4.0 EXISTING ENVIRONMENT

4.1 PHYSICAL ENVIRONMENT

4.1.1 *TOPOGRAPHY*

Bernic Lake is located on the Precambrian drift plain of the Canadian Shield (Davies et al. 1962). This ice-scoured upland region ranges from rolling to hilly. Relief is generally low, typically less than 15 m, and is provided by granite outcrops and numerous eskers. Considerable glacial drift overlies the region. Approximately 40 to 60% of the area is comprised of lakes and bogs, reflecting the poor and disorganized drainage.

4.1.2 *CLIMATE*

Climate data for the regional study area were obtained from Environment Canada (EC) meteorological stations located in Pinawa and Bissett, Manitoba. Pinawa is located approximately 50 km southwest of the Project Site and Bissett is approximately 60 km to the north (Figure 4.1). These stations were chosen because of their proximity to the Project Site and the long periods of record at each location.

Data were assembled for the most recent 30 year period, which was from 1978 to 2007 at the Pinawa station and from 1968 to 1997 at the Bissett station. The Bissett station was discontinued in 1997. Monthly averages were calculated from the daily data supplied by EC (Table 4.1).

Hourly wind data from the Pinawa station were assembled for the years 2003 to 2007 to develop a windrose for the site. Monthly averages (Table 4.2) were calculated from hourly data supplied by EC. Windrose Pro Ver. 2.3.20 was used to create a windrose plot and determine prevailing wind direction for the region. Mean monthly wind speed varies little over the year, ranging from 7.2 km/hr in July to 10.3 km/hr in April, and mean annual wind speed is 8.8 km/hr. The prevailing wind direction is primarily from the northwest and secondarily from the southeast in the spring and fall months (Table 4.2; Figure 4.2).

In general, precipitation falls primarily as snow during the winter months, with the greatest snowfalls occurring in November, December and January. Annual average precipitation ranges from 573 to 577 mm with precipitation peaking in June (Table 4.1). The most recent rainfall frequency data were available from the Bissett station up to the year 1984. Mean 24-hour rainfall intensity was 52.7 mm (Table 4.3). Rainfall event relationships for various durations and probability of occurrence were developed by the Atmospheric Environment Service using rainfall records in Winnipeg, Manitoba (Tables

4.4 and 4.5). Rainfall event relationships are based on data collected from 1948 to 1990 and have been pro-rated using an adjustment factor of 1.05 to account for the project location relative to Winnipeg (Environment Canada, Atmospheric Environment Service).

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FIGURE 4.1
ENVIRONMENT CANADA METEOROLOGICAL STATIONS NEAR THE TANCO MINE

1001660200-SKT-V0011-A3

Table 4.1 Summary of historical meteorological data collected at Pinawa, MB (1978-2007) and Bissett, MB (1968-1997) (Environment Canada 2008).

		January		February		March		April		May		June		July	
	Units	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett
Temperature - Mean	°C	-17.1	-19.3	-13.6	-15.3	-6.1	-7.4	3.8	2.7	11.2	10.5	16.3	15.8	19.2	18.3
Temperature - Mean Min	°C	-22.6	-25.7	-19.5	-22.4	-12.0	-14.4	-2.6	-4.2	4.6	3.4	10.2	9.0	13.2	11.7
Temperature - Extreme Min	°C	-44.0	-46.1	-43.0	-44.5	-44.0	-39.5	-28.9	-30	-8.0	-11.5	-2.0	-2.5	3.0	-0.6
Temperature - Mean Max	°C	-11.6	-12.8	-7.7	-8.1	-0.2	-0.4	10.2	9.4	17.8	17.5	22.4	22.4	25.3	24.9
Temperature - Extreme Max	°C	9.5	7.5	12.0	9	17.0	15.3	32.5	30	34.5	34	37.5	37.5	37.0	35
Rainfall - Total	mm	0.3	0.3	1.9	0.4	10.9	7.7	19.6	20.8	65.8	49.5	94.3	88.0	85.4	72.6
Snowfall - Total	cm	21.5	26.2	15.3	18.0	15.5	19.1	9.3	10.6	2.4	2.8	0.0	0.3	0.0	0.0
Precipitation - Total [a]	mm	21.9	24.2	17.2	16.9	26.4	26.3	28.8	31.7	68.2	52.5	94.3	88.3	85.4	72.6

Table 4.1 (cont'd) Summary of historical meteorological data collected at Pinawa, MB (1978-2007) and Bissett, MB (1968-1997) (Environment Canada 2008).

		August		September		October		November		December		Annual	
	Units	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett	Pinawa	Bissett
Temperature - Mean	°C	18.0	17.1	12.4	10.8	5.0	4.2	-4.5	-5.9	-13.2	-16.0	2.6	1.3
Temperature - Mean Min	°C	11.9	10.5	6.7	4.9	0.4	-0.5	-8.3	-10.3	-17.7	-21.5	-3.0	-5.0
Temperature - Extreme Min	°C	-1.5	-1.5	-6.0	-6.7	-15.5	-17	-34.5	-38.5	-40.0	-43.3	-44.0	-46.1
Temperature - Mean Max	°C	24.1	23.7	18.0	16.7	9.6	8.9	-0.7	-1.6	-8.6	-10.4	8.2	7.5
Temperature - Extreme Max	°C	36.0	36.5	36.0	35.5	28.5	27.5	20.0	21.7	9.5	9	37.5	37.5
Rainfall - Total	mm	65.2	78.4	61.5	67.5	39.1	34.3	9.5	5.2	1.6	1.0	455.0	425.7
Snowfall - Total	cm	0.0	0.0	0.4	0.6	8.0	11.9	20.0	26.7	25.5	22.7	117.9	138.8
Precipitation - Total [a]	mm	65.2	78.4	61.9	68.1	47.1	46.8	29.4	30.1	27.1	21.3	572.9	557.2

[a] The sum of the total rainfall and the water equivalent of the total snowfall observed during the day. In most cases a 10:1 ratio can be applied to the amount of snow to determine its water equivalent.

Table 4.2 Monthly prevailing wind conditions at Pinawa, MB (2003-2007) (Environment Canada 2008).

Parameter	Units	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Wind Speed - Mean	km/hr	8.6	7.9	9.2	10.3	9.6	8.3	7.2	8.3	8.5	9.5	9.6	8.6	8.8
Wind Direction		NW	NW	NW	SE	SE	W	NW	SE	SE	SE	W	S	NW

Table 4.3 Rainfall intensity (mm) at Bissett, MB (1969-1984) (Environment Canada 2008).

Year	5 Min	10 Min	15 Min	30 Min	1H	2H	6H	12H	24H
1969	7.4	11.2	12.2	21.8	22.4	22.4	30	30.2	40.6
1970	5.1	8.6	11.2	13.5	17.5	26.2	37.8	47.5	47.5
1971	6.6	11.2	15.5	19.8	21.8	25.9	27.9	34	46.2
1972	5.8	10.4	11.2	13.2	14.2	14.2	20.6	27.2	29.2
1973	5.8	9.9	13.7	19.8	21.6	35.6	36.3	38.1	51.6
1974	4.3	5.6	6.3	7.6	12.2	17.3	25.7	50.3	65.5
1975	4.8	7.1	8.4	10.7	11.7	15	28.4	34.8	38.4
1976	6.9	13.5	17.3	23.6	28.4	30.7	33.8	34	47
1977	10.2	15.2	20.1	27.9	29	35.3	42.4	64	80.8
1978	7.2	10.9	12.8	18.9	23.4	23.6	27.6	34	41.1
1979	11.8	12.4	17.4	20.5	20.7	21.8	30.6	37.4	54.4
1980	5.9	9.8	14.2	21.5	30	46.8	69.1	84.9	92.3
1981	9.7	9.7	10.7	17.1	21.4	24.7	30.6	44	52.4
1982	8	12.4	15.7	16.3	17.8	21.5	25.2	25.7	30.4
1983	4.6	7.2	7.9	7.9	11.8	12.7	22.2	23	28.4
1984	6.2	10.3	14.8	18.8	31.4	36.9	74.3	96.6	96.8
MEAN	**6.9**	**10.3**	**13.1**	**17.4**	**21**	**25.7**	**35.2**	**44.1**	**52.7**
SD	**2.1**	**2.5**	**3.8**	**5.6**	**6.5**	**9.4**	**15.4**	**21**	**21.1**

Table 4.4 Rainfall events for the local study area.

Probability	Rainfall Amount (mm)				
	15 min	30 min	1 hour	6 hours	24 hours
50%	16.4	21.5	25.6	39.6	51.2
20%	21.9	29.2	34.7	52.8	66.3
10%	25.6	34.1	40.6	61.6	76.2
5%	29.2	38.9	46.2	69.9	85.8
2%	33.8	45.3	53.7	80.9	98.2
1%	37.2	49.9	59.2	89	107.4

Table 4.5 Annual rainfall occurrence probability in the local study area.

Yearly Total Precipitation (mm)	Probability of Yearly Precipitation Being Greater (Wetter) Than Yearly Total Precipitation	Probability of Yearly Precipitation Less (Drier) Than Yearly Total Precipitation
420	98%	2%
439	95%	5%
460	90%	10%
486	80%	20%
549	50%	50%
632	20%	80%
688	10%	90%
741	5%	95%
810	2%	98%

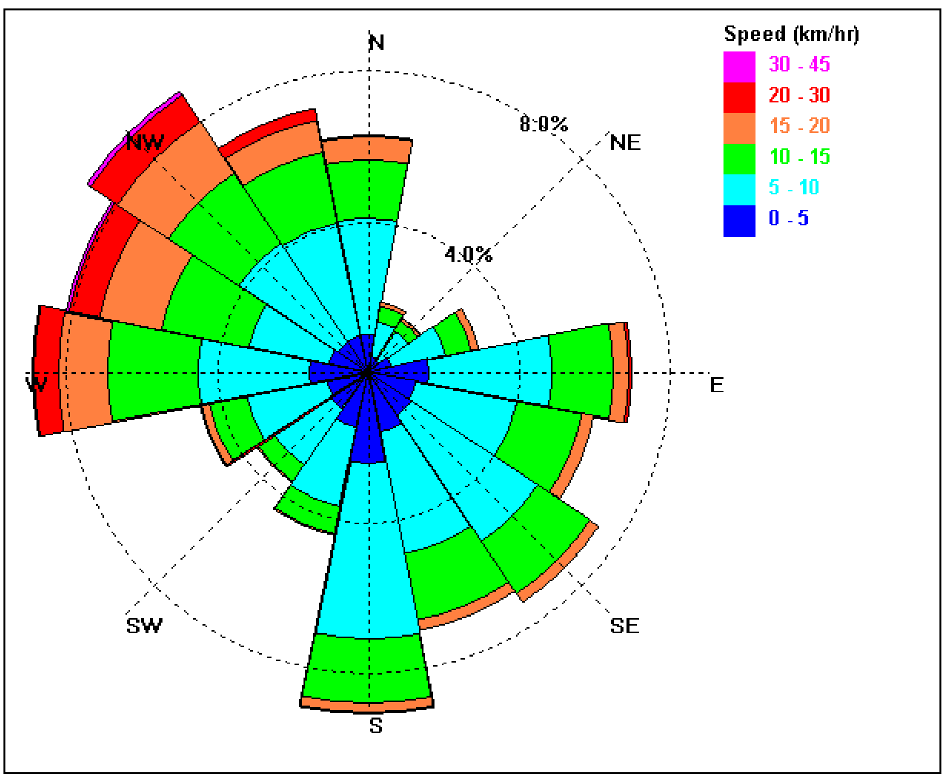

Figure 4.2 Windrose showing wind direction and speed at Pinawa from 2003-2007.

