March 2010

DRAFT REPORT - FOR REVIEW PURPOSES ONLY

Surface Water Study - Horn River Basin

Submitted to:
Oil and Gas Division
Ministry of Energy, Mines and Petroleum Resources
Victoria, B.C.

DRAFT REPORT

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March 31, 2010

Oil and Gas Division
Ministry of Energy, Mines and Petroleum Resources
5th Floor, 1810 Blanshard Street
Victoria, B.C.
V8W 9N3

Attention: Teresa Morris

Re: Surface Water Study – Horn River Basin

Dear Ms. Morris:

We are pleased to submit, for your review and comments, the draft report on the above-referenced study.

Please contact me at (604) 850 8786 should you require any clarification regarding this submission.

Yours truly,

GOLDER ASSOCIATES LTD.

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Executive Summary

The Ministry of Energy, Mines and Petroleum Resources (MEMPR) is collaborating with the Ministry of Environment, First Nations and the Horn River Producers Group (HRPG) in an effort to minimize the environmental footprint of oil and gas development activities in the Horn River Basin (HRB).

MEMPR commissioned Golder Associates Ltd. (Golder) to undertake a surface water study of the HRB. The main objectives of the study were to gain additional understanding of the surface water availability in the HRB and potential for water scarcity as gas development activities continue to expand. The outcomes of this study are intended to assist surface water allocation decision makers and identify gaps in surface water information.

As part of the study, two of Golder's team members travelled to Fort Nelson to meet with the FNFN representatives to provide an overview of the Project, a brief non-technical explanation of some of the science behind the hydrological modelling, and to discuss TEK/TU information, such as dry and wet years, that could be used as part of the project.

The HSPF hydrologic model was calibrated and validated on three gauged watersheds close to the HRB. The calibration statistics are considered to be reasonable given that the Fort Nelson climate station was the only index station available with long-term model input data.

The HRB was divided into 12 sub-basins. The calibrated and validated HSPF model was implemented on two of the major sub-basins of the HRB, that is, the Kiwigana River sub-basin and the Snake River sub-basin. The two major sub-basins have very different surficial geologic characteristics and represent the range of surficial geological characteristics of the HRB. The results indicate that the mean annual runoff from the watersheds in the Snake River sub-basin, dominated by muskeg, ranges from 60 to 80 mm. In the till-dominated Kiwinaga River sub-basin, the mean annual runoff from the watersheds range from 145 to 185 mm, more than twice the yield from sub-basin 6.

The regionally calibrated HSPF model can be similarly implemented on the other sub-basins in the HRB. As an alternative, unit monthly/seasonal/annual flows were developed from the simulation results of the two sub-basins representative of the HRB that can be transferred to the other sub-basins with similar characteristics. Improving the accuracy of the yield from the sub-basins is at this stage dependent on good resolution of the spatial variability in precipitation and adequate hydrometric data for model calibration. The monthly, seasonal and annual yields were calculated for three ranges of drainage areas: 100 to 400 km^2, 400 to 1,500 km^2 and greater than 1,500 km^2.

A generic procedure was developed for assessing the hydrologic risk of an imbalance between water yield and water demand in the HRB. The characterization of the risk of a water yield-demand imbalance in any sub-basin requires quantification of the water yield and water demand in that sub-basin. A key "demand" on the natural flow regime in any sub-basin is for instream flow needs (IFN). A hydrologic risk index is proposed that combines the probability of exceeding IFN threshold values and the ratio of the remaining water available in the stream and estimated demand. The approach will require fine-tuning as more reliable water yield and detailed water demand become available.

The study has highlighted the lack of sufficient climate, flow/water level and water use (current and future) data to implement a detailed hydrologic modelling analysis of the HRB and to assess the risk of water imbalances in the sub-basins of the HRB. Several recommendations on the approach to address the current date deficiency have been made. These are summarized below:

- It is recommended that detailed hydrometric data collection be carried out to refine the model and to support future assessments and decision making. Four to seven baseline hydrometric stations should be established.
- It is recommended that regular flow monitoring be conducted and records retained for all watercourses with surface water diversions. Consideration should be given to the establishment of hydrometric stations on these watercourses if the characteristics of the watersheds fall within the desired range discussed above.
- It is recommended that at least three new meteorological stations be established to provide better characterization of spatial and temporal variability in meteorological conditions within the HRB.
- It is recommended that a snow survey be carried out at the end of the two winter seasons to complement the station data and to assist in quantifying the water content of the pack snow at the end of winter and to determine the amount snow that is lost to sublimation and therefore not available for runoff.
- The Horn River Basin is characterized by areas extensively covered with muskeg. It is recommended that a network of four to seven (number to be determined during field program scoping) baseline/background shallow groundwater level monitoring stations be established.
- Due to the significance of interflow contribution to stream flow rates, it is recommended monitoring shallow groundwater levels be set up adjacent to sites where water is extracted from impoundments including borrow pits, reservoirs and other man-made/natural water bodies.
- It is recommended that once a full year of data has been collected, the HSPF model should be run with the monitoring data to determine if the simulated flows adequately replicate observed flows. The calibration of the regional HSPF model should be refined once two or three years of data have been collected to enable implementation on specific sub-basins. The level of uncertainty in the site-specific outputs should be assessed to enable proper risk assessment of present and future water supply-demand conditions.

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1.0 INTRODUCTION

1.1 Background

The Ministry of Energy, Mines and Petroleum Resources (MEMPR) is collaborating with the Ministry of Environment, First Nations and the Horn River Producers Group (HRPG) in an effort to minimize the environmental footprint of oil and gas development activities in the Horn River Basin (HRB).

The area known as the Horn River Basin, which is about 1.2 million hectares in area, lies near the northeast corner of BC. With an estimated potential to hold 14 trillion cubic meters of gas, it is currently being developed as a world class shale gas play. Target shales include the Keg River, Evie, Otter Park, Muskwa and Fort Simpson formations. While the thick shale deposits of the area, which lies along the northwest edge of the Western Canada Sedimentary Basin, have been known for years to contain natural gas, it is only with the advent of improved hydrofracking and horizontal drilling that operators have been successful in liberating the natural gas in large quantities. The availability of the large volumes of water required for hydrofracking of the shales has become a key component of successful shale gas development.

MEMPR desires to gain additional understanding of the surface water resources in the HRB, and invited proposals to study and compare surface water availability to current and planned water use in the HRB to assist surface water allocation decision makers. The Terms of Reference (TOR) for the study are provided in Appendix I.

After a review of all proposals submitted, MEMPR commissioned Golder Associates Ltd. (Golder) to undertake the surface water study of the HRB. The main objectives of the study were to gain additional understanding of the surface water availability in the HRB and potential for water scarcity as gas development activities continue to expand. The outcomes of this study are intended to assist surface water allocation decision makers and identify gaps in surface water information.

1.2 Scope of Work

The key tasks undertaken for this study included the following:

- *Background Data Collection*:
  - Collection of information on topography, meteorological data, hydrometric data, surficial geology and land cover types in the HRB.
- *First Nation and Horn River Producer Group Consultation*:
  - Meetings with the Fort Nelson First Nation (FNFN) leadership, Lands Director and the FNFN Researchers to provide an overview of the project, a brief non-technical explanation of some of the science behind the hydrological modelling, and a discussion of how FNFN information may be used as part of the study.
  - Meeting with representatives of the Horn River Producers Group (HRPG) to determine availability of data that the HRPG is or has collected in the HRB that could be useful for the study.

- *Hydrologic Modelling*:
  - Selection of hydrologic model for implementation on the HRB.
  - Calibration and validation of hydrologic model.
  - Division of HRB into sub-basin.
  - Simulation of seasonal and annual water yield from sub-basins of HRB.
- *Evaluation of Water Availability and Hydrologic Risk*:
  - Inventory of current surface water diversions.
  - Analysis of the current diversions relative to the estimated seasonal flow rates from the corresponding sub-basins.
  - Develop a forecast of anticipated water demand over the next five years and compare these to the estimated seasonal flow rates.
  - Identify areas of current and potential future hydrologic risk in each sub-basin.
- *Identification of Data Requirements*:
  - Identify sub-basins where water scarcity is likely and recommend locations where further detailed hydrometric data collection may be necessary to support future assessments or decision making.
- *Reporting and Deliverables*:
  - Prepare a study report for review and discussion with MEMPR and the FNFN.

One of the key study objectives was to involve the local First Nation communities in the project formulation process and to communicate the study's findings. This ensured that the First Nations water needs were understood and taken into consideration in the study as well as assisted in augmenting the technical understanding of regional water allocation issues.

2.0 MEETINGS WITH FIRST NATIONS AND HORN RIVER PRODUCERS GROUP

2.1 First Nations

Regional resource studies can greatly benefit from an understanding of First Nations interests and the incorporation of relevant traditional ecological knowledge (TEK) and traditional use (TU) information.[1] Although the scope of this study did not include efforts to incorporate previously undocumented TEK/TU information, available results of existing research were reviewed, summarized and integrated with other data sources to provide Project context, to inform hydrological modeling and to formulate appropriate recommendations. Study team members collaborated with FNFN researchers to evaluate existing TEK/TU materials for relevance to water use. Specifically, information related to general watershed observations and timings of seasonal peak and low flows were sought.

Two study team members travelled to Fort Nelson on February 4th and 5th, 2010 to meet with the FNFN representatives to provide an overview of the Project, a brief non-technical explanation of some of the science behind the hydrological modelling, and a discussion of how TEK/TU information would be used as part of this Project. The discussion included clarification on FNFN confidentiality protocols associated with the use of TEK/TU information. During the first trip to Fort Nelson, meetings with the Northern Rockies Regional Municipality and representatives of the BC Oil and Gas Commission were also held.

The study team members made a second trip to Fort Nelson on February 22nd to 24th to conduct interviews of FNFN community members with knowledge of the hydrologic setting within the study area. FNFN Lands Department representatives identified the interviewees and facilitated interviews. Six interviews were conducted. Future research opportunities were also discussed with representatives of the FNFN Lands Department.

One of the objectives of this study was the development of a numerical model which would simulate the typical seasonal flow rates in the major watersheds of the HRB. One challenge to the development of a robust and accurate numerical model was the scarcity of recorded hydrometric or meteorological data recorded within the study area. The intent of the interviews was to gain information based on TEK/TU which could be used to fine tune and validate the numerical model.

In order to provide geographic diversity in observations, interviewees with experience in different parts of the HRB were selected. Each interview included discussions related to the following topics:

- Typical annual timing of watercourse fluctuations including freeze-up, ice break-up, peak flow and low flow;
- Average snow depth throughout the winter;
- Historically wet or dry years; and
- Site specific observations of any watercourses which exhibited characteristic flow patterns which were in some way different than would be anticipated.

[1] TEK studies involve collaboration with communities to document knowledge held by aboriginal communities specifically related to the environment, which are passed on primarily through the oral tradition. TU studies are more geography targeted efforts to document aboriginal use of lands and resources, and focus on the mapping of site-specific and non site-specific values and interests.

A summary of hydrologically significant observations is included in Appendix II.

2.2 Horn River Producers Group

Two members of the study team met with representatives of the HRPG in Calgary on February 2, 2010 to discuss the surface water data being collected in the HRB that would be of value to the study. Hydrometric, climate and water use data were of particular interest. The members of the HRPG described their surface water data collection programs and their existing data sets. Following the meeting, several members of the HRPG provided their available data. A summary of the data provided is presented in Table 2.1.

A review of the data indicates that, in general, the data provided by the HRPG may not be immediately useful for hydrologic modelling purposes or for estimating seasonal and annual water use amounts (current and future) in the sub-basins of the HRB with an adequate degree of certainty. It is recommended that a systematic program of hydrometric, climate and water use, and subsequent hydrologic modelling efforts be undertaken to achieve the original objectives of the study for hydrologic risk assessment of the sub-basins in the HRB.

The study team discussed the data limitations with officials of the MEMPR on March 8, 2010 and their impacts on the original scope of the study.

Specifically, two issues that may affect the scope the task on "Evaluation of Water Availability and Hydrologic Risk" are:

1) Water demand data in the HRB is currently sparse and it may not be possible to disaggregate them to provide seasonal or annual total withdrawal amounts from specific water bodies in the respective sub-basins of the HRB. In addition, 5-year demand forecasts at the sub-basin scale may have even more significant uncertainty.

2) Only three sub-basins (outside the HRB) have been gauged and have data that can be used for hydrologic model calibration and validation (see Sections 3 of this report). Short-term monitoring data on stream flows within the HRB is very sparse. Hence, surface water availability (seasonal and annual) at the sub-basin scale may also be subject to some level of uncertainty.

These two issues limit the extent to which a reliable hydrologic risk assessment (sub-basin by sub-basin) can be undertaken.

The study team proposed the following to address these two issues to some extent:

1) Focus the study efforts on assessing the water availability in each sub-basin based on the currently available information on recorded flows.

2) Provide recommendations on further investigations and data collection programs that may be required to improve water availability assessments at the sub-basin scale.

3) Provide an approach in an Appendix to the study report on how the demand-availability assessment and assignment of risk (vulnerability) can be undertaken.

The suggested approach was discussed with MEMPR on March 8, 2010. It was agreed that the approach would address the TOR for the study given the current data availability issues.

Table 2.1: Data Available from Horn River Producers Group

HRPG Member	Climate	Stream Flow	Lake Level	Lake Volume/Bathymetry	Withdrawals from Identified Sources	Current Water Use	Future Water Use-5-year
Devon	Not Available			2008. 4 lakes, including Tsea Lake, in Komie area. Bathymetry of Lake A			
Apache							
EOG	Some observations on precipitation events in 2009 (amounts not recorded).		2009. Water Level in Maxhamish Lakes 2 and 7.				
Nexen	Weather station (?). Komie snowpack in Apr 2009.	6 flow stations (?). Discharge measurements on Tsea River: Jan/Apr/Jun 2009. 2009 flows in Tsea River. 2009 AMEC Hydrology Report - used regional data.	5 lake level stations.		2008 water amounts hauled from several sources.		
StoneMountain				Basic lake info on 7 lakes on Emile/Fortunr creeks.		Jun 2008 to Jun 2009 water withdrawal amounts.	
Esso						Volume used in 2009 .	

3.0 HYDROLOGIC MODELLING OF THE HORN RIVER BASIN

3.1 Introduction

The tasks undertaken to set up, calibrate and implement a hydrologic model for the Horn River Basin (HRB) were as follows:

- Selection of hydrologic model for implementation in the HRB;
- Collection of information on topography, meteorological data, hydrometric data, surficial geology and land cover types in the HRB;
- Division of HRB into sub-basin;
- Calibration and validation of hydrologic model; and
- Simulation of seasonal and annual water yield from sub-basins of HRB.

3.2 Selection of Hydrologic Model for the Horn River Basin

3.2.1 Hydrologic Models Considered

As part of the initial review and project scoping process, the study team identified three hydrologic models for consideration. The three models were selected from an extensive list based on a comparison of key technical components of the alternative models and consideration of such issues as model capabilities, technical support and history of application in this region. The three models that were considered for further consideration were:

- MIKE-SHE (DHI);
- HSPF (USEPA); and
- UBC Watershed Model.

Details on the models are provided below.

MIKE-SHE

MIKE-SHE offers several different approaches for hydrologic simulation, ranging from simple, lumped and conceptual approaches to advanced, distributed and physically-based approaches. It considers precipitation (rain or snow), evapotranspiration, including canopy interception, overland sheet flow, channel flow, unsaturated sub-surface flow, and saturated groundwater flow. If the unsaturated zone is considered, MIKE-SHE will calculate infiltration, actual evapotranspiration and recharge.

MIKE-SHE has the advantage of including both simple and advanced hydrologic process descriptions that can operate at either a grid-scale or a sub-watershed scale. It has good modules for simulating key hydrologic processes, can use data from remote sensing and GIS as inputs, and has the ability to import gridded climate data. Hence, the user can choose the hydrologic module component that more appropriately makes effective use of the available data, achieves the purpose of the hydrologic modelling exercise and provides the required end results to maximize computational efficiency.

HSPF

HSPF uses a version of the Stanford Watershed Model, which is a deterministic, lumped, conceptual hydrologic model, and hence has modest data requirements. It distributes the incoming rainfall into canopy interception, impervious areas, surface runoff or interflow, and infiltration which is further divided into active and inactive groundwater storages. The three conceptual storages regulate soil moisture and groundwater storage, while evapotranspiration can extract moisture from the interception, surface and groundwater storages. Runoff from the channel inflow is routed by a hydrologic routing technique that accounts for attenuation by the storage effects of the channels.

HSPF has the advantage in terms of practical application for more than 20 years, public-domain software, having a central data base management capability, easy to set-up and has graphical user interface for pre and post-processing, and detailed user manuals and documents.

UBC Watershed Model

The UBC Watershed Model was developed to simulate the hydrologic responses of watersheds in mountainous areas. The model uses maximum and minimum daily temperatures, and daily precipitation as inputs. Precipitation inputs on a watershed are made functionally dependent on elevation and on the temperature regime. The set-up of the UBC Watershed Model also requires a number of watershed parameters as inputs. These parameters provide the model with a physical representation of the watershed, which determines how the watershed responds to temperature and precipitation inputs. The UBC Watershed Model can use up to five climate stations and one hydrometric station for its calibration. The calibration process compares the observed hydrographs of a gauged stream with the hydrographs calculated by the UBC Watershed Model. The model uses historic meteorological and stream flow records as reference data and calculates statistics on volume and the simulated hydrograph shape. The model uses watershed elevation, divided into elevation bands, to simulate the variability in snow depth and melt rate, as well as orographic effects on rainfall intensities. The model calculates watershed outflows resulting from local snowmelt and rainfall. In addition, the model has been specifically designed for simulating runoff from glacier melt in mountainous areas. One possible disadvantage of the UBC Watershed Model is that technical support for the model may be limited.

3.2.2 HSPF as Selected Model

After further review and discussions with MEMPR, HSPF was selected as the model best suited to provide the desired output format for the current study and to support any anticipated follow up studies. The reasons for the choice were as follows:

- HSPF is a public domain model, thus allowing for its implementation by MEMPR and others without any cost.
- The study team has considerable experience with implementing HSPF on muskeg-type terrain. Muskeg is the dominant land cover in the HRB.
- Data limitations (lack of extensive hydrometric and detailed topographic and land cover data) restrict the use of physically-based models such as MIKE-SHE, while HSPF can accommodate the data limitations through calibration parameters.

3.3 Compilation of Data

3.3.1 Hydrometric and Climate Data

Climate Data

Climate data are collected at a number of Environment Canada's (EC) meteorological stations in and around the HRB. Table 3.1 lists the climate stations and Figure 3.1 shows the locations of the stations. Based on a review of the data, the Fort Nelson Airport Meteorological Station (No. 1192940), located along the south central edge of the HRB, has the longest climate record (72 years) within the HRB area. Data from this station indicates an annual average temperature of -0.7°C and an annual precipitation depth of 497 mm of which 189 mm (water equivalent) falls as snow. The data at this station was deemed to be appropriate for the hydrologic modelling and was selected as the index climate station for the HRB.

