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PRAIRIE PROVINCES WATER BOARD

Report #172

Basin Review
Calculation of Apportionable Flow
for the
North Saskatchewan River
at the
Alberta/Saskatchewan Interprovincial Boundary

Prepared for the Prairie Provinces Water Board
By the Committee on Hydrology

December 2015

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Executive Summary

In 2011, the Prairie Provinces Water Board's (PPWB) Committee on Hydrology (COH) embarked on a process of reviewing the apportionable flow calculation procedures for each of the basins subject to apportionment under the Master Agreement on Apportionment (MAA). The purpose of completing these basin reviews is to explore the existing apportionable flow calculation procedures, and to recommend improvements or adjustments where appropriate. Such improvements could be related to changes that have occurred in the basin over time, or reflect the availability of more information and improved calculation tools.

The North Saskatchewan River is the first basin to undergo this review process. With a gross drainage area of approximately 57,000 km^2 at the apportionment point, the North Saskatchewan River is one of the largest rivers subject to apportionment under the MAA. Significant features of the basin include two major reservoirs (Lake Abraham and Brazeau Reservoir) and the City of Edmonton. Development in the basin is relatively sparse. Under the hydrologic conditions of the recent past, and the existing level of consumptive use, Alberta uses only a small percentage of its share of the river, typically passing close to 100% of the apportionable flow on an annual basis.

The conclusion of this review was that several improvements could be made to the apportionable flow calculation procedures. The original apportionable flow calculation procedures for the North Saskatchewan River were developed by the PPWB in the mid 1970's. The assumptions on which the calculations are based were largely made in the interest of simplifying the calculation procedures. In contrast to the situation at that time, calculations can now easily be completed in Excel spreadsheets and the PPWB's apportionable flow calculation program (River Basin Assessment Tool, or RBAT). Thus, it is no longer necessary to reduce the complexity of the calculations in order to facilitate their implementation. The remaining issue to be considered when developing apportionable flow calculation procedures is achieving an acceptable balance between the data availability, data accuracy, and expense of data collection relative to the accuracy required to provide reasonable and fair estimates of the apportionable flow and to ensure that the requirements of the MAA are being adhered to.

Firstly, apportionable flow for the North Saskatchewan River is currently calculated based on recorded flow at the station 05EF001 'North Saskatchewan River near Deer Creek'. This station is located some 37 km downstream from the interprovincial border. Between the border and the station there is, of course, local inflow into the river, as well as various licenced consumptive uses. Up until now no correction has been made in the apportionable flow calculation to account for this. It is recommended that, in the long term, the hydrometric station be relocated upstream to allow apportionment under the MAA to be monitored at a location as close to the border as possible. However, for more immediate purposes it is recommended that the apportionable flow calculation include a correction to adjust for the location of the gauge. The method proposed is based on a static estimate of median inflow and licenced water use between the border and Deer

Creek and does not represent any increase in the data requirements for the apportionable flow calculation.

In terms of consumptive use in the basin, no changes to the calculation procedures relating to water stored in Lake Abraham and Brazeau Reservoir are proposed, as they were already included in the calculation. Data supplied by Alberta Environment and Parks (AEP) was used to assess the impact of water withdrawal by other consumptive uses on the apportionable flow calculations. Such uses are not currently accounted for in the apportionable flow calculations. It is recommended that these other consumptive uses be incorporated into the calculation procedures based on a combination of estimated net consumption for larger volume licences, and net licenced consumption for smaller volume licences. Accounting for these consumptive uses will not add appreciably to the complexity of the calculations, but will add to the accuracy of the apportionable flow result. The required data regarding licenced use in the basin is already tracked by the province of Alberta.

Using the results of a study completed by the Meteorological Service of Canada (MSC), the impact of evaporation from Lake Abraham and Brazeau Reservoir was investigated. The current apportionable flow calculation procedures do not include consideration of reservoir evaporation. From the analysis completed, evaporation losses from Lake Abraham and Brazeau Reservoir were determined to be of equal significance to the other larger consumptive uses in the basin. It is, therefore, recommended that reservoir evaporation be included in the revised calculation procedure. Evaporation is proposed to be calculated based on long term gross evaporation estimates in combination with recorded precipitation data. This allows for a reasonable estimate of evaporation without substantially adding to the annual data requirements.

Travel times along the river were explored and compared to the routing procedures currently in use. Based on the results, new routing procedures which involve calculation of travel times in the basin based on the flow measured at Edmonton are recommended for eventual implementation. This applies to all adjustments: reservoir storage, reservoir evaporation and consumptive use. In the initial phase of implementation it is proposed to route all consumptive uses (aside from the reservoirs) from Edmonton. However, in the future, routing for these licences may be adjusted to account for their location along the river. For immediate implementation in RBAT, the travel time equations have been applied to determine the average travel times for 1975-2012. These average travel times will be used in the ‘fixed percentage’ routing option currently available in the RBAT program. Should additional routing options become available in RBAT in the future, the recommended flow dependent routing equations should then be introduced.

The proposed changes to the calculation procedures have a minimal effect on the apportionable flow results on an annual basis. For the period between 1979 and 2013 the average percent delivery using the existing calculation procedures was 100%, and the maximum and minimum percent delivery were 103% and 97%, respectively. Whereas, applying the proposed apportionable flow calculation procedures over the same 1979 to 2013 time period results in an average percent delivery of 97%, and a maximum and minimum percent delivery of 100% and 94%.

Implementation of the recommended calculation procedures will require precipitation data in order to estimate evaporation from Lake Abraham and Brazeau Reservoir. The current licenced net consumptive use will also need to be reported by AEP on an annual basis. On an occasional basis updates on reported net consumption for licenced allocations will also need to be provided by AEP. Additionally, the gross evaporation estimate for both the reservoirs will require updating over time as new information becomes available. If the recommended routing options are eventually applied, flow data from one additional hydrometric station (05DF001 North Saskatchewan River at Edmonton) will also be required.

Table of Contents

List of Figures

List of Tables

1. Introduction

1.1 Study Background

The North Saskatchewan River is one of the rivers subject to apportionment under the 1969 Master Agreement on Apportionment (MAA), an agreement between the Prairie Provinces and Canada regarding the sharing of eastward flowing rivers by the three provinces. The Prairie Provinces Water Board (PPWB) is the body that oversees the implementation of the MAA. This report documents a review of the apportionable flow calculation procedures for the North Saskatchewan River at the Alberta/Saskatchewan border. The current computation procedures were documented in a report issued by the PPWB in 1975 and, although minor modifications have been made over time, this is the first comprehensive review that has been undertaken. This review is being completed as part of the PPWB basin review process which was initiated in 2011 in order to ensure regular evaluation and improvement to the apportionable flow calculation procedures for all basins subject to apportionment. The North Saskatchewan River is the first to undergo this review. The target is that each basin will be reviewed approximately every ten years.

1.2 Basin Overview

The headwaters of the North Saskatchewan River lie on the eastern slopes of the Rocky Mountains. From there, the river flows through the Alberta foothills, into the parkland area, onto the prairie and continues east beyond the Alberta/Saskatchewan border. The North Saskatchewan River joins the South Saskatchewan River near Prince Albert to become the Saskatchewan River, eventually emptying into Lake Winnipeg. A map of the North Saskatchewan River Basin in Alberta is shown in Figure 1-1.

The flow in the North Saskatchewan River is comprised of glacial meltwater, mountain runoff and prairie runoff. Major tributaries to the North Saskatchewan River in Alberta are the Brazeau, Nordegg, Ram, Clearwater, Baptiste, Sturgeon, Redwater and Vermilion Rivers. At hydrometric station 05EF001 ‘North Saskatchewan River near Deer Creek’, the gross and effective drainage areas of the North Saskatchewan River are approximately 57,186 km^2 and 41,606 km^2, respectively. This results in an EDA/GDA ratio of 0.73. Peak flows in the river generally correspond to melting of the alpine snowpack and spring rain on snow type events in the mountains. Few of the annual peak flow events along the river are attributed to runoff derived from the prairie portion of the drainage basin.

The majority of the population along the North Saskatchewan River in Alberta reside in the city of Edmonton, which had a population of 812,201 at the time of the 2011

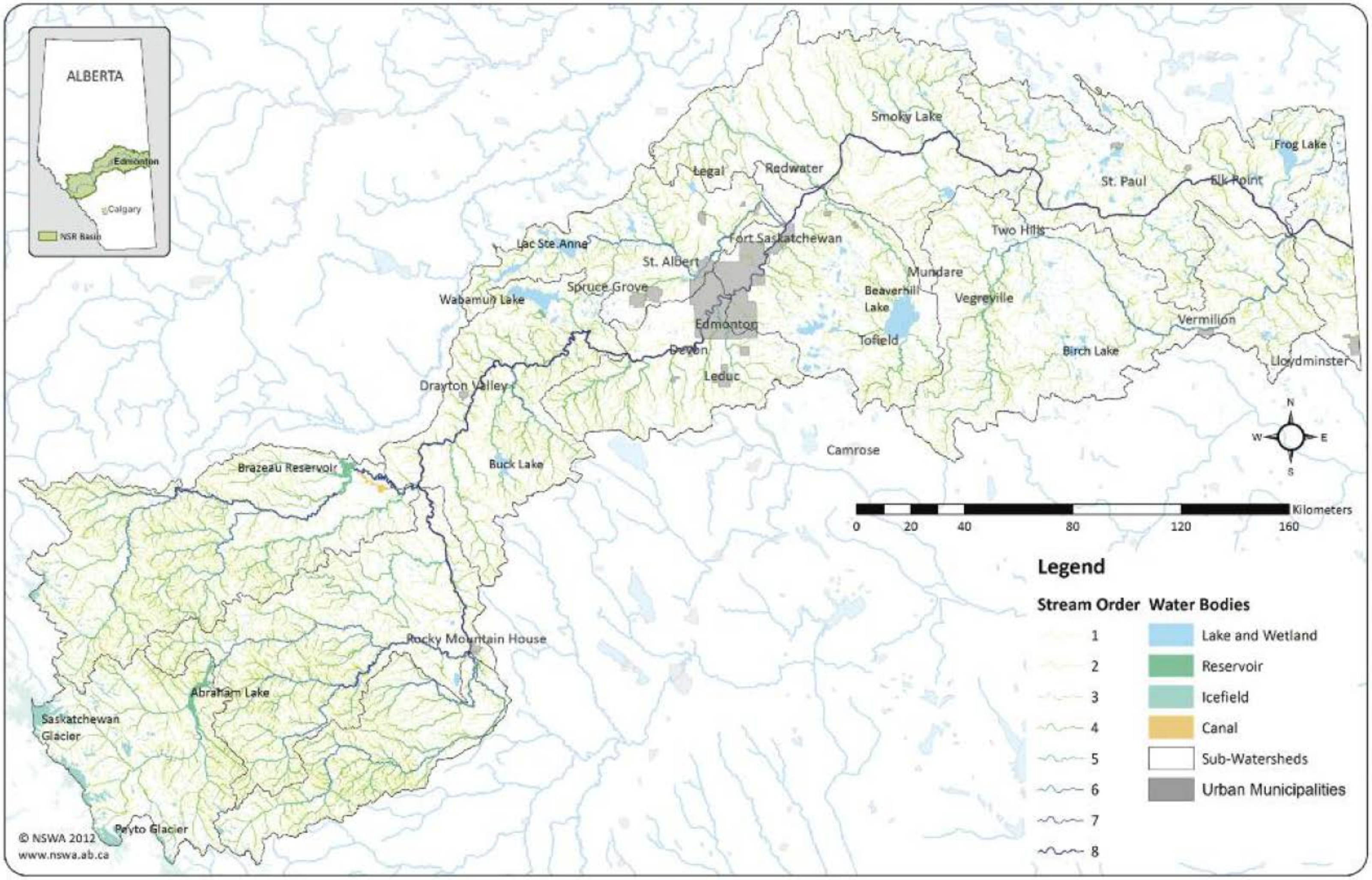

Figure 1-1: Map of the North Saskatchewan River Basin in Alberta (figure from North Saskatchewan River Alliance, 2012).

Canadian Census (Statistics Canada, 2011). Other settlements located along the river in Alberta include Rocky Mountain House, Drayton Valley, Elk Point and Lloydminster.

Within the province of Alberta there are many users that consume water in the North Saskatchewan River basin. The province issues various types of water use licences in order to control and track the amount of water being utilized. Typical consumptive uses include municipal water supply, agriculture, cooling water, oil refineries and other commercial and industrial applications.

There are two major reservoirs located in the Alberta portion of the North Saskatchewan River Basin (NSRB). The Brazeau Dam, which impounds the Brazeau Reservoir, is located on the Brazeau River, just upstream from the confluence with the North Saskatchewan River. Controlling a drainage area of approximately 5,660 km^2, this dam came into operation in October 1961. Located on the main stem of the North Saskatchewan River, the Bighorn Dam, which impounds Lake Abraham, came on-line in August 1972. This dam controls a drainage basin area of approximately 3,890 km^2. Both dams are owned and operated by TransAlta Utilities for the purpose of power generation.

The general operating regime for the Bighorn and Brazeau dams is that water is stored during the peak flow months (spring- summer) and released through the winter. Figure 1-2 shows the combined mean monthly change in storage for the Brazeau Reservoir and Lake Abraham for the period from 1970-2010.

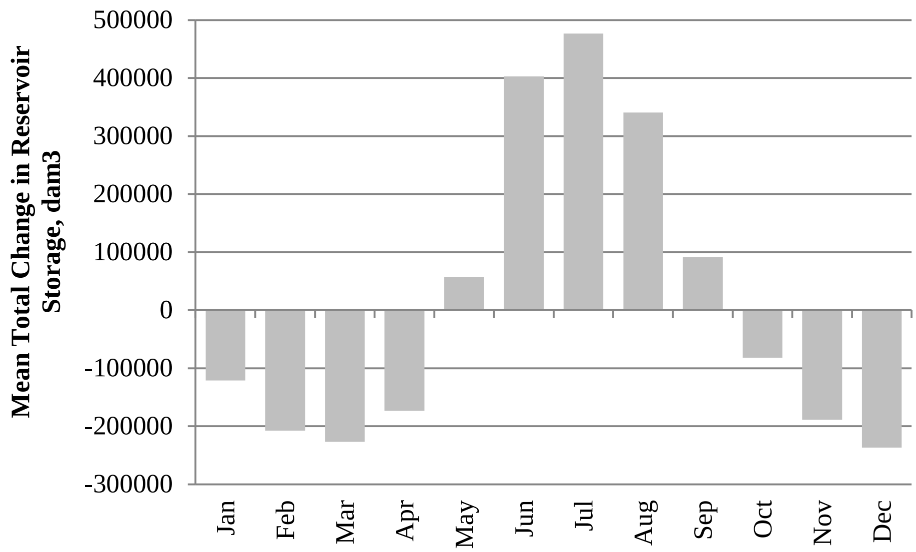

Figure 1-2: Mean monthly total change in storage for Brazeau Reservoir and Lake Abraham for the period from 1970 to 2013.

When reviewing flow rates for the North Saskatchewan River downstream of these reservoirs the 62 years of record available (discontinuous between 1917-2009) must be divided into pre and post regulation periods. Table 1-1 gives the monthly mean flow for both conditions.

Table 1-1: Pre-regulation (1917-1961) and post-regulation (1962-2009) flow at station North Saskatchewan River near Deer Creek (05EF001).

	Mean Flow, m^3/s	
	Pre Regulation	Post Regulation
Jan	38	107
Feb	36	110
Mar	37	128
Apr	183	283
May	373	278
Jun	587	381
Jul	542	397
Aug	428	256
Sep	275	198
Oct	142	161
Nov	77	129
Dec	40	113

1.3 Apportionment Details

Apportionable flow is the term used to describe the volume of water that is subject to apportionment under the MAA. It is similar to natural or pre-development flow; however, in order to keep data requirements and calculations reasonable, the apportionable flow computations are generally less rigorous than a true natural flow calculation.

The terms of the agreement between Alberta and Saskatchewan are contained in Schedule A of the MAA. Under the agreement, Saskatchewan is entitled to receive a minimum of 50% of the water that would naturally have flowed into the province from Alberta during each apportionment period. The remaining 50% is available for either storage or consumptive use by Alberta. Unlike the agreement between Saskatchewan and Manitoba (Schedule B to the MAA), which specifies that apportionment is based on the period from January 1 to December 31, the agreement between Alberta and Saskatchewan states only that:

> “..actual flow shall be adjusted from time to time on an equitable basis
> during each calendar year...”

Thus, the apportionment period during which Alberta is obligated to meet the apportionable flow is somewhat more vague.

The apportionable flow calculation procedures for each basin are agreed upon by the member agencies of the PPWB and must be adhered to, unless modifications are formally approved. Apportionable flow calculations for the North Saskatchewan River have been completed since the late 1970's. For the North Saskatchewan River the point of apportionment is at the hydrometric station near Deer Creek (05EF001). The apportionable flow at this location is currently calculated based on a monthly time step, but computations are completed and reported annually at the end of the calendar year.

Table 1-2 shows the historical annual flow volumes recorded at Deer Creek for the period from 1979 to 2013, along with the apportionable flow volume calculated by the PPWB. As these figures indicate, historically there has been no issue in regards to Alberta meeting the apportionment requirements for this river on an annual basis with the current apportionable flow calculation procedures.

Table 1-3 shows the average and lowest percent of apportionable flow delivered for each month between 1979 and 2013. As previously noted, apportionment for the North Saskatchewan River is currently considered annually, such that the monthly apportionment balance is presented for interest only. The months when the recorded flow is closest to 50% of the apportionable flow are June to August and there are 14 instances during that time period where the recorded flow is less than 55% of the apportionable flow. The general time periods of these occurrences were in the mid 1980's, early 1990's and early 2000's. Of course, the cumulative apportionable flow in those years was still much greater than 50%, due to the artificially high over-winter flows.

1.4 Report Overview

This report begins by summarizing the current apportionable flow calculation procedures (Section 2). The following aspects of the computations are then reviewed separately: consumptive use (Section 3), evaporation (Section 4), and routing adjustments (Section 5). The total impact of the proposed changes on apportionable flows is then evaluated as a whole (Section 6). Based on the proposed calculation procedures the data requirements are discussed (Section 7 to Section 9). Finally, the findings of the report are sumarized along with commentary on level of apportionment monitoring and future requirements for updates to the apportionable flow calculation procedures.

Table 1-2: Historic annual recorded and apportionable flows for the North Saskatchewan River near Deer Creek (05EF001).