4.1.3 SURFICIAL GEOLOGY

The TANCO Mine is located in the Precambrian Shield Physiographic Region. The region consists primarily of hummocky terrain of eroded crystalline bedrock and is partly covered with Quaternary deposits. Surface elevation within the physiographic region generally does not exceed 350 metres above sea level (masl) and relief does not typically exceed 30 m.

Precambrian rocks form the bedrock throughout most of the eastern parts of Manitoba. These rocks belong to the Superior Province and consist primarily of granitic and gneissic rock types (NHRI 1995). The thickness of glacial and lacustrine sediment overlying the Precambrian shield is variable but generally thin with bedrock outcrop being common in many areas.

4.1.4 SOILS

Surficial deposits consist of glacial drift predominated by granitic materials. Acidic soils prevail on uplands, including podzolic and grey-wooded types while organic soils prevail in bogs.

4.1.5 HYDROGEOCHEMISTRY

East Tailings Management Area

The TANCO site has been the subject of several studies related to assessment of the potential groundwater impacts of residue placement in the Old TMA. These studies include Lakefield Research Limited (2000); Agassiz North (2001); UMA (2001); SEACOR (2004); SEACOR (2005); Wardrop (2009b); Solylo (2010); and Tetra Tech (2011a; Appendix I).

Since 1998, 43 monitoring wells (Tables 4.6 and 4.7) have been installed in the Old TMA (Figure 4.3). Based on borehole logs, the hydrostratigraphy of the Old TMA includes tailings (comprising fine sand to silt sized sediment, 7 to 11 m thick), interlayered organics and silt (0.9 to 3.4 m thick), silty clay (2.4 m thick), silty sand, sand and gravel (0.8 to 1.2 m thick), and bedrock (UMA 2001). Bedrock was intersected in boreholes between 23.0 and 57.5 feet below ground surface and bedrock forms a bounding valley to the Old TMA facility.

A hydrogeology study of the Old TMA was conducted in 2001 prior to starting residue placement and described the unconfined aquifer with saturation at depths between 0.5 and 3.0 metres below the surface of the tailings (UMA 2001). Aquifer gradients were calculated between 0.001 and 0.012. Groundwater divides were located near the north end of the Old TMA with aquifer flow toward the East, West, and Main Dams. The most recent potentiometric map by Wardrop (2010b) indicates similar flow directions (Figure 4.3).

Average linear groundwater velocities were calculated from gradients, slug test estimates of hydraulic conductivity, and porosity estimates to be between 1.4 and 2.9 m/y (Wardrop 2009b). Based on aquifer properties, estimated annual seepage from the TMA was estimated to be in the range of 3,200 m^3/year to 6,700 m^3/year primarily through four key discharge locations (North Dam, East Dam, West Dam, and Main Dam) (Figure 4.3).

The documented hydrogeologic conditions formed the basis for the CPF residue dry stack placement plan in the Old TMA. The dry stack was strategically located on groundwater divides in the northern part of the TMA to maximize the travel time to points of discharge to surface waters as well as to maximize the dilution of residue leachate (Figure 4.3).

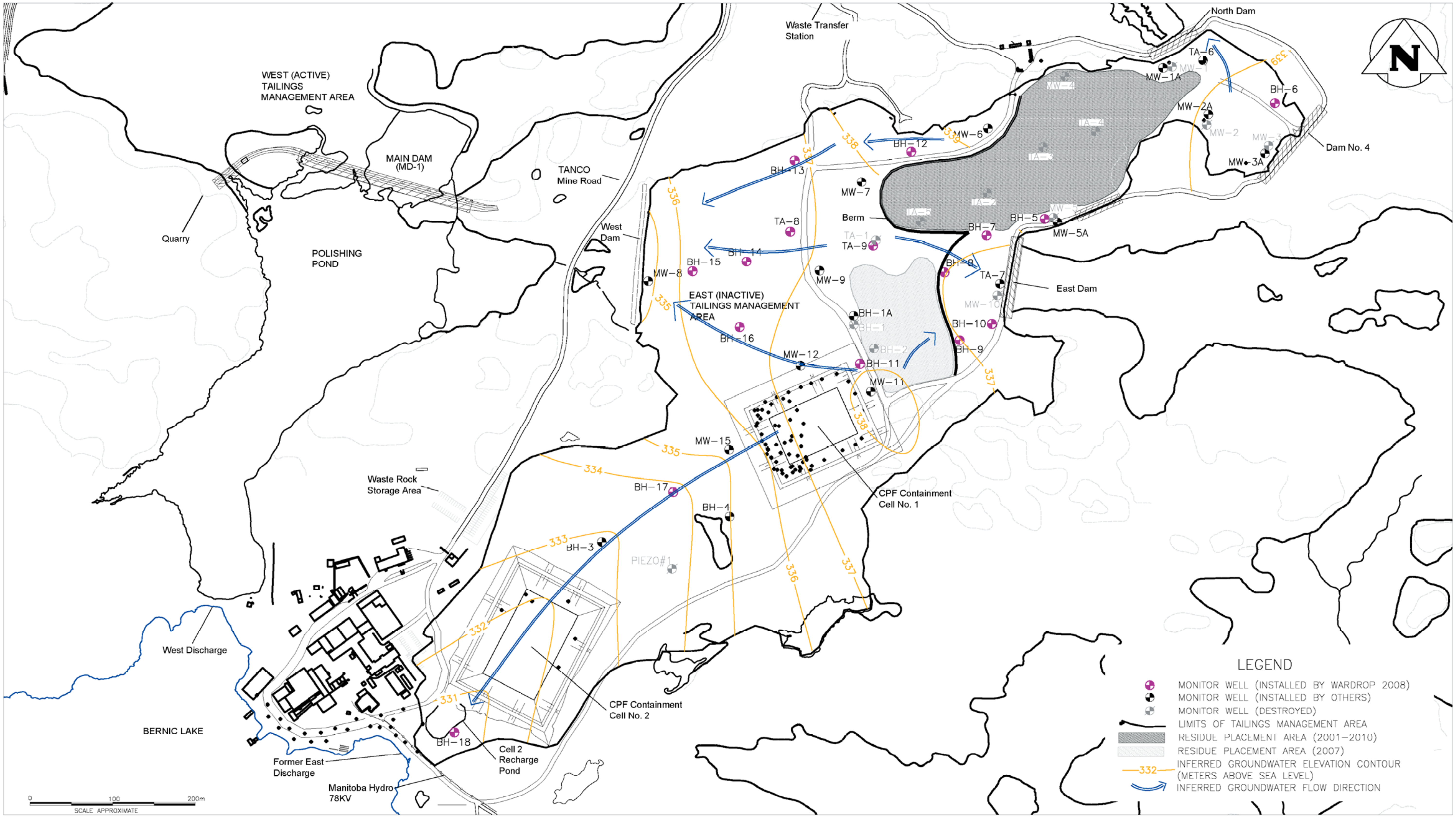

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FIGURE 4.3
INFERRED POTENTIOMETRIC MAP
(SEPTEMBER 2010)

Table 4.6 Nested wells completed within the East TMA.

Nested Well	Installed	Period of Record of Available Data	Screened Interval
TA-1-1	2000	Jun-07 - Jun-08	Shallow
TA-1-2	2000	No Record Available	Deep
TA-1-3	2000	Jun-07 - Jun-08	Overburden
TA-2-1	2000	Oct-00 - Summer-07	Shallow
TA-2-2	2000	Oct-00 - Summer-07	Deep
TA-3-1	2000	Oct-00 - Summer-05	Shallow
TA-3-2	2000	Oct-00 - Summer-05	Deep
TA-3-3	2000	Oct-00 - Summer-05	Overburden
TA-4-1	2000	Oct-00 - Autumn-01	Shallow
TA-4-2	2000	Oct-00 - Autumn-01	Deep
TA-4-3	2000	Oct-00 - Autumn-01	Overburden
TA-5-1	Oct-02	Oct-02 - Summer-08	Shallow
TA-5-2	Oct-02	Oct-02 - Summer-08	Deep
TA-5-3	Oct-02	Oct-02 - Summer-08	Overburden
TA-6-1	Oct-02	Oct-02 - Present	Shallow
TA-6-2	Oct-02	Oct-02 - Present	Deep
TA-6-3	Oct-02	Oct-02 - Oct-08	Overburden
TA-7-1	Jun-08	Jun-08 - Present	Shallow
TA-7-2	Jun-08	Jun-08 - Present	Deep
TA-7-3	Jun-08	Jun-08 - Present	Overburden
TA-8-1	Jun-08	Jun-08 - Present	Shallow
TA-8-2	Jun-08	Jun-08 - Present	Deep
TA-8-3	Jun-08	Jun-08 - Present	Overburden
TA-9-1	Jun-08	Jun-08 - Present	Shallow
TA-9-2	Jun-08	Jun-08 - Present	Deep
TA-9-3	Jun-08	Jun-08 - Present	Overburden

Shallow: screens placed just below the water table.
Deep: screened in the lower portion of the tailings above the clay liner.
Overburden: screened in the underlying overburden.

Table 4.7 Single wells completed within the East TMA.

Single Well	Installed	Period of Record of Available Data	Screened Interval
Piezometer 4	2000	Oct-00 - July-01	Shallow
MW-1	2000	Oct-00 - July-01	Shallow
MW-1A	Oct-02	Oct-02 - Present	Shallow
MW-2	2000	Oct-00 - July-01	Shallow
MW-2A	Oct-02	Oct-02 - Present	Shallow
MW-3	2000	Oct-00 - July-01	Shallow
MW-3A	Oct-02	Oct-02 - Present	Shallow
MW-4	2000	Oct-00 - July-01	Shallow
MW-5	2000	Oct-00 - July-01	Shallow
MW-5A	Oct-02	Oct-02 - Present	Shallow
MW-6	2000	2000 - Present	Shallow
MW-7	2000	2000 - Present	Shallow
MW-8	2000	2000 - Present	Shallow
MW-9	2000	2000 - Present	Shallow
MW-10	2000	2000 - 2005	Shallow
BH-1	1998	1998 -2001	Shallow
BH-1A	2002	Oct-02 - Present	Shallow
BH-2	1998	1998 - 2007/8	Shallow
BH-3	1998	1998 - Present	Shallow
BH-4	1998	1998 - Present	Shallow
BH-5	Jun-08	Jun-08 - Present	Shallow
BH-6	Jun-08	Jun-08 - Present	Shallow
BH-7	Jun-08	Jun-08 - Present	Shallow
BH-8	Jun-08	Jun-08 - Present	Shallow
BH-9	Jun-08	Jun-08 - Present	Shallow
BH-10	Jun-08	Jun-08 - Present	Shallow
BH-11	Jun-08	Jun-08 - Present	Shallow
BH-12	Jun-08	Jun-08 - Present	Shallow
BH-13	Jun-08	Jun-08 - Present	Shallow
BH-14	Jun-08	Jun-08 - Present	Shallow
BH-15	Jun-08	Jun-08 - Present	Shallow
BH-16	Jun-08	Jun-08 - Present	Shallow
BH-17	Jun-08	Jun-08 - Present	Shallow
BH-18	Jun-08	Jun-08 - Present	Shallow

Shallow: screens placed just below the water table.
Deep: screened in the lower portion of the tailings above the clay liner.
Overburden: screened in the underlying overburden.

