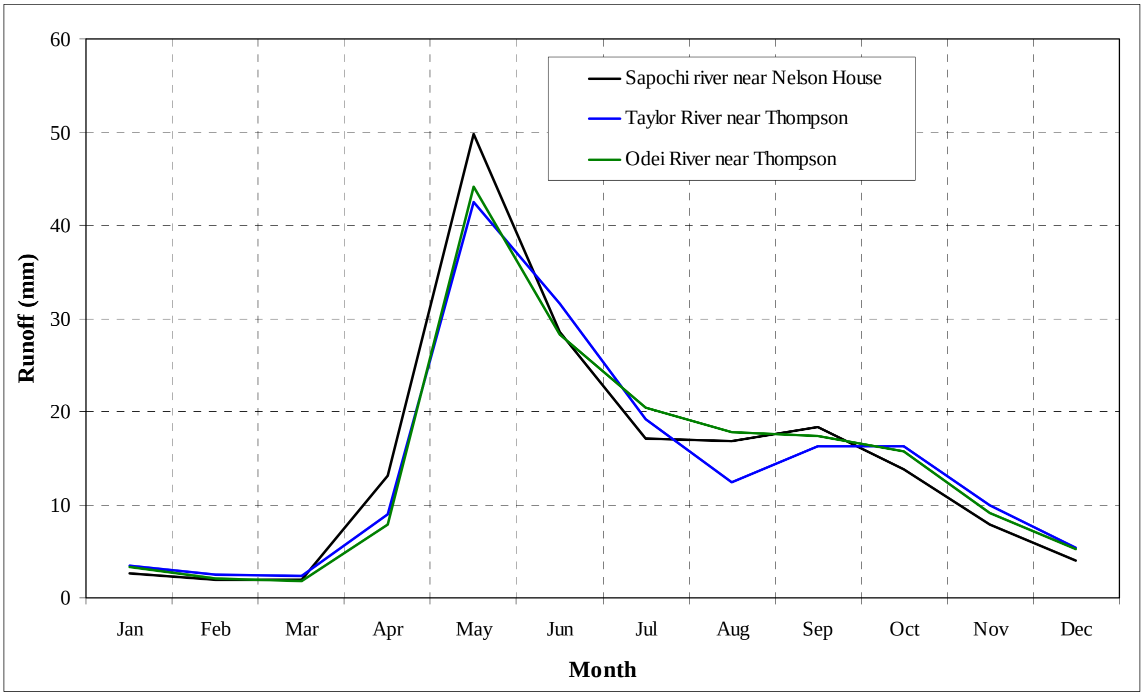
at the stations for a given period expressed in terms of volume by the watershed area at the corresponding stations. The runoff estimates represent:

- The water yield of the watershed at its outlet; and
- Total precipitation in the watershed minus total losses (evapotranspiration, infiltration, sublimation and snow redistribution) occurring within the watershed area.

The amount of runoff is dependent on precipitation input amount and on the characteristics of the watershed such as the proportion of lakes and wetland with respect to watershed area, vegetation and soils, which would impact evapotranspiration and infiltration. Based on the results of Table 7.4-9 and on the monthly water runoffs given in Figures 7.4-5 to 7.4-7, three groups of watersheds were identified:

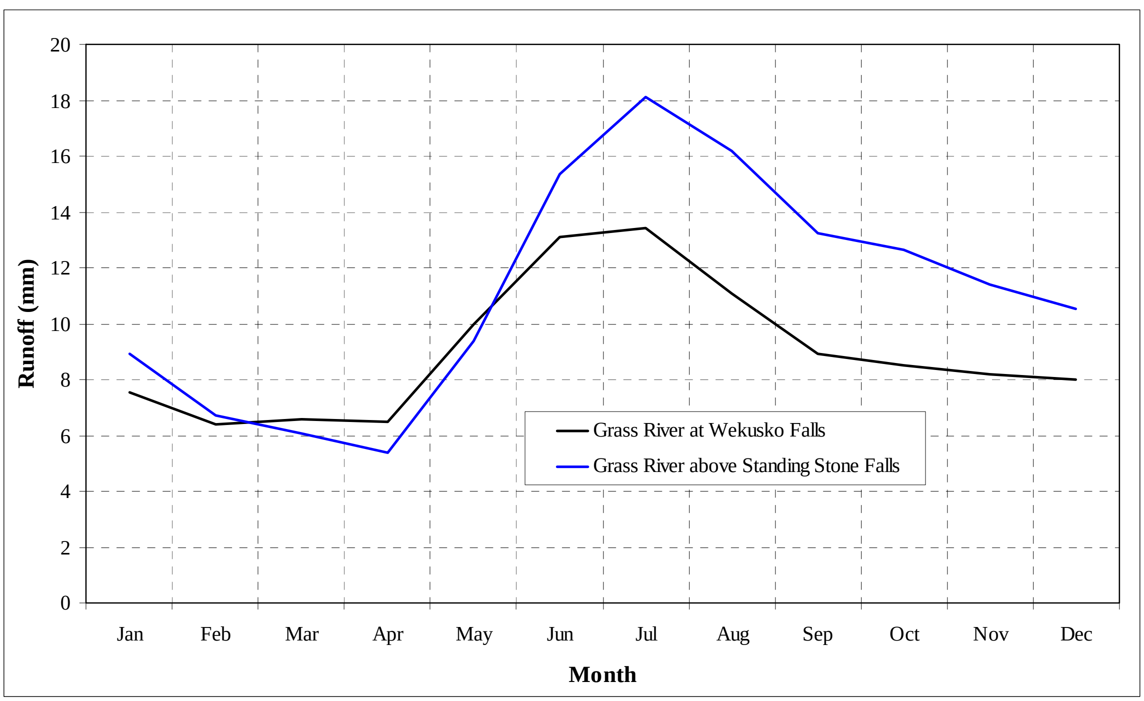
- **Sapochi, Taylor and Odei River Watersheds (Figure 7.4-5):** These watersheds are located further northeast from the project site, in a region of relatively higher precipitation, and covered with trees in relatively larger areas of the watersheds. Annual runoff (171 to 176 mm on average per year) is relatively higher from these watersheds than the others listed in Table 7.4-9. Their corresponding annual runoff coefficient, which is the ratio of mean annual runoff over mean annual total precipitation, ranges from 0.30 to 0.31 (Table 7.4-10).
- **Grass River Watersheds (Figure 7.4-6):** This river spans from the southwest to the northeast, north of the project site. The upstream watershed is in an area with moderate precipitation, and is dominated by fens and lakes and wetland, where evapotranspiration is potentially higher compared to forested areas. The result is a relatively low annual runoff (108 mm, for an annual runoff coefficient of 0.21). Further downstream, the Grass River traverses through a region of wooded areas and high precipitation, resulting in a comparatively higher water yield (133 mm, for an annual runoff coefficient of 0.24). The monthly distribution of runoff for the Grass River differs from those of the other regional stations listed in Table 7.4-9. Specifically, the peak occurs in July instead of May, as is the case for the other rivers.
- **Footprint, Gunisao and Burntwood River Watersheds (Figure 7.4-7):** These rivers are located in regions with moderate to high precipitation. However, their landscape is dominated by fens and wetland, resulting in comparatively low to moderate annual runoff varying between 117 and 154 mm (Table 7.4-10 for the Gunisao and Footprint Reivers, respectively). The monthly distribution of runoff is comparable for all three watersheds, with a peak runoff for the freshet occurring in May. Annual runoff coefficient for these watershed varies between 0.20 and 0.27 (Table 7.4-10 for the Gunisao and Footprint Rivers, respectively).

The hydrologic characteristics (in terms of vegetation, waterbody characteristics as well as peak runoff in May from the freshet) of the local watersheds near the project site would more likely resemble those of the third group of watersheds discussed above. Runoff coefficients for these



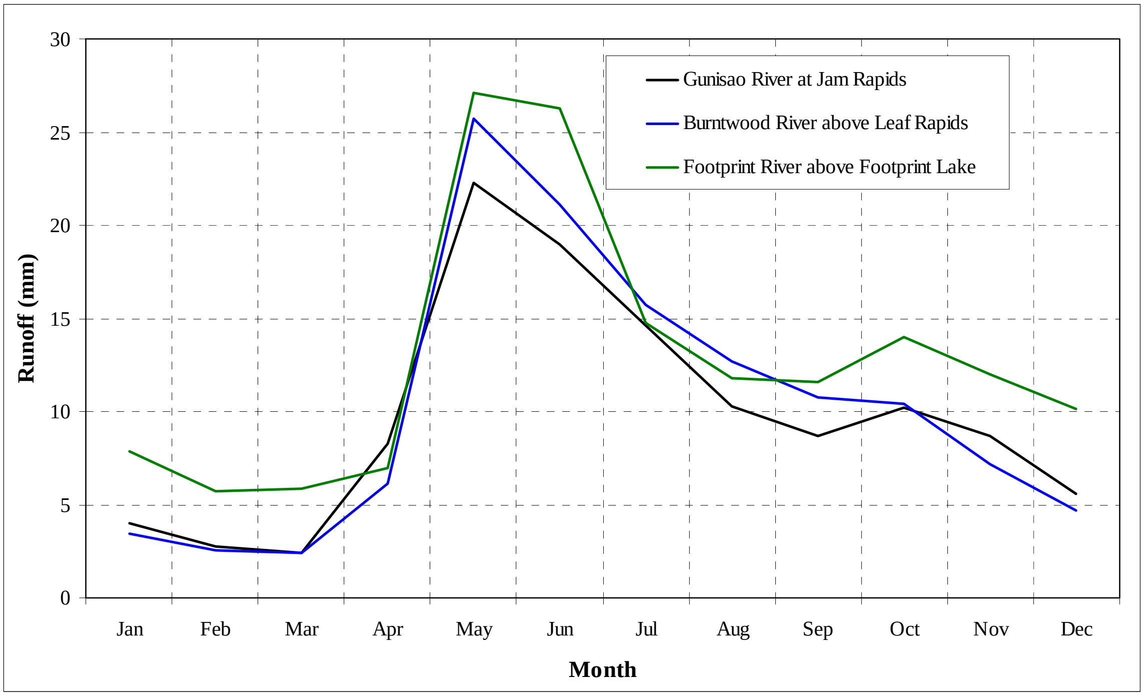
Source: Golder Associates, 2009

Figure 7.4-5 Average Monthly Runoff for the Sapochi, Taylor and Odei Rivers



Source: Golder Associates, 2009

Figure 7.4-6 Average Monthly Runoff for the Grass River



Source: Golder Associates, 2009

Figure 7.4-7 Average Monthly Runoff for the Gunisao, Burntwood and Footprint Rivers

Table 7.4-10 Regional Annual Runoff Coefficients

Station Name	Watershed Area (km^2)	Annual Runoff (mm) [1]	Total Annual Precipitation (mm) [2]	Runoff Coefficient
Sapochi River near Nelson House	391	176	573	0.31
Taylor River near Thompson	886	171	550	0.31
Odei River near Thompson	6,110	173	573	0.30
Grass River at Wekusko Falls	3,260	108	520	0.21
Grass River above Standing Stone Falls	15,400	134	550	0.24
Footprint River above Footprint Lake	643	154	573	0.27
Gunisao River at Jam Rapids	4,800	117	594	0.20
Burntwood River above Leaf Rapids	5,810	123	550	0.22

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008d)).
2. Data source: Golder Associates, 2009 (Secondary source: EC (2008b)).

local watersheds would also be assumed to be in the same range as those of the Footprint, Gunisao and Burntwood Rivers.

The average of the runoff coefficients at Footprint, Gunisao and Burntwood Rivers (Table 7.4-10) is considered in the present analysis as an adequate runoff coefficient for the local watersheds of the Minago Project. Based on an estimated average annual total precipitation of 510 mm (Table 7.1-10) and the assumed average runoff coefficient of 0.23, the corresponding annual water yield or mean annual runoff from the Oakley Creek and Hargrave, Minago and William River watersheds would be about 117 mm.

7.4.5.3 Annual Water Balance and Evapotranspiration/Infiltration

An annual water balance of the local project site watersheds was performed using the local watershed runoff estimated (117 mm), the estimated local precipitation (Table 7.1-10), and an assumed loss to sublimation and snow redistribution equal to 39% of the snowfall. The local annual water balance results are presented in Table 7.4-11.

It should be noted that losses due to ground infiltration and evapotranspiration could not be estimated from available local data and are therefore lumped together and are assumed equal to the total losses minus losses to sublimation and snow redistribution. The total watershed losses (i.e., evapotranspiration/infiltration, sublimation and snow redistribution) were computed as the total precipitation minus the runoff.

Table 7.4-11 Local Annual Water Balance

Component	Description	Value (mm)
Precipitation	Rainfall	369
	Snowfall	141
	Total Precipitation	510
Losses	Evapotranspiration / Infiltration	338
	Snow Losses [1]	55
	Total Losses	393
Water Runoff	Runoff [2]	117

Source: Golder Associates, 2009

1. Snow losses are the result of sublimation and snow redistribution and assumed to be about 39% of the snowfall.
2. Total losses are equal to the total precipitation minus runoff.

Estimates of the evapotranspiration losses for the local watersheds are functions of the regional variability in lake area, wetland area, and vegetation and terrain types. In particular, additional evaporative loss and resulting reduced runoff could occur from the presence of a significantly sized lake in a watershed. Table 7.4-12 lists the proportions of lake areas within the Hargrave,

Table 7.4-12 Ratio of Lake Areas to Total Watershed Area

Watershed	Lakes Considered [1]	Lake Area (km^2)	Watershed Area (km^2) at Monitoring Station	Ratio of Lake over Watershed Area (%)
Footprint River	Leftrook and Ugik Lakes	77	643	12%
Gunisao River	Gunisao, Bennett, Lebris and Costes Lakes	147	4,800	3%
Burnwood River	Apeganau, File, Loonhead, Batty, Limestone Point, Hassett, Guttrie and Burntwood Lakes	259	5,810	4%
Hargrave River	Hargrave Lake	80	1,512 at HRW1	5%
Minago River	None	Negligible	214 at MRW2	Negligible
			716 at MRW1	
			785 at MRW3	
Oakley Creek	None	Negligible	93 at OCW2	Negligible
			123 at OCW1	
			303 at OCAWR	
William River	William and Little Limestone Lakes	151	654 at WRAR	23%
			815 at WRW2x	19%
			836 at WRAOC	18%
			1,139 at WRW1x	13%

Source: Golder Associates, 2009

1. Only significantly sized lakes on 1:250,000 scale topographic maps were considered.

William, Minago and Oakley watersheds, and compares them to those of the Footprint, Gunisao and Burntwood River watersheds. The proportions are limited to significantly sized lakes within the watersheds, with all other waterbodies considered as negligible.

As indicated in Table 7.4-12, proportions of lakes are appreciably higher in the William River watershed compared to those of the Footprint, Gunisao and Burntwood River watersheds. Consequently, evapotranspiration/infiltration losses from the William River watershed may be potentially higher, or runoff may be comparatively less, than is assumed in the water balance results presented in Table 7.4-11.

7.4.5.4 Monthly Water Balance

In addition to the average annual watershed balance presented above, an average monthly water balance was also completed for the Hargrave, William, Minago and Oakley watersheds. The calculation of the monthly water balance was completed in the same manner as for the annual balance with the additional assumption that the monthly distribution for evapotranspiration/infiltration is similar to that of lake evaporation (Table 7.1-16). Evapotranspiration/infiltration and lake evaporation rates are, in general, similarly influenced by the seasonal variation in precipitation and energy fluxes. Furthermore, it was also assumed that the monthly runoff distribution for the Hargrave, William, Minago and Oakley watersheds would be equal to that of the Burntwood River (Figure 7.4-7). The Burntwood River watershed is located in close proximity to the project site with precipitation and temperature regimes that are expected to be similar to that of the local watersheds. The resulting monthly water balance is presented in Table 7.4-13.

7.4.5.5 Peak and Low Flows

7.4.5.5.1 Regional Area Peak Discharges

A frequency analysis of flood flows was performed using peak discharge data during the freshet period from April to May and during the summer/fall period from June to October that were available at the regional hydrometric stations. Any high flow event from November to March was of lower magnitude than those of the freshet or summer/fall periods. Freshet events are expected to generate higher peaks than summer/fall events for all watersheds, with the exception of those on the Grass River.

The three groups of watersheds identified in Surface Water Runoff Section for watershed runoff assessments are also applicable to the evaluation of peak discharges. Peak discharges from a watershed are dependent upon precipitation and on the characteristics of the watershed such as the proportion of lakes and wetland, and the vegetation and soil types. Productivity (i.e., the peak discharge divided by the watershed area and expressed in L/s/km^2) is relatively high for the Sapochi, Taylor and Odei River watersheds due to the higher precipitation amounts and lower proportions of wetland areas compared to other watersheds (Tables 7.4-14 and 7.4-15). Alternatively, lakes would act to route flood flows and consequently dampen peaks. This is assumed to occur on the Grass River watersheds and, to some extent, on the Footprint, Gunisao and Burntwood River watersheds as well.

Flow routing through the drainage system of a watershed would typically dampen peaks. As a result it is expected that the ratio of flood peaks to the watershed area (i.e., productivity) would be higher for smaller watersheds (Sapochi, Taylor and Odei River in Tables 7.4-14 and 7.4-15, for example).

It is expected that peak discharge characteristics for watersheds in the area of the project site would be similar to those of the Footprint, Gunisao and Burntwood River watersheds because of similar responses to wetlands. However, the smallest watershed within this group is the Footprint River watershed (643 km^2) and it is anticipated that smaller watersheds, such as those of the Minago River (MRW2) and Oakley Creek (OCW2, OCW1 and OCAWR), would have higher peak productivity than those observed for the group as a whole.

Estimated peak productivity for the Footprint, Gunisao and Burntwood River watersheds are 17, 28 and 43 L/s/km^2 for the 2-, 10- and 100-year freshet peaks, and 11, 19 and 31 L/s/km^2 for 2-, 10- and 100-year summer/fall peaks, respectively. These values are assumed to be applicable for watersheds in the vicinity of the proposed project site that are larger than 643 km^2

Table 7.4-13 Local Monthly Water Balance

Month	Precipitation			Losses			Runoff [2]
	Rainfall	Snowfall	Total Precipitation	Evapotranspiration/ Infiltration	Snow Losses [1]	Total Losses	
Jan	0.2	20.1	20.2	0.0	7.8	7.8	3.3
Feb	0.2	17.5	17.8	0.0	6.8	6.8	2.4
Mar	1.6	20.9	22.4	0.0	8.1	8.1	2.3
Apr	11.0	15.8	26.8	10.5	6.2	16.7	5.9
May	38.6	4.2	42.8	66.8	1.6	68.4	24.6
Jun	74.2	0.2	74.4	72.0	0.1	72.1	20.2
Jul	78.3	0.0	78.3	75.6	0.0	75.6	15.0
Aug	69.6	0.0	69.6	64.1	0.0	64.1	12.1
Sep	64.6	1.1	65.8	38.2	0.4	38.6	10.3
Oct	27.5	11.5	39.0	10.5	4.5	15.0	9.9
Nov	2.9	25.3	28.2	0.0	9.9	9.9	6.8
Dec	0.2	24.8	25.0	0.0	9.7	9.7	4.5
Annual	369	141	510	338	55	393	117

Source: Golder Associates, 2009

1. Snow losses are the result of sublimation and snow redistribution and equal 39% of the snowfall.
2. Total losses are equal to the total precipitation minus runoff.

Table 7.4-14 Regional Flood Frequency Estimates during Freshet

Station Name [1]	Watershed	Peak Discharge (m^3/s)			Peak Productivity ($L/s/km^2$)		
	Area (km^2)	2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
Sapochi River near Nelson House	391	14	30	42	35.3	77.1	107.6
Taylor River near Thompson	886	25	45	62	27.9	50.4	70.2
Odei River near Thompson	6,110	173	293	396	28.3	47.9	64.8
Grass River at Wekusko Falls	3,260	18	31	45	5.7	9.7	13.9
Grass River above Standing Stone Falls	15,400	106	171	229	6.9	11.1	14.8
Footprint River above Footprint Lake	643	11	17	22	17.0	26.5	34.5
Gunisao River at Jam Rapids	4,800	50	104	183	10.4	21.7	38.1
Burntwood River above Leaf Rapids	5,810	89	164	249	15.4	28.2	42.8

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008d)).

Table 7.4-15 Regional Flood Frequency Estimates during Summer/Fall

Station Name [1]	Watershed	Peak Discharge (m^3/s)			Peak Productivity ($L/s/km^2$)		
	Area (km^2)	2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
Sapochi River near Nelson House	391	6	16	40	14.6	40.3	101.8
Taylor River near Thompson	886	14	29	55	15.7	33.2	62.6
Odei River near Thompson	6,110	83	187	354	13.6	30.6	57.9
Grass River at Wekusko Falls	3,260	19	34	51	5.8	10.3	15.5
Grass River above Standing Stone Falls	15,400	117	180	236	7.6	11.7	15.3
Footprint River above Footprint Lake	643	7	12	15	11.1	19.2	23.8
Gunisao River at Jam Rapids	4,800	36	80	149	7.5	16.6	31.1
Burntwood River above Leaf Rapids	5,810	54	101	151	9.3	17.4	26.0

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008d)).

Table 7.4-2). Estimating the productivity of the smaller watersheds in the vicinity of the project site is addressed in the following section.

7.4.5.5.2 Runoff and Peak Discharge from Smaller (<643 km^2) Watersheds

The surfaces of the smaller watersheds in the vicinity of the project site are composed largely of wetland vegetation (fens, bogs and peat). These surfaces are typically highly absorbent, usually poorly drained and have a high groundwater table that is at, or near the ground surface following the spring freshet or major storm events. Watershed runoff from these watersheds is anticipated to be comprised of surface runoff, as well as interflow and groundwater contributions. The relative magnitude of the interflow and groundwater contributions to the runoff would be dependent on the retention capacity of the watershed.

Event-based models, which are typically used for determining peak flows, would generally not be suitable for these watershed characteristics because they generally consider surface runoff only. Instead, a continuous model is required to account for the retention capacity of the watersheds.

In this report, a simple daily water balance was used as a continuous model to obtain an initial and preliminary estimate of runoff from the smaller watersheds in the vicinity of the Minago Project. Water inputs to the daily water balance model include rainfall and snowmelt water, while snow losses from sublimation and potential redistribution of snow out of the watershed were accounted for by assuming a reduction in the calculated snowpack snow water equivalent (SWE) by 39%. Losses from evapotranspiration and infiltration were incorporated in the model through runoff production rates.

The snowmelt module assumed for the daily water balance model was based on the degree-day method and considers the daily mean air temperature, rainfall and snowfall series generated for the project site (discussed in Section 7.1). The limited climate data available for the study area prevented the use of more physically-based snowmelt simulation models. It is expected that modelling results based on the water balance model approach contain some degree of uncertainty.

The degree-day model uses the following equation to calculate the daily snowmelt:

$$M = M_f\,(T_i - T_b)$$

where:

M	-	daily snowmelt (mm)
M_f	-	melt factor (mm/^{o}C/day)
T_b	-	base air temperature above which melt begins (^{o}C)
T_i	-	air temperature (°C).

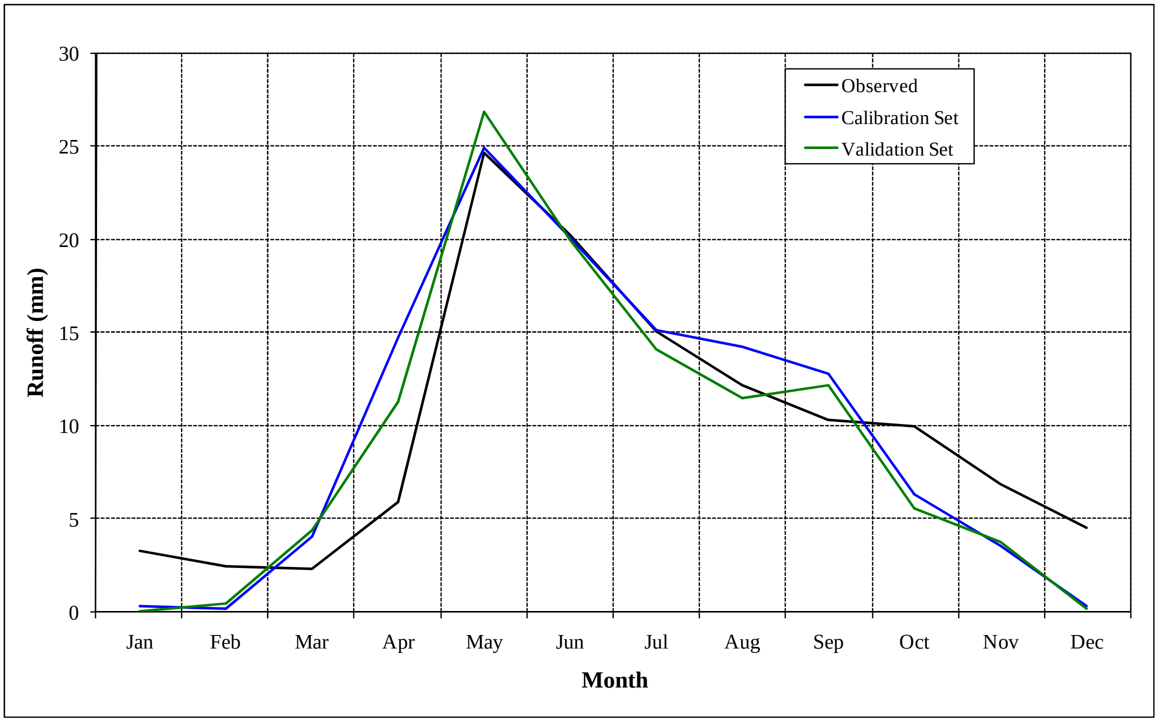
The runoff production rate is the ratio of water depth from rainfall or snowmelt that generates a runoff. This rate is a calibration parameter that is indicative of the retention capacity of that watershed. A low runoff production rate would suggest a longer retention time because of the larger losses from evapotranspiration and infiltration. Runoff production rates, P_m, for use in the daily water balance model were established on a monthly basis (m = 1 to 12).

Runoff production rates for the winter period (November to March) were assumed equal to 1, since the ground is presumed frozen and has therefore no retention. This implies that all of the rainfall in these months would contribute to runoff, even though some of the water would likely be retained by the snowpack. From April to October, the rates were assumed to be roughly equivalent to a runoff coefficient. Runoff production rates during the freshet were assumed to be higher than those of the summer/fall months due to the presumed saturated conditions of the soil, which would be indicative of a lower retention capacity.

The model did not account for overland and channel routing. The model also neglects the storage of melt in the snowpack, micro-topography, and small lakes.

The daily water balance model estimates maximum daily runoff rates based on daily air temperature, rainfall and snowfall data collected at The Pas station from 1951 to 2007, adjusted to the Minago Project site location. A total of 60% of the data were employed for the calibration of the model, while the remaining 40% were used as a validation set. Model calibration consisted of adjusting the assumed values for M_f, T_b and P_m until computed watershed monthly runoff depths were in general agreement with those presented for the Minago River and Oakley Creek watersheds in Table 7.4-13.

Figure 7.4-8 compares the observed and predicted (calibration and validation sets) watershed runoff on a monthly basis. The predicted runoffs were obtained by setting M_f and T_b equal to 0.9 mm/°/day and 2.5 ^oC, respectively. The runoff production rates, P_m, were set equal to 1 from November to March, 0.26 from April to June, and 0.19 from July to October. The estimated annual runoff for the Minago and Oakley watersheds is 117 mm, while the model predicted values were 117 mm and 110 mm, respectively for the calibration and validation data sets.



Source: Golder Associates, 2009

Figure 7.4-8 Comparison of Predicted and Observed Water Yield in the Degree-Day Model

The developed degree-day model is limited in its capacity to predict runoff from December to March. Only runoff from rainfall is accounted for; however, groundwater flow would be a significant contributor to runoff during the winter. It is also understood that applying monthly runoff production rates represent a simplified formulation of runoff generation processes. Production rates may vary significantly on a daily basis. In subsequent stages of the mine project, the predictions of runoff from this model should be confirmed with the use of a continuous watershed runoff model that includes a comprehensive formulation of hydrologic processes for the generation of flows (i.e., surface, interflow and groundwater) (Golder Associates, 2009).

Following model calibration, the annual maximum daily runoff depths, which are the water depths from rainfall and snowmelt weighted by the runoff production rates, were obtained from the model for the freshet and summer/fall periods. The runoff depths were then used in a frequency analysis to determine runoff depths for selected return periods for small watersheds (Table 7.4-16). As indicated, the resulting productivity estimates are higher than those from the regional analysis of peaks presented in Tables 7.4-14 and 7.4-15.

Table 7.4-16 Flood Frequency Estimates for Smaller Study Area Watersheds

Period	Peak Daily Runoff (mm)			Peak Daily Productivity (L/s/km^2)		
	2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
Freshet (Apr-May)	4.1	7.7	15.6	48	89	181
Summer/Fall (Jun-Oct)	2.8	5.4	10.4	33	62	120

Source: Golder Associates, 2009

7.4.5.5.3 Local Area Peak Discharges

The estimation of peak discharges for watersheds in the vicinity of the proposed project site combine the result of the regional analysis (larger watersheds) and daily water balance model (smaller watersheds) as follows:

- The productivity obtained from the frequency analysis of daily runoff (Table 7.4-16) was considered applicable to the smallest monitored watershed in the vicinity of the proposed project site (Oakley Creek at OCW2; 93 km^2);
- Peak productivity for watersheds in the vicinity of the project site that are larger than the Footprint River watershed (643 km^2) were assumed to be equal to the maximum values observed at Footprint, Gunisao and Burntwood River;
- Peak productivity for intermediate watersheds was obtained through linear interpolation as a function of surface area; and
- Peak discharges were then obtained by multiplying the resulting productivity by the watershed area.

The corresponding peak discharges and productivities for the watersheds in the vicinity of the proposed project site are provided in Tables 7.4-17 and 7.4-18 for the freshet and summer/fall periods, respectively.

Table 7.4-17 Flood Frequency Estimates for Local Study Area Watersheds during the Freshet Period

Station Name	Watershed Area (km^2)	Peak Discharge (m^3/s)			Peak Productivity ($L/s/km^2$)		
		2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
OCW2	93	4.4	8.3	16.7	47.7	89.2	180.7
OCW1	123	5.8	10.6	21.4	47.0	85.9	173.1
OCAWR	303	11.0	20.1	39.1	36.2	66.4	129.0
MRW2	214	8.8	16.3	32.3	41.0	76.1	151.0
MRW1	716	12.2	20.1	30.6	17.0	28.2	42.8
MRW3	785	13.3	22.1	33.6	17.0	28.2	42.8
WRAR	654	11.1	18.4	28.0	17.0	28.2	42.8
WRW2x	815	13.8	22.9	34.9	17.0	28.2	42.8
WRAOC	836	14.2	23.5	35.8	17.0	28.2	42.8
WRW1x	1,139	19.3	32.1	48.7	17.0	28.2	42.8
HRW1	1,512	25.7	42.6	64.7	17.0	28.2	42.8

Source: Golder Associates, 2009

Table 7.4-18 Flood Frequency Estimates for Local Study Area Watersheds during the Summer/Fall Period

Station Name	Watershed Area (km^2)	Peak Discharge (m^3/s)			Peak Productivity ($L/s/km^2$)		
		2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
OCW2	93	3.1	5.8	11.1	33.0	62.5	120.2
OCW1	123	4.0	7.4	14.2	32.5	60.1	115.4
OCAWR	303	7.5	14.0	26.3	24.8	46.3	86.9
MRW2	214	6.0	11.4	21.6	28.2	53.2	101.0
MRW1	716	7.9	13.8	22.3	11.1	19.2	31.1
MRW3	785	8.7	15.1	24.4	11.1	19.2	31.1
WRAR	654	7.2	12.6	20.4	11.1	19.2	31.1
WRW2x	815	9.0	15.7	25.4	11.1	19.2	31.1
WRAOC	836	9.2	16.1	26.0	11.1	19.2	31.1
WRW1x	1,139	12.6	21.9	35.4	11.1	19.2	31.1
HRW1	1,512	16.7	29.1	47.1	11.1	19.2	31.1

Source: Golder Associates, 2009

7.4.5.5.4 Low Flows

A frequency analysis was performed on the 7-day low flow series observed at the regional hydrometric stations during the ice-cover period from November to March and open water period from April to October. The results of the frequency analysis are given in Tables 7.4-19 (ice-cover period) and 7.4-20 (open water period).

Low flow characteristics are typically indicative of the watershed contribution from interflow and groundwater flow. These two types of flows would be a function of the water retention in a watershed, based on the amount of lake, wetland and absorbing vegetation. Watersheds with significant amount of wetland (Grass, Footprint, Gunisao and Burntwood Rivers)) generally show higher productivity in Tables 7.4-19 and 7.4-20 for the 2- and 10-year events than those with lesser amount of wetland area (Sapochi, Taylor and Odei Rivers). Productivity is more variable for the 100-year events.

Table 7.4-19 Seven-Day Low Flows at Regional Stations during the Ice-Cover Period

Station Name	Watershed Area (km^2)	7-Day Low Flow (m^3/s)			Productivity ($L/s/km^2$)		
		2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
Sapochi River near Nelson House	391	0.23	0.13	0.09	0.59	0.34	0.23
Taylor River near Thompson	886	0.7	0.33	0.12	0.74	0.38	0.13
Odei River near Thompson	6,110	3.1	1.2	0.22	0.51	0.19	0.04
Grass River at Wekusko Falls	3,260	7.8	3.2	0.001	2.40	0.99	0.0003
Grass River above Standing Stone Falls	15,400	44.0	22.2	10.5	2.85	1.44	0.68
Footprint River above Footprint Lake	643	1.3	0.66	0.11	2.02	1.02	0.18
Gunisao River at Jam Rapids	4,800	3.9	1.8	0.77	0.81	0.37	0.16
Burntwood River above Leaf Rapids	5,810	4.0	2.5	2.0	0.69	0.43	0.35

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008d)).

Table 7.4-20 Seven-Day Low Flows at Regional Stations during the Open-Water Period

Station Name	Watershed Area (km^2)	7-Day Low Flow (m^3/s)			Productivity ($L/s/km^2$)		
		2-Year	10-Year	100-Year	2-Year	10-Year	100-Year
Sapochi River near Nelson House	391	0.37	0.19	0.15	0.95	0.49	0.38
Taylor River near Thompson	886	0.75	0.084	0.015	0.84	0.10	0.02
Odei River near Thompson	6,110	14.7	6.6	4.0	2.40	1.07	0.66
Grass River at Wekusko Falls	3,260	7.3	3.1	0.23	2.25	0.95	0.07
Grass River above Standing Stone Falls	15,400	36.0	19.0	7.9	2.34	1.24	0.51
Footprint River above Footprint Lake	643	1.3	0.42	0.001	2.02	0.66	0.00
Gunisao River at Jam Rapids	4,800	8.1	2.7	0.59	1.70	0.55	0.12
Burntwood River above Leaf Rapids	5,810	11.5	3.6	1.1	1.98	0.62	0.18

1. Data source: Golder Associates, 2009 (Secondary source: EC (2008d)).

Based on wetland and vegetation characteristics, it was assumed that the low flow conditions in the Footprint, Gunisao and Burntwood River watersheds are similar to those in the area of the Minago Project. Productivity in that area was assumed to be equal to the average productivity estimated for the Footprint, Gunisao and Burntwood River watersheds. These average productivity values are respectively 1.17, 0.61 and 0.23 $L/s/km^2$ for the 2-, 10- and 100-year ice-cover low flow, and 1.90, 0.61 and 0.10 $L/s/km^2$ for 2-, 10- and 100-year open water low flow (Tables 7.4-19 and 7.4-20).

Local low flows may be obtained by multiplying productivity by the watershed area. The corresponding low flows are provided in Tables 7.4-21 and 7.4-22, respectively for the ice-cover and open water periods.

7.4.5.6 Sediment Yield

Sediment yield from a watershed is affected by climatic, hydrologic, and geomorphic characteristics including precipitation, vegetation cover (especially wetlands), basin runoff, land use, topography, drainage density, sediment storage, sediment transport capacity, and soil erodibility. Accurate determination of basin sediment yield requires rigorous and continuous measurements of the bed load, suspended load, and the amount of dissolved sediment in a receiving stream.

Table 7.4-21 Seven-Day Low Flows at Local Stations during the Ice-Cover Period

Station Name	Watershed Area (km^2)	7-Day Low Flow (m^3/s)		
		2-Year	10-Year	100-Year
OCW2	93	0.11	0.057	0.021
OCW1	123	0.14	0.075	0.028
MRW2	214	0.25	0.13	0.049
OCAWR	303	0.36	0.18	0.069
WRAR	654	0.8	0.40	0.15
MRW1	716	0.8	0.44	0.16
MRW3	785	0.9	0.48	0.18
WRW2x	815	1.0	0.50	0.19
WRAOC	836	1.0	0.51	0.19
WRW1x	1,139	1.3	0.69	0.26
HRW1	1,512	1.8	0.9	0.34

Source: Golder Associates, 2009

Table 7.4-22 Seven-Day Low Flows at Local Stations during the Open-Water Period

Station Name	Watershed Area (km^2)	7-Day Low Flow (m^3/s)		
		2-Year	10-Year	100-Year
OCW2	93	0.18	0.057	0.010
OCW1	123	0.23	0.075	0.013
MRW2	214	0.41	0.13	0.022
OCAWR	303	0.58	0.18	0.031
WRAR	654	1.2	0.40	0.07
MRW1	716	1.4	0.44	0.07
MRW3	785	1.5	0.48	0.08
WRW2x	815	1.5	0.50	0.08
WRAOC	836	1.6	0.51	0.09
WRW1x	1,139	2.2	0.69	0.12
HRW1	1,512	2.9	0.9	0.16

Source: Golder Associates, 2009

However, such rigorous measurement programs are rare, and most of the basin sediment yields are approximated based on discontinuous (spot) measurements of the suspended sediment load.

Table 7.4-23 presents an estimate of sediment yield over a 6-month period for the local (i.e., Hargrave, Minago and William Rivers and Oakley Creek) and regional watersheds. The estimate considers the following:

- The yield is estimated from May to October, which was the sampling period at the local watersheds in 2006 and 2007;
- The annual yield is considered to be similar to the calculated semi-annual yield because very little sediment is generated during the winter months;
- The TSS samples below the detection limits were set equal to half the detection limit value;
- The TSS yield in mg/L is equal to the average of the water samples; and
- Sediment density has been assumed to be 2,650 kg/m^3.

Table 7.4-23 Estimates of Semi-Annual Sediment Yield

River	Station Name	Drainage Area (km^2)	Number of Years of Data Available	Estimated Annual Yield ~ Calculated Semi-annual Sediment Yield	
				(mg/L)	(mm)
Regional Rivers	Taylor River near Thompson	886	6	39.1	0.0019
	Odei River near Thompson	6,110	4	47.2	0.0024
	Burntwood River above Three Point Lake	6,670	6	32.4	0.0011
Oakley Creek	OCW3	43	2	1.1	<0.0001
	OCW2	93	2	2.0	0.0001
	OCW1	123	2	3.0	0.0001
Minago River	MRW2/2x	214	1	4.0	0.0001
	MRW1	716	2	2.0	0.0001
	MRW3	785	1	3.0	0.0001
William River	WRW2x	815	1	30.4	0.0009
	WRW1x	1,139	1	17.6	0.0005
Hargrave River	HRW1	1,512	1	26.6	0.0007

Source: Golder Associates, 2009

From Table 7.4-23, the following observations may be made:

- The low yields at Oakley Creek and Minago River are indicative of lower land erosion in their watersheds compared to the watersheds of the other local and regional rivers.
- The lower yield at WRW1x than that at WRW2x would likely result from the low loadings coming from Oakley Creek. WRW1x is downstream of the confluence of Oakley Creek and William River.

7.4.6 Minago's Wetlands and some of their Characteristics

The study area is a relatively flat, low-lying region with extensive wetlands. The poorly drained bogs located within the study area consist essentially of treed bogs (Figure 7.4-9). The tree stratum is dominated by black spruce (*Picea mariana*) and tamarack (*Larix laricina*). The shrub stratum is dominated by shrub birch (*Betula glandulosa*) and bog rosemary (*Andromeda glaucophylla*). Bog sedge (*Carex magellanica*) and swamp horsetail (*Equisetum fluviatile*) are among the dominant herbs. The nonvascular stratum is dominated by peat moss (*Sphagnum* spp.) and feather mosses (*Helodium blandowii*, *Pleurozium schreberi*, etc.) (URS, 2008d).

Source: Roche, 2008a

Figure 7.4-9 Treed Bog

Other than being one of the most important components of the regional landscape, wetlands play a role that no other ecosystem can since they act as natural water treatment plants. Wetlands tend to slow down the force of water, encouraging the deposition of sediments carried in the water. This is beneficial further downstream where deposition of sediments may block waterways. Nutrients are often associated with sediments and can be deposited at the same time. These nutrients may accumulate in the sub-soil, be transformed by chemical and biological processes or be taken up by wetland vegetation. Moreover, by storing the water in the soil or retaining it in the surface waters of lakes, marshes, etc., wetlands reduce the need for expensive engineered structures. Wetland vegetation also plays a role in slowing down the flow of water and may reduce the thermal impact that discharge of relatively warm water would have on stream habitats (Roche, 2010).

Many wetland plants have the capacity to remove toxic substances that have come from pesticides, industrial discharges and/or mining activities. Some wetland plants have been found to accumulate heavy metals in their tissues at 100,000 times the concentration in the surrounding water and can detoxify certain kinds of effluent (Ramsar, 2000). Some *Typha* and *Phragmites* species have been used to treat effluents from mining areas that contain high concentrations of heavy metals such as cadmium, zinc, mercury, nickel, copper and vanadium (Higgins and Mattes, 2003) and to treat waters running off roads and highways (Sérodes et al., 2003).

Indeed, wetlands have several functions that aid in the removal of metals in waters. These characteristics are required for certain processes to occur: adsorption and ion exchange, bioaccumulation, bacterial and abiotic oxidation, sedimentation, neutralization, reduction, and dissolution of carbonate minerals (Perry and Kleinmann, 1991; Kadlec and Wallace, 2008).

Wetlands have organic-rich substrates, which exchange dissolved metals. This exchange occurs between the dissolved metals and abundant humic and fulvic acids contained within the substrate (Wildeman et al., 1991). Moreover, especially in bogs, *Sphagnum*'s cation exchange capacity (CEC) is one of the most important mechanisms by which dissolved metals are adsorbed and represents the capacity of a soil to exchange and retain positively charged ions (cations). *Sphagnum* mosses, the main components of peat deposit, are essentially made of polysaccharides (many saccharide units linked by glycosidic bonds) which provide a high CEC and, by the way, a high acidifying capacity (van Breeman, 1995). The high CEC enables an efficient retention of nutrients from the surrounding environment (air and plant decomposition) coupled with the release of H^+ ions. CEC is also an indicator of a soil's capacity to prevent potential contamination of groundwater and surface water since cations such as arsenic, copper, iron, nickel, lead and zinc may also be retained within the peat deposit (Roche, 2010).

Wetland sediments are generally anoxic or anaerobic below a thin oxidized surface layer and contain organic carbon for microbial growth. The anoxic zone of the sediments provides conditions, which favour microbial and chemical reducing processes. Soluble metals are converted to insoluble forms by the anoxic conditions of wetland sediments. Settling of suspended solids occurs from water velocity control by the wetland's vegetation (Ramsar, 2000).

Processes within natural wetlands have been found to remediate contaminants contained in acid rock drainage (ARD). Kleinmann (1985) found that iron concentrations dropped from 20-25 mg/L to 1 mg/L, manganese concentrations dropped from 30-40 mg/L to 2 mg/L in a *Typha* wetland. *Sphagnum* spp. may also have a significant effect on concentrations of iron, manganese, sulfate, and other mineral concentrations (Kleinmann, 1985; Weider et al., 1985). Plant roots will retain arsenic and other metals (Sobolewski, 1997). Plants also generate microenvironments that assist in the reduction and oxidation processes (Wildeman et al., 1991).

Gabor et al. (2004) and others have demonstrated that wetlands can efficiently remove contaminants from runoff water. Gabor et al. (2004) reported that artificial wetlands have reduced total nitrogen (by 30 to 87%), total phosphorous (by 4 to 90%), suspended solids (by 45 to 99%) and pathogen contents (by 61 to 99%) in waters passing through them. Halverson (2004) reported that wetlands to reduced metal contents by 36 to 98% in runoff waters that contained Ag, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn.

7.4.7 Effects Assessment Methodology

7.4.7.1 Scope of Assessment

Issues and Selection of Valued Ecosystem and Cultural Components (VECCs)

The open pit mine and the industrial complex will be located in the headwaters of Oakley Creek.

It is VNI’s intention to concentrate the project footprint and associated effects on hydrology, as much as possible, within the Oakley Creek and Minago River drainages and to manage impacts to minimize downstream effects.

The surface water hydrology was identified as a VECC for the project assessment as it is a key factor with respect to both project design and operation and associated environmental effects. Issues of concern with respect to hydrology include:

- water availability for project use (domestic and process water uses);
- input to project water balance during all project phases including closure (such as long-term saturation of ultramafic rock for ARD management);
- design of site water management facilities (sizing of diversion and drainage ditches, settling ponds, culverts);
- assimilative capacity of surface waters for project-related discharges; and
- availability of physical instream habitat for fish and aquatic life.

Based on the above, Environmental Baseline Studies were conducted and presented to government agencies and Communities of Interest (COI) and the following factors, detailed in Table 7.4-24, were selected for further analysis to characterize and assess project effects on the surface water hydrology VECC.

Table 7.4-24 Hydrologic Processes Analyzed, VECC Selection Rationale, and Data Sources

Parameter	Rationale for Selection	Linkage to Regulatory Drivers	Baseline Data for EIS
Runoff (mean annual and mean monthly stream flow)	• Key input to stream flow analysis • Influences sediment	• Identified in Environmental Baseline Studies (EBS)	• Project field manual and automated data collection • Water Survey of Canada regional hydrology data • Climate data and climatic modeling of precipitation
Peak/flood flows (magnitude and timing)	• Required for water management facility and stream crossing designs • Affects stream channels (stability and morphology) and sediment transport • Floods are a natural hazard that must be considered in project design	• Identified in EBS Work plan	• Field data • Regional data • Flood frequency modeling
Low flows (magnitude and timing)	• Affects water quality and assimilative capacity of streams for project effluents • Affects instream habitat for fish and aquatic life • Affects availability of water for processing and camp use	• Identified in EBS Work plan	• Field data • Regional data • Low flow modeling
Evaporation	• Affects water levels in TWRMF and other storage facilities • Evaporation affects site water balance	• Identified in EBS Work	• Regional data • Modeling
Snowmelt rate	• Together with rainfall, snowmelt forms the principal hydrologic inputs to the system	• Identified in EBS Work	• Regional data • Field data • Modeling

Temporal Boundaries

Baseline data collection in the project area began in 2006 with the identification of drainages of interest. Regional hydrometric data from Water Survey of Canada was also used to supplement this data.

The assessment timeframe includes the period of record for applicable baseline data collection stations; project construction, operation and decommissioning, and the closure period up to the time when the groundwater table in the pit area will have been reestablished and contributions to stream base flows will have stabilized. It is planned that additional manual and automated data collection will be installed throughout the project life, using the established station network.

Study Area

With respect to surface water hydrology, there are three scales of interest: site-specific, local and regional. The site-specific scale covers areas directly affected or potentially directly affected by the mine and associated infrastructure. This includes the headwaters of Oakley Creek.

The local scale includes the entire drainages of Oakley Creek, and the Minago and William Rivers. The local scale covers an area that is larger area than the site-specific area. The site-specific scale and local scale together comprise the Local Study Area (LSA), in which hydrology will affect and be affected by the project design. The Regional Area includes the headwaters of William River and Hargrave Rivers.

7.4.7.2 Determination of Effects Significance

The significance of residual project and cumulative effects will be determined based on the defined effects attributes. An effect will be considered significant, if it is:

- an adverse effect of high likelihood, moderate magnitude and that is far future in duration or irreversible;
- an adverse effect of high likelihood and high magnitude, unless it is local in geographic extent and short- to long-term in duration;
- an adverse effect of high likelihood and high magnitude, that is local in geographic extent and far future in duration or irreversible.

Otherwise, effects will be rated as not significant.

7.4.8 Project Effects

Effect attributes for the assessment of the surface water hydrology are summarized in Table 7.4-25. There are several ways in which the project can potentially affect surface water hydrology throughout the life of the project:

Table 7.4-25 Effect Attributes for Surface Water Hydrology

Attribute	Definition
	Direction
Positive	Condition of VECC is improving.
Adverse	Condition of VECC is worsening or is not acceptable.
Neutral	Condition of VECC is not changing in comparison to baseline conditions and trends.
	Magnitude
Low	Effect occurs that might or might not be detectable, but is within the range of natural variability and does not compromise ecological, economic or social/cultural values.
Moderate	Clearly an effect but unlikely to pose a serious risk to the VECC or represent a management challenge from an ecological, economic or social/cultural standpoint.
High	Effect is likely to pose a serious risk to the VECC and represents a management challenge from an ecological, economic or social/cultural standpoint.
	Geographic Extent
Site-specific	Effect on VECC confined to a single small area within the Local Study Area (LSA).
Local	Effect on VECC within Local Study Area (LSA).
Regional	Effect on VECC extends into the Regional Study Area (RSA).
	Duration [1]
Short term	Effect on VECC is limited to the <1 year.
Medium term	Effect on VECC occurs between 1 and 4 years.
Long term	Effect on VECC lasts longer than 4 years but does not extend more than 10 years after decommissioning and final reclamation.
Far future [2]	Effect on VECC extends >10 years after decommissioning and abandonment.
	Frequency (Short Term duration effects that occur more than once)
Low	Effect on VECC occurs infrequently (< 1 day per month).
Moderate	Effect on VECC occurs periodically (seasonal or several days per month).
High	Effect on VECC occurs frequently throughout the year (weekly).
	Reversibility
Reversible	Effect on VECC will cease to exist during or after the project is complete.
Irreversible	Effect on VECC will persist during and/or after the project is complete.
	Likelihood of Occurrence
Unknown	Effect on VECC is not well understood and based on potential risk to the VECC, effects will be monitored and adaptive management measures taken, as appropriate.
High	Effect on VECC is well understood and there is a high likelihood of effect on the VECC as predicted.