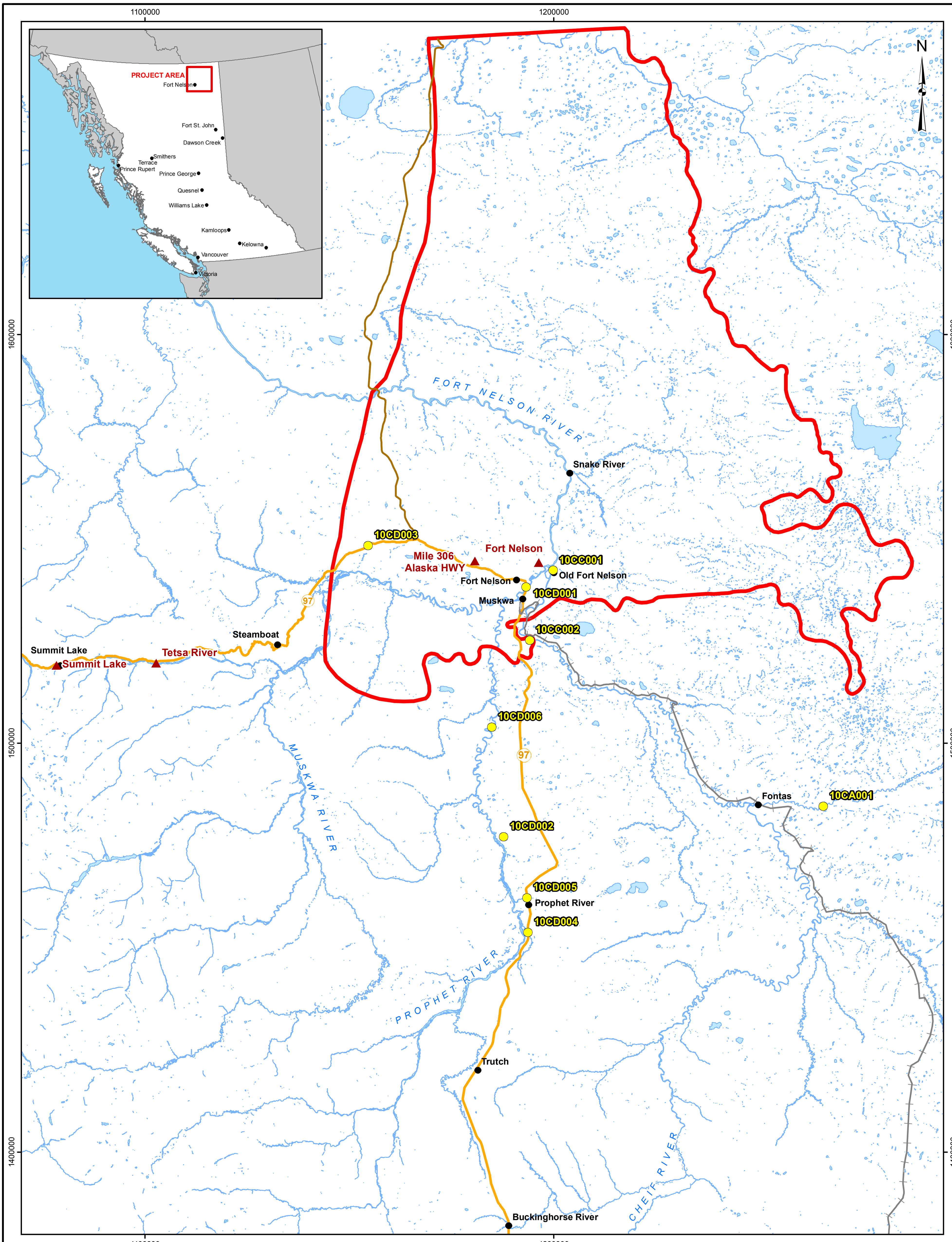
Table 3.1: Environment Canada Climate Stations in and around the Horn River Basin

Station Name	Climate Station ID	Elevation [masl]	Period of Record [year]	Latitude [DM]	Longitude [DM]
Fort Nelson A	1192940	382	1937 to 2009	58° 50.40' N	122° 36.00' W
Mile 306 Alaska HWY	11951B9	451	1984 to 1991	58° 51.00' N	122° 52.20' W
Summit Lake	1197860	1281	1976 to 1991	58° 39.00' N	124° 39.00' W
Tetsa River	1195J29	793	1982 to 2007	58° 39.00' N	124° 13.80' W

Hydrometric Data

There are nine hydrometric stations operated by Environment Canada on streams and rivers in and around the HRB. Only three of these stations are located within the HRB. Table 3.2 lists the hydrometric stations operated by Water Survey Canada (WSC) of Environment Canada (EC) in and around the HRB. Figure 3.1 shows the locations of the stations. A review of the data from these stations indicates a high degree of spatial variation amongst the stations, with annual average yield ranging from 3.8 L/s/km^2 to 15.5 L/s/km^2. This variation indicates the need for sub-basin specific hydrologic modelling in order to characterize the variable hydrologic settings within the HRB.

Although the EC hydrometric data provides insight into the regional hydrologic characteristics, these stations are generally located on very large systems that extend well beyond the limits of the HRB. The use of these data for the calibration of hydrologic models of sub-basins within the HRB is limited.



LEGEND

- Climate Monitoring Station
- Hydrometric Station
- Populated Place
- Highway
- Highway - Secondary
- Railway
- Watercourse
- Horn River Basin Boundary
- Waterbody

20 0 20

SCALE 1:900,000 KILOMETRES

DRAFT

REFERENCE

Watershed data obtained from the BC LRDW. Other data obtained from the BC MEMPR.
Projection: BC Albers Datum: NAD 83

PROJECT
MEMPR
HORN RIVER BASIN
FORT NELSON, B.C.

TITLE

HYDROMETRIC AND CLIMATE STATIONS

Golder Associates
Greater Vancouver Office, B.C.

PROJECT NO. 09-1450-5058			PHASE No.	
DESIGN	DS	31 Mar. 2010	SCALE AS SHOWN	REV. 0
GIS	JW	31 Mar. 2010	FIGURE 3-1	
CHECK				
REVIEW				

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Table 3.2: Hydrometric Stations in and around the Horn River Basin

Station Name	Station Number	Location[a]		Period of Record Used			Drainage Area[b] [km^2]	Mean Annual Flow [m^3/s]	Missing Data [Day]	Status
		Latitude	Longitude	Start Year	End Year	Number of Years				
Fontas River near the mouth	10CA001	58°16'15" N	121°27'50" W	1988	2007	20	7,400	30.6	1,760	active
Bougie Creek at kilometer 368 Alaska High way[c]	**10CD004**	**58°1'49" N**	**122°43'7" W**	**1981**	**2007**	**27**	**332**	**2.65**	**0**	**active**
Adsett Creek at kilometer 386 Alaska High way[c]	**10CD005**	**58°6'22" N**	**122°42'56" W**	**1983**	**2007**	**25**	**109**	**0.867**	**0**	**active**
Parker Creek near the mouth	10CD002	58°14'33" N	122°48'5" W	1979	1982	4	60.6	0.437	329	discontinued
Prophet River above Cheves Creek	10CD006	58°29'2" N	122°49'47" W	1988	1995	8	7,320	74.6	0	discontinued
Fort Nelson River above Muskwa River	10CC002	58°40'15" N	122°38'15" W	1978	2004	27	22,800	138	534	discontinued
Muskwa River near Fort Nelson	10CD001	58°47'18" N	122°39'33" W	1944	2007	64	20,300	213	1,777	active
Raspberry Creek near the mouth[c]	**10CD003**	**58°53'38" N**	**123°19'9" W**	**1979**	**2007**	**29**	**273**	**1.07**	**0**	**active**
Fort Nelson River at Fort Nelson	10CC001	58°49'20" N	122°32'30" W	1960	1978	19	43,500	334	337	discontinued

(a) Station location shown in DMS co-ordinates (datum NAD83).

(b) Gross drainage area by Environment Canada.

(c) Watersheds used for calibration.

3.3.2 Physical Characteristics of Horn River Basin

Sources of data for the physical characterization of the Horn River Basin included the National Topographic Series (NTS) maps (1:50,000) and the Terrain Resource Inventory Mapping (TRIM) from the Government of British Columbia. Appendix III shows maps depicting the physical characteristics of the HRB and includes the following:

- Figure III-1: Digital Elevation Model of the HRB
- Figure III-2: Surficial Geology of the HRB
- Figure III-3: Land Cover Types in the HRB (2 maps at BCLS 3 and 4)

A summary of the surficial geology-land cover characteristics in the HRB is shown as Table 1 in Appendix III.

3.4 Sub-Basins of the Horn River Basin

The HRB was divided into twelve (12) sub-basins considering major topographic divides, drainage towards the Fort Nelson River, locations of EC hydrometric stations, major classes of surficial geology and land cover types, ground slope, and hydrographic connectivity. Each sub-basin was further divided into smaller watersheds with drainage areas in the 20 to 30 km^2 range for modelling purposes. This level of sub-division provides the means to capture variability in topography, surficial geology and land cover type within a sub-basin. Based on drainage at the watershed level, the watersheds were aggregated for flow reporting purposes to form watershed units with drainage areas of approximately 20,000 ha to 25,000 ha (200 to 250 km^2) each as specified in the RFP. Figure III-4 in Appendix III shows the sub-basins and the watersheds within each sub-basin.

3.5 Calibration and Validation of the HSPF Model for the Horn River Basin

Three gauged watersheds (Adsett Creek, Bougie Creek and Raspberry Creek) were selected for the calibration and validation of the HSPF model. Their characteristics are listed in Table 3.2. The watersheds are shown in Figure III-5 in Appendix III. Of the three watersheds, two are outside the HRB, with the Raspberry Creek watershed being only partially in the HRB. This highlights the lack of gauged small to medium size watersheds within the HRB for a more site-specific model calibration. Nevertheless, these three gauged watersheds were useful for developing a preliminary regional HSPF model for the HRB. Further refinement of the model would be required for site-specific assessment of water availability and hydrologic risk from water withdrawals.

3.5.1 Calibration Process

The steps in the calibration and validation of the HSPF model on the three gauged watersheds close to the HRB were as follows:

- Prepare a model schematic showing the linkages between the land types and reaches between each sub-watershed within each of the three watersheds. The model schematic for each calibration watershed is shown as Figure IV-1 in Appendix IV.
- Compile data on climate, flow, soil/surficial geology, vegetation, etc., for each watershed. The surficial geology characteristics of the watersheds used for calibration are provided in Appendix III.

- Determine relationship between seasonal precipitation and elevation to enable correction when transferring Fort Nelson precipitation to calibration watersheds as well as other watersheds in the HRB. The relationship is shown as Figure 1 in Appendix V.
- Derive evapotranspiration and lake evaporation data using the Morton Model, with air temperature, dew point temperature, precipitation and solar radiation from the Fort Nelson climate station as input data.
- Divide the available concurrent climate and hydrometric data for each of the three watersheds into two time periods. One period (1979-1990) is used for calibration and the other for validation (1991-1998) of the model within a given gauged watershed.
- Run the model using one of the time periods to calibrate the model (continuous simulation) and the other time period to validate the model under natural watershed conditions.
- Implement the model over the entire calibration and validation periods (1979-1998).
- Determine hydrologic statistics such as the mean annual, seasonal and monthly for the observed and simulated data on each watershed for the calibration, validation and implementation periods.
- Model parameters are adjusted based on model simulations and observed flow data at gauged locations, until the implementation characteristics are deemed reasonable.

3.5.2 Results of Calibration and Validation

Tables 3.3 to 3.5 show the calibration, validation and implementation statistics on each gauged watershed. Figures 3.2, 3.4 and 3.6 show a comparison of simulated and recorded mean monthly flows over the implementation period for each calibration watershed. Figures 3.3, 3.5 and 3.7 illustrate the simulated and observed hydrographs for selected years.

In general, the calibration, validation and implementation statistics appear to be reasonable. Mean annual flows are estimated to within 10%, mean seasonal flows between 5% and 15%, and mean monthly flows between 10% and 30%, although there are large differences in these three statistics in some instances. This is to be expected as the precipitation at Fort Nelson requires correction for elevation when the data is transferred to the watersheds. The correction (see Figure 1 in Appendix V) is based on limited precipitation data available at Fort Nelson and Tetsa. This highlights the need for precipitation data at several locations in the HRB covering a range of elevations to capture the precipitation-elevation relationship more accurately.

3.5.3 Corroboration from TEK/TU Observations

The hydrographs in Figures 3.3, 3.5 and 3.7 tend to corroborate the observations reported during the study team's meetings with community members of the Fort Nelson First Nation (FNFN). The open-water low flow month is October on average. Winter low flows tend to be relatively small with the lowest flows occurring in January and February. 1987 was an exceptionally wet year on Adsett Creek and Bougie Creek, however, the same year was quite dry on Raspberry Creek. This highlights the spatial variability in the hydrologic regime in and around the HRB.

Table 3.3: Statistics of Recorded and Simulated Flows for Raspberry Creek at 10CD003 (273 km^2)

Statistic	Implementation (1979-1998)		% difference	Calibration (1979-1990)		% difference	Validation (1991-1998)		% difference
	Recorded	Simulated		Observed	Simulated		Observed	Simulated	
Mean Annual Flow (m^3/s)	**1.07**	**1.01**	**-6%**	1.13	1.02	-10%	1.00	1.02	2%
Mean Monthly Flows (m^3/s)									
Jan	**0.00**	**0.01**	**-**	0.00	0.01	-	0.00	0.01	-
Feb	**0.00**	**0.00**	**-**	0.00	0.00	-	0.00	0.00	-
Mar	**0.00**	**0.00**	**-**	0.00	0.00	-	0.01	0.00	-
Apr	**0.74**	**0.83**	**12%**	0.30	0.75	153%	1.23	0.91	-27%
May	**5.26**	**3.99**	**-24%**	6.17	4.54	-26%	4.23	3.38	-20%
Jun	**2.18**	**2.46**	**13%**	2.15	2.15	0%	2.22	2.80	26%
Jul	**1.72**	**1.79**	**4%**	1.82	1.61	-12%	1.56	1.99	28%
Aug	**1.27**	**1.32**	**4%**	1.27	1.03	-19%	1.32	1.76	33%
Sep	**1.00**	**1.11**	**11%**	1.16	1.28	10%	0.77	0.96	24%
Oct	**0.52**	**0.47**	**-11%**	0.57	0.65	14%	0.49	0.29	-40%
Nov	**0.10**	**0.11**	**11%**	0.11	0.15	40%	0.10	0.08	-23%
Dec	**0.02**	**0.03**	**-**	0.02	0.04	-	0.02	0.02	-
Mean Seasonal Flows (m^3/s)									
Dec-Mar	**0.01**	**0.01**	**-**	0.01	0.01	-	0.01	0.01	-
Apr-May	**3.00**	**2.41**	**-20%**	3.24	2.65	-18%	2.73	2.15	-22%
Jun-Aug	**1.73**	**1.85**	**8%**	1.75	1.59	-9%	1.70	2.18	28%
Sep-Nov	**0.54**	**0.56**	**4%**	0.61	0.69	13%	0.46	0.45	-2%

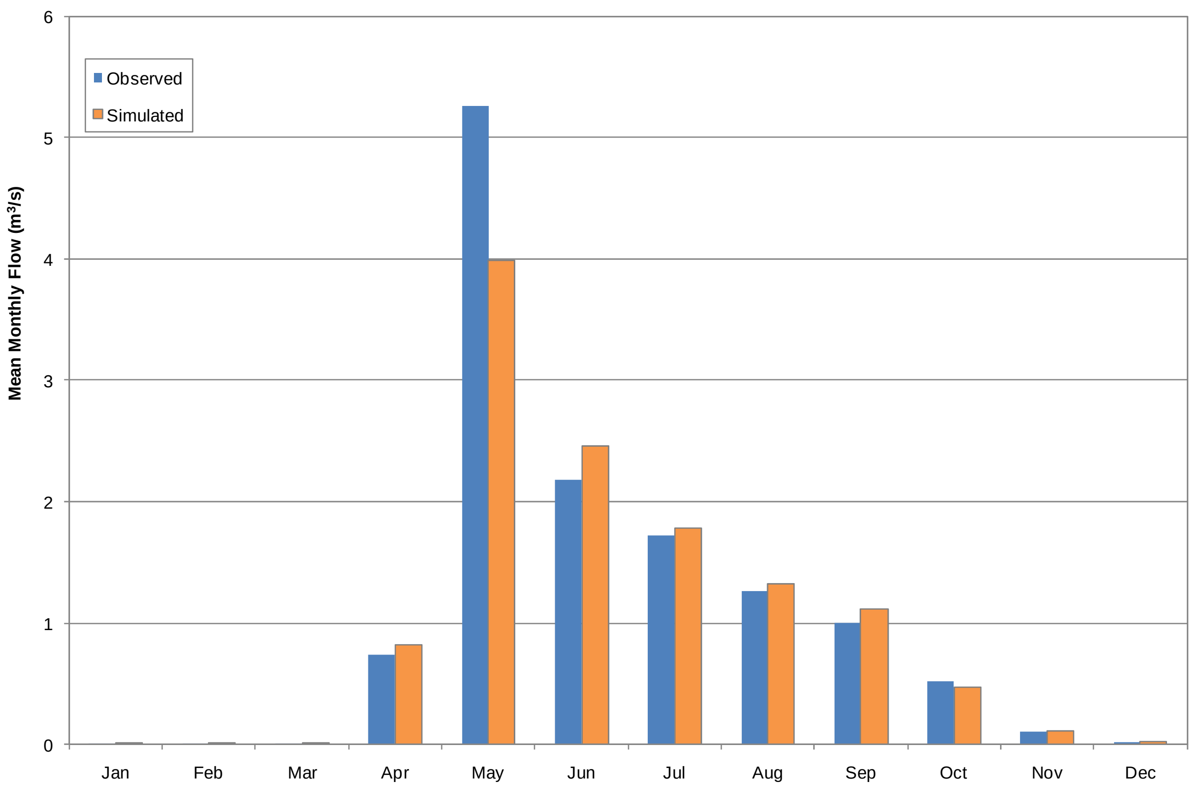

Figure 3.2: Observed and Simulated Mean Monthly Flows on Raspberry Creek at 10CD003 (273 km^2)

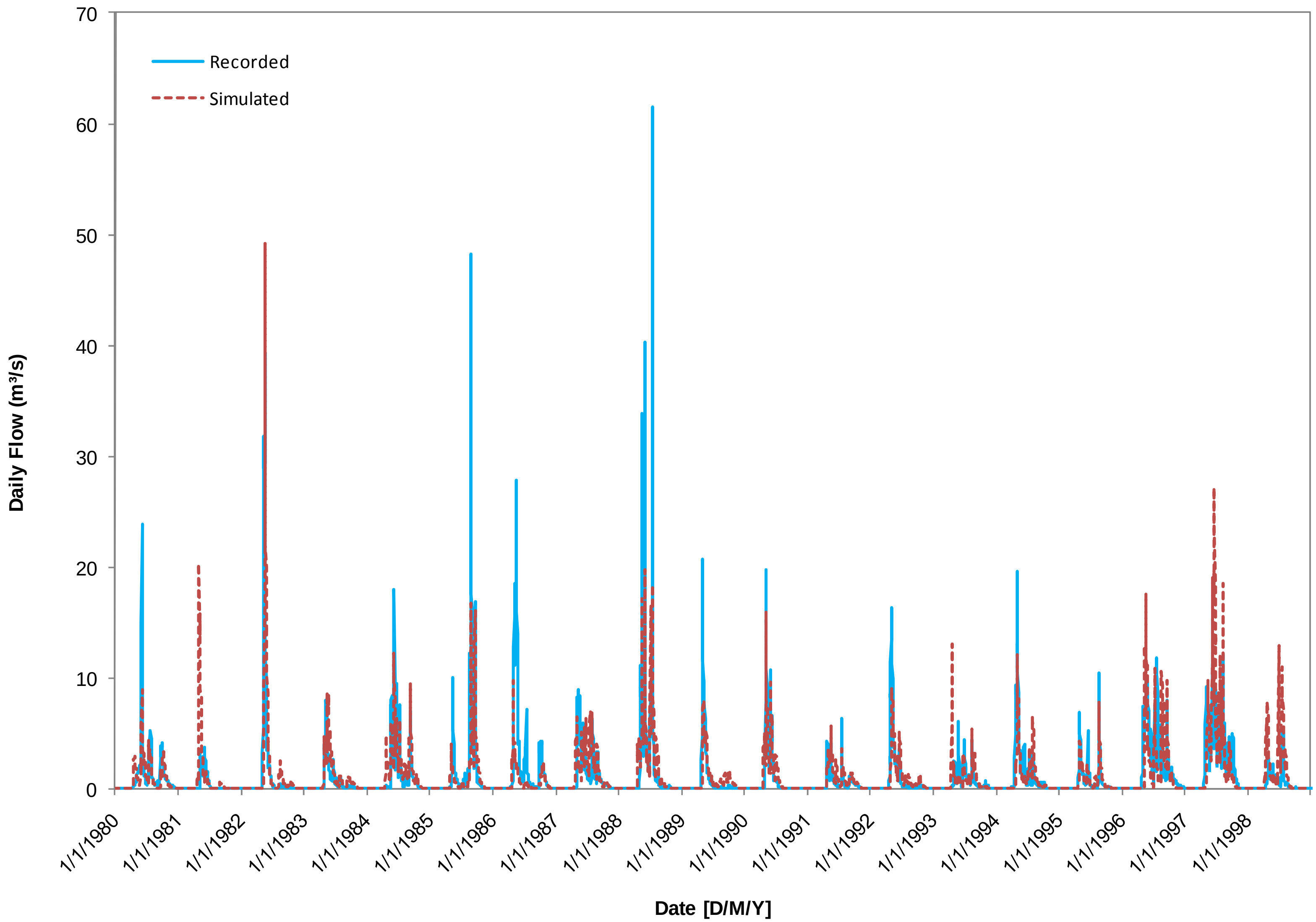

Figure 3.3: Observed and Simulated Daily Flows on Raspberry Creek at 10CD003 (273 km^2)

Table 3.4: Statistics of Recorded and Simulated Flows for Adsett Creek at 10CD005 (109 km^2)

