ANNEX X: APPENDIX F

BASELINE MODEL CALIBRATION

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Abbreviations

Abbreviation	Definition
e.g.	for example
BSA	baseline study area
GIS	Geographic Information System
LiDAR	light detection and ranging
RC	rainfall runoff coefficient
SC	snowfall runoff coefficient

Units of Measure

Unit	Definition
%	percent
<	less than
>	greater than
ha	hectare
°C	degrees Celsius
km^2	square kilometres
m	metre
m^3/s	cubic metres per second
masl	metres above sea level
mm	millimetre
mm/°C	millimetres per degrees Celsius
w ($m^{1.5}/s$)	weir equation coefficient variable “w”

F1 INTRODUCTION

A water balance model was developed for the Lac de Gras basin to assess mean characteristics and natural variability of discharge and water levels of lake outlets in the baseline area. This appendix describes the water balance model including input data, model structure, calibration, preliminary validation, and results.

The water balance model was developed using GoldSim software with a 4-hour time step and input data for the period of 1959 to 2013. Model output results were obtained for years 1964 to 2013, after a five-year output period in which lake elevations were allowed to equilibrate. The output time period was selected to correspond with the climate data derived for the site and with long-term hydrological monitoring data from the Point Lake (Station 10PB001) and Desteffany Lake (Station 10PA001) stations on the Coppermine River (Environment Canada 2014). The basic water balance elements for each modelled lake reservoir considered rainfall and snowmelt runoff, lake evaporation, changes in lake storage, and outflow to downstream basins.

The model was calibrated using runoff coefficients for land surfaces, lake outlet stage-discharge rating curves, and degree-day models for snowmelt and formation of ice in outlet channels. Runoff coefficients for land surfaces account for water losses to ground infiltration and summer evapotranspiration. The runoff coefficients were calibrated to the calculated annual water yield of hydrometric stations on the Coppermine River. Lake outlet stage-discharge rating curves and degree-day models were calibrated to site-specific data in the Lac du Sauvage and Lac de Gras basins.

The calibrated model was used to generate daily time series datasets of lake stages and lake outlet discharges for the baseline area, including the entire Lac du Sauvage basin, the Paul Lake basin, and key sub-basin lake outlets to Lac de Gras. Frequency analyses performed for key sites provide a historical baseline of lake stage and lake outlet discharge regimes.

F2 OBJECTIVES AND LIMITATIONS

The water balance model for the Lac du Sauvage and Lac de Gras basins was developed to allow baseline conditions and changes due to the Project to be estimated on broader and finer spatial and temporal scales than represented by historical or site-specific data. It allows changes to be evaluated for waterbodies with limited or no gauging data, with consideration of long-term natural variability.

The water balance model considers physical characteristics of the basins and derived long-term meteorology for the hydrology baseline study area (BSA). The baseline meteorology is intended to represent the long-term mean and variability at the Project, but is not intended to represent conditions at specific locations on specific dates. For example, a rainstorm that may have occurred in the Lac du Sauvage basin in the summer of a specific year may not be present in the baseline meteorology series. Similarly, differences in site-specific snowpack and temperature are expected to be present for any given year. However, over the long term, mean and extreme rainfall characteristics at that location should be represented.

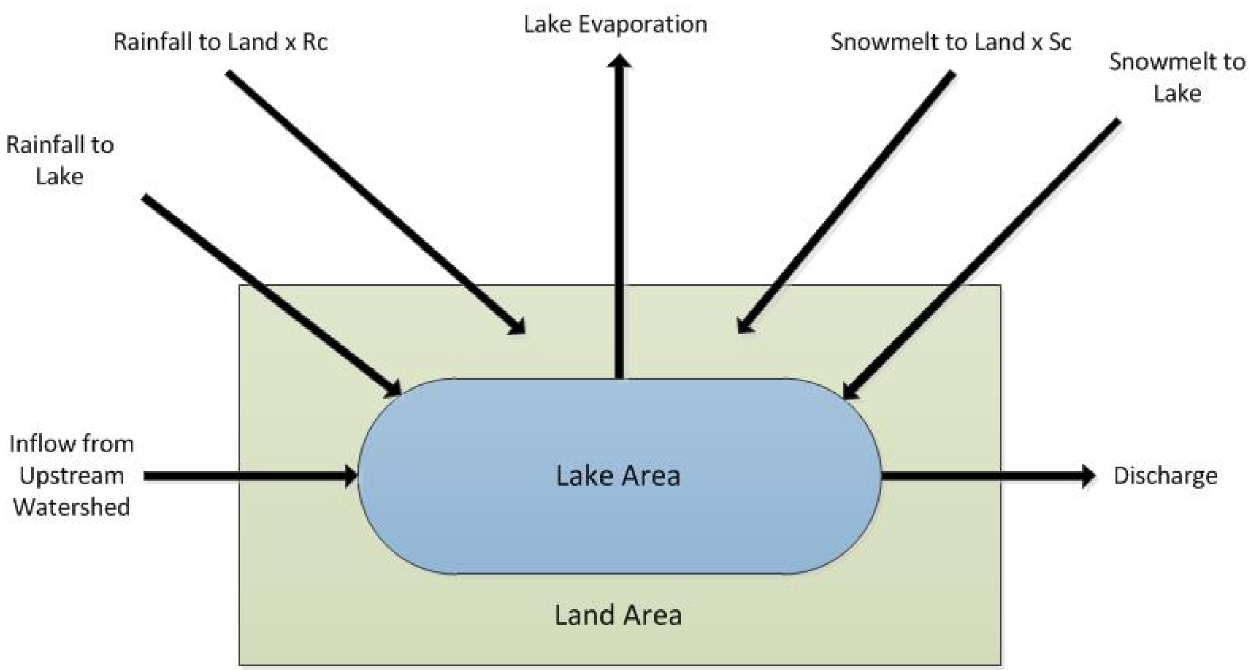
For this reason, measured and modelled hydrographs at specific locations are not expected to match precisely. However, the hydrological statistics at specific locations (e.g., the Lac de Gras outlet) are expected to be adequately represented by the water balance model. It is recognized that future monitoring efforts should focus on further validation and, if necessary, re-calibration of the water balance model.

F3 MODEL STRUCTURE

Each lake in the Lac du Sauvage basin with a surface area greater than 4 hectares (ha) (refer to Basin Characteristics, Appendix D) was modelled as a reservoir as described in the schematic diagram (Figure F3-1). Inflows to the reservoir consisted of inflows from upstream basins and local basin rainfall and snowmelt, including a runoff coefficient to account for infiltration and evapotranspiration losses. Snow water equivalents were calculated based on a sublimation coefficient to account for snowpack losses, and snowmelt rates were calculated using a degree-day model. Outflows consisted of lake outlet discharges and evaporative losses. Modelled lakes accounted for differences between inputs and outputs by calculating corresponding changes in lake storage volumes.

A key assumption of the model is that losses to deep groundwater and changes to shallow groundwater storage are not significant, due to the local permafrost regime and the associated low connectivity of shallow and deep groundwater systems.

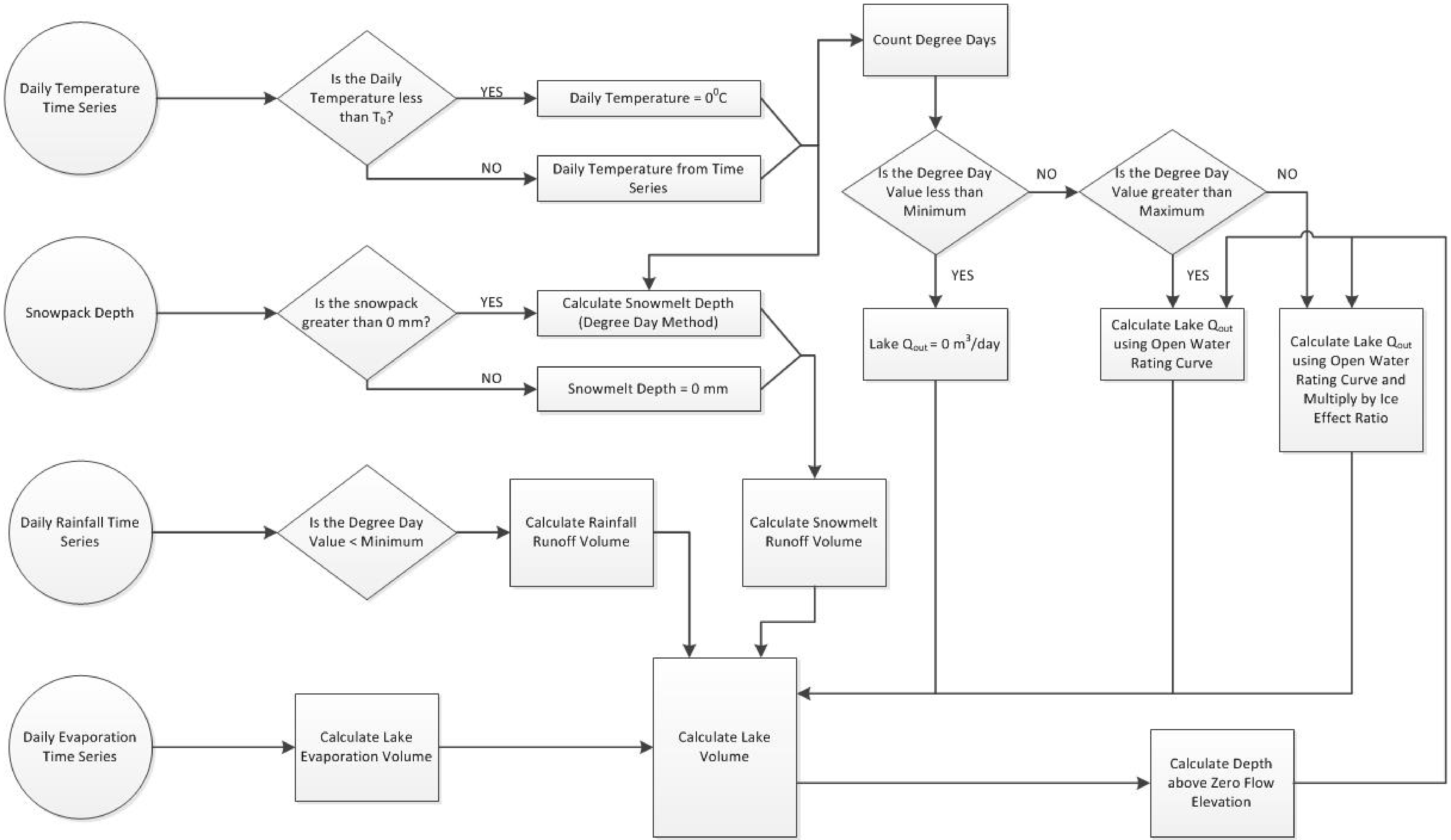
Figure F3-1 Schematic of Typical Lake Reservoir Model