Notes:

1 Reclamation goals are to approximate original (pre-mine) climate and hydrology within the range of natural variability or to approximate regional climate, if post-operational regional climate differs from pre-operational regional climate.

2 Effects to some VECCs may be permanent (see reversibility).

- **Water Use for Domestic and Industrial Purposes** – There will be no direct extraction of water from surface water bodies for project use during the operations phase. Potable water will be supplied from deep aquifer wells. The majority of water for ore processing will come from pit dewatering wells and reclaim water originating from the Polishing Pond (PP). The PP, in turn, will be fed by discharge from the Tailings and Waste Rock Management Facility (TWRMF), dewatering wells and other point sources. Water supplied from deep aquifers for the project will not result in a drawdown or dewatering of the Oakley Creek or the Minago River and thus will not affect the surface water hydrology (Golder Associates, 2008b). Additional information is provided in Section 7.6.
- **Project Site and Transportation Corridors Clearing and Soil Compaction** – Removal of vegetation and site development causes reduced transpiration, increased soil moisture and decreased infiltration leading to increased site runoff. The potential effect of increased runoff on stream flows will be minimal as the disturbed area is very small in comparison to the total drainage areas and site water management will further minimize potential of effects (see below).
- **Project Site Water Management** – Clean water diversions around facility sites, site drainage collection ditches and settling ponds will minimize potential effects of ground surface disturbance on runoff and stream flows in the project area.
- **Transportation Corridors Development** – Transportation corridor (Road) ditches will intercept shallow subsurface flow and will bring it to the surface. Road surfaces become compacted and relatively impermeable, reducing infiltration of precipitation. Road ditches and drainage structures form preferred pathways for drainage, hastening runoff. The density of roads that will be built is low (far less than 1 km of road length per square kilometre of drainage area), which indicates that the overall contribution of the road drainage network to watershed runoff will not be significant. Increased runoff from road development is not expected to affect peak flows in local streams. Road drainage structures and stream crossings will be appropriately sized for passing design flows and will be capable of passing bed load sediment of the size range normally transported by the streams.
- **Snow plowing** – Piling up of snow, compaction by vehicle travel, and introduction of sediment, particularly dust, to the snowpack in the vicinity of the project site and transportation corridors, will result in both more rapid snowmelt (in the case of dirty snow) and slower snowmelt (in the case of compacted or piled snow). Localized changes in the snowpack melt rate resulting from more rapid melting, and slower melting, will be small and should cancel each other out. No measurable effects on peak flows during spring freshet are expected.
- **Mine dewatering affecting flows in the Minago River and Oakley Creek** – Open pit mine development will intercept groundwater flows, primarily in the Oakley Creek basin. The process waters will be conveyed to the TWRMF, and subsequently, the TWRMF discharge and excess dewatering well water will be collected in the Polishing Pond (PP). Water from the PP will either be recycled to the process plant or discharged to Oakley Creek and Minago River in the spring, summer and fall months (May – October) and discharged to the

Minago River watershed in the winter months (November to April). VNI does not contemplate to discharge PP water to Oakley Creek during the winter months, because the creek is frozen solid during those months. At full development, Polishing Pond discharges could potentially result in measurable flow increases in Oakley Creek and the Minago River.

- **Polishing Pond Discharges to the Minago River and Oakley Creek** – Excess water accumulated in the PP will be discharged into Oakley Creek and Minago River. This stream is termed as final effluent. Therefore, its flow is the one at which water will be entering the discharge pipeline. From May to October, the final effluent will be discharged to both the Minago River (70%) and the Oakley Creek (30%). From November to April, water will only be discharged to the Minago River.

  From May to October, the final effluent will first be discharged in a treed bog before being collected by the Oakley Creek or the Minago River. The receiving treed bog will be upstream of the Minago River Bridge for the case of the Minago River discharge point and the discharge point for the Oakley Creek watershed will be through an existing discharge ditch. From November to April, the final effluent will be discharged in a rock-filled channel before being released to the Minago River.

7.4.8.1 Seasonal Issues

As water will not be discharged consistently in one place over the year, there might be some impacts on the receiving environment. The following sections describe those impacts and provide an evaluation of their potential and importance.

7.4.8.1.1 Impacts on Hydrological Conditions

The boreal region, which encompasses the study area, has a subarctic climate that is subject to considerable inter-annual variability. Climate influences the seasonal stream flow regime, which typically exhibits winter low flow, terminated by spring freshet, followed by summer flow recession. Therefore, three periods of time have been considered for this analysis: the winter low flow period, from November to April, the spring freshet, in May, and the summer flow period, from June to October. Water flows were measured in the Oakley Creek and the Minago River for these three periods as part of the Environmental Baseline Studies.

In terms of hydrology, the impact of discharging a significant volume of water every day in a stream can be quite important, especially if the volume of water being discharged causes an increase in the stream flow that exceeds the stream's natural capacity, i.e. the stream high-water flow associated with the spring freshet.

Table 7.4-26 details the predicted flow increases as the final effluent will be discharged in the receiving Oakley Creek and Minago River while Table 7.4-27 presents the associated increases in water depth. Figures 7.4-10 and 7.4-11 illustrate the relation between those two parameters for both receiving watercourses.

For the Minago project, water being discharged in the Oakley Creek and the Minago River from June to April will not increase the stream flow up to a level exceeding the high-water flow, which,

Table 7.4-26 Projected Flow Rates (m^3/s) as the Final Effluent will be Discharged in the Receiving Watercourses

Flow (m^3/s)	Year 1			Year 2			Year 3			Year 4		
	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October
Minago River - Upstream	0.80	10.00	1.90	0.80	10.00	1.90	0.80	10.00	1.90	0.80	10.00	1.90
Discharge to Minago River	0.24	0.97	0.36	0.29	1.04	0.36	0.29	1.02	0.36	0.29	1.00	0.36
Minago River - Downstream	1.04	10.97	2.26	1.09	11.04	2.26	1.09	11.02	2.26	1.09	11.00	2.26
Oakley Creek - Upstream	0.00	4.00	0.50	0.00	4.00	0.50	0.00	4.00	0.50	0.00	4.00	0.50
Discharge to Oakley Creek	0.00	0.41	0.15	0.00	0.45	0.15	0.00	0.44	0.15	0.00	0.43	0.15
Oakley Creek - Downstream	0.00	4.41	0.65	0.00	4.45	0.65	0.00	4.44	0.65	0.00	4.43	0.65
Increase in Minago River	31%	10%	19%	36%	10%	19%	36%	10%	19%	36%	10%	19%
Increase in Oakley Creek	0%	10%	31%	0%	11%	31%	0%	11%	31%	0%	11%	31%

Flow (m^3/s)	Year 5			Year 6			Year 7			Year 8		
	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October
Minago River - Upstream	0.80	10.00	1.90	0.80	10.00	1.90	0.80	10.00	1.90	0.80	10.00	1.90
Discharge to Minago River	0.29	0.97	0.36	0.29	0.95	0.36	0.29	0.92	0.36	0.29	0.91	0.36
Minago River - Downstream	1.09	10.97	2.26	1.09	10.95	2.26	1.09	10.92	2.26	1.09	10.91	2.26
Oakley Creek - Upstream	0.00	4.00	0.50	0.00	4.00	0.50	0.00	4.00	0.50	0.00	4.00	0.50
Discharge to Oakley Creek	0.00	0.42	0.15	0.00	0.41	0.15	0.00	0.40	0.15	0.00	0.39	0.15
Oakley Creek - Downstream	0.00	4.42	0.65	0.00	4.41	0.65	0.00	4.40	0.65	0.00	4.39	0.65
Increase in Minago River	36%	10%	19%	36%	9%	19%	36%	9%	19%	36%	9%	19%
Increase in Oakley Creek	0%	10%	31%	0%	10%	31%	0%	10%	31%	0%	10%	31%

Flow (m^3/s)	Year 9			Year 10			Closure			Year 12		
	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October
Minago River - Upstream	0.80	10.00	1.90	0.80	10.00	1.90	0.80	10.00	1.90	0.80	10.00	1.90
Discharge to Minago River	0.04	0.12	0.07	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minago River - Downstream	0.84	1.12	1.97	0.80	10.00	1.90	0.80	10.00	1.90	0.80	10.00	1.90
Oakley Creek - Upstream	0.00	4.00	0.50	0.00	4.00	0.50	0.00	4.00	0.50	0.00	4.00	0.50
Discharge to Oakley Creek	0.00	0.00	0.00	0.00	0.37	0.07	0.00	0.00	0.00	0.00	0.00	0.00
Oakley Creek - Downstream	0.00	4.00	0.50	0.00	4.37	0.57	0.00	4.00	0.50	0.00	4.00	0.50
Increase in Minago River	5%	1%	4%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Increase in Oakley Creek	0%	0%	0%	0%	9%	14%	0%	0%	0%	0%	0%	0%

Flow (m^3/s)	Year 13		
	November - April	May	June - October
Minago River - Upstream	0.80	10.00	1.90
Discharge to Minago River	0.00	0.00	0.00
Minago River - Downstream	0.80	10.00	1.90
Oakley Creek - Upstream	0.00	4.00	0.50
Discharge to Oakley Creek	0.00	0.00	0.00
Oakley Creek - Downstream	0.00	4.00	0.50
Increase in Minago River	0%	0%	0%
Increase in Oakley Creek	0%	0%	0%

Table 7.4-27 Projected Water Depths (m) as the Final Effluent will be Discharged in the Receiving Watercourses

Water level (m)	Year 1			Year 2			Year 3			Year 4		
	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October
Minago River - Upstream	0.44	1.76	0.72	0.44	1.76	0.72	0.44	1.76	0.72	0.44	1.76	0.72
Discharge to Minago River	0.22	0.49	0.28	0.24	0.52	0.28	0.24	0.51	0.28	0.24	0.50	0.28
Minago River - Downstream	0.52	1.84	0.80	0.53	1.85	0.80	0.53	1.85	0.80	0.53	1.85	0.80
Oakley Creek - Upstream	0.00	1.24	0.41	0.00	1.24	0.41	0.00	1.24	0.41	0.00	1.24	0.41
Discharge to Oakley Creek	0.00	0.37	0.21	0.00	0.39	0.21	0.00	0.38	0.21	0.00	0.38	0.21
Oakley Creek - Downstream	0.00	1.30	0.48	0.00	1.31	0.48	0.00	1.31	0.48	0.00	1.31	0.48
Increase in Minago River	17%	5%	10%	19%	5%	10%	19%	5%	10%	19%	5%	10%
Increase in Oakley Creek	0%	5%	16%	0%	5%	16%	0%	5%	16%	0%	5%	16%

Water level (m)	Year 5			Year 6			Year 7			Year 8		
	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October
Minago River - Upstream	0.44	1.76	0.72	0.44	1.76	0.72	0.44	1.76	0.72	0.44	1.76	0.72
Discharge to Minago River	0.24	0.50	0.28	0.24	0.49	0.28	0.24	0.48	0.28	0.24	0.48	0.28
Minago River - Downstream	0.53	1.84	0.80	0.53	1.84	0.80	0.53	1.84	0.80	0.53	1.84	0.80
Oakley Creek - Upstream	0.00	1.24	0.41	0.00	1.24	0.41	0.00	1.24	0.41	0.00	1.24	0.41
Discharge to Oakley Creek	0.00	0.37	0.21	0.00	0.37	0.21	0.00	0.36	0.21	0.00	0.36	0.21
Oakley Creek - Downstream	0.00	1.30	0.48	0.00	1.30	0.48	0.00	1.30	0.48	0.00	1.30	0.48
Increase in Minago River	19%	5%	10%	19%	5%	10%	19%	5%	10%	19%	5%	10%
Increase in Oakley Creek	0%	5%	16%	0%	5%	16%	0%	5%	16%	0%	5%	16%

Water level (m)	Year 9			Year 10			Closure			Year 12		
	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October	November - April	May	June - October
Minago River - Upstream	0.44	1.76	0.72	0.44	1.76	0.72	0.44	1.76	0.72	0.44	1.76	0.72
Discharge to Minago River	0.08	0.15	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Minago River - Downstream	0.46	1.77	0.74	0.44	1.76	0.72	0.44	1.76	0.72	0.44	1.76	0.72
Oakley Creek - Upstream	0.00	1.24	0.41	0.00	1.24	0.41	0.00	1.24	0.41	0.00	1.24	0.41
Discharge to Oakley Creek	0.00	0.00	0.00	0.00	0.35	0.13	0.00	0.00	0.00	0.00	0.00	0.00
Oakley Creek - Downstream	0.00	1.24	0.41	0.00	1.30	0.44	0.00	1.24	0.41	0.00	1.24	0.41
Increase in Minago River	3%	1%	2%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Increase in Oakley Creek	0%	0%	0%	0%	4%	7%	0%	0%	0%	0%	0%	0%

Water level (m)	Year 13		
	November - April	May	June - October
Minago River - Upstream	0.44	1.76	0.72
Discharge to Minago River	0.00	0.00	0.00
Minago River - Downstream	0.44	1.76	0.72
Oakley Creek - Upstream	0.00	1.24	0.41
Discharge to Oakley Creek	0.00	0.00	0.00
Oakley Creek - Downstream	0.00	1.24	0.41
Increase in Minago River	0%	0%	0%
Increase in Oakley Creek	0%	0%	0%

Figure 7.4-10 Relationship between Flow Rate and Water Depth in the Minago River with Discharge

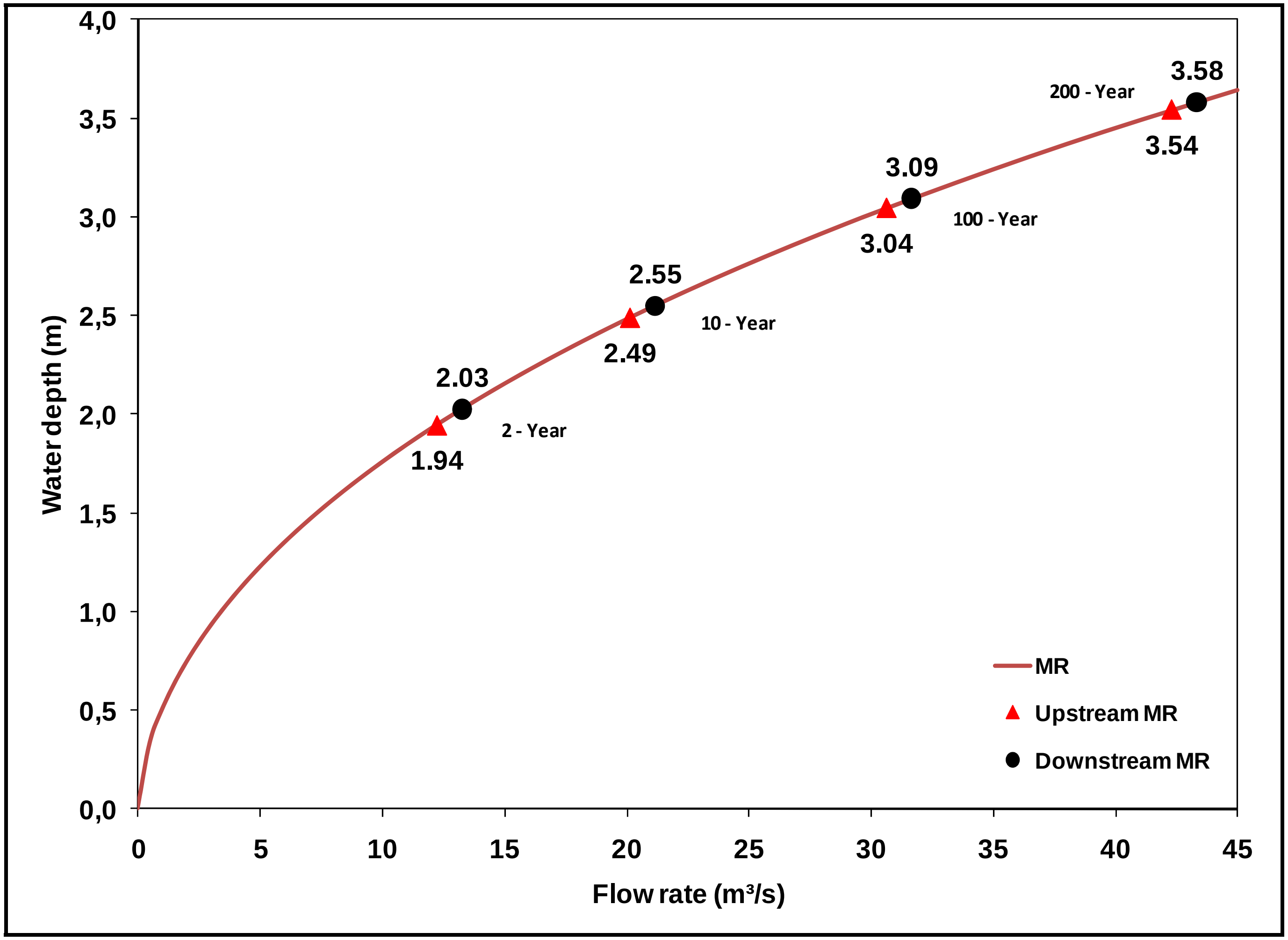
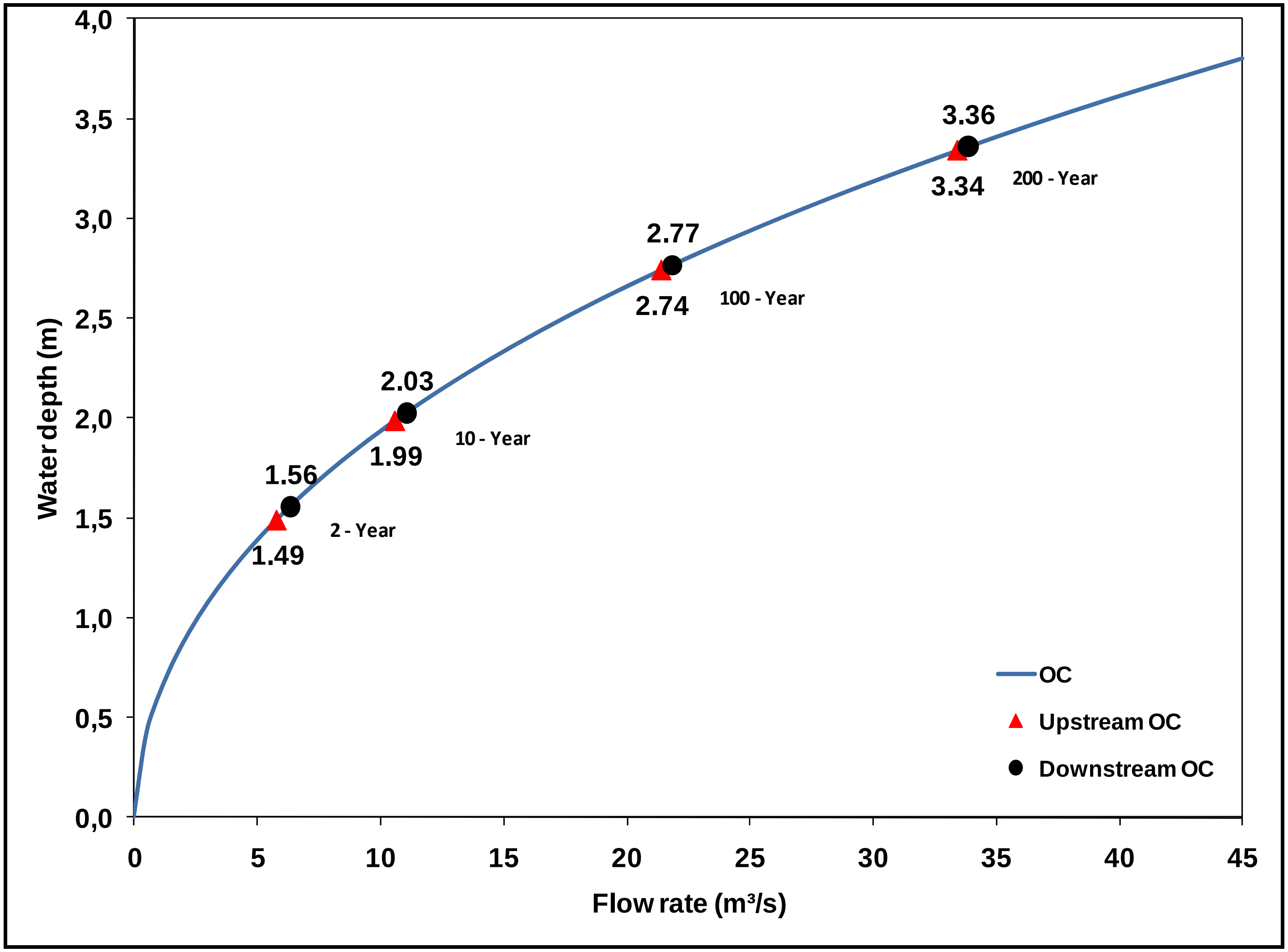


Figure 7.4-11 Relationship between Flow Rate and Water Depth in the Oakley Creek with Discharge



in this area, occurs in May (Table 7.4-26). This means that these streams have the natural capacity to receive the discharged water. On the other hand, in May, i.e. at the high-water level, increases in terms of flow rate, while the discharge of the final effluent will be at its maximum rate (year 2), will be about 10% for the Minago River and 11% for the Oakley Creek (Table 7.4-26). These increased flow rates will result in a projected increase in water depth of 5% for both watercourses (Table 7.4-27). The estimation of those related increases in water depth due to the discharge of the final effluent in the receiving watercourses were calculated using URS (2008a) channel-description data for reaches directly impacted by the final effluent, i.e. where it will be discharged. Table 7.4-28 details these channel parameters, measured by URS (2008a).

Table 7.4-28 Channel Characteristics for Minago River and Oakley Creek

Parameters	Minago River (From J3 to MRW1)	Oakley Creek (From OCW1 to WRW1x)
Channel bottom width (m)	7.2	4.3
Slope ratio	3:1	3:1
Channel slope (m/m)	0.0008	0.0017
Manning's Roughness Coefficient	0.07	0.09

The boreal region is sensitive to variations in the climate. It is also an area where many rivers have been regulated (Ye et al., 2003), notably for hydroelectric power generation. Both natural and human factors cause variations and changes in the timing and magnitude, hence the seasonal rhythm of river discharge. Therefore, such small variations in the stream flow at the high-water level are within the natural variation occurring in such boreal conditions and should not have any significant impact on the receiving hydrological environment. Figures 7.4-10 and 7.4-11 illustrates how small those flow increases will be for the Minago River and the Oakley Creek when compared to 1:10, 1:100 and 1:200 peak flow discharges. It is also important to note that the increased flows during a normal year (1:2) at the high water level are not high enough to correspond to a 1:10 peak flow event, to which the river system is well-adapted.

Moreover, from May to October, the final effluent will first be discharged in a vast treed bog so that its flow will be reduced before being released in the receiving streams. This means that values shown in Table 7.4-26 should be considered as maximum values since they represent a situation in which water is being directly discharged in the Oakley Creek or the Minago River without passing through a wetland before. Moreover, Table 7.4-27 also presents data that must be considered as maximum values since those were estimated based on a trapezoidal-shape channel which represents a situation that does not account for vegetation on riverbanks, which attenuate flows and other topographical/bathymetrical features that could help in reducing the potential effects of the final effluent on natural flow rates.

The potential negative impacts of the final effluent (total suspended solids, heavy metals content) on water quality will be mitigated, since water will run through a treed bog before reaching the receiving streams. The bog's capacity to receive discharged water can be easily demonstrated based on relatively simple observations. First, the presence of trees and the absence of ponds within a bog indicate that drainage is not as limited as it would be in large open bogs with several ponds (Thibault, 2006). This means that these bogs still have the capacity to store additional water by creating ponds (Tremblay and Garneau, 2008).

An adaptative monitoring program will be implemented to monitor flows in the receiving watercourses upstream and downstream of the discharge points. The final effluent flow will also be monitored and signs of change within the watercourses will be documented (photographs will be taken annually during similar flow periods or times of year).

7.4.8.1.2 Impacts on Biological Aspects

Two main components of the receiving environment could be impacted by how the final effluent will be managed, namely wetlands and stream habitats.

Impacts on Wetlands

From May to October, the final effluent will first be discharged in a vast treed bog before being released to the receiving streams. These bogs still have the capacity to store additional water by creating ponds.

A small marsh will certainly be created where the final effluent will be discharged. However, it would be quite surprising to see such a significant transformation over the entire bog's surface (creation of ponds and reduction of the tree cover) given that:

- no ponds at all have been observed within these bogs;
- they cover significant areas and are parts of a vast complex of wetlands that are hydrologically connected together and form one of the most important ecosystem in the region.

Still, if a significant transformation of the bog's surface were to occur, it is important to note that it is widely accepted that open bogs with ponds represent more attractive habitats for many wildlife species such as waterfowl and amphibians. Ducks Unlimited Canada, as well as *Québec's ministère du Développement durable, de l'Environnement et des Parcs* (Department of Sustainable Development, Environment and Parks), has recognized this general concept and use it to evaluate the ecological value of a bog. Poulin (2002) has also proposed a set of criteria to assess a bog's ecological value, including the area covered by ponds.

A diffuser will be installed to reduce erosion at the point where the final effluent will be released in the bog. Rocks (riprap) will also be installed at this same location.

Impacts on Stream Habitats

The fact that water will first be discharged in a bog before being released in the receiving streams means that the increases shown in Table 7.4-26 should be considered as maximum values since they represent a situation in which water is being directly discharged in the Oakley Creek or the Minago River without passing through a wetland before. Given the capacity of wetlands, such as those bogs, to slow the water flow coming to the receiving streams, the impact on stream habitats should be low, or not significant, particularly in May. However, if an increase in the amount of water flowing in those streams should occur, the impact on stream habitat quality would likely be positive, especially in winter low flow conditions.

Low flows are defined as those typical during a prolonged dry period (Smakhtin, 2001), or more precisely in the Canadian context, those that occur during periods without significant rainfall or snowmelt input. During low flows, most stream habitat types are reduced in extent and changes in water quality can occur, which can be stressful for fish and other biota (IFC, 2004).

Therefore, especially from November to April, higher water flows and thus water levels would help maintaining the existing stream habitat types and limit changes in water quality that can occur, therefore limiting seasonal stresses for some fish species and other biota. Such positive impacts of higher winter flow have been observed in northern Québec by Hydro-Québec along rivers regulated for hydroelectric power generation purposes.

Water coming out of a mine is usually not at the same temperature than water flowing in the surrounding streams. However, before being released as the final effluent, that water will have to flow through the TWRMF and the Polishing Pond, therefore being exposed to rainfall and ambient temperatures for some days. Based on these facts, the thermal impact of the water being discharged to the receiving environment is considered to be not significant.

Finally, to avoid any erosion of the riverbed in the Minago River while water will not pass through a bog first (from November to April), a rock-filled channel will be implemented between the river and where the final effluent will be released (end of the pipeline). However, aerial surveys will be performed during the summer of 2010 to evaluate if some other small unmapped stream, located in the immediate vicinity of the Minago River where the final effluent is to be discharged, could be used in order to avoid the implementation of a rock-filled channel and to reduce the potential footprint of the project.

An adaptative monitoring program will be implemented to monitor flows in the receiving watercourses upstream and downstream the discharge points. The final effluent flow will also be monitored and signs of change within the watercourses will be documented (photographs will be taken annually during similar flow periods or times of year).

7.4.8.2 Closure Issues

As it was the case for transitional period (seasonal) issues, the potential impacts of ending the discharge of the final effluent to the receiving environment affect two main components, namely hydrological conditions (river and creek) and biological aspects (wetlands and stream habitats).

As discussed in the previous sections, the impacts of increasing or decreasing the water flow in the Minago River and the Oakley Creek will be low, or not significant, in terms of hydrology since they are within the natural variation occurring in this region.

These impacts will also be low on wetlands since these vast ecosystems are quite resilient. Indeed, mosses, sedges and ericaceous shrubs are among the most widespread species in the region and can easily acclimatize themselves to a wide variety of conditions (Campbell and Rochefort, 2001). Gradually, vegetation cover is expected to change back to what it was before if no other change in climatic conditions occurs; otherwise, it will adapt itself to the prevailing climatic conditions. Bogs are not as sensitive as forest stands to climatic conditions, especially rainfall, since they are already wet ecosystems that have the capacity to store additional water. In fact, the development of a bog is mainly due to a combination of factors, such as temperature and precipitation favouring, a positive net annual water balance.

The impacts of a reduction in the water flow on stream habitats could however be potentially significant. Indeed, especially in winter low flow conditions, lower water flows and thus water levels reduce stream habitat types and increase the risk of changes in water quality, increasing seasonal stresses for fish and other biota.

Therefore, mitigation measures will have to be implemented in order to limit the potential impacts of such a change in water level conditions, meaning that water will have to be stored in the PP in such a way that the final effluent flow will be gradually reduced and not drastically. This would enable a comeback to pre-mining (natural) conditions.

The areas on which the pipeline, the rock-filled channel, if needed, and the diffuser will be implemented will have to be rehabilitated, meaning that they will be re-vegetated with indigenous species.

7.4.8.2.1 Open Pit Closure

A common extraction method for metal mining is open pit mining, which results in (a) residual pit(s) being left on the landscape. The excavated pits will be of various depths and sizes, but all will require environmental reclamation. One possible reclamation endpoint could be the creation of end-pit lakes, which will be formed by water filling the open pit left upon the completion of mining operations. These pits can be filled by artificially flooding or allowing the pits to fill naturally through hydrological processes such as precipitation and/or groundwater infiltration. Depending on water quality, it may also be possible to modify or enhance pits to create aquatic habitat for fish and wildlife.

At Minago, it has been decided not to create a fish habitat using the pit once it will have been flooded. Therefore, it will be necessary to create obstacles to fish circulation between the Oakley Creek and the pit since water from the pit will be flowing towards the Oakley Creek using a network of drainage ditches.

To that effect, residual waste rock wil be used to block the ditches since such coarse material would allow the free movement of water while preventing fish from swimming through them.

However, fish may be introduced into a pit lake during or after flooding by waterfowl and other fish-eating bird species, which could drop fishes while passing over the pit or simply stopping by. Species such as the Northern pike or Walleye could therefore be observed in the pit lake.

Based on the magnitude of the project footprint in the affected drainage basins and site water management to minimize effects of increased runoff, no measurable effects on surface water hydrology are expected from surface disturbances. The main issue with respect to project effects on hydrology is groundwater interception due to pit dewatering, which will be managed through the Polishing Pond. This effect would occur primarily during operations, decommissioning and initial years of closure, when the groundwater table will be re-established in the mine area. Effects and mitigation are described in detail below.

Oakley Creek

The effect of pit dewatering on groundwater contributions to stream flow will be insignificant in Oakley Creek. No reductions in flows are expected to occur (Golder Assoicates, 2008b) in Oakley Creek as there is no recorded hydraulic connection between the open pit dewatering activities and Oakley Creek. Furthermore, under current conditions, Oakley Creek freezes solid at times during the winter when it has a net discharge of zero.

Following closure of the mine, the restoration of the groundwater regime will proceed in two phases: the refilling of the pit itself will take approximately eleven years (pit volume = 156.7M m^3 at a recharge rate of 40,000 cubic metres per day). The flow from the pit will be directed to the Oakley Creek watershed. Fisheries and benthic community in the Oakley Creek will not be impacted by open pit dewatering operations. Therefore, there are no concerns regarding impacts on productive instream habitat for benthic communities and fish. Flow monitoring in Oakley Creek will continue during operations to confirm the no effects phenomena as a result of pit dewatering and assess the related effects on fish habitat in the lower reaches.

Minago River

Based on the Golder Associates (2008b) report, the Minago groundwater regime will not be affected by the pit dewatering operations. Therefore, there will be no negative impacts on the Minago watershed groundwater flows.

7.4.8.3 Residual Project Effects

There are no predicted residual effects of mine dewatering on low flow conditions in both Oakley Creek and the Minago River and therefore, open pit dewatering will not be of a concern during the operational and closure phases. Accordingly, residual effects of mine dewatering on the Minago River and Oakley Creek will be insignificant or non existent. Predicted residual effects of Polishing Pond discharges on flows in the Minago River and Oakley Creek are positive or neutral, low, local and reversible. The likelihood of effects as predicted is low. No mitigation measures will be required, because the predicted effects are not a concern with respect to hydrologic conditions or aquatic habitat.

7.4.8.4 Cumulative Effects

The residual project effects identified in the previous section are site-specific to local in geographic extent. No additional projects are currently planned within the area, which would overlap with predicted project effects. Therefore, there will be no significant adverse cumulative or residual cumulative effects in the project area. The likelihood of occurrence of effects as predicted is high.

Mitigation measures pertaining to project effects on surface water hydrology are summarized in Table 7.4-29.

7.4.8.5 Monitoring and Follow-up

Follow-up Studies

Existing water quality monitoring sites established for the project will continue to be used during project construction, operations and decommissioning phases. Additionally, automated monitoring equipment will be installed at various sites (stations) on the Minago River, William River and Oakley Creek to better quantify flows. Moreover, more a detailed description of the watercourses along reaches directly impacted by the final effluent will also be undertaken to be able to more precisely estimate the associated increases in water depth. Data collected will also be used to improve and refine stage-discharge curves and estimated peak and low flow magnitudes for specified return periods. Improved values will lead to a more accurate understanding of the project hydrology and the range of natural variability. Due to potential fisheries concerns related to discharges to the Oakley Creek and the Minago River, stream flows will be monitored on an ongoing basis in conjunction with observations of effects on fish habitat to define minimum instream flow requirements for fish habitat.

Monitoring Programs

Selected manual and automated monitoring sites will be installed and will be used for monitoring surface water flow, in conjunction with planned monitoring for fisheries and water quality (Table 7.4-30). The final effluent flow will also be monitored and signs of change within the watercourses will be documented (photographs will be taken annually during similar flow periods or times of year).

Table 7.4-29 Mitigation Measures for Effects on Surface Water Hydrology

Potential Project Effect	Mitigation Measures
Effects of clearing and construction on runoff and stream flows	• See Site Water Management Plan • See Erosion and Sediment Control Plan
Effects of stream crossings on stream flows	• Design flow specifications to allow unobstructed passage of flows and bed load • See Erosion and Sediment Control Plan

Improved values will lead to a more accurate understanding of the project hydrology and the range of natural variability. Due to potential fisheries concerns related to discharges to the Oakley Creek and the Minago River, stream flows will be monitored on an ongoing basis in conjunction with observations of effects on fish habitat to define minimum instream flow requirements for fish habitat.

7.4.8.6 Summary of Effects

Table 7.4-31 provides a tabular summary of the project effects on surface water hydrology.

Table 7.4-30 Monitoring and Follow-up Programs for Hydrology

Potential Project Effect	Program Objectives	General Methods	Reporting	Implemen-tation
Follow-Up and Monitoring Programs				
Site water management	• Develop stage discharge curves and refine peak and low flow projections for water management purposes	• Ongoing operation of recording pressure transducers • Continued monthly manual monitoring • Install new manual monitoring stations	• Internal	Proponent
Increased flows in Minago River and Oakley Creek from Polishing Pond discharges	• Define maximum instream flow requirements for aquatic habitat • Maintain flows that are less than or equal to the identified maximum by monitoring effects and implementing mitigation measures as required	• Installation of automated monitoring equipment in Oakley Creek and the Minago River (both upstream and downstream of the Polishing Pond Discharge points) • Develop stage/discharge relationship to assess effects on wetted stream habitat	• Internal for adaptive management purposes • to the MB Gov.'t as required • to DFO as required	Proponent
Monitoring Programs				
Project effects on flows in Oakley Creek and the Minago River	• Monitor flows to check effects predictions and support interpretation of water quality monitoring results	• Ongoing operation of recording pressure transducers on Oakley Creek and Minago River • Monthly summer manual monitoring at stations on Oakley Creek and Minago River (upstream and downstream of the Minago Project discharges) • Manual discharge measurements in conjunction with water quality sampling • Annual taking of photographs during similar flow periods or times of year	• to DFO as required for compliance with the *Metal Mining Effluent Regulations* (MMER)	Proponent

Table 7.4-31 Summary of the Project Effects on Surface Water Hydrology

Potential Effect	Level of Effect						Effect Rating	
	Direction	Magnitude	Extent	Duration/ Frequency	Reversibility	Likelihood	Project Effect	Cumulative Effect
Construction, Operations and Decommissioning								
Increased flows in Oakley Creek and Minago River due to Polishing Pond Discharges	Positive	Moderate	Local	Long-term	Reversible	High	Not significant	Not significant
Closure								
Reduced low flows in Oakley Creek and Minago River to base flow due to discontinued discharges to the watersheds	Adverse	Moderate	Site specific	Long-term	Reversible	High	Not significant	Not significant

7.5 Surface Water Quality

This section summarizes the monitoring program of surface water quality. The objectives of the surface water quality program were to:

- establish pre-mining baseline surface water quality conditions for the Minago Project Area;
- provide baseline surface water quality data required to complete an Environmental Impact Assessment of the Minago Project under the Manitoba *Environmental Assessment Act*;
- provide baseline surface water quality data required to complete bankable Feasibility Study on the Minago Project; and
- provide baseline surface water quality data for water quality modeling, engineering design, water management and determining impacts to aquatic resources.

No known historical records were found for surface water quality data for the Minago Project Area.

7.5.1 Relevant Water Quality Guidelines

Relevant water quality guidelines and regulations for the Minago Project include:

- *Manitoba Water Quality Standards, Objectives and Guidelines* (Williamson, 2002);
- Canadian *Guidelines for the Protection of Aquatic Life* (CCME, 2007); and
- *Metal Mining Effluent Regulations* (Environment Canada, 2002a).

The intent and applications of these regulations and guidelines are summarized below whereas their detailed concentration limits are listed in subsection 7.5.3 as part of the discussion of surface water quality results obtained for Minago watercourses.

7.5.1.1 Manitoba Tier I Water Quality Standards, Tier II Water Quality Objectives, and Tier III Water Quality Guidelines

Manitoba Tier I Water Quality Standards identify minimum standards for common classes of discharges in Manitoba. These standards form the basis for the technology-based approach to the prevention of pollution. The *Manitoba Tier I Water Quality Standards* may also contain Canada-Wide Standards developed and negotiated by the Canadian Council of Ministers of the Environment (CCME) under the Canada-Wide Accord on Environmental Harmonization (Williamson, 2002).

Manitoba Tier II Water Quality Objectives are defined for a limited number of common pollutants (such as dissolved metals and nutrients) in Manitoba that are routinely controlled through licencing under the Manitoba *Environment Act. Manitoba Tier II Water Quality Objectives* typically form the

basis for the water quality base approach when additional restrictions need to be developed to protect important uses of ground or surface waters beyond those defined in Tier I Water Quality Standards or other controls to which discharges are subject (Williamson, 2002).

Manitoba Tier III Water Quality Guidelines contain guidelines developed by the federal Canadian Council of Ministers of the Environment (CCME), which were developed to ensure that the most sensitive species in the aquatic receiving environment are protected at all times along with an adequate margin of safety (Williamson, 2002).

7.5.1.2 Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2007)

Canadian Water Quality Guidelines for the Protection of Aquatic Life define acceptable levels for substances or conditions that affect water quality such as toxic chemicals, temperature and acidity. As long as conditions are within the levels established by the guidelines, one would not expect to see negative effects in the environment (CCME, 2007). These guidelines are based on toxicity data for the most sensitive species of plants and animals found in Canadian waters and act as science-based benchmarks.

7.5.1.3 Metal Mining Effluent Regulations (MMER)

The *Metal Mining Effluent Regulations* (MMER) were registered on June 6, 2002, under subsections 34(2), 36(5), and 38(9) of the *Fisheries Act*. The MMER replaced the MMLER and the associated Metal Mining Liquid Effluent Guidelines, which came into force in February 1977.

The MMER prescribe authorized concentration limits for deleterious substances in mine effluents that discharge to waters frequented by fish. The regulated parameters are arsenic, copper, cyanide, lead, nickel, zinc, total suspended solids (TSS), Radium 226, and pH.

The MMER apply to all Canadian metal mines (except placer mines) that exceeded an effluent flowrate of 50 m^3 per day at any time after the Regulations were registered. Mines are defined as facilities where ore is mined or milled and include mines under development, new mines, and reopened mines.

The MMER apply to effluent from all final discharge points (FDPs) at a mine site. A FDP is defined in the Regulations as a point beyond which the mine no longer exercises control over the quality of the effluent.

7.5.2 Scope of Surface Water Quality Assessment

7.5.2.1 Introduction

Surface water quality in watercourses surrounding the Minago Project was assessed by Wardrop (2007) from May to October 2006, URS (2008g) from May to August 2007, and KR Design Inc. from September 2007 to May 2008. Wardrop (2007) monitored water quality in Oakley Creek and Minago River while URS (2008g) and KR Design Inc. regularly monitored water quality in Oakley Creek, Minago River, William River, and Hargrave River. One-time assessments of surface water quality were also completed for William Lake, Little Limestone Lake, Russell Lake, and two locations near the confluence of William River and Limestone Bay on Lake Winnipeg (Figure 7.5-1, Table 7.5-1). The selected locations for surface water sampling stations were based on:

- a review of topographic maps, orthophoto and drainage features at and surrounding the Minago Project Site;
- considerations associated with the simultaneous collection of hydrological data, stream sediment and benthic samples during one or more of the surface water sampling events;
- considerations associated with the selection of representative stations both upstream and downstream of the Minago Project Site for the development of long-term sampling stations to monitor long-term trends in surface water quality during the exploration phase of the Minago Project and during potential development, operation and post-closure phases of the Minago Project mine life.

Water samples were analyzed for field parameters (pH, temperature, conductivity, oxidation-reduction potential (ORP), and dissolved oxygen (DO)), nutrients, major ions, metals, Radium-226 and other physicochemical parameters. Collection methods conformed to the guidelines outlined in the federal *Metal Mining Guidance Document for Aquatic Environmental Effects Monitoring* (MMER-EEM; Environment Canada 2002b).

7.5.2.2 Scope of Assessment – 2006 Program

Wardrop established the following four water quality sampling stations on Oakley Creek and Minago River (Wardrop, 2007):

- OCW-1 is located on the west-side of Highway 6 and receives drainage from Oakley Creek and the ditches along Highway 6;
- OCW-2 is located 2.2 km upstream of OCW-1 and receives the drainage from forks of Oakley Creek;
- OCW-3 is located 550 m upstream of OCW-2 and receives drainage from the southwest forks of Oakley Creek;

LEGEND:

- Watershed Boundaries
- Sub-Watershed Boundaries
- Surface Water Stations

N, W, E, S

0 5 10 15 20 km

1:500,000

URS

PROJECT AREA WATERSHEDS AND SURFACE WATER STATIONS

Environmental Baseline Studies
Minago Project, Northern Manitoba

VICTORY NICKEL INC.

DATE:	PROJECT NO.:	DRAWN BY:	REVISION NO.:	DRAWING NO.:
May 2008		TS/KR	0	

Table 7.5-1 Nomenclature and Coordinates of Minago Surface Water Monitoring Stations

VNI Sample Location	UTM (NAD 83)		UTM (NAD 83)		
(as of Sept. 15, 2007)	Northing	Easting	Latitude	Longitude	Description
HRW1	6028072	495606	54°24.041' N	99°04.051' W	Hargrave River immediately west of Highway 6
MRW1	6005277	488671	54°11.721' N	99°10.420' W	Minago River immediately west of Highway 6
MRW2	6001212	472476	54°09.494' N	99°25.290' W	Minago River near Habiluk Lake
MRW2x	6001166	472571	54°09.470' N	99°25.206' W	Minago River near Habiluk Lake (~ 100 m downstream of MRW2)
MRW3	6007895	494274			Minago River downstream of Highway 6 near powerline cut
OCW1	5990510	489322	54°03.762' N	99°09.786' W	Oakley Creek immediately east of Highway 6
OCW2	5990961	487463	54°04.002' N	99°11.492' W	Oakley Creek immediately downstream of north tributary
OCW3	5990892	487230	54°03.965' N	99°11.707' W	Oakley Creek immediately upstream of north tributary
WRW2x	5987162	495416	54°01.963' N	99°04.199' W	William River approx. 6 km upstream of the Oakley Creek confluence
WRW1x	5986554	498523	54°01.637' N	99°01.350' W	William River approx. 100 m downstream of the Oakley Creek confluence
WRAOC	5986647	498452	54°01.685' N	99°01.416' W	William River approx. 50 m upstream of the Oakley Creek
OCAWR	5986744	498457	54°01.738' N	99°01.414' W	Oakley Creek approx. 50 m above William River
WRALSB	5969206	503935	53°52.278' N	98°56.410' W	William River approx. 100 m above Limestone Bay
LSBBWR	5968889	504092	53°52.107' N	98°56.262' W	Limestone Bay approx. 250 m below William River
Little Limestone Lake	5954922	478725			Little Limestone Lake (at end of road)
Russell Lake	5967117	482571			Russell Lake (at end of road)
William River (Winter)	5973774	485141	53°54.730' N	99°13.574' W	William River east of Highway 6
William River at Road	5973791	485078			William River west of Highway 6
William Lake	5973831	479083			William Lake at end of access road

- MRW-1 was established on the Minago River at the Highway 6 crossing, approximately 15 km north of Oakley Creek.

Coordinates for all stations were recorded using a handheld Trimble GeoXM-2005 series GPS with 1 m horizontal resolution (Table 7.5-2).

Table 7.5-2 Coordinates – Wardrop (2007) Surface Water Monitoring Locations

Monitoring Station	Northing (m)	Easting (m)
OCW-1	5990528	489238
OCW-2	5990974	487559
OCW-3	5990931	487048
MRW-1	6005275	488684

In the field, Wardrop (2007) measured water temperature, dissolved oxygen (DO) concentration and percent oxygen saturation, conductance, oxidation-reduction potential (ORP), total dissolved solids (TDS), salinity, and pH once per month from May to October, 2006 using a YSI 600 QS Multiparameter Sampling System. All measurements were made at mid-water column depth.

Water samples for laboratory analyses were collected at all sampling stations once a month from May to October 2006. Samples were analysed for nutrients, major ions, metals, Radium-226, and other physicochemical parameters. Maxxam Analytics Inc., of Burnaby, BC, conducted the analyses for all parameters, except Radium-226, which was analyzed at Becquerel Laboratories Inc. in Mississauga, Ontario. Wardrop's (2007) field sampling protocol for their surface water quality sampling program is given in Appendix 7.5.

7.5.2.3 Scope of Assessment - URS (2008g)

URS (2008g) collected monthly surface water quality samples from the Minago River, William River, Hargrave River and Oakley Creek between May and August 2007 (Figure 7.5-1 and Table 7.5-1).

Surface water quality sampling at each sampling station included measurement of field parameters (pH, temperature, conductivity, oxidation-reduction potential (ORP), and dissolved oxygen (DO)) and the collection of surface water samples for laboratory analysis. Laboratory analysis included:

- **Physical Tests:** pH, conductivity, hardness, total dissolved solids, total suspended solids and turbidity;
- **Anions and Nutrients:** ammonia, acidity, alkalinity, bromide, chloride, fluoride, sulphate, nitrate, nitrite, total kjeldahl nitrogen and total nitrogen;

- **Metals:** total and dissolved; and
- **Other Parameters**: total cyanide and Radium-226.

ALS Laboratory Group, of Vancouver, BC, conducted the analyses for all parameters, except Radium-226, which was analyzed at SRC Analytical, of Saskatoon, SK. URS' (2008g) field protocol for water quality sampling is given in Appendix 7.5.

7.5.2.4 Scope of Assessment – KR Design Inc.

KR Design Inc. collected surface water quality samples from the Minago River, William River, Hargrave River and Oakley Creek in September and October 2007 and March and May 2008. One-time surface water quality samples were also collected from William Lake, Little Limestone Lake, Russell Lake, and two locations near the confluence of William River and Limestone Bay on Lake Winnipeg (Figure 7.5-1, Table 7.5-1).

Surface water quality sampling at each sampling station included measurement of field parameters (pH, temperature, conductivity, oxidation-reduction potential (ORP), Total Dissolved Solids, dissolved oxygen (DO), and barometric pressure) and the collection of surface water samples for laboratory analysis. Field parameters were assessed with a YSI 600QS multiparameter probe. This probe was calibrated prior to every field sampling event. The probe's pH meter was calibrated with pH 7.0 and pH 10.0 standard solutions. The dissolved oxygen and depth sensors were calibrated immediately before every field measurement.

Laboratory analysis included:

- **Physical Tests:** pH, conductivity, hardness, total dissolved solids, total suspended solids and turbidity;
- **Anions and Nutrients:** ammonia, acidity, alkalinity, bromide, chloride, fluoride, sulphate, nitrate, nitrite, total kjeldahl nitrogen and total nitrogen, dissolved and total organic carbon;
- **Metals:** total and dissolved; and
- **Other Parameters**: weak acid dissociable cyanide and Radium-226.

ALS Laboratory Group, of Vancouver, BC, conducted the analyses for all parameters, except Radium-226, which was analyzed at SRC Analytical, of Saskatoon, SK. KR Design Inc.'s field protocol for water quality sampling is given in Appendix 7.5.