	Recorded Flow, dam^3	Apportionable Flow, dam^3	% Apportionable Delivered
1979	5,520,000	5,440,000	101%
1980	8,370,000	8,230,000	102%
1981	7,720,000	7,800,000	99%
1982	7,310,000	7,470,000	98%
1983	5,830,000	5,640,000	103%
1984	5,020,000	4,960,000	101%
1985	5,890,000	5,750,000	102%
1986	8,940,000	8,930,000	100%
1987	5,410,000	5,360,000	101%
1988	4,790,000	4,710,000	102%
1989	7,190,000	7,290,000	99%
1990	8,950,000	8,950,000	100%
1991	8,400,000	8,320,000	101%
1992	5,590,000	5,480,000	102%
1993	6,300,000	6,360,000	99%
1994	5,990,000	5,930,000	101%
1995	7,270,000	7,430,000	98%
1996	6,860,000	6,910,000	99%
1997	6,980,000	7,090,000	98%
1998	7,660,000	7,650,000	100%
1999	8,360,000	8,280,000	101%
2000	5,710,000	5,750,000	99%
2001	4,880,000	4,710,000	104%
2002	4,840,000	4,840,000	100%
2003	6,100,000	6,030,000	101%
2004	5,620,000	5,780,000	97%
2005	9,520,000	9,520,000	100%
2006	5,630,000	5,490,000	103%
2007	7,650,000	7,680,000	100%
2008	7,020,000	6,910,000	102%
2009	4,700,000	4,580,000	103%
2010	5,820,000	5,990,000	97%
2011	8,450,000	8,450,000	100%
2012	7,950,000	7,860,000	101%
2013	8,190,000	8,200,000	100%
Average	6,760,000	6,740,000	100%

Table 1-3: Average and lowest percent of apportionable flow delivered by month from 1979 to 2013.

	Average % of Apportionable Flow Delivered	Lowest % of Apportionable Flow Delivered
Jan	870	243
Feb	490	237
Mar	324	160
Apr	142	115
May	99	72
Jun	72	50
Jul	67	50
Aug	64	49
Sep	79	67
Oct	113	96
Nov	214	142
Dec	604	211

2. Apportionable Flow Calculation Procedures

2.1 Documented Calculation Procedures

General Procedures

The only documented apportionment calculation methods for the North Saskatchewan River are described in PPWB Report No. 45, dated March 1975. The procedure described in that report applies the Project Depletion Method to account for the operation of the Brazeau and Bighorn Dams (Brazeau Reservoir and Lake Abraham) in Alberta. Based on the study completed at that time, other uses such as municipal and industrial consumption were considered insignificant. Therefore, these items were not included in the COH approved calculation of apportionable flow. Evaporation losses from the two reservoirs were also excluded from the recommended apportionable flow calculations. Analysis summarized in the 1975 report justified this by showing that, even in the summer months, evaporative losses equaled less than one percent of the flow in the river.

The resulting apportionable flow calculation is as follows:

Apportionable Flow = Recorded Flow Volume at Station 'North Saskatchewan River near Deer Creek' (05EF001)

+ Change in Storage at Brazeau Reservoir (05DD006) Adjusted for Routing

+ Change in Storage at Lake Abraham (05DC009) Adjusted for Routing

+ Carryover Routing Adjustment from Preceding Month for Lake Abraham Storage

+ Carryover Routing Adjustment from Preceding Month for Brazeau Reservoir Storage

Reservoir Storage Routing Adjustment

The 1975 Natural Flow report provides equations that were developed for each reservoir to determine the travel time from the reservoir to the apportionment point at Deer Creek. Documentation on how the routing equations were developed is not provided. The equations are based on the mean daily flow recorded at the hydrometric gauges North Saskatchewan River at Edmonton (05DF001) and North Saskatchewan River near Rocky Mountain House (05DC001) for the last five days of each month. The equations are:

Lake Abraham

$$T = 0.66 \times 10^{1.820-0.105 \log Q_R} + 1.00 \times 10^{2.897-0.315 \log Q_E} + 1.10 \times 10^{2.947-0.309 \log Q_E} \quad (2\text{-}1)$$

Brazeau Reservoir

$$T = 1.27 \times 10^{2.460 - 0.258 \log Q_E} + 1.10 \times 10^{2.947 - 0.309 \log Q_E} \quad (2\text{-}2)$$

where : Q_E = Daily Mean Flow at 05DF001 for the last five days of the month (cfs),

Q_R = Daily Mean Flow at 05DC001 for the last five days of the month(cfs), and

$T = travel\ time\ in\ hours\ from\ the\ reservoir\ to\ the\ apportionment\ point$

The report indicates that the results of these equations will be travel times of around five days when flow in the river is very low, and around two days when flow is extremely high.

2.2 FORTRAN Program for Apportionable Flow Calculation

2.2.1 Calculation Procedures in FORTRAN Program

Apportionable flows are currently calculated using a single FORTRAN Program NS.exe. According to the program notes, NS.exe was originally written in June 1977, updated to metric in June 1981, and updated to FORTRAN77 in November 1984. The version of the code currently in use is provided for reference in Appendix 1. In order to determine how the apportionable flows are computed by the program the FORTRAN code was reviewed in detail.

General Procedures

The program requires the input data to be formatted in a single text file. The text file contains rows of recorded monthly average flow for the station North Saskatchewan River near Deer Creek (in cubic metres per second) as well as month end water levels for Brazeau Reservoir and Lake Abraham (in metres). The same file is used each year, with the additional year of data appended as the bottom row. The station number and year are identified on the far right side of each line of data. Any missing values in the input data sets are filled in by the operator before running the program. If the FORTRAN program detects missing data it will insert -99999 in the output.

Although the program code is quite long, the actual calculation routine contained within is simple. The program starts with a long series of code assigning variables and names, setting up the format for the output files, reading from the input file and writing to two output files. In addition to the main body of the program, three subroutines are utilized to: read the coordinates for the stage-storage curves for the two reservoirs, relate the reservoir stage data to the stage-storage curve, and complete all unit conversions.

The computation steps within the FORTRAN program are:

1. Convert monthly mean flow at Deer Creek to a monthly flow volume (dam^3).
2. Determine the monthly change in storage (dam^3) at each of the two reservoirs based on the user inputted stage-storage curves and the change in reservoir elevation.
3. Route the monthly change in storage values for each of the two reservoirs from their location to the apportionment point (Deer Creek).
4. Add together the recorded monthly flow volume at Deer Creek and the reservoir change in storage adjusted for routing.

The program outputs two text files NSout.dat, which details all of the input values and interim calculation values, and NSNF.dat, which provides a summary table of the monthly apportionment flow values. Each year the program recalculates all the years of data in the input file.

Routing Adjustment for Reservoir Storage

The main calculation that the FORTRAN program provides is routing of the change in storage at Brazeau Reservoir and Lake Abraham from their locations to the apportionment point. The routing adjustments are based on two equations:

Brazeau Reservoir

$$Routed\ \Delta SB = 0.136\ \times\ \Delta SB_{-1} +\ 0.864\ \times\ \Delta SB \tag{2-3}$$

Lake Abraham

$$Routed\ \Delta SA = 0.172\ \times\ \Delta SA_{-1} +\ 0.828\ \times\ \Delta SA \tag{2-4}$$

where: $\Delta SB = Brazeau\ Reservoir\ change\ in\ storage\ for\ the\ calculation\ month,$

$\Delta SB_{-1} = Brazeau\ Reservoir\ change\ in\ storage\ for\ the\ previous\ month,$

$Routed\ \Delta SB = Brazeau\ Reservoir\ change\ in\ storage\ \ routed\ to\ Deer\ Creek$

$\Delta SA = Lake\ Abraham\ change\ in\ storage\ for\ the\ calculation\ month,$

$\Delta SA_{-1} = Lake\ Abraham\ change\ in\ storage\ for\ the\ previous\ month,$ and

$Routed\ \Delta SA = Lake\ Abraham\ change\ in\ storage\ routed\ to\ Deer\ Creek$

These routing calculations do not match the equations detailed in the 1975 PPWB report. No documentation of this change to the calculation methodology can be found. It is believed that the ratios used in the FORTRAN program were derived by averaging travel times calculated using the 1975 method over some time period, in order to simplify the routing calculations. For example, for the period from 1972 to 1992 (the current FORTRAN program was implemented around 1992) the average monthly carry over for Lake Abraham would have been 17.4% of the monthly change in storage, and for Brazeau Reservoir would be 14.5% of the monthly change in storage, based on the travel times calculated using the 1975 method. These values are very close to the FORTRAN routing method values of 17.2% and 13.6% (Equations 2-3 and 2-4), so it would seem that this was likely the method employed to derive these equations.

The flowchart shown in Figure 2-1 was developed to show how the FORTRAN program calculates each component of apportionable flow at the Alberta/Saskatchewan interprovincial boundary.

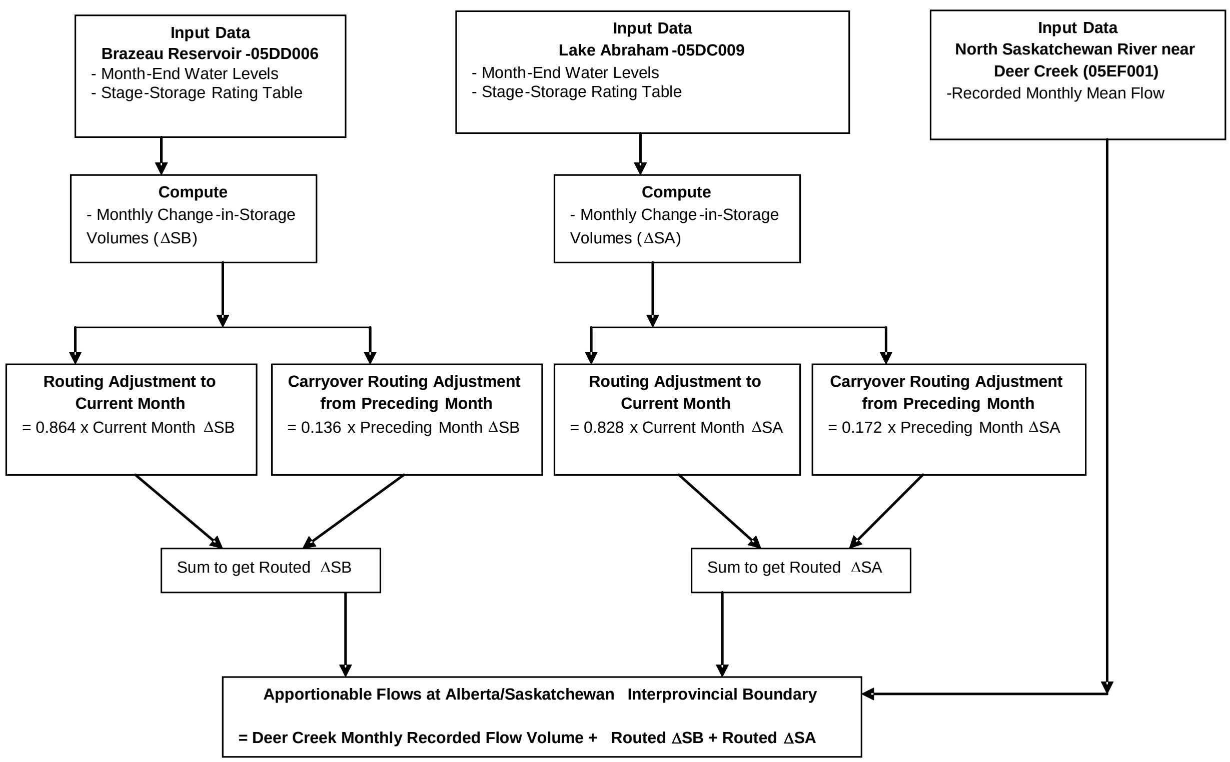

Figure 2-1: Flowchart depicting methodology used in FORTRAN program for computing apportionable flows.

Correction for Unusual Ice Conditions in January 1974

The North Saskatchewan FORTRAN program has a special correction routine to account for a situation which occurred in January 1974. During that month the measured flow volume at the Deer Creek hydrometric station was 194,988 dam^3, while the calculated adjustments based on the change in reservoir storage are equal to -234,330 dam^3, which would equate to a negative apportionable flow. For that month, an estimated apportionable flow value of 49,340 dam^3 is substituted for the calculated value, because a negative apportionable flow is not feasible.

2.2.2 Verification of FORTRAN Program Apportionable Flow Calculation Procedures

A spreadsheet was developed to complete the apportionable flow calculations, following the steps detailed in section 2.2.1, in order to verify that the FORTRAN calculation routine was accurately captured. The resulting apportionable flow volumes were all within 2 dam^3 of the results obtained using the FORTRAN program on an annual basis. The results are shown in Table 2-1.

Table 2-1: Results obtained from spreadsheet calculation using the apportionable flow calculation method outlined in Section 2.2.1.

	Excel Calculated Apportionable Flow, dam3	FORTRAN Calculated Apportionable Flow, dam3	Difference Excel vs. FORTRAN, dam3
1979	5,443,227	5,443,228	-1
1980	8,233,426	8,233,426	0
1981	7,795,177	7,795,179	-2
1982	7,471,452	7,471,453	-1
1983	5,642,239	5,642,239	0
1984	4,959,691	4,959,690	1
1985	5,753,740	5,753,740	0
1986	8,933,159	8,933,160	-1
1987	5,358,084	5,358,086	-2
1988	4,708,145	4,708,144	1
1989	7,286,326	7,286,327	-1
1990	8,954,560	8,954,560	0
1991	8,320,296	8,320,296	0
1992	5,484,973	5,484,971	2
1993	6,356,524	6,356,524	0
1994	5,930,783	5,930,785	-2
1995	7,430,641	7,430,642	-1
1996	6,911,740	6,911,741	-1
1997	7,087,742	7,087,742	0
1998	7,648,371	7,648,371	0
1999	8,275,784	8,275,784	0
2000	5,751,099	5,751,100	-1
2001	4,707,267	4,707,267	0
2002	4,842,103	4,842,102	1
2003	6,032,060	6,032,061	-1
2004	5,779,349	5,779,349	0
2005	9,516,583	9,516,581	2
2006	5,488,843	5,488,843	0
2007	7,675,949	7,675,949	0
2008	6,906,893	6,906,894	-1
2009	4,577,405	4,577,407	-2
2010	5,986,638	5,986,639	-1
2011	8,452,097	8,452,097	0
2012	7,863,911	7,863,911	0
2013	8,202,354	8,202,354	0

2.3 Comparison with the Province of Alberta's Natural Flow Model

Alberta Environment and Parks (AEP) has developed a natural flow model for the North Saskatchewan River in Alberta. The AEP model calculates daily natural flow values and takes into account storage in the reservoirs, reservoir evaporation and reported consumptive use for the largest 80 water use licences in the basin. The model uses the Streamflow Synthesis and Reservoir Regulation (SSARR) routing procedure.

The model was developed in 2005 by Stantec Consulting Ltd., based in part on modelling work that had been previously completed by the province. Using the model, Stantec generated natural flows at fourteen sites within the North Saskatchewan River Basin for the period from 1912 to 2002. The model was then modified in 2008 by staff of AEP and the run period was extended to 2008. Modifications to the model included: the creation of more natural flow computation points, revision of the regression analysis used to fill in missing station data, the addition of tributary inflow data sets derived from regional analysis, and the addition of more routing nodes, to name a few.

Figure 2-2 shows a comparison between the total annual natural flow generated by the AEP model and the total annual apportionable flow volume generated by the PPWB FORTRAN program for the period from 1970 to 2008. In all years the apportionable flow is less than the natural flow which might be attributed to the fact that the apportionable flow calculations do not take into account either reservoir evaporation or consumptive use, which the AEP natural flow values include. The mean, maximum and minimum differences between the results are shown in Table 2-3 in terms of volume and percentage of the AEP natural flow.

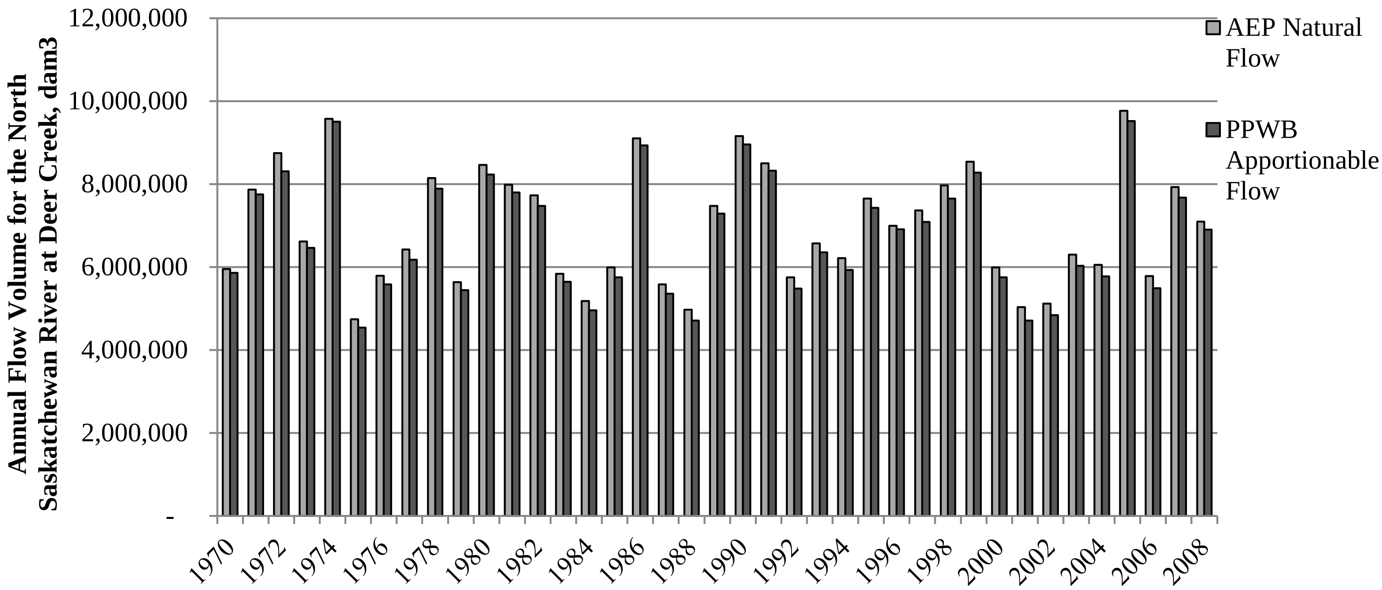

Figure 2-2: Comparison between AEP and PPWB annual apportionable/natural flow volumes from 1970 to 2008.

Table 2-2: Difference between AEP and PPWB annual flow volumes.

	Difference, dam^3	Difference, % of AEP Natural Flow
Mean	227,000	3%
Maximum	443,000	6%
Minimum	67,700	1%

2.4 Location of Apportionment Point

As described previously, the apportionable flow for the North Saskatchewan River is calculated at Deer Creek, Saskatchewan, where the closest hydrometric gauge to the border is located. In other basins where the gauge is not located at the border provisions may be made in the approved calculation procedures to adjust the recorded data and apportionable flow results to account for the difference in location, with the resulting values being reported as they would be estimated to be at the border.