West Tailings Management Area

The groundwater system in the West TMA has not been studied but is expected to function in the same manner as the extensively studied East TMA groundwater system. The tailings in the West TMA are the same as in the East TMA, with respect to ore source, grind, and mill process. Groundwater flow can be expected to be in the direction of topographic relief, which in the West TMA results in all flows being directed to the main dam, through the polishing pond, and out the West Discharge.

On the basis of extensive study in the East TMA, the tailings hydraulic conductivity is expected to be 10^{-6} m/s (± one order of magnitude), which corresponds to published ranges for silty to fine-grained sand formations (Freeze and Cherry 1979). As an active TMA, the static groundwater elevation in the West TMA tailings will fluctuate with the water level maintained in the main pond. This influence is absent from the inactive east TMA.

Groundwater chemistry will reflect tailings composition in the West TMA, diluted to varying degrees by the tailings wastewater discharges, and therefore during operations tailings porewater in the West TMA is expected to be generally similar with respect to measureable parameters although more dilute than was documented in the east TMA in 2001 prior to the start of CPF residue drystacking.

The West TMA was developed in the same manner as the East TMA and over similar terrain. Consequently the tailings groundwater system is expected to be distinct and separate from any underlying groundwater system. Flow in the tailings groundwater system will be lateral rather than vertically downward.

Local Study Area Groundwater

Precambrian bedrock in Manitoba is overlain in most areas by Quaternary deposits consisting of glacial tills, glaciolacustrine clays, silts and sands, emerged marine deposits, and/or organics (Manitoba Mineral Resources Division 1981). The stratigraphy found beneath the tailings of the East TMA is consistent with glaciolacustrine clays, silts and sands (Wardrop 2010b). Therefore, it is reasonable to assume that the glaciolacustrine depositional setting of the lower overburden aquifer in the East TMA is representative of the local study area and that groundwater is present in sandy gravel and/or sandy clay formations immediately above the bedrock. Random and frequent bedrock outcrops in the local area indicate an undulating bedrock surface. Therefore groundwater present in this depositional setting may exist as an enclosed perched water table that receives direct recharge from rain or snow melt, or as part of a larger overburden aquifer that flows according to the direction of bedrock dip. Similar to what was measured in the lower overburden aquifer of the East TMA, an average sandy clay formation would have an hydraulic conductivity of 10^{-7} m/s (± one order of magnitude), which corresponds to published ranges for sandy clay aquifers (Freeze and Cherry 1979). In areas of reduced clay content, published hydraulic conductivity ranges for clean sand and gravel formations range from 10^{-5} to 10^{-1} m/s (Freeze and Cherry 1979).

As in the lower overburden aquifer of the East TMA, detectable concentrations of aluminum, arsenic, barium, calcium, cesium, chromium, cobalt, copper, iron, lithium, magnesium, manganese, molybdenum, nickel, potassium, rubidium, sodium, strontium, and sulphur are expected. Groundwater in these types of aquifers generally contains total dissolved solids (TDS) concentrations from 300 mg/L to 500 mg/L (Betcher et al 1995). Consistent with this range, the mean East TMA lower overburden aquifer TDS concentration is 388 mg/L.

4.2 TERRESTRIAL ENVIRONMENT

4.2.1 VEGETATION

The minesite is located near the confluence of three ecodistricts: the Wrong Lake Ecodistrict, the Nopiming Ecodistrict, and the Pinawa Ecodistrict. Common tree species within the three ecodistricts include jack pine (*Pinus banksiana*) on bedrock and sandy sites and trembling aspen (*Populus tremuloides*) on deeper upland soils. Balsam fir (Abies balsamea), white spruce (*Picea glauca*) and black spruce (*Picea mariana*) also occur. Poorly drained sites generally support open to closed stands of black spruce and tamarack (*Larix laricina*) with an understory of ericaceous shrubs, and a moss ground cover (Smith *et al* 1998). Forest cover immediately surrounding the minesite is consistent with the regional description (Figure 4.4).

The minesite was cleared of vegetation for the construction of surface infrastructure. Natural vegetative re-colonization has occurred in areas that are no longer in use; including the East TMA (Figure 4.5). Some 31 species have naturally re-colonized the East TMA including 21 native and 10 weed species (Table 4.8). Five native trees identified in the East TMA are common to the surrounding forest and wetlands. Areas that had been disturbed within the previous year were dominated by weed species; however, it was apparent that, through natural succession, native species have replaced weed species in older plant communities (>8 yrs post disturbance). Surveys of the natural vegetative colonization of the conventional tailings indicate that natural re-vegetation provides rapid and adequate plant cover (89% after 1 year; and 88% on average after 8+ years) after cessation of tailings placement (Wardrop 2008).

A study of potential re-vegetation methods for the CPF residue was undertaken in 2009. The trial consisted of three vegetation plots on the residue pile, each with three seed mixtures: one was capped with a 50:50 mixture of tailings and CPF residue; one was capped with tailings only; and one was not capped, seed was sown directly into the residue. The residue stockpile is capable of supporting plant growth when capped with conventional tailings from the East TMA. Soil nutrient availability in the residue is higher than in the tailings, indicating that nutrient availability is not a limiting factor for plant growth on the residue. Soil compaction is the most likely reason for the absence of plants on the residue pile (Wardrop 2010a).

Figure 4.4 Forest cover adjacent to the minesite (Sept. 2009).

Figure 4.5 Natural vegetative establishment in the East (inactive) TMA (August 2008).

Table 4.8 Plant species identified within the East TMA (Wardrop 2008).

Common Name	*Scientific Name*
Alsike clover	*Trifolium hybridum*
Balsam poplar	*Populus balsamifera*
Black spruce	*Picea mariana*
Canada fleabane	*Erigeron canadensis*
Canada goldenrod	*Solidago canadensis*
Canada thistle	*Cirsium arvense*
Capillary thread moss	*Meesia uliginosa*
Common horsetail	*Equisetum arvense*
Common ragweed	*Ambrosia artemisiifolia*
Common reed grass	*Phragmites australis*
Common yarrow	*Achillea millefolium*
Crab grass spp.	*Digitaria*
Fireweed	*Epilobium angustifolium*
Foxtail barley	*Hordeum jubatum*
Large-leaved avens	*Geum macrophyllum*
Narrow leaved hawkweed	*Hieracium umbellatum*
Ostrich fern	*Matteuccia struthiopteris*
Purple horn toothed moss	*Ceratodon purpureus*
Pussytoe spp.	*Antennaria spp.*
Raspberry spp.	*Rubus spp.*
Rattlesnake fern	*Botrychium virginianum*
Redtop	*Agrostis stolonifera*
Smooth brome	*Bromus inermis*
Sow thistle spp.	*Sonchus spp.*
Strawberry spp.	*Fragaria spp.*
Tamarack	*Larix laricina*
Trembling aspen	*Populus tremuloides*
White birch	*Betula papyrifera*
White clover	*Trifolium repens*
White sweet clover	*Melilotus alba*
Willow spp.	*Salix spp.*

4.2.2 WILDLIFE

Characteristic regional wildlife includes mammals such as moose (*Alces alces*), black bear (*Ursus americanus*), lynx (*Lynx Canadensis*), and snowshoe hare (*Lepus americanus*). Birds in the region include ruffed grouse (*Bonasa umbellus*), pileated woodpecker (*Dryocopus pileatus*), bald eagle (*Haliaeetus leucocephalus*), as well as many waterfowl and songbird species (Smith *et al* 1998). Several wildlife species are frequently observed within the minesite itself including white tailed deer and red fox.

The local study area is approximately one kilometre southwest of the historical range of the Owl-Flintstone caribou herd of approximately 60 to 70 individuals (Figure 4.6). The range is considered of high conservation concern in Manitoba's *Conservation and Recovery Strategy for Boreal Woodland Caribou* (Manitoba Conservation 2005). The woodland caribou is listed under the Manitoba *Endangered Species Act* and is recognized as Threatened by COSEWIC and under the *Species at Risk Act*. Caribou sightings have not been reported within the local study area (MBCDC 2010) and TANCO mine staff have not reported caribou on the site or along the mine road.