RC = rainfall runoff coefficient; SC = snowfall runoff coefficient

The lake inflows and outflows were calculated according to the flowchart shown in Figure F3-2.

Figure F3-2 Water Balance Model Flowchart



°C = degrees Celsius; mm = millimetre; T_b = base temperature; Q_{out} = discharge out; m^3/day = cubic metres per day.

F3.1.1 Meteorological Data

The water balance model used a combined derived and measured daily climate set for the period of 1959 to 2013. The derived climate dataset consisted of daily rainfall, snowfall, lake evaporation, and temperature data. A description of data sources and the derivation of the climate dataset are provided in Section 3.4 and Section 4 of this Hydrology Baseline Report.

Derived Climate Data (Appendix B) of this report presents derived monthly and annual values for mean air temperature, total rainfall, total snowfall, total precipitation, and total lake evaporation.

F3.1.2 Basin Characteristics and Geographic Information System Analysis

The Lac de Gras basin is approximately 4,131 square kilometres (km^2) and contains thousands of connected lakes, with Lac de Gras as the terminal lake. The entire Lac de Gras basin was modelled to provide data regarding potential flow regime, lake outlet discharge, and lake stage changes.
The Lac de Gras basin contains the Lac du Sauvage and Paul Lake basins. Due to the Project location and description, the Lac du Sauvage and Paul Lake basins were modelled to a higher level of detail, including modelling of individual lakes within the basins.

Basin delineation and analysis was conducted on the light detection and ranging (LiDAR) dataset by Aurora Geosciences Ltd. (2013). Stream general locations were based on Canvec 1:50,000 features, alignment modified using a flow accumulation surface derived from LiDAR data. A flow direction raster was created and used to calculate all areas upstream that contributed to the catchment of each lake and stream. The lake polygons and 10-m buffers of the streams were used as “pour points” for this analysis. The lake polygons were overlaid with the resulting basin polygons to determine the ratio of water and land in each basin. The Geographic Information System (GIS) analysis was performed using ArcGIS 10.1.

F3.1.2.1 Lac du Sauvage Basin Characteristics

The Lac du Sauvage basin is a sub-basin of the Lac de Gras basin covering approximately 1,500 km^2. Lac du Sauvage is the terminal lake of its basin and discharges directly to Lac de Gras.

The Lac du Sauvage sub-basins, lakes, streams, and existing mine developments are shown in Map D-1.

F3.1.2.1.1 Land and Lake Areas

The 476 lakes of the Lac du Sauvage basin with surface area greater than 4 ha were modelled as individual reservoir elements. A list of basin characteristics used in the water balance model is provided in Appendix D.

F3.1.2.1.2 Outlet Rating Curves

Lake outlet rating curves were developed using one of the following three methods:

1) Stage-discharge rating curves were developed for Lac de Gras, Lake E10 (Ursula Lake), and Lake D3 (Counts Lake) outlets from historical stage-discharge data obtained from information requests to operators and past consultants (Vista 1997; ERM Rescan 2013a,b).

2) Stage-discharge rating curves for streams surveyed during 2013 were developed using one-dimensional (1D) hydraulic modelling software (HEC-RAS) for streams with multiple transects, or the open channel flow Manning equation for streams with one transect. The method used to develop rating curves at the hydrometric stations and hydrology survey sites visited in 2013 is listed in Table F3-1.

3) Stage-discharge rating curves were derived for lake outlets with no available data, or those with poor data, based on the assumption that in erodible terrain, the lake outlet geometry would be related to the flood flow regime, and that flood peak discharges would be roughly proportional to basin areas. The following weir equation was used to estimate the rating curve based on the basin area at the lake outlet:

Equation F3.1-1: Broad-Crested Weir Equation

$$Q = w\,y^{1.5}$$

where:

Q = discharge (m^3/s);

w (DA>90 km^2) = 0.007(DA) + 0.90 (from regional analysis);

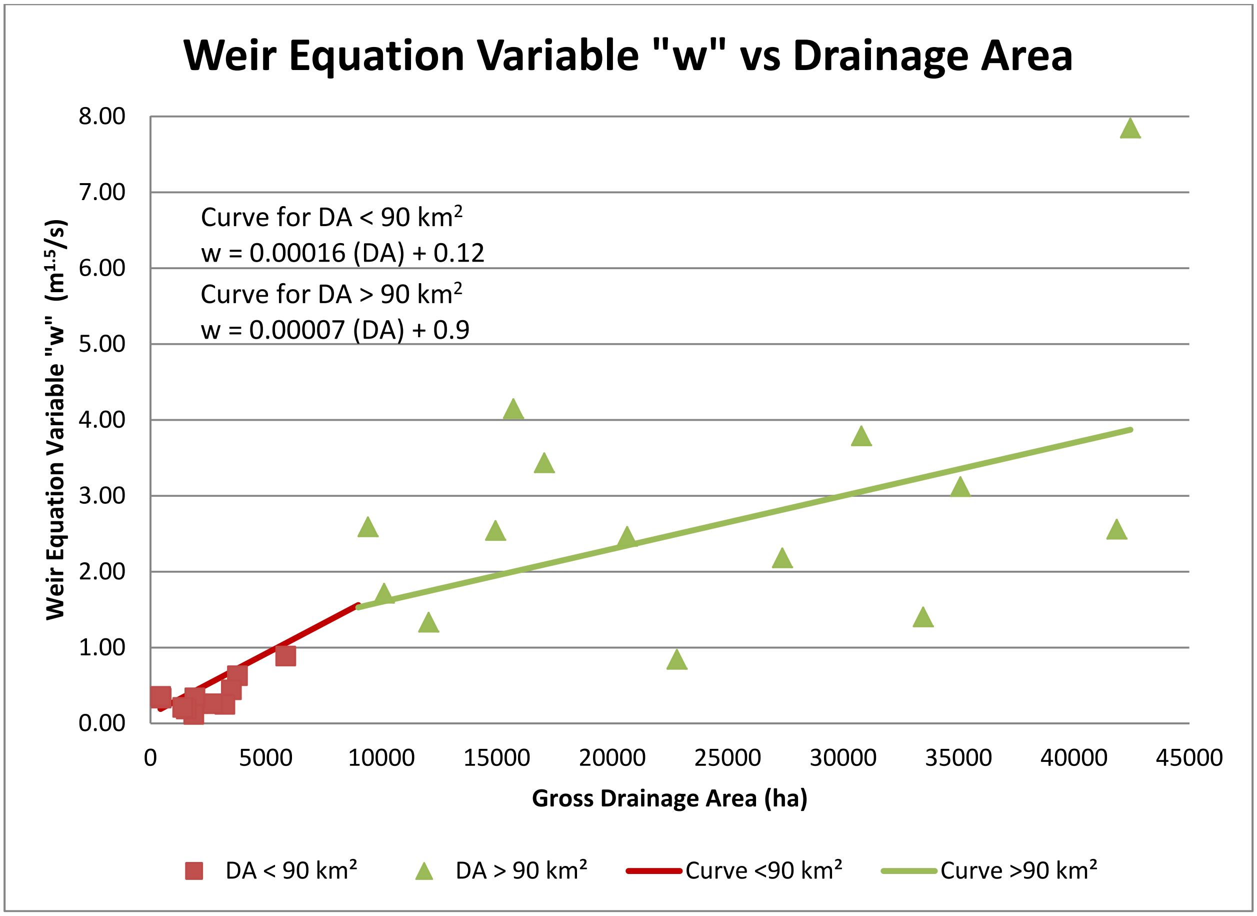
w (DA<90 km^2) = 0.016(DA) + 0.12 (from regional analysis);

y = depth above zero-flow elevation (m); and,

DA = gross basin drainage area (km^2).

The stage exponent (1.5) of the equation was specified based on the broad-crested weir equation, and values of *w* for each lake outlet were estimated to best fit the theoretical equation to each set of stage-discharge data. The equation for *w* was based on a regional analysis of stage-discharge rating curves at lake outlets monitored by the hydrometric programs, using the highest recorded discharges. An analysis was completed to determine if the equation for *w* was a function of lake outlet physical characteristics (e.g., rock garden or entrenched channel) or drainage area, but the regional equation for *w* was found to be applicable for all modelled outlet types and gross drainage areas. The coefficient *w* is presented in Figure F3-3 as a function of gross basin drainage area.