The distance from the border to Deer Creek along the river is approximately, 37.2 km. The portion of the gross drainage area of the North Saskatchewan River at Deer Creek which is located within Saskatchewan is approximately 759 km^2, of which 511 km^2 is considered part of the effective drainage area. These areas represent in the order of 1.3% and 1.2% of the total gross and effective drainage areas at Deer Creek, respectively.

In order to estimate the amount of flow contributed at the apportionment point by the area within Saskatchewan, comparison can be made to the local gauge 05EF004 which measures flow in the Monnery River. That watershed has an effective drainage area of 582 km^2 and generates a median yield of 17.5 dam^3 per square kilometer, based on recorded flows from 1968 to 1996 and 2010 to 2014 . Figure 2-2 shows the location of the Monnery River drainage basin relative to the Deer Creek station. If it is assumed both basins yield similar runoff volumes, the portion of the watershed of the North Saskatchewan River at Deer Creek that is located within Saskatchewan would be expected to generate a median annual flow volume of approximately 8,960 dam^3. This is obviously a very small portion of the flow volume recorded at Deer Creek (e.g. see Table 1-2 for comparison).

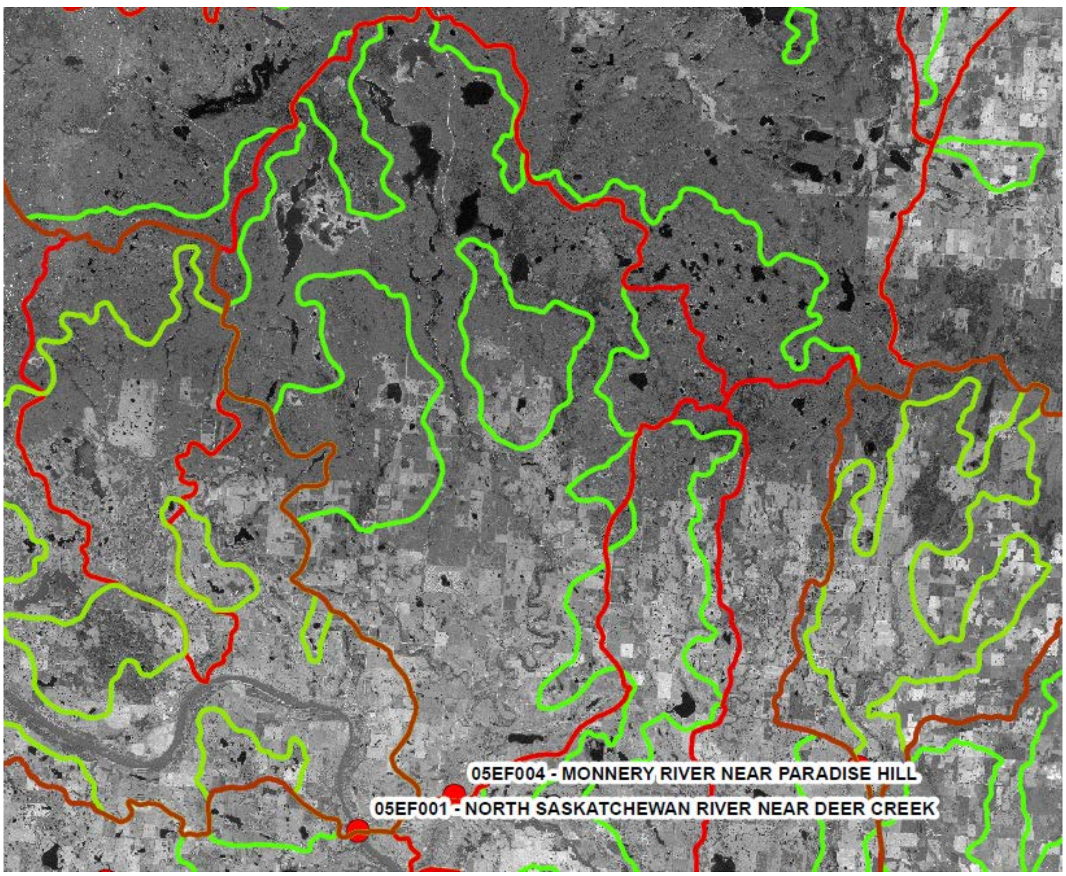

Figure 2-3: Monnery River near Paradise Hill drainage area. Red lines delineate gross drainage and green lines show non effective drainage areas. (Image courtesy of Saskatchewan Water Security Agency).

The Saskatchewan Water Security Agency completed a database scan for projects within the effective drainage area between the Alberta border and the hydrometric station at Deer Creek. At present there are 11 active surface water projects within the effective drainage area, of which four draw water directly from the river. There are also three groundwater projects adjacent to the river. The total estimated use of the surface water projects is 2999 dam^3 per year. Groundwater projects are not typically considered in apportionable flow calculations. A list of all the projects can be found in Appendix 2.

Taking the median yield and the estimated annual use in this area into consideration the net effect of the apportionment point being located downstream of the interprovincial border is that in a typical year Alberta receives credit for delivery of approximately 5,960 dam^3 of water that actually originates in Saskatchewan. The following options could be considered to account for this in the apportionable flow calculation:

a) Status Quo

As the adjustment for the volume of runoff and consumptive use that occurs in Saskatchewan upstream of the Deer Creek hydrometric station is very small relative to the total flow measured at the gauge, and Alberta currently delivers almost 100% of the apportionable flow, it may be reasonable to accept the discrepancy and continue calculating the apportionable flow as it has been done in the past.

b) Adjust Recorded Flow at Deer Creek Based on Static Estimate of Net Inflow from Saskatchewan

This option would entail subtracting a constant volume from the recorded flow at Deer Creek for each month to be used in the calculation of apportionable flow, as well as for the volume of flow delivered. As above, the estimates would be based on monthly median flow recorded at the Monnery River hydrometric station minus estimated licenced water use in Saskatchewan. This option provides a basic way of accounting for the location of the gauge with no increase in monitoring required.

c) Adjust Recorded Flow at Deer Creek Based on Annual Estimate of Inflow from Saskatchewan

This option would be similar to option b), but instead of using a static estimate of net inflow from Saskatchewan, each year an estimate would be generated based on recorded flow that year at the Monnery River hydrometric station. This would require the addition station 05EF004 to the list of PPWB monitoring stations. The result would more accurately represent conditions in each specific year, but would still have little impact on the overall result.

d) Make Changes to Hydrometric Network

This option would see either the hydrometric station on the North Saskatchewan River at Deer Creek moved to a location closer to the Alberta border, or new gauging stations being established on tributaries to the North Saskatchewan between the Alberta border and Deer Creek. This option would result in the most accurate apportionable flow calculation, but would be at very high cost.

It is recommended that the option d) be implemented, and that the hydrometric gauge used to monitor flow in the North Saskatchewan River for the purposes of apportionment be moved from Deer Creek, SK, to a location as close to the interprovincial border as possible. This provides the most accurate and straight forward accounting and, although it incurs cost in the short term, causes no increase in the overall monitoring requirements.

Considering that relocation of the hydrometric gauge will take some time and negotiation before it might be implemented, as an interim measure it is recommended that option b) be implemented. This option represents a reasonable attempt to address the inequality in the calculation, while adding no additional monitoring requirements. This option will be included in the revised apportionable flow calculation based on the monthly estimates of median net Saskatchewan inflow contained in Table 2-4.

Table 2-4: Calculation of Adjustment to Recorded Volumes at Deer Creek to Account for Inflow and Consumption in Saskatchewan

	Monnery River Median Flow at 05EF004 (1968-1996, 2010-2014), dam^3	Monnery River Median Yield, dam^3/km^2	SK Inflow Contribution at Deer Creek, dam^3	Licenced Water Use, dam^3	Net Adjustment at Deer Creek, dam^3
Jan	0	0.0	0	19	-19
Feb	0	0.0	0	19	-19
Mar	770	1.3	676	22	655
Apr	3260	5.6	2864	22	2842
May	1630	2.8	1432	22	1410
Jun	1080	1.9	949	709	240
Jul	1190	2.0	1045	709	336
Aug	760	1.3	668	709	-41
Sep	620	1.1	545	709	-164
Oct	890	1.5	782	22	760
Nov	0	0.0	0	19	-19
Dec	0	0.0	0	19	-19
Total	10 200	17.5	8961	2999	5962

2.5 Summary

The FORTRAN program currently used to calculate apportionable flows for the North Saskatchewan River was found to differ from the documented and approved calculation procedures in terms of the method used to route changes in storage occurring at Lake Abraham and Brazeau Reservoir to the apportionment point. Comparison of the PPWB apportionable flow record with natural flows generated using AEP's more detailed model of the NSRB shows that on an annual basis the results have a mean difference of 3%. The following sections will explore each aspect of the apportionable flow calculation procedures and make recommendations for changes to the procedures going forward.

The impact of the location of the apportionment point at Deer Creek, Saskatchewan, approximately 37 km downstream from the Alberta border was reviewed. It is recommended that the apportionable flow calculation be adjusted to account for the portion of the drainage area at the Deer Creek hydrometric station that is located in Saskatchewan, as well as licenced water use between the border and the station. In order to do this the monthly flow volumes shown in the far right column of Table 2-4 will be subtracted from the recorded flow at Deer Creek, prior to conducting the apportionable flow calculations. This will effectively move the apportionment point from being the North Saskatchewan River at Deer Creek to the North Saskatchewan River at the Alberta Saskatchewan border. The reporting in the PPWB annual report will be adjusted to note that estimated flow at the border is being reported, as opposed to recorded flow, and a footnote will be added to the results table to indicate the nature of the adjustment that is made.

3. Consumptive Use

3.1 Sources of Consumptive Use Data

Water rights licences for consumption of water from the North Saskatchewan River basin in Alberta are issued and monitored by AEP. Data regarding these licences has been provided by that agency to the PPWB Secretariat. In the past, licence use data was collected in annual paper reports submitted to the province by each licensee. Alberta now requires licenced users to electronically report their actual use and returns through an internet form that is automatically entered into a database of this information maintained by the province. The monitoring and reporting time steps required by the licence are not consistent and may be monthly volumes reported annually, or daily volumes reported monthly. Because the reported use data is measured and provided by the licensees, and there is only periodic quality checking of the database, the province is not able to guarantee the consistency or accuracy of the information. Data availability if dependent on the requirement in the individual licence, subject to any enforcement processes should the licensee not be in compliance.

In terms of monitoring water stored and released at the two major reservoirs, water level stations on Brazeau Reservoir (Brazeau Dam) and Lake Abraham (Bighorn Dam) are operated by TransAlta Utilities. These data are provided regularly to the Water Survey, or may be obtained directly from TransAlta.

3.2 Analysis of Consumptive Use Data

3.2.1 Net Licenced Volume

There are currently 15,653 water licences issued by the Province of Alberta for withdrawals from the North Saskatchewan River basin. The licenced net use (difference between licenced quantity and licenced return) of all licences is 398,969 dam^3. Licenced users include small and large agricultural operations, municipal water supply systems, commercial and industrial uses. Table 3-1 provides a breakdown of all the licences issued by AEP in the North Saskatchewan River basin by sector.

As mentioned in Section 2.3, the provincial natural flow model of 2008 used 80 licences located in the effective drainage area (according to rank by net licenced volume) in its North Saskatchewan River natural flow model. Several new licences have been issued since the last model run in 2008 which will increase the number of significant licences used by AEP in the next model run to 83. These top 83 licences are listed in Appendix 2 and account for 327,119 dam^3 of the total licenced net use, or about 82%. Table 3-2 summarizes the net licenced volume corresponding to various numbers of licences. The 83 licence subset was selected in order to consider the majority of the total licenced volume, without having to consider all 15,653 licences, many of which are for very small volumes. For example, Table 3-1 shows 13,941 traditional agricultural registrations that represent only 4,312 dam^3. Including a detailed accounting for these small licences would be a significant undertaking, however the overall impact of these withdrawals is very minimal. Should the PPWB Committee on Hydrology (COH) determine at some time that they prefer a larger subset of licences be used, the licenced data set under consideration could easily be expanded to include more small licences.

Table 3-1: Breakdown of all water use licences issued for the North Saskatchewan River Basin by sector (provided by AEP).

Industrial Activity	Total Allocation, dam^3	Total Return, dam^3	Net Licenced Consumptive Use, dam^3	Total Return as % of Total Allocation	Number of Licences
Agriculture	2,289	0	2,289	0	417
Commercial	1,720,067	1,475,811	244,256	86	246
Dewatering	107	25	82	23	621
Disturbance	0	0	0	0	3
Habitat Enhancement	5,466	20	5,446	0	81
Industrial	84,578	7,497	77,081	9	57
Irrigation	10,906	268	10,638	2	151
Management of Fish	330	79	251	24	17
Management of Wildlife	30	0	30	0	3
Municipal	156,685	113,909	42,775	73	37
Recreation	452	173	280	38	15
Registration	4,312	0	4,312	0	13,941
Water Management	13,729	2,286	11,444	17	54
Water Power	0	0	0	0	2
Any other purposes specified by the Director	143	60	83	42	6
Total	1,999,096	1,600,127	398,969		15,653

Table 3-2: Total net licenced volume of water that can be extracted from the North Saskatchewan River Basin in Alberta corresponding to various numbers of licences (ranked from largest to smallest net licenced volume).

Top # of Licences	Net Licenced Volume (dam^3)	% of Total Net Licenced Volume
83	327,119	82%
70	323,776	81%
60	319,030	80%
50	311,807	78%
40	301,276	76%
30	283,150	71%
20	251,284	63%
10	187,185	47%

The average total annual apportionable flow of the North Saskatchewan River at the Alberta/Saskatchewan boundary for the period from 1977 to 2011 is 6,680,000 dam^3 (see Table 1-2) and the resulting share available for use by Alberta, according to the terms of the MAA, is 3,340,000 dam^3 (50%). Therefore, the total net licenced volume is equal to approximately 12% of Alberta's share.

3.2.2 Location of Consumptive Use Licences

To help illustrate the locations of consumptive use in the basin, the locations of the largest water use licences (supplied by AEP) were plotted in Google Earth. The resulting map is shown in Figure 3-1. The projects were categorized based on their licenced volume as follows:

Class One: $\geq$100,000,000 m^3
Class Two: $\geq$10,000,000 m^3 & <100,000,000 m^3
Class Three: $\geq$1,000,000 m^3 & <10,000,000 m^3
Class Four: <1,000,000 m^3

The numbers on the labels in the Google Earth image correspond to the category of the largest licence found at that location. Due to the constraints of mapping a large number of licences, some labels represent up to six licences.

3.2.3 Reported Diversion and Return Data

Reported use and return data for the top 83 licences for 2008 to 2011 was provided by AEP and can be found in Appendix 2. As the actual net consumptive use is typically significantly lower than the net licenced volume, reported values are more representative for analyzing the amount of water actually being used.

The reported diversion and return volumes from the top 83 licences provided by AEP was reviewed for inconsistencies or problems with the data. These were not cross-checked with paper annual reports, as it would be too resource intensive. As previously noted, because the data is measured and reported by the licence holders, the accuracy of the data is uncertain and AEP cautions that its application without prior review is not advisable.

Adjustments to the reported data were made only where issues were obvious. Assumptions regarding the reported data and changes made may be summarized as follows:

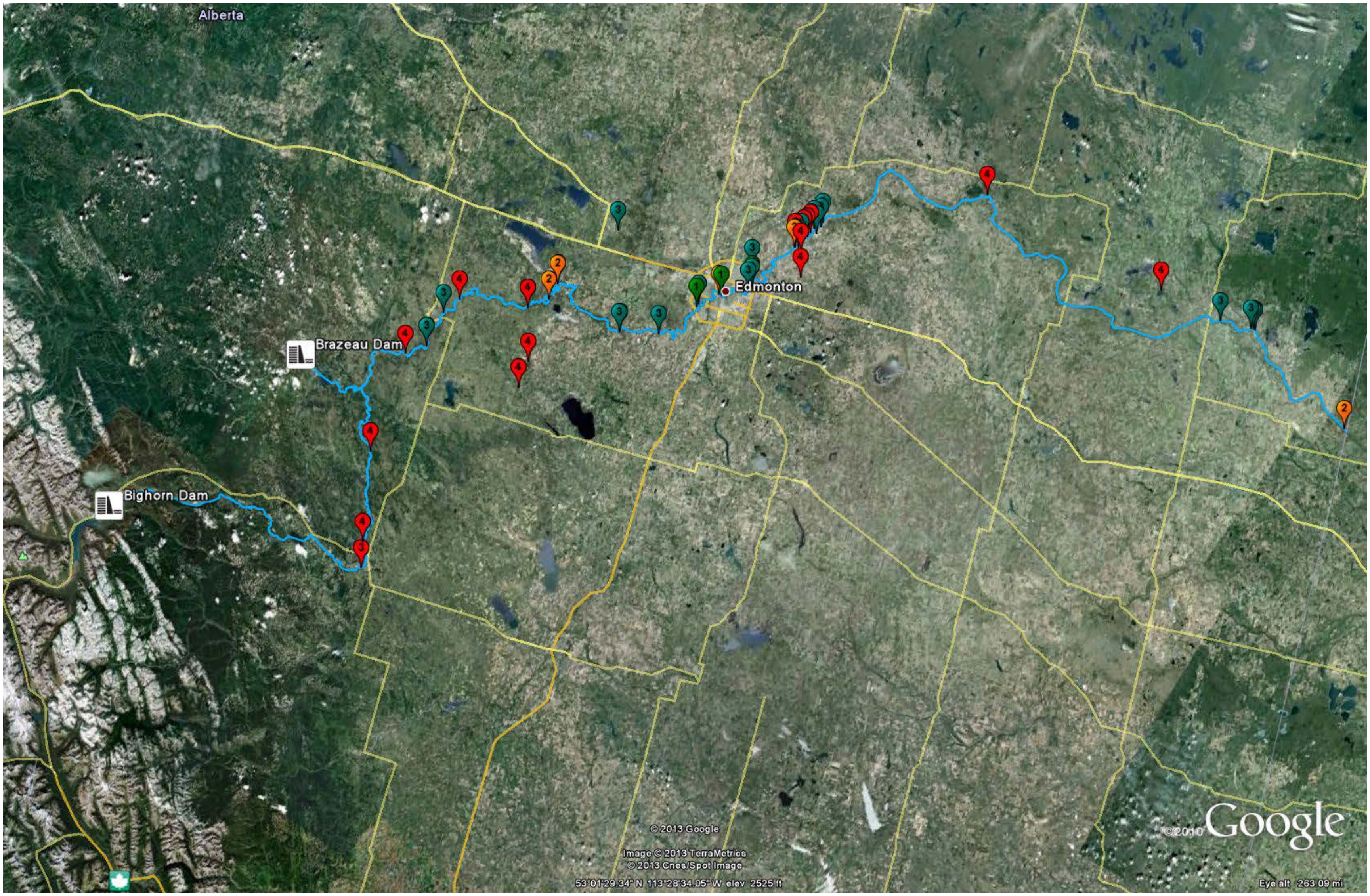

Figure 3-1: Location of largest consumptive use licences in North Saskatchewan River Basin in Alberta (data from AEP).