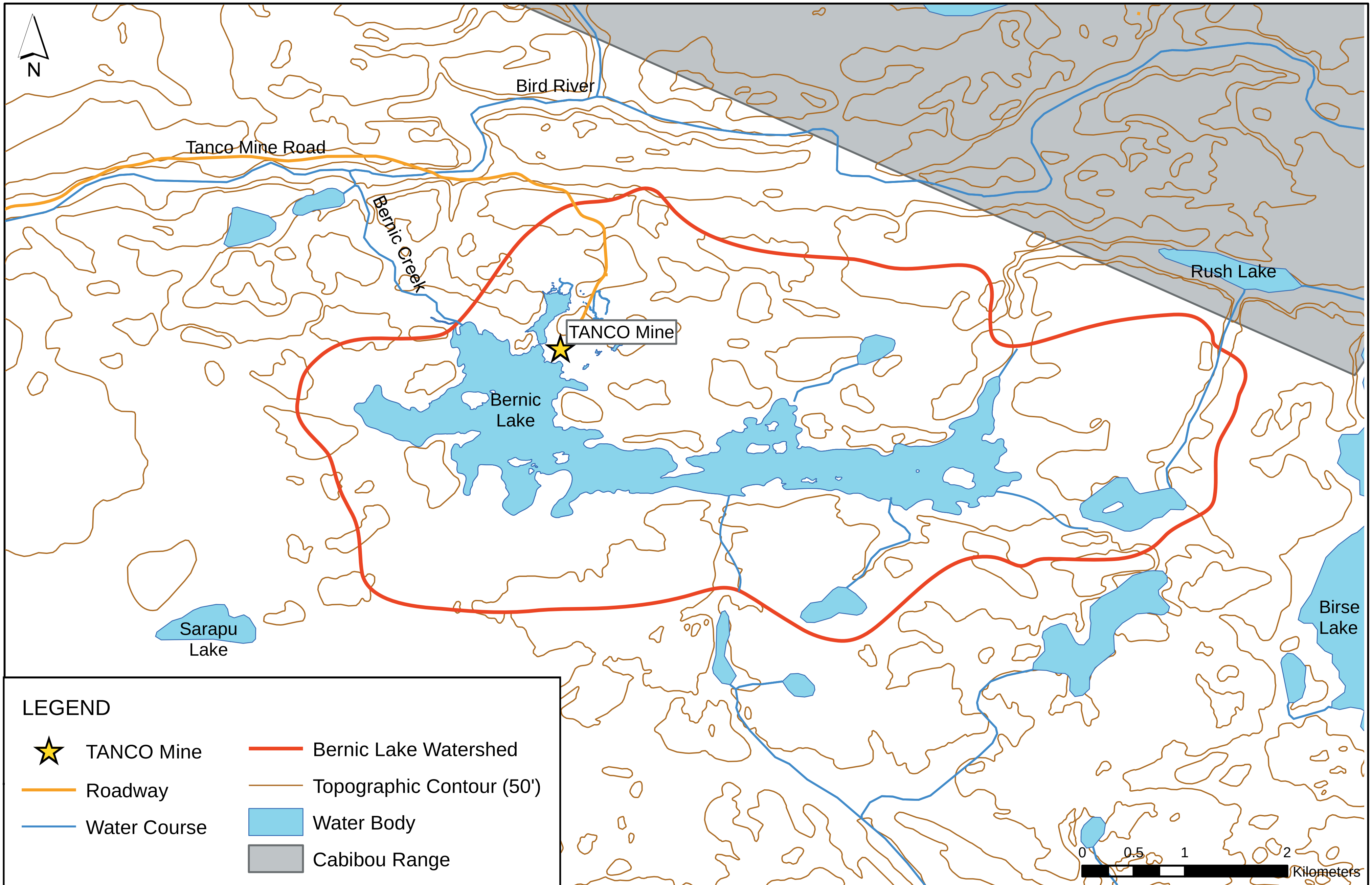

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FIGURE 4.6
OWL-FLINTSTONE CARIBOU RANGE

4.2.3 RARE SPECIES

The Manitoba Conservation Data Centre (MBCDC) tracks plant and animal species of conservation concern within the province. The MBCDC assigns each species a conservation status rank, based on how rare the species is in Manitoba, and then collects detailed information on their locations. The ranking takes into account species listed under Manitoba's *Endangered Species Act* and those which have been assigned a special designation by the Committee on the Status of Endangered Wildlife in Canada (COSEWIC). The MBCDC database was searched to determine if any rare, threatened or endangered flora or fauna have been reported in the local study area. No occurrences of species of conservation concern have been reported in the local study area.

4.3 AQUATIC ENVIRONMENT

The aquatic environment within the local study area is primarily represented by Bernic Lake and its inflowing and outflowing tributaries. Monitoring of aquatic environmental conditions within the local study area has been focused on Bernic Lake, as this is the primary receiving waterbody for effluent from the TANCO Mine, with study also conducted on the Bird River, in the vicinity of the mouth of Bernic Creek, to assess the downstream extent of the mine discharge.

Background water quality in Bernic Lake, prior to the start of mine operations in September 1969, was collected by the Province of Manitoba in May 1968 and June 1969 (Crowe 1969 and 1972a). Manitoba also conducted the initial operations environmental monitoring on Bernic Lake in 1972 and 1975 (Crowe 1972b and 1976). The majority of subsequent studies on Bernic Lake during mine operations have been related to satisfying the requirements of the *Metal Mining Effluent Regulations* (MMER) which came into effect in December 2002. The MMER require regular monitoring of mine effluent quality and of receiving area and reference area water quality. In addition, periodic biological studies are required to assess the aquatic environmental effects of the mine effluent discharge. Biological studies have since been conducted in 2002 (SEACOR 2003) and 2005 (Wardrop 2006) to assess and confirm the biological effects of the mine discharge and in 2008 (Wardrop 2009a) to assess the severity and geographic extent of these effects. An Investigation of Cause (IOC) study was completed in June 2011 to identify the specific cause of the observed biological effects (Tetra Tech 2011b). The following understanding of the current ecological conditions in Bernic Lake has been developed from the studies conducted since 1968.

4.3.1 SURFACE HYDROLOGY

Bernic Lake is a second order lake, receiving inflow from five headwater streams that drain to the eastern and central parts of the lake as well as surface flow directly from the watershed (Figure 2.2 and 4.7). Two of the eastern streams drain small headwater lakes, Birse Lake to the east and a small un-named lake to the south. All of the inflow channels are small, approximately 2 m in width where they discharge to the lake, and typically flow through low-lying bogs. Crowe (1969) indicated the lake was also fed by underground springs, although no foundation for this claim was provided and this appears to be inconsistent with what is known about local hydrogeology.

The lake is comprised of two basins of approximately equal size joined by a narrows (Figure 4.7). Both basins are characterised by relatively steep margins and wide flat bottoms. Physical dimensions of Bernic Lake and its watershed are summarized in Table 4.9.

Table 4.9 Physical characteristics of Bernic Lake and its watershed (SEACOR 2003).

Parameter	Estimate
Drainage Basin Area	1,800 ha
Lake Surface Area	390 ha
Shoreline Length	37.5 km
Mean Depth	8.0 m
Maximum Depth	11.4 m
Lake Residence Time	10 years

A single lake outlet (“Bernic Creek”) drains the western basin via a short stream to the Bird River. A waterfall on the outlet stream presents a barrier to fish movements upstream from the Bird River. The Bird River flows into Lac du Bonnet, which is a widening of the Winnipeg River created by the McArthur Falls hydroelectric generating station.

The Bernic Lake outlet is not gauged. Limited observations indicate the outlet stream may typically flow during the spring freshet but other than during extreme wet periods, the stream is dry along some sections between Bernic Lake and the Bird River.

4.3.2 *Physical Limnology*

The occurrence of open water season thermal stratification has been investigated in Bernic Lake several times over the past 35 years. These surveys (Crowe 1969; Crowe 1972a; Crowe 1972b; Crowe 1976) have clearly demonstrated the occurrence of thermal stratification in late spring and summer, followed by a period of autumnal mixing. It is not known if the lake also undergoes a period of mixing in the spring after ice-out, as sampling has not yet been undertaken sufficiently early in the open water season to capture the onset of stratification. By late June, stratification is well developed, with a uniform epilimnion (surficial mixed layer) temperature to about 4 m depth and a thermocline evident at about 5 m depth. In 2008, lake temperature had become uniform by early October, indicating the period of fall mixing was occurring.

There is some potential for a minor east-west flow in the lake during spring runoff when the outlet is flowing. Otherwise, any water currents in Bernic Lake during the open water season will be wind-driven.

4.3.3 WATER QUALITY

In its natural state Bernic Lake was considered to be a "typical" example of a soft water Shield lake (Crowe 1976), with low hardness (total hardness 10 to 37.6 mg/L), weakly buffered (total alkalinity 6 to 14 mg/L), low to moderate concentrations of TDS (36 to 60 mg/L); slightly acidic pH (6.1 to 7.01), and, transparent (Secchi visibility 1.5 to 1.9 m) but somewhat coloured waters (Table 4.10; Figure 4.7). By 1975, increases in major ion concentrations, alkalinity (total alkalinity 28 mg/L), hardness (total hardness 35.3 mg/L), and TDS (70 mg/L); were evident. These increases were attributed to the mine discharge, but the connection could not be confirmed because mine discharge quality monitoring did not include these parameters at that time (Crowe 1976). More comprehensive effluent sampling was initiated in 1997 in anticipation of the implementation of the Metal Mining Effluent Regulations (MMER), which eventually came into effect in December 2002. This more extensive sampling has since provided confirmation that such changes are attributable to the mine effluent discharge (Wardrop 2009a).

Negligible increases in alkalinity and hardness have occurred since 1975, as indicated by the ranges of the most recent measurements overlapping the 1975 measurements (Table 4.10). The elevated TDS concentrations were evident in 1970, shortly after the mine went into operation, and similarly elevated TDS concentrations were measured in 1975, 2002, 2003, and 2004. A step increase in TDS occurred between 2004 and 2005, with the higher mean concentrations measured through 2010, but with no evidence of a further increase. The cause of this increase is unclear and cannot be traced to any operational change.

No changes in turbidity or suspended solids concentrations appear to have occurred since the pre-development baseline studies but Secchi disk visibility, a measure of water transparency, has decreased markedly, Mean values were 1.9 m in 1968 and 1.5 m in 1969, with mean values of 1.0 m in 2002 and 2003, and with values then gradually declining to 0.5 m by 2009 (Table 4.10). This decrease has occurred in the absence of a significant source of inorganic turbidity to the lake. No areas of shoreline erosion have developed since the baseline studies and the TSS concentrations in the mine discharge are managed in accordance with MMER effluent quality regulations.

The reduced water transparency appears to be attributable to increased algal standing crops. Seasonal mean chlorophyll a concentrations in Bernic Lake have ranged between 0.009 mg/L and 0.032 mg/L from 2002 through 2009, with a mean concentration of 0.019 mg/L over this period (Table 4.10).

The increased algal standing crops in Bernic Lake are directly attributable to the increased total phosphorus concentrations in the lake and the increase in phosphorus can be traced directly to the mine effluent discharge.