7.5.3 Baseline Conditions – Surface Water Quality

In this document, water quality results were compared to the Final Draft Manitoba Water Quality Standards, Objectives and Guidelines (Williamson, 2002). For the purposes of assessing baseline surface water quality for the Minago Project Area, the Tier III Water Quality Guidelines were applied. The Tier III Water Quality Guidelines contain guidelines developed by the federal Canadian Council of Ministers of the Environment (CCME), which were developed to ensure that the most sensitive species in the aquatic receiving environment are protected at all times along with an adequate margin of safety. Where specific parameters are not available under the Tier III Water Quality Guidelines, Tier II Water Quality were applied to assess baseline surface water quality conditions, and in anticipation of the further assessment of potential impacts on surface water quality from the Minago Project mine development plan. For completeness, summaries of Minago surface water quality results also list guideline limits for the *Canadian Water Quality Guidelines for the Protection of Aquatic Life* (CCME, 2007) and the *Metal Mining Effluent Regulations* (MMER).

7.5.3.1 Data Validity

The vast majority of surface water quality results were judged to be valid based on results obtained for monitoring stations and quality control and assurance samples (travel blanks, field blanks and field duplicates). However, a few data validity issues were encountered. These included slight contamination of field and travel blanks, replicate duplicate analyses for which the relative percent difference (RPD) was greater than 20%, and higher dissolved versus total element concentrations.

Slight contamination in some of the quality control samples was encountered and analytical results for these samples are summarized in Appendix 7.5. Results for replicate duplicate analyses ranged from an RPD of 0.03 to 189% for element concentrations, compared to the typically accepted and mandated 20%. In general, Maxxam laboratory data had higher RPD values than ALS Laboratory Group data. Details of replicate analyses are given in Appendix L7.5 as part of the presentation of analytical laboratory certified results.

Higher dissolved versus total element concentrations were measured on numerous occasions. In theory, dissolved element concentrations are never higher than the total element concentrations. As part of the investigation of this finding, error bounds were calculated for all of the Minago water quality data based on the Data Quality Objectives (DQO) for precision provided by the ALS Laboratory Group. Precision was assumed to be the absolute value of the Relative Percent Difference (RPD) for laboratory duplicate samples plus/minus the additional value of square root of 2 multiplied by the detection limit (DL) to deal with variability of the two results near the detection limit. Thus, the difference between results was assumed to be:

$$\leq \left| RPD \times mean \right| + (\sqrt{2} \times DL) .$$

A sample calculation of the error bounds is given in Appendix L7.5.

For water samples for which the reported dissolved element concentrations were higher than the total element concentrations further data analysis was undertaken to determine whether those differences were actually significant based on the calculated error bounds. For the vast majority of water samples, the differences between the measured total and dissolved element concentrations were not significant. However, for some of the water samples the differences were significant. Table 7.5-3 summarizes the number of test results for which the differences were significantly different and could not solely be explained with the error bounds. Details of the element concentrations for these water samples and their error bounds are presented at the end of each of the monthly water quality data presented in Appendix L7.5.

For samples for which the differences were significant, the error might have been due to laboratory method variability as well as other factors such as:

- field sampling method variability;
- bias introduced during general handling, storage, transportation and/or analysis of the sample; and
- field sample grab bias - where separate grab samples are processed to produce total and dissolved samples.

Table 7.5-3 Number of Test Results with Significant Higher Dissolved versus Total Concentrations

Sampling Date	Number of Results that could not be fully explained with the error bounds assuming RPD as measured or 20% for which no RPD existed	Number of Results that could not be fully explained with the error bounds assuming RPD was 20%	Consultant / Lab
03-May-06	1	1	Wardrop / Maxxam
16-May-06	5	0	Wardrop / Maxxam
20-Jun-06	0	0	Wardrop / Maxxam
18-Jul-06	18	0	Wardrop / Maxxam
22-Aug-06	3	0	Wardrop / Maxxam
19-Sep-06	6	0	Wardrop / Maxxam
12-Oct-06	3	0	Wardrop / Maxxam
15-May-07	5	3	URS / ALS Vancouver
12-Jun-07	1	0	URS / ALS Vancouver
15-Jul-07	4	0	URS / ALS Vancouver
15-Aug-07	6	5	URS / ALS Vancouver
12-Sep-07	3	2	KR Design / ALS Vancouver
15-Oct-07	0	0	KR Design / ALS Vancouver
11-Mar-08	1	0	KR Design / ALS Vancouver
6-9 May-08	32	0	KR Design / ALS Vancouver

7.5.3.2 Summary of Water Quality Results

The following summary of water quality results is indicative of baseline conditions in watercourses in the vicinity of the Minago Project. Detailed water quality results, tabulated by sampling station and compared to Manitoba Water Quality Objective and Guidelines and CCME Water Quality Guidelines, are given in Appendix 7.5. All certified analytical laboratory reports for the water quality analyses, inclusive water quality control results, are provided in Appendix L.7.5.

Table 7.5-4 presents an overview of water quality results in terms of average, median, minimum and maximum concentrations for all surface water sampling stations, monitored between May 2006 and May 2008. These water quality results are tabulated alongside Manitoba Water Quality Objective and Guidelines, *Canadian Water Quality Guidelines for Protection of Aquatic Life* (CCME, 2007), and Metal Mining Effluent Regulations (Environment Canada, 2002a). Detailed results for each and every sampling station, including a listing of minimum and maximum concentrations, are presented in Appendix 7.5.

Overall, water quality was good at the Minago Project and its vicinity with only some of the parameters exceeding Manitoba and/or CCME limits. These exceedances are discussed and illustrated below after a general description of the water quality surrounding the Minago Project.

Considering all stations and all sampling events, most of the elements for which and total and dissolved concentrations were assessed had similar dissolved and total concentrations. For those elements, the ratio (expressed as percent) of dissolved to total concentrations was 93% or greater. Exceptions to this finding, detailed in Table 7.5-5, were for aluminum, iron, cobalt, manganese, lead, nickel, and chromium. On average, the ratio of dissolved to total element concentration was 32% for aluminum, 46% for iron, 64% for cobalt, 70% for manganese, 78% for lead and nickel, and 82% for chromium.

7.5.3.2.1 pH and Alkalinity

To date, all water samples collected were alkaline with a pH ranging from 7.01 to 8.84. All pH measurements met the *Manitoba Tier II Water Quality Objectives*. The average and median field pH were 7.82 and and 7.81, respectively (Table 7.5-4). The alkaline pH in the area may be attributed to the limestone prevalent in the area. An illustration of pH levels in the surface waters surrounding the Minago site can be found in Appendix 7.5.

Considering all sampling stations and events, the total alkalinity ranged from 56.6 to 703.0 mg/L (as $CaCO_3$) with average and median concentrations of 166.3 mg/L and 161.5 mg/L, respectively (Table 7.5-4). Most of the alkalinity was likely due to bicarbonate, because whenever both total and bicarbonate alkalinity were assessed, those two parameter concentrations were equal (Appendix 7.5).

Table 7.5-4 Overview of Surface Water Quality at Minago

	Units	AVERAGE[1] May-Oct. All stations	MEDIAN[1] May-Oct. All stations	MINIMUM May-Oct. All stations	MAXIMUM May-Oct. All stations	REGULATIONS: Manitoba Water Quality Standards, Objectives and Guidelines (Williamson, 2002) – TIER II Water Quality Objectives	REGULATIONS: Manitoba – TIER III - Water Quality Guidelines – DRINKING MAC	REGULATIONS: Manitoba – TIER III - Water Quality Guidelines – Freshwater Aquatic Life	REGULATIONS: Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2007)
Field Properties									
Temperature	°C	12.8	11.6	**1.0**	**25.6**			Tier II	**narrative** [s]
Specific Conductance	uS/cm at 25°C	291.3	300.8	**127.0**	**580.0**	1000			
Conductance	uS/cm	214.2	215.5	**69.3**	**346.0**				
Total dissolved solids	g/L	0.191	0.202	**0.083**	**0.266**				
Diss. oxygen (% saturation)	sat %	90.3	92.3	**61.4**	**109.2**				
Dissolved oxygen	mg/L	9.6	9.6	**5.7**	**13.4**	varies with life-stages & temperature; 6.5 mg/L (30-Day, 3-Year if temp. > 5°C); Instantaneous Minimum 5 mg/L (if T>5°C)			
Depth		0.075	0.069	**0.002**	**0.242**				
pH	pH Units	7.82	7.81	**7.01**	**8.84**			6.5-9	**6.5-9**
ORP	mV	210.1	207.8	**115.8**	**309.0**				
Barometric pressure	kN/m²	97.0	98.6	**14.4**	**99.6**				
Salinity	ppt	0.2	0.2						
Physical Tests									
Hardness (as CaCO3)	mg/L	173.9	170.0	**61.5**	**715.0**				
Conductivity (in laboratory)	uS/cm	284.5	282.0	**109.0**	**1170.0**	1000			
pH	pH Units	8.07	8.07	**7.71**	**8.56**				**6.5-9**
Total Dissolved Solids	mg/L	189.2	186.0	**60.0**	**739.0**	700			
Total Suspended Solids	mg/L	11.5	5.0	**0.5**	**65.0**	Dependent on background TSS (5 mg/L (30-Day, 3 Year) or 25 mg/L (1-Day, 3-Year) or 10% (1-Day, 3-Year) of induced change from background)		Tier II	**narrative**
Turbidity	NTU	6.0	1.5	**0.2**	**38.1**		1.0	Tier II	**narrative**
True Colour	Col. Unit	46.9	50.0	**10.0**	**70.0**				
Anions and Nutrients									
Ammonia (NH4)	mg/L	0.023	0.020	**0.005**	**0.155**	pH and temperature dependent (lowest concentration for all categories = 1.17 mg/L for pH 7.8)		Tier II	**see factsheet**
Acidity (as CaCO3)	mg/L	2.6	2.4	**1.0**	**10.7**				
Alkalinity, Total (as CaCO3)	mg/L	166.3	161.5	**56.6**	**703.0**				
Alkalinity (PP as CaCO3) **	mg/L	0.3	0.3						
Alkalinity, Carbonate (as CaCO3)	mg/L	1.0	1.0	**<2.0**	**<2.0**				
Alkalinity, Hydroxide (as CaCO3)	mg/L	1.0	1.0	**<2.0**	**<2.0**				
Alkalinity, Bicarbonate (as CaCO3)		184.0	141.5	**56.6**	**703.0**				
Bromide (Br)	mg/L	0.025	0.025	**<0.050**	**<0.050**				
Chloride (Cl)	mg/L	0.90	0.70	**0.52**	**11.10**				
Fluoride (F)	mg/L	0.087	0.073	**0.036**	**0.590**		1.5		
Sulphate (SO4)	mg/L	1.19	0.73	**0.52**	**10.90**				
Nitrate (NO3-N)	mg/L	0.22	0.003	**0.01**	**1.35**		10		2.93 [c,u]
Nitrate (NO3)	mg/L	0.011	0.010	**0.020**	**0.030**		45		13 [c,u,y]
Nitrite (NO2-N)	mg/L	0.042	0.001	**<0.0010**	**0.29**		0.97	CCME	0.06 [z]
Nitrite (NO2)	mg/L	0.006	0.003	**0.005**	**0.049**		3.2	CCME	0.197
Nitrate-N plus Nitrite-N						10			
Total Kjeldahl Nitrogen (Calc)	mg/L	0.515	0.500	**0.153**	**1.440**				
Total Nitrogen	mg/L	0.566	0.512	**0.184**	**2.590**				
Diss. Organic Carbon	mg/L	13.66	13.65	**1.86**	**35.10**				
Diss. Inorganic Carbon (C)	mg/L	42.5	43.9	**31.8**	**60.0**				
Total Organic Carbon	mg/L	13.74	13.65	**2.41**	**35.80**				
Tot. Inorganic Carbon (C)	mg/L	43.1	42.5	**25.3**	**61.0**				
Cyanides									
Cyanide, **Total**	mg/L	0.0097	0.0095	**0.0056**	**0.0140**		0.2		
Cyanide, **Weak Associable Cyanide**	mg/L	0.0025	0.0025	**<0.0050**	**<0.0050**	0.0052 mg/L (4-Day, 3-Year)		Tier II	0.005 (as free CN)
Radiological Parameters									
Radium-226	Bq/L	0.005	0.003	**0.005**	**0.050**		0.6		

NOTE:
1 If the sample concentration was less than the detection limit, half the detection limit was used to compute the average and median.

Table 7.5-4 (Cont.'d) Overview of Surface Water Quality at Minago

		AVERAGE[1] May - Oct. All stations	MEDIAN[1] May - Oct. All stations	MINIMUM May - Oct. All stations	MAXIMUM May - Oct. All stations	REGULATIONS: Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2007)	REGULATIONS: Manitoba Water Quality Standards, Objectives (Williamson, TIER III - Water Quality Guidelines: Drinking			REGULATIONS: Metal Mining Effluent Regulations (MMER) (2002)
Matrix	Units	Water	Water	Water	Water	(see Footness for details)	MAC	IMAC	Freshwater	(Monthly Mean)
Physical Tests										
Hardness (as CaCO3)	mg/L	173.9	170.0	**61.5**	**715.0**					
Conductivity (in laboratory)	uS/cm	284.5	282.0	**109.0**	**1170.0**					
pH	pH Units	8.07	8.07	**7.71**	**8.56**	**6.5-9**				6.0-9.5
Total Elements										
Aluminum (Al)-Total	mg/L	0.197	0.053	**0.001**	**1.94**	**0.005 - 0.1**			0.005 - 0.1	
Antimony (Sb)-Total	mg/L	0.00009	0.00003	**0.000051**	**0.00110**			0.006		
Arsenic (As)-Total	mg/L	0.00066	0.00060	**0.00014**	**0.00452**	**0.005[k]**		0.025	0.15 mg/L (4-Day, 3-Year) [A]	0.5
Barium (Ba)-Total	mg/L	0.020	0.019	**0.008**	**0.066**		1			
Beryllium (Be)-Total	mg/L	0.0001	0.0001	**<0.00020**	**<0.00050**					
Bismuth (Bi)-Total	mg/L	0.00020	0.00025	**0.00008**	**0.00020**					
Boron (B)-Total	mg/L	0.01183	0.01000	**0.0035**	**0.128**			5		
Cadmium (Cd)-Total	mg/L	0.00003	0.00001	**0.00001**	**0.00118**	**0.000017[c,l]**	0.005			
Calcium (Ca)-Total	mg/L	36.4	34.7	**10.8**	**142.0**					
Chromium (Cr)-Total	mg/L	0.00065	0.00044	**0.00013**	**0.00298**		0.05			
Trivalent Chromium (Cr-III)	mg/L					**0.0089[c,k]**				
Hexavalent Chromium (Cr-VI)	mg/L					**0.001[k]**				
Cobalt (Co)-Total	mg/L	0.00014	0.00005	**0.00002**	**0.00095**					
Copper (Cu)-Total	mg/L	0.00070	0.00037	**0.00010**	**0.00643**	**0.002-0.004[m]**				0.3
Iron (Fe)-Total	mg/L	0.271	0.137	**0.025**	**1.89**	**0.3[d]**			0.3	
Lead (Pb)-Total	mg/L	0.00017	0.00007	**0.00002**	**0.00221**	**0.001-0.007[o]**	0.01			0.2
Lithium (Li)-Total	mg/L	0.00283	0.00250	**0.00190**	**0.01800**					
Magnesium (Mg)-Total	mg/L	20.0	18.8	**7.5**	**81.6**					
Manganese (Mn)-Total	mg/L	0.0294	0.0145	**0.0007**	**0.9730**					
Mercury (Hg)-Total	mg/L	0.00002	0.00003	**0.00006**	**0.00007**		0.001		0.0001	
Inorganic Mercury	mg/L					**0.000026**				
Methylmercury	mg/L					**0.000004[c,w]**				
Molybdenum (Mo)-Total	mg/L	0.00014	0.00009	**0.00005**	**0.00094**				0.073	
Nickel (Ni)-Total	mg/L	0.00076	0.00040	**0.00011**	**0.00641**	**0.025-0.15[p]**				0.5
Phosphorus (P)-Total	mg/L	0.113	0.150	**0.003**	**0.027**	**narrative [x]**				
Potassium (K)-Total	mg/L	1.07	1.00	**0.19**	**12.2**					
Selenium (Se)-Total	mg/L	0.00045	0.00025	**0.00011**	**0.00135**	**0.001[d]**	0.01		0.001	
Silicon (Si)-Total	mg/L	4.06	3.95	**0.92**	**18.8**					
Silver (Ag)-Total	mg/L	0.00002	0.00001	**0.00001**	**0.00083**	**0.0001[d]**			0.0001	
Sodium (Na)-Total	mg/L	2.88	2.44	**0.51**	**21.2**					
Strontium (Sr)-Total	mg/L	0.04539	0.04020	**0.0113**	**0.2640**		5 Bq/L			
Thallium (Tl)-Total	mg/L	0.00003	0.00003	**<0.000050**	**<0.00010**	**0.0008[j]**			0.0008	
Tin (Sn)-Total	mg/L	0.00010	0.00005	**0.00005**	**0.00060**					
Titanium (Ti)-Total	mg/L	0.01001	0.00500	**0.0005**	**0.06500**					
Uranium (U)-Total	mg/L	0.00017	0.00015	**0.00002**	**0.00098**			0.02		
Vanadium (V)-Total	mg/L	0.00066	0.00050	**0.00006**	**0.00440**					
Zinc (Zn)-Total	mg/L	0.00152	0.00100	**0.0007**	**0.0060**	**0.03[d]**				0.5

NOTE:

1 If the sample concentration was less than the detection limit, half the detection limit was used to compute the average and median.

Table 7.5-4 (Cont.'d) Overview of Surface Water Quality at Minago

	Units	AVERAGE[1] May-Oct. All stations	MEDIAN[1] May-Oct. All stations	MINIMUM May-Oct. All stations	MAXIMUM May-Oct. All stations	REGULATIONS: Manitoba Water Quality Standards, Objectives, and Guidelines (Williamson, 2002)			
						TIER II Water Quality Objectives	TIER III - Water Quality Guidelines		
							DRINKING		Freshwater
							MAC	IMAC	Aquatic Life
Physical Tests									
Hardness (as CaCO3)	mg/L	173.9	170.0	**61.5**	**715.0**				
pH	pH Units	8.07	8.07	**7.71**	**8.56**				
Dissolved Elements									
Aluminum (Al)-Dissolved	mg/L	0.026	0.005	**0.001**	**0.319**				0.005 - 0.1
Antimony (Sb)-Dissolved	mg/L	0.00009	0.00003	**0.00005**	**0.00114**			0.006	
Arsenic (As)-Dissolved	mg/L	0.00064	0.00060	**0.00014**	**0.00456**	0.15 mg/L (4-Day, 3-Year) [A]		0.025	Tier II
Barium (Ba)-Dissolved	mg/L	0.01915	0.01855	**0.00721**	**0.06300**		1		
Beryllium (Be)-Dissolved	mg/L	0.00014	0.00010	**<0.00020**	**<0.00050**				
Bismuth (Bi)-Dissolved	mg/L	0.00019	0.00025	**<0.00050**	**<0.00050**				
Boron (B)-Dissolved	mg/L	0.0122	0.0100	**0.0034**	**0.1970**			5	
Cadmium (Cd)-Dissolved	mg/L	0.00004	0.00001	**0.00001**	**0.00218**	Hardness dependent [B] (e.g. 0.00163 mg/L chronic; 0.00267 mg/L acute at hardness 65 mg/L $CaCO_3$)	0.005		Tier II
Calcium (Ca)-Dissolved	mg/L	36.5	35.6	**10.9**	**151.0**				
Chromium (Cr)-Dissolved	mg/L	0.00031	0.00025	**0.00015**	**0.00199**	Hardness dependent [C] (e.g.,0.052 mg/L Cr-III chronic at hardness 65 mg/L; 0.011 mg/L Cr-VI 4-Day, 3-Year)	0.05		Tier II
Cobalt (Co)-Dissolved	mg/L	0.00006	0.00005	**0.00002**	**0.00084**				
Copper (Cu)-Dissolved	mg/L	0.00049	0.00032	**0.00010**	**0.00630**	Hardness dependent [D] (e.g.,0.0062 mg/L chronic at hardness 65 mg/L $CaCO_3$)			Tier II
Iron (Fe)-Dissolved	mg/L	0.088	0.052	**0.010**	**1.190**				0.3
Lead (Pb)-Dissolved	mg/L	0.00008	0.00003	**0.00002**	**0.00212**	Hardness dependent [E] (e.g., 0.00157 mg/L chronic at hardness 65 mg/L $CaCO_3$)	0.01		Tier II
Lithium (Li)-Dissolved	mg/L	0.00284	0.00250	**0.00210**	**0.01800**				
Magnesium (Mg)-Dissolved	mg/L	20.05	19.00	**7.17**	**82.10**				
Manganese (Mn)-Dissolved	mg/L	0.02054	0.00697	**0.00025**	**0.90600**				
Mercury (Hg)-Dissolved	mg/L	0.00002	0.00003	**<0.000010**	**<0.00010**		0.001		0.0001
Molybdenum (Mo)-Dissolved	mg/L	0.00010	0.00009	**0.00005**	**0.00067**				0.073
Nickel (Ni)-Dissolved	mg/L	0.00041	0.00025	**0.00010**	**0.00585**	Hardness dependent [F] (e.g., 0.036 mg/L chronic at hardness 65 mg/L $CaCO_3$)			Tier II
Phosphorus (P)-Dissolved	mg/L	0.112	0.150	**0.002**	**0.015**				
Potassium (K)-Dissolved	mg/L	8.10	1.00	**0.18**	**705.00**				
Selenium (Se)-Dissolved	mg/L	0.00021	0.00025	**0.00014**	**0.00081**		0.01		0.001
Silicon (Si)-Dissolved	mg/L	3.77	3.43	**0.76**	**18.30**				
Silver (Ag)-Dissolved	mg/L	0.00002	0.00001	**0.00001**	**0.00058**				0.0001
Sodium (Na)-Dissolved	mg/L	2.87	2.41	**0.52**	**21.30**				
Strontium (Sr)-Dissolved	mg/L	0.0448	0.0393	**0.0112**	**0.2680**		5 Bq/L		
Thallium (Tl)-Dissolved	mg/L	0.00003	0.00003	**<0.000050**	**<0.00010**				0.0008
Tin (Sn)-Dissolved	mg/L	0.00011	0.00005	**0.00010**	**0.00134**				
Titanium (Ti)-Dissolved	mg/L	0.004	0.005	**0.012**	**0.026**				
Uranium (U)-Dissolved	mg/L	0.00017	0.00015	**0.00001**	**0.00102**			0.02	
Vanadium (V)-Dissolved	mg/L	0.00037	0.00029	**0.00005**	**0.00428**				
Zinc (Zn)-Dissolved	mg/L	0.00095	0.00050	**0.00060**	**0.00580**	Hardness dependent [G] (e.g., 0.082 mg/L chronic at hardness 65 mg/L $CaCO_3$)			Tier II

NOTE:

1 If the sample concentration was less than the detection limit, half the detection limit was used to compute the average and median.

Notes:

MAC - Maximum Acceptable Concentration
IMAC Interim Maximum Acceptable Concentration

A Arsenic limits:	0.15 mg/L for averaging duration 4 days (4-Day, 3-Year or 7Q10 Design Flow); 0.34 mg/L for averaging duration 1 hr (1-Day, 3-Year or 1Q10 Design Flow)
B Cadmium limits:	[e{0.7852[ln(Hardness)]-2.715}]×[1.101672-{ln(Hardness)(0.041838)}] for 4 days averaging duration. [e{1.128[ln(Hardness)]-3.6867}]×[1.136672-{ln(Hardness)(0.041838)}] for 1 hour averaging duration.
C Chromium limits:	Chromium III: [e{0.8190[ln(Hardness)]+0.6848}]×[0.860] for 4 days averaging duration. Chromium III: [e{0.8190[ln(Hardness)]+3.7256}]×[0.316] for 1 hour averaging duration. Chromium VI: 0.011 mg/L for averaging duration 4 days (4-Day, 3-Year or 7Q10 Design Flow); 0.016 mg/L for averaging duration 1 hr (1-Day, 3-Year or 1Q10 Design Flow)
D Copper limits:	[e{0.8545[ln(Hardness)]-1.702}]×[0.960] for 4 Days hour averaging duration. [e{0.9422[ln(Hardness)]-1.700}]×[0.960] for 1 hour averaging duration.
E Lead limits:	[e{1.273[ln(Hardness)]-4,705}]×[1.46203 -{ln(Hardness)(0.145712)}] for 4 Days averaging duration. [e{1.273[ln(Hardness)]-1.460}]×[1.46203 -{ln(Hardness)(0.145712)}] for 1 hour averaging duration.
F Nickel limits:	[e{0.8460[ln(Hardness)]+0.0584}]×[0.997] for 4 Days averaging duration. [e{0.8460[ln(Hardness)]+2.255}]×[0.998] for 1 hour averaging duration.
G Zinc limits:	[e{0.8473[ln(Hardness)]+0.884}]×[0.976] for 4 Days averaging duration. [e{0.8473[ln(Hardness)]+0.884}]×[0.978] for 1 hour averaging duration.

Footnotes for the CCME (Canadian Council of Ministers of the Environment) Aquatic Guidelines. 2006. (= Canadian water quality guidelines for the protection of aquatic life).

c Interim guideline.
d No fact sheet created.
g Aluminium guideline= 5 µg·L^{-1} at pH <6.5
= 100 µg·L^{-1} at pH = 6.5 or greater
h Ammonia guideline: Expressed as µg unionized ammonia·L^{-1}. This would be equivalent to 15.2 µg ammonia-nitrogen·L^{-1}. Guideline for total ammonia is temperature and pH dependent, please consult factsheet for more information.
j The technical document for the guideline is available from the Ontario Ministry of the Environment.
k Substance has been re-evaluated since CCREM 1987 + Appendixes. Either a new guideline has been derived or insufficient data existed to derive a new guideline.
l Cadmium guideline = 10{0.86[log(hardness)] - 3.2}.
m Copper guideline = 2 µg·L^{-1} at [CaCO3] = 0–120 mg·L^{-1}
= 3 µg·L^{-1} at [CaCO3] = 120–180 mg·L^{-1}
= 4 µg·L^{-1} at [CaCO3] >180 mg·L^{-1}
n Dissolved oxygen for warm-water biota: early life stages = 6000 µg·L^{-1}
other life stages = 5500 µg·L^{-1}
for cold-water biota: early life stages = 9500 µg·L^{-1}
other life stages = 6500 µg·L^{-1}
o Lead guideline = 1 µg·L^{-1} at [CaCO3] = 0–60 mg·L^{-1}
= 2 µg·L^{-1} at [CaCO3] = 60–120 mg·$^{L-1}$
= 4 µg·L^{-1} at [CaCO3] = 120–180 mg·L^{-1}
= 7 µg·L^{-1} at [CaCO3] = >180 mg·L^{-1}
p Nickel guideline = 25 µg·L^{-1} at [CaCO3] = 0–60 mg·L^{-1}
= 65 µg·L^{-1} at [CaCO3] = 60–120 mg·L^{-1}
= 110 µg·L^{-1} at [CaCO3] = 120–180 mg·L^{-1}
= 150 µg·L^{-1} at [CaCO3] = >180 mg·L^{-1}
s Temperature: (for more information, see CCREM 1987)
Thermal Stratification: Thermal additions to receiving waters should be such that thermal stratification and subsequent turnover dates are not altered from those existing prior to the addition of heat from artificial origins.
Maximum Weekly Average Temperature: Thermal additions to receiving waters should be such that the maximum weekly average temperature is not exceeded.
Short-term Exposure to Extreme Temperature: Thermal additions to receiving waters should be such that the short-term exposures to maximum temperatures are not exceeded. Exposures should not be so lengthy or frequent as to adversely affect the important species.
u For protection from direct toxic effects; the guidelines do not consider indirect effects due to eutrophication.
w May not protect fully higher trophic level fish; see factsheet for details.
x Canadian Trigger Ranges (for further narrative see factsheet), Total Phosphorus (ug·.L^{-1}):
ultra-oligotrophic <4
oligotrophic 4-10
mesotrophic 10-20
meso-eutrophic 20-35
eutrophic 35-100
hyper-eutrophic >100
y Guidelines are expressed in µg nitrate·L^{-1}. These values are equivalent to 2900 µg nitrate-nitrogen·L^{-1}, and 3600 µg nitrate-nitrogen·L^{-1}, for freshwater and marine respectively.
z Guideline is expressed as µg nitrite-nitrogen·L^{-1}. This value is equivalent to 197 µg nitrite·L^{-1}.

Table 7.5-5 Average Ratio of Dissolved versus Total Element Concentrations

Element	Average Ratio of Dissolved versus Total Element Concentrations [1]
Aluminum (Al)	32%
Iron (Fe)	46%
Cobalt (Co)	64%
Vanadium (V)	65%
Titanium (Ti)	67%
Manganese (Mn)	70%
Lead (Pb)	78%
Nickel (Ni)	78%
Chromium (Cr)	82%
all other elements	93% or greater

NOTE: If the dissolved or total element concentration was less than the detection limit, half the detection limit was used to compute the average.

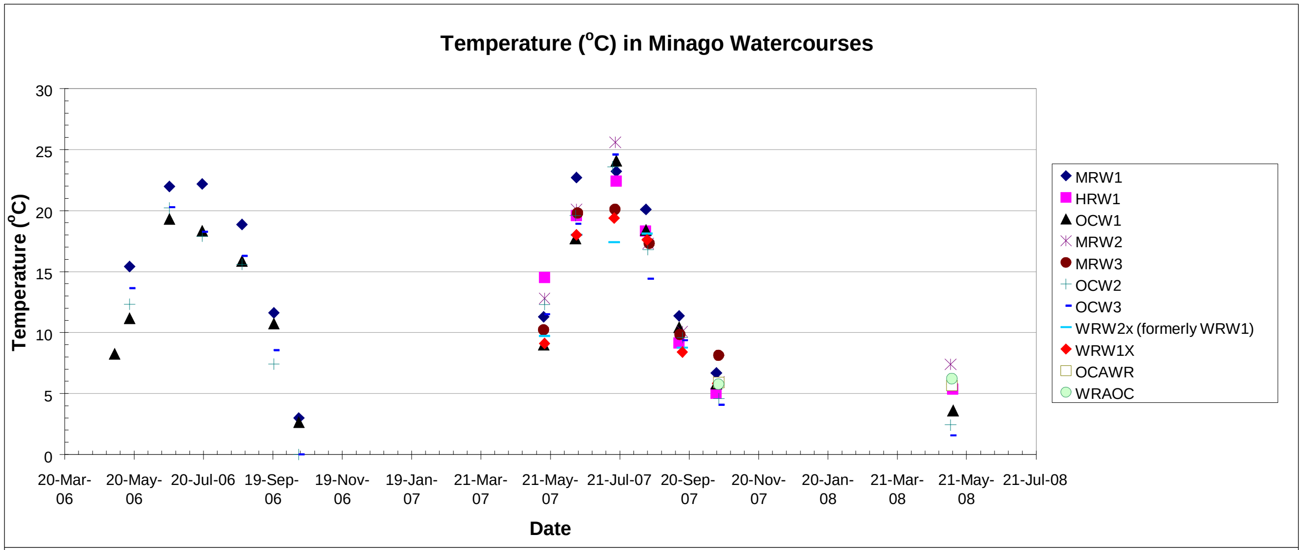
7.5.3.2.2 Hardness

Water in watercourses surrounding the Minago site is relatively hard. The recorded hardness ranged from 61.5 to 715 mg/L (as $CaCO_3$). The average and median hardness was 173.9 mg/L and 170 mg/L (as $CaCO_3$), respectively (Table 7.5-4). At these levels of hardness, all recorded dissolved metal concentrations met the *Manitoba Tier II Water Quality Objectives*.

7.5.3.2.3 Temperature and Dissolved Oxygen

The temperature, recorded between May and October of 2006, 2007, and 2008 varied seasonally in the Minago surface watercourses (Figure 7.5-2). Creeks and streams warmed quickly in the spring and cooled off in the fall. Seasonal variations in the water termperatures occurred as a response to ambient air temperatures. Recorded water temperatures ranged from a minimum of 2.7^{o}C to a maximum of 22.2^{o}C in 2006 and from a minimum of 4.7^{o}C to a maximum of 25.6^{o}C in 2007. The maximum temperature was recorded on July 19 at station MRW1 in 2006 and on July 17 at station MRW2 in 2007.

The dissolved oxygen concentration ranged from a minimum of 5.8 mg/L (recorded on Jul. 19, 2006 at OCW3) to a maximum of 12.6 mg/L in 2006 and from a minimum of 5.7 mg/L (recorded on Jun. 13, 2007 at MRW1) to a maximum of 13.4 mg/L in 2007. In percent saturation, the reported dissolved oxygen concentrations ranged from 61.4 to 106.3% in 2006 and from 83.6 to 109.2% in 2007 (Figure 7.5-3). Dissolved oxygen concentrations were lowest in the summer



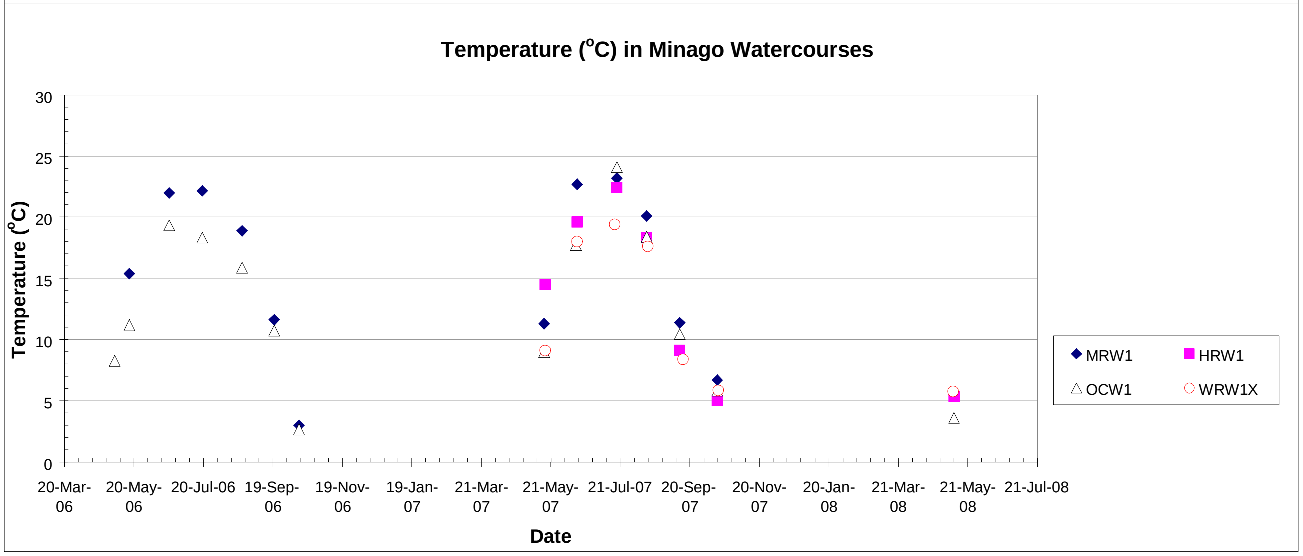


Figure 7.5-2 Temperature in Minago Surface Watercourses

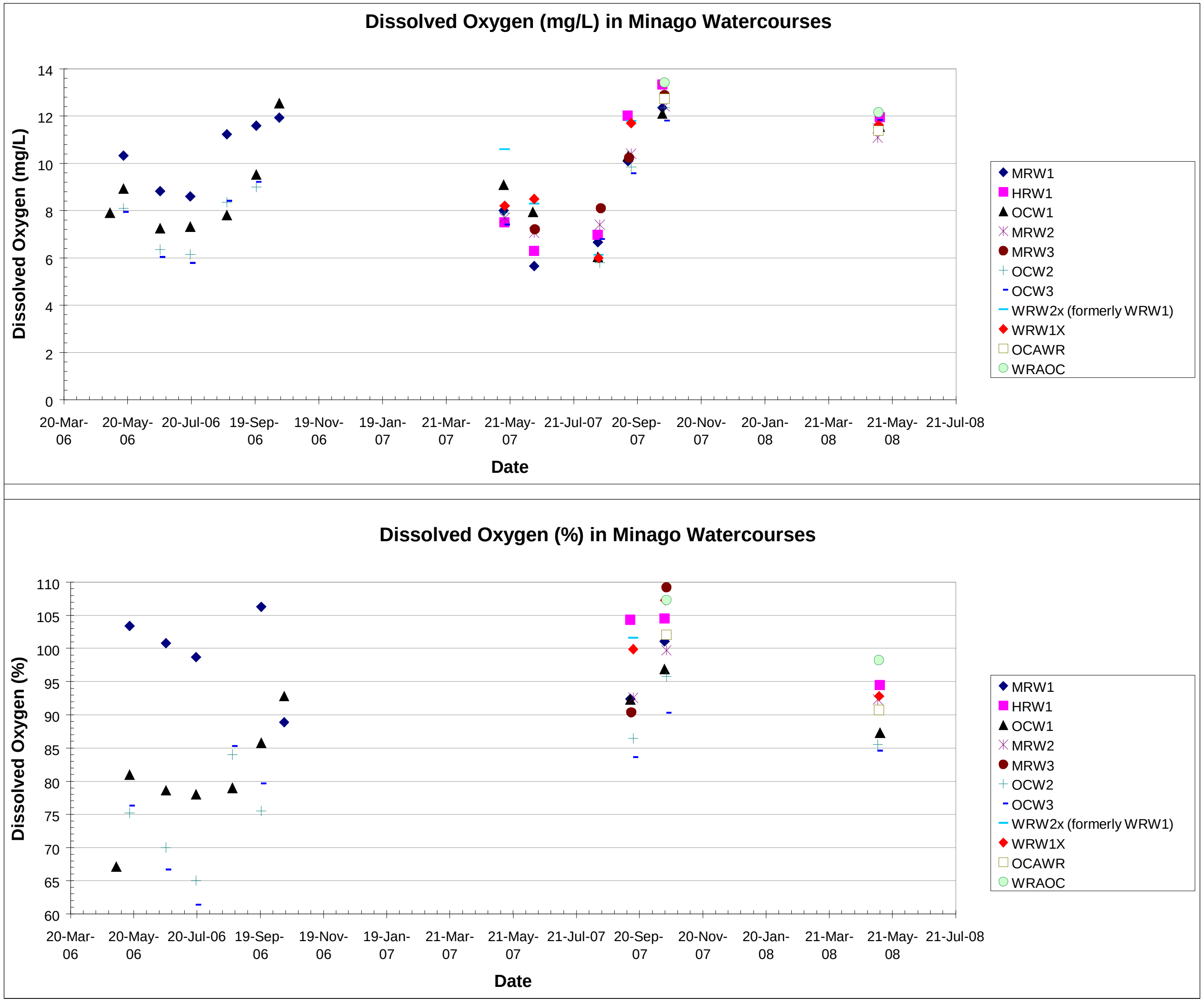


Figure 7.5-3 Dissolved Oxygen in Minago Surface Watercourses

months corresponding with the higher water temperatures recorded in the summer (Figure 7.5-3). This was expected as dissolved oxygen in water is governed by Henry's Law (higher temperature results in lower dissolved oxygen) if all other environmental conditions are the same. At Minago, all measured dissolved oxygen concentrations met the *Manitoba Tier II Water Quality Objectives* (Table 7.5-4).

7.5.3.2.4 Conductivity and Oxidation-Reduction Potential

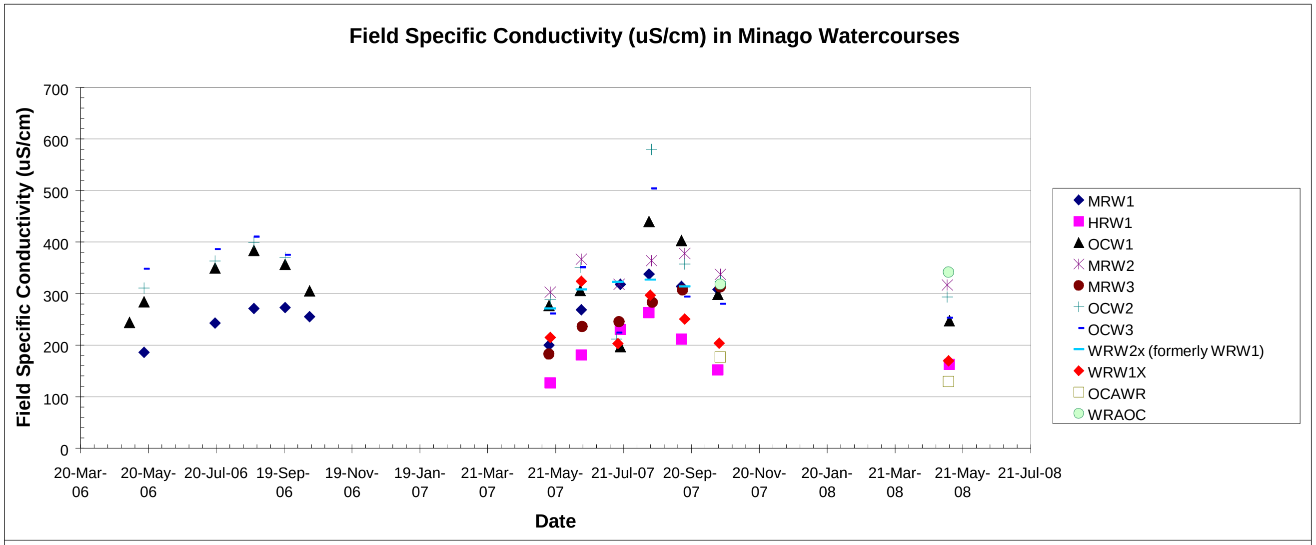
The field specific conductivity (conductivity measured at *in situ* water temperature corrected to 25^oC) ranged from 127 to 580 μS/cm with average and median values of 214.2 and 215.5 μS/cm, respectively (Table 7.5-4 and Figure 7.5-4). Conductivities, measured in the laboratory after sample shipment, ranged from 129 to 467 μS/cm in all but one sample. That sample, collected on Mar. 11, 2008 from the Hargrave River sampling station HRW1, had a conductivity of 1,170 μS/cm. To date, all conductivity measurements met the *Manitoba Tier II Water Quality Objective* of 1,000 μS/cm with the exception of the Mar. 11, 2008 conductivity recorded at HRW1. The average and median values for conductivities, measured in the laboratory, were 284.5 and 282.0 μS/cm, respectively.

The Oxidation-Reduction Potential (ORP or redox potential) is an important characteristic of natural waters. The ORP is a measure of the oxidizing or reducing power of water. The ORP measures the ability of the aquatic system to supply electrons to an oxidizing agent (for example, oxygen) and to take up electrons from a reducing agent. Reduction-oxidation (redox) reactions occur simultaneously (Radojevic and Bashkin, 2006; Manahan, 2005). In redox reactions, the substance that is reduced accepts electrons and the substance that supplies electrons is oxidized. For example, the reduction of oxygen (O_2) by organic matter (represented by $\{CH_2O\}$),

$$\{CH_2O\} + O_2 \rightarrow CO_2 + H_2O$$

results in oxygen depletion in the water that can potentially kill fish, if the depletion is severe enough.

At Minago, the ORP ranged from 116 to 309 mV with average and median values of 210 mV and 208 mV, respectively (Table 7.5-4). In typical surface water, ORP ranges from 100 to 500 mV (Radojevic and Bashkin, 2006; Manahan, 2005). Thus, the ORP of surface watercourses in the vicinity of the Minago site is on the lower (more reducing) side of the normal range. ORP measurements at Minago are illustrated in Appendix 7.5.



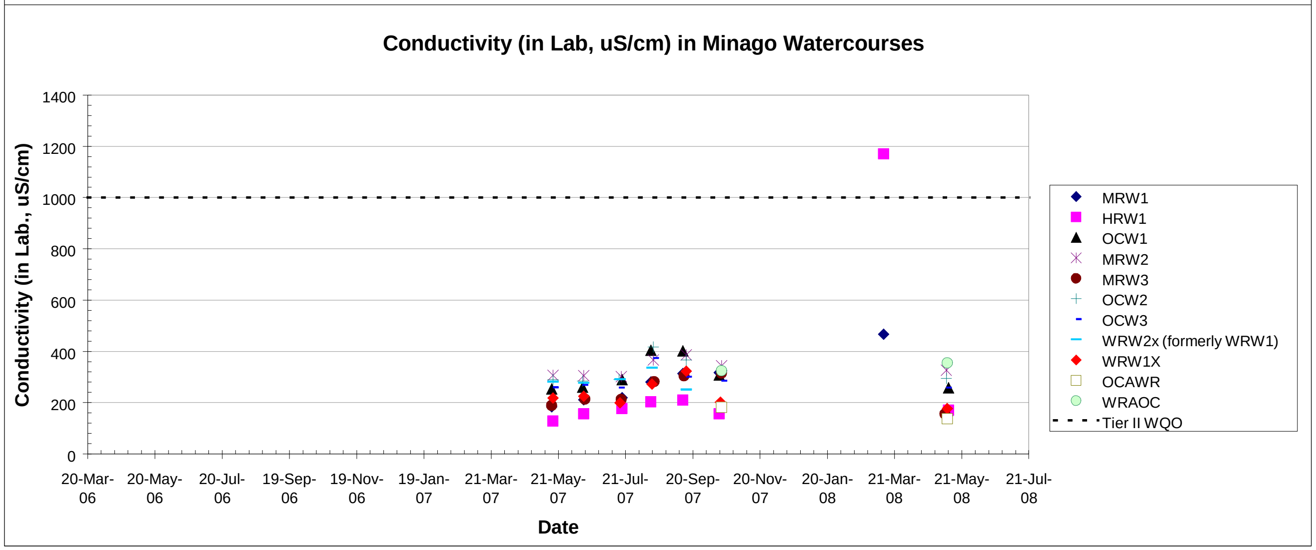


Figure 7.5-4 Conductivity (μS/cm) in Minago Surface Watercourses

7.5.3.2.5 Exceedances of Water Quality Guidelines and Objectives

Overall, the water quality was good in the vicinity of the Minago Project with only some parameters exceeding Manitoba and/or CCME (Canadian Council of Ministers of the Environment) limits for the protection of freshwater aquatic life. The most common exceedances of Manitoba water quality guidelines occurred for aluminum (Figure 7.5-5) and iron (Figure 7.5-6) followed by Nitrite-N (Figure 7.5-8), copper (Figure 7.5-9), Total Dissolved Solids (TDS) (Figure 7.5-10), and selenium and silver (Figure 7.5-11). These exceedances are discussed below.

Aluminum, Iron and Turbidity

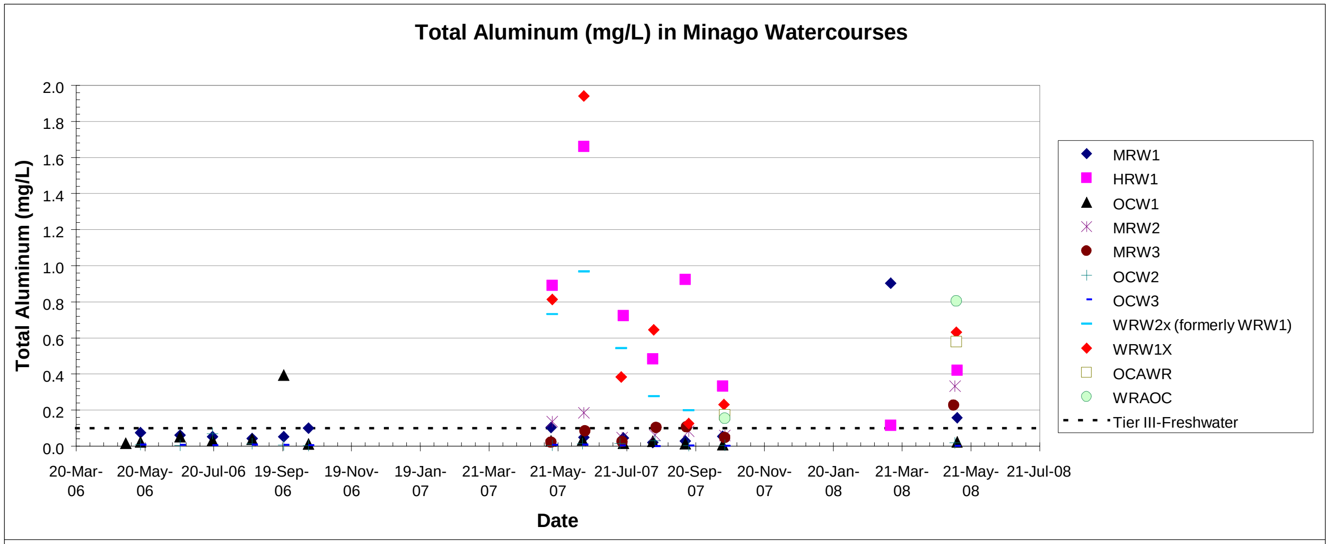
In watercourses surrounding the Minago site, the total aluminum concentration ranged from 0.001 to 1.94 mg/L with average and median values of 0.197 mg/L and 0.053 mg/L, respectively (Table 7.5-4, Figure 7.5-5). In comparison, the maximum guideline level for aluminum, defined in the *Manitoba Tier III Freshwater Quality Guidelines* and the CCME (2007) guidelines for the protection of Aquatic Life, is 0.1 mg/L for a pH greater than 6.5. Thus, average total aluminum levels were significantly above guideline levels. Generally, the total aluminum concentration was higher for rivers and reaches with larger flow volumes (at the Hargrave River station and William River WRW2x and WRW1x; Figure 7.5-5).