Statistic	Implementation (1983-1998)		% difference	Calibration (1983-1992)		% difference	Validation (1993-1998)		% difference
	Recorded	Simulated		Recorded	Simulated		Recorded	Simulated	
Mean Annual Flow (m^3/s)	**0.85**	**0.81**	**-4%**	0.82	0.77	-5%	0.91	0.88	-4%
Mean Monthly Flows (m^3/s)									
Jan	**0.01**	**0.00**	**-**	0.01	0.00	-	0.01	0.00	-
Feb	**0.01**	**0.00**	**-**	0.01	0.00	-	0.00	0.00	-100%
Mar	**0.02**	**0.00**	**-**	0.03	0.00	-	0.01	0.00	
Apr	**0.51**	**0.55**	**8%**	0.46	0.52	13%	0.61	0.61	1%
May	**2.32**	**2.61**	**12%**	2.88	2.90	1%	1.40	2.13	52%
Jun	**1.86**	**1.81**	**-2%**	1.77	1.44	-19%	1.99	2.43	22%
Jul	**2.06**	**1.74**	**-16%**	1.66	1.51	-9%	2.85	2.11	-26%
Aug	**2.06**	**1.59**	**-23%**	1.66	1.23	-26%	2.72	2.20	-19%
Sep	**0.86**	**1.13**	**32%**	0.86	1.29	49%	0.86	0.88	3%
Oct	**0.33**	**0.27**	**-17%**	0.31	0.34	10%	0.36	0.16	-55%
Nov	**0.09**	**0.02**	**-77%**	0.08	0.02	-70%	0.10	0.01	-87%
Dec	**0.03**	**0.00**	**-**	0.03	0.00	-	0.03	0.00	-
Mean Seasonal Flows (m^3/s)									
Dec-Mar	**0.02**	**0.00**	**-94%**	0.02	0.00	-94%	0.01	0.00	-
Apr-May	**1.42**	**1.58**	**12%**	1.67	1.71	2%	1.00	1.37	37%
Jun-Aug	**1.99**	**1.71**	**-14%**	1.70	1.39	-18%	2.52	2.25	-11%
Sep-Nov	**0.42**	**0.48**	**12%**	0.42	0.55	32%	0.44	0.35	-20%

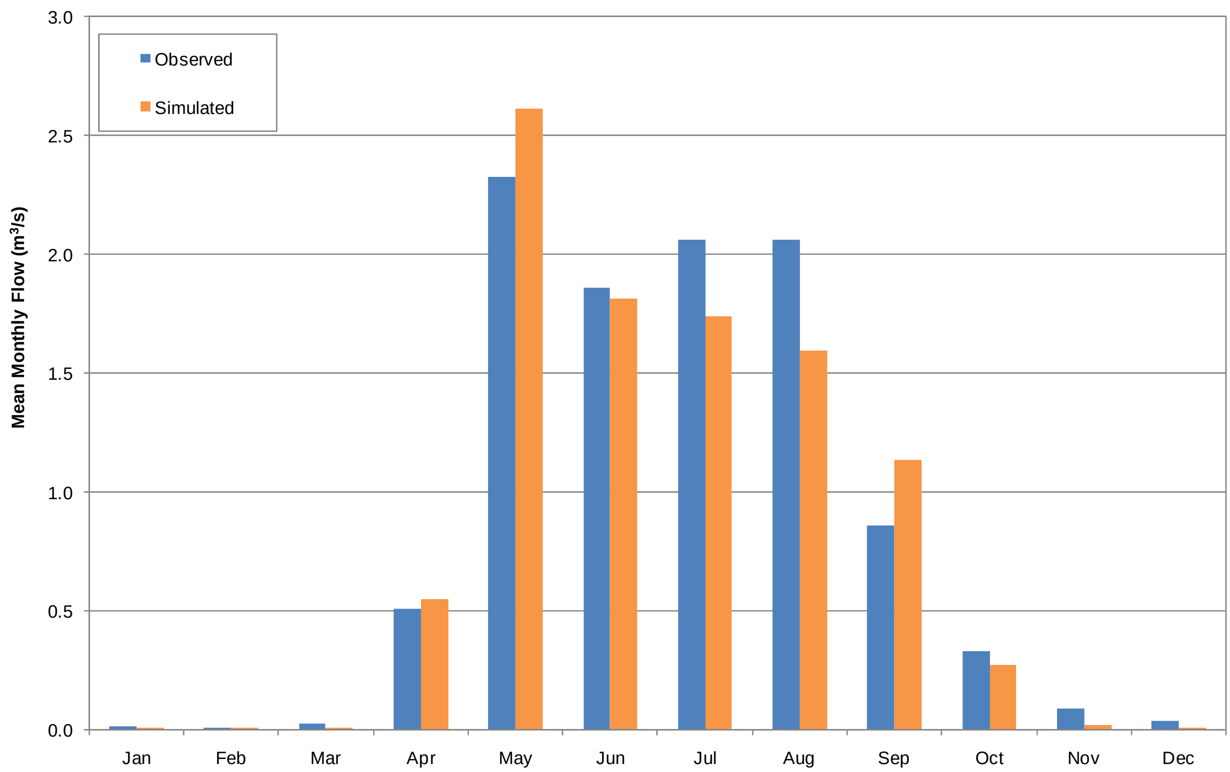

Figure 3.4: Observed and Simulated Mean Monthly Flows on Adsett Creek at 10CD005 (109 km^2)

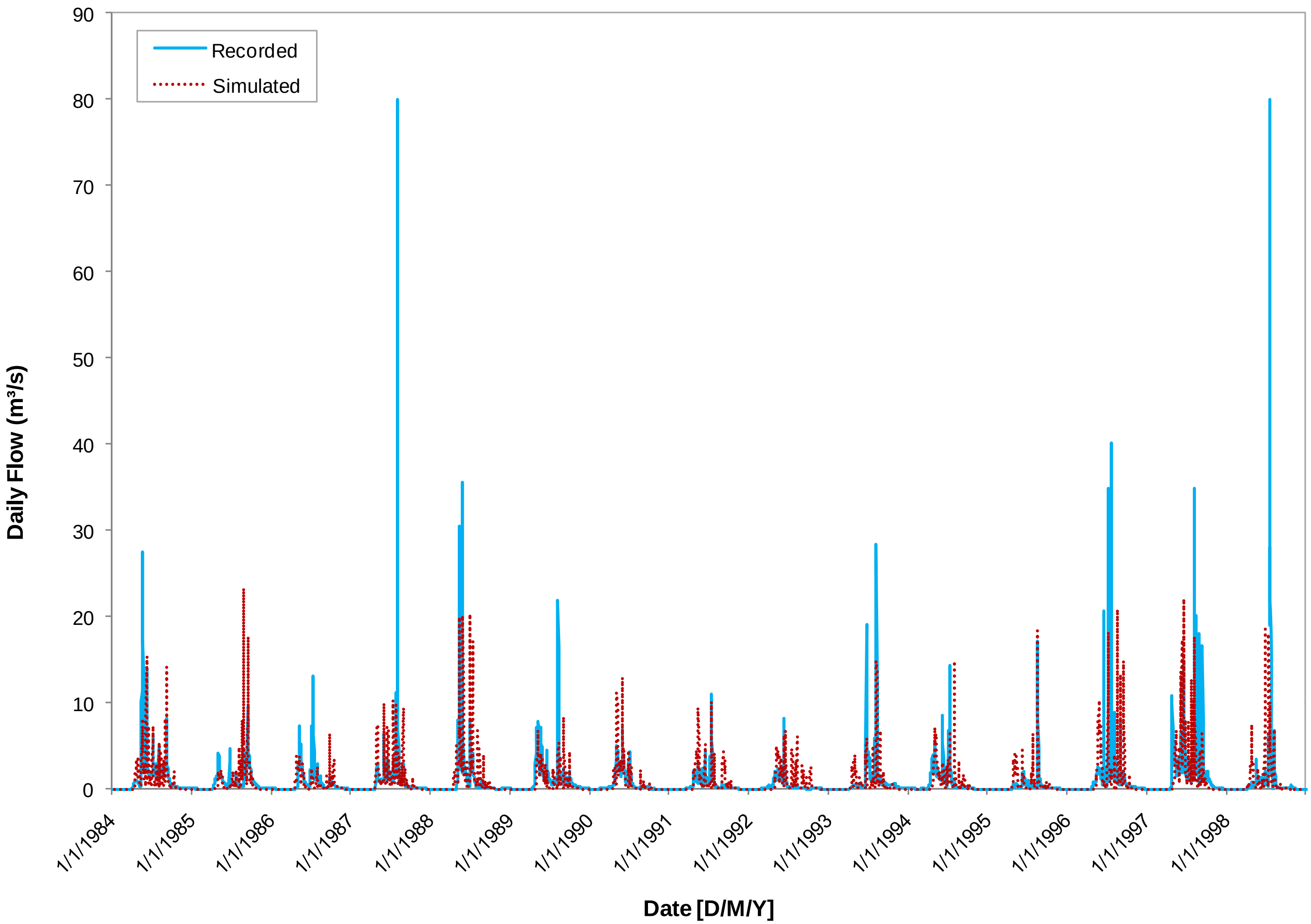

Figure 3.5: Observed and Simulated Daily Flows on Adsett Creek at 10CD005 (109 km^2)

Table 3.5: Statistics of Recorded and Simulated Flows for Bougie Creek at 10CD004 (332 km²)

Statistic	Implementation (1981-1998)		% difference	Calibration (1981-1990)		% difference	Validation (1991-1998)		% difference
	Recorded	Simulated		Recorded	Simulated		Recorded	Simulated	
Mean Annual Flow (m^3/s)	**2.68**	**2.51**	**-6%**	2.52	2.45	-3%	2.75	2.49	-9%
Mean Monthly Flows (m^3/s)									
Jan	**0.01**	**0.00**	**-**	0.00	0.00	-	0.01	0.00	-
Feb	**0.01**	**0.00**	**-**	0.00	0.00	-	0.01	0.00	-
Mar	**0.05**	**0.00**	**-**	0.03	0.00	-	0.07	0.00	-
Apr	**1.64**	**1.22**	**-26%**	1.12	1.08	-4%	2.32	1.37	-41%
May	**8.75**	**8.84**	**1%**	10.8	10.5	-3%	5.69	6.97	22%
Jun	**6.67**	**6.12**	**-8%**	5.87	5.45	-7%	7.48	6.88	-8%
Jul	**7.09**	**5.01**	**-29%**	5.54	4.01	-28%	9.11	5.63	-38%
Aug	**5.02**	**4.66**	**-7%**	3.95	3.80	-4%	5.47	5.37	-2%
Sep	**2.01**	**3.32**	**65%**	1.87	3.34	79%	1.93	2.94	52%
Oct	**0.76**	**0.87**	**15%**	0.81	1.00	24%	0.64	0.62	-4%
Nov	**0.16**	**0.11**	**-28%**	0.16	0.13	-18%	0.18	0.08	-55%
Dec	**0.03**	**0.02**	**-**	0.04	0.02	-	0.04	0.01	-
Mean Seasonal Flows (m^3/s)									
Dec-Mar	**0.02**	**0.01**	**-**	0.02	0.01	-	0.03	0.00	-
Apr-May	**5.19**	**5.03**	**-3%**	5.95	5.79	-3%	4.01	4.17	4%
Jun-Aug	**6.26**	**5.26**	**-16%**	5.12	4.42	-14%	7.35	5.96	-19%
Sep-Nov	**0.97**	**1.43**	**47%**	0.95	1.49	57%	0.92	1.21	32%

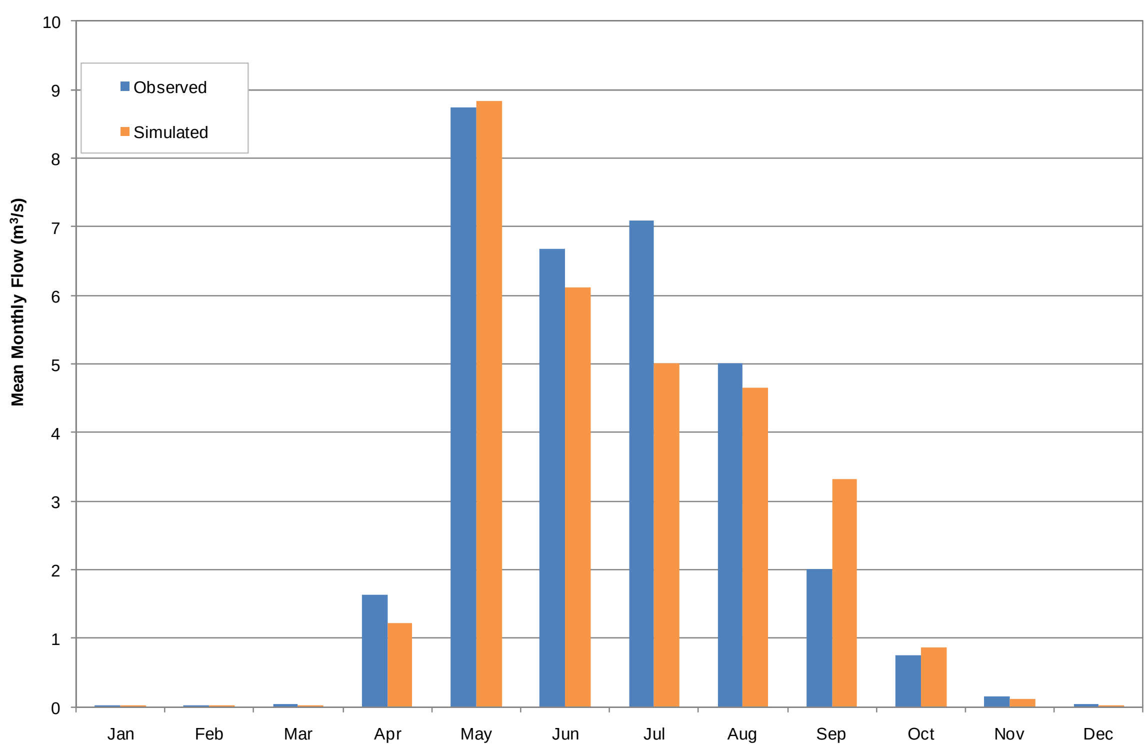

Figure 3.6: Observed and Simulated Mean Monthly Flows on Bougie Creek at 10CD004 (332 km²)

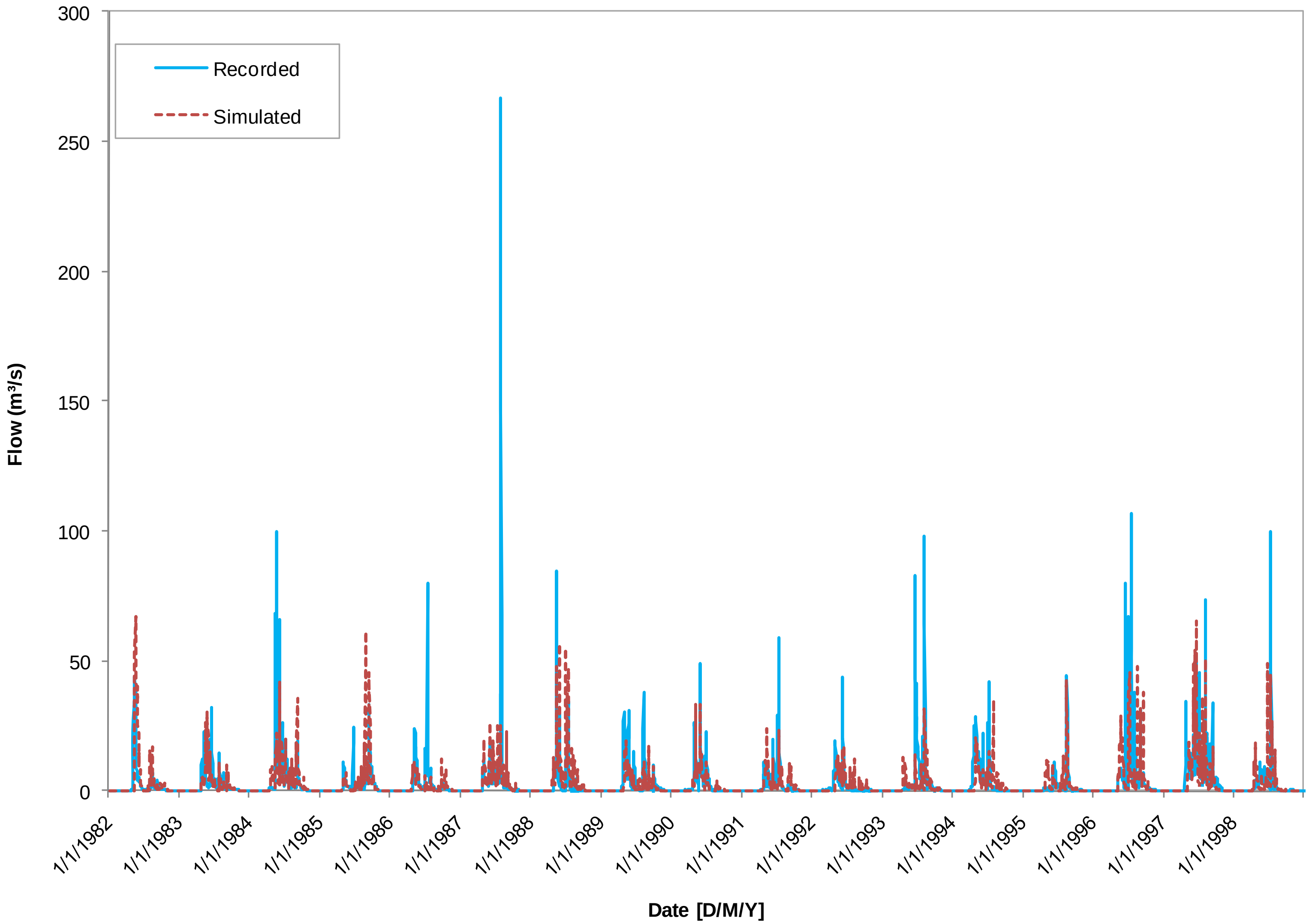

Figure 3.7: Observed and Simulated Daily Flows on Bougie Creek at 10CD004 (332 km^2)

4.0 WATER YIELD FROM SUB-BASINS OF THE HORN RIVER BASIN

The Horn River Basin (HRB) was divided into 12 sub-basins as shown in Figure III.4 in Appendix III. The calibrated and validated HSPF model was implemented on two of the major sub-basins of the Horn River Basin (HRB), that is, the Kiwigana River sub-basin (denoted as sub-basin 6 in Figure III.4 in Appendix III) and the Snake River sub-basin (denoted as sub-basin 12 in Figure III.4 in Appendix III). The two major sub-basins have very different surficial geologic characteristics and represent the range of surficial geological characteristics of the HRB.

Table 4.1 and 4.2 show the surficial geology characteristics of the Kiwigana River and Snake River sub-basins. The key difference between the two sub-basins is that the Snake River sub-basin (12) is dominated by muskeg (organics), while the Kiwigana River sub-basin (6) is mostly till. Muskeg-dominated watersheds tend to have low water yields because of the loss of significant amounts of water from the perched water table through evaporation. The stream flow regime tends to be driven by the interflow through the muskeg layers.

The HSPF model schematics for the two major sub-basins in the HRB are provided in Appendix IV. As discussed in Section 3, each sub-basin was divided into smaller watersheds with drainage areas in the 20 to 30 km^2 range for modelling purposes. Each watershed was then further divided according to the land types within the watershed. This level of sub-division provides the means to capture variability in topography, surficial geology and land cover type within a sub-basin. Based on drainage at the watershed level, the watersheds were aggregated for flow reporting purposes to form watershed units with drainage areas of approximately 20,000 ha to 25,000 ha (200 to 250 km^2) each as specified in the RFP. **NOTE**: Maps will be prepared to show the schematic on each sub-basin so that the model connectivity can be visualized as flow paths. Figure 4.1 is for Snake River as an example.

The calibrated HSPF model was simulated on each of the two major sub-basins for the period from 1972 to 1998 when all climate data inputs for the model are available. The model was run on a daily time step. The simulated daily flow series at the outlet of each watershed of the two major sub-basins were used to characterize the mean monthly, seasonal and annual water yield at that location.

A summary of the water yield conditions in selected watersheds of the two major sub-basins of the HRB is provided in Table 4.3 and Table 4.4. The results indicate that the mean annual runoff from the watersheds in the Snake River sub-basin (12), dominated by muskeg, ranges from 60 to 80 mm. In the till-dominated Kiwinaga River sub-basin (6), the mean annual runoff from the watersheds range from 145 to 185 mm, more than twice the yield from sub-basin 12.

NOTE: Maps will be prepared for each sub-basin showing the cumulative mean annual runoff (or mean annual flow) for incremental watershed areas of about 200 km^2, for example, for the 8 watersheds shown in Table 4.2. It is proposed that the mean monthly and mean seasonal runoff (or flow rates) be provided as tables on a DVD given the large number of maps that would be required for all the 12 sub-basins.

The regionally calibrated HSPF model can be similarly implemented on the other sub-basins in the HRB. Alternatively, it is proposed that at this stage unit monthly/seasonal/annual flows from the simulation results of the two sub-basins be developed and transferred to the other sub-basins with similar characteristics. It is likely that uncertainties introduced by using precipitation amounts derived for the other sub-basins from the Fort Nelson climate station data would dominate the uncertainties in the simulated yield estimates. In addition, a review of Figure III-2 in Appendix III indicates that the resolution of the surficial geology map is much smaller than that for the watersheds in the sub-basins of the HRB. In fact, sub-basin 12 is the only one of the 12 sub-basins that is almost 100% muskeg-dominated and the other sub-basins are essentially till-dominated, with little differentiation between them. Improving the accuracy of the yield from the sub-basins is at this stage dependent on good resolution of the spatial variability in precipitation and adequate hydrometric data for model calibration.