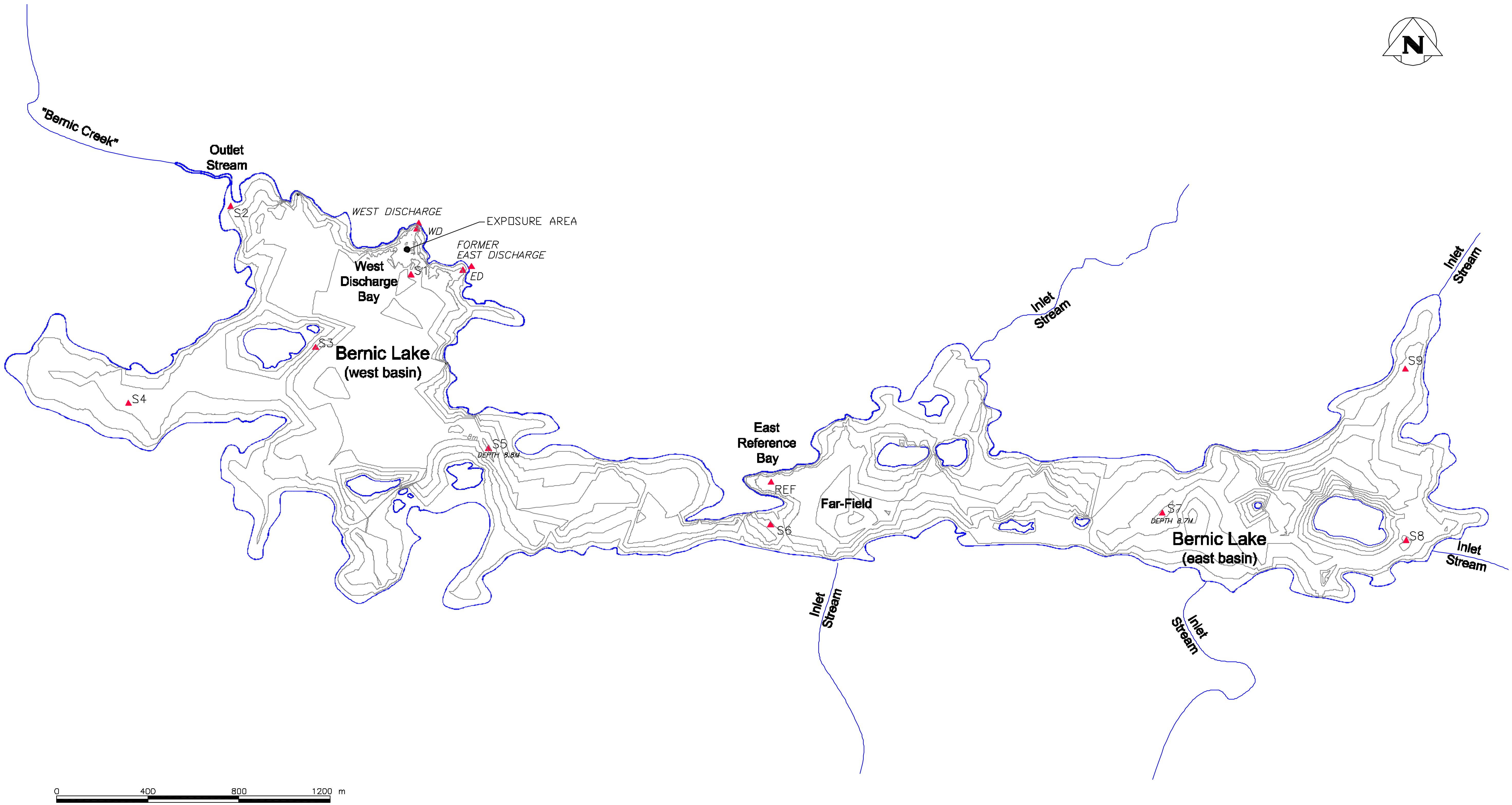
The primary nutrient limiting algal growth in Bernic Lake is phosphorus, as is typically the case in lakes of the Canadian Shield (Schindler 1977). The relative importance of phosphorus (P) and nitrogen (N) in regulating algal growth is evaluated on the basis of the ratio of the total N and total P concentrations in the lake. Sakamoto (1966) and Forsberg et al. (1978) found that P is the limiting nutrient at N:P>17, that N is limiting at N:P<10, and that N and P are jointly limiting at 10≤N:P≥17. Between 2005 and 2009, the only period for which detailed nutrient analyses have been completed in Bernic Lake, the open water seasonal mean N:P ratio in the exposure zone ranged from a low of 20.5:1 in 2009 to a high of 34.2:1 in 2006 (Table 4.10) indicating P-limited conditions throughout the period of consideration.

In the absence of an extensive characterization of baseline water quality in Bernic Lake, as would be undertaken if baseline studies were being initiated today, it is necessary to infer the baseline concentrations of many parameters through consideration of water quality in an appropriate reference lake. Tulabi Lake, located on the Bird River upstream of Bird Lake, approximately 15 km northeast of Bernic Lake is the reference lake used for MMER compliance monitoring. Tulabi Lake was selected after extensive consideration of many lakes in Nopiming Park and in agreement with Manitoba Water Stewardship and Environment Canada. The occurrence of a parameter value in Bernic Lake that differs from the value in Tulabi Lake by a factor of 2 or more is interpreted as a significant difference under the MMER approach in the absence of pre-development baseline data that suggests otherwise. Tables 4.10 through 4.15 contain all water quality data for both Bernic Lake and Tulabi Lakes through 2010 and sample stations are shown in Figures 4.8 and 4.9.

Phosphorus concentrations were not measured in Bernic Lake as part of the pre-mining baseline studies. However, the mine effluent is a documented source of phosphorus (Section 3.15.3) and the weight of evidence clearly indicates that phosphorus concentrations in the lake have increased. Sechhi disk visibility in the reference bay of Tulabi Lake currently are similar to those in Bernic Lake prior to the start of mining operations, indicating the suitability of Tulabi Lake as an indicator of baseline conditions. The open water seasonal mean total phosphorus concentration in Tulabi Lake has ranged from a low of 0.019 mg/L in 2009 to a high of 0.024 mg/L in 2005 (Table 4.11) and conditions have not changed in comparison to the 0.02 mg/L measured by Hagenson and O'Connor (1978) in 1976. In comparison, total phosphorus concentrations in the exposure zone of Bernic Lake were approximately twice as high during the same period, averaging 0.040 mg/L (Table 4.10).

These values also are consistent with the seasonal mean Secchi disk values, which ranged between 0.3 m and 0.9 m during the same period; with both parameters falling in the mesotrophic category of lake trophic status as defined by the United States Environmental Protection Agency (US EPA 1974; Table 4.16).

Notwithstanding the numerous parameters that have increased in Bernic Lake as a result of the mine discharge, most parameters have remained within the Manitoba Water Quality Standards, Objectives, and Guidelines (MWQSOG) for the protection of freshwater aquatic life. Total phosphorus concentrations in Bernic Lake exceeded the Tier III MWQSOG for the prevention of excessive growth of aquatic macrophytes and algae in water bodies where the primary limiting nutrient for algal growth is phosphorus. Seasonal mean concentrations from 2005 to 2009 ranged from 0.0345 to 0.044 mg/L, exceeding the 0.0025 mg/L guideline for lakes. Total iron also exceeded the Tier III MWQSOG in 2004 and 2006.



LEGEND

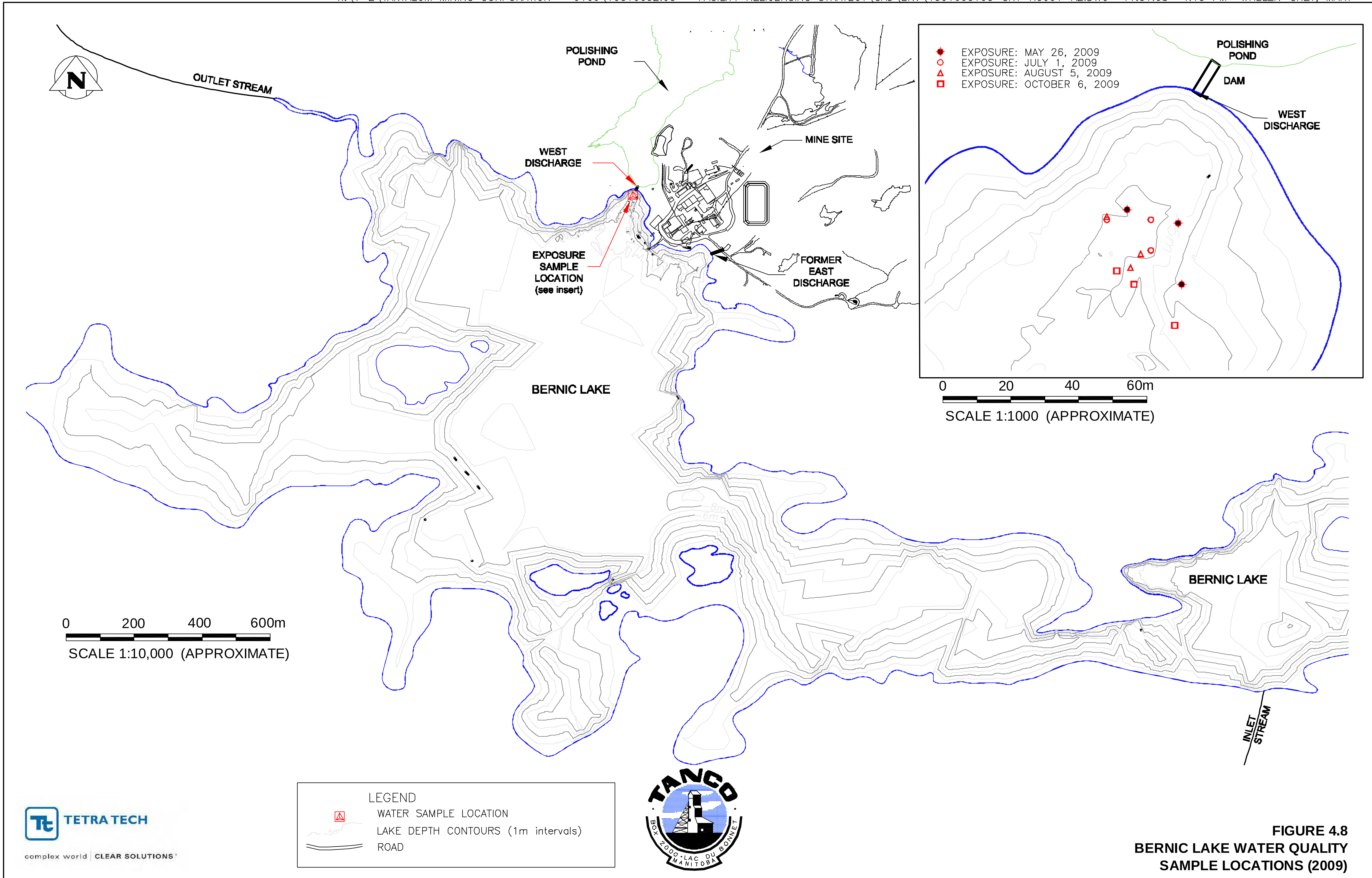
▲ SAMPLE LOCATION

TETRA TECH

complex world | CLEAR SOLUTIONS

TANCO BOX 2000 LAC DU BONNET MANITOBA

FIGURE 4.7
BERNIC LAKE BATHYMETRY AND HISTORIC (1969-1975) WATER QUALITY SAMPLING STATIONS



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TANCO
BOX 2000 · LAC DU BONNET · MANITOBA

FIGURE 4.8
BERNIC LAKE WATER QUALITY SAMPLE LOCATIONS (2009)