At Minago, the dissolved aluminum concentration ranged from 0.001 to 0.319 mg/L with average and median values of 0.026 and 0.005 mg/L, respectively (Table 7.5-4). In comparison, the maximum guideline level defined in the *Manitoba Tier III Freshwater Quality Guidelines* is 0.1 mg/L if pH is greater than 6.5. To date, the dissolved aluminum concentrations exceeded *the Manitoba Tier II Water Quality Objectives* on 4 occasions (Figure 7.5-5).

Total iron concentration ranged from 0.025 to 1.89 mg/L in watercourses surrounding the Minago site. The average and median total iron concentrations were 0.271 mg/L and 0.137 mg/L, respectively (Table 7.5-4, Figure 7.5-6). In comparison, the maximum guideline level for iron, defined in the *Manitoba Tier III Freshwater Quality Guidelines* and the CCME (2007) guidelines for the protection of Aquatic Life, is 0.3 mg/L. To date, this guideline value was exceeded on 20 occasions at Minago. Generally, the total iron concentration was higher for rivers and reaches with larger flow volumes (at the Hargrave River station and William River WRW2x and WRW1x; Figure 7.5-6).

At Minago, the dissolved iron concentration ranged from 0.01 to 1.19 mg/L with average and median values of 0.088 and 0.052 mg/L, respectively (Table 7.5-4). In comparison, the maximum guideline levels set in the *Manitoba Tier III Freshwater Quality Guidelines* is 0.3 mg/L. This guideline level was exceeded on 4 occasions in the Minago water samples collected to date.

The elevated concentrations of aluminum and iron, in light of complete absence of any type of industrial or domestic development in the vicinity of the Minago site, are likely due to eroded clay particles and leaching from the muskegs in the area. As previously mentioned, surficial soils at the Minago site consist of 1.0 to 2.1 m of peat that is underlain by



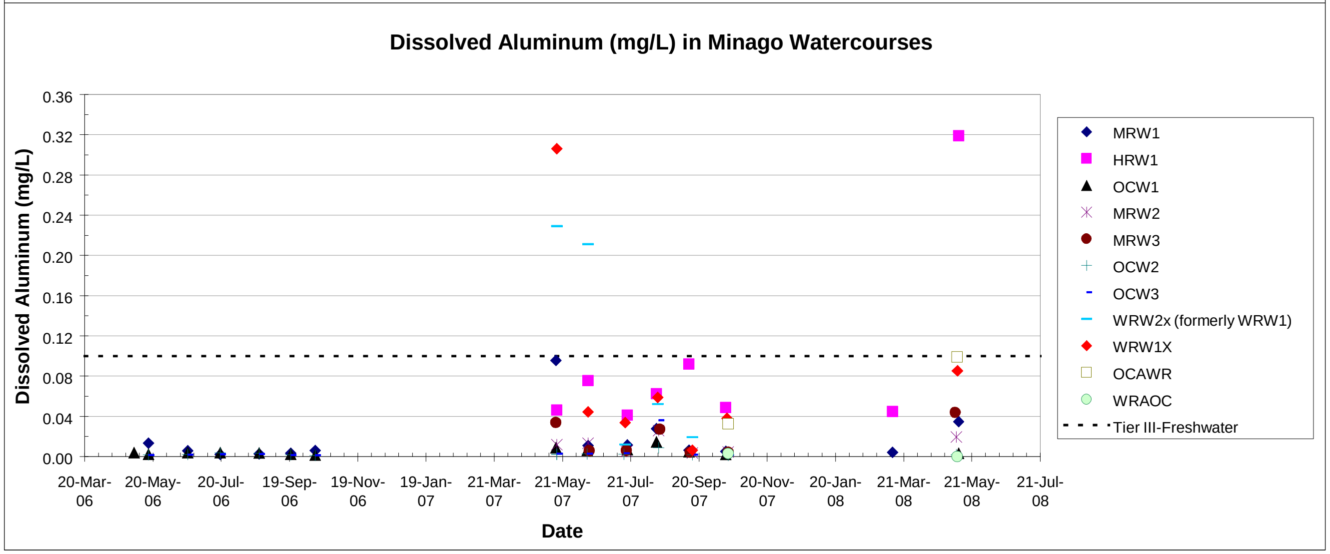
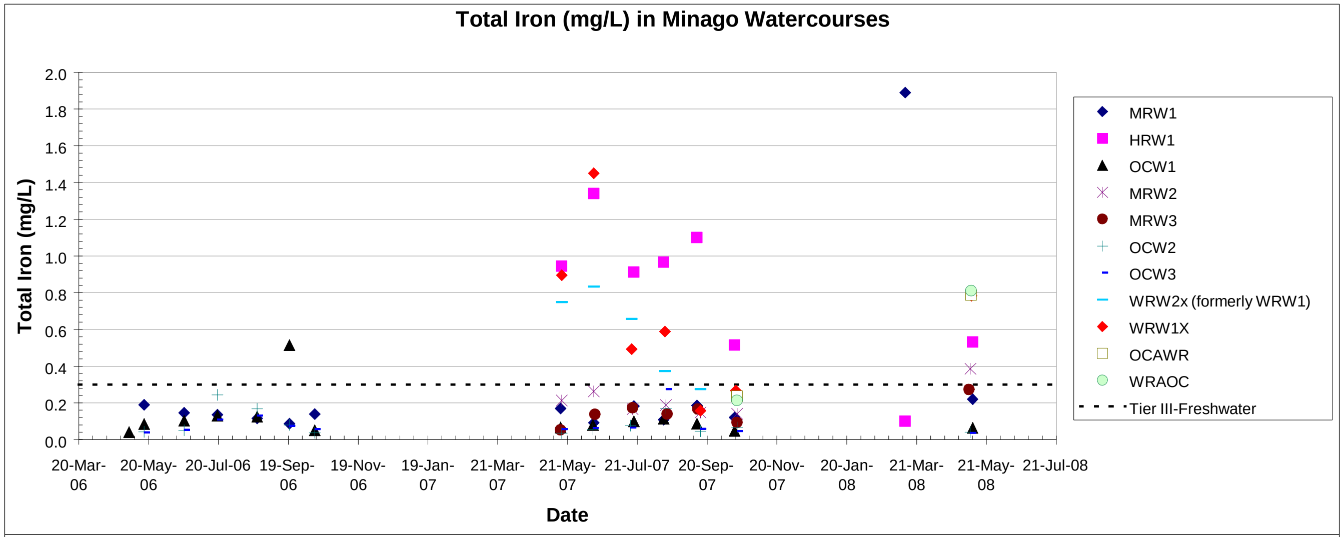


Figure 7.5-5 Total and Dissolved Aluminum (mg/L) in Minago Surface Watercourses



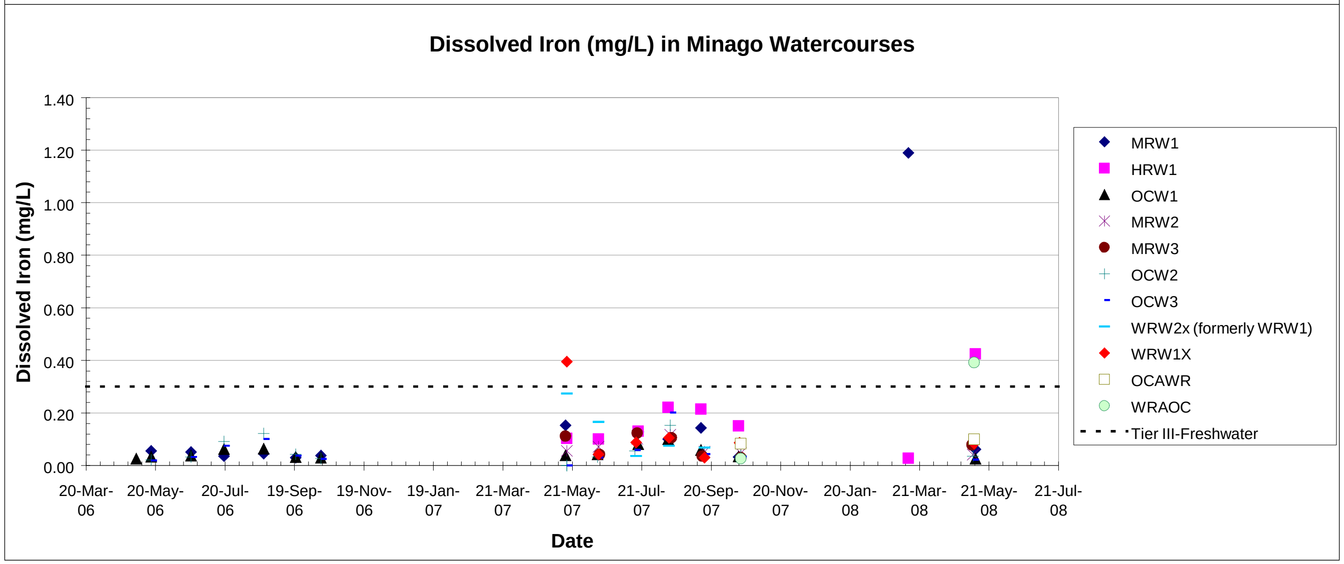


Figure 7.5-6 Total and Dissolved Iron (mg/L) in Minago Surface Watercourses

1.5 to 10.7 m of impermeable compacted glacial lacustrine clays. Many clays contain large amounts of aluminum, sodium, potassium, magnesium, calcium, and iron, as well as trace quantities of other metals. They are also readily suspended in water as colloidal particles may be leached from soil (Manahan, 2005).

All clays contain silicate and most contain aluminum and water (Manahan, 2005). All clay minerals are very small colloidal-sized crystals (diameter less than 1 μm). Chemically, they are hydrous aluminosilicates plus other metallic ions (Holtz and Kovacs, 1981). Physically, clays consist of very fine grains having sheet-like structures. There are only two fundamental crystal sheets, the silica (or tetrahedral) and the alumina (or octahedral) sheets. The particular way in which these sheets are stacked, together with different bonding and different metallic ions in the crystal lattice, constitute the different clay minerals (Holtz and Kovacs, 1981). Clay minerals differ in their general chemical formula, structure, and chemical and physical properties. For example the structural formula for the clay minerals montmorillonite and illite are $Al_2(OH)_2Si_4O_{10}$ and
$K_{0-2}Al_4(Si_{8-6}\ Al_{0-2})O_{20}(OH)_4$, respectively (Manahan, 2005).

Turbidity results for the watercourses surrounding the Minago site also point to suspended colloidal matter and soil particles (Figure 7.5-7). Recorded turbidity ranged from 0.2 to 38.1 NTU and the average and median turbidity were 6.0 and 1.5 NTU (Table 7.5-4), respectively. To date, turbidity was greater than 1 on 59 occasions at Minago. Generally, turbidity was higher for the rivers and reaches with larger flow volumes (at the Hargrave River station and William River WRW2x and WRW1x; Figure 7.5-7).

To shed some light on the connection between elevated total aluminum and total iron concentrations and turbidity, correlation analyses were conducted. For a perfect correlation, the correlation coefficient R is 1 and R^2 is equal to 1. Based on the water quality results obtained to date, total aluminum concentrations correlated very well (R^2 > 0.86) with turbidity for stations OCW1, WRW2x and MRW1 while total iron concentrations correlated well (R^2 > 0.81) with turbidity for stations WRW2x, OCW1, HRW1, and MRW1. Results of the correlation analyses are presented in Table 7.5-6. Detailed correlation graphs for these analyses are given in Appendix 7.5.

Table 7.5-6 Results of Correlation Analyses – Total Aluminum and Total Iron versus Turbidity

		Total Alumimum versus Turbidity	**Total Iron versus Turbidity**
Stream / Creek	**Sampling Station**	R^2	R^2
Oakley Creek	**OCW1**	**0.958**	**0.912**
William River	**WRW2x**	**0.941**	**0.958**
	WRW1x	0.162	0.366
Minago River	**MRW1**	**0.867**	**0.813**
	MRW2	0.685	0.584
Hargrave River	**HRW1**	0.434	**0.820**

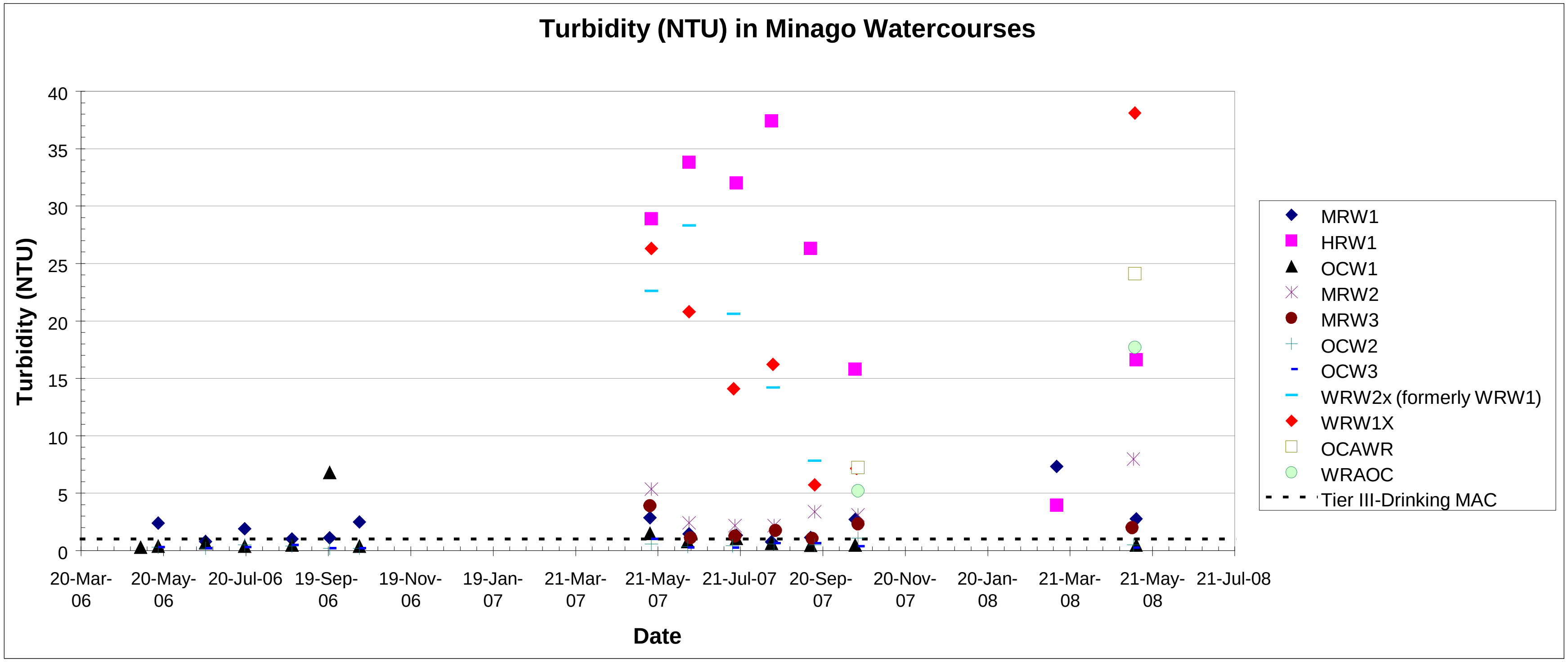


Figure 7.5-7 Turbidity (NTU) in Minago Surface Watercourses

Nitrite-N

The nitrite-N concentration in watercourses surrounding the Minago site ranged from <0.001 to 0.29 mg/L with average and median concentrations of 0.04 mg/L and 0.0005 mg/L, respectively (Table 7.5-4, Figure 7.5-8). In comparison, the maximum guideline level for nitrite-N, defined in the CCME (2007) guidelines for the protection of Aquatic Life, is 0.06 mg/L. To date, this guideline value was exceeded on 13 occasions in watercourses surrounding the Minago Project.

Copper

The total copper (Cu) concentration in watercourses surrounding the Minago site ranged from <0.0001 to 0.0064 mg/L with average and median concentrations of 0.0007 mg/L and 0.00037 mg/L, respectively (Table 7.5-4, Figure 7.5-9). In comparison, the maximum guideline level for total copper in the CCME (2007) guidelines for the protection of Aquatic Life, ranges from 0.002 to 0.004 mg/L depending on hardness. Based on the recorded total copper and hardness levels at Minago, the CCME guideline limit was exceeded twice (in Sept. 2007 and Mar. 2008) at sampling station HRW1 and once (in May 2006) at sampling station MRW1.

Total Dissolved Solids (TDS)

TDS in watercourses surrounding the Minago site ranged from 60 to 739 mg/L with average and median concentrations of 189.2 mg/L and 186.0 mg/L, respectively (Table 7.5-4, Figure 7.5-10). In comparison, the maximum TDS level, set in the *Manitoba Tier II Water Quality Objectives*, is 700 mg/L. Based on the recorded TDS levels at Minago, the Tier II guideline limit was exceeded once in March 2008 at sampling station HRW1.

Selenium and Silver

The total selenium (Se) concentration in watercourses surrounding the Minago site ranged from 0.0001 to 0.00135 mg/L with average and median concentrations of 0.00045 mg/L and 0.00025 mg/L, respectively (Table 7.5-4, Figure 7.5-11). In comparison, the maximum guideline level for total selenium, set in the Manitoba Tier III and the CCME (2007) guidelines for the protection of Aquatic Life, is 0.001 mg/L. Based on the recorded total selenium levels at Minago, the selenium guideline limit was only exceeded once in May 2007 at sampling station WRW1x.

The total silver (Ag) concentration in watercourses surrounding the Minago site ranged from 0.00001 to 0.00083 mg/L with average and median concentrations of 0.0002 mg/L and 0.00001 mg/L, respectively (Table 7.5-4, Figure 7.5-11). In comparison, the maximum guideline level for total silver, defined in the Manitoba Tier III and the CCME (2007) guidelines for the protection of Aquatic Life, is 0.0001 mg/L. Based on the recorded total silver levels at Minago, the silver guideline limit was only exceeded once in July 2007 at sampling station MRW2.

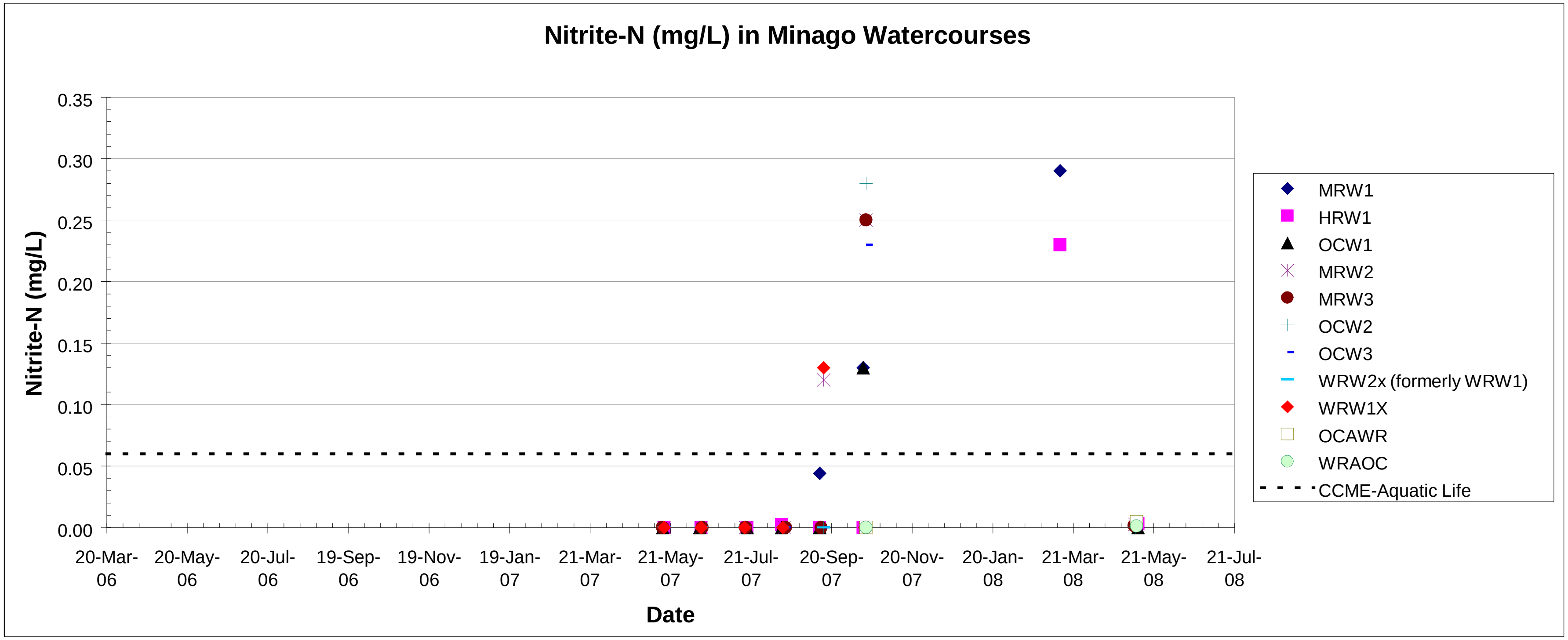


Figure 7.5-8 Nitrite-N (mg/L) in Minago Surface Watercourses

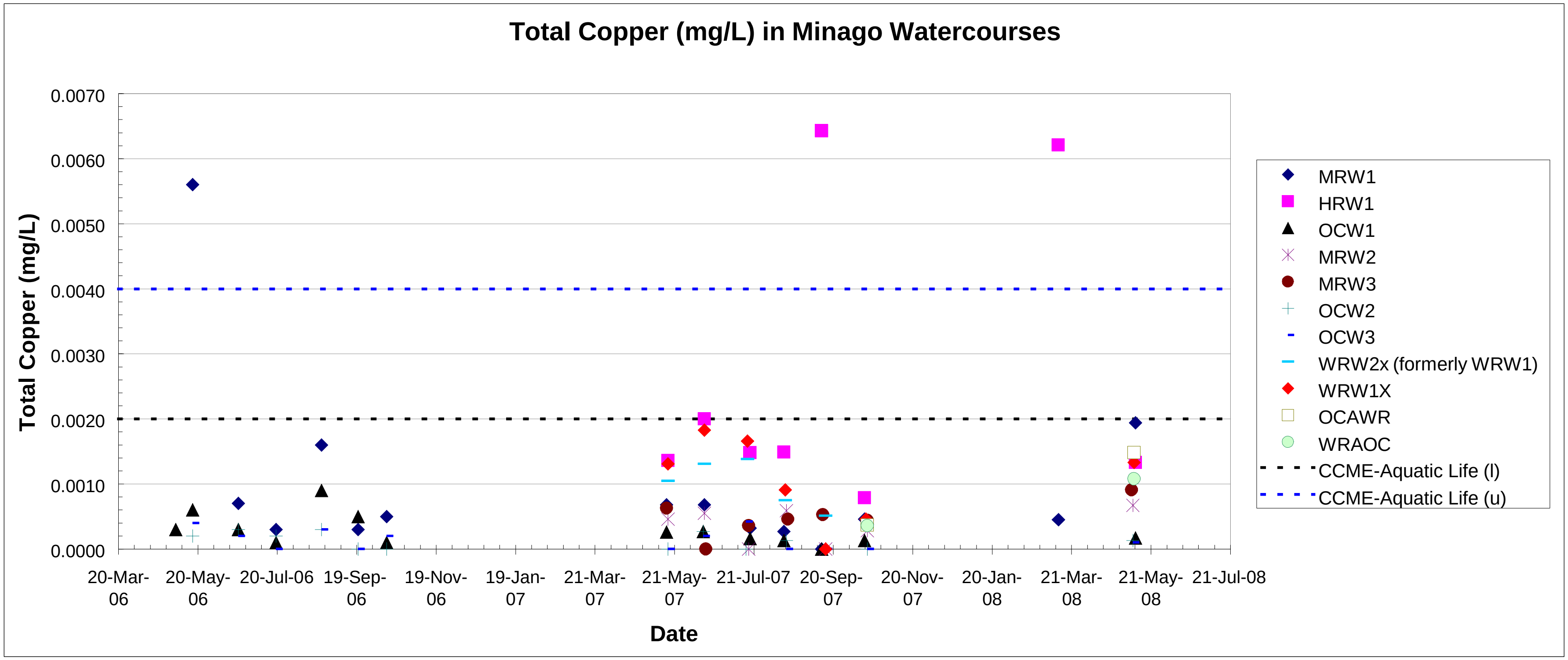


Figure 7.5-9 Total Copper (mg/L) in Minago Surface Watercourses

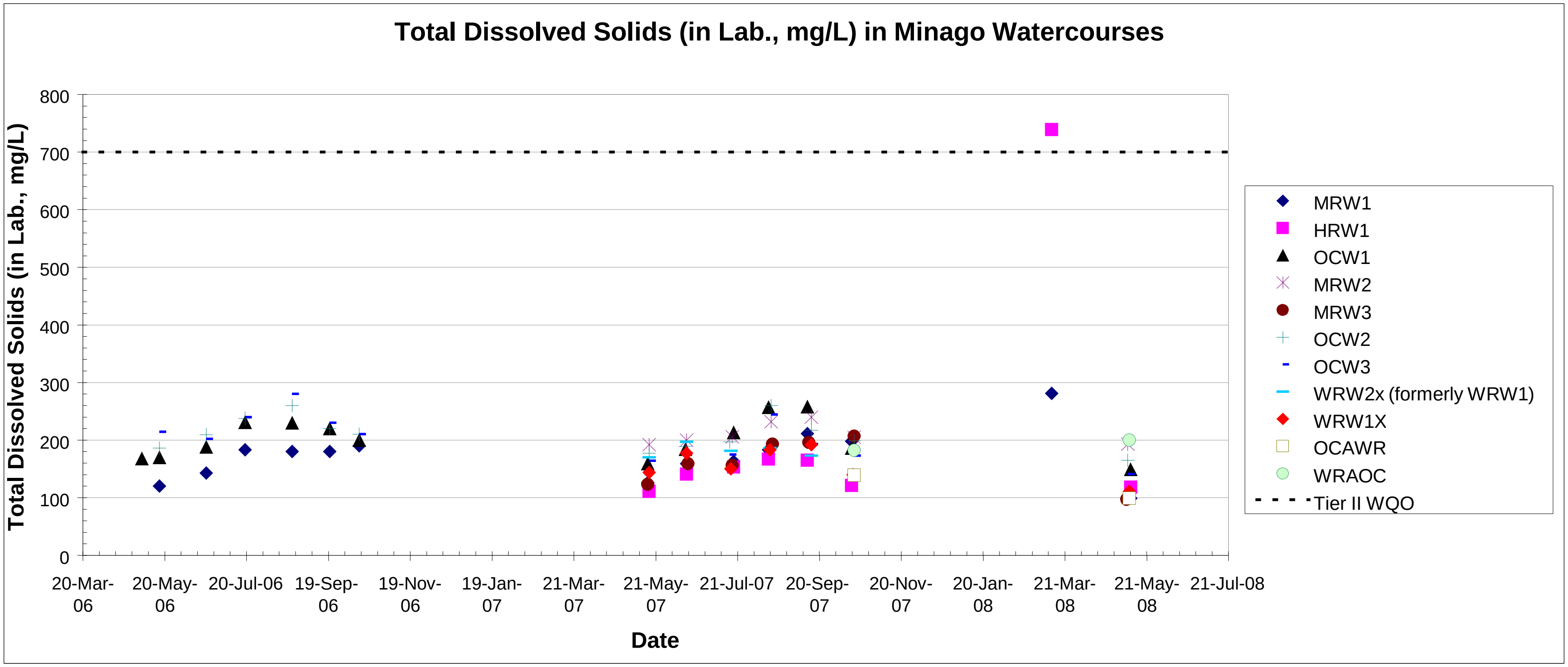
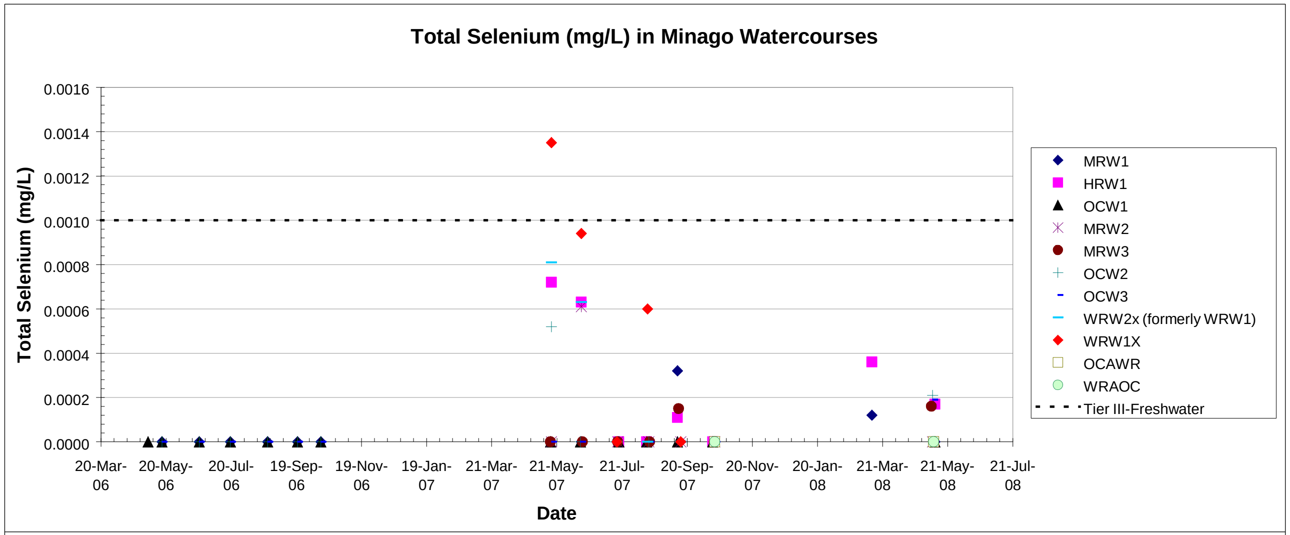


Figure 7.5-10 Total Dissolved Solids (mg/L) in Minago Surface Watercourses



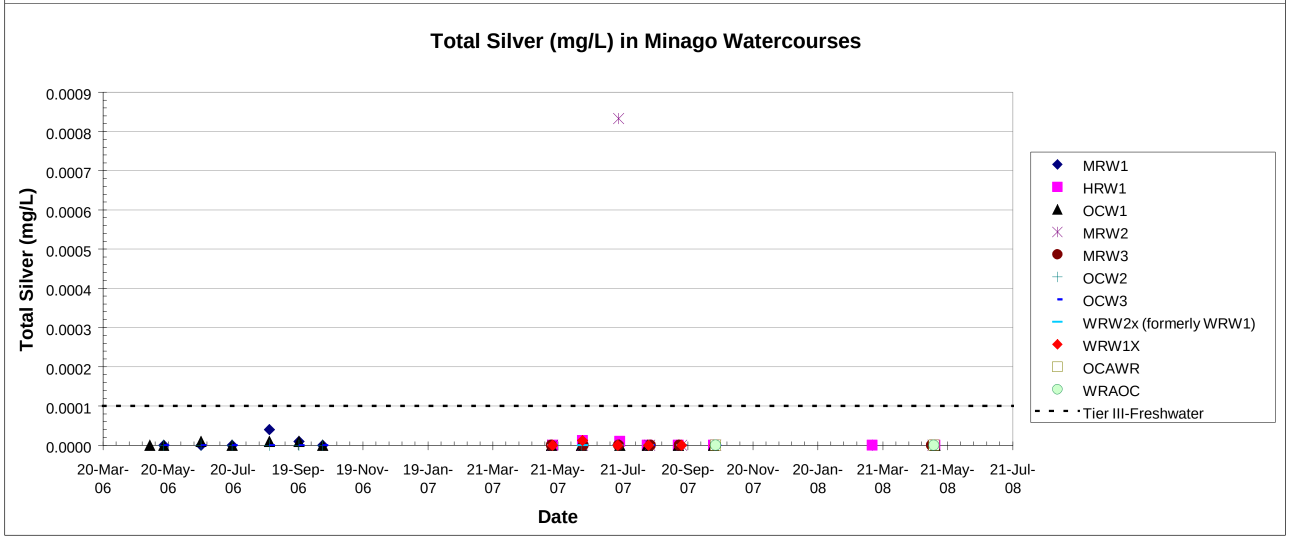


Figure 7.5-11 Total Selenium (mg/L) and Total Silver (mg/L) in Minago Surface Watercourses

7.5.3.2.6 Water Quality Results compared to Metal Mining Effluent Regulations

Table 7.5-7 presents average and median water quality results for all stations and all sampling events against limits of the Metal Mining Effluent Regulations (Environment Canada, 2002a). The only water quality parameter that exceeded MMER was Total Suspended Solids (TSS) (Figure 7.5-12). The MMER guideline value for TSS is 15 mg/L for a monthly mean and 30 mg/L for grab samples. At Minago, the total suspended solids measurements ranged from 0.5 to 65 mg/L with average and median concentrations of 11.5 mg/L and 5.0 mg/L, respectively. TSS exceeded the 2002 MMER guideline value of 30 mg/L for grab samples on 4 occasions at HRW1, on two occasions at WRW1x and WRW2x, and once each at OCAWR and WRAOC.

Table 7.5-7 Comparison of Water Quality Results to Metal Mining Effluent Regulations

		AVERAGE[1] May - Oct. All stations	**MEDIAN[1] May - Oct. All stations**	**MINIMUM May - Oct. All stations**	**MAXIMUM May - Oct. All stations**	**Metal Effluent Mining Regulations**	
Matrix	**Units**	Water	Water	Water	Water	(Monthly Mean)	Grab Sample
pH (Field)	pH Units	7.82	7.81	**7.01**	**8.84**	6.5-9.5	6-9.5
pH (Laboratory)	pH Units	8.07	8.07	**7.71**	**8.56**	6.0-9.5	6-9.5
Arsenic (As)-Total	mg/L	0.00066	0.00060	**0.00014**	**0.00452**	0.5	1.00
Copper (Cu)-Total	mg/L	0.00070	0.00037	**0.00010**	**0.00643**	0.3	0.60
Cyanide, Total	mg/L	0.0097	0.0095	**0.0056**	**0.0140**	1	2.00
Lead (Pb)-Total	mg/L	0.00017	0.00007	**0.00002**	**0.00221**	0.2	0.40
Nickel (Ni)-Total	mg/L	0.00076	0.00040	**0.00011**	**0.00641**	0.5	1
Zinc (Zn)-Total	mg/L	0.00152	0.00100	**0.0007**	**0.0060**	0.5	1
Tot. Suspended Solids	mg/L	11.5	5.0	**0.5**	**65.0**	15	30
Radium-226	Bq/L	0.00492	0.00250	**0.0050**	**0.050**	0.37	1.11

NOTE: 1 If the sample concentration was less than the detection limit, half the detection limit was used to compute the average and median.

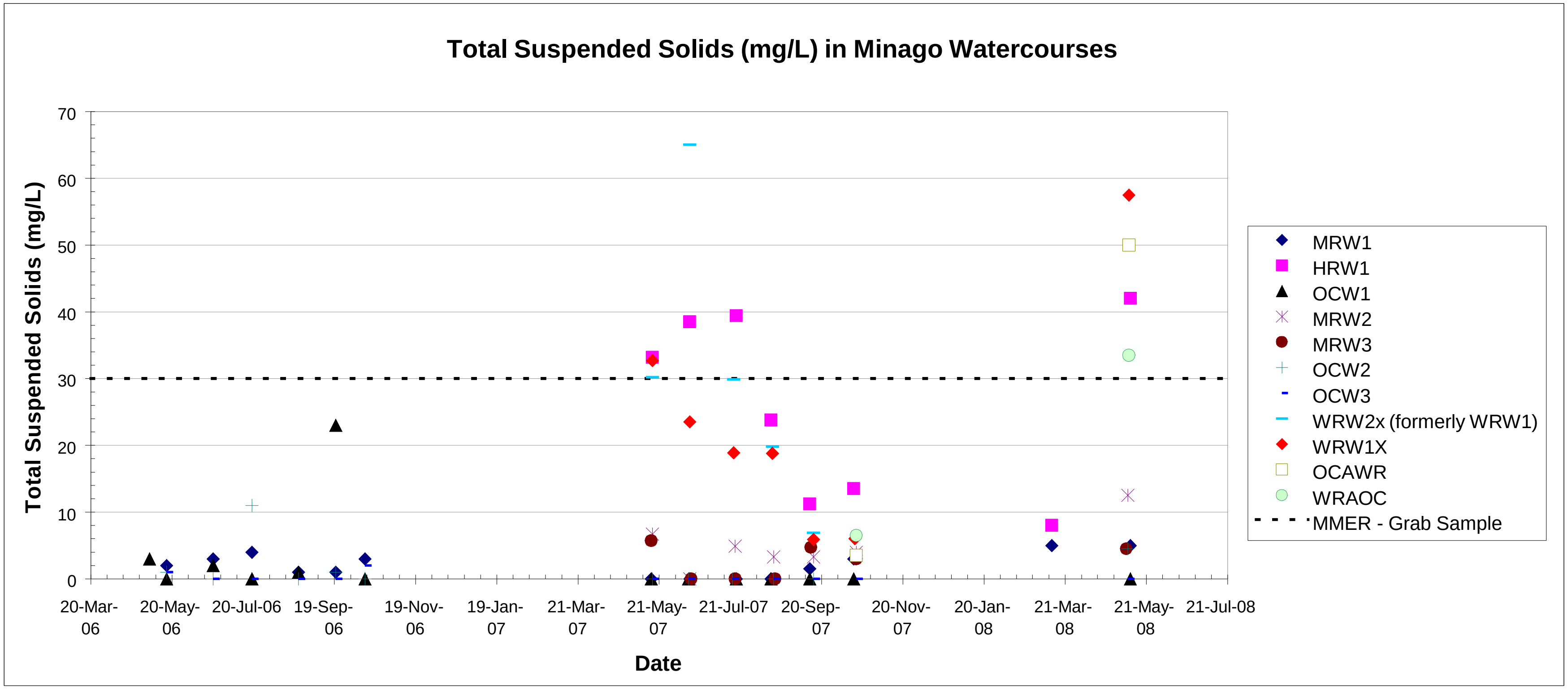


Figure 7.5-12 Total Suspended Solids (mg/L) in Minago Surface Watercourses

7.5.4 Effects Assessment

This section examines potential project effects on surface water and sediment quality. Existing conditions in the project area are characterized and effects of project activities are predicted. Effects predictions are based on Site Water Management Plans described in Section 2.14: Site Water Management. Projections of drainage and effluent quality from ongoing testing and assessment of ARD and metals leaching from the ultramafic waste rock and planned development rock are described in Section 2.8: Geochemical Rock Characterization, and planned infrastructure is detailed in Section 2.15: Site Facilities and Infrastructure. Information on predicted project effects on stream flows (Section 7.4: Surface Water Hydrology) and groundwater flows and quality (Section 7.6: Hydrogeology and Groundwater Quality) are integrated into the assessment of effects on surface water and sediment quality.

The findings of this section provide the basis for the assessment of potential project effects on aquatic biota discussed in Section 7.7: Benthos, Periphyton and Sediment Quality and in Section 7.8: Fish Resources. This section describes project effects under routine construction and operating conditions as well as during decommissioning and at closure. Potential effects of project-related accidents and malfunctions on surface water and sediment quality are discussed in Section 8: Accidents and Malfunctions.

7.5.4.1 Scope of Assessment

Surface water and sediment quality are identified as VECCs because they are sensitive to project effects and because they provide a vital link to sustaining healthy aquatic ecosystems. Assessment of project effects on water and sediment quality provides an indication of potential effects on aquatic organisms at the population and community levels. Many aquatic organisms have known tolerances and responses to metals, nutrients and sediment typically associated with mining operations. Potential project effects on water and sediment quality can result from the:

- introduction of sediments (total suspended solids (TSS)) to receiving waters due to runoff from disturbed areas during the construction and operational phases;
- changes to the Oakley Creek flow regime and water and sediment quality, related to clean water diversions and site water management (drainage collection and discharges from the Polishing Pond);
- discharge of effluent from the Polishing Pond to the Oakley Creek and the Minago River;
- seepage of contaminated groundwater from the Tailings and Ultramafic Waste Rock Management Facility (TWRMF) to Oakley Creek;
- discharge of TWRMF pond supernatant via the Polishing Pond to the Oakley Creek following mine closure.

Direct and indirect effects of water and sediment quality on aquatic life have been well recognized for over a century (Wetzel, 2001). Currently, the Canadian Council of Ministers of the Environment (CCME) maintains and updates a list of scientifically derived water and sediment quality guidelines for the protection of various users, including aquatic life (CCME, 2007). Both periphyton and benthic invertebrates are used as indicators of water quality because of their recognized sensitivity to changes in nutrients, sediment (TSS) and metal levels. Water quality and biological community sampling are typically linked in government-developed biomonitoring programs in Canada (Environment Canada, 2002b) and the United States (Barbour et al., 1999).

Discharge of the Polishing Pond effluent to the receiving environment has potential for direct adverse effects on aquatic ecosystems, through toxicity of metals, nutrient enrichment (elevated nitrate/ammonia content from blasting residues), increased sulphate levels, changes in pH, and release of suspended sediments. Potential environmental effects of mine effluent discharge have been well documented, and may include excessive growth of periphyton resulting from nitrate or ammonia discharges, reduced abundance of periphyton and benthic invertebrates in areas close to discharge points, elimination of sensitive species, changes in community structure and deformities of periphyton induced by metals. Changes in periphyton and benthos productivity can have an effect on fish assemblages (abundance, size, bioaccumulation of metals in tissue), which can then affect birds and wildlife that consume fish. Project potential effects on periphyton and benthic invertebrate communities are detailed in Section 7.7: Benthos, Periphyton and Sediment Quality.

Metal Mining Effluent Regulations (MMER), under the *Fisheries Act*, and associated Environmental Effects Monitoring (EEM) programs, came into effect in 2002 and require three-year cycles of effluent and receiving environment monitoring. Environment Canada administers MMER. Mine permits and MMER describe effluent quality criteria. The regulation and the EEM guidance document (Environment Canada, 2002b) define statistically and ecologically supported procedures for assessing the effects of effluent discharge on the receiving environment. These include weekly, monthly or quarterly effluent monitoring, water monitoring in the receiving environment, acute and chronic effluent toxicity testing, benthic invertebrate and fish community studies, and assessment of supporting environmental parameters (e.g., habitat quality and nutrient levels).

Project components that have the potential to influence surface water and sediment quality are described briefly below. Further information on site water management facilities and design is provided in Section 2.14: Site Water Management.

Discharge of Site Drainage: Surface drainage will be collected in drainage ditches and directed to the Oakley Creek watershed. One of the main areas of surface disturbance in the Oakley Creek basin will be the Overburden Disposal Facility (ODF). Drainage from the ODF will be collected in ditches and pumped to the TWRMF. As noted above, TWRMF water will be incorporated in the process water balance circulation and any discharges will be directed to the Polishing Pond prior to discharge to the Oakley Creek and the Minago River.

Polishing Pond Discharge to Oakley Creek and Minago River: All open pit dewatering water and frac sand and ore processing water will be pumped to the Polishing Pond. Any excess water from this system will be discharged to the Oakley Creek and the Minago River. Effluent quality has been projected based on inputs to the Polishing Pond and discharges from the Polishing Pond to Oakley Creek and the Minago River. Receiving water quality in Oakley Creek and Minago River has been predicted based on the proposed rates of effluent discharge and receiving water flows and quality, which are outlined in Section 2.14.

The Polishing Pond effluent will meet or exceed MMER effluent quality criteria prior to discharge. Effluent will be discharged at approximately 70% and 30% to the Minago River and the Oakley Creek in the summer months (May to October), respectively; and at 65% and 0% to the Minago River and the Oakley Creek in the winter months (Nov.- Apr.), respectively. In the winter months (Nov. - Apr.), 35% of the Polishing Pond influent will be held back in the Polishing Pond for later discharge during the spring freshet (May).

Victory Nickel intends to develop Site-specific Water Quality Objectives (SS-WQO) for the project. The SS-WQO will be developed in conjunction with regulatory agencies, and will be based on CCME and Manitoba Tier II guidelines for the protection of aquatic life. The SS-WQO will take into consideration ambient water chemistry, e.g., the potential Contaminant(s) of Concern (COCs) level(s) in Minago River, William River and Oakley Creek.

All metal and ammonia levels in the Minago River and Oakley Creek will meet or exceed the SS-WQO, CCME and Tier II guidelines at the designated water quality compliance sites. There will be an increase in flows at and downstream of the discharge points on the Oakley Creek and Minago River, which provide dilution. Arsenic, copper, lead, nickel and zinc levels will meet CCME/Manitoba Tier II guideline limits immediately downstream of the effluent discharge point all year round.

Discharge of potentially contaminated groundwater seepage from the TWRMF to Oakley Creek: Seepage from the TWRMF during operations will be intercepted by seepage ditches surrounding the facility, and will be pumped back to the TWRMF.

Discharge from the TWRMF facility after mine closure: At the end of operations, the TWRMF will remain in place, with a water cover to prevent leaching of metals from the ultramafic waste rock and tailings. The supernatant water will be monitored for at least five years and potentially treated, if required.

A list of water and sediment quality VECCs has been defined for the project environmental assessment based on the EAP Report Guidelines (Fisheries and Oceans Canada) and COI. The selected VECCs and rationale for their selection are described in Table 7.5-8.

7.5.4.1.1 Temporal Boundaries

The temporal boundaries applicable to water and sediment quality include the period of record for the collection of baseline data and all phases of the project (construction, operation, decommissioning and closure). The potential for introduction of silt and sediment to area streams will be present in all phases, but greatest during construction. The potential for introduction of metals or nitrate/ammonia to streams will be present in all phases, but greatest during operation.

Table 7.5-8 Selected VECCs and Rationale for their Selection

VECC	Rationale for Selection	Linkage to EAP Report Guidelines or Other Regulatory Drivers	Baseline Data for EAP
Water Quality: total suspended solids (TSS)	• Potential for project effects due to ground disturbance, construction, and associated erosion and sedimentation, and dust and particulates in runoff from mine facilities (stockpiles, waste areas).	• Information requested in EAP Report Guidelines and EBS Work plan • CCME or other guidelines for protection of aquatic life • Will be required for MMER	2006 – 2008 Baseline Data
Water quality: pH, conductivity and alkalinity	• Potential for project effects due to ARD and ML affecting Polishing Pond effluent discharges to Oakley Creek and the Minago River and groundwater discharge to Oakley Creek. Characterizes sensitivity of receiving waters to project-related discharges. Changes in receiving water quality potentially affect aquatic resources, including fish.	• Information requested in EAP Report Guidelines and EBS Work Plan • CCME or other guidelines for protection of aquatic life • Will be required for MMER	2006 – 2008 Baseline Data
Water quality: sulphate concentrations	• Potential for project effects due to ARD affecting Polishing Pond effluent discharges to Oakley Creek and the Minago River and groundwater discharges to Oakley Creek. • Indicator of mine related changes in water quality due to ARD and ML.	• Information requested in EAP Report Guidelines and EBS Work Plan • CCME or other guidelines for protection of aquatic life • Will be required for MMER.	2006 – 2008 Baseline Data
Water quality: metals concentrations (*e.g.* Ni, Cd, Zn)	• Potential for project effects due to ARD and metal leaching affecting Polishing Pond effluent discharges to Oakley Creek and the Minago River groundwater discharges to Oakley Creek. • Potential for bioaccumulation and toxic effects on aquatic resources and fish.	• Information requested in EAP Report Guidelines and EBS Work plan • CCME or other guidelines for protection of aquatic life • Will be required for MMER	2006 – 2008 Baseline Data
Water quality: concentrations of nitrogen compounds (NO3 & NH4)	• Potential for project effects due to blasting residue and sewage effluent discharges in the Oakley Creek drainage. • Potential effects on primary productivity and associated effects on aquatic ecology. Potential toxicity to aquatic life in high concentrations.	• Information requested in EAP Report Guidelines and EBS Work Plan • Will be required for MMER	2006 – 2008 Baseline Data
Sediment quality: metals concentrations	• Potential for project effects due to Polishing Pond effluent discharges to Oakley Creek and the Minago River. • Effects on sediment quality provide an indicator of potential effects on benthic communities and related effects on fish. food.	• Information requested in EAP Report Guidelines and EBS Work Plan • Will be required for MMER	2006 – 2008 Baseline Data

decommissioning will include a period to stabilize the quality of TWRMF discharge to the Polishing Pond for ultimate closure.

Monitoring will be conducted following the reclamation of the TWRMF and its appurtenances to check the quality of TWRMF supernatant water and seepage, provide passive treatment at the Polishing Pond, if required, prior to discharge to Oakley Creek in order to ensure effective long-term management of ARD and metal leaching by submerging the tailings and ultramafic waste rock. The assessment of the closure phase assumes the stabilization of water quality conditions in the reclaimed TWRMF. It is anticipated that this will be possible, based on monitoring during the operations and decommissioning phases, and adaptive management to ensure effective long-term management of potential project effects originating from the tailings and groundwater.

7.5.4.1.2 Study Area

The local and regional study areas are shown in Figure 7.5-13. The local study area (LSA) includes all streams and associated waterbodies that may be influenced by mine site activities and transportation corridors (TCs). This includes the Oakley Creek watershed, William River, and the Minago River. Specifically, the LSA includes:

- the Oakley Creek watershed, which will be affected by diversions, the TWRMF, the industrial complex, the open pit operations, borrow areas, the campsite development, and permitted discharges from the Polishing Pond;
- Minago River, which will receive permitted effluent discharges from the Polishing Pond.