Figure F3-3 Rating Curve Value and Gross Drainage Area Relationship



$m^{1.5}/s$ = weir equation coefficient; km^2 = square kilometres; < = less than; > = greater than; ha = hectare; DA = drainage area.

The list of lake outlets with hydrometric data and the method used to calculate the rating curve is provided in Table F3-1.

Table F3-1 Rating Curve Development Method

Method Used to Develop Outlet Rating Curve	Survey or Hydrometric Station Site	Comment
1) Historical stage-discharge data	Lac de Gras	2004 to 2012 hydrometric station data used
	D3 (Counts Lake)	2000, 2003 to 2012 hydrometric station data used
	E10 (Ursula Lake)	2001 to 2003 hydrometric station
2) HEC-RAS model of surveyed transects	Lac du Sauvage	Measured discharge calibrated to observed water levels
	B0	
	E1	
	E381	
	E387	
	E391	
	E409	
	E8	
	F1	
	G1	
	G13	
	G17	
	G2	
	G4	
	G4A	
	G521	
	G6	
	H1	
	I100	
	I103	
	I1A	
	I1B	
	I2	
	I2B	
	I3 (Sterlet Lake)	
	J1	
	J76	
	J77	
	L1	
3) Regional stage-discharge curves	C1	Survey completed downstream of outlet
	E2	No defined outlet; survey completed downstream of outlet
	E12	Discharge too low to determine
	G474	Survey interrupted due to poor weather
	G5	Poor field data
	J3	No defined outlet; survey completed downstream of outlet
	Paul Lake	Poor survey data due to poor weather

F3.1.2.2 Paul Lake Basin Characteristics

Paul Lake is the terminal lake in the Paul Lake basin and discharges directly into Lac de Gras. The Paul Lake basin has an area of 125 km^2 and was modelled using the same methodology and structure as the Lac du Sauvage basin.

F3.1.2.2.1 Land and Lake Areas

The land and lake areas for each modelled lake in the Paul Lake basin are presented in Appendix D.

F3.1.2.2.2 Outlet Rating Curves

The Paul Lake basin outlet rating curves were developed using regional stage-discharge rating curves. The equations and methodology are described in Section F3.1.2.1.2.

F3.1.2.3 Lac de Gras Basin Characteristics

The Lac de Gras basin was divided into 10 sub-basins including the Lac du Sauvage basin. Of the Lac de Gras sub-basins, only the Lac du Sauvage sub-basin was surveyed by field crews during the 2013 season. The Lac du Sauvage sub-basin was modelled at an individual lake level; the remaining nine sub-basins were modelled based on their total discharge areas and their respective land area to lake area ratios.

F3.1.2.3.1 Land and Lake Areas

The Lac de Gras land and lake areas for all sub-basins except Lac du Sauvage are presented in Table F3-2, and a figure showing the sub-basins is provided in Map F3-1.

Table F3-2 Lac de Gras Basins Excluding Lac du Sauvage

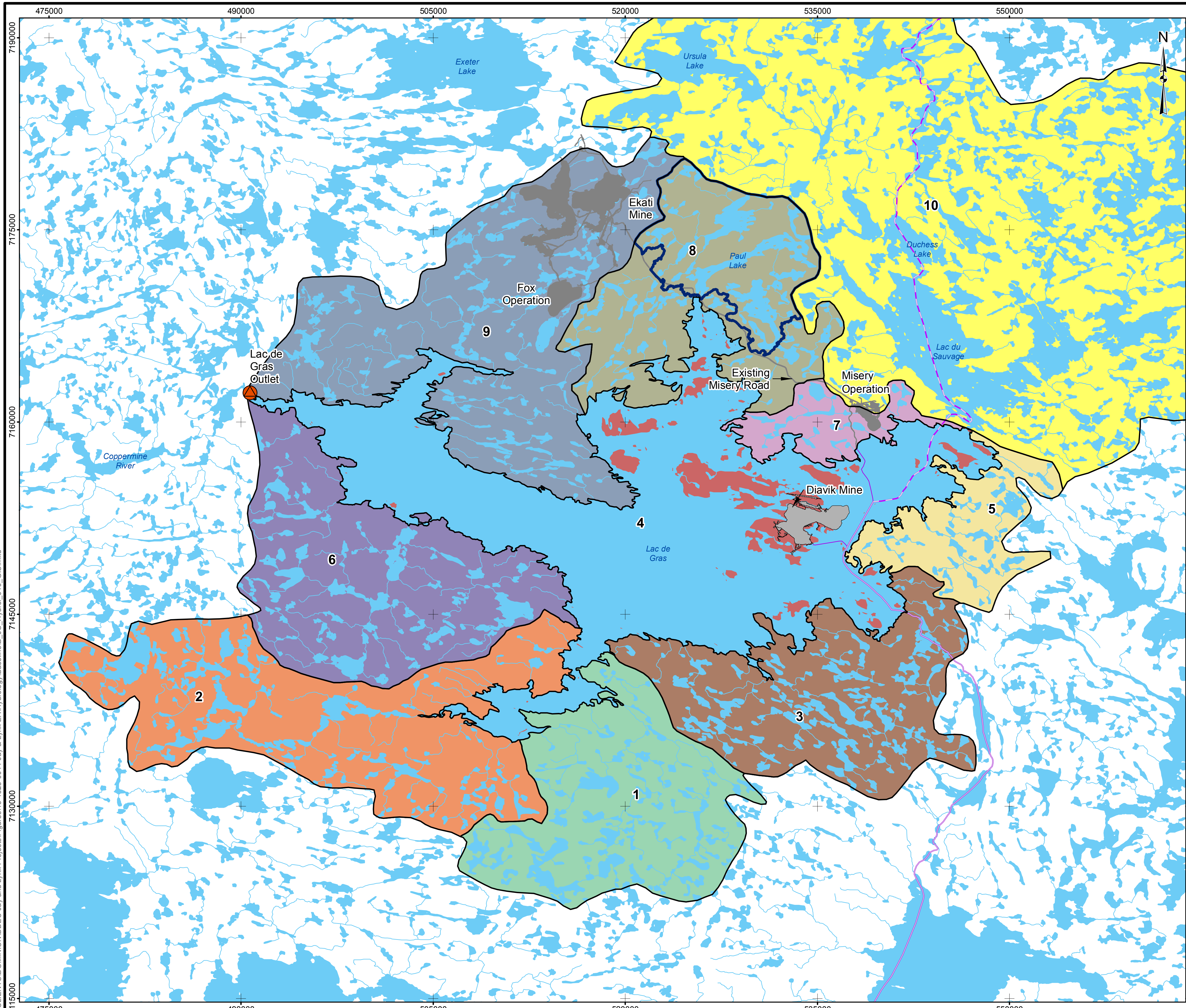
Basin	Land Area (ha)	Lake Area (ha)	Total Area (ha)
1	22,046	4,215	26,261
2	30,418	5,590	36,008
3	22,101	4,642	26,742
4	6,455	57,297	63,752
5	8,760	1,431	10,191
6	26,055	4,367	30,421
7	4,789	649	5,438
8	19,930	4,517	24,447
9	36,264	5,342	41,605

ha = hectare.

F3.1.2.3.2 Outlet Rating Curves

The sub-basins discharging directly to Lac de Gras, other than Lac du Sauvage, were modelled as discrete reservoirs using the structure in Figure F3-1 and rating curves developed with the rating curve relationship described in Section F3.1.2.1.2.

Further rating curve calibration was required for the Lac de Gras basin rating curves. Because no field data were available, the hydrographs of Lac de Gras basin tributary discharges were calibrated to the shape of the Slipper-Lac de Gras presented in the Ekati Mine Aquatic Effects Monitoring Program for the 2012 year (ERM Rescan 2013c). The shape of the Slipper-Lac de Gras graph is shown in Figure F3-4.



LEGEND

- EKATI MINE FOOTPRINT
- DIAVIK MINE FOOTPRINT
- WINTER ROAD
- TIBBITT TO CONTWOYTO WINTER ROAD
- NORTHERN PORTION OF TIBBITT TO CONTWOYTO WINTER ROAD
- WATERCOURSE
- WATERBODY
- LAC DE GRAS OUTLET

LAC DE GRAS BASIN

- 1
- 2
- 3
- 4
- 5
- 6
- 7
- 8
- 9
- 10
- PAUL LAKE AND PAUL CREEK BASIN

REFERENCE

LAC DE GRAS WATERSHED OBTAINED FROM GOLDER, 2007
CANVEC © NATURAL RESOURCES CANADA, 2012
NATURAL RESOURCES CANADA, CENTRE FOR TOPOGRAPHIC INFORMATION, 2012
DATUM: NAD83 PROJECTION: UTM ZONE 12N