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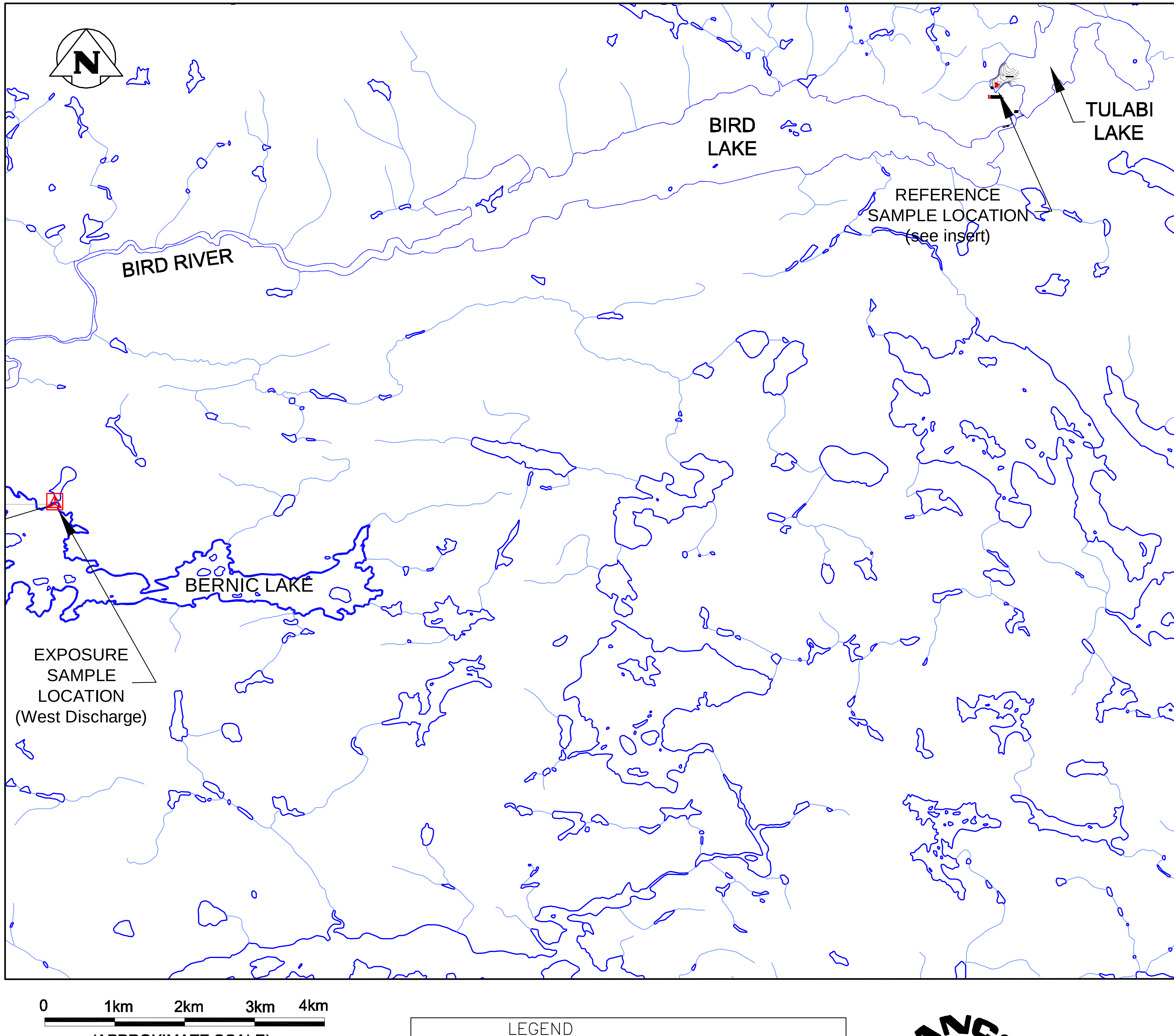

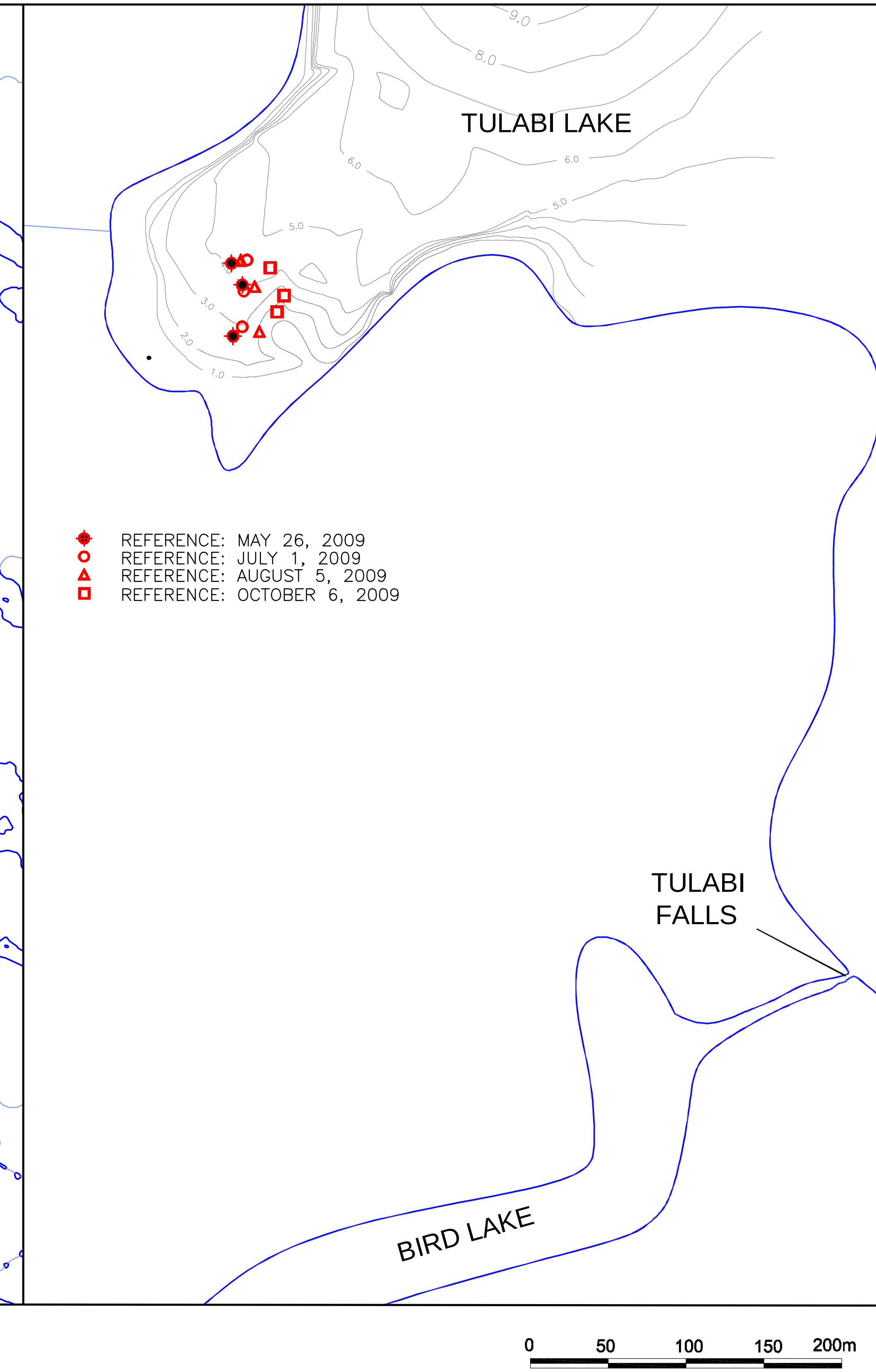

LEGEND
WATER SAMPLE LOCATION
LAKE DEPTH CONTOURS (1m intervals)
ROAD

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TANCO BOX 2000 · LAC DU BONNET MANITOBA

FIGURE 4.9
TULABI LAKE WATER QUALITY SAMPLE LOCATIONS (2009)

Table 4.10 **Water quality in Bernic Lake; 1968 to 1975 and 2002 to 2010. Shaded values exceed the Manitoba Water Quality Standards, Objectives and Guidelines for the Protection of Aquatic Life (MWQSOG, Williamson 2002). See Figures 4.7 and 4.8 for sampling locations. Units are mg/L except as noted.**

Sampling Date	Jun 1968[a] (n = 9; S1 - S9)			May 1969[b] (n = 9; S1 - S9)			May 1970[c] (n = 9; S1 - S9)			Dec 1975[d] (n = 1)	October 2002 (n = 3, summary of S2, S5 & S7)				
Parameter	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**	**Mean**	**Max**	**Min**		**Mean**	**SD**	**Max**	**Min**	**MWQSOG**
Physicochemical															
pH (pH units)	6.85	7.01	6.71	6.5	6.72	6.1	7	7.4	6.7	7.4	7.67	0.08	7.75	7.6	6.5 - 9.0
Hydroxide (OH^-)	--	--	--	--	--	--	--	--	--	--	<5	<5	<5	<5	
Specific Conductance (µS/cm@25°C)	45	48	40	52	80	42	52	70	44	58	132	6	137	126	
Total Dissolved Solids	42	44	36	52	60	42	75	101	55	70	71	5	75	66	
Hardness, dissolved	--	--	--	--	--	--	--	--	--	--	33.9	1.1	35.1	32.9	
Hardness, total	18	19	18	21.8	37.6	10	25	44	20	35.3					
Alkalinity (PP as $CaCO_3$)	--	--	--	--	--	--	--	--	--	--	<5	<5	<5	<5	
Alkalinity (Total as $CaCO_3$)	13	14	12	10	14	6	16	24	12	28	46	4	51	43	
Bicarbonate	15.9	17.1	14.6	12.2	15	7.3	20	29.3	14.6	34	56	5	62	52	
Carbonate	0	--	--	0	--	--	0	--	--	0	<6	<6	<6	<6	
Total Suspended Solids	9	16	4	13	30	2	7	24	1	<5	16	1	16	15	
Turbidity (NTU)	5	15	2	7	25	1	7	10	4	3	--	--	--	--	
True Colour (Col. Units)	36	38	33	61	65	55	65	70	60	5	--	--	--	--	
Secchi depth (m)	1.91	2.45	1.5	1.53	2.15	1.4	--	--	--	--	1.05	0.15	1.15	0.85	
Major Ions															
Potassium, dissolved (K+)	--	--	--	--	--	--	--	--	--	--	3.8	0.4	4.3	3.5	
Sodium, dissolved (Na^+)	1.6	1.9	1.3	2.2	2.8	1.5	1.44	1	2	<10.0	10.4	0.3	10.8	10.2	
Calcium, dissolved (Ca^{2+})	5.7	6.4	5.6	6.8	12.8	5	7.8	12	4.8	7.5	9.7	0.4	10.1	9.4	
Magnesium, dissolved (Mg^{2+})	0.88	1.2	0.48	1.3	2	0.63	1.84	2.44	1.46	4	2.3	0.1	2.4	2.3	
Chloride, dissolved (Cl^-)	0.7	0.9	0.6	1.3	1.5	1.2	0.88	1	0.5	4	6.1	0.8	6.8	5.2	
Fluoride, dissolved (F^-)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Sulphate, dissolved (SO_4^-)	--	--	--	--	--	--	--	--	--	<5.0	11.0	0.7	11.7	10.3	
Nutrients															
Organic Carbon, dissolved	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Organic Carbon, total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrite	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.06
Nitrate	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Nitrate_Nitrite	--	--	--	--	--	--	--	--	--	--	<0.006	<0.006	<0.006	<0.006	
Ammonia	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Total Kjeldahl Nitrogen	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Total Nitrogen	--	--	--	--	--	--	--	--	--	--	--	--	--	--	
Phosphorus, dissolved	--	--	--	--	--	--	--	--	--	--	<0.05	<0.05	<0.05	<0.05	
Phosphorus, total	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.025
Biological															
Chlorophyll a	--	--	--	--	--	--	--	--	--	--	0.032	0.000	0.032	0.032	
Radiochemical															
Radium-226 (Bq/L)	--	--	--	--	--	--	--	--	--	--	--	--	--	--	

Table 4.10 (cont'd) Water quality in Bernic Lake; 1968 to 1975 and 2002 to 2010. Shaded values exceed the Manitoba Water Quality Standards, Objectives and Guidelines for the Protection of Aquatic Life (MWQSOG, Williamson 2002). See Figures 4.7 and 4.8 for sampling locations. Units are mg/L except as noted.