The regional study area (RSA) includes water bodies and watersheds beyond the LSA that reflect the general region to be considered for cumulative effects and that provide suitable reference areas for determining background conditions. It includes Hargrave River, Cross Lake, William Lake and Limestone Bay.

7.5.5 Baseline Conditions

7.5.5.1 Methods

Existing information from previous studies conducted for the project is summarized in this report. Water and sediment quality data have been compared to CCME and Manitoba (MB) Tier II guidelines for protection of aquatic life (CCME, 2007). Table 7.5-9 shows CCME guideline levels for water and sediment for the protection of aquatic life (CCME, 2002 and 2007).

7.5.5.2 Effects Assessment Methodology

Project effects on water and sediment quality were assessed in accordance with the EAP Report Guidelines using effects attributes defined in Table 7.5-10. The ecological and social contexts of effects are integrated in the magnitude attributes.

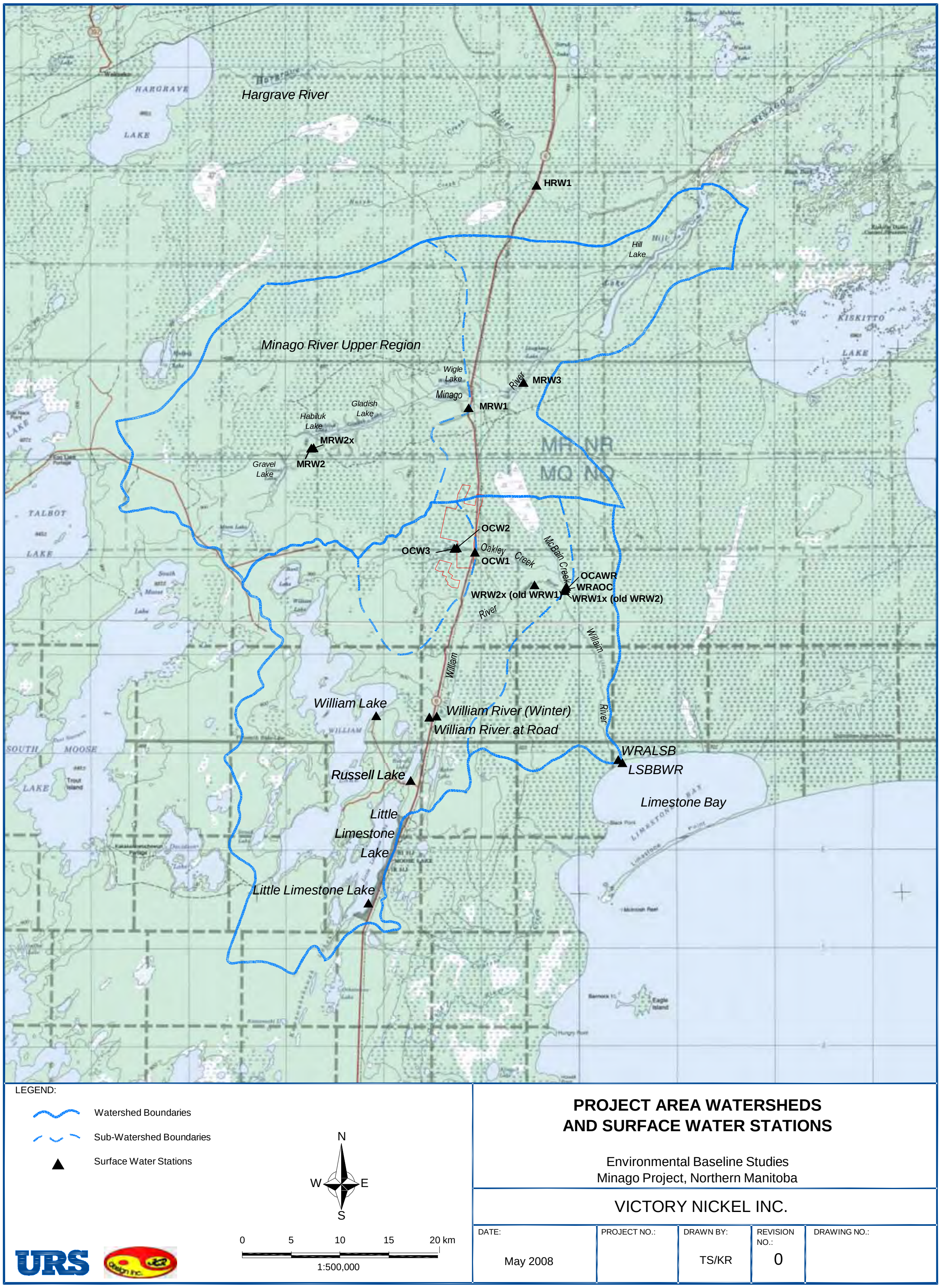


Figure 7.5-13 Watersheds in the LSA and RSA Study Areas

Table 7.5-9 CCME Guidelines for Protection of Freshwater Aquatic Life

Metal (total)	In Water (mg/L) (CCME, 2007)	In Sediment (µg/kg) (CCME, 2002)	
		ISQG[1]	PEL[2]
Aluminum	0.100	-	-
Arsenic	0.005	-	-
Cadmium	0.000017 or $10^{\{0.86[\log(hardness)]-3.2\}}$	600	3,500
Chromium	0.0089	-	-
Copper	0.002 (hardness = 0-120 mg/L $CaCO_3$) 0.003 (hardness = 120-180 mg/L $CaCO_3$)	35,700	197,000
Iron	0.30	-	-
Lead	0.001 (hardness = 1-60 mg/L $CaCO_3$) 0.002 (hardness = 60-120 mg/L $CaCO_3$) 0.004 (hardness = 120-180 mg/L $CaCO_3$)	35,000	91,300
Mercury		170	486
Molybdenum	0.073	-	-
Nickel	0.025 (hardness = 1-60 mg/L $CaCO_3$) 0.065 (hardness = 60-120 mg/L $CaCO_3$) 0.110 (hardness = 120-180 mg/L $CaCO_3$)	-	-
Selenium	0.001	-	-
Silver	0.0001	-	-
Zinc	0.030	123,000	315,000

Notes: [1] ISQG = interim sediment quality guideline
[2] PEL = probable effects level

Table 7.5-10 Effect Attributes for Surface Water and Sediment

Attribute	Definition
Direction	
Positive	Condition of VECC is improving.
Adverse	Condition of VECC is worsening or is not acceptable.
Neutral	Condition of VECC is not changing in comparison to baseline conditions and trends.
Magnitude	
Low	Effect on VECC can be quantified and there will be no change in a variable from ambient conditions.
Moderate	Effect on VECC can be quantified as a change in a variable from ambient conditions but change does not exceed threshold levels (in CCME and Manitoba Tier II Water or CCME Sediment Quality Guidelines).
High	Effect on VECC can be quantified as a change in a variable that exceeds threshold levels (in CCME Water or Interim Sediment Quality Guidelines).
Geographic Extent	
Site-Specific	Effect on VECC confined to a reach of a stream in the LSA (e.g. <500m).
Local	Effect on VECC extends throughout the LSA.
Regional	Effect on VECC extends into the RSA.
Duration	
Short-term	Effect on VECC is measurable for up to 1 year.
Medium term	Effect on VECC is measurable for 1 to 5 years.
Long-term	Effect on VECC measurable for longer than 5 years, but does not extend more than 10 years after decommissioning and final reclamation.
Far future	Effect on VECC measurable >10 years after decommissioning and abandonment.
Frequency (Short-term duration effects that occur more than once)	
Low	Effect on VECC occurs infrequently (<1 day per month).
Moderate	Effect on VECC occurs frequently (seasonal or several days per month).
High	Effect on VECC occurs continuously.
Reversibility	
Reversible	Effect on VECC will cease to exist during or after the project is complete.
Irreversible	Effect on VECC will persist during and/or after the project is complete.
Likelihood of Occurrence	
Unknown	Effect on VECC is not well understood and based on potential risk to the VECC, effects will be monitored and adaptive management measures taken, as appropriate.
High	Effect on VECC is well understood and there is a high likelihood of effect on the VECC as predicted.

Determination of Effects Significance

A residual effect on water and sediment quality will be considered significant for the project or cumulatively, based on the attributes defined in Table 7.5-10, if it is:

- a moderate magnitude adverse effect of high likelihood and long-term in duration or irreversible;
- a high magnitude adverse effect of high likelihood, except when it is only site-specific;
- a high magnitude adverse effect of high likelihood that is site-specific and far future in duration or irreversible.

Otherwise, effects are rated as not significant. In addition, the probability of occurrence of any significant adverse residual effects and the degree of confidence for each prediction are stated with a supporting rationale.

7.5.5.3 Project Effects

Potential project effects during construction, operations, decommissioning and closure are described by watershed in the following sections. Most project actions are expected to affect stream rather than lake water and sediments. Mitigation measures are also presented. Mitigation measures to protect water and sediment quality will also protect other aquatic VECCs (benthic invertebrates, periphyton, fish and fish habitat).

7.5.5.3.1 Construction

Oakley Creek

Facilities that will be constructed in the Oakley Creek basin include the open pit area and dewatering wells, the TWRMF, ore stockpiles, waste rock storage dumps and the industrial complex.

Oakley Creek is a short, low gradient stream, flowing on surface throughout, with limited fish resources. Baseline aluminum, iron, nitrate concentrations exceeded CCME 2007 guidelines for the protection of aquatic life. Moreover, chromium content in sediments was found to be naturally higher than criteria set by the CCME (2002). Thus, metal levels in surface waters and sediments are at times higher than CCME guidelines, reflecting the mineralized nature of the watershed. Data for the depositional river/lake sediments will provide a good basis for monitoring the effectiveness of the Water Management Plan over time.

The Oakley Creek basin has already been affected by access road construction and exploration programs. Potential project effects on Oakley Creek during construction include:

- **Increased suspended sediment solids in runoff from construction sites for various facilities in the basin:** VNI will implement its Erosion and Sediment Control Plan (Section 9: Environmental Management Plans) to minimize the risk of introducing suspended sediments to surface waters. Throughout the life of the project, project activities will involve ground disturbance with potential for erosion and stream sedimentation. In addition, all site drainage in the minesite construction zone will be collected in drainage ditches, directed towards surface sumps, and pumped to the Polishing Pond (Section 2.14: Site Water Management). Water will be contained in the Polishing Pond for use as process water and the balance will be discharged to the Oakley Creek and the Minago River watersheds. Prior to the construction of the Polishing Pond, existing and new ditches and sumps will be used and water will be settled, tested, treated with flocculants and coagulants as needed, before being discharged. Accordingly, no effects on water quality in Oakley Creek are anticipated.

- **Runoff from waste rock dumps, frac sand and ore stockpiles with potentially elevated nitrogen compounds, metals and suspended sediments**: The foundations of the waste rock dumps and ore stockpile areas are underlain by low permeability clays. Seepage from the dumps will be collected in ditches and directed towards local sumps, with ultimate discharge to the Oakley Creek.

- **Diversion of surface water drainage from disturbed areas in the Oakley Creek basin to the water management system**: Diversion of surface water flows may result in a small reduction of stream flows; those are however considered to be not significant since waters will ultimately flow back to the Oakley Creek, once they will have passed through the Polishing Pond.

Site management to collect mine water and potentially contaminated runoff in the construction zone is expected to minimize potential impacts on water quality in the Oakley Creek basin. No effect on water or sediment quality outside of natural variability is expected. Therefore, project effects on water and sediment quality in Oakley Creek during construction are predicted to be neutral or low magnitude and site-specific. Effects will continue through operations (see below) and so will be long-term. Effects of reduced surface water flows on water quality are expected to gradually decrease and return to pre-mining conditions during closure, and so will be reversible.

Minago River

There will be no effect during the early stages of construction as there will be no discharges to the Minago River. Discharge of water from the Polishing Pond will have minimum effects on the Minago River system. During construction, the main source of the water in Polishing Pond will be from the dewatering wells.

7.5.5.3.2 Operations

Oakley Creek and Minago River

Potential project effects on water and sediment quality in Oakley Creek that were identified for the construction phase will continue during operations. The Site Water Management Plan will continue to minimize potential impacts on the water quality in the Oakley Creek basin. Reclamation and stabilization of disturbed areas following construction will further reduce the risk of sedimentation from surface water runoff. Effluent discharge from the pit dewatering wells to the Polishing Pond will continue.

Potable water will be supplied from the dewatering wells. The majority of water for ore processing will come from mine dewatering, the remainder will be reclaim water from the Polishing Pond.

The main incremental effects on water and sediment quality in Oakley Creek during operations will be as follows:

- **TWRMF:** TWRMF seepage water with potentially elevated concentrations of metals and nutrients is expected to seep into seepage collection ditches. The seepage collection ditches will be located immediately downstream of the TWRMF to intercept the seepage. Seepage water will be recycled to the TWRMF.

- **Discharge of the Polishing Pond Effluent to Oakley Creek and Minago River:** The Polishing Pond will retain pit water, excess TWRMF supernatant (containing process effluents from the mill and Frac Sand Plant, sewage treatment plant effluent from the industrial complex, and site drainage). Discharge of effluent has the potential to result in elevated metals, sulphate, nitrate or ammonia (from blasting residues) and TSS levels in receiving waters. There may also be effects related to deposition and transport of particulate metals, resulting in increased metal levels in stream sediments. Further discussion of predicted receiving water quality in Oakley Creek is provided below.

The water balance for open pit dewatering and ore processing will result in a net increase on an annual basis, so discharges from the Polishing Pond to the Oakley Creek and the Minago River will be required. Effluent will be discharged under permit to the Minago River and the Oakley Creek. Stream flows will dilute the discharges. Section 2.14 provides a prediction of effluent quality and water quality in Oakley Creek and Minago River. Discharged effluent will meet MMER requirements at the discharge points downstream. Discharge of effluent to the Oakley Creek will occur mainly from May through October. Polishing Pond discharge to Minago River will occur all year round.

The following points are relevant to effluent discharge into Oakley Creek and the Minago River:

- all discharged effluent will meet MMER effluent criteria, including those for pH; and

- immediately downstream of the effluent discharge point, dilution alone will be sufficient to meet CCME guidelines and Manitoba Tier II water quality guidelines for the protection of aquatic life.

Nitrate levels may be elevated relative to baseline conditions throughout Oakley Creek and the Minago River downstream of the discharge. The CCME guideline (13 mg/L) is established in relation to nitrate toxicity, rather than eutrophication potential, and will not be exceeded in Oakley Creek. Nitrate/ammonia inputs from blasting will decrease over the operational phase and denitrification will reduce nitrate levels in effluent and stream water. Aquatic plants in the creek will also take up and store nitrate during the growing season, and release it later during decomposition, resulting in lower nitrate levels. Nitrate levels are likely to stimulate periphyton growth in the Oakley Creek and the Minago River.

From the baseline results, nitrate levels tend to be very low, rendering the stream sensitive to enrichment effects from nitrate. The magnitude and direction of the periphyton response to enrichment will depend on stream flows, light, temperature and available phosphorus, as well as inorganic nitrogen. In oligotrophic systems, some nutrient enrichment can be considered beneficial to benthic communities.

The effect of nutrient enrichment can be considered to continue over long distances, given the continual cycle of uptake in algae, decomposition and nutrient release, commonly described as “nutrient spiralling” (Wetzel, 2001). As a result, some effects on William River and Minago River may not be a problem due to the additional dilution provided by William River and Hargrave River, respectively.

Accumulation of selenium and other metals in depositional areas has become an issue of concern for mines (McDonald and Strosher, 2000; Chapman, 2004). However, research on the relationship between ambient levels and organism responses is in progress. Selenium has been noted to bio-accumulate in fish tissue, probably through consumption of benthic invertebrates that dwell in close contact with the metal-containing sediment. Current recommendations are for a maximum of 2 mg/kg in sediment (Engberg et al., 1998; Lemly, 2002). Selenium levels in Oakley Creek and Minago River sediment have been below that level, but will be monitored during mine operations. If levels show an increasing trend and are approaching guideline levels, additional sampling of benthic invertebrates and fish (sculpin) tissue metals analysis will be conducted in downstream fish-bearing areas. In the event of an increasing trend in sediment and tissue concentrations, adaptive management to reduce bio-available selenium levels will be implemented.

7.5.5.3.3 Decommissioning

Decommissioning will include:

- flooding of the pit;
- dismantling of the ore processing facilities and offices;

- modifications of the TWRMF embankment as required to ensure long-term saturation of the tailings and ultramafic waste rock and to provide a spillway for ultimate passive decanting of the TWRMF at closure;
- recontouring and revegetation of disturbed areas;
- decommissioning of clean water diversions; and
- reinstatement of natural drainage patterns.

The Polishing Pond will remain open.

In the initial phase, all extraneous project facilities will be removed and the disturbed areas left by their removal will be reclaimed. The sequence of decommissioning will allow flow stabilization and reclamation of large disturbed areas prior to the removal of redundant site water management facilities such as drainage collection ditches and settling ponds. An Erosion and Sediment Control Plan will be implemented (Section 9: Environmental Management Plans) in order to minimize effects of erosion and sedimentation on surface waters.

Minago River

At the end of the Nickel Processing Plant operations, pit dewatering will cease and at the end of Year 9 operations, discharges of the final effluent to the Minago River will cease. As the mine site is located within the Oakley Creek basin, decommissioning will have no effect on the Minago River other than a staged decrease in stream flows discussed in Section 7.4: Surface Water Hydrology.

Oakley Creek

The TWRMF closure design will ensure that the tailings and ultramafic waste rock will be saturated. The facility will be covered with a minimum of 1.5 m of water cover, so that minimal metals leaching will occur. Based on humidity cell tests, it is expected that the supernatant water quality of the TWRMF will reach an equilibrium with the aging tailings such that most, if not all, water quality parameters will meet the discharge criteria at closure. ARD/ML is not predicted to occur. The TWRMF supernatant will be monitored following the first phase of decommissioning before discharge to Oakley Creek via the Polishing Pond.

7.5.5.3.4 Closure

The Mine Closure Plan is described in Section 3.4 and in a separate report, entitled, “Minago Project - Closure Plan, 2010”. The Water Management Plan for closure is presented in Section 2.14.

Minago River

The potential impacts of ending the discharge of the final effluent from the Polishing Pond to the receiving environment will effect two main components, namely biological aspects (wetlands and stream habitats) and hydrological conditions (in Minago River and Oakley Creek).

These impacts will be low on wetlands since these vast ecosystems are quite resilient. Indeed, mosses, sedges and ericaceous shrubs are among the most widespread species in the region and can easily acclimate themselves to a wide variety of conditions (Campbell and Rochefort, 2001). Gradually, vegetation cover should switch back to what it was before, if no other change in climatic conditions will occur; otherwise, it would adapt itself to the prevailing climatic conditions. Bogs are not as sensitive as forest stands to climatic conditions, especially rainfall, since they are already wet ecosystems that have the capacity to store additional water. In fact, the development of bogs is mainly due to a combination of allogenic factors, such as temperature and precipitation, favouring a positive water balance (Payette, 1988; Foster and Wright, 1990).

The impacts of increasing water flow in the Minago River in terms of hydrology will likely be not significant since they are within the natural variation occurring in this region.

The impacts of a reduction in the water flow on stream habitats would be more significant, especially in winter low flow conditions. Lower water flow and thus water level would reduced stream habitat types and increase the risk of changes in water quality, therefore increasing seasonal stresses for fish and other biota.

Therefore, mitigation measures will have to be implemented in order to limit the potential impacts of such a change in water level conditions, meaning that water will have to be stored in the Polishing Pond in such a way that the final effluent flow after closure will be gradually reduced and not drastically. This would enable a comeback to pre-mining conditions. Staging flow to the Minago River will be developed.

The areas on which the discharge pipeline to the Minago River, the rock-filled channel and the diffuser will have been installed will be rehabilitated, meaning that they will be re-vegetated with green alders.

Oakley Creek

At closure, the quality of TWRMF supernatant will not cause a change in the quality of Oakley Creek water beyond the natural variability established over the period of baseline monitoring, as discussed above for the decommissioning phase. Accordingly, there will be no further effects of the project on Oakley Creek at closure. Legal discharge limits will be met.

7.5.5.4 Residual Project Effects and Significance

Residual adverse effects of the project on water and sediment quality are discussed below.

Polishing Pond Effluent - Oakley Creek

Residual effects during operations are expected to include some elevated levels of metals in Oakley Creek for a distance of up to 7 km downstream of the discharge point, with potential accumulation of metals in stream sediments in the same region. Downstream of the compliance point, levels of these substances will be below CCME / Manitoba guideline limits. No adverse effects are predicted downstream in fish-bearing waters of lower Oakley Creek (Section 2.14: Site Water Management).

There is potential for localized accumulation of metals in depositional sediment within the affected reach, with potential for uptake in periphyton and benthos, although this is considered unlikely due to the annual freshet that will mobilize and disperse stream sediments. From an ecological perspective, elevated metals in benthic invertebrates that drift downstream into fish-bearing reaches could contribute to bioaccumulation of metals in fish, although the likelihood of this is unknown, given the intervening areas of beaver pond and riffle habitat. Baseline fish tissue data has been collected for future reference. The EEM program will monitor water and sediment metals levels. If increasing trends are noted in sediment concentrations, follow-up monitoring of metals in fish tissue will be conducted to assess the possibility of bioaccumulation and improve mitigation, if necessary.

The project will be subject to the Metal Mining Effluent Regulations (MMER) (Environment Canada, 2002a) and will be required to monitor effluent discharges and the receiving environment using an EEM program, overseen by Environment Canada. Benthic invertebrate and fish communities will be monitored on a multi-year cycle to provide data about the effectiveness of the Water Management Plan and the environmental effects of discharges on the benthic community of Oakley Creek, and will guide decisions on mine practices and monitoring requirements.

In summary, the greatest effect of Polishing Pond effluent discharges on water quality in the Oakley Creek system will be between the effluent discharge point and the compliance point during operations. Effects in this reach are rated as adverse, moderate, local, long-term and reversible. All other effects on Oakley Creek are rated as low magnitude. The adverse effects of effluent discharge on water and sediment VECCs are expected to be not significant, throughout all phases of the project and at closure. The likelihood of effects occurring as predicted is high.

Flow Regime Changes - Oakley Creek

Some changes to flow regimes of Oakley Creek are anticipated (Section 7.4: Surface Water Hydrology) as a result of partial diversion of runoff to flood the pit for a period of approximately 10.6 years. Flows will remain higher than summer low flows. Using criteria in Section 7.5-12, the adverse effects of flow regime changes on water and sediment VECCs are expected to be not significant, throughout all phases of the project and at closure. The likelihood of effects occurring as predicted is high.

TWRMF Discharge – Oakley Creek at Closure

Tailings and ultramafic waste rock stored in the TWRMF will be covered with a minimum of 1.5 m of water following decommissioning of the operations, so that minimal metals leaching will occur. It is expected that the supernatant water quality of the TWRMF will reach an equilibrium with the aging of tailings such that most water quality parameters will meet the discharge criteria at closure. Tailings supernatant is not predicted to result in adverse effects on the Oakley Creek water quality (Section 2.14: Site Water Management).

7.5.5.5 Cumulative Effects and Significance

The only other development in the RSA that could affect water and sediment quality in stream basins affected by the project is the PTH6. The highway crosses Oakley Creek, Minago River and William River. Cumulative effects could potentially arise from introduction of pollutants to these streams from road accidents, spills and maintenance (sediment introductions from road drainage).

Localized residual effects of the project on water and sediment quality are expected to be not significant, and will not affect the overall ecological health of the streams. Contaminants from the PTH6 could potentially influence the Oakley Creek, Minago River, and William River. Effects on benthic communities could vary depending on the nature and volume of contaminants introduced, the season of occurrence and the associated ecological importance of these stream reaches to fish production at the time. Effects could vary from not significant to significant. Any contribution of project related effects to cumulative effects arising from the PTH6 are expected to be not significant.

7.5.5.6 Mitigation Measures

Mitigation measures are described in Table 7.5-11.

7.5.5.7 Monitoring and Follow-up

Follow-up Studies

At this point, it is felt that the 2006, 2007 and 2008 baseline studies will provide sufficient data for seasonal baseline water quality and sediment characterizations at the most relevant locations within the LSA and RSA. Additional monitoring programs will be established prior and during the construction and operational phases.

Monitoring Programs

Monitoring programs are recommended where the likelihood of project effects is unknown and there is concern that effects on the VECC might give rise to a management issue in a regulatory or social context. These programs are summarized in Table 7.5-12. Monitoring will be implemented by VNI.

The main monitoring program identified to determine effects on water and sediment quality from residual and cumulative effects will be the EEM program required under MMER for mines operating with a permitted discharge point. Monitoring for metal levels, particularly selenium, in sediment (depositional areas) will also be conducted.

Construction monitoring for release of sediment (TSS) to streams will be conducted as part of the Erosion and Sediment Control Plan (Section 9: Environmental Management Plans) during facility and transportation corridors construction, to monitor the effectiveness of mitigation measures.

Minago River and Oakley Creek flows will be monitored to assess predicted effects of hydrologic changes.

7.5.5.8 Summary of Effects

Project and cumulative effects are summarized in Table 7.5-13. Adverse effects that are rated moderate in magnitude and far future in duration are considered significant, as are those rated high in magnitude, that are local or regional in extent and of high likelihood or site specific, far future in duration or irreversible and of high likelihood.

Table 7.5-11 Mitigation Measures for Effects on Water and Sediment Quality

Potential Project Effect	Mitigation Measures
Construction	
Changes in water and sediment quality in Oakley Creek from contaminated construction site runoff, waste rock storage, and ore stockpiles	• Implement the Erosion and Sediment Control Plan (Section 9.2: Environmental Protection Plan) and Site Water Management Plan (Section 2.14) to ensure no contaminated drainage water enters Oakley Creek.
Minesite clearing of vegetation and increased sediment input to Oakley Creek	• Minimize vegetation removal and soil disturbance within the RSA. • Implement the Erosion and Sediment Control Plan and the Site Water Management Plan (Section 2.14) to ensure no sediment laden water enters Oakley Creek. • Revegetate disturbed areas as soon as possible.
Sediment inputs during the construction of transportation corridors in the Oakley Creek watershed basin	• Implement the Erosion and Sediment Control Plan (Section 9.2: Environmental Protection Plan). • Adhere to appropriate guidance documents for work around watercourses. • Revegetate cleared areas with native flora.
Operations	
Changes in water and sediment quality from TWRMF seepage to Oakley Creek and Minago River (metals, TSS, nutrients)	• Intercept seepage in collection ditches and recycle back to the TWRMF. Ultimate discharge to the receiving environment will be via the Polishing Pond. • Monitor effluent and receiving water quality and initiate adaptive management as required.
Changes in water and sediment quality in Oakley Creek and Minago River from the Polishing Pond discharges (metals, TSS, nutrients)	• Ensure effluent quality meets CCME / Manitoba Tier II guidelines at Station OCAWR. • Discharge wastewater in accordance with Manitoba and federal regulations. • Monitor effluent and receiving water quality and initiate adaptive management as needed.
Accumulation of metals in sediment of Oakley Creek and Minago River that have a potential for bioaccumulation	• Monitor water and sediment concentrations in Oakley Creek and Minago River. If results indicate an increasing trend, collect benthic invertebrates and sculpin for tissue metals analysis. • Apply adaptive management measures, if necessary.
Introduction of sediment and other road runoff contaminants into Oakley Creek and Minago River	• Reclaim/revegetate disturbed areas that are no longer in use. • Implement the Erosion and Sediment Control Plan (Section 9: Environmental Protection Plan).
Decommissioning	
Changes in water and sediment quality in Oakley Creek from site runoff where facilities have been removed and/or the ground has been recontoured	• Implement the Erosion and Sediment Control Plan (Section 9: Environmental Protection Plan) and the Site Water Management Plan (Section 2.14) to ensure no contaminated drainage water enters Oakley Creek. • Reseed recontoured areas as soon as possible.
Changes in water and sediment quality in Oakley Creek from the Polishing Pond effluent discharges (metals, TSS, nutrients)	• Discharge wastewater in accordance with Manitoba and federal regulations. • Ensure all discharges meet or exceed permit requirements. • Monitor effluent and receiving water quality and initiate adaptive management as required.
Closure	
Changes in water and sediment quality of Oakley Creek from ongoing tailings and waste rock storage	• Adhere to the Mine Closure Plan • Monitor water and sediment quality during decommissioning to confirm the effectiveness of management. • Maintain a water cover on top of the TWRMF as designed to minimize ARD/ML concerns.

Table 7.5-12 Monitoring and Follow-up Programs for Water and Sediment Quality

Potential Project Effect	Program Objectives	General Methods	Reporting	Implementation
Follow-up Programs				
None				
Monitoring Programs				
Monitoring for suspended sediments	• To confirm effectiveness of mitigation and immediately address compliance issues	• Monitor TSS at settling basins and in receiving waters according to permit schedule	• Manitoba Gov.'t and DFO as required	Proponent
Accumulation of selenium and other metals in depositional habitat	• To check potential for bioaccumulation. As needed, initiate contingency plans to address unexpected effects	• Concurrent with EEM program on three-year cycle. • Initiate benthic invertebrate of fish tissue sampling based on results of sediment analysis.	• Report to Manitoba Gov.'t and DFO	Proponent

Table 7.5-13 Summary of Effects on Water and Sediment Quality

Potential Effect	Level of Effect[1]						Effect Rating[2]	
	Direction	Magnitude	Extent	Duration/Frequency	Reversibility	Likelihood	Project Effect	Cumulative Effect
Construction								
Changes in water sediment quality in Oakley Creek from contaminated construction site runoff, waste rock storage, ore and frac sand stockpile	Adverse	Low	Site-specific	Short-term, Moderate frequency	Reversible	Low	Not significant	N/A
Operations								
Changes in Oakley Creek flow regime related to Open pit dewatering and diversion, affecting dilution capacity	Neutral	Low	Site-specific	Long-term	Reversible	Low	Not significant	N/A
Changes in water and sediment quality from TWRMF seepage to the Oakley Creek and the Minago River (metals, TSS, nutrients)	Adverse	Low	Site-specific	Long-term	Reversible	Unknown	Not significant	N/A
Changes in water and sediment quality in Oakley Creek from various discharges (metals, TSS, nutrients)	Adverse	Moderate	Local	Long-term	Reversible	High	Not significant	N/A
Changes in nitrate levels in Oakley Creek and Minago River from effluent discharges	Potentially positive	Moderate	Local to Regional	Long-term	Reversible	Unknown	Not significant	N/A
Accumulation of metals in sediment of Oakley Creek and Minago River with a potential for bioaccumulation in benthic communities and higher trophic levels	Adverse	Low	Site-specific	Long-term	Reversible	Unknown	Not significant	N/A

Table 7.5-13 (Cont.'d) Summary of Effects on Water and Sediment Quality

Potential Effect	Level of Effect[1]						Effect Rating[2]	
	Direction	Magnitude	Extent	Duration/Frequency	Reversibility	Likelihood	Project Effect	Cumulative Effect
Operations								
Introduction of sediment and other road runoff contaminants into Oakley Creek and Minago River	Adverse	Low	Site-specific	Long-term	Reversible	High	Not significant	N/A
Decommissioning								
Changes in water and sediment quality in Oakley Creek from site runoff where facilities have been removed and/or the ground has been recontoured	Adverse	Low	Site-specific	Short-term	Reversible	High	Not significant	N/A
Closure								
Changes in water and sediment quality of Oakley Creek from ongoing TWRMF supernatant discharge	Adverse	Low	Site-specific	Far future	Reversible	Unknown	Not significant	N/A

Notes: 1 Based on criteria in Table 7.5-11.

2 As outlined in the Effects Assessment Methodology

N/A not applicable

7.6 Hydrogeology and Groundwater Quality

With the Minago deposit situated under muskeg and under the Ordovician dolomite and Winnipeg Formation sandstones, the open pit will require dewatering to enable mining. Wardrop (2007) conducted an initial hydrogeological assessment in early 2007 with a goal to determine the underground flow regime and hydraulic conductivity of the various geological units that will be affected by mining. Groundwater quality was also characterized through chemical and physical analyses including pH, conductivity, alkalinity, sulphate, metals, and nitrogen compounds.

Preliminary pumping tests indicated that the peat and clay were water bearing but at very low yields and low hydraulic conductivity and thus of limited groundwater producing potential. The Ordovician limestone and sandstone, however, were found to have significant groundwater producing potential. Wardrop (2007) found that the principle stratigraphic units were overburden (peat and clay; OB), shallow limestone (SLS), limestone (LS), sandstone (SS), and granite (GR). Limestone at Minago is 55 m (180 ft) thick and consists of shallow limestone that has an upper zone of water bearing fractures (up to 40 m depth) and deep limestone underlying this zone. Underlying the limestone is approximately 10 m (30 ft) of sandstone, followed by some shale and weathered granite of the Precambrian Shield (Wardrop, 2007; Golder Associates, 2008a, 2008b).

The preliminary hydrogeological program, conducted in 2007, was followed by a comprehensive hydrogeological characterization of the site in the summer of 2008. The comprehensive hyrdogeological program, undertaken by Golder Associates and Golder Associates Innovative Applications (GAIA), involved pumping of four high capacity dewatering wells located along the perimeter of the proposed open pit mine and monitoring the hydrogeologic response in these wells and in 24 observation wells. Long-term pumping tests were conducted to lower the hydraulic heads within the limestone (LS) unit significantly below the limestone-overburden contact (i.e. allow its conversion from a confined to an unconfined aquifer). Results of the long duration pumping test program were used to develop a conceptual hydrogeological model of the Site and a groundwater flow model of the proposed open pit area. The complete report of the comprehensive hydrogeological study (Golder Associates, 2008b) is given in Appendix 7.6.

7.6.1 Objectives of the Comprehensive Hydrogeological Program

Minago's comprehensive hydrogeological program was conducted to determine the following aspects:

1. Estimate the hydrogeologic parameters for the main hydrostratigraphic units identified at the Site (i.e., transmissivity, storativity, and specific yield); The transmissivity, T, of an aquifer is a measure of how much water can be transmitted horizontally, such as to a pumping well. Storativity, S, is the volume of water released from storage per unit decline in hydraulic head in the aquifer, per unit area of the aquifer;
2. Identify key hydrogeologic boundaries, if any, that may affect the dewatering system;

3. Measure potential changes in shallow groundwater conditions as a result of pumping from the bedrock aquifers;
4. Assess the potential hydraulic connection of the bedrock aquifers with nearby surface water bodies;
5. Provide data for establishing the maximum yields for the planned dewatering wells; and,
6. Collect groundwater quality data from the bedrock aquifers to assess the potential impact of discharging groundwater to surface water bodies during development of an open-pit mine.

The above information was used to develop and calibrate a numerical groundwater flow model for the Minago Project site. The model was used as a tool to estimate the pumping rates and configuration of the dewatering well system that is required to provide sufficient dewatering for the proposed open pit and to estimate the extent of the drawdown cone created during mining. The overall objectives for the groundwater modelling study were to determine the number, location and depth of the dewatering wells and the total quantity of groundwater discharge that will likely be generated by the proposed open-pit mine.

7.6.2 Methodology - Pumping Test Program

The comprehensive hyrdogeological program involved pumping four high capacity dewatering wells (Figure 7.6-1) and monitoring hydrogeologic response in these pumping wells and in 24 observation wells. Golder Associates Innovative Applications (GAIA) carried out the installation of pumps, construction of well-head assemblies, and the connection of generators for this program, which was conducted over the period between July 30 and August 19, 2008.

Figure 7.6-2 shows the two locations (HG-3 and HG-7) of the dewatering wells, installed by Friesen Drilling in February 2008, together with the locations of the 24 observation wells that were installed as nine nested wells (MW-X-1 through MW-X-9).

At each dewatering well location, two pumping wells were completed, one in the limestone unit (HG-X-LS) and one in the sandstone unit (HG-X-SS). Each limestone dewatering well consists of 0.28 m (11-inch) diameter open hole wells, completed to a depth of 58 m (190 ft) in the fractured limestone unit, and cased through the overburden. Each sandstone dewatering well consists of a 0.25 m (10-inch) diameter steel-screened well completed to a depth of 72 m (237 ft) in the sandstone unit and sealed from the water-producing zone of the limestone unit above 57 m (188 ft) depth (Golder Associates, 2008a).

The monitoring wells were installed in each of the four primary stratigraphic units (9 OB wells, 6 SLS wells, 5 LS wells, 2 SS wells, and 2 GR wells). Figure 7.6-3 provides a schematic diagram of the pumping and monitoring well installations into the OB, SLS, LS, SS, and GR stratigraphic units. The distance of the monitoring wells to the pumping wells was approximately 40 m, 80 m, 300 m, and 2,000 m (Golder Associates, 2008b). Table 7.6-1 presents surveyed positions of each pumping and observation well. Detailed well log information is provided in Appendix 7.6.

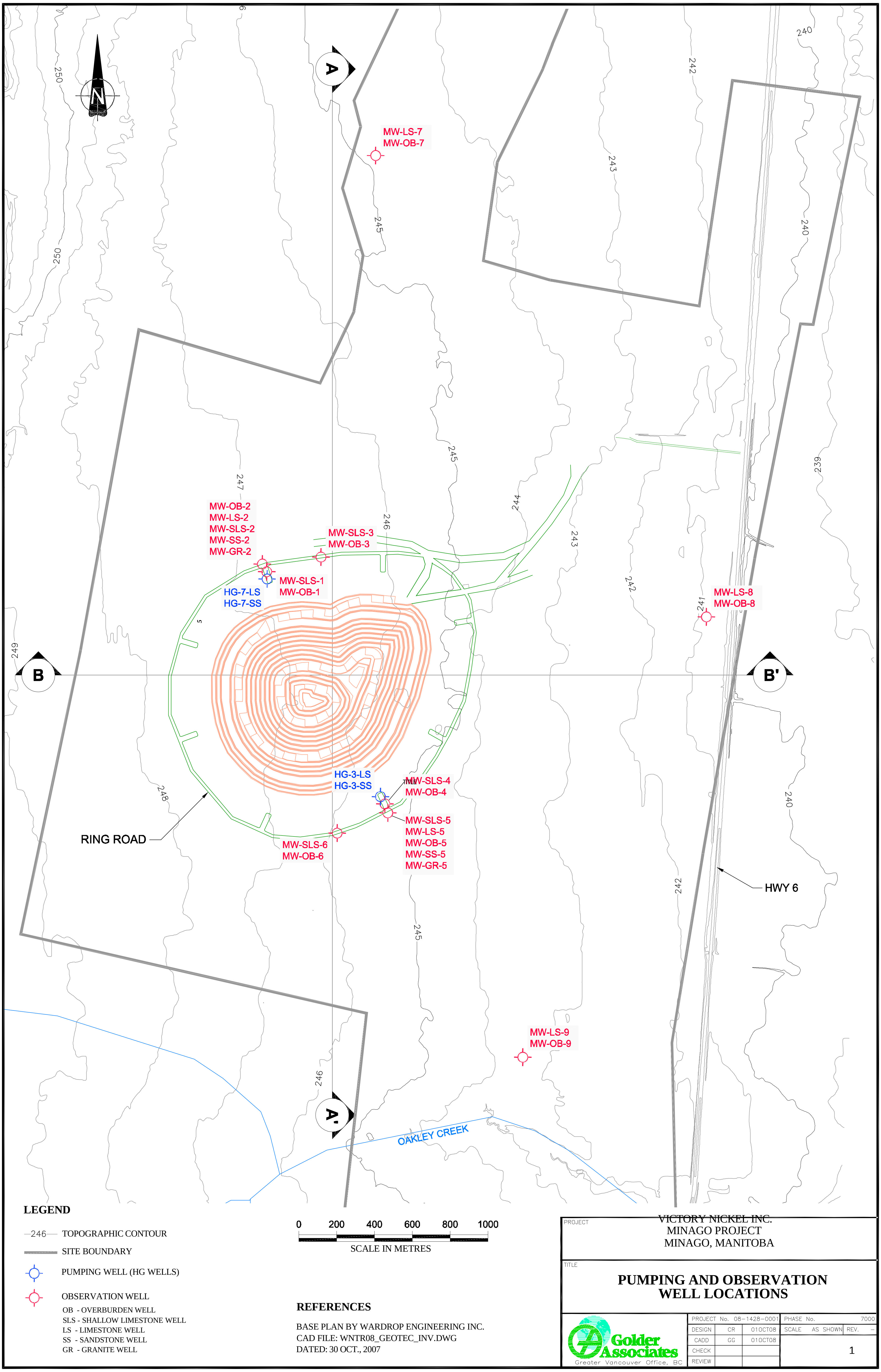
Source: VNI and Golder Associates (2008b)

Figure 7.6-1 Setup for the Groundwater Pump Test

Throughout the pumping program, the groundwater level was recorded at each well location using both manually operated water level metres and pressure transducers equipped with data loggers (Solinst Gold Leveloggers) and direct-read cables. A barologger was also deployed at the Site (i.e., it was placed within the above-ground protective steel casing of observation well MW-SS-5) to collect barometric pressure data throughout the program. This data was used to provide barometric correction to all the data generated by the pressure transducers.

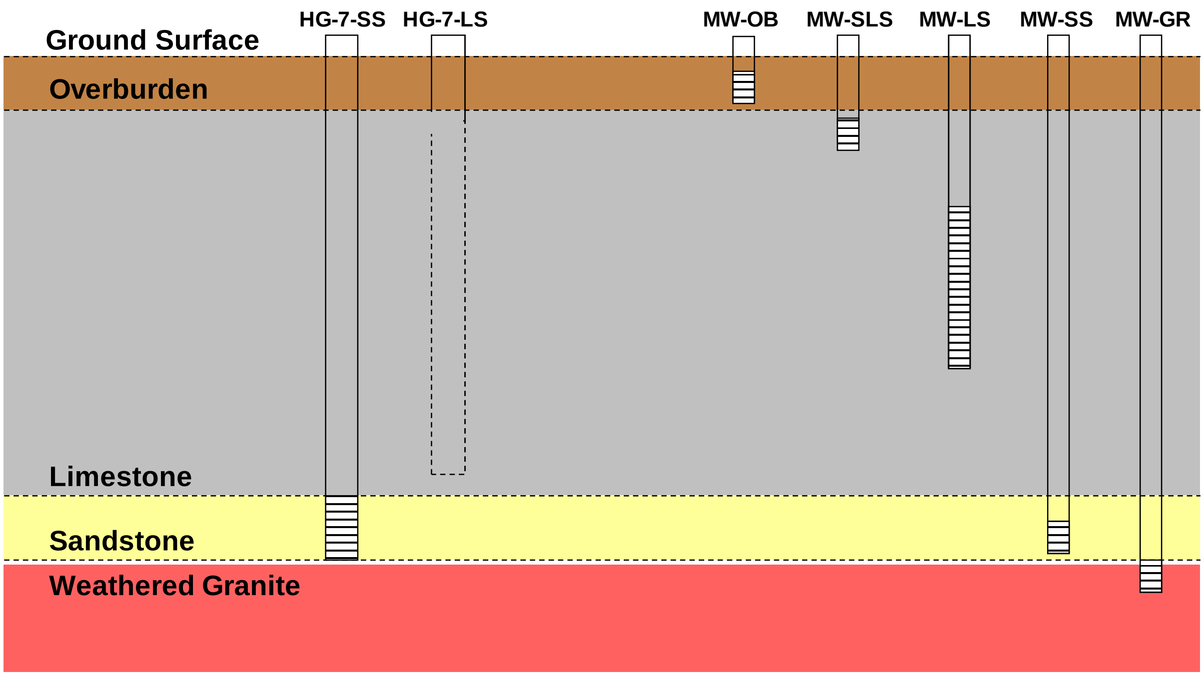
Prior to pumping, water level loggers were installed at all 28 well locations (4 dewatering and 24 monitoring wells) and water levels were recorded for 3 days to establish baseline water levels. This period was followed by a 4-day, individual step-drawdown tests at each pumping well to determine pumping rates for the long-term test of (Golder Associates, 2008b):

- 900 US gpm (204.3 m^3/h) at HG-7-LS;
- 100 US gpm (22.7 m^3/h) at HG-7-SS;
- 300 US gpm (68.1 m^3/h) at HG-3-LS; and,
- 100 US gpm (22.7 m^3/h) at HG-3-SS.



Source: Golder Associates (2008b)

Figure 7.6-2 Pumping and Observation Well Locations



Source: Golder Associates (2008b)

Notes:

HG-7-SS	Pumping Well 7, installed in sandstone (SS)
HG-7-LS	Pumping Well 7, installed in limestone (LS)
MW-OB	Monitoring well, installed in overburden
MW-SLS	Monitoring well, installed in shallow limestone
MW-LS	Monitoring well, installed in limestone
MW-SS	Monitoring well, installed in sandstone
MW-GR	Monitoring well, installed in granite

Figure 7.6-3 Schematic Well Installation Diagram

Table 7.6-1 Groundwater Pumping Test Well Locations

Well Name	NAD'83 UTM NORTH m	ZONE 14 UTM EAST m	Ground ELEV. m.a.s.l.	Top of Well m.a.s.l.	Stickup m
Pumping Wells:					
HG-3 LS	5992847.45	487656.77	245.89	246.89	1.00
HG-3 SS	5992857.95	487658.47	245.98	246.98	1.00
HG-7 LS	5993994.85	487056.57	247.21	248.26	1.05
HG-7 SS	5993984.75	487059.04	247.17	248.22	1.05
Observation Wells:					
MW-OB-1	5994026.08	487057.86	247.35	248.29	0.94
MW-OB-2	5994071.56	487050.07	247.16	248.20	1.04
MW-OB-3	5994103.21	487343.64	246.72	247.60	0.88
MW-OB-4	5992813.12	487681.64	245.71	246.84	1.13
MW-OB-5	5992782.12	487706.24	245.61	247.02	1.41
MW-OB-6	5992660.75	487430.95	246.13	247.33	1.21
MW-OB-7	5996197.10	487635.76	244.89	246.02	1.13
MW-OB-8	5993790.96	489383.37	240.82	241.95	1.13
MW-OB-9	5991490.11	488407.52	243.58	244.56	0.98
MW-SLS-1	5994027.41	487057.94	247.21	248.21	0.99
MW-SLS-2	5994066.57	487051.00	247.17	248.20	1.03
MW-SLS-3	5994103.97	487341.27	246.65	247.55	0.90
MW-SLS-4	5992815.51	487681.22	245.60	246.58	0.98
MW-SLS-5	5992779.40	487703.58	245.53	246.68	1.15
MW-SLS-6	5992663.53	487430.71	246.13	247.23	1.10
MW-LS-2	5994067.23	487038.93	247.22	248.27	1.04
MW-LS-5	5992774.04	487706.88	245.60	246.61	1.01
MW-LS-7	5996198.77	487632.33	244.99	246.64 *	1.64
MW-LS-8	5993791.16	489380.18	240.87	242.90 *	2.04
MW-LS-9	5991493.31	488409.36	243.54	244.91 *	1.38
MW-SS-2	5994070.24	487040.64	247.16	248.33	1.17
MW-SS-5	5992781.61	487699.45	245.67	246.56	0.88
MW-GR-2	5994070.48	487047.49	247.05	248.08	1.03
MW-GR-5	5992770.51	487697.33	245.67	246.64	0.96

Notes:
* Value includes pipe added to the well before the pumping test, due to artesian conditions.
m.a.s.l. - meters above sea level

Source: Golder Associates (2008b)

After the step drawdown test, a 5-day long-term pumping test was conducted in all pumping wells followed by two days of recovery. Thereafter, eight single well response tests were conducted to assess hydraulic parameters of the overburden (6 wells) and granite (2 wells) stratigraphic units.

7.6.2.1 Long-term Pump Test

The pumping test was carried out over the period between August 11 to 18, 2008, and consisted of five days of pumping and two days of recovery. Pumping of the dewatering wells was initiated sequentially, on separate days, such that pumping at HG-7-LS began at the start of Day 1, at HG-3 LS at the start of Day 2, at HG-7-SS on Day 3, and at HG-3-SS on Day 4. On Days 4 and 5, all the wells were pumping simultaneously, at a combined rate of approximately 1,400 USgpm (7,630 m^3/d). At the start of Day-6, all the pumps were turned off and well recovery monitoring occurred over Days 6 and 7.

During the long-term pumping test, the following was monitored:

- water levels every 10 to 30 seconds depending on the monitoring well location;
- pumping rates three times per day using an inline paddlewheel flow gauge (model F-1000 Rate-Totalizer from Blue White Industries). In addition, pumping rates were measured manually on approximately a daily basis using a 205 litre barrel and a stopwatch in order to calibrate the flow gauges and to verify the discharge measurements;
- general groundwater quality (pH, electrical conductivity, and temperature) twice daily for pH, temperature, specific conductance, and oxidation-reduction potential, using a WTW pH/Cond 3400i multi-meter;
- a groundwater sample was collected from each of the four dewatering wells on the fifth day of the long-term pumping test (August 15, 2008). Duplicate samples were taken from HG-7-LS and HG-3-SS for quality assurance/quality control (QA/QC) purposes;
- surface water flowrates at the Oakley Creek station OCW1 (daily) and at four roadside ditch locations several times during the pump test.

The potential for ground subsidence in response to decreased pore pressure in the overburden, was also monitored during the pumping test by assessing the change in vertical distance between two arbitrary reference points on the well heads of the granite observation wells, located approximately 80 m from the nearest dewatering wells. The results of the above monitoring programs are detailed elsewhere (Golder Associates, 2008b).