- Where it appeared holders of multiple licences had incorrectly reported their total water use against one licence, or the total volume for all licences was reported for each individual licence, the volumes were redistributed.
- In some instances, data for a single year was out by a factor of 10x or 100x based on the licenced volume and reported data for other years. In those cases, the reported numbers were reduced by the appropriate amount.
- Some licences had reported consistent use volumes in three of the four years of data, although not reporting anything in the other year. In these cases, data for the missing year was estimated based on the reported volumes from the other years.
- In a few cases, reported diversion and return data did not correspond and produced negative consumptive use values. In cases where large negative annual net values were produced, the data was adjusted based on reasonable assumptions. For example, in some cases it appeared diversion and return data had been switched.
- There are several large cooling water licences for which the reporting of diversions and returns is believed to have been combined; however, the exact mechanics of this is unclear, and without further investigation, AEP is not able to confirm how the reported data should be interpreted. For the purposes of this analysis, assumptions have been made based on advice from AEP.

Some general assumptions that were passed on by AEP were that for licences where zero diversion was reported in most years, but nothing was reported in other years, zero diversion was assumed for all years. Also, for licences where no record was entered for return flow, a return flow of zero was assumed.

Even after these changes were made to the reported use data, there are still many questionable entries. However, a balance had to be struck between creating an estimated data set, versus using the available reported data.

Table 3-3 shows the percent of the total net licenced volume reported as actually consumed by the top 83 licences for each year from 2008 to 2011. Based on these four years, and taking into account the uncertainty in the data, this data suggests that 35% would be a conservative estimate of the current average percent of the net licenced volume that is actually consumed by this subset of licences. This would translate to an estimated average net consumptive use of approximately 115,000 dam^3 (i.e. 35% of 327,119 dam^3).

Table 3-4 shows the reported consumptive use data for the top 83 licences broken down by activity. Of note is the fact that this subset of the largest licences only includes the categories of Commercial, Industrial, Irrigation (one licence) and Municipal. It does not include any of the other categories shown in Table 3-1. The Commercial and Industrial licences, which make up 77 of the top 83 licences, reported an average % of net licenced use very close to the 35% general estimate. The five Municipal licences reported a slightly lower percentage of use, while the one Irrigation licence reported an average use of over 100% of its net licenced volume. This may be due to an error in reporting (e.g. possibly units of measurement), which would be typical of the types of problems found in the reported use information.

Table 3-3: Reported net consumption by the top 83 licences for the years 2008-2011.

Year	Reported Net Use, dam^3	Average % of Net Licenced Volume Consumed
2008	84,584	26%
2009	106,745	33%
2010	120,847	37%
2011	100,707	31%

Table 3-4: Breakdown of Reported Consumptive Use Data for Top 83 Licences by Activity.

Activity	Commercial	Industrial	Irrigation	Municipal
Number of Licences in Top 83	46	31	1	5
Licenced Allocation, dam3	224,481	61,276	406	40,956
2008 Reported Consumptive Use, dam3	54,132	23,677	241	6,534
2009 Reported Consumptive Use, dam3	69,065	26,530	285	10,861
2010 Reported Consumptive Use, dam3	97,122	17,686	732	5,307
2011 Reported Consumptive Use, dam3	77,722	18,905	732	3,349
Average % of Net Licenced Use Reported as Consumed 2008-2011, dam3	33%	35%	123%	16%
Average % Return Flow, dam3	22%	5%	0%	37%

3.2.4 Annual Distribution of Reported Use

The reported consumptive use for the top 83 licences varies over the year, with the highest values occurring from late spring through fall. Table 3-4 lists the average monthly reported net use as a percentage of the total annual reported net use. As previously noted, the subset of the largest 83 licences, for which reported data was provided by AEP, has licences representing only a few of the activity type categories listed in Table 3-1 used to classify water use. Within the top 83 licences the majority are year round activities. However, within the group there are eight licences in the Commercial category for seasonal operations as well as one Irrigation category licence. The presence of these licences is the reason behind the seasonal distribution in the monthly percentages seen in Table 3-5.

Table 3-5: Average monthly reported net consumptive use from 2008-2011 as a percentage of the total annual reported net consumptive use volume for the top 83 licences.

	% of Annual Reported Net Use
Jan	6%
Feb	6%
Mar	7%
Apr	6%
May	8%
Jun	10%
Jul	9%
Aug	13%
Sep	10%
Oct	9%
Nov	8%
Dec	8%
Total	100%

Before investigating the seasonality of the complete set of 15,653 licences issued by AEP, the following licences were removed from the list (based on communications with AEP):

- 31 licences with a source listed as unnamed aquifer (various categories)
- 20 licences with a source listed as unnamed lake non-contributing (various categories)
- 621 Dewatering licences
- 3 Disturbance licences
- 81 Habitat Enhancement licences
- 3 Management of Wildlife licences
- 54 Water Management licences

The Disturbance and Dewatering licences have been issued for diversion of water from one location to another in the basin (e.g. to drain a field into a water course). The Management of Wildlife, Habitat Enhancement and Water Management licences generally have no volumes assigned to them. AEP recommended that these licences could be considered as null.

In addition to the Industrial Activity category already mentioned, AEP further divides licences based on a Specific Activity category. Using this information the remaining 14,840 licences can be divided into subcategories of water use as shown in Table 3-6. Included in this table are the numbers of licences in each group and the total licenced volumes as well as an estimate of the seasonality of each category, which was determined based on input from AEP.

Table 3-6: Breakdown of licences issued by AEP by Specific Activity category including seasonal distribution.

Industrial Activity	Specific Activity	Number of Licences	Total Category Allocation, dam^3	Total Category Return, dam^3	Total Category Net d, dam^3	Estimated Months of Operation
Commercial	COOLING	23	1,594,447	1,440,090	154,356	12
Commercial	OTHR	66	106,728	29,161	77,566	12
Industrial	GAS/PTRO	18	52,493	7,135	45,358	12
Municipal	URBAN	25	156,628	113,909	42,719	12
Industrial	INJECTN	39	32,085	361	31,723	12
Irrigation	CROP	151	10,906	268	10,638	4 (Jun-Sept)
Commercial	GRDN	51	4,757	0	4,757	4 (Jun-Sept)
Registration	REGISTRY	13941	4,312	0	4,312	12
Commercial	GLFCRS	40	3,378	0	3,378	4 (Jun-Sept)
Commercial	PRK	36	2,276	0	2,276	4 (Jun-Sept)
Agriculture	STCKWT	415	2,154	0	2,154	12
Commercial	AGGWSH	20	8,378	6,560	1,818	12
Recreation	RCRTN	15	452	173	280	12
Management of Fish	FISHERY	17	330	79	251	12
Agriculture	FEEDLT	2	136	0	136	12
Commercial	BTTLNG	6	101	0	101	12
Other	SOTHER	6	143	60	83	12
Municipal	COOPD	7	41	0	41	12
Municipal	MOTHER	2	9	0	9	12
Municipal	SUBDIVD	3	7	0	7	12
Commercial	CNSTRCT	4	4	0	4	12
Water Power	HYDRPWR	2	0	0	0	12

3.3 Significance of Consumptive Use Relative to Apportionable Flow

Table 3-7 illustrates the significance of the consumptive uses in Alberta by showing 35% of the 2011 net licenced volume as a percent of the apportionable flow for the years from 1977 to 2010 (35% is based on the information presented in Section 3.2.3). This assumes that the 35% estimate, based on the reported consumption data for the top 83 licences, is representative of all licences issued by AEP. In the lowest flow year (2009) the estimated consumptive use is equivalent to approximately 6% of Alberta’s share of the annual apportionable flow (3% of the total annual apportionable flow). In contrast, in the highest flow year (2005), the estimated consumptive use is equivalent to approximately 3% of Alberta’s share of the annual apportionable flow (1.5% of the total annual apportionable flow).

Table 3-7: Estimated typical net consumptive use as a percentage of the annual apportionable flow volume from 1979 to 2013.

Year	Apportionable Flow	Estimated Consumptive Use as a % of Apportionable Flow
1979	5,440,000	2.6%
1980	8,230,000	1.7%
1981	7,800,000	1.8%
1982	7,470,000	1.9%
1983	5,640,000	2.5%
1984	4,960,000	2.8%
1985	5,750,000	2.4%
1986	8,930,000	1.6%
1987	5,360,000	2.6%
1988	4,710,000	3.0%
1989	7,290,000	1.9%
1990	8,950,000	1.6%
1991	8,320,000	1.7%
1992	5,480,000	2.5%
1993	6,360,000	2.2%
1994	5,930,000	2.4%
1995	7,430,000	1.9%
1996	6,910,000	2.0%
1997	7,090,000	2.0%
1998	7,650,000	1.8%
1999	8,280,000	1.7%
2000	5,750,000	2.4%
2001	4,710,000	3.0%
2002	4,840,000	2.9%
2003	6,030,000	2.3%
2004	5,780,000	2.4%
2005	9,520,000	1.5%
2006	5,490,000	2.5%
2007	7,680,000	1.8%
2008	6,910,000	2.0%
2009	4,580,000	3.0%
2010	5,990,000	2.3%
2011	8,450,000	1.7%
2012	7,860,000	1.8%
2013	8,200,000	1.7%

Tables 3-8 and 3-9 show how the monthly reported net use for the top 83 licences compares to the apportionable flow on a monthly basis. In the winter months, when the apportionable flow is lower, the consumptive use represents a larger percent of the apportionable flow. These months are also when water is being released from the upstream reservoirs resulting in recorded flows that are much larger than the apportionable flow (thereby mitigating the impact of other consumptive uses). In the summer months, consumptive use is relatively small compared to flow in the river. However, these are also the months when historically the monthly recorded flow is closest to the monthly apportionable flow.

Table 3-8: Actual reported net use for top 83 licences as a percent of apportionable flow.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	11.3%	8.1%	5.4%	3.3%	0.5%	0.5%	0.6%	1.5%	1.5%	2.6%	3.3%	5.5%
2009	16.0%	10.8%	6.9%	1.0%	2.3%	1.6%	1.1%	1.7%	2.5%	3.7%	4.7%	19.8%
2010	25.4%	14.8%	7.2%	3.9%	1.7%	0.8%	0.9%	1.5%	1.4%	2.4%	4.3%	9.5%
2011	8.6%	19.2%	10.6%	0.5%	0.8%	0.2%	0.3%	1.3%	2.3%	2.3%	4.8%	10.0%

Table 3-9: Actual reported net use for top 83 licences as a percent of recorded flow at Deer Creek.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2008	1.4%	1.6%	1.4%	1.4%	0.6%	0.7%	0.9%	2.2%	1.7%	2.0%	1.8%	1.6%
2009	2.2%	1.9%	1.8%	0.6%	2.0%	2.7%	2.1%	3.1%	3.5%	2.9%	2.3%	2.9%
2010	4.0%	3.6%	2.5%	2.5%	1.5%	1.1%	1.5%	2.3%	1.8%	2.5%	2.5%	2.8%
2011	2.4%	3.3%	2.7%	0.3%	0.9%	0.3%	0.4%	1.7%	3.0%	2.2%	2.5%	3.4%

3.4 Recommended Procedures for Incorporating Consumptive Use in Apportionable Flow Calculations

3.4.1 Consumptive Use Projects to be included in Apportionable Flow Calculations

Standard selection criteria for inclusion of consumptive uses in the calculation of apportionable flow have not been established by the PPWB COH. The only water use currently included in the apportionable flow computations for the North Saskatchewan River is the storage of water in Brazeau Reservoir and Lake Abraham. These projects have a significant impact on the river hydrology, and will obviously continue to be included in the apportionable flow calculations.

It is clear that the net licenced consumptive use volume is generally not a realistic representation of the actual volume of water being consumed, although, as noted by AEP, the accuracy of the water consumption data reported by licence holders is also questionable.

As shown in Table 3.6, estimated consumptive use volumes make up only a few percent of the annual apportionable flow at the border based on conditions in the basin since 1977. However, on a monthly basis, consumptive use can have a much more significant impact on apportionable flow computations, as shown in Tables 3.7 and 3.8. The issue of what consumptive uses will be included in the apportionable flow calculations and how they will be estimated will be discussed in the following sections.

3.4.2 Calculation Procedures for Lake Abraham and Brazeau Reservoir

Changes in storage in Lake Abraham and Brazeau Reservoir are accounted for in the current apportionable flow calculation procedures. For each reservoir the change in reservoir elevation is compared to stage-storage curves in order to determine the change in stored volume. These volumes are then routed downstream to the apportionment point and used to adjust the recorded flow volumes. The adjustment can either be a loss or gain to the system depending on the season and the specific operations at the dams. The general pattern of operation is that water is accumulated in the reservoirs from the late spring (May-June) through to the early fall (Sept-Oct) and then released over the winter months.

The 1975 Natural Flow report contains storage tables for Lake Abraham and Brazeau Reservoir dated January 1974 and February 1974, respectively. These curves are shown in Figures 3-2 and 3-3. The input file used for the FORTRAN programs also contains storage tables. This file is carried forward from year to year and is not adjusted unless new information becomes available. These curves were confirmed to be the same as those contained in the 1975 Natural Flow Report. AEP confirmed that these storage curves are the most recent available for both reservoirs.

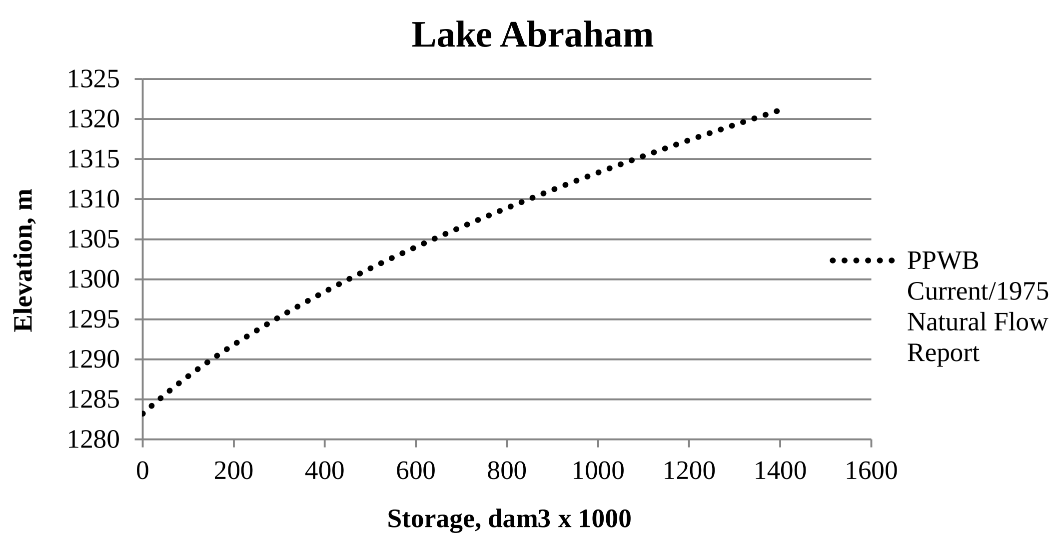

Figure 3-2: Stage-Storage curve for Lake Abraham. The FORTRAN program curve and the 1975 PPWB version are identical.

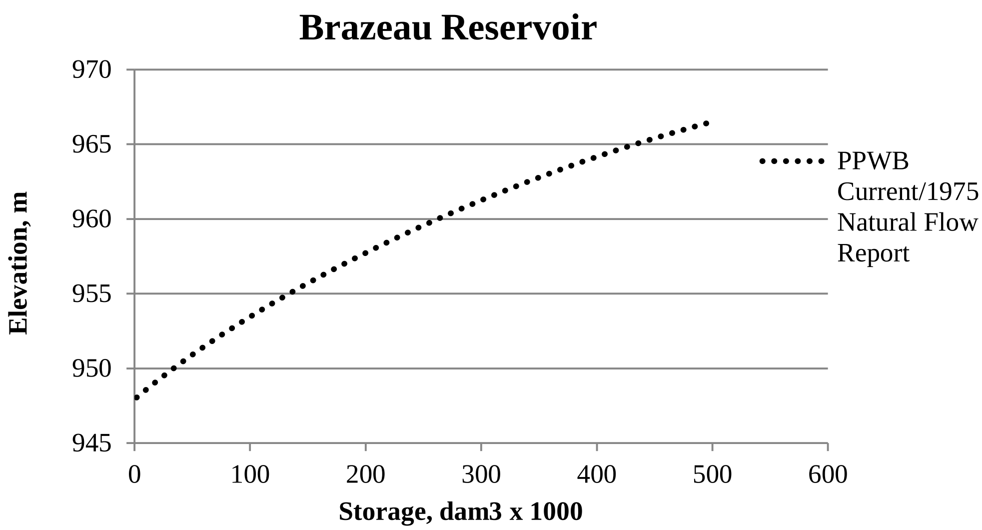

Figure 3-3: Stage-Storage curves for Brazeau Reservoir. The FORTRAN program curve and the 1975 PPWB version are identical.

There will be no change related to the procedure to account for reservoir storage in the new apportionable flow calculation procedures. Water level data will be used to determine the change in storage which will be added to the recorded flow at Deer Creek. Consideration of evaporation and routing of these values will be covered in a subsequent section of this report.

3.4.3 Calculation Procedures for Other Consumptive Uses

The following options for accounting for consumptive uses, other than by the two reservoirs, in the apportionable flow calculations could be considered:

a) Do Not Include Other Consumptive Uses in the Apportionable Flow Calculations

This is the option exercised in the current approved apportionable flow calculations for the North Saskatchewan River. The benefit of this option is that consumptive use data, for which accuracy and availability of data can be problematic, is not required for the calculations. When the existing apportionable flow calculation procedures were established in 1975, the calculations were likely completed manually, so not having to consider consumptive uses would have been a substantial benefit. Also, at the time the existing calculation procedures were implemented any kind of tracking of actual consumptive use would have been through reviewing paper annual reports, licence by licence.

As shown in the previous sections, collectively consumptive uses, other than at the reservoirs, can be important and should be considered in the apportionable flow calculations. As there are no justifiable impediments to their inclusion, the option for continuing to omit them will not be considered further.

b) ***Include the Estimated Consumptive Use for a Subset of the Top Consumptive Use Licences in the Apportionable Flow Calculations***

Under this option consumptive use for a subset of the largest licences issued by AEP would be included in the apportionable flow calculations. The reasoning behind this is that a relatively small number of the largest licences accounts for the majority of the consumptive use. For the purposes of this report data for the top 83 licences was provided by AEP. It will be assumed that this would be the subset utilized; however, the COH may elect to alter that to any number of licences as they see fit. This will not change the proposed method.