DOCUMENT

HYDROLOGY BASELINE REPORT

6 0 6
SCALE 1:300,000 KILOMETERS

PROJECT

DOMINION DIAMOND

JAY PROJECT
NORTHWEST TERRITORIES, CANADA

TITLE

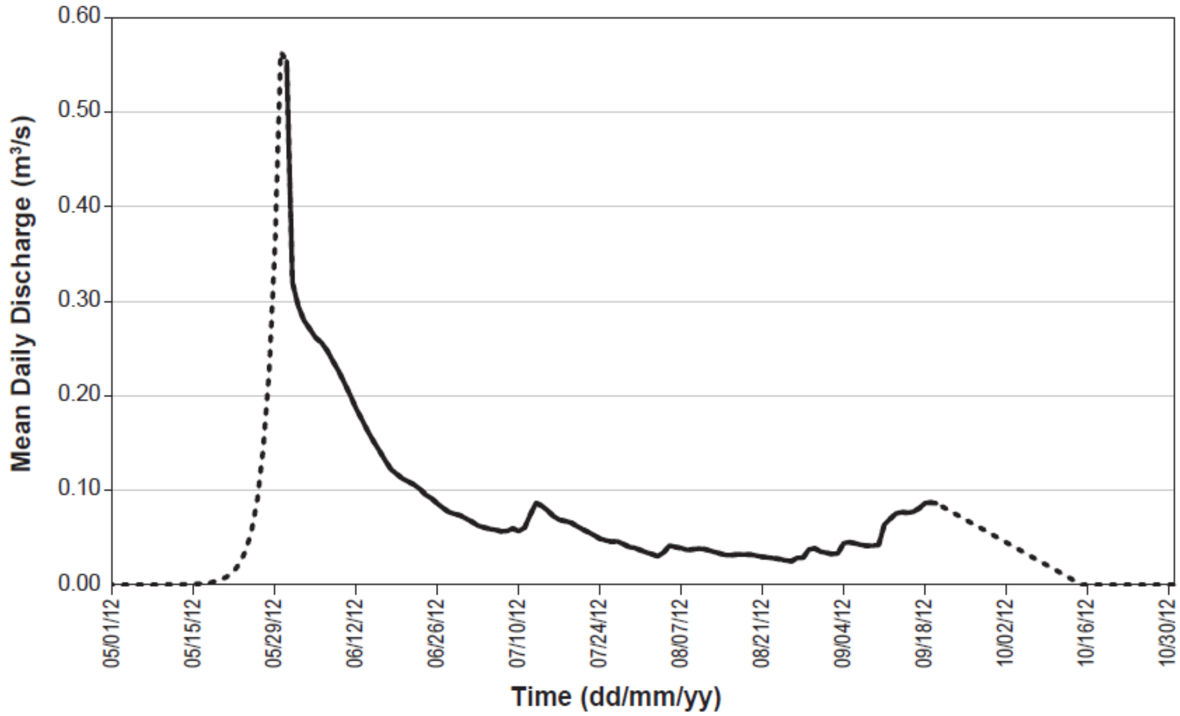
LAC DE GRAS BASIN AND TRIBUTARY SUB-BASINS

Golder Associates

PROJECT	13-1328-0041	FILE No. B_JC_Hydrol_019_GIS	
DESIGN	DC	10/04/14	SCALE AS SHOWN REV 0
GIS	NS	09/09/14	
CHECK	CG	09/09/14	MAP F3-1
REVIEW	SM	09/09/14	

G:\CLIENTS\DOMINION\DDEC Jay and Lynx Projects\Figures\13-1328-0041 Jay & Lynx EA\Hydrology\Baseline\B_JC_Hydrol_019_GIS.mxd

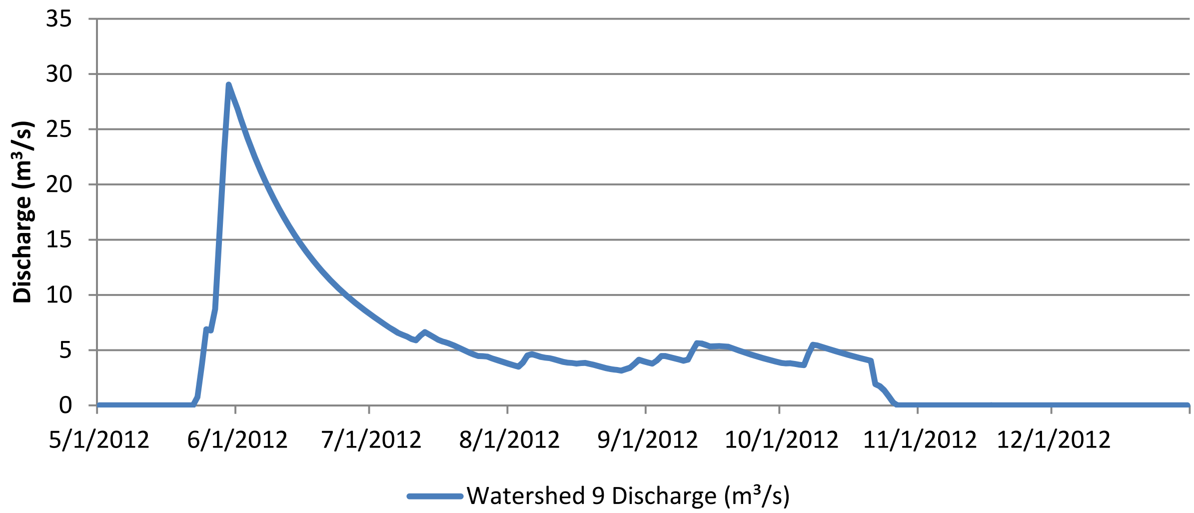
Figure F3-4 Slipper-Lac de Gras Discharge Curve from the 2012 Ekati Mine Aquatic Effects Monitoring Program



Source: ERM Rescan (2013c).
m^3/s = cubic metres per second.

The Basin 9 area was larger than the Slipper basin area and had a higher discharge rate. As Figure F3-5 shows, the modelled discharge remained higher through September and October than the measured discharge.

Figure F3-5 Basin 9 Modelled Discharge



m^3/s = cubic metres per second.

F3.1.3 Ice Effects on Lake Outlets

The formation of ice in winter constricts outflow channels and reduces lake discharge rates. Large lake outlets such as Lac de Gras and Lac du Sauvage will have reduced flow rates during periods of ice cover. The outlets for small lakes become constricted with ice and eventually freeze completely from approximately October to May each year. A numerical relationship between lake outlet discharge and cumulative degree days was developed to account for ice effects in the freezing period in water balance modelling.

Opening of lake outlets during spring is generally a rapid process. This process is related to snowmelt runoff into the lake upstream of the outlet, as well as thaw of ice in the lake outlet. Flowing water provides additional thermal input and melted or saturated snow on the outlet channel surface has a lower albedo and higher absorption of solar energy, which further accelerates melting. The change from frozen solid to fully open conditions has been observed to typically occur over a span of up to about one week. Lake outlets and borders are generally the first areas of open water during spring melt, while a floating ice cover may persist in the body of the lake for days or weeks after the outlet opens.

F3.1.3.1 Hydrometric and Meteorological Data

Hydrometric data were available for several lakes in the Lac du Sauvage basin. The hydrometric data capture flow during open-water conditions. Discharge measurements and the installation and removal of lake data loggers generally occur during periods of open water. The freshet discharge and the late fall discharges are often missing from the hydrometric dataset due to difficulty in accessing hydrometric stations, and therefore, the duration of the ice-free period is often underestimated.

The ice break-up and freeze-up at Lac de Gras was previously modelled (Golder 1997). The mean duration of the ice-cover season was estimated to be about 242 days, typically from October 15 to June 14. The dates of ice freeze-up and break-up modelled in the 1997 baseline study are presented in Table F3-3.

A summary of ice observations for the Coppermine River is provided in Section 5.4.4 of the Hydrology Baseline Report.

Table F3-3 Dates of Lake Freeze-Up and Break-Up Based on Simulation Modelling

Event	Earliest Date	Mean Date	Latest Date
First occurrence of ice deterioration	May 20	June 1	June 16
End of ice-cover season	May 30	June 14	July 15
Lake water clear of ice	June 9	June 26	July 14
First occurrence of permanent ice	September 28	October 9	October 23
Beginning of ice-cover season	October 4	October 15	October 31
Complete lake freeze over	October 5	October 21	November 5

Source: Golder (1997).
Note:
Simulation modelling over 1969 to 1996 period of record, as described in Golder 1997.
First occurrence of permanent ice occurs when ice cover thickness ceases to be zero.
Complete lake freeze over is when ice cover thickness is equal to 0.1 metre (m).
Beginning of ice-cover season is the mid-date between first permanent ice and complete freeze over.

F3.1.3.2 Method

F3.1.3.2.1 General Lake Outlet Method

The degree-day method was used to simulate the effect of ice conditions on discharge at each lake outlet. Degree-days were added above a base temperature of 0 degrees Celsius (°C) based on daily mean temperatures, which typically begin to exceed 0°C in early June.

The effect of ice on discharge was quantified by the following ratio:

$$\text{Ice Effect Ratio} = Q_{actual} / Q_{predicted}$$

where

Q_{actual} = Discharge measured at the outlet under ice conditions; and,

$Q_{predicted}$ = Discharge predicted using an open-water rating curve for the specific outlet.

The degree-day method determined the timing of outlet freeze-up in the fall and outlet break-up in the spring. The initial modelling parameters were determined based on experience at other northern mining sites. The final modelling parameters used are presented in Table F3-4.

Table F3-4 Model Parameters for Break-Up and Freeze-Up Degree Day Methods

Model Element	Value
Outlet break-up - closed	15
Outlet break-up - open	40
Outlet freeze-up - open	76.5
Outlet freeze-up - closed	1.4

F3.1.3.2.2 Lac du Sauvage and Lac de Gras Outlet Method

The Lac du Sauvage and Lac de Gras outlet flows will be reduced during the period of ice cover due to reduced inflow rates and the physical blocking of the channel from ice formation. A reduction was applied to the Lac du Sauvage and Lac de Gras open-water stage discharge rating curves using the ratio calculated in Equation 1. The method described below (Golder 1997) was used to estimate flow reduction due to ice cover.