The monthly, seasonal and annual yields were calculated for three ranges of drainage areas: 100 to 400 km^2, 400 to 1,500 km^2 and greater than 1,500 km^2. The results are shown in Tables 4.5 and 4.6 for muskeg and till dominated sub-basins, respectively. The yield values can be applied to watersheds in the other sub-basins to calculate the mean monthly, seasonal and annual flow rates for given watershed areas.

Table 4.1: Surficial Geology of the Kiwigana River Sub-Basin – 6

Location	R3	R6	R9	R14	R18	R21	R26	R29	R30	R36	R38	R41	R44	R49	R51
Area [km2]	155	123	387	181	334	882	175	334	1289	117	324	1706	176	137	2200
Mean Elevation (masl)	518	554	514	661	590	531	561	536	526	574	546	527	499	417	507
Surficial Geology	Area, km²														
Till Blanket (Tb)	115	69	293	141	257	711	117	266	1051	109	303	1446	125	137	1889
%	74%	56%	76%	78%	77%	81%	67%	80%	82%	93%	94%	85%	71%	100%	86%
Till Veneer (Tv)	40	54	94	40	77	170	59	68	238	8	21	259	51	0	311
%	26%	44%	24%	22%	23%	19%	33%	20%	18%	7%	6%	15%	29%	0%	14%
Organic (O)	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%

Table 4.2: Surficial Geology of the Snake River Sub-Basin – 12

Location	R54	R57	R62	R65	R70	R71	R76	R79	R85
Total Area [km^2]	143	304	541	107	909	89	346	1440	1687
Mean Elevation [masl]	456	445	434	400	428	508	474	440	435
Surficial Geology	Area, km²								
Till Blanket	0.0	0.0	0.0	65.4	85.7	6.8	124.6	321.6	555.3
%	0%	0%	0%	61%	9%	8%	36%	22%	33%
Till Veneer	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
%	0%	0%	0%	0%	0%	0%	0%	0%	0%
Organic	143	304	541	41	823	82	221	1118	1132
%	100%	100%	100%	39%	91%	92%	64%	78%	67%

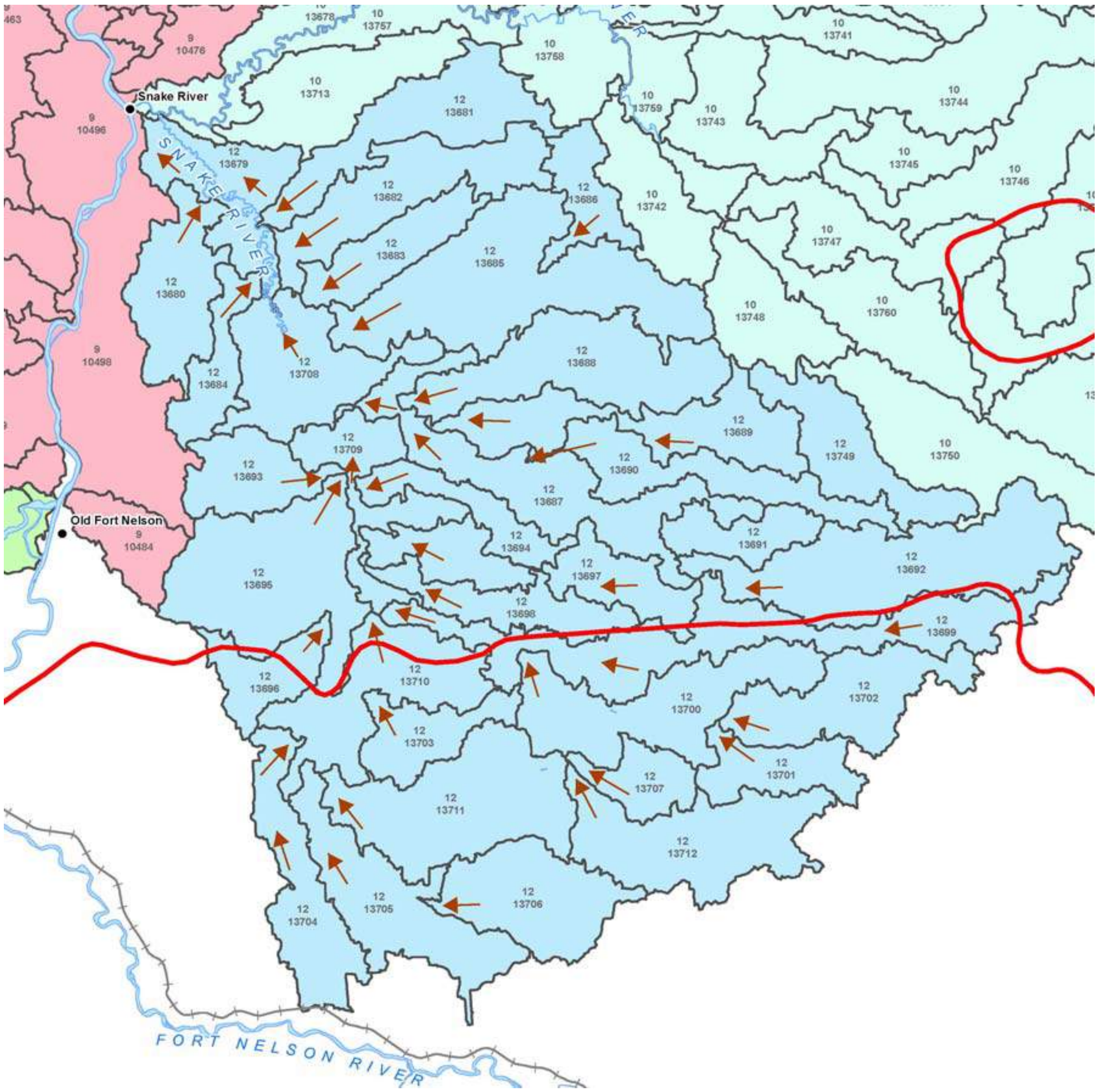

Figure 4.1: Generalized Flow Path Corresponding to Model Schematic of Snake River Sub-Basin

Table 4.3: Simulated Flow Statistics for Selected Watersheds in the Kiwigana River Sub-Basin – 6

Location	R3	R6	R9	R14	R18	R21	R26	R29	R30	R36	R38	R41	R44	R49	R51
Area [km²]	155	123	387	181	334	882	175	334	1289	117	324	1706	176	137	2200
Monthly Flow [m³/s]															
January	0.005	0.003	0.013	0.007	0.013	0.051	0.002	0.005	0.080	0.003	0.010	0.110	0.014	0.003	0.167
February	0.001	0.001	0.004	0.004	0.006	0.023	0.001	0.001	0.036	0.000	0.003	0.050	0.006	0.001	0.080
March	0.000	0.000	0.001	0.001	0.001	0.007	0.000	0.000	0.012	0.000	0.000	0.016	0.001	0.000	0.028
April	0.266	0.205	0.606	0.111	0.378	0.982	0.325	0.664	1.46	0.196	0.517	1.80	0.273	0.372	2.45
May	2.93	2.68	7.27	4.28	7.25	16.6	4.14	7.22	24.2	2.43	6.25	31.3	3.38	2.18	38.8
June	1.85	1.62	4.75	3.38	5.35	12.3	2.56	4.59	18.0	1.63	4.27	23.9	2.37	1.35	29.8
July	1.39	1.27	3.55	2.25	3.78	8.73	2.08	3.64	12.9	1.20	3.10	16.9	1.82	1.09	21.3
August	1.00	0.997	2.58	1.63	2.75	6.22	1.56	2.62	9.18	0.809	2.08	11.8	1.35	0.692	14.7
September	0.746	0.714	1.92	1.20	2.02	4.74	1.10	1.87	6.99	0.592	1.55	9.08	1.03	0.519	11.5
October	0.276	0.222	0.728	0.388	0.711	1.87	0.362	0.682	2.79	0.210	0.591	3.65	0.426	0.253	4.83
November	0.061	0.033	0.169	0.091	0.166	0.527	0.061	0.132	0.792	0.045	0.141	1.07	0.122	0.070	1.51
December	0.011	0.005	0.035	0.020	0.037	0.137	0.009	0.021	0.208	0.007	0.025	0.282	0.039	0.013	0.42
Annual Flow [m³/s]	**0.717**	**0.650**	**1.82**	**1.12**	**1.89**	**4.38**	**1.02**	**1.80**	**6.44**	**0.597**	**1.55**	**8.38**	**0.909**	**0.548**	**10.5**
Runoff [mm]	146	167	148	196	178	157	184	170	158	161	151	155	163	127	151
Seasonal Flow [m³/s]															
Dec-Mar	0.004	0.002	0.013	0.008	0.014	0.054	0.003	0.007	0.084	0.003	0.010	0.115	0.015	0.005	0.173
Apr-May	1.60	1.44	3.94	2.19	3.81	8.78	2.23	3.94	12.9	1.31	3.38	16.6	1.83	1.28	20.6
June-Aug	1.42	1.29	3.63	2.42	3.96	9.09	2.07	3.62	13.4	1.21	3.15	17.5	1.85	1.04	21.9
Sep-Nov	0.361	0.323	0.941	0.559	0.967	2.38	0.509	0.896	3.52	0.282	0.760	4.602	0.527	0.281	5.94

Table 4.4: Simulated Flow Statistics for Selected Watersheds in the Snake River Sub-Basin – 12

Location	R54	R57	R62	R65	R70	R71	R76	R79	R85
Area [km²]	143	304	541	107	909	89	346	1440	1687
Monthly Flow [m³/s]									
January	0.005	0.014	0.023	0.004	0.034	0.003	0.015	0.059	0.078
February	0.004	0.010	0.016	0.001	0.023	0.002	0.009	0.036	0.047
March	0.002	0.005	0.009	0.001	0.013	0.001	0.004	0.019	0.024
April	0.292	0.596	1.10	0.248	1.98	0.151	0.553	2.67	2.60
May	1.45	2.91	5.01	1.05	8.55	1.09	4.05	14.4	17.4
June	0.508	1.06	1.83	0.525	3.28	0.442	1.99	6.24	8.09
July	0.384	0.782	1.36	0.392	2.48	0.319	1.40	4.50	5.79
August	0.273	0.553	0.959	0.259	1.73	0.220	0.921	3.04	3.84
September	0.327	0.663	1.15	0.232	1.95	0.245	0.924	3.27	3.94
October	0.193	0.408	0.718	0.128	1.19	0.134	0.499	1.91	2.29
November	0.039	0.091	0.156	0.030	0.253	0.029	0.128	0.450	0.628
December	0.009	0.027	0.044	0.005	0.064	0.007	0.030	0.110	0.159
Annual Flow [m³/s]	**0.293**	**0.598**	**1.04**	**0.241**	**1.81**	**0.222**	**0.882**	**3.09**	**3.77**
Runoff [mm]	64	62	61	71	63	79	80	68	71
Seasonal Flow [m³/s]									
Dec-Mar	0.005	0.014	0.023	0.003	0.034	0.004	0.015	0.056	0.077
Apr-May	0.872	1.75	3.06	0.649	5.26	0.621	2.30	8.56	10.0
June-Aug	0.389	0.799	1.38	0.392	2.50	0.327	1.43	4.60	5.91
Sep-Nov	0.187	0.387	0.674	0.130	1.13	0.136	0.517	1.88	2.29

Table 4.5: Yield from Muskeg-dominated Watersheds in Sub-Basins of the Horn River Basin

Location	Area Range		
Area [km^2]	100-400	400-1500	>1500
Monthly Runoff [mm]			
January	1	1	1
February	1	1	1
March	0	0	0
April	61	64	49
May	337	302	326
June	143	119	151
July	104	88	108
August	71	61	72
September	76	69	74
October	43	42	43
November	10	9	12
December	2	2	3
Annual Runoff [mm]	71	64	71
Seasonal Runoff [mm]			
Dec-Mar	1	1	1
Apr-May	199	183	187
June-Aug	106	89	111
Sep-Nov	43	40	43

Table 4.6: Yield from Till-Dominated Watersheds in Sub-Basins of the Horn River Basin

Location	Area Range		
Area [km^2]	100-400	400-1500	>1500
Monthly Runoff [mm]			
January	1	2	2
February	0	1	1
March	0	0	0
April	52	40	34
May	652	593	568
June	438	423	435
July	328	306	309
August	236	219	214
September	173	166	166
October	63	65	68
November	14	17	21
December	3	4	6
Annual Runoff [mm]	164	154	153
Seasonal Runoff [mm]			
Dec-Mar	1	2	2
Apr-May	352	317	301
June-Aug	334	316	319
Sep-Nov	83	83	85

5.0 EVALUATION OF HYDROLOGIC RISK IN THE HORN RIVER BASIN

The original scope of work for this study was to use the results of the water supply analysis and the available water demand information to develop tables and GIS maps depicting water supply-demand conditions on a seasonal and annual for each of the sub-basins of the HRB. The intent was to classify the current and anticipated future vulnerability of each sub-basin based on criteria for low, medium and high risk to demand-supply balance. However, as discussed in Section 2.2, the lack of reliable water demand data and the current lack of site specific hydrometric data for each sub-basin in the HRB limit the scope of this task to a generic description of the hydrologic risk assessment. The generic approach is described in Appendix VI.

6.0 RECOMMENDATIONS

As discussed in previous sections of the report, there is currently a lack of sufficient climate, flow/water level and water use (current and future) data to implement a detailed hydrologic modelling analysis of the HRB and to assess the risk of water imbalances in the sub-basins of the HRB. This section of the report makes several recommendations on the approach to address the current date deficiency.

- It is recommended that detailed hydrometric data collection be carried out to refine the model and to support future assessments and decision making.

  Four to seven baseline hydrometric stations should be established. If possible, one station within each of the seven major sub-basins in the HRB: Lower Petitot River; Lower Fort Nelson River; Tsea River; Middle Fort Nelson River; Sahtaneh River; Lower Muskwa River and Kotcho Lake watershed. Small portions of the Lower Prophet River and Lower Fort Nelson River watersheds fall within the HRB but these areas are considered too small to justify the establishment of hydrometric stations. Efforts should be made to locate the hydrometric stations within watersheds of approximately 200 km^2 with little or no existing water diversions related to petroleum development and low probabilities of future development.

  The selection of the locations of the hydrometric stations will need to consider the following:

  - Distribution of surficial geology land types. The strategy would be to select watersheds that span the range of the land type distribution that exists within the HRB.
  - Relief and aspect. Land elevation has a significant influence on precipitation and aspect will control the timing of snow melt.

  The hydrometric monitoring program should be run for at least two to three years to capture the temporal variability over the water year. The monitoring data can then be correlated with data from longer term Environment Canada hydrometric stations to determine if the correlations can be used to synthetically hindcast the monitoring data.

- It is recommended that regular flow monitoring be conducted and records retained for all watercourses with surface water diversions. Consideration should be given to the establishment of hydrometric stations on these watercourses if the characteristics of the watersheds fall within the desired range discussed above.

- It is recommended that at least three new meteorological stations be established to provide better characterization of spatial and temporal variability in meteorological conditions within the HRB. The meteorological stations should be equipped to collect data on at least precipitation (rainfall and snowfall), and temperature, preferably solar radiation and wind speed as well.

  Locating the meteorological stations within the proposed gauged watersheds would lessen the uncertainty in transferring meteorological data from more distant stations. However, as discussed for the proposed gauged watersheds, elevation and aspect can influence the meteorology of an area. Thus, these factors also need to be considered.

  Consideration may be given to establishing one station within the Lower Petitot River or the Lower Fort Nelson River watersheds and the other within the Sahtaneh River or the Kotcho Lake watersheds.

Consideration may also be given to strategically locating these stations near the boundaries of the HRB to support possible future studies related to development within Liard Basin or the Cordova Embayment and avoid redundancy.

- In addition to the automatic meteorological stations, it is recommended that a snow survey be carried out at the end of the two winter seasons to complement the station data and to assist in quantifying the water content of the pack snow at the end of winter and to determine the amount snow that is lost to sublimation and therefore not available for runoff.
- The Horn River Basin is characterized by areas extensively covered with muskeg. It is anticipated that a significant portion of the surface water flows in HRB watercourses is derived from muskeg interflow and base flow in these streams are therefore very sensitive to groundwater levels in the shallow perched aquifer of the muskeg. It is recommended that a network of four to seven (number to be determined during field program scoping) baseline/background shallow groundwater level monitoring stations be established. Efforts should be made to locate the shallow groundwater level monitoring stations in locations outside the influence of existing diversions or impoundments and with low probabilities of future development. The establishment of baseline stations will allow for the identification of natural seasonal groundwater level fluctuations and trends. .
- Due to the significance of interflow contribution to stream flow rates, it is recommended monitoring shallow groundwater levels be set up adjacent to sites where water is extracted from impoundments including borrow pits, reservoirs and other man-made/natural water bodies. Data recorded at these monitoring stations could be compared to baseline/background data to support an evaluation of the significance of any recorded draw downs while accounting for natural fluctuations.
- It is recommended that once a full year of data has been collected, the HSPF model should be run with the monitoring data to determine if the simulated flows adequately replicate observed flows. If they do not, the field program strategy should be re-visited to determine if important basin or meteorological characteristics have been missed or are not being properly represented in the sampling design.
- The calibration of the regional HSPF model should be refined once two or three years of data have been collected to enable implementation on specific sub-basins. The level of uncertainty in the site-specific outputs should be assessed to enable proper risk assessment of present and future water supply-demand conditions.

Report Signature Page

We trust the above meets your present requirements. If you have any questions or require additional details, please contact the undersigned.

GOLDER ASSOCIATES LTD.

Report prepared by:

Report reviewed by:

<u>SUBMITTED FOR REVIEW PURPOSES ONLY</u>

Chris Coles, M.A.Sc., P.Eng.
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7.0 THIRD PARTY DISCLAIMER

This draft report has been prepared by Golder Associates Ltd. (Golder) for the benefit of the client to whom it is addressed. The information and data contained herein represent Golder's best professional judgment in light of the knowledge and information available to Golder at the time of preparation. Except as required by law, this report and the information and data contained herein are to be treated as confidential and may be used and relied upon only by the client, its officers and employees. Golder denies any liability whatsoever to other parties who may obtain access to this report for any injury, loss or damage suffered by such parties arising from their use of, or reliance upon, this report or any of its contents without the express written consent of Golder and the client.

APPENDIX I

Terms of Reference for Surface Water Study – Horn River Basin

Request for Proposals
Surface Water Study - Horn River Basin

Ministry of Energy, Mines and Petroleum Resources Request for Proposals Number: 3004

Issue date: November 30, 2009

Closing Time: Proposal must be received **before** 2:00 PM Pacific Time on: December 21, 2009

GOVERNMENT CONTACT PERSON: All enquiries related to this Request for Proposals (RFP), including any requests for information and clarification, are to be directed, in writing, to the following person who will respond if time permits. Information obtained from any other source is not official and should not be relied upon. Enquiries and any responses will be recorded and may be distributed to all Proponents at the Province's option.

Teresa Morris, Director, Oil and Gas Division,
Ministry of Energy, Mines and Petroleum Resources
5th Floor, 1810 Blanshard Street
Victoria, B.C. V8W 9N3
Fax: (250)953-3770
Email: Teresa.Morris@gov.bc.ca

DELIVERY OF PROPOSALS:

Proposals must not be sent by mail, facsimile or e-mail. Proposals are to be submitted to the closing location as follows:

A. Five (5) complete hard-copies and one (1) copy on diskettes or CD must be delivered by hand or courier to:

Oil and Gas Division
c/o 5th Floor, 1810 Blanshard Street
Victoria, B.C. V8W 9N3
Attention: Teresa Morris

Proposal envelopes should be clearly marked with the name and address of the Proponent, the Request for Proposals number, and the project or program title.

PROPONENTS' MEETING:

A Proponents' meeting **will not** be held.

PROPONENT SECTION:

For hard-copy proposals, a person authorized to sign on behalf of the Proponent **must** complete and sign the Proponent Section (below), leaving the rest of this page otherwise unaltered, and include the originally-signed and completed page with the first copy of the proposal. **For electronic proposals**, all parts of the Proponent Section (below) must be completed except the signature field, as the BC Bid e-bidding key is deemed to be an original signature. The rest of this page must be otherwise unaltered and submitted as part of your proposal.

The enclosed proposal is submitted in response to the above-referenced Request for Proposals, including any addenda. Through submission of this proposal we agree to all of the terms and conditions of the Request for Proposals and agree that any inconsistent provisions in our proposal will be as if not written and do not exist. We have carefully read and examined the Request for Proposals, including the Administrative Section, and have conducted such other investigations as were prudent and reasonable in preparing the proposal. We agree to be bound by statements and representations made in our proposal.

Signature of Authorized Representative:	***Legal Name of Proponent*** *(and Doing Business As Name, if applicable):*
Printed Name of Authorized Representative:	*Address of Proponent:*
Title:	
Date:	*Authorized Representative phone, fax or email address (if available):*

B. Requirements and Response

1. Summary of the Requirement

The Ministry invites proposals that will assist government and others in the understanding of surface water resources in the Horn River Basin (see Figure 1). The objective of initiating this RFP is to further the understanding of where and when surface water diversion and use is appropriate and sustainable, and where necessary, recommend where more detailed information may be required.