In order to estimate the net consumptive use volume to be applied to each year, it is suggested that the 35% estimate developed in Section 3.2.3 could be applied to the net licenced volume. This volume could then be distributed through the year based on the monthly distribution presented in Table 3-5. This would require AEP to provide updates from their licensing database from which the breakdown of net licenced volume by Industrial Activity and Specific Activity could be obtained. Periodically the reported use data would also need to be analyzed to update the estimate of the percent of the licenced volume actually being consumed.

The benefit of this option is that it would represent the impact of consumptive use based only on the top licences. The drawback to this option is that it does not account for all other smaller licences. It also assumes that the top net licenced volumes represent the actual top consumptive uses (i.e. some of the largest licences may only use a small fraction of their allocation, or even be dormant, whereas some of the smaller licences may use the majority of their allocation, but not be included at all).

c) ***Include the Estimated Consumptive Use for All Licences in the Apportionable Flow Calculations***

This option would apply the estimated 35% percent of net licenced use consumed against all the licences issued by AEP. The estimated use would then be distributed over the year based on the various activity categories as shown in Table 3-5. This would result in a higher estimate of consumptive use than option a) or b).

The advantage of including consumptive use in this manner is that all licences would be represented in the apportionable flow calculation without requiring any more data than that required for option b). One downside of this option is that applying the estimated percentage of net licenced use determined based on reported data from the top 83 licences may not be representative of the use by these smaller licences.

d) ***Include the Estimated Consumptive Use for a Subset of the Top Licences and the Net Licenced Use for the Remainder of the Licences in the Apportionable Flow Calculations***

Under this option the estimated consumptive use for a subset of the top licences issued by AEP would be calculated as in option b). The consumptive use for the remaining licences would be assumed to equal their net licenced use. These volumes would be distributed over the year, based on the patterns of use shown in Table 3-5. This option would result in the highest estimate of consumptive use of the four options presented.

The benefit of this option is that is does not rely on the percentage of net licenced use of the top licences to determine the use for the remaining smaller licences. The majority of the smaller licences fall into AEP's Registry classification which represents traditional agricultural uses, for which the 35% estimated use may not be appropriate.

Table 3-10 shows the estimated consumptive use for options a) through d) as described above, based on the information provided by AEP. Table 3-11 shows the average change in apportionable flows that would result from the application of the three options for the years 1979-2013. Note that as specified in Section 3.2.4 a number of licences were removed from the data set in consultation with AEP. As such, the volumes in Table 3-10 do not reconcile to the totals in Table 3-6, because those totals included all licences.

Table 3-10: Estimated monthly consumptive use in dam^3 for options a) through d). Options b) and d) are based on a subset of the top 83 licences being used for the estimate, although this number may be adjusted.

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total	Total as % of Average Annual Apportionable Flow
Option a)	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0%
Option b)	9435	9435	9435	9435	9435	9753	9753	9753	9753	9435	9435	9435	114492	1.7%
Option c)	10523	10523	10523	10523	10523	12363	12363	12363	12363	10523	10523	10523	133631	2.0%
Option d)	12542	12542	12542	12542	12542	17210	17210	17210	17210	12542	12542	12542	169174	2.5%

Table 3-11: Average change in apportionable flows from 1979-2013 with consumptive use included as described in options b), c) and d). Option a) would result in no change from the current procedure.

	% Difference Apportionable Flow with Option b)	% Difference Apportionable Flow with Option c)	% Difference Apportionable Flow with Option d)
Jan	30%	34%	40%
Feb	18%	20%	23%
Mar	7%	8%	9%
Apr	2%	2%	3%
May	4%	4%	5%
Jun	1%	1%	1%
Jul	3%	3%	4%
Aug	1%	1%	2%
Sep	2%	2%	3%
Oct	3%	4%	4%
Nov	5%	6%	7%
Dec	20%	23%	27%

It is recommended that option d) be incorporated into the apportionable flow calculations. As shown in Table 3-10, on an annual basis the difference in the consumptive use estimate between the various options compared to the average annual apportionable flow is minimal. The advantage of choosing option d) is that it presents the most conservative estimate and does not extend the estimated consumptive use pattern derived from the reported data for the larger licences into the unrelated licence categories that the smaller licences occupy.

3.5 Changes to Consumptive Use Over Time

3.5.1 Anticipated Future Consumptive Use Projects

There are currently no specific projects imminently anticipated, however, continued growth in industrial water demand in the North Saskatchewan River Basin in Alberta is expected in the future. In addition, continued development and population growth in the City of Edmonton and surrounding area may also lead to increased municipal water consumption.

One change in consumptive use that has recently been identified is the use of the City of Edmonton's treated waste water for industrial applications. In 2012 a portion of the city's return flow began being used by Suncor in one of its refineries. There is potential for this type of use to increase.

A plan has also been proposed for treated water from the Lloydminster water treatment plant to be distributed through a regional system serving neighbouring communities in Alberta. The City of Lloydminster raw water intake is located approximately 3 km upstream of the Hwy 17 Bridge and return flow to the river is via pipeline to an outfall located approximately 3 km downstream of Hwy 17. Both locations are upstream of the recorded flow station at Deer Creek. The City of Lloydminster municipal licence is included in the top 83 licences used to estimate consumptive use in Alberta.

3.5.2 Future Consumptive Use Scenarios – Impact on Apportionable Flow

To explore the impact of increasing consumptive use in the Alberta portion of the NSRB on apportionable flows at the Alberta/Saskatchewan boundary scenarios of increased consumptive use were investigated. This analysis is somewhat limited because it is based on assessing future increased consumptive use against historical apportionable flows and does not reflect how the increased use levels might interplay with future changes in river hydrology that might occur over time. Table 3-12 shows the impact of an increase in consumptive use of 10% and 25%, over the estimated consumptive use calculated using method d), relative to the apportionable flow record from 1979 to 2013. It appears that increases in that range would not have a significant impact on the annual apportionable flow value.

3.5.3 Procedure for Updating Consumptive Uses in Apportionable Flow Calculations

Apportionable flows are currently calculated annually for the North Saskatchewan River. As part of the data collected to feed into these calculations, it is recommended that AEP provide an annual update of the total net licenced volume (i.e. total volume of water that has been allocated under licences issued by the province). In addition, AEP would also supply occasional updates of the reported net consumptive use volume (i.e. the volume of water reported as actually consumed by licenced users). This information would be used to track any changes in consumption that would require an increase or decrease to the assumed actual consumptive use percentage (i.e. the 35% value as recommended for current conditions). The data could also be used to check in on the monthly distribution pattern to determine if changes have occurred that would require adjustment to the values listed in Table 3-5.

Table 3-12: Effect of increases of 10 and 25% in consumptive use as a percent of the apportionable flow for 1979-2013.

Year	Apportionable Flow	Estimated 10% Increase in Consumptive Use as a % of Apportionable Flow	Estimated 25% Increase in Consumptive Use as a % of Apportionable Flow
1979	5,440,000	2.8%	3.2%
1980	8,230,000	1.9%	2.1%
1981	7,800,000	2.0%	2.2%
1982	7,470,000	2.1%	2.3%
1983	5,640,000	2.7%	3.1%
1984	4,960,000	3.1%	3.5%
1985	5,750,000	2.7%	3.0%
1986	8,930,000	1.7%	2.0%
1987	5,360,000	2.9%	3.3%
1988	4,710,000	3.3%	3.7%
1989	7,290,000	2.1%	2.4%
1990	8,950,000	1.7%	2.0%
1991	8,320,000	1.8%	2.1%
1992	5,480,000	2.8%	3.2%
1993	6,360,000	2.4%	2.7%
1994	5,930,000	2.6%	2.9%
1995	7,430,000	2.1%	2.3%
1996	6,910,000	2.2%	2.5%
1997	7,090,000	2.2%	2.5%
1998	7,650,000	2.0%	2.3%
1999	8,280,000	1.9%	2.1%
2000	5,750,000	2.7%	3.0%
2001	4,710,000	3.3%	3.7%
2002	4,840,000	3.2%	3.6%
2003	6,030,000	2.5%	2.9%
2004	5,780,000	2.7%	3.0%
2005	9,520,000	1.6%	1.8%
2006	5,490,000	2.8%	3.2%
2007	7,680,000	2.0%	2.3%
2008	6,910,000	2.2%	2.5%
2009	4,580,000	3.4%	3.8%
2010	5,990,000	2.6%	2.9%
2011	8,450,000	1.8%	2.1%
2012	7,860,000	2.0%	2.2%
2013	8,200,000	1.9%	2.1%

3.6 Summary of Recommendations

In summary, the recommendations for accounting for consumptive uses in the North Saskatchewan River apportionable flow calculations are as follows:

- Storage in Lake Abraham and Brazeau Reservoir will be included in the calculations, as is currently the case.
- Other estimated consumptive uses will be incorporated into the calculations. For a subset of the largest AEP water use licences the estimated consumptive use will be based on a percentage of the net licenced use determined from analysis of reported use data. Within this report the number of licences included in this group has been 83, based on the recommendation of AEP, although this number can be changed at the discretion of the COH. An appropriate estimate of consumptive use is proposed to be 35% of the net licenced use. The remaining water use licences will be included in the apportionable flow calculation procedure based on their net licenced use.
- Annual consumptive use volume estimates will be distributed throughout the year based on the activity category associated with each licence.
- The consumptive use estimates used in the apportionable flow calculation should be updated at the discretion of the COH when new information becomes available (e.g. if significant new licences are issued by AEP).

4. Reservoir Evaporation

4.1 Reservoir Evaporation in Current Apportionable Flow Calculation Procedures

The storage of water in reservoirs affects the water balance of a basin through evaporation from the reservoir water surface area. The current apportionable flow calculations do not include consideration of evaporation from Lake Abraham and Brazeau Reservoir. The 1975 PPWB Natural Flow report provides the following support to this decision:

- The mean annual water loss due to evapotranspiration from a natural area in the region of the reservoirs (Marmot Creek experimental watershed) was estimated to be 17 inches (~430 mm).
- The mean gross annual evaporation loss from the reservoirs calculated with the Meyer formula was estimated to be between 20 and 25 inches (~510 to 640 mm).
- Based on those estimates, the mean annual loss was assumed to be between three and eight inches (~80-200 mm).
- The water surface area covered by each of the two reservoirs was approximated as 10,000 acres (~40 km^2). Six inches of evaporation over a surface area of that size would be equivalent to a daily flow of 15 cfs (0.42 cms) spread over the entire year.
- The report concluded that, even in the hot summer months, the monthly evaporation loss would amount to less than one percent of the natural flow in the North Saskatchewan River.

4.2 Review of Methods to Account for Reservoir Evaporation

4.2.1 Summary of Reservoir Evaporation Study

As a precursor to the basin review process the COH requested that a study be completed on the evaporation losses from Lake Abraham and the Brazeau Reservoir. Environment Canada Meteorological Services (MSC) Division issued the report 'Evaluation of Lake Evaporation in the North Saskatchewan River Basin' (Liu et al., 2014). The report documents development of a model for estimating evaporation in the North Saskatchewan River Basin and application of the model to estimate the precipitation – evaporation balance for Lake Abraham and Brazeau Reservoir for the portion of the historical record with sufficient data available.

The following 11 evaporation calculation methodologies were investigated for use in the North Saskatchewan River Basin:

- Meyer
- PRFA Modified Meyer
- Penman (mass transfer component)
- Priestly Taylor
- Alberta Irrigation Modified Priestly Taylor

- Abtew
- Hargreaves and Samani
- Penman (radiation component)
- Penman (combined)
- Water Survey of Canada (WSC) Modified Penman
- Morton

The comparison was based on calculations using MSC station data and bias-corrected North American Regional Reanalysis data. For Brazeau Reservoir, the required data was available for the period from 1979-2010 (32 years). For Lake Abraham only ten years of data coverage, from 2001-2010, was available. Further information on the data utilized in the evaporation calculations can be obtained from the Liu et al. (2014) report.

A large spread was found between the evaporation results using the various calculation methods. Of those listed above, several have been utilized by other studies for estimating evaporation from lakes on the Canadian Prairies, these are the PFRA-Modified Meyer, the Morton and the WSC-Modified Penman methods. Without access to direct evaporation measurements for model validation, the study compared the results of the various models and assessed how closely the results matched.

From the 11 methods tested, a suite of six models was found to produce similar results; these models included the three noted to be suitable for use on the Prairies. These seven models were:

- PFRA Modified Meyer ($E_{MYR\text{-}PFRA}$)
- Penman (E_{PM})
- Alberta Irrigation Modified Priestley Taylor ($E_{PT\text{-}AI}$)
- Hargreaves and Samani (E_{HS})
- WSC Modified Penman ($E_{PM\text{-}WSC}$)
- Morton (E_{MOT})

The evaporation estimates from this selection of models are shown in Figures 4-1 and 4-2 for the Brazeau Reservoir and Lake Abraham, respectively.

The results of these methods were selected for input to an Ensemble Estimation System (EES) for Brazeau Reservoir and Lake Abraham. The EES mean annual evaporation at Brazeau Reservoir was found to be 580 mm with an uncertainty of less than +/- 75 mm. The ensemble EES mean annual evaporation at Lake Abraham was found to be about 545 mm with an uncertainty of about +/- 75 mm.

Figure 4-3 and 4-4 show the mean monthly distribution of evaporation for Brazeau Reservoir and Lake Abraham, respectively. Both locations present similar patterns with evaporation peaking in July and at its lowest through December and January.

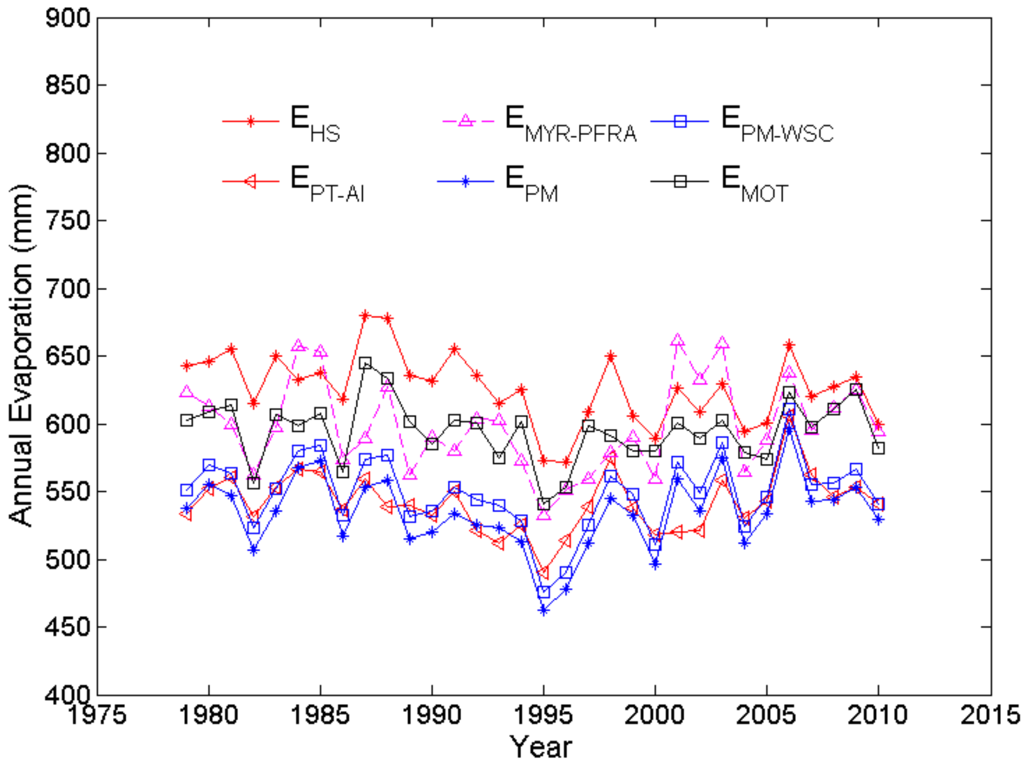

Figure 4-1: Estimates of annual evaporation over Brazeau Reservoir using methods included in the EES (figure from Liu et al., 2014).

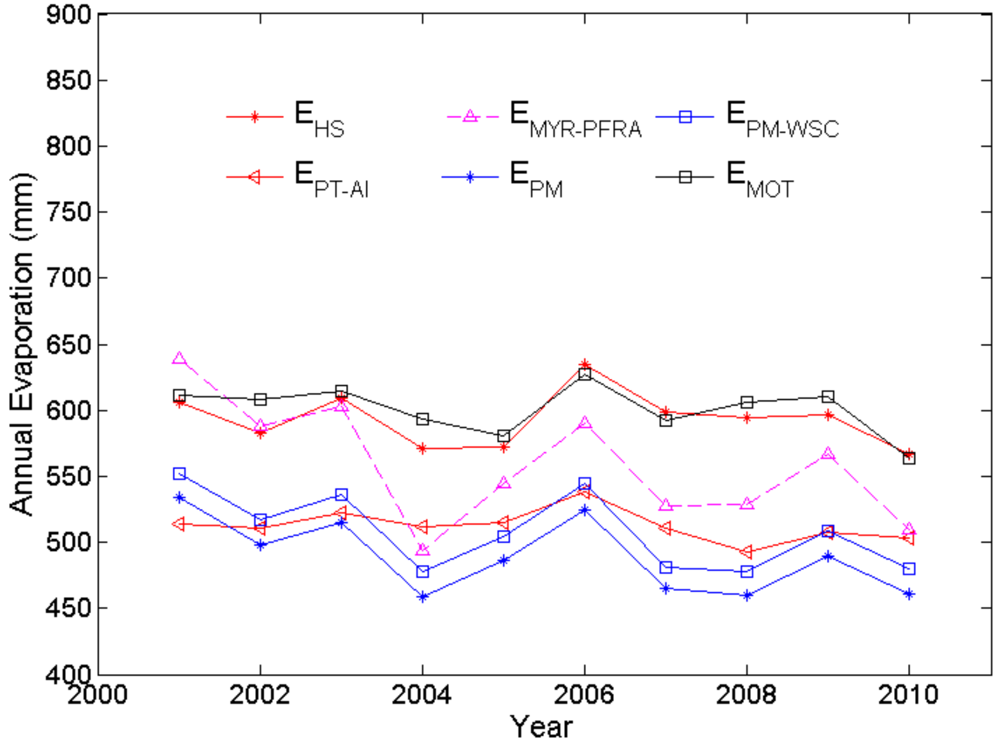

Figure 4-2: Estimates of annual evaporation over Lake Abraham using methods included in the EES (figure from Liu et al., 2014).