Equation 1: Outlet Flow Reduction Ratio Equation

$$\frac{Q_i}{Q_w} = \frac{n_w}{(n_w^{1.5} + n_i^{1.5})^{2/3}}$$

where

Q_i – outflow during ice cover condition;

Q_w – outflow during open water condition;

n_i – Manning’s roughness of ice cover (0.024); and,

n_w – Manning’s roughness of channel bed.

The calculation of the flow reduction due to ice cover is shown in Table F3-5.

Table F3-5 Lac de Sauvage and Lac de Gras Outlet Flow Reduction due to Ice Cover

Parameter	Lac du Sauvage	Lac de Gras
n_w	0.050	0.035
$\frac{Q_i}{Q_w}$	0.834	0.741

F3.1.3.3 Results and Discussion

The lake freeze-up and breakup dates were modelled over the period of 1964 to 2013 using the degree day method and the derived temperature dataset. The results of the degree day method for lake outlet opening and closing are shown in Table F3-6. The definitions for the terms used are:

Earliest Modelled Date – the earliest date the lake outlets start to break up or freeze up.

Mean Modelled Date – the mean date on which the lake outlets were 50 percent (%) open during break-up and freeze-up.

Latest Modelled Date – the latest date that the lake outlets break up or freeze up, meaning completely open outlets in the spring and closed outlets in the fall.

Table F3-6 Modelled Outlet Freeze-Up and Break-Up Dates

Model Date	Lake Outlet Break-Up	Lake Outlet Freeze-Up
Earliest Modelled Date	May 21	October 8
Mean Modelled Date	June 3	October 12
Latest Modelled Date	June 23	November 4

The modelled results are consistent with existing hydrometric data in the Lac de Gras basin. As previously discussed, access to stream outlets is a challenge at northern mine sites and the modelled break-up and freeze-up dates bracket the measured flows.

F3.1.4 Snowmelt

Snowmelt is generated predominantly by the melting of the accumulated snowpack during the period of spring freshet. The spring freshet occurs over a period of several weeks and is a major contributor of overall annual precipitation and lake inflows in northern environments.

Snowfall that occurs after freshet in the spring and before consistent freezing temperatures in the fall is modelled as reporting directly to the receiving waterbodies as snowmelt.

F3.1.4.1 Hydrometric and Meteorological Data

The spring freshet is characterized by high runoff flows during the spring melt period. The peak flows of freshet are short in duration, and are sometimes difficult to capture due to site safety issues including unsafe ice. Freshet peaks are often not captured by hydrological monitoring programs in remote northern locations and there are limited freshet peak data for the Lac de Gras basin.

The water balance model assumes a uniform snow depth throughout the Lac de Gras basin. This assumption adds uncertainty to the model results due to natural spatial differences in actual snow depths due to uneven accumulation and redistribution. The location of weather stations used in the derivation of the climate dataset may report total snowfall different than the actual snow accumulated in individual basins; however, the methods used are considered best estimates of on-ground snowpack.

F3.1.4.2 Method

In the model, snowfall from the derived climate data accumulates as snowpack during fall and winter when temperatures are below freezing. A 30% reduction is applied to the modelled snowpack to represent sublimation losses. This 30% reduction was determined following a literature review described in Section 2.1 of the Hydrology Baseline Report and is consistent with previous modelling of the Lac de Gras basin (Golder 2008).

Snowmelt begins when the daily average temperature rises above the base temperature (T_b). The snowmelt rate is determined in Equation 1.

Equation 1: Snowmelt Equation

$$\text{Daily Snowmelt Runoff} = R_{cs} \times M_f \times (T - T_b)$$

Where

R_{cs}= Snowmelt runoff coefficient (dimensionless);

M_f = Melt factor (mm/°C);

T = Mean daily air temperature (°C); and,

T_b = Base temperature (°C).

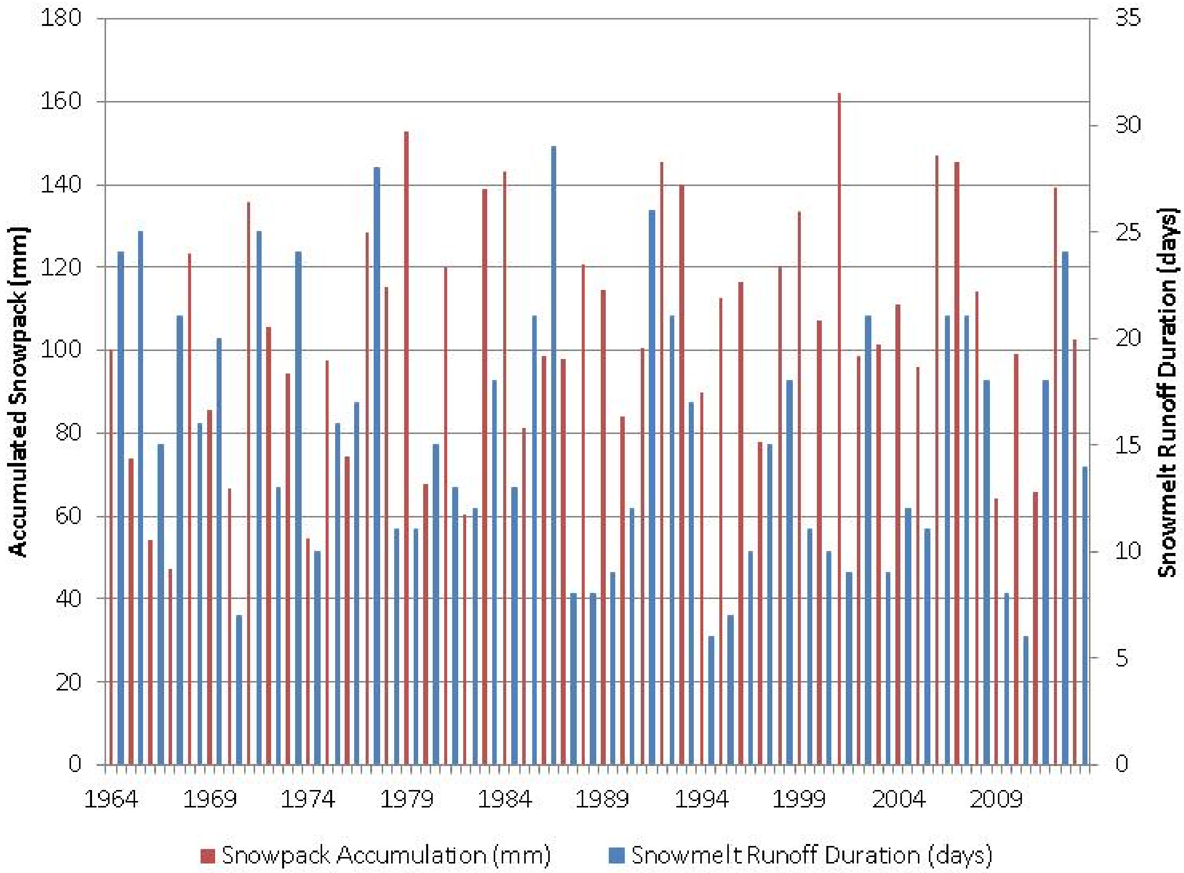
The Melt factor and Base temperature were determined during previous Lac de Gras basin modelling efforts to be 3.5 millimetres per degree Celsius (mm/°C) and 1.0°C respectively (Golder 2008). The values were varied during calibration of this water balance model but were not found to bring appreciable improvements to the modelled discharges compared to measured data.

The snowmelt runoff coefficient R_{cs} was calibrated to expected freshet yields and annual basin yields. This calibration is discussed in greater detail in Section 3.2.

F3.1.4.3 Results and Discussion

Accumulated snowpack in the model is released as freshet snowmelt runoff. The total modelled accumulated snowpack and the modelled duration of snowmelt runoff for each year from 1964 to 2013 is shown in Figure F3-6.

Figure F3-6 Modelled Snowpack Accumulation and Snowmelt Runoff Duration



mm = millimetre.

Modelled snowmelt runoff start times, end times, and durations are shown in Table F3-7. The modelled snowmelt runoff period starts on average in the last week of May and lasts for about two weeks.

Table F3-7 Modelled Snowmelt Runoff Dates and Duration

	Minimum	Mean	Maximum	Standard Deviation
Snowmelt runoff start	3-May	23-May	12-June	9.8
Snowmelt runoff end	20-May	7-June	23-June	8.4
Snowmelt runoff duration (days)	6.0	15.5	29.0	6.3
Accumulated snowpack (mm)	47.3	104.5	161.9	28.8

mm = millimetre.

Further results of model calibration and validation are described in Section 3.3.

F3.2 Annual Water Yield

Water yield for drainage basins is expressed as a depth of water, and is a function of a basin's land and lake area ratio, precipitation, evaporation, infiltration rates, runoff rates, and snow sublimation. Annual water yield is the depth of water per unit area available to enter the hydrologic system for a given drainage basin. Water yield can be used to calculate basin discharges by multiplying the depth of water by the area of the drainage basin, and dividing by a unit of time.

The annual water yield for the Lac de Gras basin was used to calibrate the model.