By assembling and analyzing available water quantity data and performing a hydrological analysis and modelling at the sub-basin level, an estimate of water volumes, seasonal fluctuations in these volumes and recharge rates should be apparent for sub-basins within the main watersheds in the Horn River Basin. Overlaying these modelled outcomes with actual hydrometric data and surface water diversion and use information as to which sub-basin industry is operating in or plans to operate in the future, should provide a risk-based model and tool to guide surface water allocation decision-makers. Where risks are deemed high and alternatives (e.g. groundwater) are scarce, outcomes from this project should assist in identifying where further detailed collection and analysis of surface water information may be necessary.

Proposals must build upon the assembly and analysis of existing available surface water, climate, streamflow, lake volume and related hydrometric information including surface water information collected by industry. This RFP does <u>not</u> envision setting up new data collection sites and the collection of new streamflow or hydrometric information; however recommendations as to where and the type of information required to fill any knowledge gaps is a component where risks are deemed to be high.

Proposals should include an outline on how local First Nation communities, in particular the Fort Nelson First Nation, will be included in the communication of proposed work and study recommendations. Funding for First Nation involvement in particular for gathering existing traditional use study information regarding water use and values and participation in a community meeting where the Contractor explains study results and recommendations should be identified in the budget.

2. Additional Definitions

In addition to the Request for Proposals Definitions set out in paragraph 1 of Section A, throughout this Request for Proposals, the following definitions will apply:

a) **Horn River Basin –** the location of a major unconventional gas play in northeast BC with the potential to hold 500 trillion cubic feet of gas (see Figure 1).

b) **Shale Gas –** natural gas contained within shale formations that requires stimulation techniques such as hydraulic fracing, in order to allow gas to flow. These stimulation techniques are what characterize shale gas development as "unconventional".

c) **Hydraulic Fracturing or Fracing –** technique used to flow gas from unconventional gas plays by injecting a fluid, primarily composed of fresh water, at a high enough pressure to fracture or crack the rock. Sand is normally mixed with the fluid to hold the cracks open once the pressure is lowered.

d) **Horn River Producers Group –** an association of 11 companies formed to take a collaborative approach to information sharing during the early stages of development in the Horn River Basin by working together to identify opportunities to reduce surface impacts.

e) **Sub-basin –** a subdivision of a watershed (area of land where water from rain or snow melt drains downhill into a body of water such as a river, lake, reservoir, estuary or wetland) of approximately 20,000 to 25,000 ha in size.

3. Ministry Situation/Overview

3.1 Ministry Responsibility

The Ministry manages the responsible development of British Columbia's energy, mining and petroleum resource sectors. Through the promotion of teamwork and positive working relationships with First Nations, government colleagues and industry clients, the Ministry facilitates a climate for thriving, safe, environmentally responsible and competitive energy, mining and petroleum resource sectors. It is through these initiatives that the Ministry will continue to contribute to the economic growth and development of communities throughout British Columbia.

The Oil and Gas Division provides strategic direction and policy that guides the management of the Province's petroleum resources. The division manages and develops an economically vibrant, environmentally sustainable and socially responsible industry by providing analysis and implementing programs and policies. The division is driven to help meet Ministry goals while focusing on priorities of ensuring the orderly, timely and responsible development of British Columbia's oil and gas resources. The Oil and Gas Commission regulates oil and gas activities.

The Ministry is working closely with other provincial agencies such as the Ministry of Environment and the Oil and Gas Commission as well as First Nations such as the Fort Nelson First Nation, and the Horn River Producers Group, to collaborate on studies that will reduce the environmental footprint of oil and gas development activities. In particular, the Ministry, the Ministry of Environment and the Oil and Gas Commission have formed an Oil and Gas Water Stewardship Committee and are coordinating efforts with a sub-committee of the Horn River Producers Group mandated to deal with surface water issues associated with industry's water needs for fracing. This RFP is representative of one of these cooperative efforts.

Industry has been collecting surface water and related hydrometric information over the last few years in support of applications made for surface water use under the Water Act: either short term water permits issued by the Oil and Gas Commission or longer term water licences issued by the Ministry of Environment. This recent water information will augment government's long term water quantity data, help model streamflows, timing and available volumes for areas where limited information is available, leading to a better understanding as to surface water resources and timing of future water use.

3.2 Background

The Horn River Basin located in northeast BC (see Figure 1) refers to a subsurface geological shale formation. The area is over 1.1 million hectares in size with little existing infrastructure and is predicted to hold a significant amount of gas resources. Over $ 2.2 billion in petroleum and natural gas rights have been sold to natural gas development interests. These interests or companies have formed the Horn River Producers Group to take a collaborative approach to development, including information sharing at early stages of development, assisting the industry in reducing their environmental footprint. Government is working closely with this group to ensure efforts to gather information are coordinated and logically sequenced.

Shale gas well completions require a reasonably short duration of time (i.e., weeks not months) and large volumes of water when compared with conventional gas development. Water is used to stimulate the shale formation in order for the gas to flow to surface. Industry is primarily using surface water for this purpose obtained through and regulated by short term water use permits issued by the Oil and Gas Commission or longer term water licenses issued by the Ministry of Environment.

Government agencies and industry anticipate future water needs will be met from surface water bodies, shallow groundwater, and deep groundwater aquifers. Additional surface water information is required by government regulators to mitigate impacts from surface water diversion and use in high risk sub-basins while trying to optimally manage shale gas extractions and the aquatic ecosystems.

With respect to groundwater, government and industry are already collaborating on efforts to find non-surface water sources in the Horn River Basin. Further, Geoscience B.C. is providing funding to match in-kind contributions from industry to secure more information in this area.

This RFP is confined to modelling surface water availability, by season and on a sub-basin level and does not include research into the location of groundwater sources.

3.3 Project Scope/Budget

The scope of the project includes assembling recent surface water and hydro-metric information from industry; considering First Nation existing traditional use study information related to water; working with First Nations to augment their technical understanding and seek their input on future study; conducting hydrological analyses and modelling to determine surface water availability, seasonal changes in these volumes and recharge rates; presenting all findings and recommendations for future study where risks are deemed high and alternative water sources are scarce, including scope and location, in a draft and final report that includes map products of sub-basin information at a minimum of 1:20,000 scale or 1:10,000 scale where practical. Detailed requirements for proposals are set out in section 4.0.

The overall budget for this proposal is $50,000 and the final report must be received by March 31, 2010. The budget should include all fees (hourly rate) and expenses to undertake the requirements listed in section 4.0.

One trip is required to Calgary to meet and establish relationships with representatives of the Horn River Producers Group and gather information. A maximum of two trips to Fort Nelson should be included in the proposal to work with the Fort Nelson First Nation. Travel expenses associated with the applicable members of the contractor’s team are based on Province of BC Group II rates (see Appendix B). Expenses for government personnel are outside the scope of this budget.

Included in the budget should be funding for First Nations, budgeted at $5,000, for them to gather existing traditional use study information related to water use and values and to participate in a community meeting where the Contractor explains study findings, recommendations and seeks First Nation input. Proponents are encouraged to contact Lana Lowe, Acting Director, Lands Department, Fort Nelson First Nation at (250) 774-6313 (lana.lowe@fnnation.ca) when preparing their proposal including budget details.

Proposals must indicate what deliverables would be provided.

The Ministry may, at its sole option, accept all or a subset of the proposed deliverables from the successful proponent, or may negotiate a different level of service with the successful proponent.

4. Requirements

The Ministry requires a successful proponent to:

- Assemble and analyze recent surface water and hydrometric information (e.g., lake attributes like depth and areas, streamflow data, precipitation data) in the Horn River Basin, largely undertaken by industry.
- Model surface water quantity and timing of flow or availability and recharge for as many as 30 1:20,000 scale sub-basins in the four major watersheds that are partially within the area known as the Horn River Basin. Major watersheds are mapped by the province at 1:50,000 scale in the BC Watershed Atlas (see Figure 2). These BC government mapped watersheds include named drainages like Kiwigana Creek, Capot-Blanc Creek, Emily Creek and a number of unnamed tributaries to the Petitot, Liard and Fort Nelson River systems. Some of these named streams may be a sub-basin in this study.
- Map, using government approved software (ARCINFO), watershed boundaries to the 1:20,000 scale (minimum) or where practical mapped down to 1:10,000 scale. These geographical areas are to be the units for hydrological analysis and modelling.
- Interact with government officials and water science experts and industry water hydrological consultants as appropriate throughout the study to guide the work and remain within scope.
- Undertake an analysis and an inventory of current surface water diversions and forecasts for the next 5 years by sub-basin and season. This work should be done for each company in the Horn River Producers Group. If information is readily available and appropriate, future surface water use forecasts may be assembled for sub-basins for longer periods of 10 and/or 20 years.
- Engage with local First Nations, in particular the Fort Nelson First Nation, for the purposes of:
    - explaining the nature of the work been undertaken under the proposal;
    - including First Nation traditional use study information about water use and values that they have gathered from existing study sources; and,
    - participating in a community meeting where interim study results and recommendations are discussed and input sought and reported on in the final report, including recommendations for future studies specific to First Nation interests.
- Perform hydrological analyses and related modelling at the sub-basin level that results in an estimate of water volumes, seasonal fluctuations in these volumes and recharge rates.
- Map all study results at a minimum of 1:20,000 scale at the sub-basin level and 1:10,000 scale where possible. Where 1:20,000 scale is used, a GIS map (ARCINFO shape file) at 1:20,000 for field reference must be supplied to government (ILMB GeoBC standards).

- Provide a draft report and final report that includes, among other things, raw data and analysis; modelled results; description of study methodology; results of discussions and meetings with the Fort Nelson First Nation; results of discussions and meeting with the Northern Rockies Regional Municipality and other agencies; maps; recommendations as to water volumes available for industry use; seasonal constraints to volume availability and recharge rates and recommendations as to the nature and location of future hydrometric data collection, if any, aimed at closing a critical knowledge gap in information.
- Include, in the report for each hydrological unit (i.e., each sub-basin) a risk rating (high, medium and low risk) according to the vulnerability of the sub-basins modelled water availability including the time of year when water may be available for diversion and use without negatively impacting other uses and aquatic ecosystems. A sub-basin may have more than one risk value. For example, "low" risk during the spring freshet yet "high" risk during freeze-up.
- Recommend where more surface water information is needed. Any recommendations for future collection of hydrometric information and subsequent analysis should be directed to highest risk sub-basins where industry indicates a need for large volumes of surface water in seasons where water availability may be uncertain.
- The Final Report including maps must be provided in electronic form, as well as five hard copies.

Proposals should address the above requirements and also include the following information:

- if applicable, a commitment that any data produced will comply with data standards established through the Resources Information Standards Committee (RISC) of the Province of British Columbia. Information about this committee and data standards can be found at the website: http://www.ilmb.gov.bc.ca/risc/about.htm
- a list of government agencies that will be contacted early in the work cycle that includes as a minimum, the Ministry of Energy, Mines and Petroleum Resources, the Ministry of Environment, the Oil and Gas Commission, and the Northern Rockies Regional Municipality. Identification of other organizations that may be approached, such as Ducks Unlimited, should also be identified.
- identification of the responsible person and qualifications of the person(s) overseeing major components of the work.
- a Project Work Plan in table format that lays out as a minimum, the task, lead responsibility and timing for initiation/completion for key milestone activities/deliverables including provision of a Draft Report and incorporation of any comments received on the Draft Report into a Final Report.

5. Evaluation

This section details all of the mandatory and desirable criteria against which proposals will be evaluated. Proponents should ensure that they fully respond to all criteria in order to receive full consideration during evaluation. Proponents should note that the Ministry will invite participation from the oil and gas industry, the Fort Nelson First Nation, the Ministry of Environment and the Oil and Gas Commission in the evaluation of proposals.

5.1 Mandatory Criteria

Proposals not clearly demonstrating that they meet the following mandatory criteria will be excluded from further consideration during the evaluation process.

APPENDIX II

TEK/TU Hydrologically Significant Observations

TEK/TU - Hydrologically Significant Observations

The study team members visited the Fort Nelson First Nation (FNFN) on February 22nd to 24th to conduct interviews of FNFN community members with knowledge of the hydrologic setting within the study area. The interviews were organized and facilitated by FNFN Lands Department representatives. Six interviews were conducted.

The intent of the interviews was to derive information related to the typical seasonal hydrologic patterns within the Horn River Basin (HRB). Due to the scarcity of recorded hydrometric or meteorological data recorded within the study area, the information derived from these interviews was an important tool which was used to tune and validate the numerical model which was developed to simulate the typical seasonal flow rates in the major watersheds of the HRB.

The following sub-sections include the topic of discussion during the interviews, observations reported by the interviewees and in some cases, a hydrologic interpretation of these observations.

Typical annual timing of watercourse cycles

All watercourses are reported to be ice covered throughout the winter months. Although being ice covered, all watercourses are reported to sustain flow below the ice throughout the winter. Ice breakup typically occurs during the last week of April but has been reported as early as mid April and as late as mid May. Reports of the timing of annual high flow vary widely from the mid May to mid July. Annual low flow was reported to occur during the months of September and October. Ice cover typically forms during the last week of October and has been observed as early as the first week of October and as late as mid November. The ice is typically thick enough to drive on with a light vehicle by the last week of November and for heavy traffic by January.

Although the annual low flow was reported to occur during the months of September and October, there were also reports of frequent hanging ice. These reports suggest that the base flow recession throughout the winter months is significant enough to leave an air gap between the ice and the water surface indicating an annual low flow period which would occur during the late winter. This low flow period would likely be unobservable due to the ice cover.

Average Winter Snow Depth

Average winter snow depths were reported to range between 0.60 m and 0.75 m during a typical year and 0.90 m would represent a heavy snow pack year. Slightly heavier snow packs were reported in the north and eastern portions of the study area.

Identification of Hydrologically Significant Years and Other Notable Events

Exceptionally wet or dry years and years with non-typical hydrologic event timing were discussed and are summarized in Table 1.

Table 1: Hydrologically Significant Years and Other Notable Events

Exceptionally Wet Years	Exceptionally Dry Years	Other Observations
• 1959 • 1964 • 1972 • 1975 • 1977 • 1978 • 1987	• 1957 • 1965 • 2004	• 1942 Exceptionally deep snowpack • 1942 Early ice breakup (mid April) • 1946 Late ice breakup (mid May) • 1980 Exceptionally deep snowpack • 1980 Late ice cover (mid November) • 1996 Late season flood on Kotchea River (September)

APPENDIX III

Physical Characteristics of Horn River Basin

Table 1: Summary of Surficial Geology-Land Cover Characteristics in the Horn River Basin

Soil Type	Area	
	km2	%
Till Blanket (Tb)	11,836	84%
Till Veneer (Tv)	566	4.0%
Organic (O)	1,515	10.7%
Fglacio Lacustrine (fl)	178.9	1.3%
Colluvial Rubble (rC)	10	0.1%
Total	14,106	100%

Soil Type	Tb		Tv		O		fl		rC		Total	
Land Cover	Area		Area		Area		Area					
	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%	km^2	%
Uplands												
Exposed Land	64	0.5%	2.6	0.5%	2.2	0.1%	0.0	0.0%	0.0	0.0%	69	0.5%
Herbs	54	0.5%	3.0	0.5%	3.4	0.2%	1.7	0.9%	0.0	0.0%	62	0.4%
Shrubs	773	6.5%	26	4.6%	48	3.2%	1.3	0.7%	0.2	1.5%	848	6.0%
Tree	8656	73.1%	506	89.5%	1141	75.3%	55.8	31.2%	10.1	98%	10370	73.5%
Bryoid	10	0.1%	0.0	0.0%	0.09	0.0%	0.0	0.0%	0.0	0.0%	10	0.1%
Waterbody	0.0	0.0%	0.0	0.0%	0.00	0.0%	0.0	0.0%	0.0	0.0%	0.0	0.0%
Wetlands												0.0%
Exposed Land	0.4	0.0%	0.0	0.0%	0.00	0.0%	0.00	0.0%	0.0	0.0%	0	0.0%
Herbs	182	1.5%	0.3	0.1%	19	1.2%	0.5	0.3%	0.0	0.0%	202	1.4%
Shrubs	305	2.6%	1.0	0.2%	95	6.3%	6.7	3.7%	0.0	0.0%	408	2.9%
Tree	1601	13.5%	26.0	4.6%	191	12.6%	109	60.8%	0.0	0.0%	1927	13.7%
Bryoid	1.6	0.0%	0.0	0.0%	0.1	0.0%	0.1	0.0%	0.0	0.0%	2	0.0%
Waterbody	187	1.6%	1.0	0%	15	1%	4.0	2%	0.0	0%	207.5	1.5%
Total	11835	100%	566	100%	1515	100%	179	100%	10	100%	14106	100.0%

Table 2-1 Summary of Surficial Geology and Land Cover for Raspberry Creek

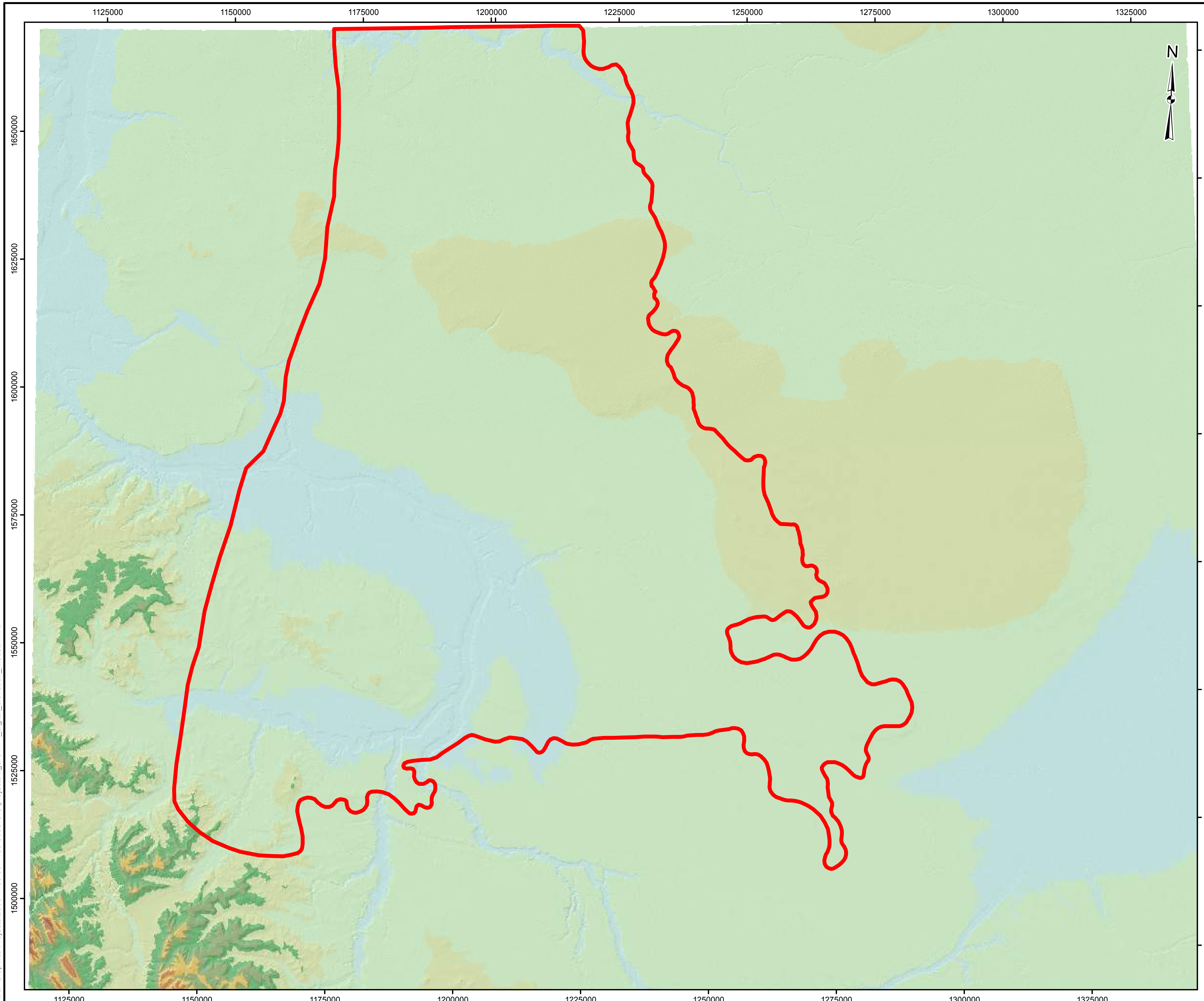
Soil Type	Area		Soil Type	Tb		Tv		Total	
	km^2	%	Land Cover	Area		Area			
Till Blanket (Tb)	264	97%		km^2	%	km^2	%	km^2	%
Till Veneer (Tv)	9	3.1%	**Uplands**						
Organic (O)			Exposed Land	4.0	1.5%	0.00	0.0%	4.0	1.5%
Fglacio Lacustrine (fl)			Herbs	0.1	0.1%	0.00	0.0%	0.1	0.1%
Colluvial Rubble (rC)			Shrubs	23.4	8.9%	0.54	6.3%	24.0	8.8%
Total	273	100%	Tree	173.5	65.6%	8.03	93.7%	181.5	66%
			Waterbody	0.0	0.0%	0.00	0.0%	0.0	0.0%
			Wetlands						
			Exposed Land	0.0	0.0%	0.0	0.0%	0.0	0.0%
			Herbs	0.1	0.0%	0.0	0.0%	0.1	0.0%
			Shrubs	6.7	2.5%	0.0	0.0%	6.7	2.4%
			Tree	56.1	21.2%	0.0	0.0%	56.1	20.6%
			Waterbody	0.5	0.2%	0.0	0%	0.5	0.2%
			Total	**264**	**100%**	**9**	**100%**	**273**	**100%**