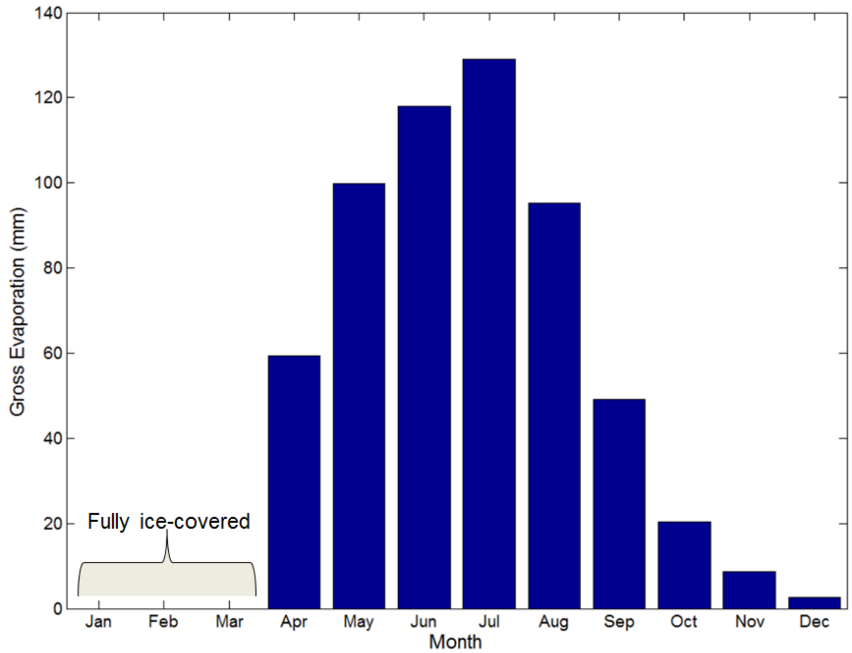

Figure 4-3: Estimated mean monthly evaporation at Brazeau Reservoir for the period from 2001-2010.

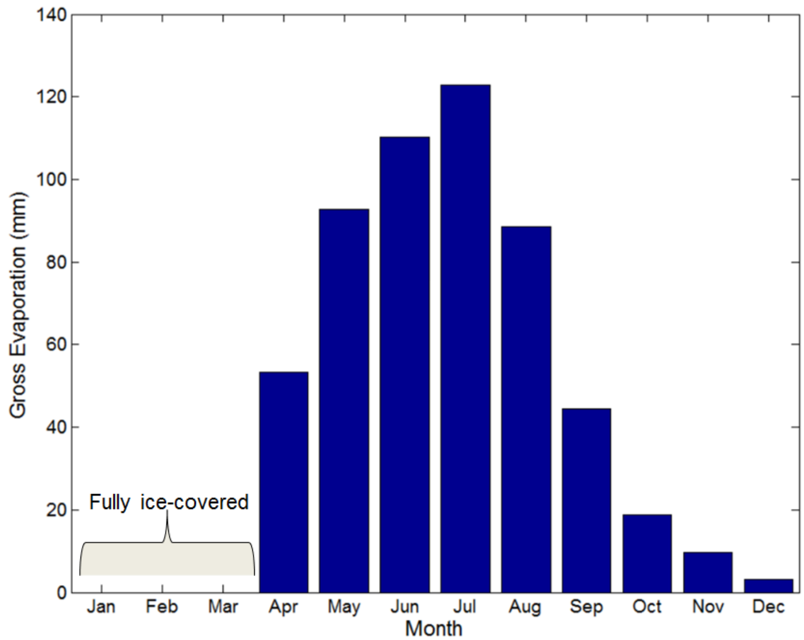

Figure 4-4: Estimated mean monthly evaporation at Lake Abraham for the period from 2001-2010.

The following recommendations for calculating lake evaporation in the North Saskatchewan River Basin are taken directly from the Liu et al. (2014) study report:

1) If all the required input data are available, the ensemble approach is recommended.
2) If both radiation and routine meteorological observation data are available, the WSC-Penman model is recommended.
3) If only routine meteorological observation data are available, such as air temperature, wind speed, and dew point temperature, the PFRA-modified Meyer model is recommended.
4) If wind speed data are missing or cannot represent the station conditions, but if radiation data is available, the Morton model is recommended.
5) If only radiation data and air temperature data are available, the Alberta Irrigation modified Priestley Taylor model is recommended.

Figures 4-5 and 4-6 show the net evaporation minimum, maximum and mean values for the available periods of record for Brazeau Reservoir and Lake Abraham. Based on the ensemble mean model and the period of data available for Brazeau Reservoir and Lake Abraham the Liu et al. (2014) study estimated the annual net evaporation at both sites to be about 150 to 200 mm for a typical dry year and about -100 to -150 mm for a typical wet year. Based on the common period 2001 – 2010, the mean annual net evaporation for Brazeau Reservoir was found to be about 94 mm and about 46 mm for Lake Abraham.

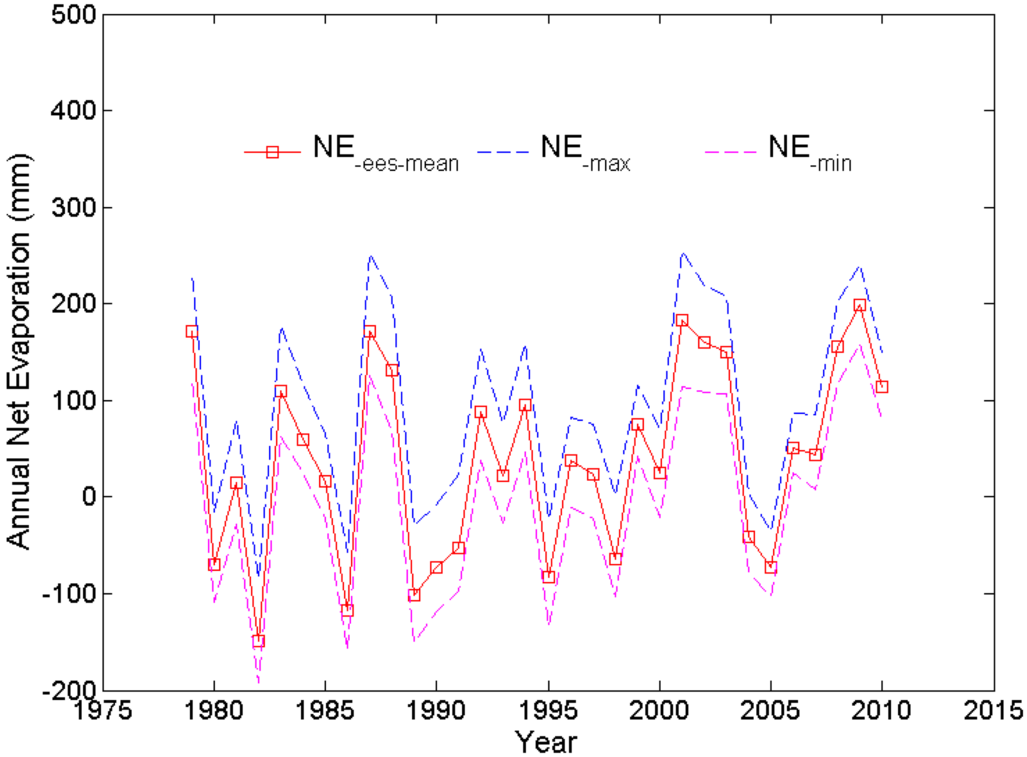

Figure 4-5: Minimum, maximum and EES mean annual net evaporation for Brazeau Reservoir (figure from Liu et al., 2014).

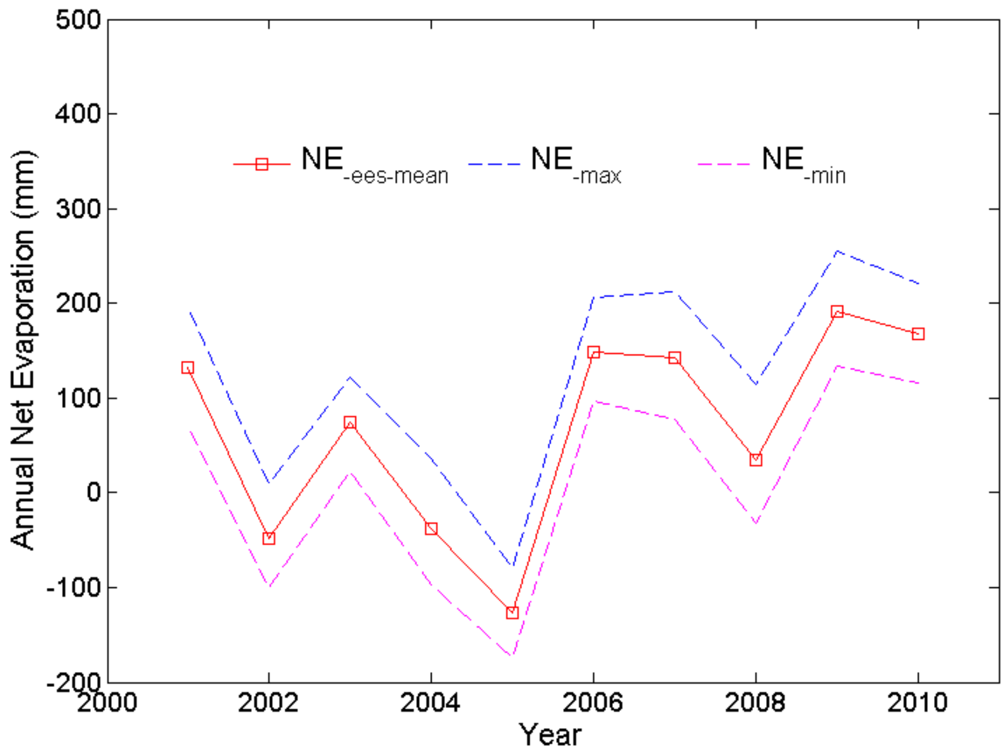

Figure 4-6: Minimum, maximum and EES mean annual net evaporation for Lake Abraham (figure from Liu et al., 2014).

4.2.2 Reservoir Evaporation Estimates

The net evaporation values calculated by Liu et al. (2014) were used to assess the impact of evaporation at Brazeau Reservoir and Lake Abraham on the flow in the North Saskatchewan River at the apportionment point at Deer Creek, Saskatchewan. First the recorded month end water levels at each of the reservoirs were translated to surface areas using information supplied by AEP, then the monthly net evaporation estimates from the Liu et al. (2014) study were used to calculate the net evaporative volume loss (or gain). Figure 4-7 shows the stage-area relationships for each of the reservoirs. The equations used are shown below and are the same as those used in AEP's North Saskatchewan River natural flow model.

Brazeau Reservoir (WL>947.92m)

$$Area = 0.049314\ (WL_{Brazeau} - 947.92)^2 + 0.32672(WL_{Brazeau} - 947.92) + 0.19084(WL_{Brazeau} - 906.0) + 8.197683$$

$$where\ WL_{Brazeau}\ is\ the\ water\ surface\ elevation\ of\ Brazeau\ Reservoir\ in\ m\ and\ Area\ is\ in\ km^2.$$

Lake Abraham

$$Area = -3.892\ x\ 10^{-5}\ (WL_{Abraham} - 1234.44)^3 + 0.01107(WL_{Abraham} - 1234.44)^2 - 0.03129(WL_{Abraham} - 1234.44)$$

$$where\ WL_{Abraham}\ is\ the\ water\ surface\ elevation\ of\ Lake\ Abraham\ in\ m\ and\ Area\ is\ in\ km^2.$$

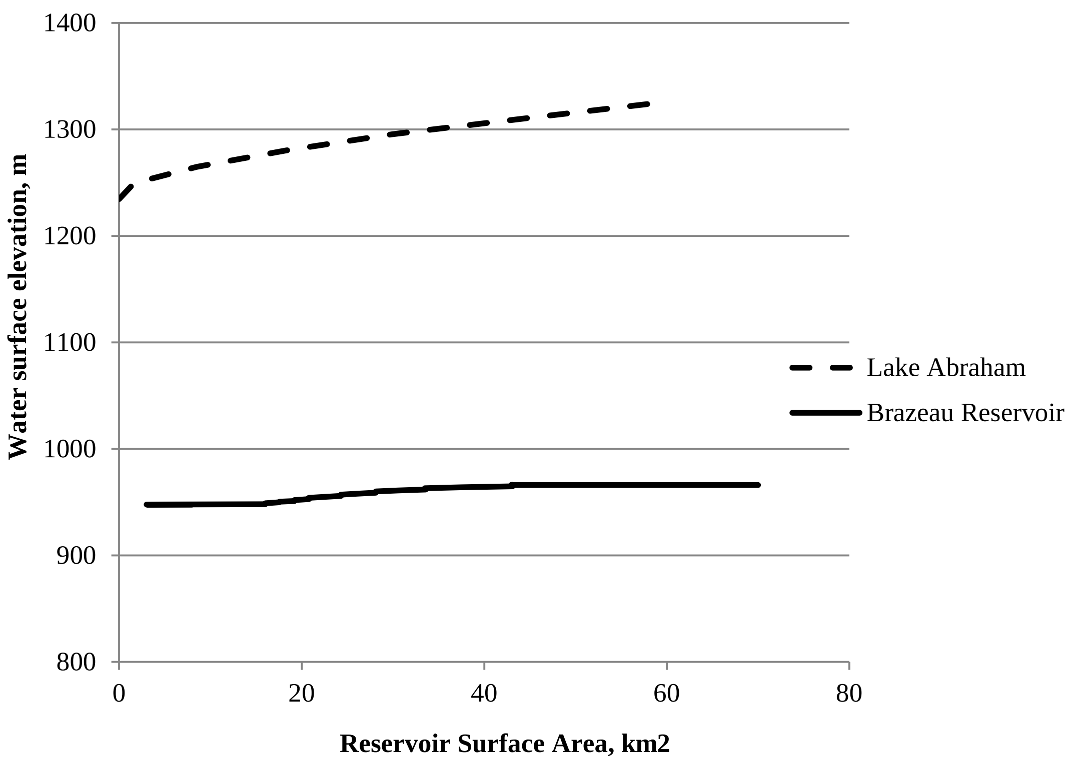

Figure 4-7: Stage-Area curves for Brazeau Reservoir and Lake Abraham.

When calculated on an annual basis (based on mean annual reservoir surface area), net evaporation was found to be very small in terms of the recorded flow at Deer Creek. The total annual net evaporation volumes from Brazeau Reservoir and Lake Abraham are shown in Figures 4-8 and 4-9, respectively. Figures 4-10 and 4-11 show these volumes as a percentage of recorded flow at Deer Creek. For Brazeau Reservoir, the total annual net evaporation (not routed) for the thirty two years of comparison (1979-2010) ranged from -0.06% (1982) to 0.13%

(2001) of the annual volume measured at Deer Creek. For Lake Abraham, the total annual net evaporation (not routed) for the ten years of comparison (2001-2010) ranged from -0.05% (2005) to 0.18% (2009) of the annual volume measured at Deer Creek.

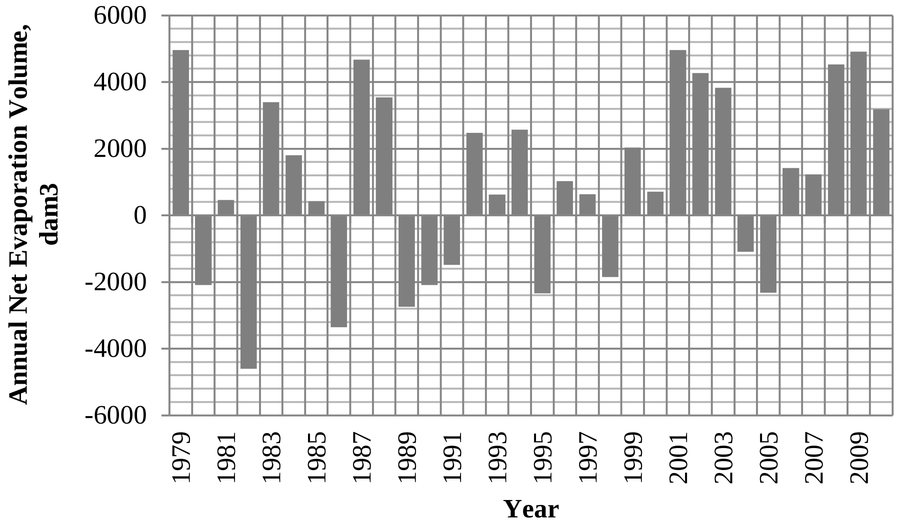

Figure 4-8: Annual net evaporation volume (dam^3) for Brazeau Reservoir from 1979-2010. Net evaporation data from Liu et al. (2014).

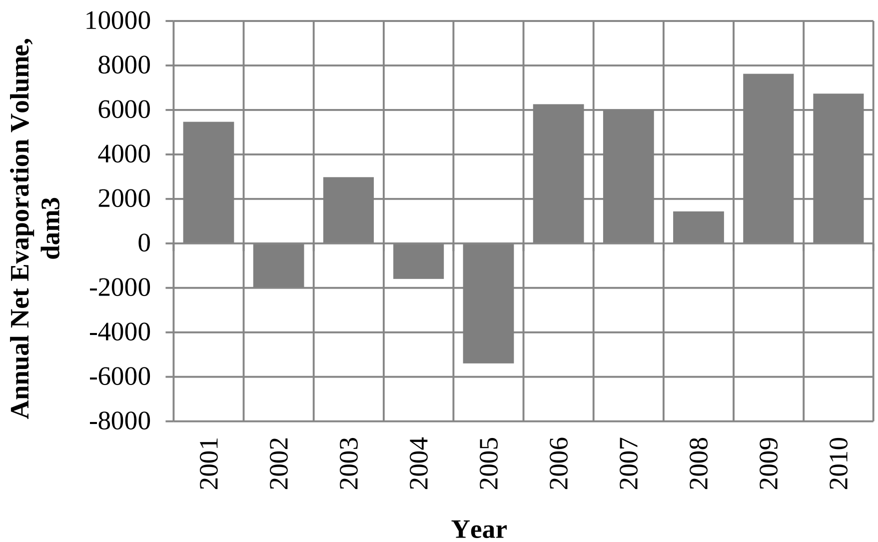

Figure 4-9: Annual net evaporation volume (dam^3) for Lake Abraham from 2001-2010. Net evaporation data from Liu et al. (2014).