F3.2.1 Hydrometric Data

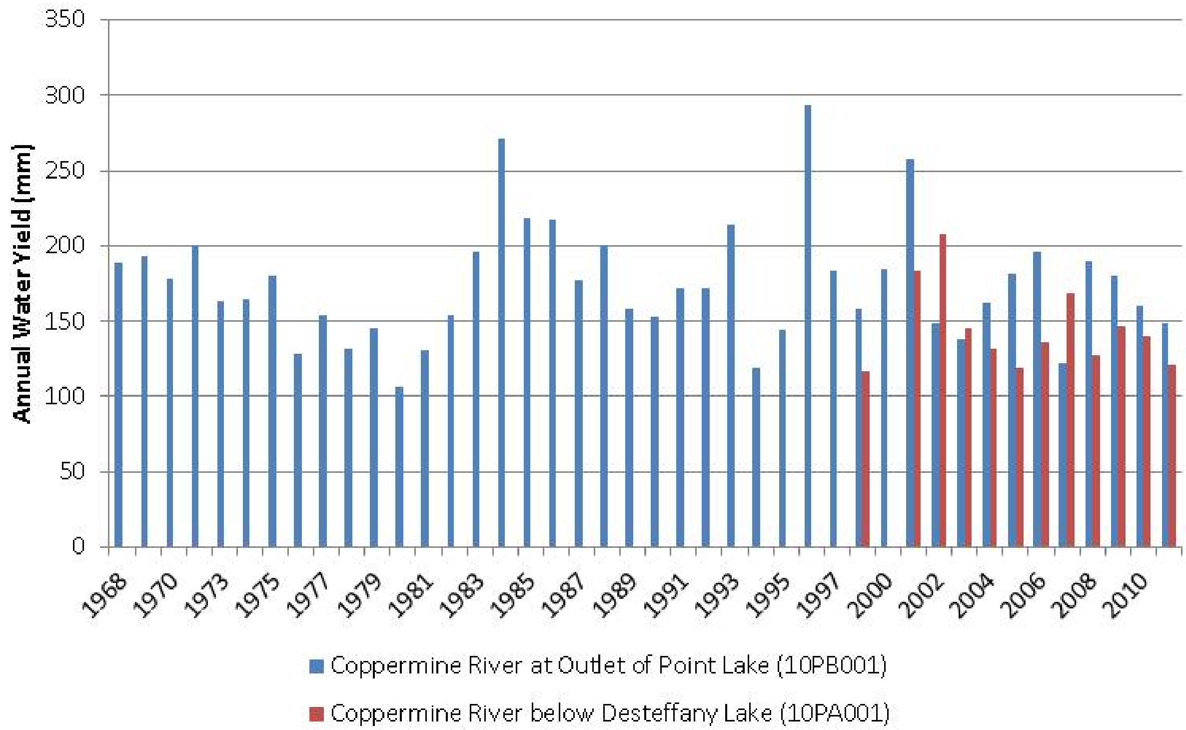
The mean annual water yield for the Lac de Gras basin was calculated from downstream Coppermine River hydrometric data from the stations shown in Map F3-2.

Coppermine River at Outlet of Point Lake (Station 10PB001) daily discharge data were available for 1965 to 2011 on the Water Survey of Canada website (Environment Canada 2014); data from years 1964 and 1972 are incomplete. The total drainage area for Point Lake is 19,200 km^2 and the mean annual water yield over the period of record was 177 mm.

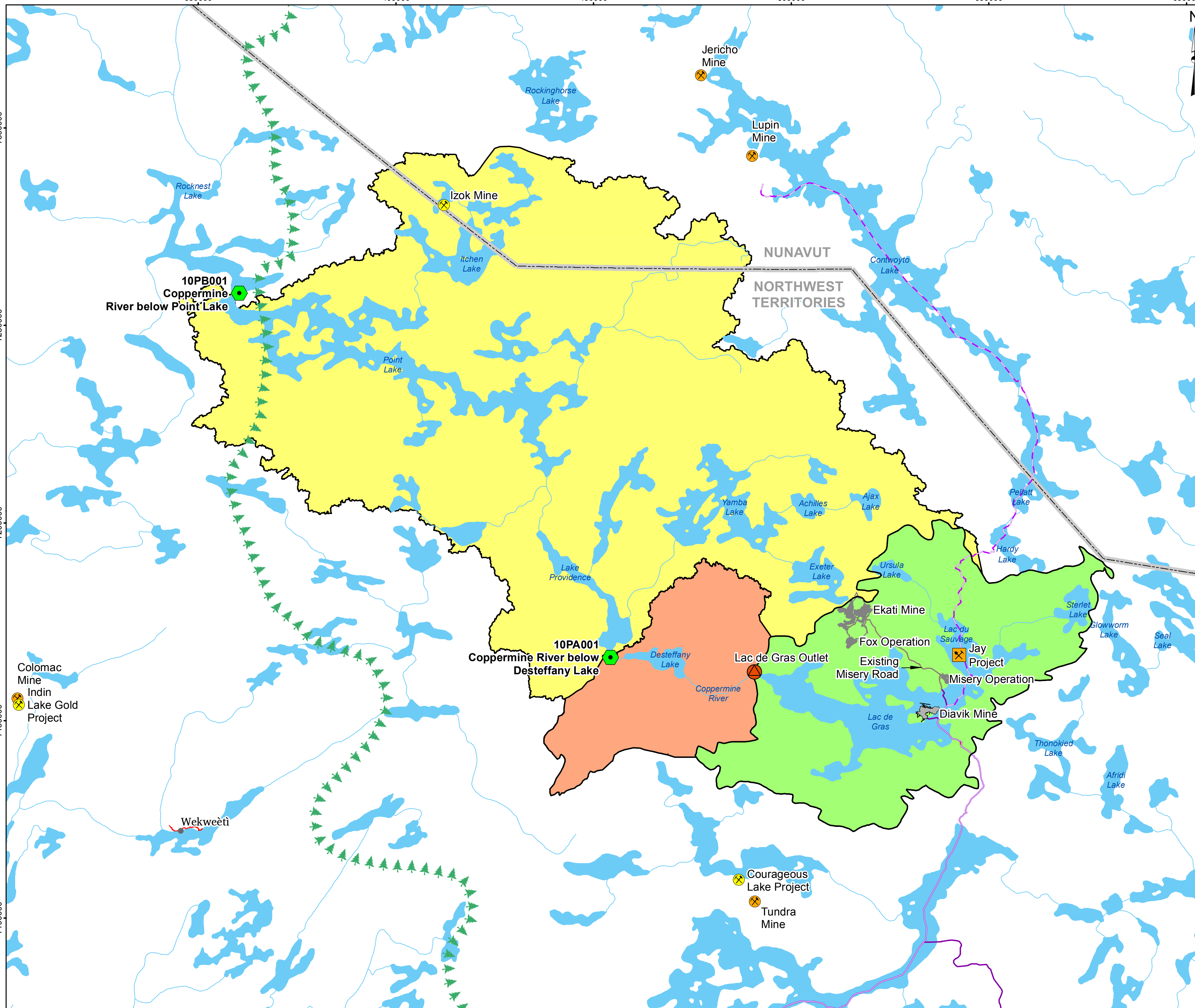
Coppermine River below Desteffany Lake (Station 10PA001) daily discharge data were available from 1994 to 2012; the years 1994, 1996, 1997, 2011, and 2012 are incomplete. Desteffany Lake has a drainage area of 6,116 km^2, and contains the 4,131 km^2 Lac de Gras basin. The Desteffany Lake mean annual water yield over the period of record was 145 mm.

The annual water yields for the Point Lake and Desteffany Lake stations are shown in Figure F3-7.

Figure F3-7 Annual Water Yields of Coppermine River below Desteffany Lake and at Outlet of Point Lake



mm = millimetre.



LEGEND

- EKATI MINE FOOTPRINT
- DIAVIK MINE FOOTPRINT
- JAY PROJECT
- EXISTING MINE OR PROJECT
- PROPOSED MINE PROJECT
- POPULATED PLACE
- WINTER ROAD
- TIBBITT TO CONTWOYTO WINTER ROAD
- NORTHERN PORTION OF TIBBITT TO CONTWOYTO WINTER ROAD
- TERRITORIAL/PROVINCIAL BOUNDARY
- TREELINE
- WATERCOURSE
- WATERBODY
- HYDROMETRIC STATION
- LAC DE GRAS OUTLET
- DESTEFFANY LAKE BASIN
- LAC DE GRAS BASIN
- POINT LAKE BASIN

REFERENCE

POINT AND DESTEFFANY LAKE WATERSHEDS DERIVED FROM 1:50,000 DEM; CDED, NATURAL RESOURCES CANADA
LAC DE GRAS WATERSHED OBTAINED FROM GOLDER, 2007
WATER OBTAINED FROM ATLAS OF CANADA
NATURAL RESOURCES CANADA, CENTRE FOR TOPOGRAPHIC INFORMATION, 2012
DATUM: NAD83 PROJECTION: UTM ZONE 12N

DOCUMENT

HYDROLOGY BASELINE REPORT

20 0 20
SCALE 1:1,000,000 KILOMETRES

PROJECT
DOMINION DIAMOND
JAY PROJECT
NORTHWEST TERRITORIES, CANADA

TITLE
POINT LAKE, DESTEFFANY LAKE AND LAC DE GRAS BASINS

Golder Associates

PROJECT	13-1328-0041	FILE No. B_JC_Hydrol_020_GIS	
DESIGN	DC	10/04/14	SCALE AS SHOWN	REV 0
GIS	NS	11/09/14	
CHECK	CG	11/09/14	MAP F3-2
REVIEW	SM	11/09/14	

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F3.2.2 Method

The Lac de Gras mean annual yield was estimated using data from the Point Lake (10PB001) and Desteffany Lake (10PA001) hydrometric stations on the Coppermine River. The mean annual yield was calculated by using the long-term station data from Point Lake and the Desteffany Lake station data, which is more representative of the Lac de Gras basin. The annual water yields of Point Lake and Desteffany Lake were compared over the concurrent period of 1998 and 2000 to 2010, as shown in Table F3-8.