Table 2-2 Summary of Surficial Geology and Land Cover for Adsett Creek

Soil Type	Area		Soil Type	Tb		Tv		Total	
	km^2	%	Land Cover	Area		Area			
Till Blanket (Tb)	38	35%		km^2	%	km^2	%	km^2	%
Till Veneer (Tv)	71	65.2%	**Uplands**						
Organic (O)			Exposed Land	0.0	0.0%	0.0	0.0%	0.0	0.0%
Fglacio Lacustrine (fl)			Herbs	0.6	1.7%	0.1	0.2%	0.7	0.3%
Colluvial Rubble (rC)			Shrubs	3.8	10.5%	2.9	4.3%	6.7	2.4%
Total	109	100%	Tree	31.8	87.6%	63.4	95.5%	95.2	34.9%
			Waterbody	0.0	0.0%	0.0	0.0%	0.0	0.0%
			Wetlands						
			Exposed Land	0.0	0.0%	0.0	0.0%	0.0	0.0%
			Herbs	0.1	0.2%	0.0	0.0%	0.1	0.0%
			Shrubs	0.0	0.0%	0.0	0.0%	0.0	0.0%
			Tree	0.0	0.0%	0.0	0.0%	0.0	0.0%
			Bryoid	0.0	0.0%	0.0	0.0%	0.0	0.0%
			Waterbody	0.0	0.0%	0.0	0%	0.0	0.0%
			Total	36	100%	65	100%	109	100%

Table 2-3 Summary of Surficial Geology and Land Cover for Bougie Creek

Soil Type	Area		Soil Type	Tb		Tv		Total	
	km^2	%	Land Cover	Area		Area			
Till Blanket (Tb)	219	66%		km^2	%	km^2	%	km^2	%
Till Veneer (Tv)	113	34%	**Uplands**						
Organic (O)	-	0.0%	Exposed Land	0.0	0.0%	0.0	0.0%	0.0	0.0%
Fglacio Lacustrine (fl)	-	0.0%	Herbs	5.2	2.4%	1.0	0.9%	6.2	2.3%
Colluvial Rubble (rC)	-	0.0%	Shrubs	4.9	2.2%	13.4	11.8%	18.3	6.7%
Total	332	100%	Tree	205.7	94.1%	98.9	87.2%	304.6	111.6%
			Waterbody	0.0	0.0%	0.0	0.0%	0.0	0.0%
			Wetlands						
			Exposed Land	0.00	0.0%	0.0	0.0%	0.0	0.0%
			Herbs	0.42	0.2%	0.0	0.0%	0.4	0.2%
			Shrubs	0.00	0.0%	0.0	0.0%	0.0	0.0%
			Tree	1.73	0.8%	0.0	0.0%	1.7	0.6%
			Bryoid	0.00	0.0%	0.0	0.0%	0.0	0.0%
			Waterbody	0.65	0.3%	0.0	0%	0.6	0.2%
			Total	219	100%	113	100%	332	100%



LEGEND

- Horn River Basin Boundary

Elevation (masl)

- 218 - 400
- 400 - 600
- 600 - 800
- 800 - 1,000
- 1,000 - 1,200
- 1,200 - 1,400
- 1,400 - 1,600
- 1,600 - 1,800
- 1,800 - 2,000
- 2,000 - 2,200
- 2,200 - 2,400
- 2,400 - 2,600
- 2,600 - 2,800

DRAFT

REFERENCE

Base data obtained from the BC MEMPR.
Projection: BC Albers Datum: NAD 83

15 0 15

SCALE 1:750,000 KILOMETRES

PROJECT

MEMPR
HORN RIVER BASIN
FORT NELSON, B.C.

TITLE

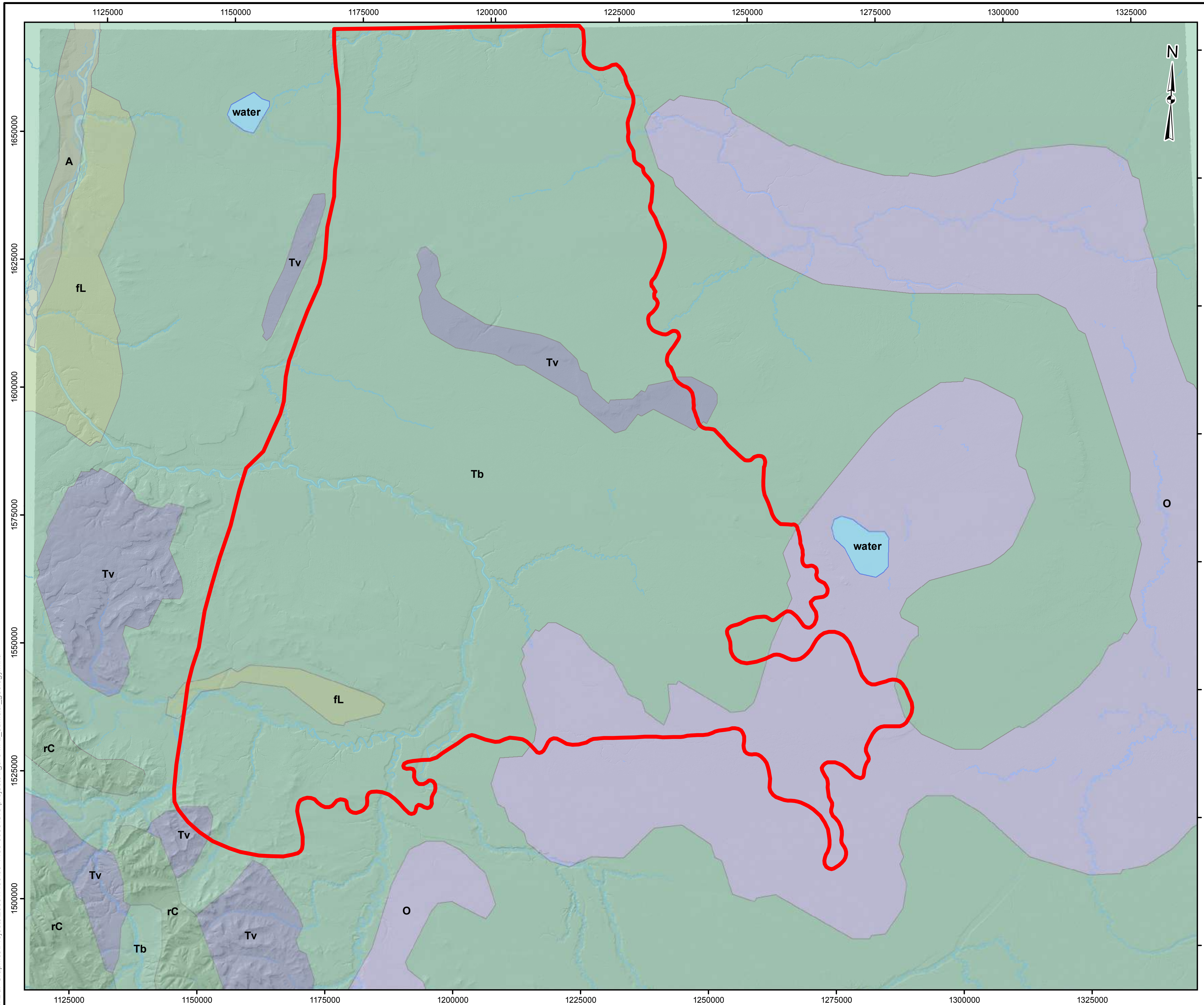
DIGITAL ELEVATION MODEL

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1450-5058			PHASE No.	
DESIGN	DS	31 Mar. 2010	SCALE AS SHOWN	REV. 0
GIS	JW	31 Mar. 2010		
CHECK				
REVIEW				

FIGURE III-1

N:\Bur-Graphics\Projects\Projects\2009\1450\09-1450-5058\GIS\projects\figure-III-1_digital_elevation_modeal.mxd



N:\Bur-Graphics\Projects\2009\1450\09-1450-5058\GIS\projects\figure-III-2_surficial_geology.mxd

LEGEND

- Horn River Basin Boundary

Surficial Geology (NRC - 1:5,000,000)

- A
- O
- Tb
- Tv
- fL
- rC
- Water

DRAFT

REFERENCE

Base data obtained from the BC MEMPR.
Projection: BC Albers   Datum: NAD 83

15   0   15
SCALE 1:750,000   KILOMETRES

PROJECT

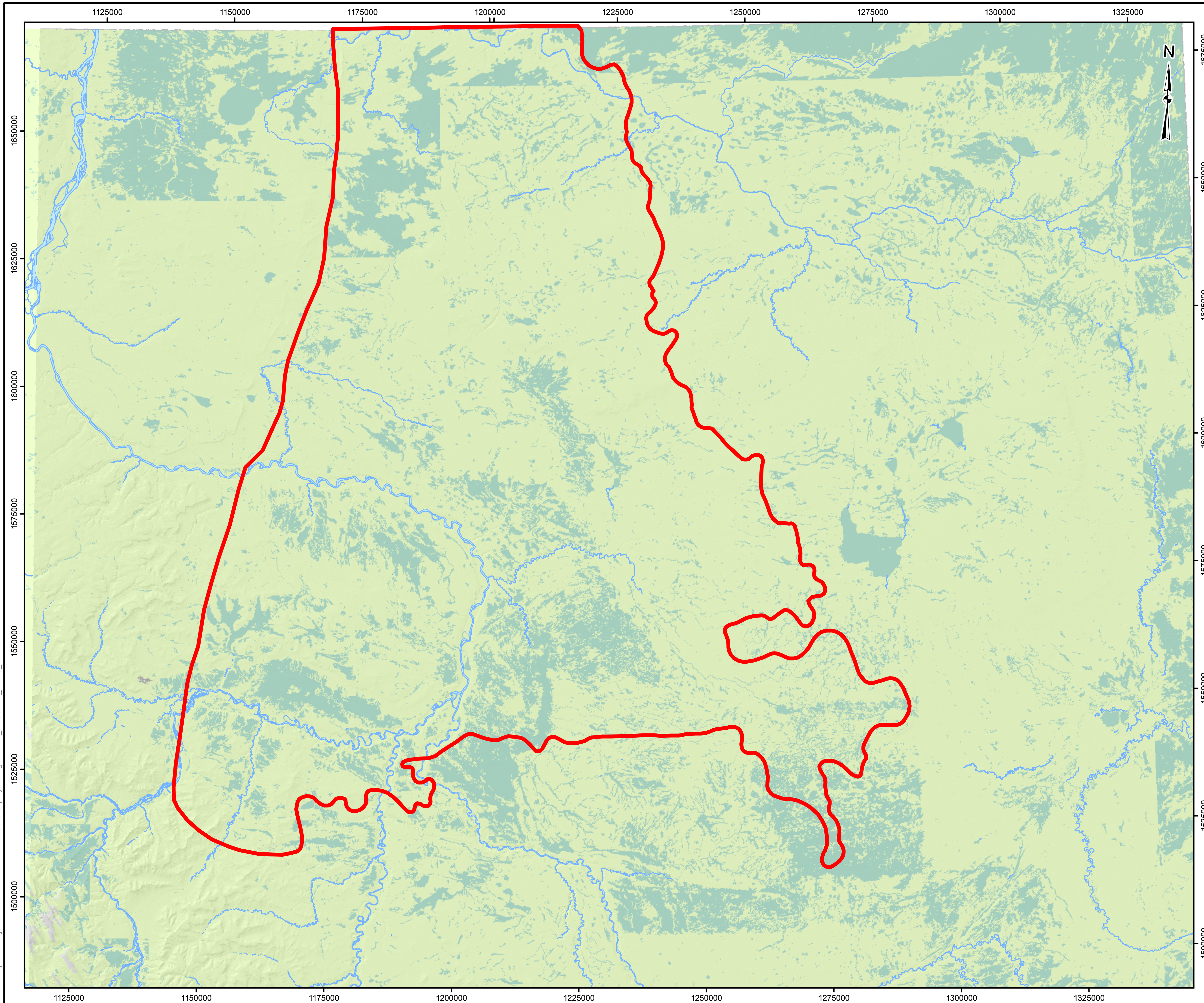
MEMPR
HORN RIVER BASIN
FORT NELSON, B.C.

TITLE

SURFICIAL GEOLOGY

Greater Vancouver Office, B.C.

PROJECT No. 09-1450-5058			PHASE No.	
DESIGN	DS	31 Mar. 2010	SCALE AS SHOWN	REV. 0
GIS	JW	31 Mar. 2010	**FIGURE III-2**	
CHECK				
REVIEW				



LEGEND

Horn River Basin Boundary

British Columbia Land Cover Classification Scheme Level 3

Alpine

Upland

Wetland

DRAFT

REFERENCE

Base data obtained from the BC MEMPR.
Projection: BC Albers Datum: NAD 83

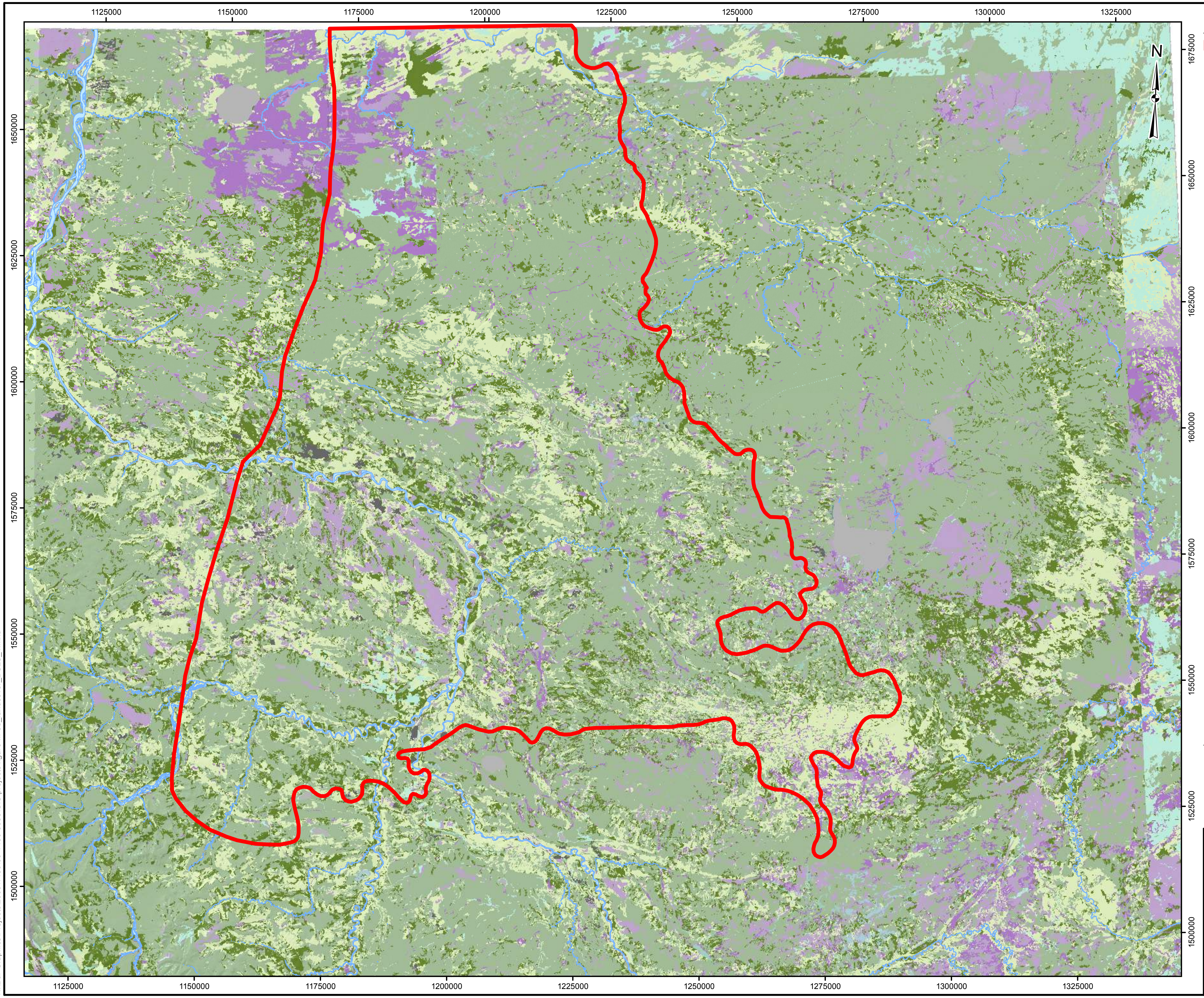
15 0 15

SCALE 1:750,000 KILOMETRES

PROJECT	MEMPR HORN RIVER BASIN FORT NELSON, B.C.
TITLE	**LAND COVER BCLS 3**

Golder Associates Greater Vancouver Office, B.C.	PROJECT No. 09-1450-5058			PHASE No.
	DESIGN	DS	31 Mar. 2010	SCALE AS SHOWN REV. 0
	GIS	JW	31 Mar. 2010	**FIGURE III-3a**
	CHECK			
	REVIEW			

N:\Bur-Graphics\Projects\2009\1450\09-1450-5058\GIS\projects\figure-III-3_landcover_BCLS_3.mxd



LEGEND

Horn River Basin Boundary

British Columbia Land Cover Classification Scheme Level 4

- Byroid - Lichens
- Byroid - Moss
- Bryoid
- Exposed Land
- Herb
- Herb - Forbs
- Herb - Graminoids
- Rock/ Rubble
- Snow/ Ice
- Shrub Low
- Shrub Tall
- Treed - Broadleaf
- Treed - Coniferous
- Treed - Mixed

DRAFT

REFERENCE

Base data obtained from the BC MEMPR.
Projection: BC Albers Datum: NAD 83

15 0 15

SCALE 1:750,000 KILOMETRES

PROJECT

MEMPR
HORN RIVER BASIN
FORT NELSON, B.C.

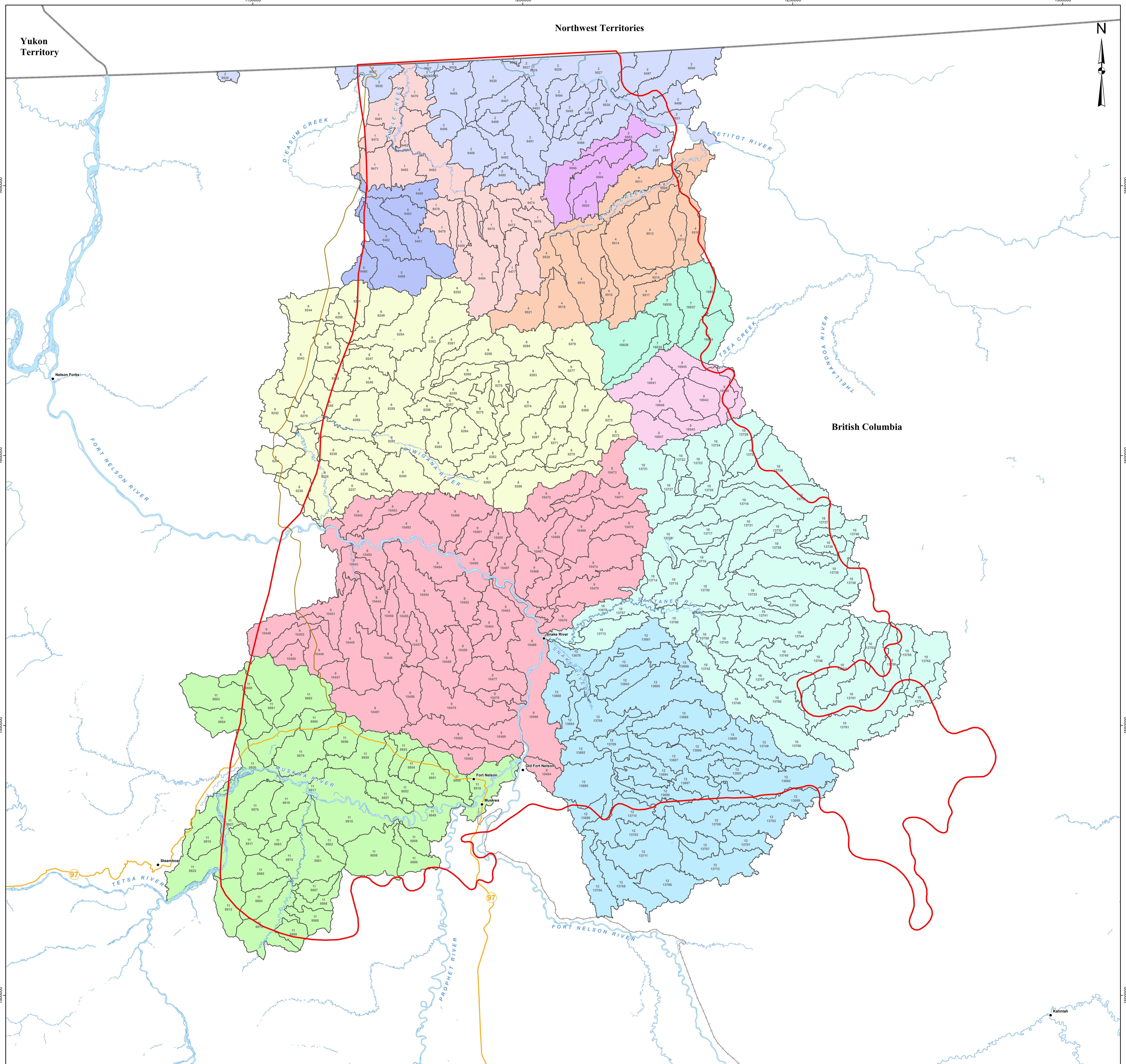
TITLE

LAND COVER BCLS 4

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1450-5058			PHASE No.	
DESIGN	DS	31 Mar. 2010	SCALE AS SHOWN	REV. 0
GIS	JW	31 Mar. 2010	**FIGURE III-3b**	
CHECK				
REVIEW				

N:\Bur-Graphics\Projects\2009\1450\09-1450-5058\GIS\projects\figure-III-3b_landcover_BCLS_4.mxd



LEGEND

- Populated Place
- Highway
- Highway - Secondary
- Railway
- Watercourse
- Horn River Basin Boundary
- Provincial Boundary

Major Sub-basins

1
2
3
4
5
6
7
8
9
10
11
12

Sub-Watershed

Sub-Watershed ID

REFERENCE

DRAFT

Watershed data obtained from the BC LRDW.
Other data obtained from the BC MEMPR.
Projection: BC Albers Datum: NAD 83

20 0 20

SCALE 1:250,000 KILOMETRES

PROJECT

MEMPR
HORN RIVER BASIN
FORT NELSON, B.C.