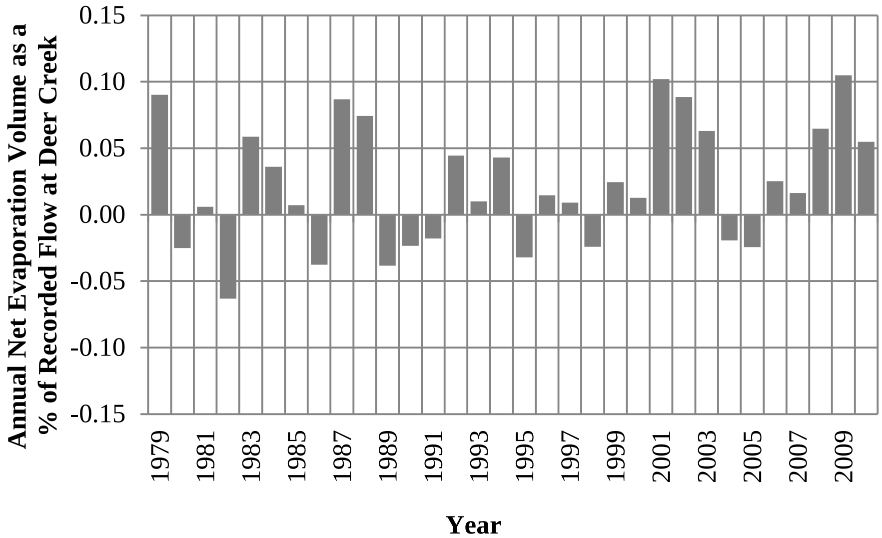

Figure 4-10: Annual net evaporation at Brazeau Reservoir as a percentage of recorded flow at Deer Creek for 1979-2010. Net evaporation data from Liu et al. (2014).

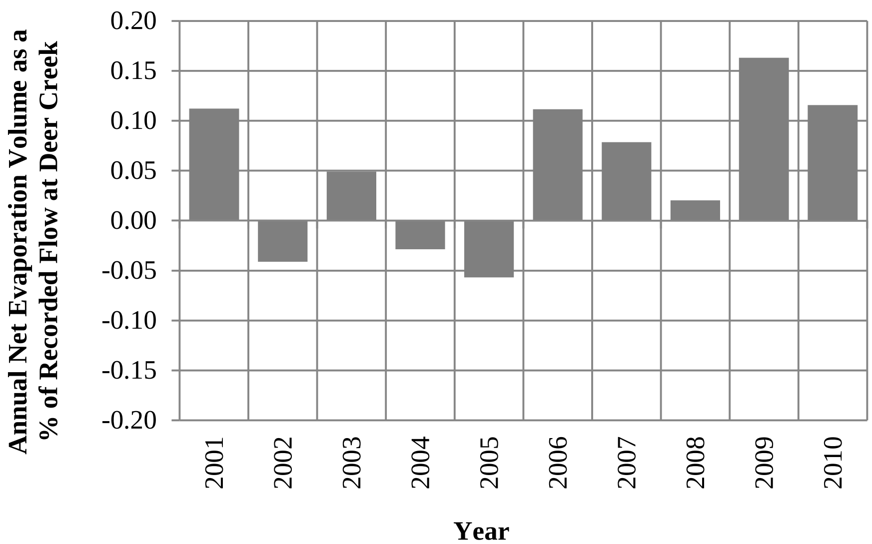

Figure 4-11: Annual net evaporation at Lake Abraham as a percentage of recorded flow at Deer Creek for 2001-2010. Net evaporation data from Liu et al. (2014).

4.3 Impact of Reservoir Evaporation on Apportionable Flow

The net evaporation data was used to calculate the apportionable flows if evaporation were to be considered within the current calculation procedure.

In areas where ice cover is present for a portion of the year, evaporation during the winter months is typically assumed to resemble the natural state and, therefore, adjustments to account for evaporation are limited to only the ice free period. For example, the apportionable flow calculations for the Saskatchewan River at the Saskatchewan Manitoba boundary include evaporative losses from Lake Diefenbaker and Tobin Lake only during the period from May through to the end of November. Although the ice free period for Brazeau Reservoir and Lake Abraham may start earlier in the fall and extend later into the spring due to their geographic location, no information regarding ice cover dates was found to be available. As a result, the May through November time period was adopted in order to conservatively account for evaporation losses.

Figure 4-12 and 4-13 show the total seasonal (May-November) net evaporation at each of the two reservoirs for their respective years of record. In Figures 4-14 and 4-15 the net evaporation is broken down into monthly mean values to show the typical variability over the year.

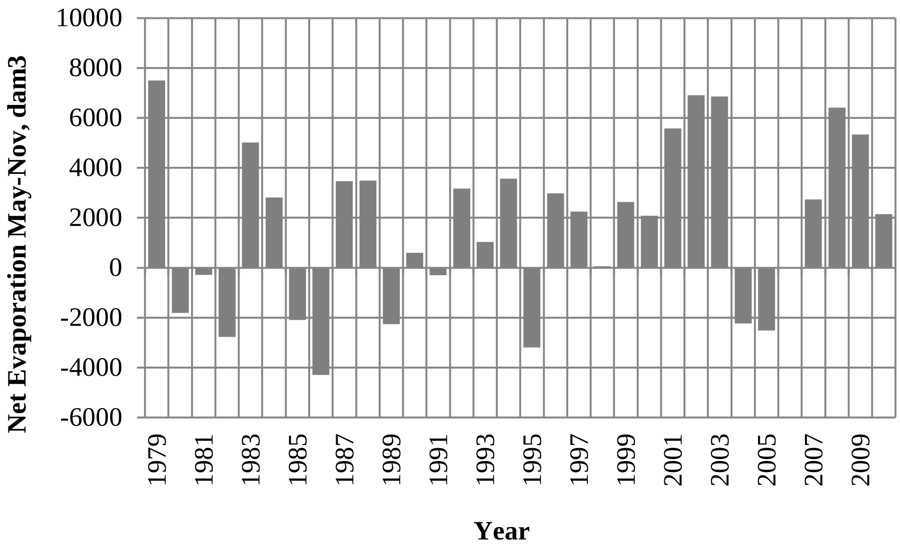

Figure 4-12: Net evaporation volume from Brazeau Reservoir for period from May through November for 1979-2010. Net evaporation data from Liu et al. (2014).

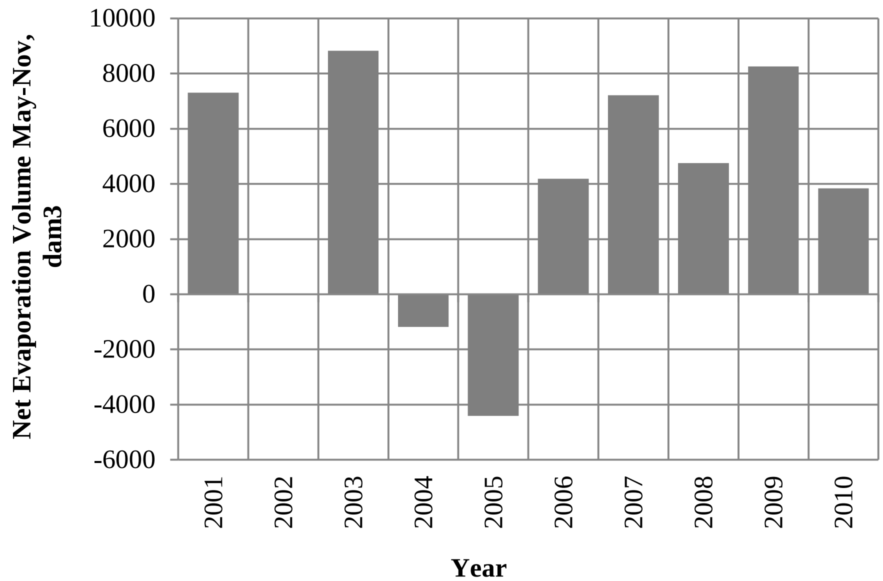

Figure 4-13: Net evaporation from Lake Abraham for period from May through November for 2001-2010. Net evaporation data from Liu et al. (2014).

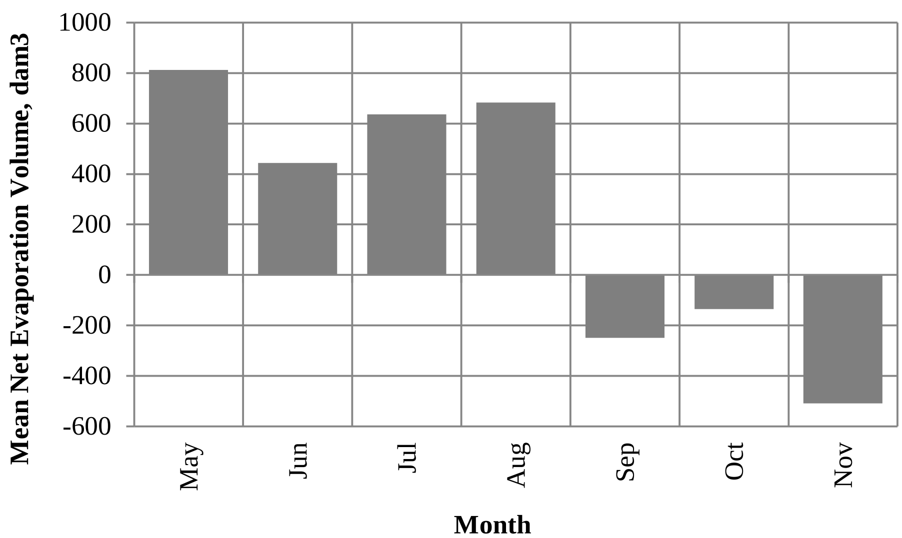

Figure 4-14: Mean monthly net evaporation volume from Brazeau Reservoir for ice-free season based on 1979-2010. Net evaporation data from Liu et al. (2014).

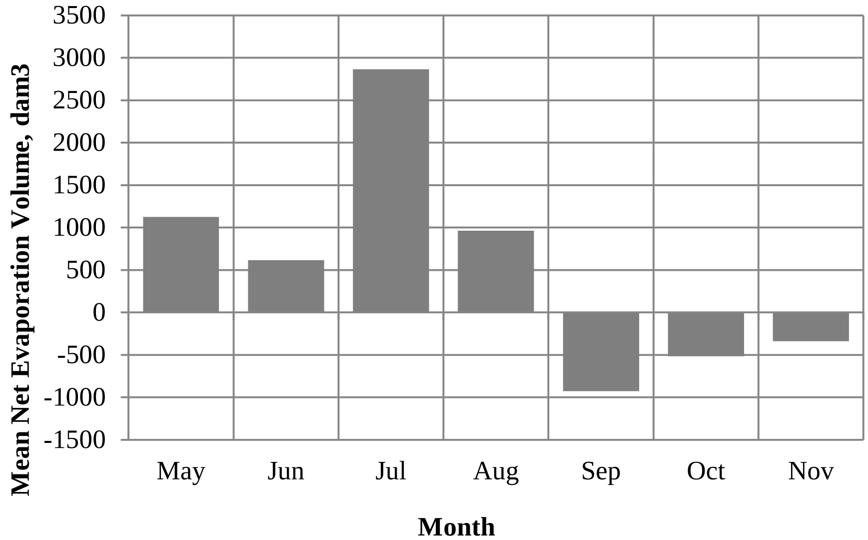

Figure 4-15: Mean monthly net evaporation volume from Lake Abraham for ice-free season based on 2001-2010. Net evaporation data from Liu et al. (2014).

The routing equations used in the FORTRAN program (Section 2.2.1) were used to transfer the revised monthly change in storage at each of the reservoirs downstream to the apportionment point at Deer Creek.

The apportionable flows were calculated from 2001 to 2009, the period for which complete evaporation data were available for both reservoirs (precipitation data was not available for Lake Abraham for 2010). The results, in terms of the difference in apportionable flows with and without net evaporation considered, are shown as volumes in Table 4-3. In seven of the nine years the inclusion of net evaporation in the calculations resulted in an increase in the annual total apportionable flow. The average increase in apportionable flow resulting from net evaporation from the two reservoirs for the period from 2001-2009 is 6670 dam^3.

Table 4-1: Difference in apportionable flow calculated with net evaporation vs. without in units of dam^3.

	2001	2002	2003	2004	2005	2006	2007	2008	2009
Jan									
Feb									
Mar									
Apr									
May	4015	1468	1968	-479	2429	2591	897	456	2300
Jun	1027	6613	2696	2268	-6525	2161	560	356	3618
Jul	119	3306	6309	3979	2491	5666	8014	2558	3260
Aug	6660	-929	5512	-1879	640	2375	503	4140	3140
Sep	3385	-2079	1395	-3446	-3984	-4505	-219	1215	2393
Oct	-899	-1646	-960	-2884	-601	-2812	715	1634	-808
Nov	-1233	82	-1061	-885	-1150	-1145	-419	721	-296
Dec	-184	66	-4128	-93	-223	-137	-105	83	-20
Total	12890	6882	11732	-3419	-6925	4194	9945	11164	13588

4.4 Options for Accounting for Reservoir Evaporation in Apportionable Flow Calculations

The following options are available in terms of reservoir evaporation in the North Saskatchewan River apportionable flow calculation procedures:

a) Do Not Include Reservoir Evaporation in Apportionable Flow Calculations

Under this scenario, the apportionable flow calculations would be completed disregarding the impact of evaporation from the reservoirs. This is the current practice in the approved apportionable flow calculations for the North Saskatchewan River.

The advantage of this is that no meteorological data is required to support the evaporation calculations. The basis of this simplification is that the effect of reservoir evaporation on the apportionable flow results is minimal.

Comparing the total annual volumes associated with reservoir evaporation (Table 4-3) to the consumptive use volumes discussed in Section 3 and listed in Appendix 2, it is apparent that reservoir net evaporation is not negligible when considered in the broader context of water use in the basin. In drier years, the total annual reservoir evaporation loss would place relatively high on the list, for example, in 2001, 2008 and 2009 evaporation would place 2nd in terms of consumptive use (based on a 35% estimated use of the net licenced volume for consumptive use licences).

b) Include Reservoir Evaporation Based on Static Monthly Net Evaporation

Under this scenario, reservoir evaporation would be included in the apportionable flow calculations based on historic average monthly net evaporation (mm) which would remain constant from year to year, unless updated. These net evaporation values would be used along with the reservoir surface area (calculated based on recorded reservoir level) to determine the net evaporation volume.

Alternatively, evaporation losses could be included in the apportionable flow based on historic average net evaporation losses (dam^3), such as those shown in Figure 4-14 and 4-15. This would further simplify the inclusion of evaporation in the apportionable flow calculation.

The benefits of these options are that reservoir evaporation would be included in the calculations, without requiring additional data on an annual basis. The reservoir net evaporation estimates could be updated from time to time as deemed necessary by the COH.

The drawback to these options would be that, as shown in Figure 4-12 and 4-13, there is a significant variation in net evaporation from year to year which would not be captured.

c) Include Reservoir Evaporation Based on a Static Estimated Monthly Gross Evaporation in Combination with Recorded Precipitation Data

This option would see reservoir evaporation included in the apportionable flow calculations based on monthly net evaporation values calculated from historic average estimated gross evaporation and annual recorded precipitation values. Over the long term the mean gross evaporation values are relatively constant, whereas there is greater variability in precipitation from year to year. Estimation of open water evaporation also requires more extensive data collection, whereas precipitation is a single measurement. Table 4-2 illustrates the variability in gross evaporation and precipitation values for the two reservoirs from the Liu et al. (2014) evaporation study.

The advantage of this option would be that it would allow reservoir evaporation to be included in the apportionable flow calculations with a minimal increase in data requirements. The evaporation estimates based on this methodology would be significantly more accurate than option b (applying the static estimated net evaporation). The gross evaporation estimates could be updated over time as deemed necessary by the COH.

The drawback to this option is that it is less accurate than using gross evaporation values calculated from recorded meteorological data.

Table 4-2: Average, maximum and minimum values of gross evaporation and precipitation for Lake Abraham and Brazeau Reservoir. From the Liu et al. (2014) evaporation study.

		Gross Evaporation, mm	Precipitation, mm
Lake Abraham (2001-2010)	Minimum	514	346
	Average	544	476
	Maximum	577	660
Brazeau Reservoir (1979-2010)	Minimum	512	394
	Average	574	534
	Maximum	622	699

d) Include Reservoir Evaporation Based on Calculated Net Evaporation

This alternative would utilize recorded meteorological data to calculate actual monthly net evaporation values for each of the two reservoirs which would then be used in the apportionable flow calculations. The advantage of this option is that it presents the greatest accuracy. The drawback is that it has the highest level of meteorological data requirements.

4.5 Summary of Recommendations

In summary, the findings of the report by Liu et al. (2014) were used to estimate evaporation from Lake Abraham and the Brazeau Reservoir over select periods of record.

Four options for the consideration of evaporation in the PPWB apportionable flow calculations were reviewed. It is recommended that option c), calculation of monthly net evaporation based on average gross evaporation and recorded precipitation data, be incorporated into the calculation procedure. Utilizing this method presents the best balance between achieving the desired accuracy while requiring only minimal additional data.

5. Routing Adjustments for Consumptive Use Projects

5.1 Documented Routing Adjustment Method

Lake Abraham and the Brazeau Reservoir, which are located in the upstream end of the NSRB, are currently the only consumptive uses included in the apportionable flow calculation. Because of their location and size, withdrawals (i.e. storage) and releases are adjusted for travel time before they are added to the recorded flow at Deer Creek. As described in Section 2.1, the 1975 PPWB Natural Flow report provides equations to calculate the travel time from each of the two reservoirs in the North Saskatchewan River Basin to the apportionment point at Deer Creek near the Alberta/Saskatchewan Boundary.

According to this method, the travel times are computed based on recorded flow over the last five days of each month at the stations North Saskatchewan River near Rocky Mountain House (05DC001) and North Saskatchewan River at Edmonton (05DF001) using Equations 2-1 and 2-2. The change in storage at each reservoir during their respective travel times is then calculated and carried over to the following month.

5.2 FORTRAN Program Routing Adjustment Method

As noted in Section 2.2.1, the FORTRAN program currently in use to calculate apportionable flows for the North Saskatchewan River does not utilize the routing method described in the 1975 PPWB report. It is believed that this change in routing method took place sometime around 1992. Attempts were made to locate information documenting this adjustment (e.g. meeting minutes, reports etc.); however, nothing was uncovered.

The equations used in the FORTRAN apportionable flow computation were provided in Section 2 as Equations 2-3 and 2-4. These equations calculate a routed change in storage value for each month based on a static ratio of the current and previous month's change in storage at each reservoir. It is assumed that these equations were devised to simplify the calculation procedure and to reduce the number of gauging sites required for the apportionable flow calculations during the 1990's.

In order to test this hypothesis the routing equations from the 1975 Natural Flow report were used to compute average monthly routing adjustments for the period from 1975 to 1992. These average values were found to be almost exactly equivalent to the equations used in the FORTRAN program. Applying these ratios is essentially equivalent to travel times of just over 5 days for Lake Abraham and just over 4 days for Brazeau Reservoir, as shown in Table 5-1.

Table 5-1: Number of days of reservoir storage carried over to account for travel time in FORTRAN methodology.