Table F3-8 Annual Water Yields of Point Lake and Desteffany Lake

Year	Point Lake (Station 10PB001) Annual Water Yield (mm)	Desteffany Lake (Station 10PA001) Annual Water Yield (mm)
1998	157.7	117.3
2000	185.0	183.5
2001	257.6	207.5
2002	149.0	145.0
2003	138.0	131.9
2004	162.1	119.1
2005	181.2	135.5
2006	196.2	168.7
2007	122.5	127.8
2008	189.5	146.2
2009	180.1	140.6
2010	160.4	121.3
Concurrent mean	173.2	145.4
Long-term mean	178.0	150.2[(a)]

a) Calculated using correction factor of 1.034.
mm = millimetre.

The long-term (1965 to 2011) mean annual water yield at Station 10PB001 is 178.0 mm. From the ratio of the long -term mean annual water yield to concurrent period mean annual water yield at Station 10PB001, a correction factor of 1.034 was applied to the Station 10PA001 concurrent period mean annual water yield to provide an estimate of the long-term mean annual water yield.

The water balance model was calibrated so that the modelled Lac de Gras mean annual water yield was equal to the Station 10PA001 estimated long-term mean annual water yield of 150.2 mm.

F3.2.3 Results and Discussion

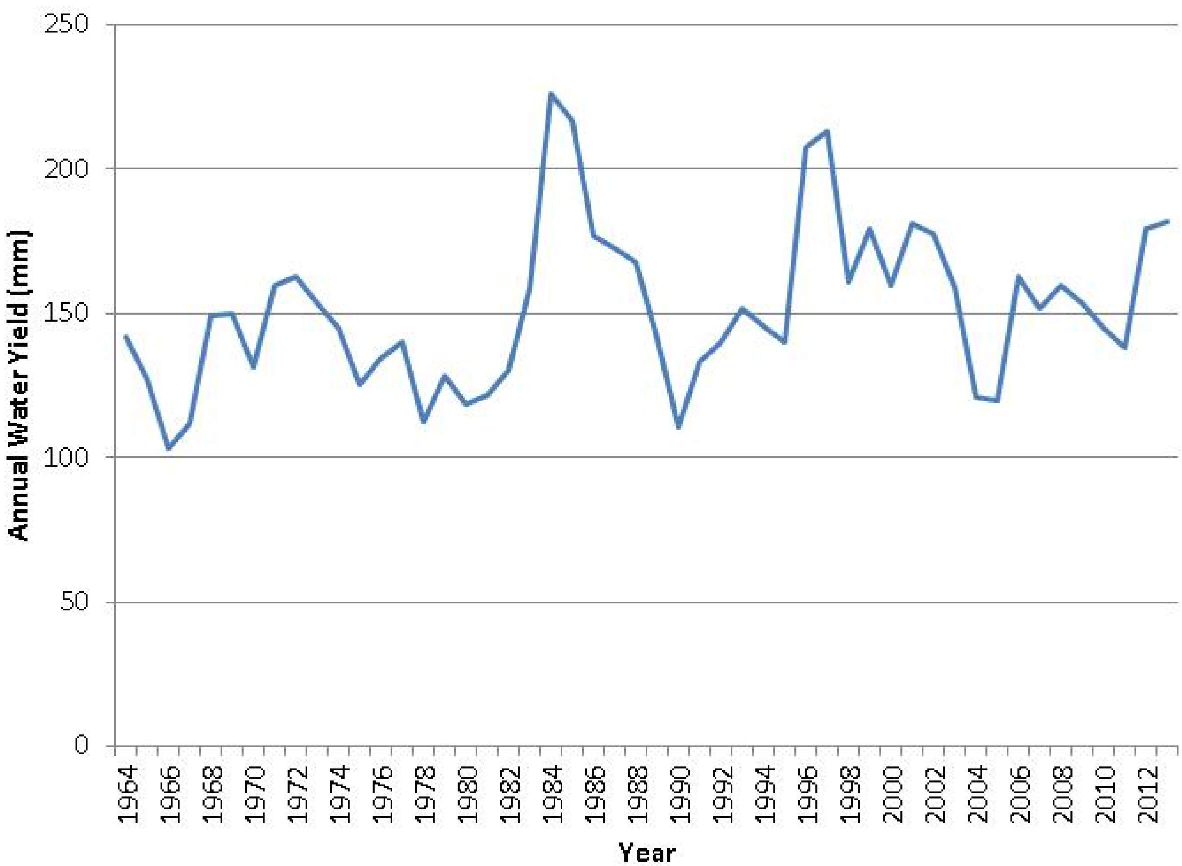
Runoff coefficients were determined by calibrating the model mean annual water yield to the long-term mean annual water yield for Lac de Gras. Calibrated runoff coefficients are shown in Table F3-9. The GoldSim model output for annual water yield is shown in Figure F3-8.

Table F3-9 Runoff Coefficients from Model Calibration

Runoff Coefficient Variable	Value
Rainfall on land (RC_Land)	0.57
Rainfall on lake (RC_Lake)	1.00
Snowfall on land (SC_Land)	1.00
Snowfall on lake (SC_Lake)	1.00

SC = snowfall runoff coefficient; RC = rainfall runoff coefficient.

Figure F3-8 Lac de Gras Annual Water Yield GoldSim Model Output



mm = millimetre.

The runoff coefficients derived in the water balance model were calibrated to the mean annual water yield of the Lac de Gras basin. The runoff coefficients for rainfall and snowfall runoff on land are 0.2 to 0.3 units higher than those found in the literature review in the Annotated Bibliography (Appendix A). It is expected that runoff coefficients vary in hydrological studies, as they are calibrated to measured data and may include inconsistent treatments of factors including sublimation, evapotranspiration, and infiltration losses.

F3.3 Model Calibration and Validation

The lake reservoirs in the water balance have a consistent structure and logic. Physical characteristics of each modelled lake reservoir include local contributing lake and land areas, total discharge areas, and connectivity with other lakes.

The volume and timing of lake discharges are the predominant model outputs. The key calibration variables for the volume of water discharged are runoff coefficients. Calibration variables for the timing of water discharge are part of the degree-day method, the snowmelt model, and the stage-discharge rating curves.

F3.3.1 Model

Historic hydrometric data were available for selected lakes in the Lac du Sauvage basin and for Lac de Gras. These data are discussed in Section 5.0 of the Hydrology Baseline Report and summarized in Table F3-10.

Table F3-10 Hydrometric Data for Model Validation

Lake	Years with Data Available	Type of Data Available
Lake D3 (Counts)	2000, 2003 to 2012	Discharge and stage data for open-water season
Lake E10 (Ursula)	2001 to 2003	Discharge and stage data for open-water season
Lac de Gras	2004 to 2012	Limited water level data and limited discharge data

Field data were collected in the Lac du Sauvage basin and are presented in 2013 Field Program Data (Appendix E). These field data were used to develop site-specific and regional stage-discharge rating curves. The meteorological data derived for the Project from 1959 to 2013 are key model inputs and are summarized in Appendix B.

Calibration variables were not used to match modelled data to specific years, dates, or individual basins, because actual runoff for any given year may not correspond to the derived site-specific meteorological inputs. However, derived output hydrographs should qualitatively resemble the measured output hydrographs, based on physical characteristics of the lakes. The water yield of the Lac de Gras basin was the major calibration factor for the water balance model.

F3.3.1.1 Method

The water balance model was developed using the modelled lake structure described Figure F3-2.

Rainfall and snowfall inputs were based on the derived climate dataset included in Appendix B. The runoff coefficient (R_c) was applied to rainfall runoff to account for evapotranspiration and infiltration losses. The runoff coefficient for snowmelt on land, snowmelt on lakes, and rainfall runoff on lakes were set to 1.0, after adjusting snowpack by applying sublimation losses of 30% to snowfall values. Discharges from lake outlets were modelled using stage-discharge rating curves in conjunction with outlet break-up and freeze-up sub-models.

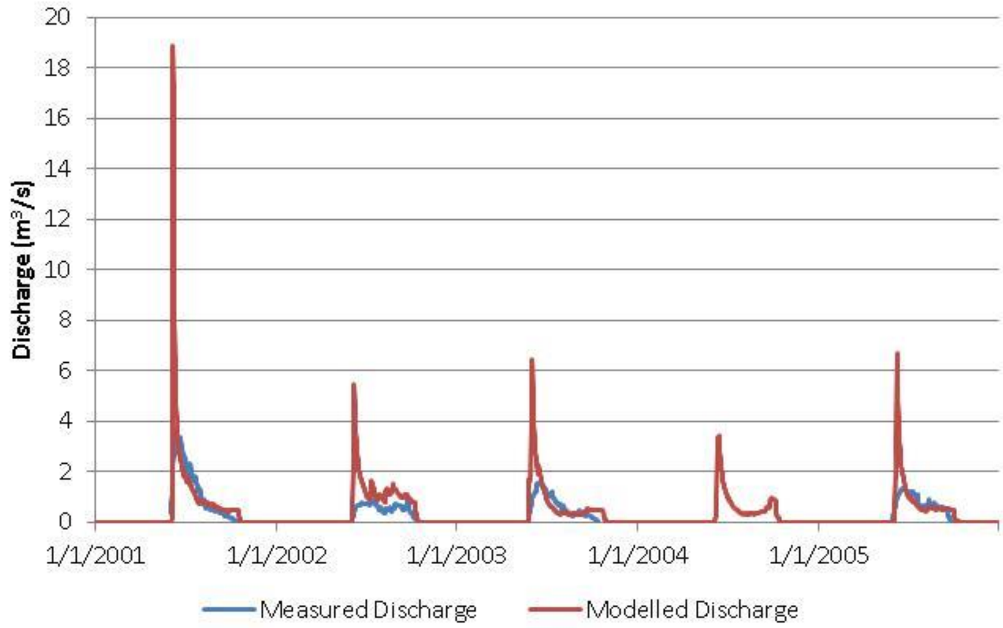
The calibration process was as follows:

- **Calibration:** The model was run on a 4-hour time-step from 1959 to 2013 using the derived climate dataset as input values. The water yield was calibrated with an initial runoff coefficient for rainfall on land of 0.35 and increased incrementally until the modelled and calculated water yields for Lac de Gras were consistent.
- **Validation:** The model was validated using all available datasets and calibrated parameters from previous stages. The model output hydrographs were plotted along with measured hydrographs for comparison.