Sampling Date	June to September 2003 (n = 6; S2, S5, S7)				March to September 2004 (n = 5; S2, S5, S7, W)				March to October 2005 (n = 6)				June to September 2006 (n = 4)				
Parameter	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	MWQSOG
Physicochemical																	
pH (pH units)	8.54	0.84	9.35	7.72	7.74	0.38	8.38	7.39	6.8	0.2	7.1	6.7	7.9	0.3	8.3	7.5	6.5 - 9.0
Hydroxide (OH^-)	<5	<5	<5	<5	--	--	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Specific Conductance (µS/cm@25°C)	166	27	221	148	--	--	--	--	152	23	196	135	171	22	203	151	
Total Dissolved Solids	83	3	88	78	--	--	--	--	133	30	182	90	106	12	120	92	
Hardness, dissolved	38.4	0.9	39.9	37.1	--	--	--	--	39	5	48	35	--	--	--	--	
Hardness, total	--	--	--	--	39.5	2.4	43.2	36.9	--	--	--	--	46	5	53	41	
Alkalinity (PP as $CaCO_3$)	--	--	--	--	--	--	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Alkalinity (Total as $CaCO_3$)	50	4	55	45	49	7	55	38	34.5	1.7	36.8	31.5	38.3	3.1	41.4	34.9	
Bicarbonate	53	13	67	40	--	--	--	--	42.1	2.1	44.8	38.4	46.7	3.8	50.5	42.6	
Carbonate	5	3	8	<5	--	--	--	--	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Total Suspended Solids	6	5	12	2	7	3	11	4	8	2	10	4	8	2	11	6	
Turbidity (NTU)	5.8	1.6	8.3	4.4	--	--	--	--	10	3	13	7	10.9	2.4	14.0	8.2	
True Colour (Col. Units)	21	3	24	18	--	--	--	--	33	11	40	15	24	8	30	15	
Secchi depth (m)	1.00	0.10	1.15	0.85	--	--	--	--	0.68	0.03	0.70	0.65	0.89	0.09	0.97	0.76	
Major Ions																	
Potassium, dissolved (K+)	3.8	0.3	4.2	3.4	--	--	--	--	--	--	--	--	--	--	--	--	
Sodium, dissolved (Na^+)	10.9	0.4	11.4	10.2	--	--	--	--	10.1	1.4	12.7	8.7	11.55	1.45	13.60	10.20	
Calcium, dissolved (Ca^{2+})	11.4	0.3	11.9	10.9	--	--	--	--	12.2	1.7	15.3	10.8	14.33	1.89	17.10	12.90	
Magnesium, dissolved (Mg^{2+})	2.45	0.04	2.50	2.39	--	--	--	--	2.15	0.18	2.48	1.96	2.37	0.15	2.56	2.24	
Chloride, dissolved (Cl^-)	6.4	0.2	6.7	6.1	--	--	--	--	5.5	0.7	6.8	5.0	6.0	0.7	6.5	4.9	
Fluoride, dissolved (F^-)	0.31	0.03	0.34	0.27	--	--	--	--	0.3	0.0	0.4	0.3	0.41	0.12	0.58	0.31	
Sulphate, dissolved (SO_4^-)	18.3	1.5	19.6	15.7	--	--	--	--	25.5	6.6	37.9	19.6	30.3	9.2	44.0	24.3	
Nutrients																	
Organic Carbon, dissolved	15.1	0.5	15.8	14.6	--	--	--	--	17	1	17	16	13.1	0.9	13.9	12.2	
Organic Carbon, total	15.6	1.0	17.1	14.3	--	--	--	--	15	0	15	15	12.8	0.8	13.6	12.0	
Nitrite	--	--	--	--	--	--	--	--	<0.005	<0.005	0.011	<0.005	0.005	0.005	0.013	<0.005	0.06
Nitrate	--	--	--	--	0.15	0.15	0.38	<0.05	0.2	0.3	0.7	<0.02	0.09	0.05	0.13	<0.02	
Nitrate_Nitrite	<0.05	<0.05	0.06	<0.05	--	--	--	--	0.2	0.3	0.7	<0.02	0.09	0.05	0.13	<0.02	
Ammonia	0.16	0.15	0.30	<0.05	0.22	0.16	0.37	<0.05	0.09	0.18	0.46	0.01	0.010	0.009	0.020	<0.005	
Total Kjeldahl Nitrogen	--	--	--	--	--	--	--	--	1.2	0.1	1.3	1.0	1.09	0.49	1.80	0.70	
Total Nitrogen	--	--	--	--	--	--	--	--	1.3	0.4	2.0	1.1	1.18	0.53	1.93	0.70	
Phosphorus, dissolved	<0.05	<0.05	0.06	<0.05	--	--	--	--	<0.005	<0.005	0.009	<0.005	0.01275	0.014	0.033	0.004	
Phosphorus, total	<0.05	<0.05	0.10	<0.05	--	--	--	--	0.044	0.013	0.059	0.023	0.0345	0.006	0.041	0.027	0.025
Biological																	
Chlorophyll a	0.017	0.006	0.025	0.011	--	--	--	--	0.009	0.005	0.015	0.004	0.02705	0.0154	0.0489	0.0133	
Radiochemical																	
Radium-226 (Bq/L)	--	--	--	--	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	

Table 4.10 (cont'd) **Water quality in Bernic Lake; 1968 to 1975 and 2002 to 2010. Shaded values exceed the Manitoba Water Quality Standards, Objectives and Guidelines for the Protection of Aquatic Life (MWQSOG, Williamson 2002). See Figures 4.7 and 4.8 for sampling locations. Units are mg/L except as noted.**

Sampling Date	June to October 2007 (n = 4)				June to October 2008 (n = 4)				May to October 2009 (n = 4)				June to October 2010 (n = 4)				
Parameter	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	MWQSOG
Physicochemical																	
pH (pH units)	7.7	0.1	7.8	7.6	7.5	0.05	7.6	7.5	7.6	0.1	7.7	7.5	7.7	0.1	7.8	7.6	6.5 - 9.0
Hydroxide (OH^-)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Specific Conductance (µS/cm@25°C)	147	7	152	136	170	18	190	150	144	9	150	131	121	9	131	111	
Total Dissolved Solids	113	19	136	94	123	17	140	100	114	19	140	94	90	8	96	82	
Hardness, dissolved	39.8	1.3	40.9	38.6	42.9	2.6	46.3	40.6	39.0	2.1	40.2	35.9	33.9	0.8	34.6	32.9	
Hardness, total	40.0	2.1	41.3	36.8	43.8	2.4	46.1	41.2	37.9	3.0	41.5	34.7	35.7	2.2	38.8	33.6	
Alkalinity (PP as $CaCO_3$)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Alkalinity (Total as $CaCO_3$)	32.7	2.3	35.6	30.1	28.0	2.2	31.0	26.0	33	2	35	30	37	3	39	32	
Bicarbonate	39.9	2.9	43.5	36.8	34.3	2.6	38.0	32.0	40	3	43	36	45	4	48	39	
Carbonate	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Total Suspended Solids	7	2	10	5	8	1	10	7	11	1	12	9	13	2	15	10	
Turbidity (NTU)	9.2	3.2	12.0	6.0	11.3	1.6	12.7	9.0	17.6	2.2	19.5	14.4	16.4	3.0	19.1	12.2	
True Colour (Col. Units)	33	5	40	30	33	5	40	30	40	8	50	30	48	5	50	40	
Secchi depth (m)	0.73	0.29	1.10	0.40	0.60	0.28	0.90	0.25	0.52	0.28	0.93	0.25	0.30	0.01	0.35	0.3	
Major Ions																	
Potassium, dissolved (K+)	3.36	0.25	3.61	3.12	3.69	0.29	3.95	3.36	2.99	0.20	3.22	2.75	2.55	0.06	2.60	2.50	
Sodium, dissolved (Na^+)	9.6	0.7	10.4	8.9	9.32	0.84	10.40	8.40	8.00	0.64	8.56	7.44	6.82	0.37	7.29	6.40	
Calcium, dissolved (Ca^{2+})	12.4	0.4	12.8	12.0	13.48	0.90	14.60	12.70	12.1	0.7	12.5	11.0	10.3	0.4	10.7	9.9	
Magnesium, dissolved (Mg^{2+})	2.16	0.06	2.25	2.10	2.25	0.10	2.37	2.12	2.15	0.07	2.20	2.05	2.02	0.09	2.10	1.90	
Chloride, dissolved (Cl^-)	5.1	0.2	5.3	5.0	4.9	0.5	5.4	4.3	4.2	0.3	4.5	3.9	3.3	0.5	3.9	2.6	
Fluoride, dissolved (F^-)	0.33	0.04	0.38	0.29	0.35	0.04	0.39	0.31	0.29	0.02	0.31	0.27	0.23	0.03	0.25	0.19	
Sulphate, dissolved (SO_4^-)	27.1	3.9	32.0	22.9	38.5	6.0	45.0	32.0	29	7	37	20	17	3	21	14	
Nutrients																	
Organic Carbon, dissolved	12.7	1.4	14.3	11.3	7.8	5.0	10.5	<0.5	11.9	1.1	12.9	10.7	12.1	1.6	14.3	10.7	
Organic Carbon, total	13.3	1.4	14.4	11.4	11.8	0.4	12.3	11.5	12.3	1.4	13.6	10.3	12.7	1.6	14.6	11.3	
Nitrite	<0.002	<0.002	0.002	<0.002	0.006	0.005	0.011	<0.002	<0.002	<0.002	0.005	<0.002	<0.002	<0.002	<0.002	<0.002	0.06
Nitrate	0.012	0.012	0.023	<0.002	0.131	0.169	0.368	0.005	0.046	0.088	0.177	<0.002	0.003	0.003	0.007	<0.002	
Nitrate_Nitrite	0.013	0.014	0.025	<0.002	0.137	0.173	0.379	0.005	0.047	0.090	0.182	<0.002	0.003	0.003	0.007	<0.002	
Ammonia	<0.005	<0.005	0.007	<0.005	0.28	0.52	1.06	<0.01	0.01	0.01	0.03	<0.005	0.02	0.02	0.02	0.005	
Total Kjeldahl Nitrogen	1.08	0.22	1.35	0.86	0.78	0.57	1.28	0.01	0.78	0.43	1.22	0.38	0.83	0.30	1.22	0.51	
Total Nitrogen	1.09	0.22	1.35	0.88	1.17	0.40	1.66	0.68	0.82	0.38	1.23	0.44	0.81	0.36	1.22	0.52	
Phosphorus, dissolved	0.032	0.020	0.053	0.005	0.011	0.003	0.014	<0.005	0.025	0.025	0.058	0.006	0.017	0.018	0.044	0.004	
Phosphorus, total	0.042	0.016	0.058	0.021	0.039	0.013	0.050	0.020	0.040	0.025	0.062	0.008	0.040	0.042	0.096	0.007	0.025
Biological																	
Chlorophyll a	0.0165	0.0085	0.0278	0.0071	0.0161	0.0064	0.0226	0.0082	0.0174	0.0064	0.0240	0.0088	0.00973	0.00476	0.0166	0.0062	
Radiochemical																	
Radium-226 (Bq/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	0.006	<0.005	<0.005	<0.005	0.007	<0.005	<0.005	<0.005	<0.005	<0.005	

[a]Crowe (1969); [b]Crowe (1972a); [c]Crowe (1972b); [d]Crowe (1976)

Table 4.11 Water quality in Tulabi Lake; 2005 to 2010. Shaded values exceed the Manitoba Water Quality Standards, Objectives and Guidelines for the Protection of Aquatic Life (MWQSOG; Williamson 2002). See Figure 4.9 for sampling locations. Units are mg/L except as noted.