7.6.2.2 Single-Well Response Tests

Single-well response tests on observation wells were carried out after completion of the long-term pumping test in the form of slug tests. These tests were conducted to estimate the hydraulic properties of the lower permeability units, namely the overburden and the weathered granite. Six overburden observation wells (MW-OB-1, MW-OB-2, MW-OB-4, MW-OB-5, MW-OB-6, and

MW-OB-7) and both granite observation wells (MW-GR-2, and MW-GR-5) were tested (Figure 7.6-2). The test was initiated by rapidly submerging a solid slug of a known volume in the well. The initial water level displacement and the rate in fall of the water level in each well was recorded using both a pressure transducer and a manually-operated water level tape. Following completion of a falling head test, the slug was rapidly removed and the rise in water level in each well was recorded as part of the rising head test. The single-well response tests were conducted on August 18 and 19, 2008.

7.6.3 Pumping Test Program Results

7.6.3.1 Limestone Outcrops and Areas of Groundwater Recharge/Discharge Potential

Limestone outcrops were observed on Site, approximately 2 km northwest of the proposed pit area at a topographic knob, and off-site, approximately 9 km south of the Site at a Highway 6 road cut, and approximately 10 km northeast of the Site in the vicinity of the Minago River (Figure 7.6-4). The upper several metres of the limestone outcrops are weathered and contain planar apertures along horizontal bedding planes at intervals of about 10 cm, as well as numerous vertical joints and fractures. These types of features exist in the aquifer on a regional scale to a depth of about 30 m below ground surface, and provide pathways for much of the flow in the aquifer (Betcher et al., 1995). The limestone outcrop areas are likely recharge areas where precipitation may directly infiltrate the limestone aquifer.

Although the surficial geology map of Matile and Keller (2006) suggests that the streambeds of both the Minago River and Oakley Creek are largely contained within the overburden unit, the Minago riverbed was observed to cut into the limestone aquifer near Highway 6, approximately 10 km north of the Site, as shown on Figure 7.6-4. It is uncertain whether this area is a discharge or recharge area for the limestone aquifer.

Pre-pumping water levels in the limestone unit were above those in the overburden unit at all the well locations except those in the vicinity of HG-7 (including MW-1, MW-2, and MW-3). These conditions, which include flowing artesian wells, indicate that the overburden is an effective aquitard. These conditions create an upward hydraulic gradient across the overburden unit, such that surface water observed on the surficial peat that covers much of the Site likely does not contribute to groundwater recharge under non-pumping conditions.

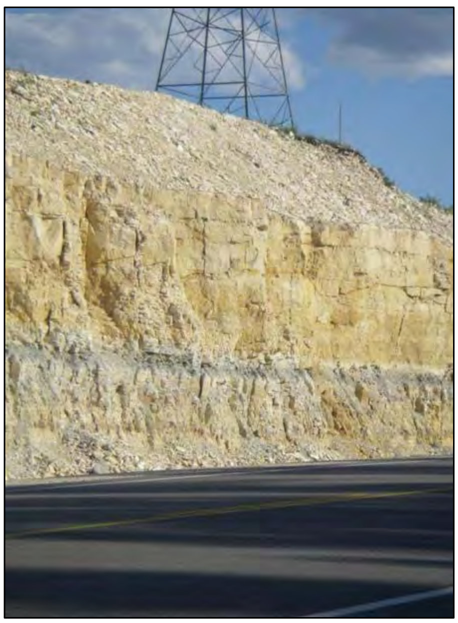
7.6.3.2 Pre-pumping Hydraulic Heads and Groundwater Flow Directions

The pre-pumping hydraulic head distribution in the overburden, limestone, sandstone, and granite units are presented in Appendix 7.6.

Figures 7.6-5 and 7.6-6 present pre-pumping hydrogeologic cross sections oriented north-south (Section A-A') and west-east (Section B-B') through the Site. Section B-B' (Figure 7.6-6) is aligned along the inferred direction of groundwater flow in the limestone and sandstone units. Based on the measurements of the hydraulic head in each well, as shown in Section B-B' (Figure 7.6-6), the inferred direction of groundwater flow in the limestone and sandstone units at the Site

A. Limestone outcrop at a quarry located approximately 12 km north-northeast of the Site.

C. Minago River at the Highway 6 bridge, approximately 12 km north of the Site.



B. Limestone outcrop along Highway 6 road cut, approximately 9 km south of the Site.

D. Flowing artesian conditions at MW-7-LS.

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PROJECT VICTORY NICKEL / MINAGO
MULTI-WELL PUMPING TEST PROGRAM
GRAND RAPIDS, M.B.

TITLE **LIMESTONE OBSERVATIONS**

Golder Associates

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Source: Golder Associates (2008b)

Figure 7.6-4 Observation of Limestone and Artesian Conditions

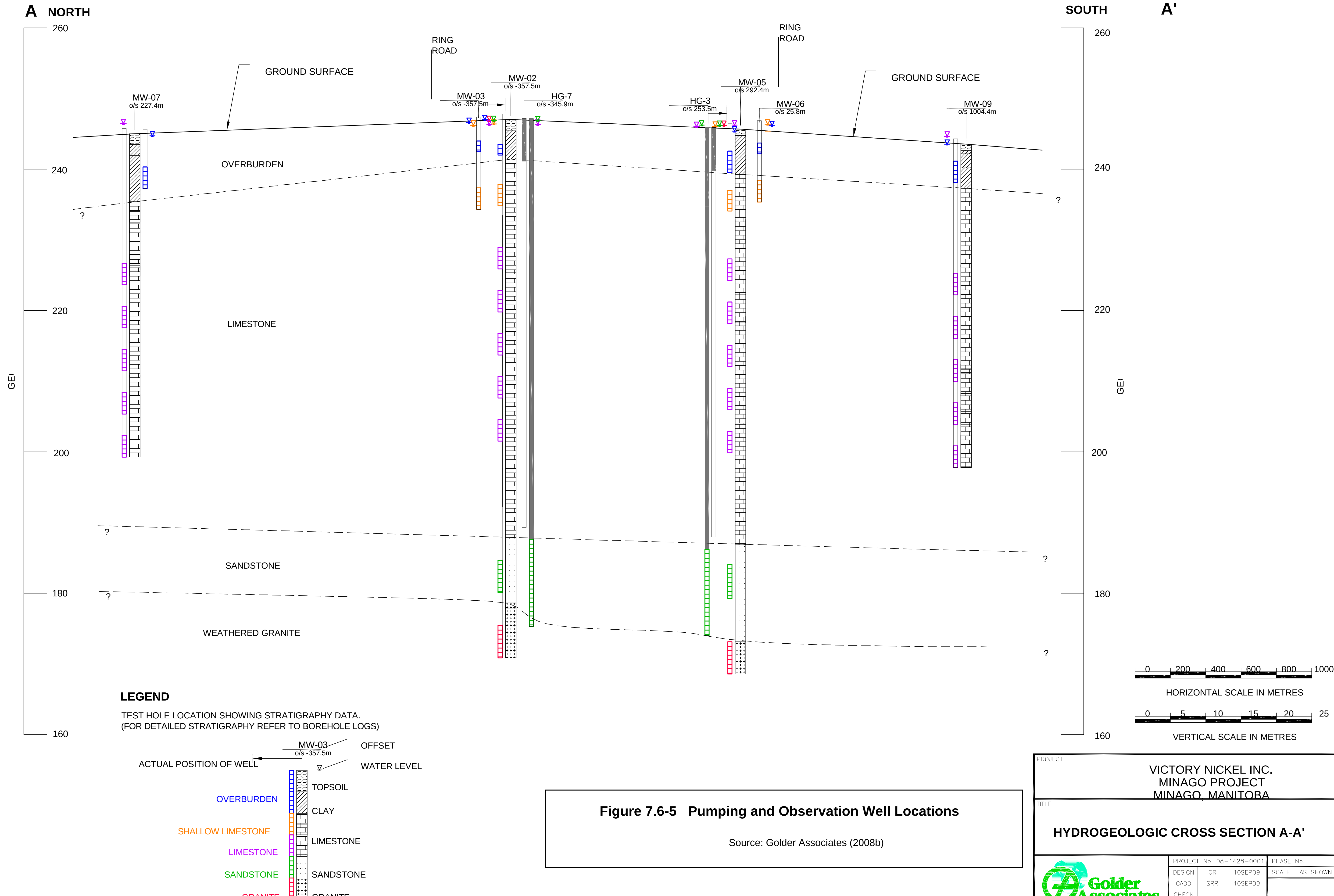

Figure 7.6-5 Pumping and Observation Well Locations

Source: Golder Associates (2008b)

PROJECT

VICTORY NICKEL INC.
MINAGO PROJECT
MINAGO, MANITOBA

TITLE

HYDROGEOLOGIC CROSS SECTION A-A'

Golder Associates
Greater Vancouver Office, BC

PROJECT No. 08-1428-0001			PHASE No. 7000	
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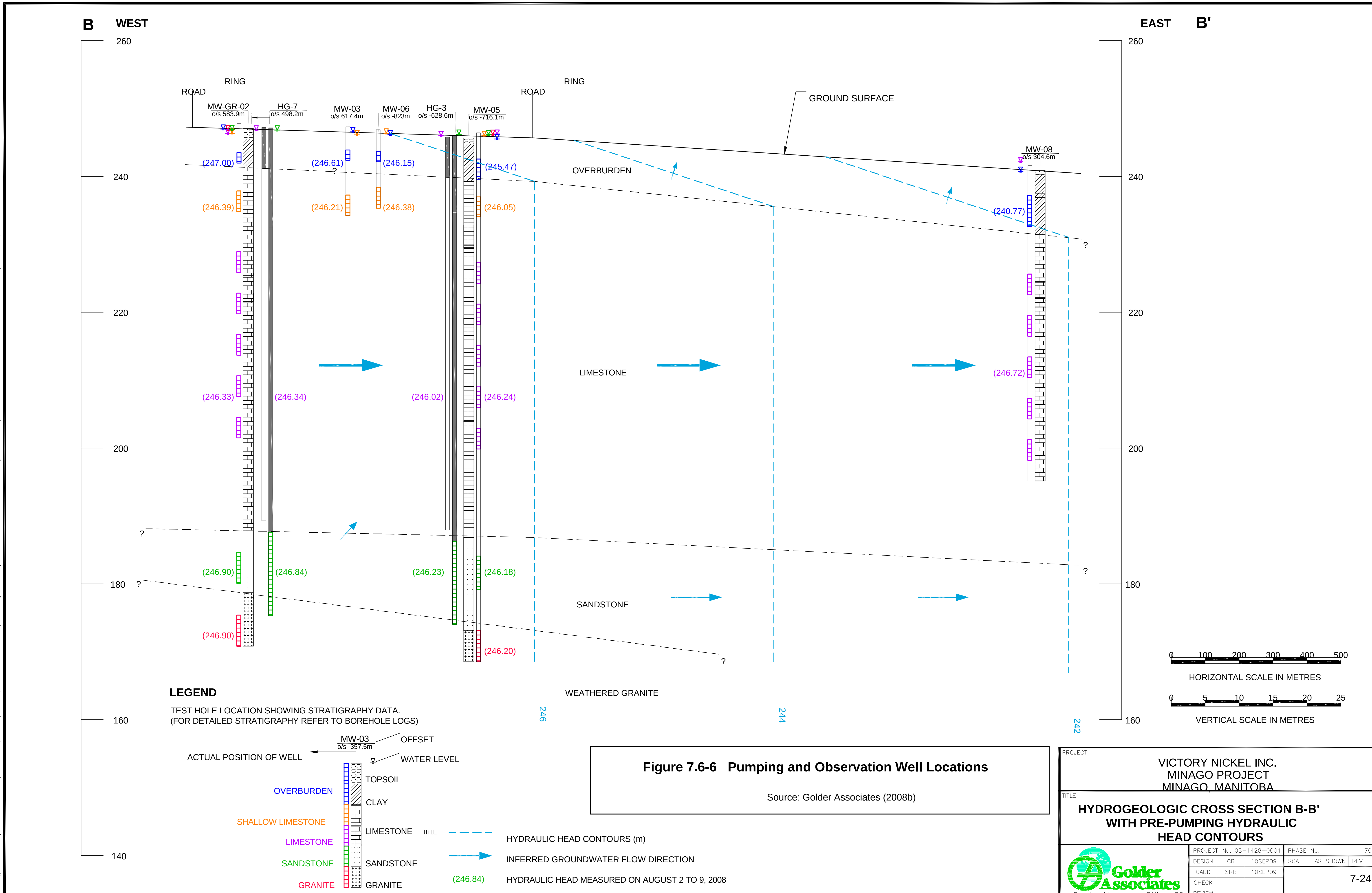


Figure 7.6-6 Pumping and Observation Well Locations

Source: Golder Associates (2008b)

is primarily horizontal (from west to east). A minor component of groundwater flow in the shallow limestone, except in the vicinity of HG-7, is inferred to be directed upward through the overburden, indicating that the ground surface is an area of groundwater discharge over much of the Site. Flowing artesian conditions prevailed at all well locations except those in the vicinity of HG-7 (including MW-1, MW-2, and MW-3). The vertical hydraulic gradient through the overburden prior to pumping was estimated to be between 0.1 and 0.6 over much of the Site, such that flow is predominantly upward through the overburden. In the vicinity of HG-7, however, the vertical gradient was estimated to be between -0.2 and -0.4, such that flow is predominantly downward. The hydraulic head in the limestone is also comparatively lower in the vicinity of HG-7, relative to those directly south, in the vicinity of HG-3. This difference in hydraulic conditions in the limestone in the vicinity of HG-7 suggests the presence of a higher hydraulic conductivity zone within the limestone in this area (Golder Associates, 2008b).

The inferred groundwater flow direction in the limestone unit is from west to east, with a horizontal hydraulic gradient of approximately 0.0018. Although there is an insufficient spacing of sandstone wells to determine the position of hydraulic head contours in the sandstone unit, the inferred direction of groundwater flow in this unit is also from west to east (Golder Associates, 2008b).

Based on the hydraulic head contours in Section B-B’ (Figure 7.6-6), the horizontal hydraulic gradient in the sandstone unit is approximately 0.003. A component of groundwater flow in the sandstone unit, in the vicinity of the proposed mine pit area, is directed upward across the sandstone-limestone contact, with an upward hydraulic gradient ranging from 0 to 0.02 (Golder Associates, 2008b).

7.6.3.3 Maximum Drawdown Observed during the Pumping Test

The maximum drawdown was 17.3 m at HG-3-LS, 18.4 m at HG-7-LS, 31.1 m at HG-7-SS and 41.9 m at HG-3-SS (Golder Associates, 2008b). The maximum drawdown observed in each of the four hydrostratigraphic units, as recorded on the fifth day of the pumping test, is listed in Table 7.6-2 and illustrated in Figures 7.6-7 and 7.6-8. The maximum drawdown in the overburden ranged from 0.01 to 0.06 m at the Site, except at MW-OB-1 (located approximately 30 m from HG-7), where the drawdown was 2.4 m. During the pumping test, the ground surface remained saturated, even in the vicinity of MW-OB-1 possibly due to horizontal surface or subsurface flow in the peat (Golder Associates, 2008b).

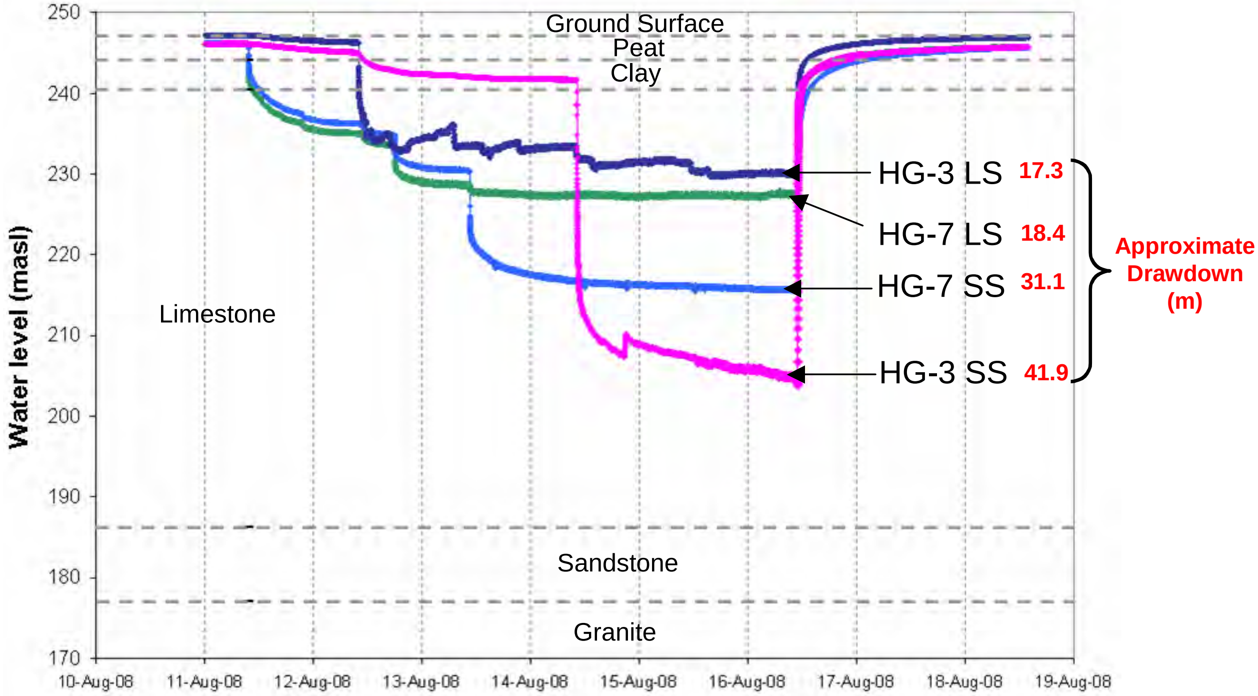
The maximum drawdowns in cross-section are shown in Figures 7.6-9 and 7.6-10. The cross sections indicate that a cone of depression was generated within each of the hydrostratigraphic units. As a result, groundwater flow at the Site was directed towards the dewatering wells, and generally toward the pit area, in all hydrogeological units, during the pumping test. The radius of influence of the pumping test is estimated to have been up to approximately 3 km around the proposed pit area based on these drawdown contours (Golder Associates, 2008b).

Table 7.6-2 Pre-Pumping Water Levels and Maximum Drawdown Levels

Well Name	Pre-pumping Water Level August 2 to 9, 2008			Water Level at Maximum Drawdown August 16, 2008 11:00AM			Drawdown
	m.a.s.l.	mbgs	mbtp	m.a.s.l.	mbgs	mbtp	m
Pumping Wells:							
HG-3-LS	246.02	-0.13	0.87	228.74	17.14	18.14	17.27
HG-3-SS	246.23	-0.25	0.75	204.37	41.60	42.60	41.86
HG-7-LS	246.34	0.87	1.92	227.92	19.29	20.34	18.42
HG-7-SS	246.84	0.33	1.38	215.80	31.38	32.43	31.05
Observation Wells:							
MW-OB-1	246.58	0.77	1.72	244.17	3.18	4.12	2.41
MW-OB-2	247.00	0.16	1.20	246.94	0.22	1.26	0.06
MW-OB-3	246.61	0.11	0.99	246.59	0.13	1.02	0.02
MW-OB-4	245.57	0.14	1.27	245.53	0.18	1.31	0.04
MW-OB-5	245.47	0.14	1.55	245.41	0.20	1.61	0.06
MW-OB-6	246.15	-0.03	1.18	246.14	-0.01	1.19	0.01
MW-OB-7	244.72	0.17	1.30	244.71	0.18	1.31	0.01
MW-OB-8	240.77	0.05	1.18	240.71	0.11	1.24	0.06
MW-OB-9	243.53	0.04	1.03	243.50	0.07	1.06	0.03
MW-SLS-1	246.30	0.91	1.91	237.26	9.95	10.95	9.04
MW-SLS-2	246.39	0.78	1.81	237.10	10.07	11.10	9.29
MW-SLS-3	246.21	0.44	1.34	239.96	6.69	7.59	6.25
MW-SLS-4	245.76	-0.16	0.81	240.98	4.62	5.60	4.78
MW-SLS-5	246.05	-0.52	0.63	242.11	3.41	4.56	3.94
MW-SLS-6	246.38	-0.25	0.85	245.37	0.76	1.86	1.01
MW-LS-2	246.33	0.90	1.94	233.59	13.63	14.68	12.74
MW-LS-5	246.24	-0.65	0.36	232.93	12.67	13.68	13.31
MW-LS-7	246.45	-1.46	0.19	244.90	0.10	1.74	1.55
MW-LS-8	242.72	-1.85	0.18	242.15	-1.28	0.75	0.57
MW-LS-9	244.67	-1.13	0.24	243.39	0.15	1.52	1.28
MW-SS-2	246.90	0.26	1.43	233.81	13.36	14.52	13.09
MW-SS-5	246.18	-0.51	0.38	236.60	9.07	9.95	9.58
MW-GR-2	246.90	0.15	1.18	233.39	13.66	14.69	13.51
MW-GR-5	246.20	-0.52	0.44	236.92	8.75	9.72	9.28

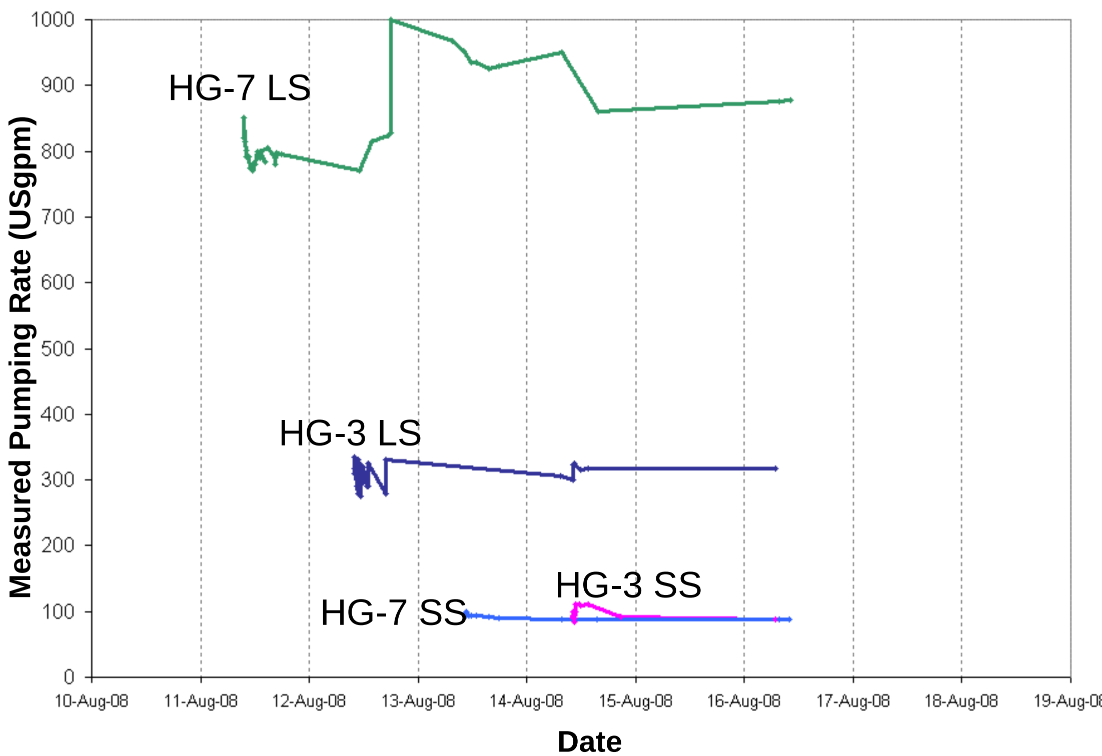
Notes:
m.a.s.l. - meters above sea level
mbgs - meters below ground surface
mbtp - meters below top of pipe

Source: Golder Associates (2008b)



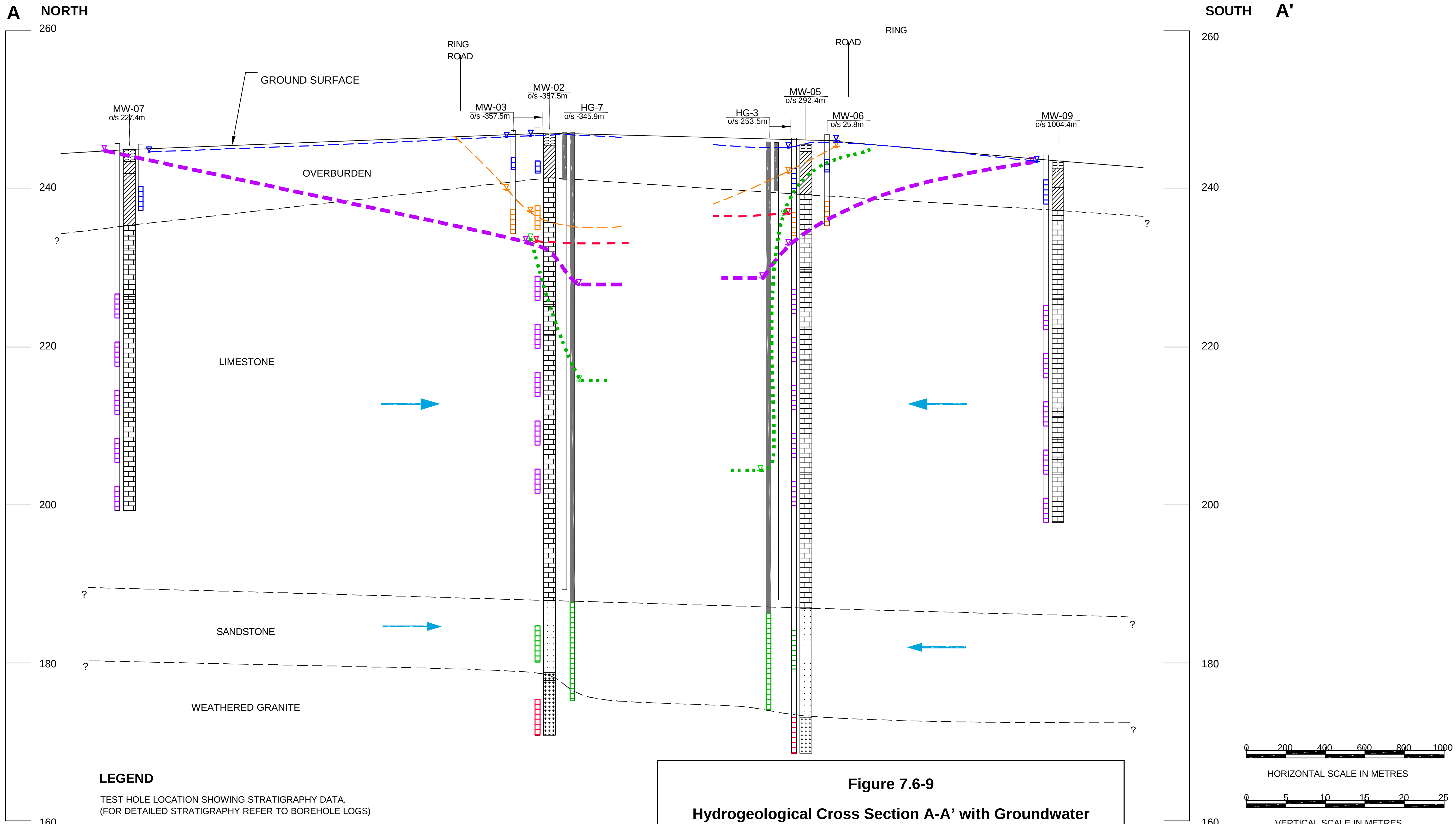
Source: Golder Associates (2008b)

Figure 7.6-7 Water Levels during the August 2008 Pump Test



Source: adapted from (VNI and Golder Associates, 2008b)

Figure 7.6-8 Pumping Rates during the August 2008 Pump Test



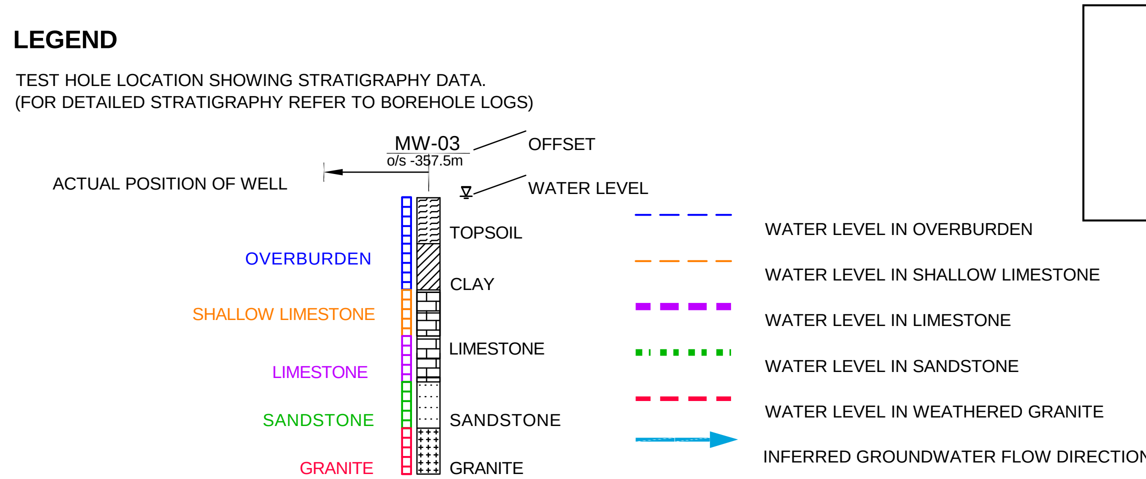


Figure 7.6-9

Hydrogeological Cross Section A-A' with Groundwater Levels at Maximum Drawdown

Source: Golder Associates (2008b)

PROJECT
VICTORY NICKEL INC.
MINAGO PROJECT
MINAGO, MANITOBA

TITLE
HYDROGEOLOGIC CROSS SECTION A-A' WITH GROUNDWATER LEVELS AT MAXIMUM DRAWDOWN

Golder Associates
Greater Vancouver Office, BC

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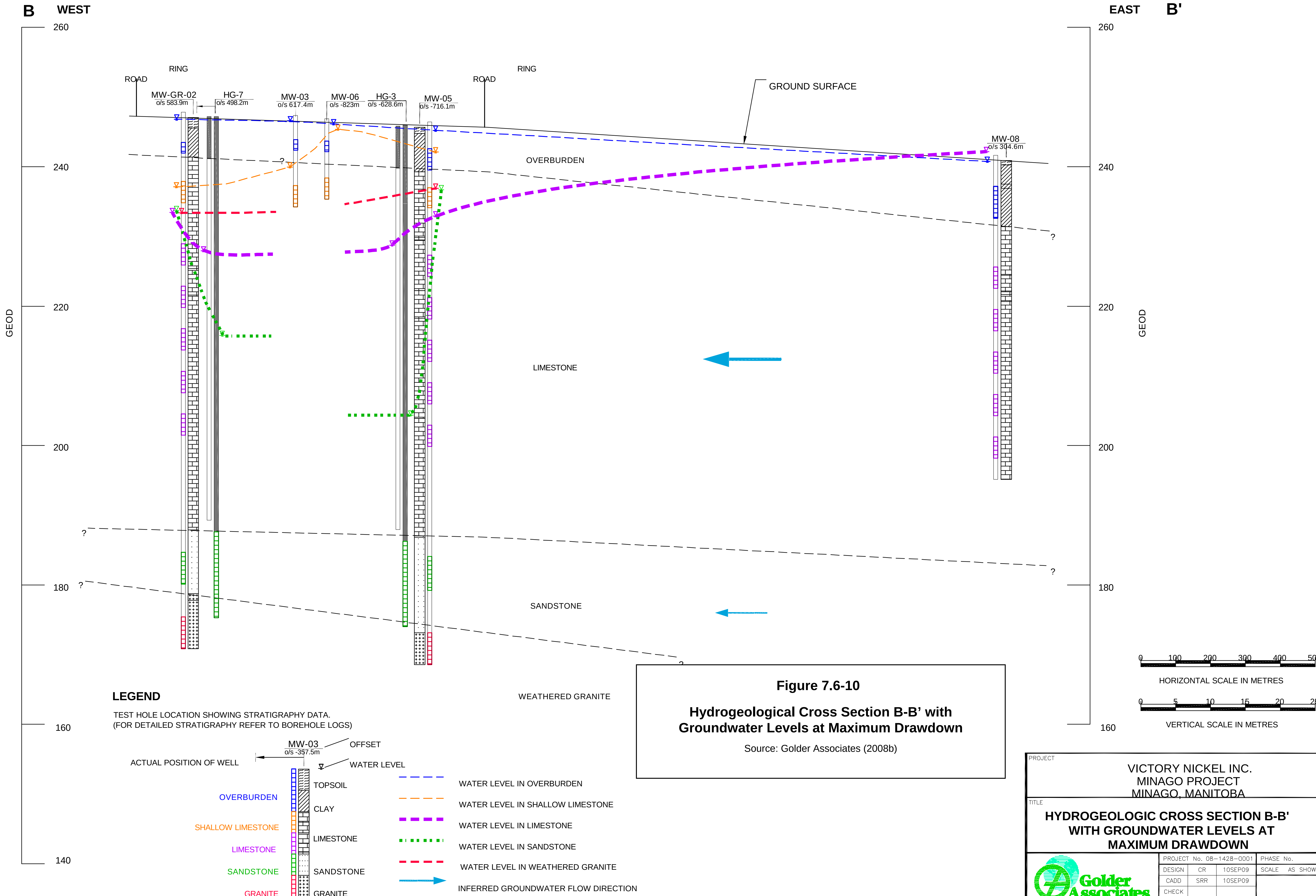

Figure 7.6-10

Hydrogeological Cross Section B-B' with Groundwater Levels at Maximum Drawdown

Source: Golder Associates (2008b)

PROJECT

VICTORY NICKEL INC.
MINAGO PROJECT
MINAGO, MANITOBA

TITLE

HYDROGEOLOGIC CROSS SECTION B-B' WITH GROUNDWATER LEVELS AT MAXIMUM DRAWDOWN

Golder Associates
Greater Vancouver Office, BC

PROJECT No. 08-1428-0001			PHASE No.	7000
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7.6.3.4 Wide Area Analysis (Analysis of Steady-State Conditions)

The Copper and Jacob (1946) distance-drawdown method was selected as the primary method to analyze the pumping test data for the limestone aquifer because it provided wide-area estimates of the aquifer parameters useful for application to the groundwater flow model. Figures 7.6-11 and 7.6-12 present the results of the distance-drawdown analysis, which was carried out separately for each limestone dewatering well (HG-7-LS and HG-3-LS) and was based on the drawdown observed in the limestone wells at a time of 4.6 days after the start of the pumping test (i.e., at approximately the end of pumping). The drawdown observed at this time was considered representative of "late-time" data that is generally applicable to steady-state solutions such as the distance-drawdown method. As the drawdown in the shallow limestone (SLS) wells was generally less than the drawdown in the deeper limestone (LS) wells, separate straight-line analyses were conducted for the shallow and the deeper limestone units.

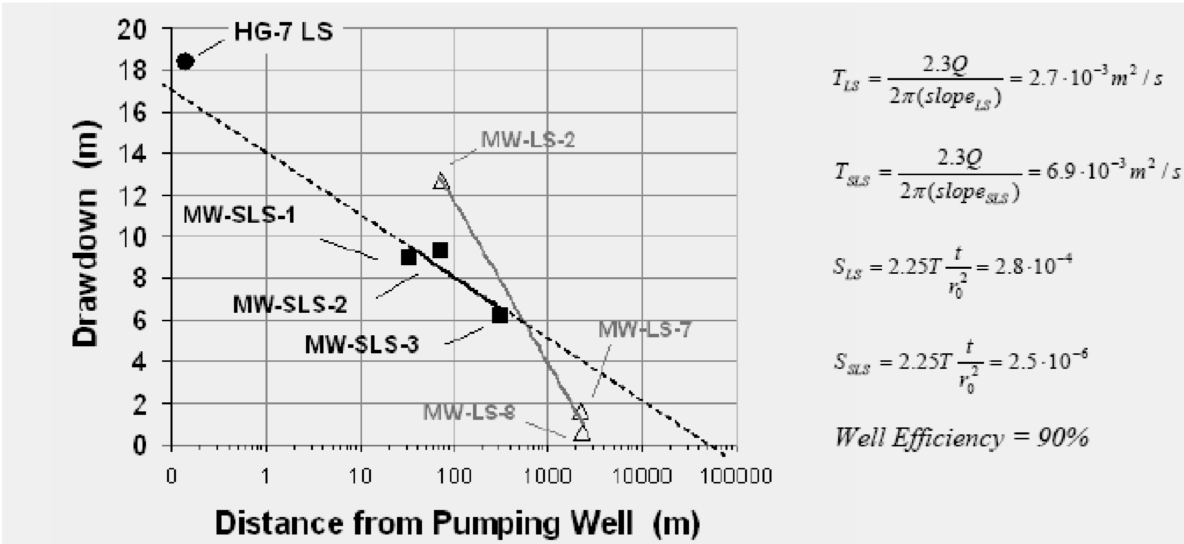
Table 7.6-3 summarizes the results of the distance-drawdown analysis for transmissivity and storativity of the limestone. The region around HG-7 is referred to as the North Pit Wall (NPW) zone and the region around HG-3 is referred to as the South Pit Wall (SPW) zone. Transmissivity at the North Pit Wall is estimated to be 6.9×10^{-3} m^2/s in the shallow limestone unit (T_{SLS}) and 2.7×10^{-3} m^2/s in the limestone unit (T_{LS}). Transmissivity at the South Pit Wall is estimated to be 1.8×10^{-3} m^2/s in the shallow limestone unit (T_{SLS}) and 8.7×10^{-4} m^2/s in the limestone unit (T_{LS}). Storativity estimates range from 2.5×10^{-6} to 4.5×10^{-3} (Golder Associates, 2008b).

Well efficiency, which quantifies the variation between the water level in the well and the water level in the formation adjacent to the well, is estimated to be 90% at HG-7-LS and 93% at HG-3-LS. A well efficiency greater than 90% is considered to be an indication of a good well construction. As the limestone dewatering wells are open hole wells, these high efficiencies were generally expected.

7.6.3.5 Detailed Analyses (Analyses of Transient Conditions)

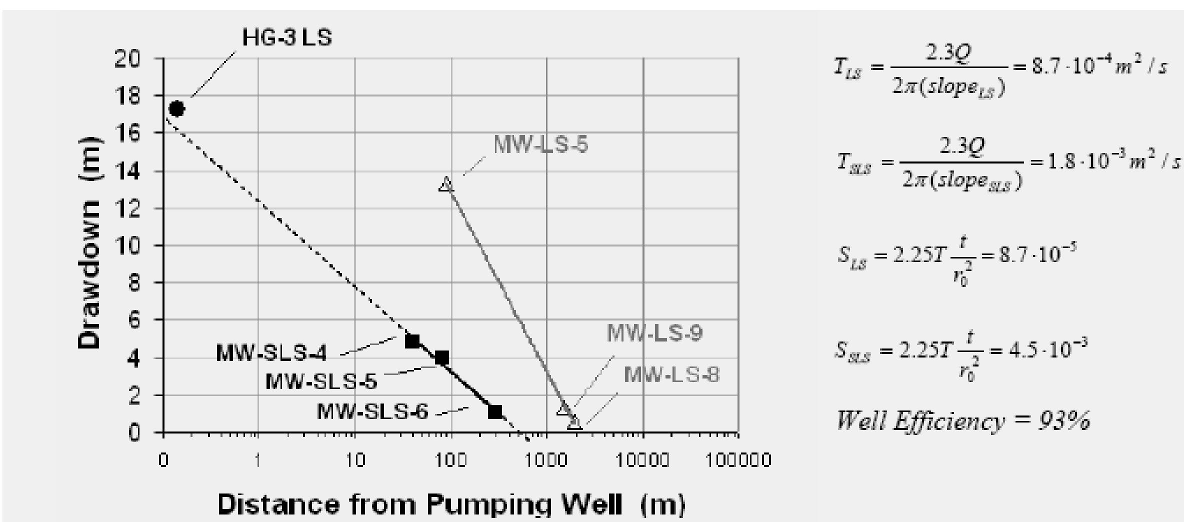
Groundwater flow to the dewatering wells at the Site during the pumping test caused water levels in the limestone aquifer to decline in a nonlinear fashion over time. As such, the time-varying drawdown data generated by the pumping test were also used to estimate the hydraulic properties of the limestone aquifer based on analytical solutions for non-steady flow to the pumping wells. The results of these analyses, presented in Table 7.3.6.5, generally support the distance-drawdown results presented above and also provide additional information regarding conditions in the aquifer and additional aquifer parameters of interest, such as specific yield (Golder Associates, 2008b).

The results listed in Table 7.3.6.5 from Butler's (1988) solution indicate that a region of high transmissivity (T) exists within approximately 350 m of HG-7 (i.e., North Pit Wall zone). This analysis accounted for pumping at all four dewatering wells by solving the groundwater flow equation at several time intervals during the pumping test and applying the principle of superposition. The associated transmissivity estimates from the Butler solution for the North Pit Wall zone (T_{SLS}: 1.4×10^{-2} m^2/s and T_{LS}: 7.5×10^{-3} m^2/s) are 2 to 3 times greater than those



Source: Golder Associates (2008b)

Figure 7.6-11 Distance-Drawdown Analysis for HG-7 LS



Source: Golder Associates (2008b)

Figure 7.6-12 Distance-Drawdown Analysis for HG-3 LS

Table 7.6-3 Distance-Drawdown Analysis

Zone	Hydrogeologic Unit	COOPER-JACOB DISTANCE DRAWDOWN METHOD: Radius of Influence (r_0) km	Pumping Rate (Q) m^3/s	Slope (s/log cycle) m/m	Elapsed Time (t) s	Transmiss-ivity (T) m^2/s	Storativity (S)	Actual Drawdown m	Theoretical Drawdown m	Approximate Well Efficiency
North Pit Wall (HG-7 LS)	LS	3	0.06	8.0	4.0E+05	**2.7E-03**	2.8E-04	18.42	24.0	*
	SLS	50	0.06	3.2	4.0E+05	**6.9E-03**	2.5E-06	18.42	16.6	90%
South Pit Wall (HG-3 LS)	LS	2.4	0.022	9.3	4.0E+05	**8.7E-04**	8.7E-05	17.27	18.0	*
	SLS	0.5	0.022	4.5	4.0E+05	**1.8E-03**	4.5E-03	17.27	16.0	93%

Notes:

* Measurements not used in the calculation of well efficiency.

Source: Golder Associates (2008b)

Table 7.6-4 Summary of Other Pumping Test Analyses

Zone	Hydrogeologic Unit	BUTLER (1988) SOLUTION Transmissivity (T) m²/s	BUTLER (1988) SOLUTION Storativity (S) -	BUTLER (1988) SOLUTION Radial Limits from HG-7 (R) m	THEIS (1935) SOLUTION Transmissivity (T) m²/s	THEIS (1935) SOLUTION Storativity (S) -	MOENCH AND PRICKETT (1972) Specific Yield (Sy) -
North Pit Wall (HG-7 LS)	LS	7.5E-03	9.0E-05				0.02
	SLS	1.4E-02	1.8E-04	<350			0.01
South Pit Wall (HG-3 LS)	LS				1.3E-03	1.5E-04	
	SLS	(2.0E-3) [a]	(2.0E-4) [a]	>350	2.5E-03	3.6E-03	0.02
> 2km North and South of Pit Area (LS-7 and LS-9)	LS	4.0E-03	2.7E-04	>350			
> 2 km East of Pit Area (LS-8)	LS	5.6E-03	1.0E-03	>350			

Notes:

a. These results are inferred to be applicable to the South Pit Wall zone but are based on analysis of data from the North Pit Wall zone which include an evaluation of limestone heterogeneity at a radial distance of 350 m from the North Pit Wall area.

References:

Butler, J.J., Jr., 1988. Pumping tests in nonuniform aquifers—the radially symmetric case, Journal of Hydrology, vol. 101, pp. 15-30.

Moench, A.F. and T.A. Prickett, 1972. Radial flow in an infinite aquifer undergoing conversion from artesian to water-table conditions, Water Resources Research, vol. 8, no. 2,

Theis, C.V., 1935. The relation between the lowering of the piezometric surface and the rate and duration of discharge of a well using groundwater storage, Am. Geophys. Union Trans. Vol. 16, pp. 519-524.

Source: Golder Associates (2008b)

estimated using the distance-drawdown method presented previously. However, the storativity of the shallow limestone for the North Pit Wall zone is almost an order of magnitude greater than that estimated using the distance-drawdown method. In the region extending beyond 350 m from HG-7 (i.e. including the South Pit Wall zone), the estimated transmissivity of the limestone based on the Butler solution (2.0×10^{-3} m^2/s) is similar to the range estimated using the distance-drawdown method. In the regions extending more than 2 km from HG-7 to the north and west, and more than 3 km from HG-7 to the south, the estimated transmissivity of the deeper limestone (4.0×10^{-3} m^2/s to 5.6×10^{-3} m^2/s) is within the range estimated for the near-pit zone (2.0×10^{-3} m^2/s near South Pit Wall to 7.5×10^{-3} m^2/s at the North Pit Wall) based on the Butler solution (Golder Associates, 2008b).

To check the quality of the distance-drawdown results for the South Pit Wall zone presented previously, the Theis (1935) solution was used to estimate the hydraulic properties of the South Pit Wall zone. To enable this analysis, the drawdown data for the South Pit Wall zone was corrected for well interference from HG-7-LS (North Pit Wall Area) and the 1-day delay in the start of pumping at HG-3-LS during the pumping test. The Theis analysis accounted for pumping from both the limestone and sandstone dewatering wells by applying the principal of superposition. The associated transmissivity estimates based on the Theis solution (T_{SLS}: 2.5×10^{-3} m^2/s and T_{LS}: 1.3×10^{-3} m^2/s) are approximately 1.5 times greater than those estimated using the distance-drawdown method presented previously (Golder Associates, 2008b).

7.6.3.6 Heterogeneity of the Limestone

Golder Associates (2008b) approximated the heterogeneity of the limestone aquifer by the following ratios in transmissivity (T) based on the analyses of both steady-state and the transient responses to the pumping test:

North Pit Wall versus South Pit Wall:

- T_{SLS} at North Pit Wall > T_{SLS} at South Pit Wall by a factor of: 4
- T_{LS} at North Pit Wall > T_{LS} at South Pit Wall by a factor of: 3

Shallow Limestone versus Deep Limestone:

- T_{SLS} at North Pit Wall > T_{LS} at North Pit Wall by a factor of: 2
- T_{SLS} at South Pit Wall > T_{LS} at South Pit Wall by a factor of: 2

Neat Pit versus Far Pit (Deep Limestone):

- T_{LS} approx. 2 km from pit > T_{LS} at South Pit Wall by a factor of: 3
- T_{LS} at North Pit Wall > T_{LS} approx. 2 km from pit by a factor of: 2

7.6.3.7 Area Impacted by Pumping During the Pumping Test

Based on the distance-drawdown analysis, the radius of influence of the pumping test in the deeper limestone is estimated to have been 3 km around HG-7-LS and 2.4 km around HG-3-LS (Golder Associates, 2008b).

7.6.3.8 Conversion to Unsaturated Conditions in the Shallow Limestone

During the pumping test, the water level dropped below the top of the limestone in the region within 75 to 300 m of HG-7 and the region within 40 m of HG-3. The Moench and Prickett (1972) method was used to assess the unconfined storage properties of the limestone aquifer for wells completed within these regions. The Moench and Prickett (1972) method solves the groundwater flow equation analytically, for flow to a pumping well in a confined aquifer that undergoes a conversion to unconfined conditions. The specific yield (S_y) of the shallow limestone unit was estimated to be between 0.01 and 0.02, as shown on Table 7.6-4. This estimate lies within the typical range of S_y for limestone, which has been reported to range from 0.005 to 0.05 (ASCE, 1996). It should be noted that this analysis yielded results for T and S for the limestone that are considered less accurate than the values reported above. This caveat is based on the assessment that the response of the aquifer to pumping was dominated by the zone of high transmissivity near HG-7, rather than the conversion to unsaturated conditions in the shallow limestone unit (Golder Associates, 2008b).

7.6.3.9 Assessment of Vertical Hydraulic Conductivity for the Overburden

The Hantush-Jacob (1995) steady state solution for leaky aquifers was used to estimate the vertical hydraulic conductivity of the overburden clay (i.e. the overlying aquitard), from the measurements of drawdown made during the pumping test. Based on the results from the overburden wells situated at least two kilometres from the pumping wells (MW7-OB, MW8-OB and MW9-OB), the vertical hydraulic conductivity (K_V) of the overburden was estimated to range from 4×10^{-9} m/s to 6×10^{-9} m/s (Golder Associates, 2008b).

7.6.3.10 Analysis of Single-Well Response Tests

Based on the single-well response tests, the horizontal hydraulic conductivity estimates for the overburden aquitard ranged from 6×10^{-6} m/s to 6×10^{-9} m/s, with a geometric mean of 4×10^{-8} m/s. This mean is one order of magnitude greater than the mean vertical hydraulic conductivity estimate for the overburden based on the pumping test analyses ($K_V = 5\times10^{-9}$ m/s), indicating an anisotropy ratio (K_H/K_V) of 10 for the overburden aquitard (Golder Associates, 2008b).

The horizontal conductivity for weathered granite was estimated to be 4×10^{-7} m/s on the north side of the proposed pit area (MW-2-GR) and 4×10^{-9} m/s on the south side of the proposed pit area. The geometric mean of these results is 4×10^{-8} m/s (Golder Associates, 2008b).

7.6.3.11 Assessment of Pre-Pumping Vertical Flow through the Overburden

Using Darcy's Law for flow through porous media (groundwater flux (q) = hydraulic conductivity (K) × hydraulic gradient ($\partial h/\partial z$)) and the estimates of hydraulic gradient and K_V presented above, the vertical flux through the overburden prior to pumping was estimated to have been (Golder Associates, 2008b):

- North Pit Wall Area: q = downward 1×10^{-9} m/s (40 mm/yr);
- South Pit Wall Area: q = upward 8×10^{-10} m/s (10 mm/yr); and,
- About 2 km from Pit: q = upward 2×10^{-9} m/s (60 mm/yr).