F3.3.2 Results and Discussion

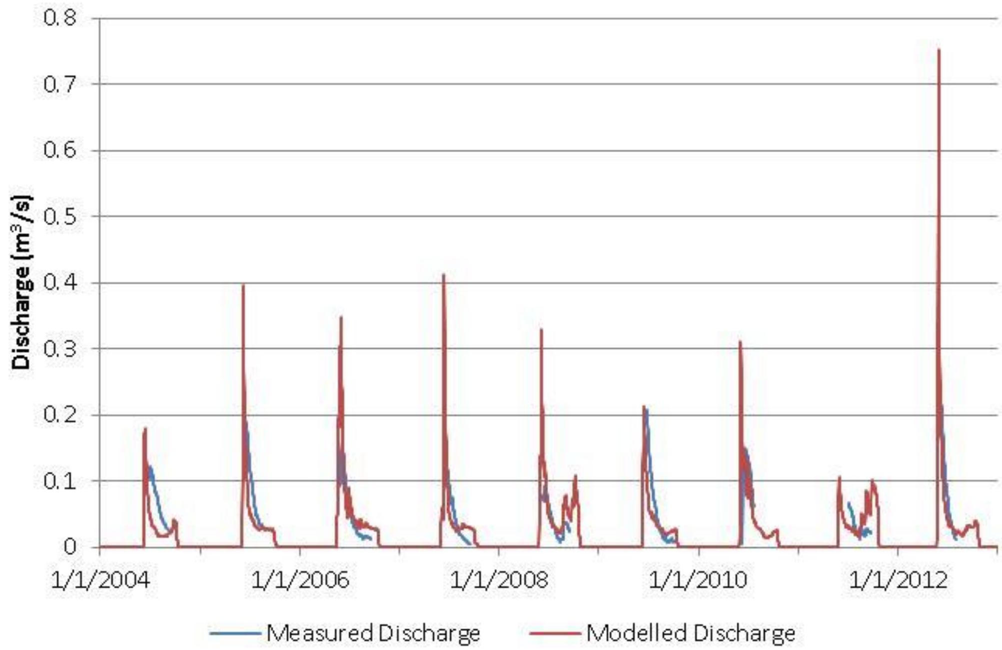
The available hydrometric data is plotted along with model output for qualitative comparison purposes. A comparison of measured to modelled discharge data is presented in Figure F3-9, Figure F3-10, and Figure F3-11. A comparison of measured to modelled water level data is presented in Figure F3-12.

Figure F3-9 Lake E10 (Ursula Lake) Measured and Modelled Discharges



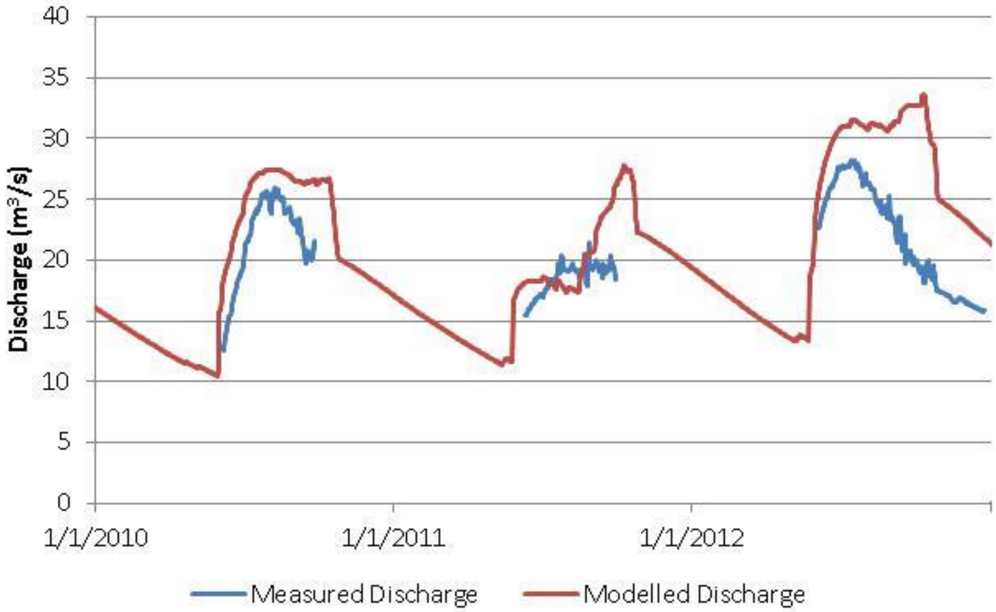
Source: ERM Rescan (2013b).
m^3/s = cubic metres per second.

Figure F3-10 Lake D3 (Counts Lake) Measured versus Modelled Discharges



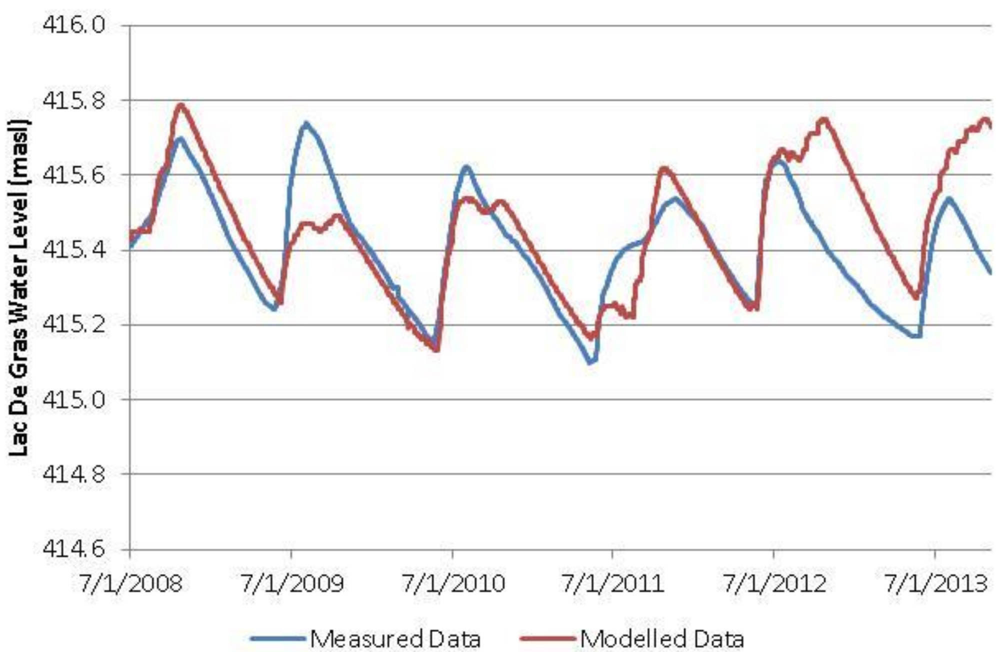
Source: ERM Rescan (2013b).
m3/s = cubic metres per second.

Figure F3-11 Lac de Gras Measured versus Modelled Discharge



Sources: Vista (1997) and ERM Rescan (2013a).
m^3/s = cubic metres per second.

Figure F3-12 Lac de Gras Measured versus Modelled Water Levels



Source: Diavik Diamond Mines Inc. (DDMI 2013).
masl = metres above sea level.

The modelled and measured elevations and discharges show good agreement, with the qualifiers listed as follows:

- Freshet peaks for E10 and D3 are modelled higher than measured data. The modelled peak freshet flows are three to four times higher than measured peak flows. This result is not unexpected, as field crews are often unable to capture peak flows due to safety concerns with site access, including unsafe ice conditions. Peaks on upper basin lakes will tend to be attenuated by the time they reach the lower basin lakes of interest (e.g., Lac du Sauvage, Lac de Gras).
- Modelled discharges tend to start earlier in the spring and continue later in the fall than measured discharges, at the smaller lakes. This result is likely due to late deployment and early removal of loggers due to safety concerns with site access during these times, including unsafe ice conditions. Low flows are also often difficult to measure, especially under ice-covered conditions. Key hydrological parameters such as annual water yields and flood discharges are not sensitive to these differences.
- The modelled flows for Lake D3 show a secondary peak in discharge which is not shown in the measured data. This modelled peak generally occurs after the last day of measured data, and until more data are gathered, it cannot be concluded if that peak actually occurs.
- The Lac de Gras model shows a late-season peak in discharge and water level over the period 2010 to 2012 which is not represented in the measured data, though monitoring data from 1995 to 1997 (Historical Hydrometric Data, Appendix C) indicates late-season peaks. These differences may arise from differences in late open-water season precipitation between the derived and local datasets.

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