Sampling Date	March to October 2005 (n = 6)				June to September 2006 (n = 4)				June to October 2007 (n = 4)				
Parameter	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	MWQSOG
Physico-chemical													
pH (pH units)	6.7	0.3	7.1	6.4	7.4	0.2	7.6	7.1	7.2	0.1	7.2	7.1	6.5 - 9.0
Hydroxide (OH^-)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Specific Conductance (µS/cm@25°C)	79	49	131	34	37	1	38	36	32	2	34	30	
Total Dissolved Solids	68	47	115	20	32	6	38	24	45	8	54	38	
Hardness, dissolved	25	11	35	14	--	--	--	--	14	1	15	14	
Hardness, total	--	--	--	--	15.8	0.5	16.0	15.0	13.9	1.0	15.2	13.0	
Alkalinity (PP as $CaCO_3$)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Alkalinity (Total as $CaCO_3$)	22.7	11.2	35.7	11.6	12.2	0.2	12.4	11.9	9.6	0.5	10.1	9.1	
Bicarbonate	27.6	13.6	43.5	14.2	14.8	0.3	15.1	14.5	11.8	0.6	12.4	11.1	
Carbonate	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Total Suspended Solids	3	2	6	<1	2	1	3	1	2	1	3	2	
Turbidity (NTU)	4.5	2.9	7.8	1.8	1.4	0.4	1.7	1.0	2.2	0.7	3.1	1.4	
True Colour (Col. Units)	44	5	50	40	33	5	40	30	43	5	50	40	
Secchi depth (m)	1.92	0.09	2.00	1.80	2.87	0.41	3.44	2.56	1.38	0.15	1.50	1.20	
Major Ions													
Potassium, dissolved (K^+)	--	--	--	--	--	--	--	--	0.65	0.05	0.70	0.60	
Sodium, dissolved (Na^+)	4.89	4.25	9.39	1.02	1.09	0.05	1.14	1.02	0.94	0.06	0.99	0.88	
Calcium, dissolved (Ca^{2+})	6.93	3.76	10.50	3.46	3.90	0.16	4.12	3.75	3.53	0.11	3.63	3.42	
Magnesium, dissolved (Mg^{2+})	1.74	0.38	2.17	1.39	1.47	0.06	1.55	1.43	1.34	0.06	1.40	1.28	
Chloride, dissolved (Cl^-)	2.6	2.0	5.2	0.8	0.5	0.4	1.1	<0.5	1.0	0.9	2.2	<0.5	
Fluoride, dissolved (F^-)	0.14	0.10	0.25	0.04	0.06	0.01	0.07	0.04	0.05	0.01	0.06	0.03	
Sulphate, dissolved (SO_4^-)	9.4	8.4	17.8	1.7	0.7	0.6	1.6	<0.5	0.7	0.3	0.9	<0.5	
Nutrients													
Organic Carbon, dissolved	13.9	3.5	19.0	10.7	10.5	0.4	11.0	10.1	11.1	0.3	11.4	10.8	
Organic Carbon, total	13.0	3.5	18.0	9.8	10.2	0.5	10.8	9.6	11.8	1.1	13.0	10.3	
Nitrite	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.002	0.0005	0.002	<0.002	0.06
Nitrate	0.0483	0.0564	0.1600	0.0100	0.0425	0.0395	0.0900	<0.020	0.0095	0.0070	0.0180	<0.002	
Nitrate_Nitrite	0.0483	0.0564	0.1600	0.0100	0.0425	0.0395	0.0900	<0.020	0.0110	0.0079	0.0200	<0.002	
Ammonia	0.068	0.109	0.290	0.015	0.013	0.012	0.024	<0.005	0.008	0.008	0.019	<0.005	
Total Kjeldahl Nitrogen	0.76	0.37	1.30	0.43	0.33	0.20	0.49	0.05	0.51	0.06	0.58	0.44	
Total Nitrogen	0.82	0.41	1.35	0.46	0.37	0.18	0.55	0.14	0.52	0.05	0.59	0.46	
Phosphorus, total dissolved	0.011	0.005	0.017	0.005	0.009	0.006	0.016	0.003	0.019	0.012	0.032	0.005	
Phosphorus, total	0.022	0.009	0.039	0.015	0.021	0.002	0.023	0.018	0.022	0.009	0.034	0.012	0.025
Biological													
Chlorophyll a	0.0060	0.0027	0.0091	0.0039	0.0029	0.0009	0.0040	0.0018	0.0047	0.0005	0.0054	0.0042	
Radiochemical													
Radium 226 (Bq/L)	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.010	<0.005	<0.005	<0.005	<0.005	

Table 4.11 (cont'd) Water quality in Tulabi Lake; 2005 to 2010. Shaded values exceed the Manitoba Water Quality Standards, Objectives and Guidelines for the Protection of Aquatic Life (MWQSOG; Williamson 2002). See Figure 4.9 for sampling locations. Units are mg/L except as noted.

Sampling Date	June to October 2008 (n = 4)				May to September 2009 (n = 4)				May to September 2010 (n = 4)				
Parameter	Mean	SD	Max	Min	Mean	SD	Max	Min	Mean	SD	Max	Min	MWQSOG
Physico-chemical													
pH (pH units)	7.0	0.2	7.3	6.8	7.1	0.1	7.2	7.0	7.07	0.10	7.20	6.98	6.5 - 9.0
Hydroxide (OH^-)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Specific Conductance (µS/cm@25°C)	32	1	33	30	31	2	33	29	31	2	33	28	
Total Dissolved Solids	38	16	62	28	33	8	42	24	21	4	26	16	
Hardness, dissolved	14	1	15	13	14	1	15	14	14.0	1.2	15.6	12.8	
Hardness, total	14.5	0.4	14.9	14.0	13.7	0.8	14.8	12.9	14.3	1.3	16.3	13.4	
Alkalinity (PP as $CaCO_3$)	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Alkalinity (Total as $CaCO_3$)	7.0	2.3	10.0	4.9	10.1	0.7	11.0	9.5	11.4	1.5	13.0	9.6	
Bicarbonate	8.6	2.7	12.0	6.0	12.3	0.5	13.0	12.0	14.0	1.8	16.0	12.0	
Carbonate	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	<0.5	
Total Suspended Solids	2	1	2	1	3	1	4	2	2	1	3	1	
Turbidity (NTU)	3.1	3.3	7.9	0.9	2.7	1.1	4.2	1.6	2.1	0.8	3.1	1.2	
True Colour (Col. Units)	43	5	50	40	55	6	60	50	48	5	50	40	
Secchi depth (m)	1.75	0.12	1.90	1.50	1.48	0.26	1.85	1.10					
Major Ions													
Potassium, dissolved (K^+)	0.58	0.05	0.62	0.51	0.57	0.04	0.61	0.53	0.6	0.0	0.6	0.5	
Sodium, dissolved (Na^+)	0.88	0.04	0.92	0.83	0.84	0.07	0.94	0.78	0.8	0.0	0.9	0.8	
Calcium, dissolved (Ca^{2+})	3.45	0.17	3.69	3.32	3.46	0.17	3.70	3.32	3.4	0.3	3.8	3.1	
Magnesium, dissolved (Mg^{2+})	1.29	0.10	1.43	1.20	1.34	0.11	1.50	1.27	1.4	0.1	1.5	1.2	
Chloride, dissolved (Cl^-)	0.8	0.2	1.1	0.6	1.0	0.1	1.2	0.9	<0.5	0.5	0.7	<0.5	
Fluoride, dissolved (F^-)	0.13	0.18	0.39	0.03	0.04	0.01	0.05	0.04	0.05	0.02	0.07	0.04	
Sulphate, dissolved (SO_4^-)	1.4	1.6	3.8	<0.5	1.0	0.4	1.3	0.5	<0.5	0.2	0.7	<0.5	
Nutrients													
Organic Carbon, dissolved	10.9	1.3	11.9	9.1	11.5	1.7	13.8	10.0	10.4	0.5	11.1	10.0	
Organic Carbon, total	10.9	0.9	11.7	9.8	11.4	1.8	13.4	9.0	10.8	0.1	10.9	10.6	
Nitrite	0.0025	0.001732051	0.005	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	<0.002	0.003	<0.002	0.06
Nitrate	0.0040	0.0041	0.0100	<0.002	0.0183	0.0154	0.0400	0.0060	0.011	0.006	0.017	0.007	
Nitrate_Nitrite	0.0063	0.0048	0.0120	<0.002	0.0183	0.0154	0.0400	0.0060	0.009	0.007	0.017	<0.002	
Ammonia	0.105	0.124	0.290	<0.01	0.038	0.055	0.120	0.008	0.033	0.026	0.058	<0.005	
Total Kjeldahl Nitrogen	0.25	0.16	0.36	0.01	0.34	0.06	0.40	0.27	0.44	0.09	0.54	0.38	
Total Nitrogen	0.32	0.04	0.36	0.28	0.36	0.06	0.42	0.31	0.48	0.10	0.60	0.39	
Phosphorus, total dissolved	0.008	0.006	0.014	<0.005	0.016	0.012	0.031	0.006	0.004	0.003	0.008	<0.002	
Phosphorus, total	0.021	0.010	0.035	0.013	0.019	0.010	0.033	0.010	0.007	0.004	0.012	0.002	0.025
Biological													
Chlorophyll a	0.0033	0.0011	0.0042	0.0017	3.3500	0.8185	4.2000	2.6000	2.5	0.5	3.2	2.0	
Radiochemical													
Radium 226 (Bq/L)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	