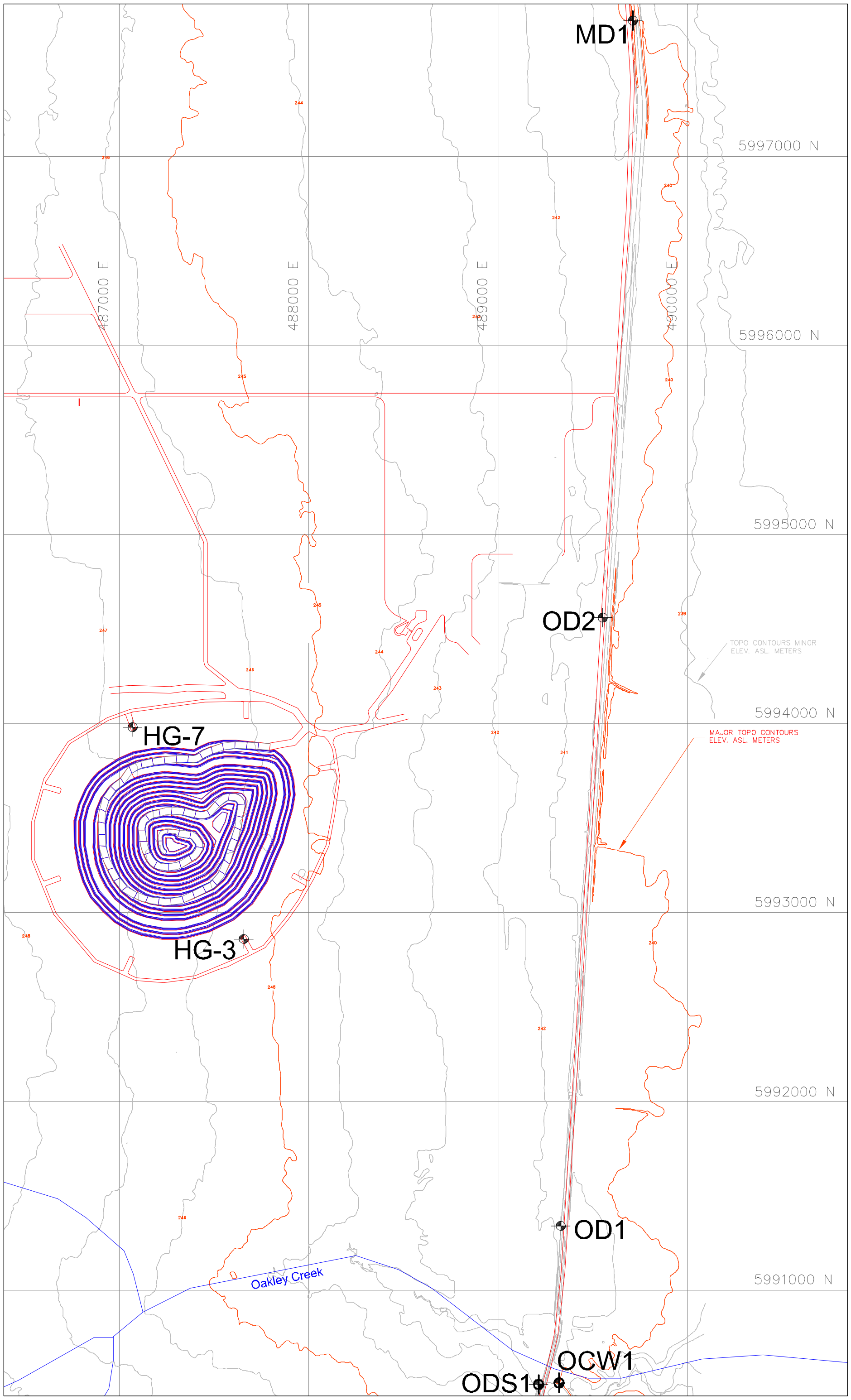
7.6.3.12 Effects of the Groundwater Pump Test on Surface Water

To determine whether the groundwater pumping test program had an efffect on the surface water, streamflow and water quality measurements were conducted at three locations (OD1, OD2, and MD1) in the roadside ditch closest to the dewatering wells, at Oakley Creek station OCW1, and at one location south and upstream of Oakley Creek (ODS1) (Table 7.6-5 and Figure 7.6-13). The groundwater pump test was conducted at HG-3 (wells HG-3 LS and HG-3 SS) and at HG-7 (wells HG-7 LS and HG-7 SS) in a sub-watershed north of Oakley Creek (Figure 7.6-13). Water quality was also assessed in William River at WRW1x, just downstream of the confluence of Oakley Creek with William River.

Station ODS1 served as a reference station, as it receives drainage from a southern sub-watershed of Oakley Creek, which was completely unaffected by the groundwater pump test, but subject to the same local precipitation. Surface water from OD1, OD2, and ODS1 drains into Oakley Creek whereas surface water from MD1 drains into Minago River.

Table 7.6-5 Coordinates of the Surface Water Monitoring Locations during the August 2008 Groundwater Pump Test

Sampling Location	GPS Coordinates (14 U NAD 83)		Location Description
	Northing (m)	Easting (m)	
OCW1	N 5990510	E 489322	Oakley Creek just east of Highway 6
ODS1	N 5990502	E 489214	Southwestern roadside ditch draining into Oakley Creek on western side of Highway 6
OD2	N 5994560	E 489553	Western roadside ditch near the Minago entrance
OD1	N 5991341	E 489332	Northwestern roadside ditch draining into Oakley Creek
MD1	N 5997719	E 489712	Roadside ditch draining into Minago River near the northern property boundary on western side of Highway 6



Source: Golder Assoicates, 2008b

Figure 7.6-13 Surface Water Monitoring Locations during the August 2008 Groundwater Pump Test Program

Discharge measurement stations were established at each monitoring site. Anchors were established on the right and left banks at each discharge measurement station, such that a tag line could be stretched between the anchors that was perpendicular to the current. Discharge was measured according to U.S. Geological Survey (USGS) standard procedures (Buchanan and Somers, 1969) with a SonTek Flow Tracker® current meter. The SonTek Flow Tracker® current meter measures velocities ranging from 0.001 m/s (0.003 ft/s) to 4.5 m/s (15 ft/s). The current meter was suspended from a wadding rod. The discharge (instantaneous streamflow) was calculated from the velocity, depth, and width measurements in the same manner as detailed in the Hydrology Section (Section 7.4).

Staff gages, installed on either the right or the left edge of the channel, were used to monitor water surface elevations and Hobo Water Level Loggers (U20-001-04; 0-4 m) were installed at every station.

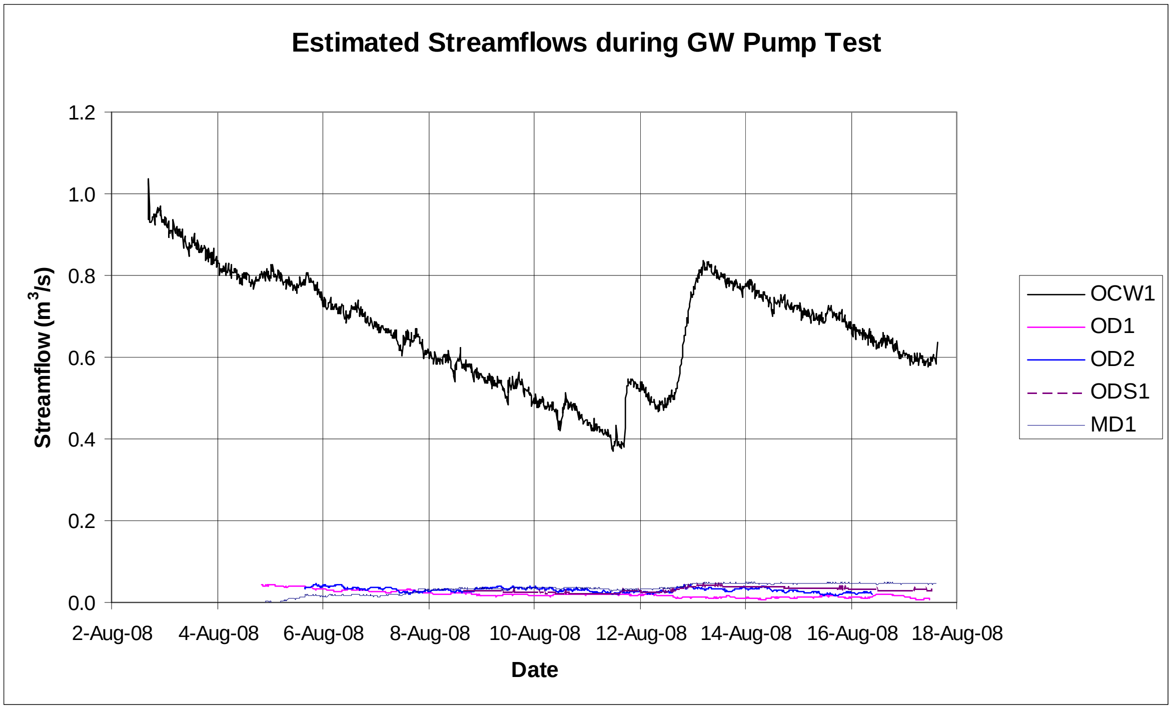
Results of the streamflow measurements are illustrated in Figure 7.6-14a for OCW1, OD1, OD2, ODS1, and MD1 and in Figure 7.6-14b for ODS1. These flow measurements are based on the water level logger measurements that were calibrated with manual flow and water elevation measurements. Details of manual flow and water elevation measurements for these streamflow measurements are provided in Appendix 7.6.

Streamflows at OCW1 were dominant. The minimum streamflow at OCW1 was 0.37 m^3/s compared to a maximum streamflow of 0.05 m^3/s recorded at any of the other surface water monitoring stations. Streamflow increases at OCW1 were likely primarily due to precipitation rather than the groundwater pump test, as the shape of the streamflow-time curve at OCW1 and ODS1 were very similar in terms of periodicity of streamflow peaks and valleys. The difference between the two streamflow-time profiles was that the streamflow at OCW1 was approximately 10 times the streamflow at ODS1 and that the streamflow peaks and valleys occurred approximately 45 minutes to 1.5 hours earlier at the upstream station ODS1 compared to the downstream station OCW1.

Figure 7.6-15 illustrates streamflows recorded at the roadside ditch surface water monitoring locations OD1, OD2 and MD1 and Figure 7.6-16 illustrates the groundwater pumping rates used during the August 2008 pump test. By comparison of those two Figures, it may be inferred that the only station that might have been slightly affected by the groundwater pump test is MD1 as its streamflow rate remained relatively constant throughout the pump test whereas the streamflows at the other stations tended to drop off after the precipitation event on August 12-13, 2008 had passed.

Surface water quality was assessed with a multiparameter YSI 600 QS Instrument. Surface water quality results are summarized in Table 7.6-6 for the stations OCW1, OD1, OD2, ODS1, and MD1. The vast majority of the water quality parameters was relatively constant. The coefficient of variation (mean divided by standard deviation) was only greater than 15% for dissolved oxygen (DO), the Oxidation-Reduction Potential (ORP), and depth. The measurement depth varied likely to different operators taking measurements. Although the measurement depth varied for the recorded water quality measurements, no correlation was found between depth and the other parameters for the data recorded.

(a)



(b)

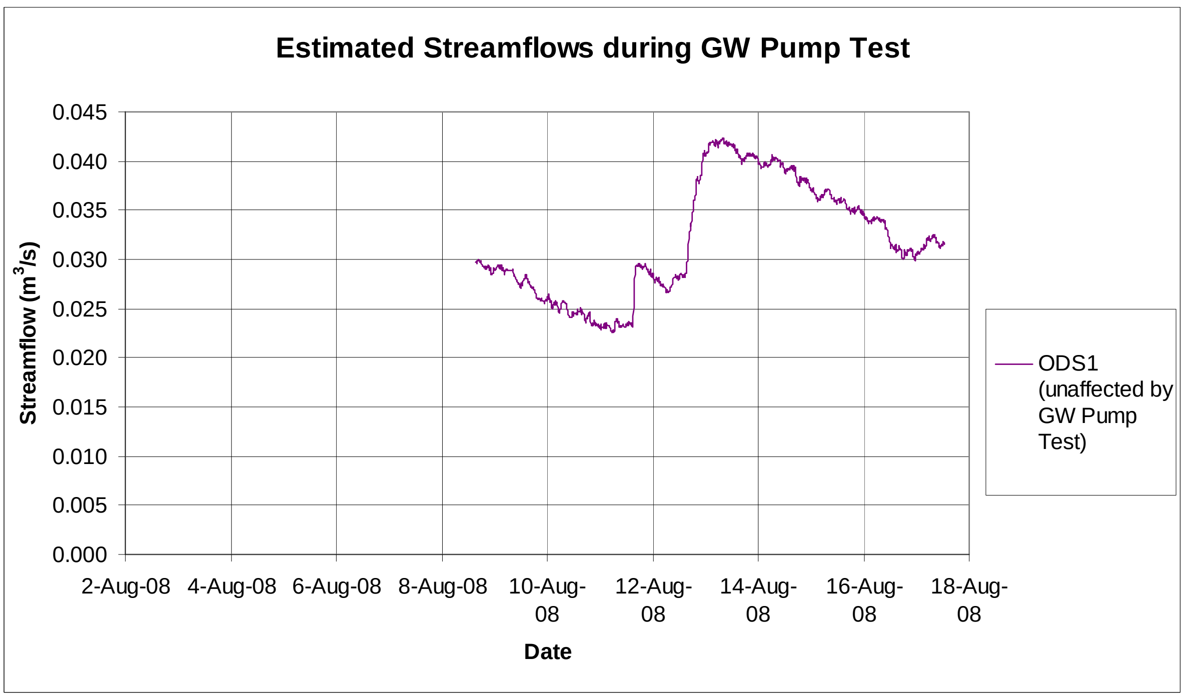


Figure 7.6-14 August 2008 Streamflows recorded at OCW1, OD1, OD2, ODS1, and MD1

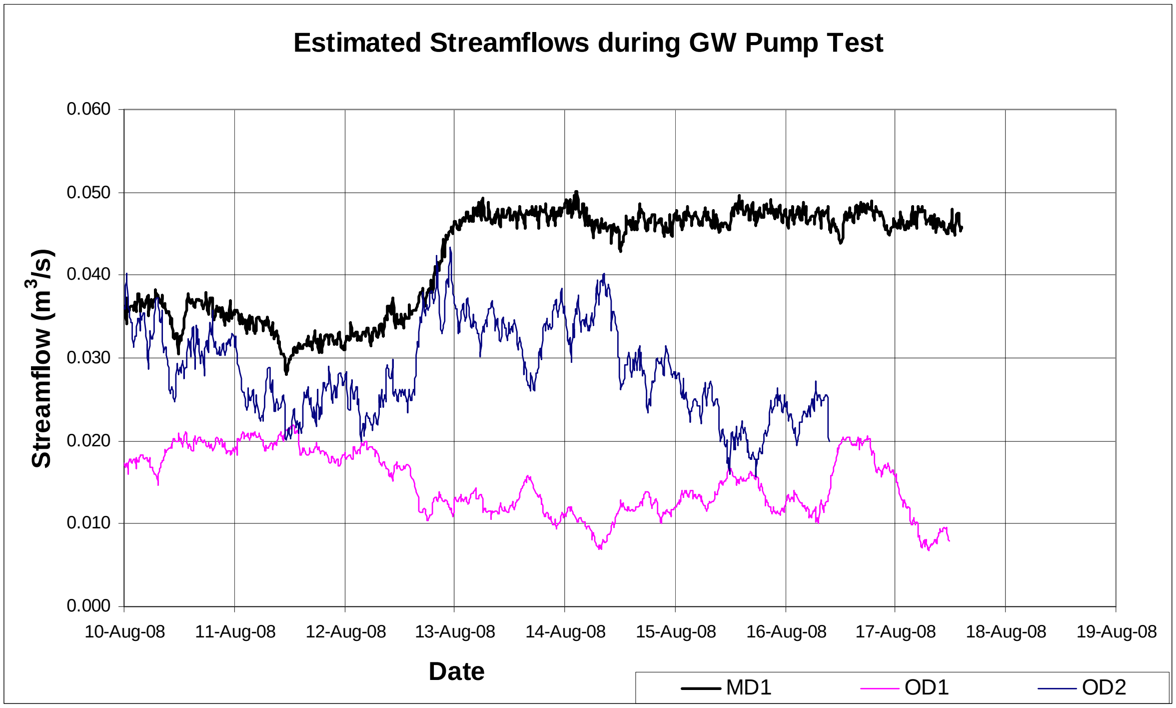
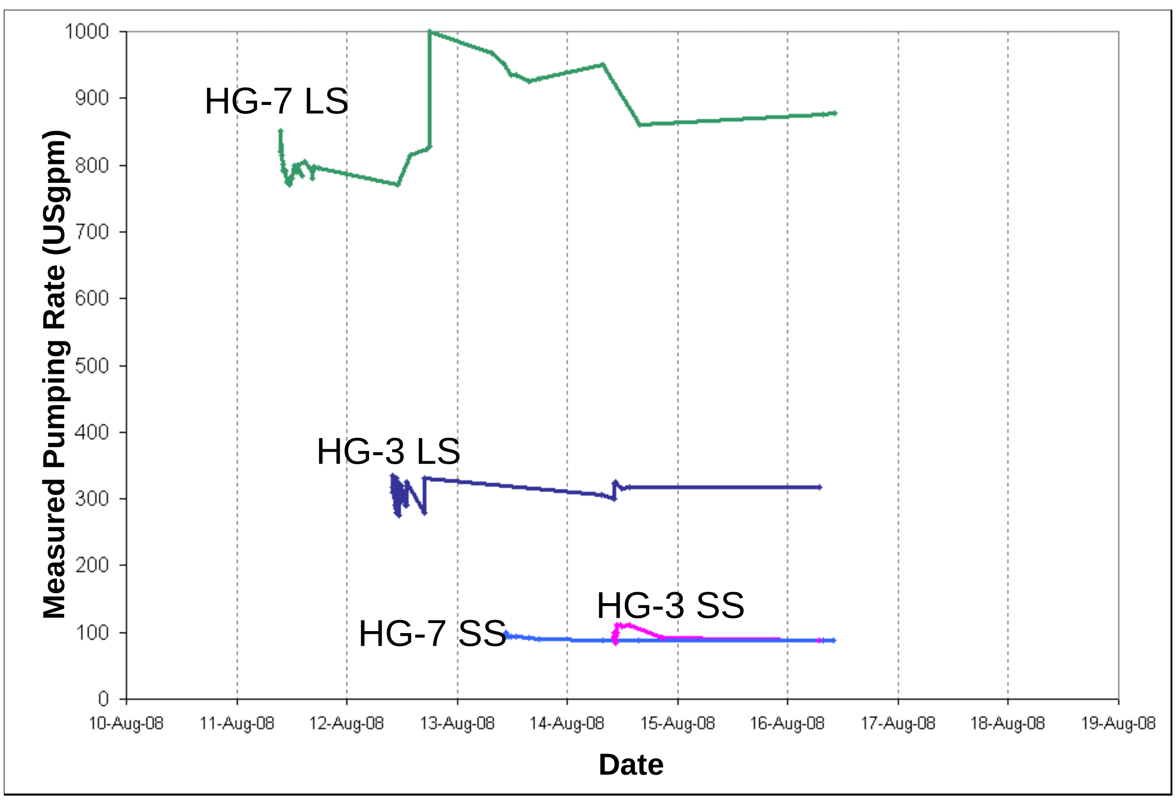


Figure 7.6-15 August 2008 Streamflows recorded at MD1, OD1, and OD2



Source: adapted from VNI and Golder Associates, 2008

Figure 7.6-16 August 2008 Groundwater Pumping Rates

Table 7.6-6 Surface Water Quality measured during the Aug-2008 Pump Test

Sampling Location	Sampling Station	Date	Temperature (°C)	Specific Conductivity (EC1) (uS/cm)	Conductivity (EC2) (uS/cm)	Total Dissolved Solids (g/L)	DO% (%)	DO Concentration (mg/L)	Depth (m)	pH	ORP (mV)	Barometric Pressure (psi)
Oakley Creek immediately east of Highway 6	**OCW1**	04-Aug-08	17.92	308	266	0.200	99.5	9.43	0.046	7.93	222	14.21
	OCW1	09-Aug-08	17.64	329	283	0.214	86.7	8.27	0.023	7.92	194	14.35
	OCW1	10-Aug-08	18.82	335	295	0.218	77.3	7.19	0.053	6.94	254	14.33
	OCW1	11-Aug-08	18.48	340	297	0.221	78.2	7.33	0.027	7.25	192	14.24
	OCW1	12-Aug-08	17.68	330	284	0.215	72.0	6.86	0.106	7.39	290	14.18
	OCW1	13-Aug-08	16.64	322	270	0.209	75.6	7.35	0.035	7.31	288	14.23
	OCW1	14-Aug-08	19.30	329	304	0.214	84.6	7.80	0.044	7.24	195	
	OCW1	15-Aug-08	20.73	341	313	0.222	85.4	7.65	0.053	7.40	219	14.34
	OCW1	16-Aug-08	18.66	347	305	0.226	71.5	6.68	0.022	7.31	238	14.31
	OCW1	17-Aug-08	20.26	352	320	0.229	82.5	7.46	0.025	7.56	199	14.24
		Average	18.61	333	294	0.217	81.3	7.60	0.043	7.42	229	14.27
		Standard Dev.	1.24	13	18	0.008	8.4	0.79	0.025	0.31	38	0.06
		Coeff. Of Variation	7%	4%	6%	4%	10%	10%	**58%**	4%	**16%**	0.4%
Southwestern roadside ditch draining into Minago River	**MD1**	4-Aug-08	14.75	136	109	0.088	91.9	9.31	0.113	7.81	231	14.19
	MD1	6-Aug-08	17.74	142	123	0.092	83.2	7.92	0.212	6.78	213	14.38
	MD1	9-Aug-08	16.39	147	123	0.095	86.2	8.43	0.064	7.74	222	14.36
	MD1	11-Aug-08	16.31	155	129	0.101	43.6	4.25	0.076	7.07	154	14.24
	MD1	12-Aug-08	16.63	150	126	0.098	54.4	5.30	0.053	7.24	230	14.18
	MD1	13-Aug-08	15.42	148	121	0.096	54.4	5.43	0.083	7.23	242	14.23
	MD1	14-Aug-08	18.47	154	135	0.100	73.6	6.91	0.042	6.50	158	14.36
	MD1	15-Aug-08	20.49	158	145	0.103	78.3	7.05	0.009	7.12	255	14.34
	MD1	16-Aug-08	20.50	168	154	0.110	35.3	3.18	0.022	7.11	128	14.27
		Average	17.41	151	129	0.098	66.8	6.42	0.075	7.18	204	14.28
		Standard Dev.	2.07	9	13	0.006	20.3	2.02	0.060	0.41	45	0.08
		Coeff. Of Variation	12%	6%	10%	6%	**30%**	**32%**	**81%**	6%	**22%**	1%
Western roadside ditch near the Minago Entrance	**OD2**	5-Aug-08	16.63	185	155	0.120	64.3	6.26	0.106	7.09	178	14.27
	OD2	6-Aug-08	18.20	191	166	0.124	51.6	4.87	0.200	7.07	49	14.39
	OD2	9-Aug-08	19.72	202	182	0.132	82.4	7.51	0.110	7.42	77	14.37
	OD2	12-Aug-08	18.90	228	201	0.148	64.4	5.97	0.097	7.21	166	14.17
	OD2	13-Aug-08	16.96	233	197	0.151	38.9	3.75	0.098	7.10	256	14.23
	OD2	14-Aug-08	18.90	231	204	0.150	52.6	4.87	0.044	6.65	98	14.37
	OD2	15-Aug-08	19.83	224	202	0.146	46.8	4.27	0.046	6.86	110	14.34
		Average	18.45	213	187	0.139	57.3	5.36	0.100	7.06	133	14.31
		Standard Dev.	1.26	20	20	0.013	14.3	1.30	0.052	0.25	71	0.08
		Coeff. Of Variation	7%	10%	11%	10%	**25%**	**24%**	**52%**	3%	**53%**	1%
Western roadside ditch draining into Oakley Creek close to Oakley Creek	**OD1**	4-Aug-08	13.73	136	107	0.089	57.1	5.92	0.028	7.47	145	14.22
	OD1	9-Aug-08	17.25	149	127	0.097	45.4	4.33	0.069	7.36	128	14.37
	OD1	11-Aug-08	15.24	154	125	0.100	46.3	4.65	0.034	6.95	160	14.25
	OD1	13-Aug-08	16.13	152	126	0.099	45.4	4.44	0.014	6.90	303	14.26
	OD1	14-Aug-08	15.12	150	121	0.098	18.3	1.81	0.115	6.61	194	14.38
	OD1	15-Aug-08	17.83	156	135	0.102	32.2	3.05	0.076	6.72	231	14.34
	OD1	16-Aug-08	17.57	159	135	0.103	38.0	3.63	0.052	6.96	230	14.27
		Average	16.12	151	125	0.098	40.4	3.97	0.055	6.99	199	14.30
		Standard Dev.	1.52	7	10	0.005	12.4	1.30	0.034	0.31	61	0.06
		Coeff. Of Variation	9%	5%	8%	5%	**31%**	**33%**	**62%**	4%	**31%**	0%
Southwestern roadside ditch draining into Oakley Creek	**ODS1**	10-Aug-08	20.09	243	220	0.158	96.5	8.76	0.005	6.66	221	14.34
	ODS1	12-Aug-08	17.42	241	207	0.157	81.7	7.82	0.005	7.14	300	14.17
	ODS1	13-Aug-08	16.74	238	200	0.155	83.1	8.07	0.040	7.30	250	14.23
	ODS1	14-Aug-08	22.23	252	239	0.164	85.5	7.45	0.060	6.93	194	14.38
	ODS1	15-Aug-08	23.25	250	237	0.163	86.7	7.40	0.033	7.05	242	14.33
	ODS1	16-Aug-08	23.16	253	244	0.165	88.4	7.56	0.018	7.37	214	14.27
		Average	20.48	246	224	0.160	87.0	7.84	0.027	7.07	237	14.29
		Standard Dev.	2.88	6	18	0.004	5.3	0.52	0.022	0.26	37	0.08
		Coeff. Of Variation	14%	3%	8%	3%	6%	7%	**81%**	4%	**16%**	1%

Note: ***16%*** Coefficients of variation greater than 15% are highlighted in bold and red.

Figure 7.6-17 illustrates the measurements for ORP and DO for the surface water monitoring locations tested. Although a response to the groundwater pump test is not discernible in the water quality results, what is noticable is that the lowest dissolved oxygen and Oxidation-Reduction Potentials were measured at OD1, OD2, and MD1 in the 4.5-8.4 m wide roadside ditches that were dug as part of the Highway #6 maintenance program. At OD1, OD2 and MD1, the DO levels were below the Tier II Manitoba guideline value of 5.5 mg/L on several occasions. In comparison, much higher dissolved oxygen concentrations and ORP values were measured at the natural Oakley Creek station OCW1 and the much narrower, incised roadside ditch location ODS1. The DO concentration ranged from 7.2 to 9.4 mg/L at OCW1 and from 7.4 to 8.8 mg/L at ODS1.

In summary, the August 2008 groundwater pump test did not have a significant effect on surface waters in the vicinity of the Minago Project as shown in Figures 7.6-14 to 7.6-16.

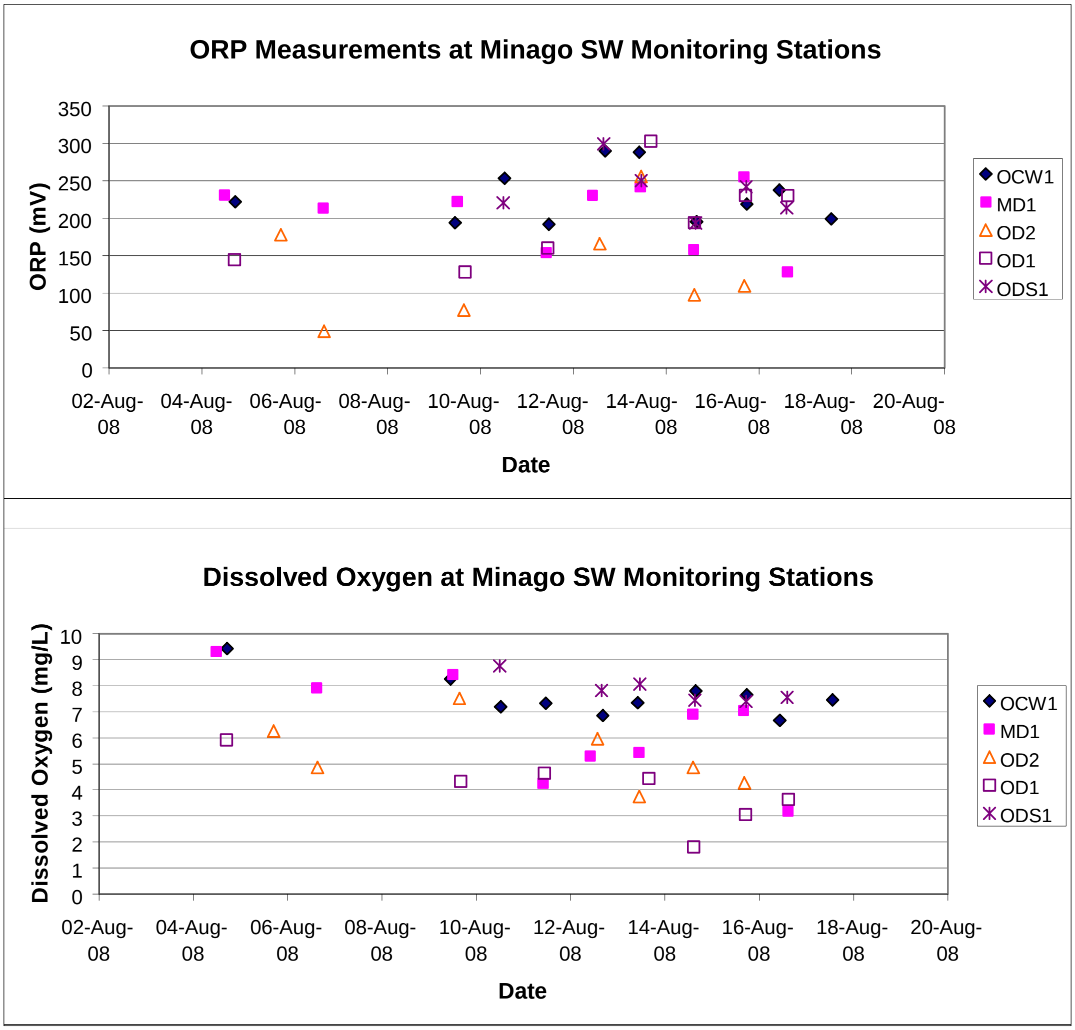


Figure 7.6-17 August 2008 Surface Water Quality Results

7.6.3.13 Summary of Pumping Test Results

A summary of the hydrogeological parameters considered representative for each of the four main hydrostratigraphic units at the Site is presented in Table 7.6-7. These values are based on the results of the pumping test and single-well response tests and also consider the conceptual hydrogeological model of the Site. In addition, the results of the pumping test program indicate the following (Golder Associates, 2008b):

1. The influence of significant hydrogeologic (recharge or zero-flux) boundaries were not identified in the hydraulic response to pumping during the pumping test program. This is likely because of the distance to the nearest surface water body in contact with the limestone aquifer (*i.e.,* the Minago River is approximately 10 km from the dewatering wells) and the limited duration of the pumping test. Oakley Creek, located approximately 1 km south of the dewatering wells is likely not in direct contact with the limestone aquifer (*i.e.,* its bed lies in the overburden); therefore, it was not observed to act as a significant hydrogeologic boundary.
2. Limestone outcrops 2 km northwest and 9 km south of the Site are likely areas where recharge to the limestone aquifer occurs through net infiltration of precipitation.
3. The overburden was not significantly affected by pumping during the pumping test, except in the near vicinity (approximately 30 m) of the North Pit Wall zone (HG-7).

7.6.4 Conceptual Model of the Groundwater Flow at Minago

Based on the regional hydrogeological setting, the well logs, and the hydraulic response to pumping, a conceptual model was developed for groundwater flow in the upper 75 m of the subsurface at the Site. The limestone aquifer forms the main aquifer at the Site. The limestone aquifer is confined by the overburden clay deposit: a 5 m-thick aquitard. The upper 20 to 30 m of the limestone unit is more permeable than the deeper limestone, particularly in the North Pit Wall region. The ambient groundwater flow direction in the limestone is from west to east. During pumping, the water level in the limestone was lowered below the top of the limestone (*i.e.,* below the bottom of the overburden unit) within about 100 m of the dewatering wells, under the pumping rates of the pumping test. In these regions, the limestone aquifer becomes unconfined, and groundwater is released through aquifer drainage. Some amount of leakage from the overburden aquitard into the limestone aquifer occurs, providing some additional flow to the dewatering wells. The sandstone aquifer is affected by pumping in the limestone, and experiences greater drawdown than in the limestone because of its comparatively lower hydraulic conductivity. The weathered granite that is in direct contact with the sandstone aquifer is likely more permeable than the underlying non-weathered granite. The non-weathered granite likely acts as a lower confining unit, or an aquitard, that provides minimal leakage to the sandstone unit, possibly through vertical fractures.

Table 7.6-7 Summary of Hydrogeologic Parameters

Hydrogeologic Unit	Overburden (OB)	Shallow Limestone (SLS)		Deeper Limestone (LS)			Sandstone (SS)	Weathered Granite (GR)
Zone	all	North Pit Wall	South Pit Wall	North Pit Wall	South Pit Wall	2 km from Pit	near Pit	near Pit
Depth to the Top of Unit (m)	0	5.9	5.7	5.9	5.7	8.4	59	70.4
Unit Thickness (m)	7	33	21	20	32	30	11.4	10
T (m^2/s)	n/a	1.E-02	2.E-03	5.E-03	1.E-03	4.5E-03		n/a
S (-)	n/a	2.E-05	3.E-03	2.E-04	1.E-04	1.0E-03		n/a
K (m/s) *	K_H = 4E-8 ; K_V = 5E-9	3.E-04	1.E-04	2.E-04	4.E-05	1.5E-04		1.E-08
S_s (m^{-1})		7.E-07	1.E-04	8.E-06	4.E-06	3.3E-05		7.E-06
S_y (-)		0.01		0.02				

Notes:

*Hydraulic conductivity (K) assumed to be isotropic unless horizontal (K_H) and vertical (K_V) hydraulic conductivity is presented.

Source: Golder Associates (2008b)

7.6.5 Numerical Groundwater Model

The conceptual hydrogeologic model presented in the previous section was used as a basis for the construction of a numerical hydrogeologic model for the site. Following calibration, this model was used to predict the dewatering requirements for limestone and sandstone units that will be intersected by the proposed open pit. Details of model construction (model code selection, model mesh, boundary conditions) and calibration are given in Golder Associates (2008b) (Appendix 7.6).

7.6.6 Dewatering System Design

The calibrated groundwater model was used to simulate the pumping wells that will be necessary for dewatering of the limestone and sandstone units. The results were used to estimate the number, location, and pumping rates for these wells, and the total pumping rate for the entire wellfield. Based on this analysis, typical well installation schematics were developed, and recommendations were provided with respect to the observation well network that will be required to monitoring dewatering progress during mine pit development.

7.6.7 Mine Dewatering Predictions and Uncertainty

Prior to the full-scale dewatering simulations, preliminary model simulations were conducted to assess the approximate amount of time required for the dewatering to occur once pumping is started. These preliminary simulations, together with the observations gathered during the 5-day pumping test, suggested that limestone dewatering is relatively rapid and that the cone of depression created by dewatering would reach a near-steady state configuration within several months after the full dewatering system is implemented. This relatively rapid response to pumping is primarily related to the low storage and high transmissive properties of the limestone unit. Consequently, it was decided that the model simulations representing the full-scale dewatering system could be conducted in steady-state without considering groundwater storage effects.

Several model runs were completed where the location and number of dewatering wells were varied in an attempt to essentially dewater the limestone unit within the pit area and depressurize the underlying sandstone unit. It is not practical to attempt full dewatering of the sandstone unit as it is of a lower permeability when compared to limestone; therefore it would receive steady recharge from above. Nevertheless, depressurization of the sandstone unit is considered to be sufficient because, due to its relatively low hydraulic conductivity it is not considered to be able to provide significant inflows to the pit. Instead, any localized and minor inflows from sandstone could be mitigated using sub-horizontal drainholes installed from the pit benches.

The dewatering wells considered in the analysis were simulated using specified head boundaries, constrained to allow outflow of groundwater only, that were assigned in model layers representing the limestone and sandstone. It was assumed that pumping from these wells would lower the water level in each well below the limestone/sandstone contact. With drawdown at each pumping well fixed, the model calculated the pumping rate at each well thus allowing rapid evaluation of various dewatering options without constant rate adjustments.

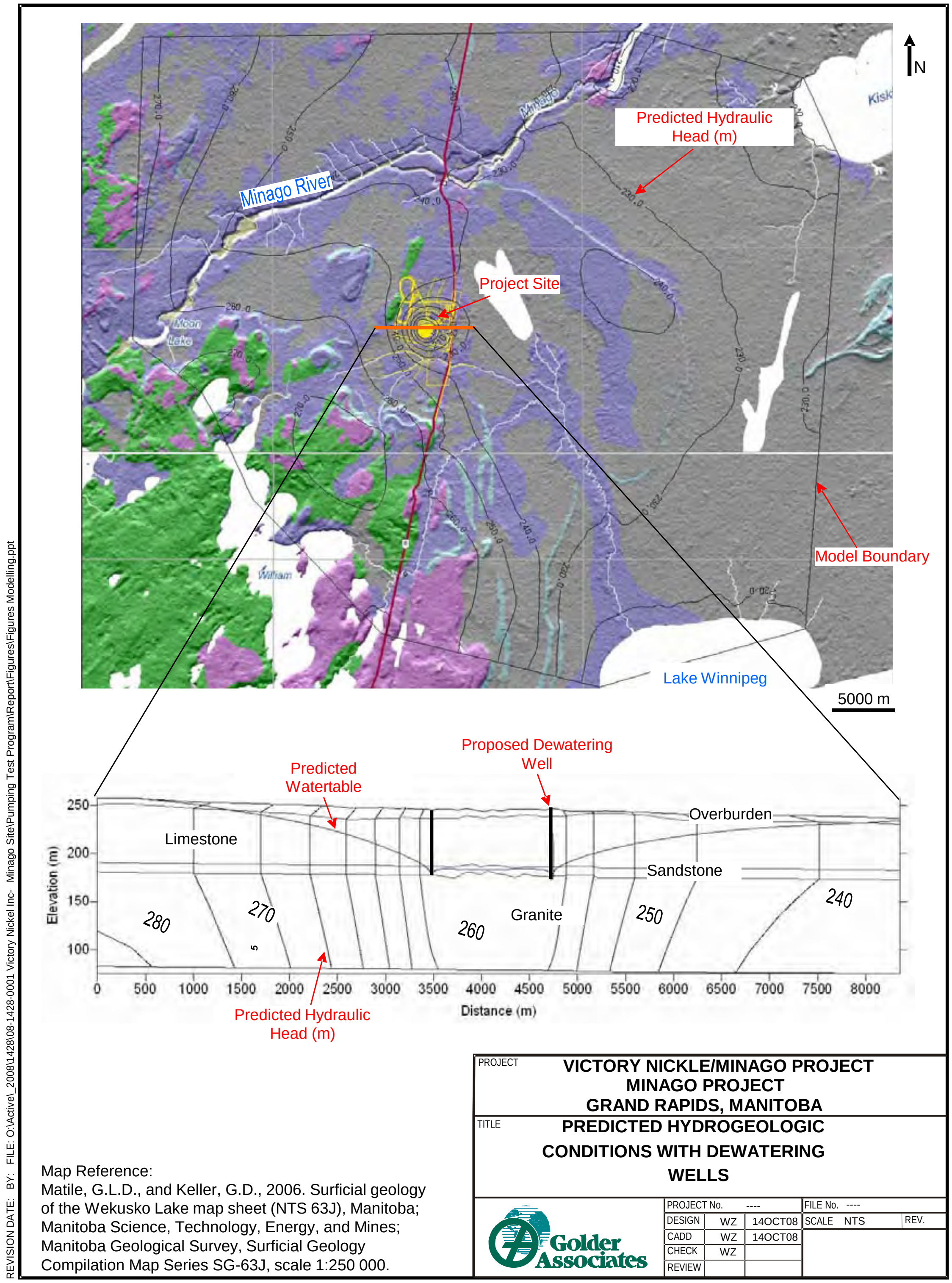
Figure 7.6-18 and Figure 7.6-19 present the hydrogeologic conditions predicted for a wellfield that provided the required dewatering of the limestone unit without excessive pumping and/or number of pumping wells. The design consists of 12 dewatering wells located at a distance of approximately 300 m to 400 m along the crest of the ultimate pit, and pumping simultaneously from the limestone and sandstone units. The total pumping rate for the wellfield is predicted to be approximately 40,000 m^3/day (7,300 IN summary, the August 2008), and the average pumping rate for an individual well is estimated at about 3,300 m^3/day (600 USgpm). As presented on Figure 7.6-18, pumping at these rates is sufficient to lower the water table to near the limestone and sandstone contact. The associated drawdown cone (Figure 7.6-19), defined using a 1 m drawdown contour, is predicted to extend laterally in the limestone to a distance of approximately 5,000 m to 6,000 m from the proposed open pit.

Although the groundwater model was developed using a comprehensive hydrogeologic dataset, and was successfully calibrated to the pre-pumping conditions and pumping test, uncertainty exists with respect to the predicted dewatering rates. This uncertainty is inherent in any hydrogeologic assessment, as it is simply not practical to drill boreholes at dense enough spacing that would allow identification and testing of all heterogeneities, discontinuities, etc. To address this uncertainty, a series of sensitivity analyses were conducted such that selected model parameters were varied over their uncertainty ranges, and their influence on the predicted dewatering rates was assessed. These parameters included the hydraulic conductivity of the limestone unit, the hydraulic conductivity of the overburden, and the recharge rate. During calibration, other model parameters were found to have a relatively small influence on model predictions. The results of this analysis suggest that the actual dewatering rate for the entire wellfield could vary from 25,000 m^3/day (4,600 USgpm) to 90,000 m^3/day (16,500 USgpm).

7.6.8 Dewatering Wells Construction

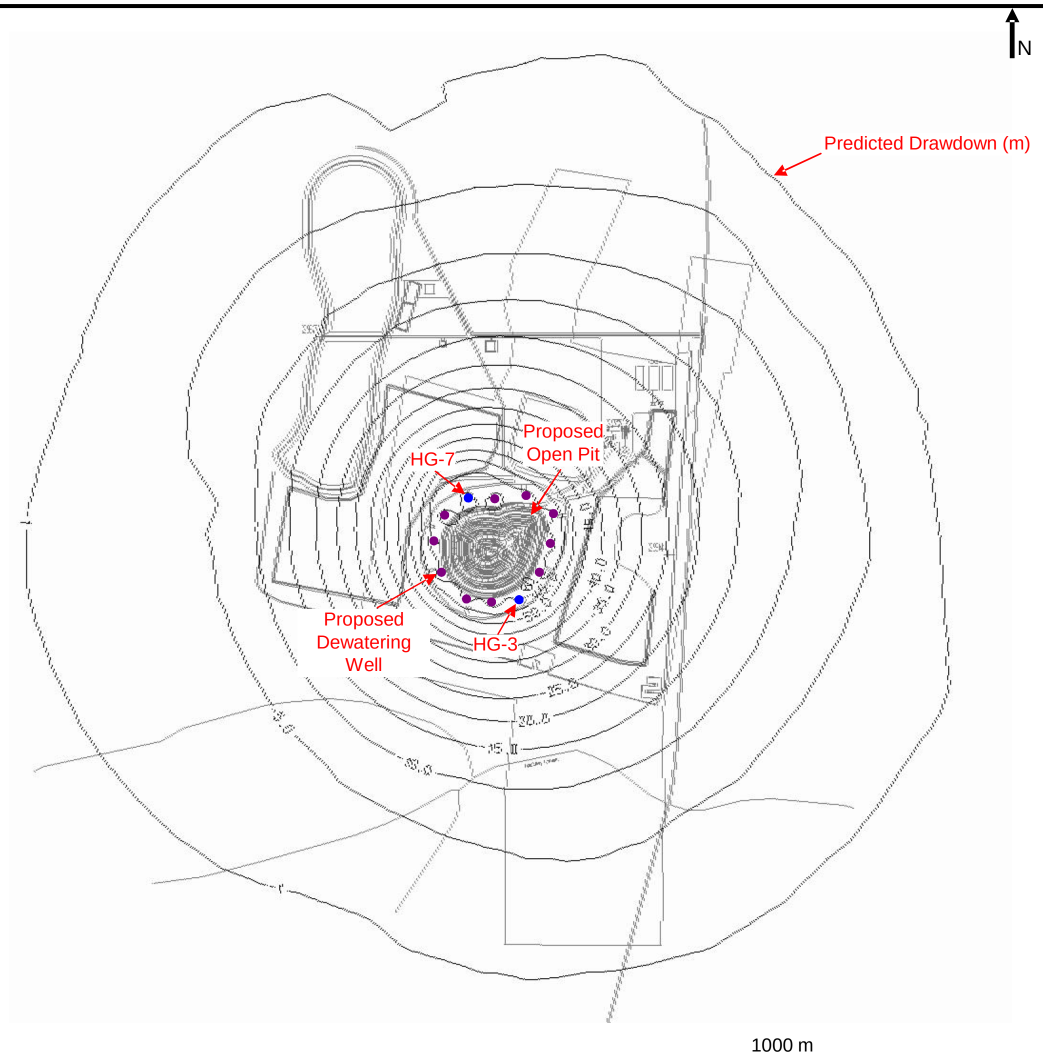
The recommended dewatering well design includes the following (Figure 7.6-20):

- Each well will be drilled 10 m into the weathered granite unit;
- A sump will be placed in the bottom 5 m of the well;
- A well screen will be placed above the sump such that it is completed in at least 5 m of limestone;
- The well casing in the limestone will be slotted throughout most of its length;
- The well annulus in the limestone will be filled with gravel to allow free downward drainage; and,
- The pump will be installed in the sump in the bottom 5 m of each well.



Source: Golder Associates, 2008b

Figure 7.6-18 Predicted Hydrogeological Conditions with Dewatering Wells



PROJECT	VICTORY NICKLE/MINAGO PROJECT MINAGO PROJECT GRAND RAPIDS, MANITOBA
TITLE	PREDICTED DRAWDOWN CONE IN THE LIMESTONE UNIT

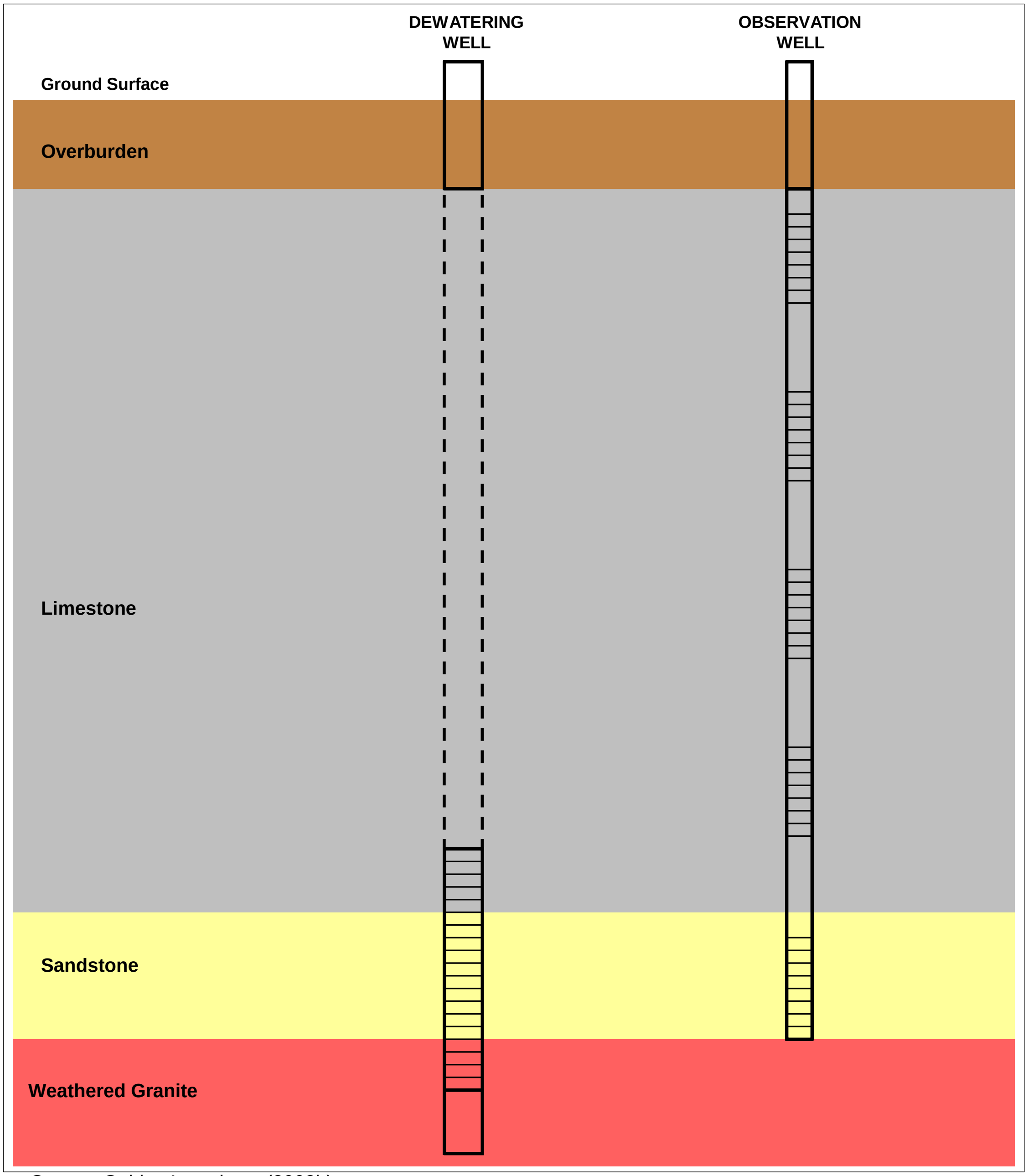
Golder Associates				
PROJECT No.	----		FILE No. ----	
DESIGN	WZ	14OCT08	SCALE NTS	REV.
CADD	WZ	14OCT08		
CHECK	WZ			
REVIEW				

Map Reference:
Wardrop file *change dump and tailings.dwg*

Source: Golder Associates, 2008b

Figure 7.6-19 Predicted Drawdown Cone in the Limestone Unit

Note: Drawdown cone is predicted to extend laterally in the limestone to a distance of approximately 5,000 m to 6,000 m from the proposed open pit.