TITLE

HRB SUBBASINS

Golder Associates
Greater Vancouver Office, B.C.

PROJECT No. 09-1450-5058			PHASE No.	
DESIGN	DS	26MAR10	SCALE AS SHOWN	REV. 0
GIS	JW	01APR10		
CHECK				
REVIEW				

FIGURE III-4

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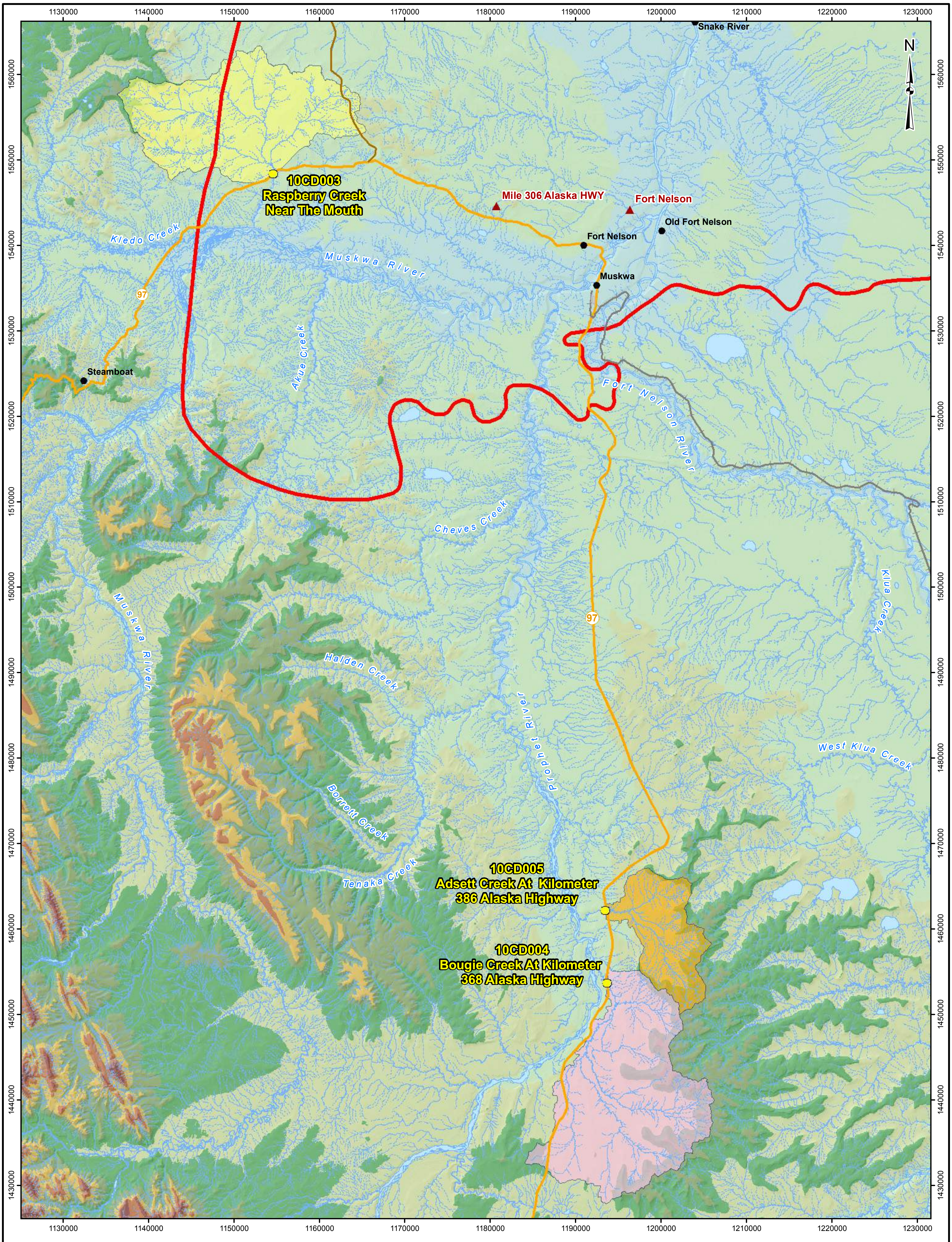

LEGEND

Climate Monitoring Station	Horn River Basin Boundary	1,200 - 1,400
Hydrometric Station	Waterbody	1,400 - 1,600
Populated Place	**Elevation (masl)**	1,600 - 1,800
Highway	218 - 400	1,800 - 2,000
Highway - Secondary	400 - 600	2,000 - 2,200
Railway	600 - 800	2,200 - 2,400
Watercourse	800 - 1,000	2,400 - 2,600
Watershed 10C003	1,000 - 1,200	2,600 - 2,800
Watershed 10C004		
Watershed 10C005		

10 0 10

SCALE 1:425,000 KILOMETRES

DRAFT

REFERENCE

Watershed data obtained from the BC LRDW. Other data obtained from the BC MEMPR.
Projection: BC Albers Datum: NAD 83

PROJECT

MEMPR
HORN RIVER BASIN
FORT NELSON, B.C.

TITLE

CALIBRATION SUBWATERSHEDS

Golder Associates
Greater Vancouver Office, B.C.

PROJECT NO. 09-1450-5058			PHASE No.	
DESIGN	DS	31 Mar. 2010	SCALE AS SHOWN	REV. 0
GIS	JW	31 Mar. 2010		
CHECK				
REVIEW				

FIGURE III-5

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APPENDIX IV

Model Schematics for Each Calibration Watershed and Sub-Basin in the Horn River Basin

Figure IV-1 Flow Chart for Calibration Watersheds

Note:
1) The first ID number (i.e. P220) in each block denotes sub-watershed ID;
2) The third line (i.e. A 60.0) in each block indicates drainage area of the sub-watershed in km^2;
3) The last line (i.e. Ele 608) in each block indicates mean elevation of the sub-watershed masl.
4) R (e.g. R52) denotes the Reach ID.

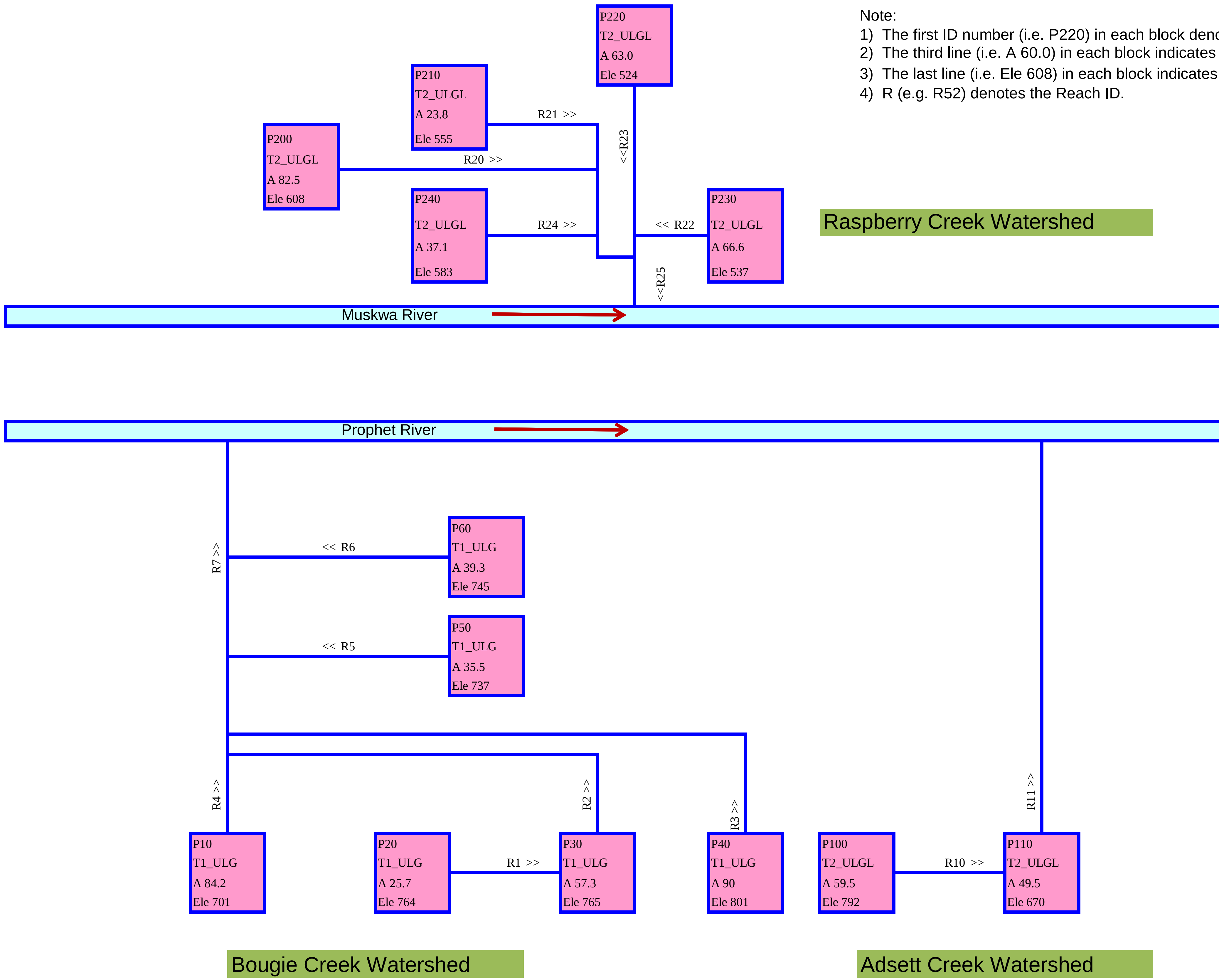
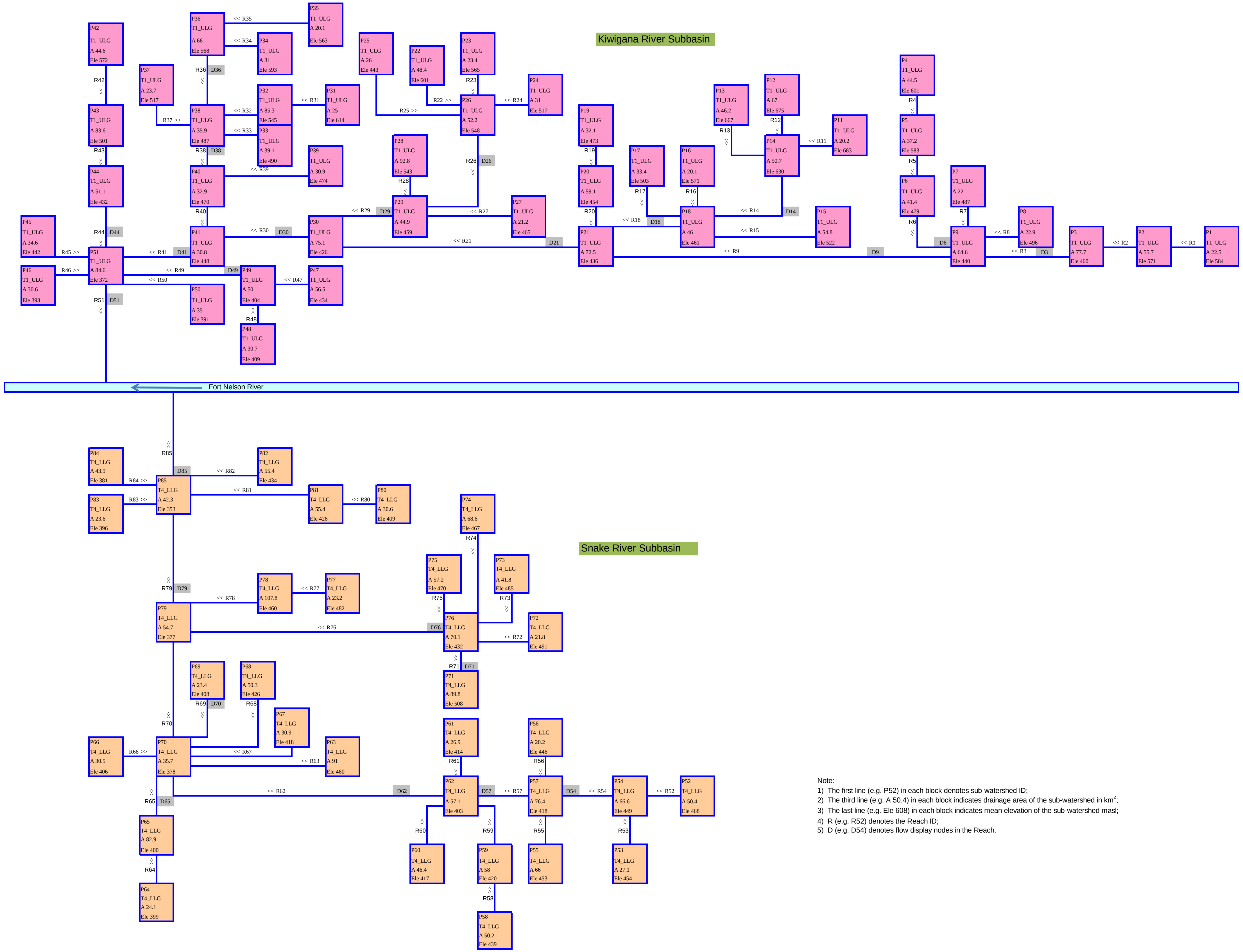


Figure IV-2 Flow Chart for Kiwingana River and Snake River Subbasins



Note:
1) The first line (e.g. P52) in each block denotes sub-watershed ID;
2) The third line (e.g. A 50.4) in each block indicates drainage area of the sub-watershed in km^2;
3) The last line (e.g. Ele 608) in each block indicates mean elevation of the sub-watershed masl;
4) R (e.g. R52) denotes the Reach ID;
5) D (e.g. D54) denotes flow display nodes in the Reach.

Subwatershed ID		Drainage Area	Mean Elevation
a	b	(km²)	(masl)
1	8272	22.5	584
2	8273	55.7	571
3	8266	77.7	460
4	8269	44.5	601
5	8268	37.2	583
6	8267	41.4	479
7	8271	22	487
8	8270	22.9	496
9	8265	64.6	440
11	8277	20.2	683
12	8278	67	675
13	8284	46.2	667
14	8283	50.7	630
15	8274	54.8	522
16	8276	20.1	571
17	8275	33.4	503
18	8282	46	461
19	8264	32.1	473
20	8263	59.1	454
21	8281	72.5	436
22	8259	48.4	601
23	8260	23.4	565
24	8258	31	517
25	8261	26	443
26	8257	52.2	548
27	8256	21.2	465
28	8262	92.8	543
29	8255	44.9	459
30	8280	75.1	426
31	8252	25	614
32	8254	85.3	545
33	8247	39.1	490
34	8251	31	593
35	8250	20.1	563
36	8249	66	568
37	8248	23.7	517
38	8253	35.9	487
39	8246	30.9	474
40	8245	32.9	470
41	8279	30.8	448
42	8244	44.6	572
43	8243	83.6	501
44	8242	51.1	432
45	8241	34.6	442
46	8236	30.6	393
47	8240	56.5	434
48	8239	30.7	409
49	8238	50	404
50	8237	35	391
51	8235	84.6	372
52	13702	50.4	468
53	13701	27.1	454
54	13700	66.6	449
55	13712	66	453
56	13707	20.2	446
57	13711	76.4	418
58	13706	50.2	439
59	13705	58	420
60	13704	46.4	417
61	13703	26.9	414
62	13710	57.1	403
63	13699	91	460
64	13696	24.1	399
65	13695	82.9	400
66	13693	30.5	406
67	13698	30.9	418
68	13697	50.3	426
69	13694	23.4	408
70	13709	35.7	378
71	13692	89.8	508
72	13691	21.8	491
73	13690	41.8	485
74	13688	68.6	467
75	13689	57.2	470
76	13687	70.1	432
77	13686	23.2	482
78	13685	107.8	460
79	13708	54.7	377
80	13683	30.6	409
81	13682	55.4	426
82	13681	55.4	434
83	13684	23.6	396
84	13680	43.9	381
85	13679	42.3	353

[a] Subwatershed ID in the Flow Chart.
[b] Subwatershed ID in Figure III -4.

APPENDIX V

Hydrologic Characteristics of Sub-Basins in the Horn River Basin

Climate Station	Elevation	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Anual	Rainfall Season (May - Sep)	Snowfall Season (Oct - Apr)	Record Period	
	masl	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	mm	year	
Fort Nelson A	381.9	17.7	10.8	14.9	21.6	57.0	58.9	88.9	78.6	50.4	36.4	19.0	13.6	468	334	134	1983-1989	58.84
Mile 306 Alaska HWY	451.1	24.2	17.3	22.4	24.2	67.0	66.3	125.6	100.4	55.4	57.0	27.0	23.3	610	415	195	1984-1989	58.85
Tetsa	792.8	19.7	19.9	25.0	34.8	74.1	108.6	156.5	97.8	81.5	49.7	21.5	18.8	708	519	189	1983-1989	58.65
Summit Lake	1280.5	16.7	18.0	26.1	44.9	70.4	133.4	204.1	126.1	79.2	56.1	22.0	14.5	811	613	198	1984-1989	58.65

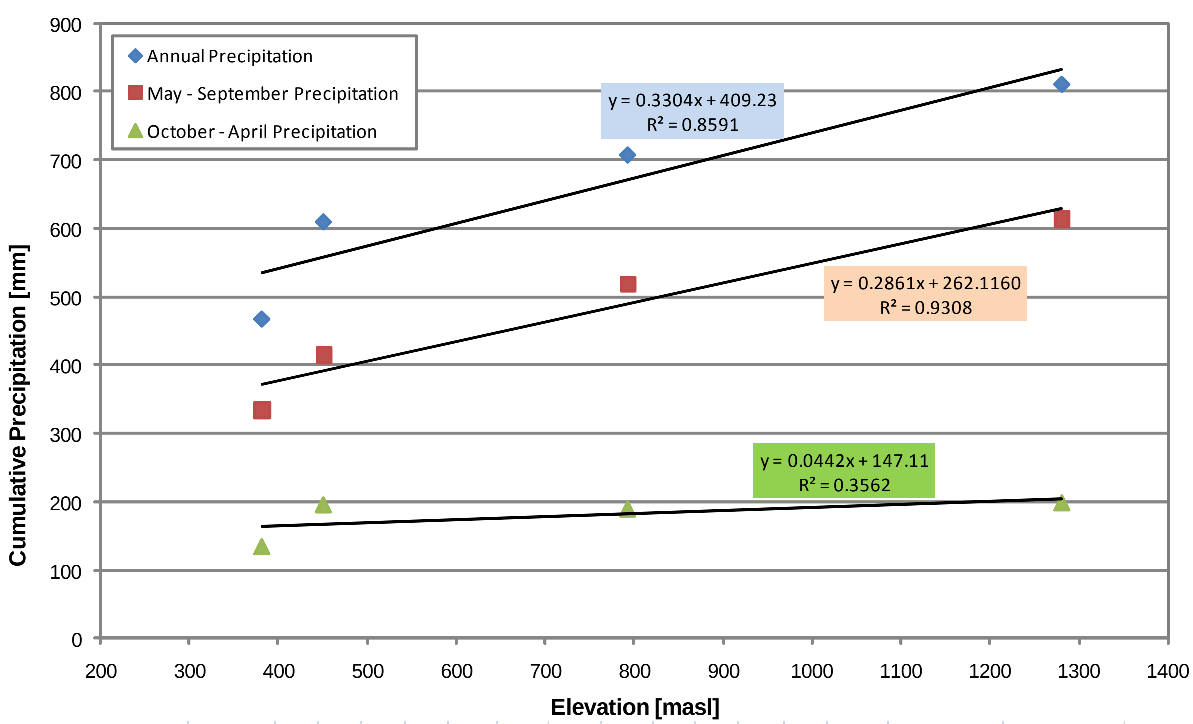


Figure 1: Precipitation-Elevation Relationship used for Transfer of Precipitation Data from Fort Nelson Climate Station to Other Locations in the Horn River Basin

APPENDIX VI

Generic Approach for Assessing Hydrologic Risk in the Sub-Basins of the Horn River Basin

HYDROLOGIC RISK OF WATER AVAILABILITY IN THE HORN RIVER BASIN

Introduction

A reliable water supply can be defined as a sufficient supply of good quality water for domestic, municipal, agricultural, industrial, recreational, instream, and other uses. As demands and competition for water grow in various sectors of society, the risk of an imbalance between supply and demand will increase. A change in the current climate may also alter the magnitude and/or timing of runoff from a watershed, which can contribute to the increasing risk of an imbalance.

The purpose of this appendix is to provide a procedure for assessing the hydrologic risk of an imbalance between water supply and water demand in the sub-basins of the Horn River Basin (HRB). The water supply is defined as the natural stream flow at or near a location of interest in the sub-basin. For the purposes of this appendix, water supply is defined as the quantity of water that is naturally available at the outlet of the sub-basin before there are any significant human interventions or alterations to the stream flow regime. Thus, the effects of dams, diversions, water transfers or pollution are assumed to be insignificant. In addition, changes in any land uses within the sub-basin are assumed to be negligible and thus do not affect the flow regime over time. The quality of water should also be taken into account during an assessment of water availability, with the quality thresholds dependent on intended water use. Water quality was not factored into the risk assessment under the current scope of this project.

The characterization of the risk of a water yield-demand imbalance in any sub-basin requires quantification of the water yield and water demand in that sub-basin. The water yield is usually characterized as the mean annual, mean seasonal and/or mean monthly flows in the stream. Shorter durations for flow characterization can be used if the flow estimates can still be considered to be within acceptable margins of error and water demands fluctuate significantly on a daily or weekly basis. Mean annual, mean seasonal and mean monthly flows can be compared with annual and monthly water demands. Changes in water yield as a result of climate change can be incorporated if the effects can be quantified, however, this issue is not addressed in this report.

Water Yield

The main section of this report describes an approach using the HSPF model for estimating monthly and annual flows from sub-basins in the HRB. The results of the model simulations are presented in terms of mean annual, seasonal and monthly flows. However, estimation of the natural water yield from a sub-basin should also include its variability or probability of occurrence. Tables 1 and 2 show the simulated mean annual and seasonal flow rates as well as their variability in terms of their 10^{th}, 25^{th}, 75^{th} and 90^{th} percentiles for three selected watersheds within each of the two sub-basins investigated. For example, the 10^{th} percentile value represents flow conditions that are exceeded 90% of the time and the 90^{th} percentile value is exceeded only 10% of the time. The reliability of the percentile values depends on the number of years used for the simulation. The simulation period with HSPF was from 1972 to 1998, thus the percentile values are based on 27 years of data. Longer simulation periods would provide greater certainty on the percentile values, however, complete model input data are currently limited to the aforementioned 27-year period.

Table 1: Percentiles of Simulated Flows in the Kiwigana River at Selected Locations in Sub-basin 6

Location	R9					R30					R51				
Area [km^2]	387					1289					2200				
	Average Case	Percentile				Average Case	Percentile				Average Case	Percentile			
		10th	25th	75th	90th		10th	25th	75th	90th		10th	25th	75th	90th
Mean Monthly Flow [m^3/s]															
January	0.013	0.003	0.005	0.018	0.020	0.080	0.024	0.045	0.102	0.126	0.167	0.055	0.105	0.211	0.248
February	0.004	0.002	0.002	0.005	0.007	0.036	0.016	0.020	0.045	0.056	0.080	0.033	0.046	0.100	0.123
March	0.001	0.000	0.000	0.001	0.001	0.012	0.005	0.007	0.014	0.019	0.028	0.011	0.019	0.032	0.045
April	0.606	0.000	0.002	0.702	1.78	1.46	0.001	0.002	0.973	4.58	2.45	0.002	0.014	2.55	7.33
May	7.27	2.75	4.52	8.63	12.4	24.2	9.94	15.2	29.0	41.9	38.8	16.0	22.9	46.4	66.5
June	4.75	1.29	1.69	5.91	8.46	18.0	5.06	7.00	22.8	33.5	29.8	8.12	11.6	38.6	55.3
July	3.55	0.433	0.793	5.13	7.32	12.9	1.47	2.65	17.5	27.0	21.3	2.09	3.86	27.2	46.3
August	2.58	0.480	0.703	3.36	5.16	9.18	1.47	3.16	12.1	16.7	14.7	2.23	5.27	20.3	24.8
September	1.92	0.273	0.604	2.09	4.97	6.99	1.11	2.31	7.07	17.8	11.5	1.33	3.70	11.3	29.4
October	0.728	0.060	0.248	1.04	1.54	2.79	0.262	1.06	3.90	5.73	4.83	0.468	1.81	6.85	10.1
November	0.169	0.012	0.058	0.222	0.292	0.792	0.082	0.311	1.08	1.44	1.51	0.187	0.616	2.08	2.71
December	0.035	0.005	0.013	0.047	0.064	0.208	0.038	0.115	0.270	0.358	0.417	0.088	0.232	0.538	0.699
Mean Annual Flow [m^3/s]	**1.82**	**1.12**	**1.31**	**2.19**	**3.09**	**6.44**	**3.92**	**4.66**	**7.87**	**10.8**	**10.5**	**6.46**	**7.56**	**12.9**	**17.8**
Mean Seasonal Flow [m^3/s]															
Dec-Mar	0.013	0.006	0.008	0.016	0.025	0.084	0.044	0.060	0.100	0.134	0.173	0.095	0.128	0.202	0.268
Apr-May	3.94	1.93	2.58	4.46	6.50	12.9	6.44	8.56	14.7	21.5	20.6	9.67	13.9	23.7	34.2
June-Aug	3.63	1.43	2.08	4.23	6.44	13.4	5.50	7.32	15.3	23.6	21.9	8.45	11.4	25.3	39.8
Sep-Nov	0.941	0.137	0.335	1.20	2.08	3.52	0.554	1.35	4.22	7.72	5.94	0.960	2.27	7.26	13.0

Table 2: Percentiles of Simulated Flows in the Snake River at Selected Locations in Sub-basin 6

Location	R57					R70					R85				
Area [km^2]	304					909					1687				
	Average Case	Percentile				Average Case	Percentile				Average Case	Percentile			
		10th	25th	75th	90th		10th	25th	75th	90th		10th	25th	75th	90th
Mean Monthly Flow [m^3/s]															
January	0.014	0.002	0.002	0.010	0.057	0.034	0.004	0.005	0.034	0.140	0.078	0.016	0.018	0.093	0.249
February	0.010	0.001	0.002	0.005	0.039	0.023	0.003	0.004	0.012	0.097	0.047	0.010	0.012	0.053	0.164
March	0.005	0.000	0.000	0.002	0.025	0.013	0.000	0.001	0.005	0.063	0.024	0.001	0.004	0.015	0.110
April	0.596	0.036	0.221	0.867	1.23	1.98	0.138	0.764	3.25	4.00	2.60	0.055	0.309	4.01	6.13
May	2.91	0.251	1.14	3.70	5.87	8.55	0.907	3.50	11.24	17.26	17.45	2.94	7.79	22.8	30.9
June	1.06	0.13	0.21	1.01	2.711	3.282	0.52	0.72	2.86	8.08	8.09	1.3	2.26	7.85	18.03
July	0.782	0.001	0.009	0.968	2.06	2.48	0.034	0.126	2.88	6.71	5.79	0.155	0.831	6.86	16.2
August	0.553	0.000	0.003	0.650	1.18	1.73	0.027	0.077	2.01	3.52	3.84	0.095	0.500	4.56	7.36
September	0.663	0.003	0.029	0.574	1.74	1.95	0.044	0.118	1.64	5.07	3.94	0.142	0.402	3.07	10.9
October	0.408	0.001	0.009	0.436	1.40	1.19	0.036	0.060	1.39	3.97	2.29	0.159	0.243	2.84	7.04
November	0.091	0.000	0.002	0.109	0.293	0.253	0.010	0.022	0.283	0.767	0.628	0.077	0.154	0.731	1.86
December	0.027	0.001	0.002	0.027	0.107	0.064	0.004	0.007	0.061	0.256	0.159	0.028	0.043	0.167	0.449
Mean Annual Flow [m^3/s]	**0.60**	**0.27**	**0.31**	**0.77**	**1.19**	**1.81**	**0.84**	**0.96**	**2.25**	**3.55**	**3.77**	**1.78**	**2.173**	**4.42**	**7.057**
Mean Seasonal Flow [m^3/s]															
Dec-Mar	0.014	0.002	0.002	0.021	0.036	0.034	0.005	0.005	0.050	0.088	0.077	0.020	0.025	0.103	0.166
Apr-May	1.75	0.225	0.689	2.23	3.05	5.26	0.952	2.17	6.94	9.02	10.0	2.81	4.72	12.7	16.7
June-Aug	0.799	0.075	0.140	0.866	2.14	2.50	0.316	0.569	2.67	6.35	5.91	1.26	1.68	6.19	14.3
Sep-Nov	0.387	0.009	0.019	0.516	0.997	1.13	0.056	0.107	1.58	2.80	2.29	0.203	0.370	3.40	5.21

Water Demand

With an estimated potential to hold 14 trillion cubic meters of gas, the HRB is currently being developed as a world class shale gas play. The availability of the large volumes of water required for hydrofracking of the shales has become a key component of successful shale gas development. One objective of this study was to gain additional understanding of the surface water availability in the HRB and the potential for water scarcity as gas development activities continue to expand. Water yield in the sub-basins of the HRB indicate the total amount of water available for a number of needs and uses. The actual water available for the oil and gas industry will be a portion of the remainder after other pre-existing allocations and the needs to maintain environmental or ecosystem flows are met. Environmental and ecosystem needs tend to be seasonally variable, thus requiring demand to be quantified on the same time scale to accurately assess the risk of imbalances during the year.

Trends in past water demand and forecasted future water demand are useful metrics for assessing past, current and future yield-demand conditions in the HRB. Current and future water demands should be obtained from various users in the HRB, primarily from available licence information and existing reports. A preliminary review of the BC Water Resource Atlas indicates that there are approximately 29 current water licenses or active applications within the HRB. In addition to the registered water licences, it is likely that most water requirements for oil and gas development in the HRB have been allocated though approvals under Section 8 of the Water Act for “Short Term Use”. Section 8 approvals often have no specified volume limits.

Water Demand by Shale Gas Industry

In the Horn River Basin, shale gas industry is still in the early stage of development, using varying amounts of water, from various sources to determine the optimum gas recovery. Water used for fracking can come from both surface sources (under Short-term Use Approval issued by the OGC or by water licence issued by MoE) and from groundwater sources (water source wells administrated by the OGC). In addition, it can also come from other authorized (borrow pits) and unauthorized water users. Water demand for hydrofracking varies on a pad by pad, well-by-well and frac by frac basis for many reasons such as geology of the formation; engineering strategy of a particular company; fracking technology; number of fracs per well; length of the well drilled (i.e. the longer the distance of shale drilled, the more fracs required). Actual water use per frac and per well may very well decrease in the future especially based experience, evolving and new technology.

As discussed in Section 2.2 of the main report, water demand and use data in the HRB is currently sparse and it may not be possible to disaggregate them to provide seasonal or annual total withdrawal amounts from specific water bodies in the respective sub-basins of the HRB. In addition, 5-year demand forecasts at the sub-basin scale may have even more significant uncertainty. Thus, the quantification of demand on an annual to monthly basis is not feasible at this point. Notwithstanding this constraint, one approach to estimate current (when detailed data are not available) and future water demands (when industry plans are not currently well defined) for hydrofracking by sub-basin is to develop

- Low, medium and high estimates of water used per frac;
- Low, medium and high estimates of number of fracs per well;
- Low, medium and high estimates of number of wells per pad; and
- Low, medium and high estimates of number of pads per sub-basin in the HRB

A conservative 5-year development scenario can be assumed for making water demand estimates for the shale gas industry in the HRB. The estimates can be developed on a monthly or seasonal or annual basis depending on the amount and quality of information available. A range of the potential water demand rate in a sub-basin can then be obtained by multiplying the above four components resulting in 16 possible demand rates. It is unlikely that the four components would all be either low or high estimates. Therefore, it is reasonable to select the median, 25th percentile and 75th percentile of the 16 demand rates as representing the low, medium and high water demand rates for the hydrologic risk analysis.

Demand for Instream Flow Needs

A key “demand” on the natural flow regime in any sub-basin is for instream flow needs (IFN). IFNs may not have been established formally for streams in the sub-basin or basin of interest. The Ministry of Water, Land and Air Protection (MWLAP), Ministry of Sustainable Resource Management (MSRM), Land and Water BC Inc. (LWBC), and Fisheries and Oceans Canada (DFO) are developing the British Columbia Instream Flow Guidelines for Fish to aid in the process of setting instream flows in British Columbia streams. These Guidelines deal specifically with instream flow requirements to support aquatic ecosystem values. They do not address other environmental protection issues related to conserving fish, wildlife or plant communities. The recommended flow threshold for fish-bearing streams is a seasonally-adjusted threshold for alterations to natural stream flows. The thresholds are calculated as percentiles of natural mean daily flows for each calendar month. These percentiles vary through the year to ensure higher protection during low flow months than during high flow months. For example, the flow threshold in the lowest flow month is set to 90th percentile of mean daily flows in that month and the flow threshold in the highest flow month is set to 20th percentile of mean daily flows in that month. The flow thresholds must be based on a minimum of 20 years of continuous natural daily flow records.

The recommended flow threshold for fishless streams is a minimum instream flow release equivalent to the median monthly flow during the low flow month.

The results provided in Tables 1 and 2 suggest that November to March is the period of the year with generally the lowest flows. In the absence of detailed analyses as required by the British Columbia Instream Flow Guidelines for Fish, one coarse approach for specifying IFNs in a sub-basin, assuming the sub-basin has fish-bearing streams, is to “reserve” the 90th percentile flow values from November to March for IFNs. The period from May to September generally experience the highest flows. For these months, in keeping with the coarse approach, it can be assumed that the 25th percentile flow values are “reserved” for IFNs. For the remaining two months, it can be assumed that the 50th percentile flow values are “reserved” for IFNs. This coarse approach does not necessarily reflect current regulatory or management limits because no consideration is given to site-specific or unique conditions, or to historic water management practices that could affect actual IFN determination. Nevertheless, the coarse approach provides a measure of instream flow needs that should be factored in the yield-demand assessment.

Hydrologic Risk

Using the coarse approach outlined above on watershed R70 in sub-basin 12 and watershed R30 in sub-basin 6, it appears from Table 3 that, generally, the probability of having “excess” water (that is, above the IFN threshold) between November and March on the two watersheds selected, one each from sub-basins 6 and 12, is about 0.1. The probability increases to about 0.75 between May and September.

Table 3 also provides the average of the monthly flows minus the IFN threshold over the years when the IFN thresholds are exceeded. These flows indicate the amount that would be available for other uses. If demands (low, medium and high) have been compiled for a watershed of interest, then the “available” flows can be compared to the demands.

Table 3: Percentiles of Simulated Flows in the Snake River at Selected Locations in Sub-basin 6

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
	Watershed R30 in Kiwinaga River Sub-Basin 6											
Mean Monthly Flow (m^3/s) = Y	**0.080**	**0.036**	**0.012**	**1.46**	**24.2**	**18.0**	**12.9**	**9.18**	**6.99**	**2.79**	**0.792**	**0.208**
Threshold IFN Flows (m^3/s)	0.126	0.056	0.019	1.46	15.2	7.00	2.65	3.16	2.31	2.79	1.44	0.358
Percent of 27 Years when Flows above IFN Threshold = P	11%	11%	11%	22%	74%	74%	74%	74%	74%	41%	11%	11%
Average Available Flow during the Years IFN Threshold Exceeded = R	0.047	0.030	0.012	4.44	13.8	15.5	14.3	8.59	6.66	2.31	0.861	0.147
Water Demand Rate (m^3/s) = D												
Water Availability Index = WAI = (R - D)/(R + D)												
Hydrologic Risk = (P/100)*WAI												
	Watershed R70 in Snake River Sub-Basin 12											
Mean Monthly Flow (m^3/s) = Y	**0.034**	**0.023**	**0.013**	**1.98**	**8.55**	**3.28**	**2.48**	**1.73**	**1.95**	**1.19**	**0.253**	**0.064**
Threshold IFN Flows (m^3/s)	0.140	0.097	0.063	1.98	3.50	0.720	0.126	0.077	0.118	1.19	0.767	0.256
Percent of 27 Years when Flows above IFN Threshold = P	11%	11%	11%	41%	74%	78%	74%	74%	74%	37%	11%	11%
Average Available Flow during the Years IFN Threshold Exceeded = R	0.024	0.014	0.007	1.62	7.58	3.38	3.20	2.24	2.50	1.72	0.243	0.051
Water Demand Rate (m^3/s) = D												
Water Availability Index = WAI = (R - D)/(R + D)												
Hydrologic Risk = (P/100)*WAI												

A simple index of surface water availability (Meigh *et al*. 1999) can be formulated as follows:

WAI = (R – D)/(R + D)

In the above equation, R = surface water availability and D = sum of demands from all sectors. The surface water availability is calculated as the average flow available after IFN needs have been met. The water availability index is then normalized to a range of -1 to +1. When demand is just equal to water availability, WAI is then zero. This value reflects an availability-demand condition equivalent to tossing a coin, that is, in any given year, there is an equal chance of demand meeting as not meeting the average available water. As D increase relative to R, the WAI decreases, suggesting a condition of potential scarcity. When R is greater than D, there is better than even chance of being able to satisfy the demand. However, all of these conditions are contingent on the flow exceeding the IFN threshold. Thus, a hydrologic risk index can then be defined as the product of the probability of exceeding the IFN threshold and the water availability index. The hydrologic risk index (HRI) can be calculated for each month of the year and for the three levels of estimated demands (low, medium, high).

For fishless streams, R would be calculated as the recorded or simulated monthly flow minus the IFN threshold that can be approximated as the mean monthly flow (Y in Table 3).

The hydrologic risk of a water yield-demand imbalance is high when HRI is between 0 and -0.5, extremely high when HRI is less than -0.5, low when HRI is between 0 and 0.5, and insignificant when HRI is greater than 0.5. The HRI can be calculated for all sub-basins of interest and mapped to provide a spatial assessment of hydrologic risk in the HRB.

Discussion

It is apparent from Table 3 that the hydrologic risk of a water yield-demand imbalance would likely be significant during the winter months, especially if the streams are fish-bearing. The magnitude of the uncertainties in the hydrologic risk calculations would depend on:

- Uncertainties in the model simulations, which could originate from:
  - Inadequate characterization of the spatial variability of precipitation and its relations with elevation,
  - Inadequate coverage of surficial geology and land cover information to characterize the watershed, and
  - Insufficient data for a reliable or site-specific calibration of the HSPF model.
- Uncertainties in IFN estimates, which could originate from:
  - Inadequate number of years of recorded daily flow data, or
  - Uncertainties in simulation data if the HSPF model is used to generate synthetic daily flows series.
- Uncertainties in characterization of monthly or seasonal demand from various sectors.

As discussed in the recommendation section of the main report, a program of climate and hydrometric data collection can assist in reducing the uncertainties in the water yield component of the hydrologic risk analysis. The advantage of a modelling approach (such as with HSPF) is that daily flows are generated that can be used both for yield estimates as well as with the IFN calculations.

When using the approach outlined above, the possibility of water conservation should also be considered. A water supply system may not be able to supply the full design quantity at all times. When there is a shortfall in supply at the source, the amount supplied to particular users may be restricted for certain periods of time. This is a different condition to an unreliable system, which would be one where the shortages are uncontrolled.

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REFERENCES

Meigh J.R., McKenzie A.A. and Sene K.J. (1999). A grid-based approach to water scarcity estimates for eastern and southern Africa. *Water Resources Management*, 13, 85-115.

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