Source: Golder Associates (2008b)

Figure 7.6-20 Schematic for Proposed Dewatering Wells and Observation Wells

The above design will allow well pumping to the extent that drawdown in the well will be near the bottom of the screen. This would effectively create a seepage face in the well screen/slotted casing that intersects the sandstone–limestone contact. A schematic of the recommended well design is presented in Figure 7.6-20.

7.6.8.1 Monitoring Network

A minimum of one standpipe piezometer will be required for up to two pumping wells, for a total of six standpipe piezometers. These piezometers would be screened throughout the entire thickness of limestone and sandstone for the purpose of monitoring the water table position during dewatering. A schematic of the recommended observation well design is presented in Figure 7.6-20.

7.6.9 Summary and Conclusions

The primary focus of the hydrogeological study was to estimate the configuration of the dewatering well system required for the operation of the proposed mine pit; to estimate the total required pumping rate for dewatering; and to estimate the extent of the drawdown cone created during open pit mining. The hydrogeological study concluded that a total of 12 dewatering wells completed in both the limestone and sandstone aquifers, at distances of approximately 300 m to 400 m along the crest of the ultimate pit, will be required to operate simultaneously (Golder Associates, 2008b). The total quantity of groundwater likely to be generated by these wells is 40,000 m^3/day (7,300 USgpm). The average pumping rate for an individual well is estimated to be 3,300 m^3/day (600 USgpm) (Golder Associates, 2008b).

7.6.10 Groundwater Quality

To date, several groundwater samples have been collected from the Minago Property. Groundwater samples were collected as part of the initial hydrogeological program in 2007, after the installation of pumping wells in March 2008, and at the end of the long-term pump test in August 2008. All groundwater samples were collected in a representative manner and according to standard groundwater sampling protocols to minimize sample contamination. For example, a groundwater sample was collected from each of the four dewatering wells on August 15, 2008, the fifth day of the pumping test. Duplicate samples were taken from HG-7-LS and HG-3-SS for quality assurance/quality control (QA/QC) purposes. The samples were collected using an in-line sampling port constructed in the well head assembly. Samples were preserved as necessary and stored at approximately 4ºC until delivered to the laboratory (ALS Laboratory Group) in Vancouver, British Columbia (Golder Associates, 2008b). The samples were analyzed for major anions, nutrients, cyanide, total organic carbon and total metals.

7.6.10.1 Water Quality Guidelines

Relevant water quality guidelines for the environmental assessment for the Minago Project are covered in a separate section on Surface Water Quality (Section 7.5). In this document, water quality results were compared to the Final Draft Manitoba Water Quality Standards, Objectives and Guidelines (Williamson, 2002) and the Canadian Council of Ministers of the Environment (CCME) Guidelines for the Protection of Aquatic Life (CCME, 2007). The Tier III Water Quality Guidelines contain guidelines developed by the federal Canadian Council of Ministers of the Environment (CCME). These guidelines were developed to ensure that the most sensitive species in the aquatic receiving environment are protected at all times along with an adequate margin of safety. Summaries of Minago groundwater water quality results also list guideline limits for the 2002 *Metal Mining Effluent Regulations* (MMER).

7.6.10.2 Summary of Groundwater Results

Table 7.6-8 summarizes the groundwater quality in the limestone and sandstone formations below the Minago Property. Table 7.6-8 lists the average, maximum and minimum concentrations measured in the limestone and sandstone. A complete summary of groundwater water quality results is presented in Appendix 7.6 and laboratory certified reports are given in Appendix L7.6.

Table 7.6-8 Summary of Groundwater Quality in Limestone and Sandstone (This page: Total Concentrations)

PARAMETER	Units	LIMESTONE AVERAGE [1] Mar-2007 & Aug-2008	LIMESTONE MAXIMUM [1] Mar-2007 & Aug-2008	LIMESTONE MINIMUM [1] Mar-2007 & Aug-2008	SANDSTONE AVERAGE [1] Mar-2007 & Aug-2008	SANDSTONE MAXIMUM [1] Mar-2007 & Aug-2008	SANDSTONE MINIIMUM [1] Mar-2007 & Aug-2008	REGULATIONS: Manitoba Water Quality Standards, Objectives, and Guidelines (Williamson, 2002) – TIER II Water Quality Objectives	Manitoba – TIER III - Water Quality Guidelines – Drinking – MAC	Manitoba – TIER III – Drinking – IMAC	Manitoba – TIER III – Freshwater	Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2007)	Metal Mining Liquid Effluents (2002) – Monthly Mean	Metal Mining Liquid Effluents (2002) – Grab Sample
Physical Tests														
Dissolved Hardness (CaCO3)	mg/L	291	297	285	286	287	285							
Hardness (as CaCO3)	mg/L	283	307	242	235	294	165							
Conductivity	µS/cm	643	682	606	673	688	633	1000						
pH	pH Units	8.12	8.2	8.04	8.12	8.18	8.05					6.5-9	6-9.5	6-9.5
Total Metals														
Aluminum (Al)-Total	mg/L	0.060	**<u>0.108</u>**	0.035	0.0231	0.0261	0.0215				0.005 - 0.1	0.005 - 0.1		
Antimony (Sb)-Total	mg/L	0.000025	0.000025	0.000025	0.000025	0.000025	0.000025			0.006				
Arsenic (As)-Total	mg/L	0.00247	0.00294	0.00218	0.00025	0.00028	0.00021			0.025	0.15 mg/L (4-Day, 3-Year) [A]	0.005[k]	0.5	1
Barium (Ba)-Total	mg/L	0.0733	0.076	0.0694	0.050	0.061	0.0445		1					
Beryllium (Be)-Total	mg/L	0.0001	0.0001	0.0001	0.0001	0.0001	0.0001							
Bismuth (Bi)-Total	mg/L	0.00025	0.00025	0.00025	0.00025	0.00025	0.00025							
Boron (B)-Total	mg/L	0.128	0.177	0.096	0.330	0.401	0.197			5				
Cadmium (Cd)-Total	mg/L	0.0000057	0.0000057	0.0000057	0.0000057	0.0000057	0.0000057		0.005			0.000017[c,l]		
Calcium (Ca)-Total	mg/L	55.0	59.7	45.7	45.7	56.8	31.6							
Chromium (Cr)-Total	mg/L	0.001	0.001	0.001	0.001	0.001	0.001		0.05					
Trivalent Chromium (Cr-III)	mg/L											0.0089[c,k]		
Hexavalent Chromium (Cr-VI)	mg/L											0.001[k]		
Cobalt (Co)-Total	mg/L	0.00028	0.00029	0.00027	0.00010	0.00019	0.00005							
Copper (Cu)-Total	mg/L	0.00077	0.00078	0.00077	0.00025	0.00029	0.00022					0.002-0.004[m]	0.3	0.6
Iron (Fe)-Total	mg/L	**<u>0.48</u>**	**<u>0.73</u>**	**<u>0.34</u>**	0.16	0.17	0.13				0.3	0.3[d]		
Lead (Pb)-Total	mg/L	0.00044	0.000493	0.000389	0.00046	0.00073	0.00030		0.01			0.001-0.007[o]	0.2	0.4
Lithium (Li)-Total	mg/L	0.0204	0.0279	0.0156	0.0396	0.0455	0.0286							
Magnesium (Mg)- Total	mg/L	35.4	38.4	31.1	29.4	37.1	21							
Manganese (Mn)-Total	mg/L	0.00930	0.00997	0.00882	0.00957	0.01200	0.00833							
Mercury (Hg)-Total	mg/L	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005		0.001		0.0001			
Inorganic Mercury	mg/L											0.000026		
Methylmercury	mg/L											0.000004[c,w]		
Molybdenum (Mo)-Total	mg/L	0.0005	0.0005	0.000393	0.0011	0.0011	0.00112				0.073			
Nickel (Ni)-Total	mg/L	0.0011	0.0012	0.00094	0.0004	0.0010	0.00013					0.025-0.15[p]	0.5	1
Phosphorus (P)-Total	mg/L	0.15	0.15	0.15	0.15	0.15	0.15					narrative [x]		
Potassium (K)-Total	mg/L	5.54	7.9	4.27	8.12	9.39	5.74							
Selenium (Se)-Total	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005		0.01		0.001	0.001[d]		
Silicon (Si)-Total	mg/L	4.87	5.06	4.76	4.03	4.06	4.01							
Silver (Ag)-Total	mg/L	0.000005	0.000005	0.000005	0.000005	0.000005	0.000005				0.0001	0.0001[d]		
Sodium (Na)-Total	mg/L	24.3	32.2	20.2	66.9	83.4	34							
Strontium (Sr)-Total	mg/L	0.233	0.262	0.218	0.353	0.372	0.314		5 Bq/L					
Thallium (Tl)-Total	mg/L	0.000025	0.000025	0.000025	0.000025	0.000025	0.000025				0.0008	0.0008[j]		
Tin (Sn)-Total	mg/L	0.00005	0.00005	0.00005	0.00005	0.00005	0.00005							
Titanium (Ti)-Total	mg/L	0.007	0.011	0.005	0.005	0.005	0.005							
Uranium (U)-Total	mg/L	0.00049	0.000624	0.000276	0.00047	0.00105	0.000183			0.02				
Vanadium (V)-Total	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005							
Zinc (Zn)-Total	mg/L	0.002	0.002	0.002	**<u>0.042</u>**	**<u>0.073</u>**	0.004					0.03[d]	0.5	1

Notes:

1 If a reported concentration was below the detection limit, half the detection limit was used for the calculations.

MAC - Maximum Acceptable Concentration

<u>0.073</u> BOLD AND UNDERLINED VALUE EXCEEDS GUIDELINE LIMIT.

IMAC - Interim Maximum Acceptable Concentration

References:

Williamson, D. 2002. Manitoba Water Quality Standards, Objectives, and Guidelines. Manitoba Conservation Report 2002-11, Water Quality Management Section, Water Branch, Manitoba Conservation, Winnipeg, MB.

Table 7.6-8 (Cont.'d) Summary of Groundwater Quality in Limestone and Sandstone (This page: Dissolved Concentrations)

PARAMETER	Units	LIMESTONE AVERAGE [1] Mar-2007 & Aug-2008	LIMESTONE MAXIMUM [1] Mar-2007 & Aug-2008	LIMESTONE MINIMUM [1] Mar-2007 & Aug-2008	SANDSTONE AVERAGE [1] Mar-2007 & Aug-2008	SANDSTONE MAXIMUM [1] Mar-2007 & Aug-2008	SANDSTONE MINIIMUM [1] Mar-2007 & Aug-2008	REGULATIONS: Manitoba Water Quality Standards, Objectives, and Guidelines (Williamson, 2002) — TIER II Water Quality Objectives	TIER III - Water Quality Guidelines — Drinking MAC	TIER III — Drinking IMAC	TIER III — Freshwater
Physical Tests											
Dissolved Hardness (CaCO3)	mg/L	291	297	285	286	287	285				
Hardness (as CaCO3)	mg/L	283	307	242	235	294	165				
Dissolved Elements											
Aluminum (Al)-Dissolved	mg/L	0.00397	0.0215	0.0001	0.00722	0.0344	0.0005				0.005 - 0.1
Antimony (Sb)-Dissolved	mg/L	0.00020	0.00045	0.000025	0.000179	0.0006	0.000025			0.006	
Arsenic (As)-Dissolved	mg/L	0.00088	0.00122	0.0003	0.0006214	0.0021	0.000162	0.15 mg/L (4-Day, 3-Year) [A]		0.025	Tier II
Barium (Ba)-Dissolved	mg/L	0.0816	0.1110	0.0542	0.0634	0.0839	0.0473		1		
Beryllium (Be)-Dissolved	mg/L	0.00006	0.00010	0.00003	0.00007	0.0001	0.000025				
Bismuth (Bi)-Dissolved	mg/L	0.00014	0.00025	0.00003	0.00016	0.00025	0.000025				
Boron (B)-Dissolved	mg/L	0.1511	0.199	0.0986	0.2572	0.361	0.171			5	
Cadmium (Cd)-Dissolved	mg/L	0.00002	0.00003	0.0000057	0.00001	0.00002	0.000005	Hardness dependent [B] (e.g. 0.00163 mg/L chronic; 0.00267 mg/L acute at hardness 65 mg/L $CaCO_3$)	0.005		Tier II
Calcium (Ca)-Dissolved	mg/L	48.3	56.7	23.9	44.4	55.1	30.4				
Cesium (Cs) - Dissolved	mg/L	0.00002	0.00003	0.000015	0.000015	0.000015	0.000015				
Chromium (Cr)-Dissolved	mg/L	0.00046	0.001	0.0001	0.000638	0.00107	0.0001	Hardness dependent [C] (e.g.,0.052 mg/L Cr-III chronic at hardness 65 mg/L; 0.011 mg/L Cr-VI 4-Day, 3-Year)	0.05		Tier II
Cobalt (Co)-Dissolved	mg/L	0.00041	0.00078	0.00005	0.00019	0.00036	0.00005				
Copper (Cu)-Dissolved	mg/L	0.000315	0.00092	0.00005	0.00024	0.00055	0.00005	Hardness dependent [D] (e.g.,0.0062 mg/L chronic at hardness 65 mg/L $CaCO_3$)			Tier II
Iron (Fe)-Dissolved	mg/L	0.018	0.049	0.005	0.0386	0.093	0.005				0.3
Lead (Pb)-Dissolved	mg/L	0.00091	0.00378	0.00001	0.0000408	0.000074	0.000025	Hardness dependent [E] (e.g., 0.00157 mg/L chronic at hardness 65 mg/L $CaCO_3$)	0.01		Tier II
Lithium (Li)-Dissolved	mg/L	0.0232	0.0299	0.0157	0.03316	0.0413	0.0265				
Magnesium (Mg)-Dissolved	mg/L	34.7	37.6	31.7	28.4	36.3	19.9				
Manganese (Mn)-Dissolved	mg/L	0.0375	0.0824	0.000318	0.02879	0.09650	0.00734				
Mercury (Hg)-Dissolved	mg/L	0.000015	0.000025	0.000005	0.00001	0.00003	0.00001		0.001		0.0001
Molybdenum (Mo)-Dissolved	mg/L	0.001512	0.003200	0.000418	0.00142	0.00242	0.00108				0.073
Nickel (Ni)-Dissolved	mg/L	0.00145	0.00230	0.00075	0.00110	0.00200	0.00005	Hardness dependent [F] (e.g., 0.036 mg/L chronic at hardness 65 mg/L $CaCO_3$)			Tier II
Phosphorus (P)-Dissolved	mg/L	0.1	0.15	0.05	0.11	0.15	0.05				
Phosphorus (P) - Dissolved by SM 4500 PF Method	mg/L	0.009	0.018	0.005	0.007	0.01	0.004				
Potassium (K)-Dissolved	mg/L	5.90	8.03	4.18	7.138	9.17	5.48				
Rubidium (Rb) - Dissolved	mg/L	0.00267	0.00293	0.00252	0.00266	0.00285	0.00246				
Selenium (Se)-Dissolved	mg/L	0.0002	0.0005	0.0001	0.00016	0.00025	0.00005		0.01		0.001
Silicon (Si)-Dissolved	mg/L	5.09	5.24	4.97	4.71	5.73	4.24				
Silver (Ag)-Dissolved	mg/L	0.0000075	0.00002	0.000005	0.00001	0.00004	0.000005				0.0001
Sodium (Na)-Dissolved	mg/L	29.9	38.7	20.6	58.0	86.9	34.4				
Strontium (Sr)-Dissolved	mg/L	0.274	0.328	0.191	0.3478	0.386	0.316		5 Bq/L		
Sulphur (S) - Dissolved	mg/L	5.1	5.8	4.7	5.15	5.3	5				
Tellurium (Te) - Dissolved	mg/L	0.0005	0.0005	0.0005	0.0005	0.0005	0.0005				
Thallium (Tl)-Dissolved	mg/L	0.000025	0.000025	0.000025	0.000025	0.000025	0.000025				0.0008
Tin (Sn)-Dissolved	mg/L	0.0000375	0.00005	0.000025	0.00005	0.00005	0.00005				
Titanium (Ti)-Dissolved	mg/L	0.002625	0.005	0.00025	0.0031	0.005	0.00025				
Tungsten (W) - Dissolved	mg/L	0.00159	0.00217	0.00122	0.00122	0.00129	0.00115				
Uranium (U)-Dissolved	mg/L	0.00048	0.000591	0.000279	0.000436	0.000996	0.000166			0.02	
Vanadium (V)-Dissolved	mg/L	0.000263	0.0005	0.000025	0.00013	0.00050	0.00003				
Zinc (Zn)-Dissolved	mg/L	**0.3092**	**0.6490**	0.0005	**0.52**	**2.54**	0.004	Hardness dependent [G] (e.g., 0.082 mg/L chronic at hardness 65 mg/L $CaCO_3$)			Tier II
Zirconium (Zr) - Dissolved	mg/L	0.0025	0.0025	0.0025	0.0025	0.0025	0.0025				

Notes:

1 If a reported concentration was below the detection limit, half the detection limit was used for the calculations.

MAC - Maximum Acceptable Concentration

IMAC - Interim Maximum Acceptable Concentration

2.54 BOLD AND UNDERLINED VALUE EXCEEDS GUIDELINE LIMIT.

References:

Williamson, D. 2002. Manitoba Water Quality Standards, Objectives, and Guidelines. Manitoba Conservation Report 2002-11, Water Quality Management Sect., Water Br., Manitoba Conservation, Winnipeg, MB.

Table 7.6-8 (Cont.'d) Summary of Groundwater Quality in Limestone and Sandstone (This page: Other Parameters)

PARAMETER	Units	LIMESTONE AVERAGE [1] Mar-2007 & Aug-2008	LIMESTONE MAXIMUM [1] Mar-2007 & Aug-2008	LIMESTONE MINIMUM [1] Mar-2007 & Aug-2008	SANDSTONE AVERAGE [1] Mar-2007 & Aug-2008	SANDSTONE MAXIMUM [1] Mar-2007 & Aug-2008	SANDSTONE MINIIMUM [1] Mar-2007 & Aug-2008	REGULATIONS: Manitoba Water Quality Standards, Objectives, and Guidelines (Williamson, 2002) – TIER II Water Quality Objectives	Manitoba – TIER III - Water Quality Guidelines – Drinking – MAC	Manitoba – TIER III – Drinking – IMAC	Manitoba – TIER III – Freshwater	Canadian Water Quality Guidelines for the Protection of Aquatic Life (CCME, 2007)	Metal Mining Liquid Effluents (2002) – Monthly Mean	Metal Mining Liquid Effluents (2002) – Grab Sample
Field-Measured Parameters														
Conductivity	µS/cm	448	451	443	486	504	451.0	1000						
Dissolved Oxygen	mg/L	6.2	8.0	**2.5**	**2.3**	**3**	**2**	varies with life-stages & temperature; 6.5 mg/L (30-Day, 3-Year if temp. > 5°C); Instantaneous Minimum 5 mg/L (if T>5°C)						
Iron II	mg/L	**0.4**	**0.6**	0.3	0.27	0.3	0.2				0.3	0.3[d]		
pH	pH units	7.46	7.49	7.44	7.56	7.61	7.47					6.5-9		
Redox	mV	44.3	51	31	46.3	51.0	37.0							
Temperature	°C	5.9	6.1	5.5	6.5	7.0	6.2							
Physical Tests														
Dissolved Hardness (CaCO3)	mg/L	291	297	285	286	287	285							
Hardness (as CaCO3)	mg/L	283	307	242	235	294	165							
Conductivity	µS/cm	643	682	606	673	688	633	1000						
pH	pH Units	8.12	8.2	8.04	8.12	8.18	8.05					6.5-9	6-9.5	6-9.5
Total Dissolved Solids	mg/L	344	372	284	369.4	390	351	700						
Total Suspended Solids		4.7	7.9	1.5	1.5	1.5	1.5	Dependent on background TSS (5 mg/L (30-Day, 3 Year) or 25 mg/L (1-Day, 3-Year) or 10% (1-Day, 3-Year) of induced change from background)			Tier II	narrative	15	30
Turbidity (NTU)	NTU	**33.7**	**69.8**	**4.82**	**21.0**	**77.6**	**1.02**		1.0		Tier II	narrative		
Colour, True		6.4	7.9	5.6	5.1	5.1	5.1							
Anions and Nutrients														
Ammonia as N	mg/L	0.089	0.143	0.058	0.151	0.265	0.080	pH and temperature dependent (lowest concentration for all categories = 1.17 mg/L for pH 7.8)			Tier II	see factsheet		
Alkalinity, Total (as CaCO3)	mg/L	323	342	300	319	344	294							
Alkalinity (PP as CaCO3)	mg/L	0.25	0.25	0.25	0.25	0.25	0.25							
Bicarbonate (HCO3)	mg/L	415	418	410	417	420	414							
Alkalinity, Carbonate (as CaCO3)	mg/L	0.25	0.25	0.25	0.25	0.25	0.25							
Alkalinity, Hydroxide (as CaCO3)	mg/L	0.25	0.25	0.25	0.25	0.25	0.25							
Chloride (Cl)	mg/L	12.9	17.8	9.8	19.2	23.9	14.2							
Fluoride (F)	mg/L	**0.32**	**0.41**	**0.244**	**0.50**	**0.70**	**0.36**		1.5			0.12[c]		
Sulfate (SO4)	mg/L	13.7	16.4	11.7	21.2	27.7	14.3							
Nitrate (as N)	mg/L	0.0039	0.008	0.0025	0.0023	0.003	0.0025		10			2.93 [c,u]		
Nitrite (as N)	mg/L	0.0023	0.005	0.0005	0.0011	0.003	0.0005		0.97		CCME	0.06 [z]		
Nitrate plus Nitrite (as N)	mg/L	0.009	0.013	0.005	0.002	0.003	0.003	10						
Total Kjeldahl Nitrogen	mg/L	0.190	0.270	0.094	0.198	0.230	0.139							
Total Nitrogen	mg/L	0.273	0.280	0.270	0.220	0.230	0.230							
Calcium (Ca)-Total	mg/L	58.1	59.7	55.7	56.8	56.8	56.8							
Magnesium (Mg)-Total	mg/L	37.5	38.4	35.9	37.0	37.1	36.8							
Radiological Parameters														
Radium-226	Bq/L	0.07	0.11	0.04	0.015	0.02	0.01		0.6				0.37	1.11
XNo class														
Total Organic Carbon		2.50	3.11	2.19	0.93	1.17	0.81							
Cyanides														
Cyanide, Weak Acid Diss		0.0025	0.0025	0.0025	0.0025	0.0025	0.0025	0.0052 mg/L (4-Day, 3-Year)			Tier II	0.005 (as free CN)		

Notes:

1 If a reported concentration was below the detection limit, half the detection limit was used for the calculations

MAC - Maximum Acceptable Concentration

IMAC - Interim Maximum Acceptable Concentration

77.6 BOLD AND UNDERLINED VALUE EXCEEDS GUIDELINE LIMIT.

References:

Williamson, D. 2002. Manitoba Water Quality Standards, Objectives, and Guidelines. Manitoba Conservation Report 2002-11, Water Quality Management Section, Water Branch, Manitoba Conservation, Winnipeg, MB.

NOTES:

A Arsenic limits: 0.15 mg/L for averaging duration 4 days (4-Day, 3-Year or 7Q10 Design Flow); 0.34 mg/L for averaging duration 1 hr (1-Day, 3-Year or 1Q10 Design Flow)

B Cadmium limits: [e{0.7852[ln(Hardness)]-2.715}]×[1.101672-{ln(Hardness)(0.041838)}] for 4 days averaging duration.
[e{1.128[ln(Hardness)]-3.6867}]×[1.136672-{ln(Hardness)(0.041838)}] for 1 hour averaging duration.

C Chromium limits:Chromium III: [e{0.8190[ln(Hardness)]+0.6848}]×[0.860] for 4 days averaging duration.
Chromium III: [e{0.8190[ln(Hardness)]+3.7256}]×[0.316] for 1 hour averaging duration.
Chromium VI: 0.011 mg/L for averaging duration 4 days (4-Day, 3-Year or 7Q10 Design Flow); 0.016 mg/L for averaging duration 1 hr (1-Day, 3-Year or 1Q10 Design Flow)

D Copper limits: [e{0.8545[ln(Hardness)]-1.702}]×[0.960] for 4 Days hour averaging duration.
[e{0.9422[ln(Hardness)]-1.700}]×[0.960] for 1 hour averaging duration.

E Lead limits: [e{1.273[ln(Hardness)]-4,705}]×[1.46203 -{ln(Hardness)(0.145712)}] for 4 Days averaging duration.
[e{1.273[ln(Hardness)]-1.460}]×[1.46203 -{ln(Hardness)(0.145712)}] for 1 hour averaging duration.

F Nickel limits: [e{0.8460[ln(Hardness)]+0.0584}]×[0.997] for 4 Days averaging duration.
[e{0.8460[ln(Hardness)]+2.255}]×[0.998] for 1 hour averaging duration.

G Zinc limits: [e{0.8473[ln(Hardness)]+0.884}]×[0.976] for 4 Days averaging duration.
[e{0.8473[ln(Hardness)]+0.884}]×[0.978] for 1 hour averaging duration.

Footnotes for the CCME Aquatic Guidelines (Canadian Council of Ministers of the Environment. Dec. 2007. Canadian water quality guidelines for the protection of aquatic life).

c Interim guideline.
d No fact sheet created.
j The technical document for the guideline is available from the Ontario Ministry of the Environment.
k Substance has been re-evaluated since CCREM 1987 + Appendixes. Either a new guideline has been derived or insufficient data existed to derive a new guideline.
l Cadmium guideline = 10{0.86[log(hardness)] - 3.2}.
m Copper guideline = 2 µg·L^{-1} at [CaCO3] = 0–120 mg·L^{-1}
= 3 µg·L^{-1} at [CaCO3] = 120–180 mg·L^{-1}
= 4 µg·L^{-1} at [CaCO3] >180 mg·L^{-1}
o Lead guideline = 1 µg·L^{-1} at [CaCO3] = 0–60 mg·L^{-1}
= 2 µg·L^{-1} at [CaCO3] = 60–120 mg·$^{L-1}$
= 4 µg·L^{-1} at [CaCO3] = 120–180 mg·L^{-1}
= 7 µg·L^{-1} at [CaCO3] = >180 mg·L^{-1}
p Nickel guideline = 25 µg·L^{-1} at [CaCO3] = 0–60 mg·L^{-1}
= 65 µg·L^{-1} at [CaCO3] = 60–120 mg·L^{-1}
= 110 µg·L^{-1} at [CaCO3] = 120–180 mg·L^{-1}
= 150 µg·L^{-1} at [CaCO3] = >180 mg·L^{-1}
u For protection from direct toxic effects; the guidelines do not consider indirect effects due to eutrophication.
w May not protect fully higher trophic level fish; see factsheet for details.
x Canadian Trigger Ranges (for further narrative see factsheet), Total Phosphorus (ug·.L^{-1}):
ultra-oligotrophic <4
oligotrophic 4-10
mesotrophic 10-20
meso-eutrophic 20-35
eutrophic 35-100
hyper-eutrophic >100
z Guideline is expressed as µg nitrite-nitrogen·L^{-1}. This value is equivalent to 197 µg nitrite·L^{-1}.

7.6.11 Effects Assessment

Groundwater circulates as part of the hydrologic cycle and can contribute significantly to surface water flow. This section describes the interface of project components with groundwater circulation and quality and the resulting effects on surface water flows and quality and the project water balance. This section refers to climate information described in Section 7.1: Climate. The findings of this section have been integrated into the assessment of surface water flows presented in Section 7.4: Surface Water Hydrology, Section 7.5: Surface Water Quality, and Section 2.14: Site Water Management.

7.6.11.1 Scope of Assessment

Issues and Selection of Valued Ecosystem and Cultural Components (VECCs)

Potential effects of the project on groundwater include:

- interception of groundwater flows by pit development with corresponding reductions in groundwater discharge to surface water flows;
- effects on groundwater quality due to exposed ultramafic rock pit walls that are potentially acid generating (PAG);
- effects on quality of surface receiving waters;
- seepage of contaminated water from the Tailings and Ultramafic Waste Rock Management Facility (TWRMF), affecting the quality of shallow groundwater flows; and
- reduction in water table due to pit dewatering.

The main effect of the project on groundwater flows and quality is related to pit development in the Oakley Creek watershed. Accordingly, the focus of this section is to assess how mine dewatering will alter groundwater levels and quality in the vicinity of the mine, as a basis for determining potential effects on surface water flow and water quality in the Oakley Creek watershed. Other potential effects are small, localized and can be readily mitigated. For the Oakley Creek watershed, all potential effects are characterized and mitigation measures are described within this section. All issues pertaining to the effects of the TWRMF on groundwater seepage and quality in the Oakley Creek watershed are presented in Section 2.14: Site Water Management.

Groundwater VECCs were defined for the project environmental assessment based on EAP Report Guidelines and Environmental Baseline Study (EBS) work and initial findings of field investigations. VECCs for groundwater were selected based on potential project effects and linkages to surface water quality and flows as well as related effects on other VECCs (water and sediment quality, aquatic biota, fish, and wildlife habitat ecosystems). Table 7.6-9 presents a summary of the groundwater VECCs that may be affected by mine dewatering.

Table 7.6-9 Groundwater VECCs, Selection Rationale and Data Sources

VECC	Rationale for Selection	Linkage to EAP Report Guidelines or Other Regulatory Drivers	Baseline Data for EAP
Groundwater quality: pH, conductivity, alkalinity, sulphate, metals, and nitrogen compounds (nitrate & ammonia)	• Potential project effects due to open pit development and associated potential for ARD, metals leaching, and blasting residue affecting groundwater quality • Provides input to characterization of changes in chemical characteristics of surface waters	• Linked to CCME, Manitoba Tier II or other guidelines for the protection of aquatic life in surface waters • Monitoring will be required for permitting	2008 field data
Groundwater flows	• Potential project effects due to pit dewatering, effects on downstream groundwater and surface flows in the Oakley Creek basin and input of diverted groundwater flows to the project water balance • Provides input to characterization of effects on flows and chemical loadings to surface waters • Provides design parameters for mine water pumping	• Linked to CCME, Manitoba Tier II or other guidelines for the protection of aquatic life in surface waters • Linked to effects on aquatic habitat in surface waters • Monitoring will be required for permitting	2008 field data

Temporal Boundaries

The timeframe for assessing effects of groundwater encompasses the period of record for the baseline data collection conducted in 2008, full development of the pit during operations (i.e., period of maximum mine dewatering), and closure (i.e., after decommissioning and the restoration of the groundwater table in the mine area). Conditions during each phase are discussed relative to baseline conditions.

Study Area

The local study area (LSA) for assessment of effects of the pit dewatering on groundwater is delineated by the Oakley Creek watershed. Groundwater intercepted by pit development will be pumped to surface where it will be introduced to the ore processing water balance and surplus water will be discharged to the Oakley Creek and the Minago River watersheds (Section 2.14: Site Water Management).

The assessment of potential changes in surface water flows in Oakley Creek and Minago River are discussed in Section 7.4: Surface Water Hydrology and Section 2.14: Site Water Management.

As no other existing or reasonably foreseeable future developments are known, which would result in effects on groundwater in the Oakley Creek or the Minago River drainages, no regional study area for cumulative effects has been defined. A regional study area for effects of the project on surface water flows and quality is detailed in Section 7.4: Surface Water Hydrology.

7.6.11.2 Effects Assessment Methodology

Groundwater extraction to dewater the pit will result in a lowered groundwater table in the vicinity of the site and may result in reduced groundwater discharge to adjacent surface water systems. Baseline conditions representing pre-mining groundwater levels were quantified and groundwater levels during the 2008 pumping test program were recorded and operational dewatering wells yields were estimated based on typical groundwater response, bedrock hydraulic conductivity, site geology, topography and available groundwater monitoring data. The groundwater seepage into the pit was estimated and the number of wells required to attain the required levels during operation were determined.

Effects Attributes for Groundwater

Residual project and cumulative effects on water and sediment quality were characterized using effects attributes defined in Table 7.6-10. Groundwater levels may affect surface water flow and quality, which are discussed in Section 7.4: Surface Water Hydrology and Section 7.5: Surface Water Quality. The ecological, economic and social contexts of effects on groundwater are reflected in the attributes for magnitude of effects on surface water flows, water and sediment quality, and associated effects on aquatic biota, fish and wildlife.

Determination of Effects Significance for Groundwater

A residual project effect on groundwater will be considered significant, if there is an adverse effect of high likelihood, moderate to high magnitude, local to regional in geographic extent, and irreversible.

The significance of project effects on groundwater will also be reflected in the determination of effects significance for other VECCs including surface water quality, hydrology, aquatic resources and wildlife.

Table 7.6-10 Effects Attributes for Pit Dewatering

Attribute	Definition
Direction	
Positive	N/A
Adverse	Large flow of water into the mine and reduced groundwater discharge into surface streams. Change in groundwater quality causing deterioration of water quality in the Polishing Pond.
Neutral	No change in groundwater discharge rate to surface streamflow; no effects on surface water quality.
Magnitude	
Low	Flow: 1 L/s Quality: Change in groundwater quality does not have a measurable effect on surface water quality.
Moderate	Flow: 10 L/s Quality: Change in groundwater quality results is a measurable effect on surface water quality parameter(s), but change does not exceed threshold level (CCME water quality guidelines).
High	Flow: 50 L/s Quality: Change in groundwater quality results is a measurable effect on surface water quality parameter(s), which exceed(s) threshold level (CCME water quality guidelines).
Geographic Extent	
Site-specific	Effect confined to localized reach of affected stream.
Local	Effect extends the length of the affected stream.
Regional	Effect extends downstream of directly affected drainage.
Duration	
Short-term	Less than 1 year
Medium term	1 to 5 years
Long-term	Mine operating period and immediately after closure
Far future	Following closure and/or permanent
Frequency (Short Term duration effects that occur more than once)	
Low	Frequency within range of annual variability and does not pose a serious risk to the VECC or its economic or social/cultural values.
Moderate	Frequency exceeds range of annual variability, but is unlikely to pose a serious risk to the VECC or its economic or social/cultural values.
High	Frequency exceeds range of annual variability and is likely to pose a serious risk to the VECC or its economic or social/cultural values.
Reversibility	
Reversible	Effects on VECC will cease during or after the project is complete.
Irreversible	Effects on VECC will persist during and/or after the project is complete.
Likelihood of Occurrence [1]	
Unknown	Effect on VECC is not well understood and based on potential risk to the VECC or its economic or social/cultural values. Effects will be monitored and adaptive management measures taken, as appropriate.
High	Effect on VECC is well understood and there is a high likelihood of effect on the VECC as predicted.

Note: 1 This attribute characterizes the likelihood that the effect will occur as predicted and as characterized by the effect attributes based on the status of scientific or statistical information, experience and observations of similar cause/effect relationships, and/or professional judgement of the author.

7.6.11.3 Project Effects

7.6.11.3.1 Operations

Effect of Pit Dewatering on Oakley Creek Basin

Results from the pumping tests conducted by Golder Associates in 2008 indicate that there is no hydraulic connection between the limestone aquifer and the Oakley Creek (Golder Associates, 2008b). This is partly due to a thick layer of clay underlying the creek bed. The clay formation has low hydraulic conductivity. Therefore, water flows in the Oakley Creek will not be affected by the pit dewatering activities. In addition, some of the water from the Polishing Pond will be returned back to Oakley Creek during the summer months (Section 2.14: Site Water Management). It is important to note that Oakley Creek is frozen in the winter months.

Dewatering of the pit is not expected to create gradients that could result in drainage of the lakes, creeks and rivers into the pit. Dewatering of the mine is not expected to affect water levels in the adjacent Oakley Creek, Minago River and William River. The lowering of the groundwater table in the pit area during operations is an adverse effect of moderate magnitude, site-specific in extent, long-term in duration and reversible when the pit is closed and dewatering ceases. As noted above, groundwater inflow rates may be higher than the projected average immediately following excavation. Such an occurrence would be an adverse effect, of potentially high magnitude, local in extent, short-term in duration and reversible. The ecological, social and cultural contexts for effects on groundwater relate to associated effects on surface water quality and aquatic habitat. Potential reductions in groundwater discharge to surface streams during low flow periods and in the winter are considered moderate, site specific in extent, long-term in duration and reversible in nature.

Pit Water Quality

Groundwater may increase metal concentrations as a result of acid rock drainage and metal leaching from the pit walls (Section 2.8: Geochemical Rock Characterization). Elevated hydrocarbon concentrations may also be expected from the use and maintenance of mechanized mining equipment and fuel oil in explosives. In addition, pit water will likely be affected by residual nitrogen in the form of nitrates or nitrites from ammonium-nitrate-based explosives. The presence of limestone may also have an effect on pit water chemistry by increasing pH levels (i.e., increasing alkalinity).

Impacted pit water will be pumped to the Polishing Pond during the Nickel Processing Plant operation (Year 1 through 8). During closure, pumping will cease and the pit will flood. No impacts to mine area groundwater quality are expected during the operations phase (Section 2.14: Site Water Management and Section 7.5: Surface Water Quality).

7.6.11.3.2 Closure

Open Pit

The pit will be left in place to flood. During the closure phase, the groundwater table in the pit area is expected to slowly return to pre-mining levels. Based on a total pit volume of 156,700,000 m^3, it could take about 10.7 years to flood the pit after closure (based on 40,000 m^3/day).

Pit Groundwater Quality at Closure

The pit water quality is anticipated to be the same as the baseline conditions. Flooding of the pit will eliminate the potential for ARD and metal leaching.

Pit discharges to the Oakley watershed will be monitored and there are no plans to create a fish habitat using the pit lake, once it is flooded. A barrier will be created to prevent fish movement between the Oakley Creek and the Pit Lake.

Groundwater is not expected to discharge immediately from the pit following closure, as it will take approximately 10.7 years to flood the pit. Initially, there is potential for pit water to contain suspended solids and possibly some metals.

A potential residual project effect is the discharge of metal and TSS contaminated pit water in the Oakley Creek basin at closure. The long water flow path to the Oakley Creek may dilute the potential effects of contaminated waters from the pit.

It is important to mention the potential function of the wetlands in the LSA and the RSA. Other than being one of the most important components of the regional landscape, wetlands play a role that no other ecosystem can provide. Wetlands act as natural water treatment systems. Wetlands tend to slow down the force of water, encouraging the deposition of sediments carried in the water. This is beneficial further downstream where deposition of sediments may block waterways. Nutrients are often associated with sediments and can be deposited at the same time. These nutrients may accumulate in the sub-soil, be transformed by chemical and biological processes or be taken up by wetland vegetation which can then be harvested and effectively removed from the system. Wetland vegetation also plays a role in slowing down the flow of water.

Many wetland plants have the capacity to remove toxic substances that have come from industrial discharges and/or mining activities. Some wetland plants have been found to accumulate heavy metals in their tissues at 100,000 times the concentration in the surrounding water and can detoxify certain kinds of effluent (Ramsar, 2000). Some *Typha* and *Phragmites* species have been used to treat effluents from mining areas that contain high concentrations of heavy metals such as cadmium, zinc, mercury, nickel, copper and vanadium (Higgins and Mattes, 2003) and to treat waters running off roads and highways (Sérodes et al., 2003).

Indeed, wetlands have several functions that aid in the removal of metals in waters. These characteristics are required for certain processes to occur: adsorption and ion exchange, bioaccumulation, bacterial and abiotic oxidation, sedimentation, neutralization, reduction, and dissolution of carbonate minerals (Perry and Kleinmann, 1991; Kadlec and Wallace, 2008).

Wetlands have organic-rich substrates, which exchange dissolved metals. This exchange occurs between the dissolved metals and abundant humic and fulvic acids contained within the substrate (Wildeman et al., 1991). Moreover, especially in bogs, *Sphagnum*'s cation exchange capacity (CEC) is one of the most important mechanisms by which dissolved metals are adsorbed and represents the capacity of a soil to exchange and retain positively charged ions (cations). *Sphagnum* mosses, the main components of peat deposit, are essentially made of polysaccharides (many saccharide units linked by glycosidic bonds) which provide a high CEC and, by the way, a high acidifying capacity (van Breeman, 1995). The high CEC enables an efficient retention of nutrients from the surrounding environment (air and plant decomposition) coupled with the release of H^+ ions. CEC is also an indicator of a soil's capacity to prevent potential contamination of groundwater and surface water since cations such as arsenic, copper, iron, nickel, lead and zinc may also be retained within the peat deposit.

Wetland sediments are generally anoxic or anaerobic below a thin oxidized surface layer and contain organic carbon for microbial growth. The anoxic zone of the sediments provides conditions, which favour microbial and chemical reducing processes. Soluble metals are converted to insoluble forms by the anoxic conditions of wetland sediments. Settling of suspended solids occurs from water velocity control by the wetland's vegetation (Ramsar, 2000).

Processes within natural wetlands have been found to remediate contaminants contained in acid rock drainage (ARD). Kleinmann (1985) found that iron concentrations dropped from 20-25 mg/L to 1 mg/L, manganese concentrations dropped from 30-40 mg/L to 2 mg/L in a *Typha* wetland. *Sphagnum* spp. may also have a significant effect on concentrations of iron, manganese, sulfate, and other mineral concentrations (Kleinmann, 1985; Weider et al., 1985). Plant roots will retain arsenic and other metals (Sobolewski, 1997). Plants also generate microenvironments that assist in the reduction and oxidation processes (Wildeman et al., 1991).

Gabor et al. (2004) and others have demonstrated that wetlands can efficiently remove contaminants from runoff water. Gabor et al. (2004) reported that artificial wetlands have reduced total nitrogen (by 30 to 87%), total phosphorous (by 4 to 90%), suspended solids (by 45 to 99%) and pathogen contents (by 61 to 99%) in waters passing through them. Halverson (2004) reported that wetlands to reduced metal contents by 36 to 98% in runoff waters that contained Ag, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb, and Zn.

The effect of discharging potentially contaminated pit water on receiving water quality conditions in the Oakley Creek is expected to be adverse, of low to moderate magnitude, local in extent, and far future in duration and ultimately reversible. Although the discharge of potentially contaminated pit water to surface waters is considered likely after the cessation of mine dewatering, the likelihood of a measurable adverse effect on surface water quality in Oakley

Creek is unknown. Water quality from the pit lake will be monitored to confirm the predictions. Adaptive management measures will be implemented as necessary and monitored. Based on the results of operations phase monitoring, post-closure monitoring may be required to confirm effectiveness of the proposed mitigative measures at closure.

7.6.11.4 Residual Project Effects and Significance

Groundwater Flow

Adverse residual project effects on groundwater will include reduced groundwater table and corresponding reduction in groundwater discharge to surface streams during operations. However, the pit dewatering will not have an effect on the Oakley Creek. At closure, the groundwater table will rise naturally to saturate the open pit.

The residual project effects of mine dewatering on groundwater in the surface streams is therefore characterized as low magnitude, site-specific, far future and reversible when the groundwater table will be restored. The residual project effects on groundwater flows in the Oakley Creek basin are determined to be not significant.

The ecological, social and cultural context of effects for groundwater relates to associated effects on aquatic habitat. Follow-up studies will improve understanding of these effects and the requirement for contingency measures, if any.

Pit Water Quality

Residual adverse project effects on surface water in the Oakley Creek basin are characterized as low to moderate magnitude, local, potentially far future and ultimately reversible. The wetlands will provide additional effluent (pit water) treatment before the water gets into the Oakley Creek and therefore, residual project effects of pit water flows on the Oakley basin are determined to be not significant.

The ecological, social and cultural context of project effects on groundwater quality relate to associated effects on surface water quality and aquatic habitat. If elevated concentrations of contaminants are noted, a corresponding surface water monitoring program will be initiated in Oakley Creek during operations. Monitoring results will improve the understanding of potential effects on aquatic habitat and the requirement for contingency measures, if any, to ensure acceptable water quality for the protection of aquatic life in Oakley Creek.

7.6.11.5 Cumulative Effects

There are no past, existing or foreseeable future activities that would result in effects on groundwater that could overlap with or add to project effects on groundwater. Accordingly, there will be no cumulative effects on groundwater in the project area.

7.6.11.6 Mitigation Measures

Table 7.6-11 presents a summary of potential mitigation measures for project effects on groundwater.

Table 7.6-11 Mitigation Measures for Project Effects on Groundwater

Potential Project Effect	Mitigation Measures
Reduced base flow in Oakley Creek resulting in impacts to aquatic habitat during low flow periods	• Based on follow up studies of effects of potential reduced low flows on fish habitat, evaluate options to reduce groundwater pumping or return more water from the Polishing Pond to the Oakley Creek.
Discharge of pit water contaminants to surface water in Oakley Creek during closure/post closure	• Monitor pit water quality. Based on results, initiate enhanced surface water quality monitoring in Oakley Creek as required. • Evaluate contingency measures for enhanced management of groundwater quality at closure/post closure.
Potential Cumulative Effect	**Mitigation Measures**
None identified.	None

7.6.11.7 Monitoring and Follow-up

Follow-up Studies

No follow-up studies are recommended for groundwater management related to pit dewatering or tailings management.

Monitoring Programs

Monitoring of flow and temperature in Oakley Creek will be done during the operational phase to assess the effects of pit dewatering on surface water hydrology and aquatic habitat. Monitoring of groundwater quality downstream of the pit and surface water quality in Oakley Creek will also be done during operations and following closure.

Ongoing water level monitoring of mine area piezometers and monitoring wells will be done to assess the effects pit dewatering is having on groundwater levels and provide advance warning of potential impacts to adjacent surface water systems. As the pit phases are advanced and mine development progresses, ongoing review of groundwater seepage into the pit and pumping rates will be conducted to refine pit inflow estimates, improve the hydrogeologic model and better assess potential impacts to adjacent surface water streams. In addition, collection of climate data such as precipitation and temperature will continue.

Table 7.6-12 presents a summary of the proposed monitoring and follow-up programs for groundwater.

7.6.11.8 Summary of Effects

Table 7.6-13 provides a summary of effects related to pit groundwater extraction.

Table 7.6-12 Monitoring and Follow-up Programs for Mine Groundwater

Potential Project Effect	Program Objectives	General Methods	Reporting	Implementation
Follow-Up Programs				
N/A	N/A	N/A	N/A	N/A
Monitoring Programs				
Reduced base flow in Oakley Creek resulting in impacts to aquatic habitat	Determine if mine dewatering is affecting water quantity and quality in Oakley Creek	Year-round (i.e., monthly) monitoring of flow, temperature and water quality in Oakley Creek.	Manitoba Gov.'t as required	Proponent
	Provide advance warning of impacts to surface water hydrology	Monitoring of water levels in mine area piezometers and recording of dewatering pumping rates.	Manitoba Gov.'t as required	Proponent
	Estimate infiltration and predict impacts to surface water hydrology	Recording of climate data such as precipitation and temperature.	Manitoba Gov.'t as required	Proponent
Discharge of contaminants to surface water in Oakley Creek watershed	Determine if water quality is being affected by discharge of pit water following closure	Monitoring of pit water and surface water quality in Oakley Creek.	Manitoba Gov.'t as required	Proponent
Follow-Up Programs				
N/A	N/A	N/A	N/A	N/A
Monitoring Programs				
N/A	N/A	N/A	N/A	N/A

Note: N/A not applicable

Table 7.6-13 Summary of Effects Related to Pit Groundwater Extraction

Potential Effect	Level of Effect[1]						Effect Rating	
	Direction	Magnitude	Extent	Duration/ Frequency	Reversibility	Like-lihood	Project Effect	Cumulative Effect
Construction, Operations and Decommissioning								
Pit dewatering resulting in groundwater table depression and reduced base flows in Oakley Creek	Adverse	Low	Local	Long-term	Reversible	High	Not significant	N/A
Closure								
Flooding of Pit and gradual recovery of groundwater levels and base flows in Oakley Creek	Adverse	Low	Local	Long-term	Reversible	High	Not significant	N/A
Contaminated Pit water from flooded Pit discharging to Oakley Creek basin and ultimately to Oakley Creek	Adverse	Low to moderate	Local	Far future	Reversible	Unknown	Not significant	N/A

Notes: 1 Based on criteria in Table 7.6-10 (Effects Attributes for Pit Dewatering).

N/A = not applicable