	Number of Days in Month		
	28 days	30 days	31 days
Lake Abraham	4.8	5.2	5.3
Brazeau Reservoir	3.8	4.1	4.2

The routing adjustments used in the 1975 PPWB method, as well as the FORTRAN program method, were calculated and compared for 2008 to 2010. For Lake Abraham the period of comparison is limited to the open water season, due to the fact that the hydrometric station 'North Saskatchewan River near Rocky Mountain House' (05DC001) has been operated seasonally since 1973. The results are shown in Figures 5-1 and 5-2.

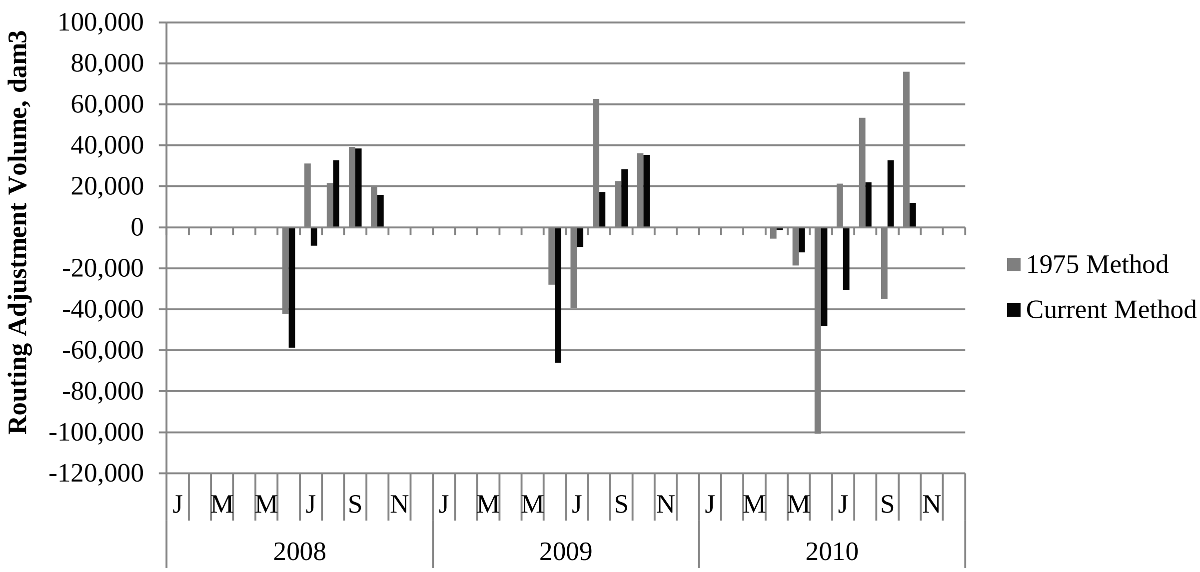

Figure 5-1: Comparison of Lake Abraham routing adjustment volumes between the 1975 PPWB method and the FORTRAN program method.

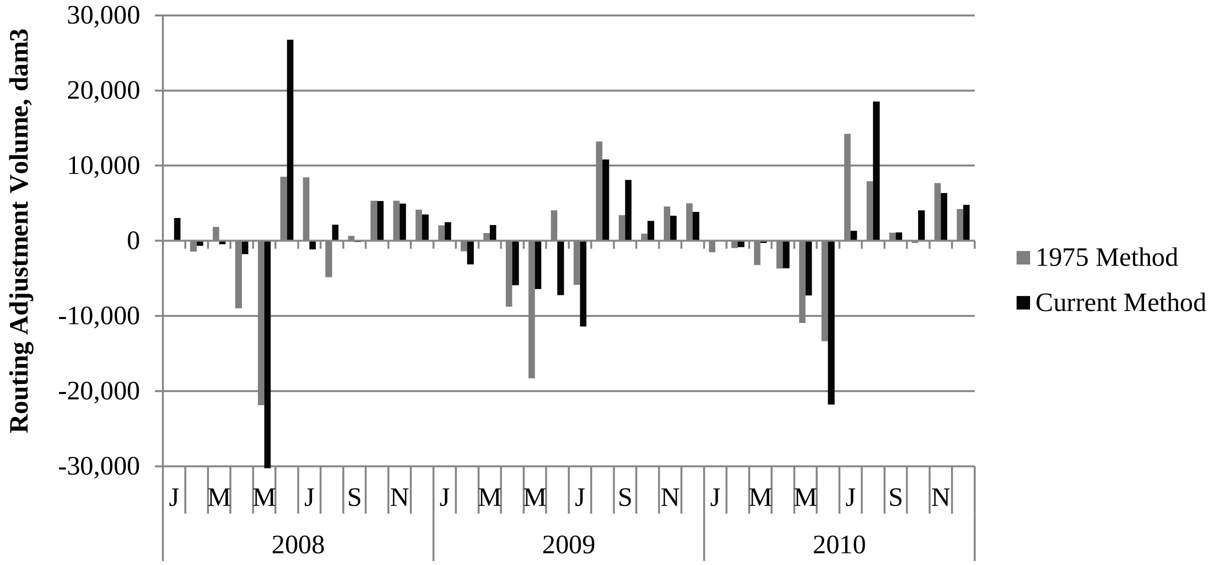

Figure 5-2: Comparison of Brazeau Reservoir routing adjustment volumes between the 1975 PPWB method and the FORTRAN program method.

From the results it is clear that the discrepancy between the two methods varies from month to month. The greatest discrepancies are attributed to months where the change in storage was significantly different at the end of the month compared to the average over the whole month. For any given month the routing adjustment is dependent on both its own month end, which is subtracted from the total change in storage, as well as the activity during the previous month's end, which is added to it. For example, for Lake Abraham Fall 2010 stands out in Figure 5-1 as having large discrepancies in routing adjustment volumes between the two methods. The reservoir elevations for Lake Abraham for September and October 2010 are shown in Figure 5-3 as an illustration of the difference that occurs between the two methods as a result of using the change in volume at the months end versus the monthly average.

When considering the accuracy of the routing methodology it should be noted that, though apportionable volumes are calculated and reported as monthly values, the apportionment for the North Saskatchewan River is determined on annual basis. On an annual basis routing adjustment makes little difference to the apportionable flow.

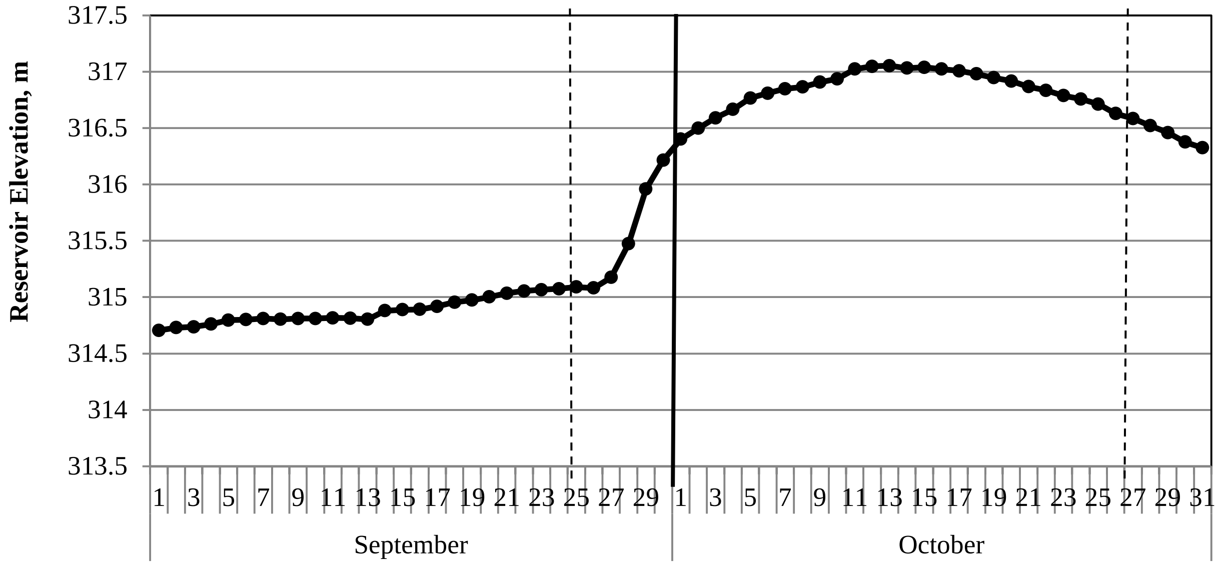

Figure 5-3: Lake Abraham elevations for September and October 2010. In these two months the average daily change in storage is not representative of the change in storage at the end of the month.

5.3 Investigation of Actual Travel Times Along the North Saskatchewan River

To assess the validity of the two available routing methods it was necessary to attempt to estimate the travel time between Lake Abraham and Brazeau Reservoir and the apportionment point at Deer Creek. This section describes the process undertaken to do that and the resulting conclusion.

5.3.1 Comparison of Mean Daily Flow Records

In order to estimate the travel times along the North Saskatchewan River the mean daily flows for various hydrometric stations were used to estimate how long flows at each station take to reach the downstream station. The segments investigated are listed in Table 5-2 along with the approximate distance between stations. Details of each of the station-to-station comparisons are provided in Appendix 3.

Travel times of four to seven days were found to be likely between Bighorn Dam and Deer Creek. Similarly, travel times of three to six days were found between Brazeau Dam and Deer Creek. As the summary in Table 5-2 shows, the travel time is most significantly dependent on the time required to travel the section between Edmonton and Deer Creek. These travel times agree well with travel times calculated using the 1975 PPWB routing method for the period from 1976 to 2010. The travel times calculated using that method are shown in Table 5-3.

Table 5-2: Estimated travel times for various segments of the North Saskatchewan River.

Station From	Station To	Period of Data Compared	Distance Between Stations**	Approximate Time for Change in Flow to be Reflected at Downstream Station
North Saskatchewan River below Bighorn Plant (05DC010)	North Saskatchewan River near Rocky Mountain House (05DC001)	1975-2010	127 km	<~150 m^3/s =1day >~150 m^3/s = same day
North Saskatchewan River near Rocky Mountain House (05DC001)	North Saskatchewan River near Lodgepole (05DE006, level only)	1978-2010	96 km	<~100 m^3/s = 1 day >~100 m^3/s = same day
Brazeau River below Brazeau Plant (05DD005)	North Saskatchewan River near Lodgepole (05DE006, level only)	1978-2010	34 km	All flow rates = same day
North Saskatchewan River near Lodgepole (05DE006, level only)	North Saskatchewan River at Edmonton (05DF001)	1978-2010	203 km	<~2.7 m = 2 days >~2.7 m = 1 day
North Saskatchewan River at Edmonton (05DF001)	North Saskatchewan River near Deer Creek (05EF001)	1981-2010	375 km	<200 m3/s = 4+ days 200-500 m^3/s = 3 days >500 m^3/s = 2 days

*Note: Each day represents any portion of that 24 hour period, e.g. 2 days may be anywhere in the period from 24-48 hours, etc. ** Distances from PFRA Report #95: Report on Determination of River Distances For the Saskatchewan-Nelson River Basin.

Table 5-3: Travel time statistics in days from Lake Abraham and Brazeau Reservoir to the Alberta/Saskatchewan Interprovincial Boundary using the 1975 methodology for 1976 to 2012.

	Lake Abraham	Brazeau Reservoir
Maximum	7.1	6.1
Minimum	3.5	2.6
Mean	5.4	4.4

5.3.2 Comparison of Instantaneous Peak Flow Records

Although comparing measured instantaneous flow information provides more precise travel times (because they can be estimated in hours instead of days), the records available are limited and not all years of available data represent the same flow peak at each station.

The instantaneous peak records for the Bighorn Plant and Rocky Mountain House stations contain only one shared event which reflects a travel time of 41 hours for a flow below Bighorn Plant of 156 m^3/s.

The instantaneous peak flow records for the Rocky Mountain House and Lodgepole stations contain six corresponding events, with flows ranging from 339 m^3/s to 2420 m^3/s and associated travel times of between 8.5 hours and 16.5 hours.

The instantaneous peak flow records for the Lodgepole and Edmonton stations were found to contain 10 related flow events. These events had water levels at Lodgepole of between 3.86 m and 7.40 m and associated travel times ranging between 18 hours and 27 hours.

The instantaneous peak flow records for the Edmonton and Deer Creek stations were found to have 31 records which appeared to correspond. Among the 31 events, the peak instantaneous flow recorded at Edmonton ranged from 487 m^3/s to 4520 m^3/s, and the travel times ranged from 27 hours to over 71 hours. Figure 5-4 illustrates the complete set of instantaneous peak flows and corresponding travel times for this section of the river. Generally speaking, flows less than 1000 m^3/s had travel times of between 48 and 72 hours, while flows greater than 1000 m^3/s had travel times between 24 and 48 hours.

The travel times determined from these instantaneous flow records are generally in keeping with the travel time findings using the mean daily flow records, especially when considering the resolution of the mean daily flow analysis.

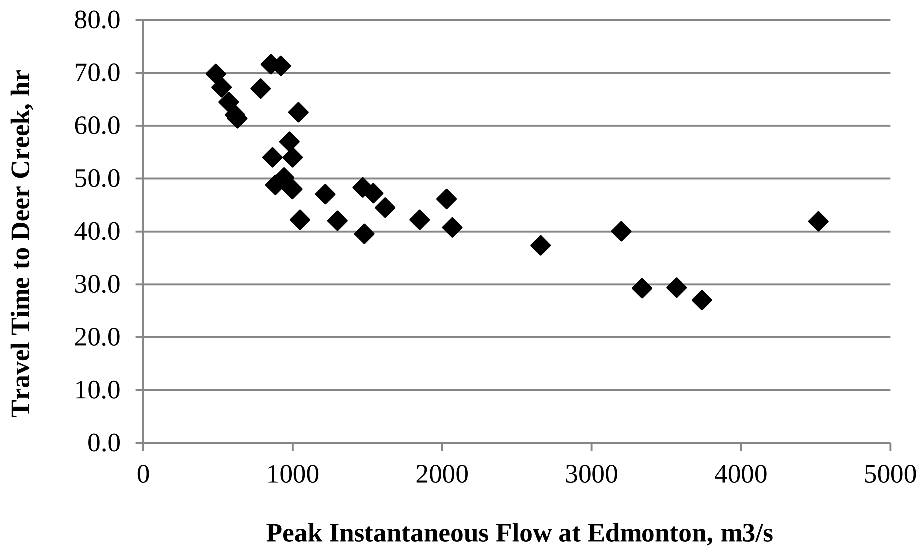

Figure 5-4: Travel times from Edmonton, AB to Deer Creek, SK for 31 historical peak instantaneous flow records.

5.3.3 Note on Effect of Moving Apportionment Point from Deer Creek to the Alberta/Saskatchewan Border

As described in Section 2.5 the apportionable flow for the North Saskatchewan River between Alberta and Saskatchewan has historically been reported at Deer Creek, SK, the location of the nearest hydrometric gauge to the border. As part of the revisions to the approved apportionable calculation procedures it is proposed to account for the net inflow in Saskatchewan between the provincial border and the Deer Creek gauge, effectively moving the point of apportionment from the gauge upstream approximately 37 km to the border. A change in location of the apportionment point will obviously also affect the routing time from upstream locations.

However, the distance is relatively small compared to the overall travel distances (i.e. 37 km vs. the distances listed in Table 5.2), and the routing times are approximations only. Bearing this in mind, along with the fact that on an annual basis routing makes almost no difference in the apportionable flow, no adjustments to the routing procedures to account for moving the point of apportionment are recommended.

5.4 Options for Routing from Lake Abraham and Brazeau Reservoir

Based on the information presented in the preceding sections, the following points are notable:

- Based on an assessment of recorded flows at various locations along the North Saskatchewan River in Alberta, the actual travel times from Lake Abraham and the Brazeau Reservoir to the apportionment point at Deer Creek were found to be from 4-7 days and from 3-6 days, respectively.
- The regression models presented in the 1975 PPWB Natural Flow report have no documentation regarding how they were developed, but the results are in general agreement with the available data.
- The current routing adjustment method used in the FORTRAN program is believed to be based on historic average values of travel times calculated using the 1975 routing method for the period from 1976 to 1992.

Based on the above considerations the following options are available to update the routing adjustment method.

a) Use 1975 Routing Equations

The 1975 PPWB routing adjustment method requires hydrometric data from two hydrometric stations (North Saskatchewan River near Rocky Mountain House and North Saskatchewan River at Edmonton), which are otherwise not required for the apportionable flow computations. Data at the station near Rocky Mountain House, used only in the travel time calculations for Lake Abraham, is currently only collected seasonally.

The travel time equation for Brazeau Reservoir from the 1975 PPWB Natural Flow report could be applied as is, as it only requires data from the Edmonton station. The 1975 travel time equation for Lake Abraham could be applied based on recorded data for the period of the year when data is available at Rocky Mountain House. For the remainder of the year the travel time would have to be estimated by other means.

The addition of two stations to the PPWB monitoring program, as well as the complication surrounding the use of the station at Rocky Mountain House, make this option undesirable.

b) Continue to Use Current Routing Method

The routing equations currently used in the FORTRAN program and discussed in section 5.2 could continue to be used. These equations could also be further refined by updating the period of record included in the travel time averages to include data from 1992 to 2013 (see option c) below).

c) Update Current Routing Method

The following steps were carried out in order to update the ratio-based routing equations (i.e. those currently used in the FORTRAN program):

1- The 1975 method was used to calculate the travel times from Brazeau Reservoir and Lake Abraham to the apportionment point at Deer Creek, SK for the period from 1972 to 2012 (data for 05DC001 was limited to the period from approximately May to November each year was not available for 2013).
2- The calculated travel times in hours were converted to days.
3- The travel times in days were converted to a fraction of time in the month by dividing each monthly value by the number of days in that month. This is the portion of the monthly change in storage that would be carried over to the following month.
4- The entire set of carryover values for each reservoir was then averaged to determine the average carryover factor.

The resulting updated routing adjustment equations are:

Brazeau Reservoir

$$Routed\ \Delta SB = 0.146\ \times\ \Delta SB_{-1} +\ 0.854\ \times\ \Delta SB \qquad (5\text{-}1)$$

Lake Abraham

$$Routed\ \Delta SA = 0.176\ \times\ \Delta SA_{-1} + 0.824\ \times\ \Delta SA \qquad (5\text{-}2)$$

where: $\Delta SB = Brazeau\ Reservoir\ change\ in\ storage\ for\ the\ calculation\ month,$

$\Delta SB_{-1} = Brazeau\ Reservoir\ change\ in\ storage\ for\ the\ previous\ month,$

$Routed\ \Delta S_B = Brazeau\ Reservoir\ change\ in\ storage\ \ routed\ to\ Deer\ Creek$

$\Delta SA = Lake\ Abraham\ change\ in\ storage\ for\ the\ calculation\ month,$

$\Delta SA_{-1} = Lake\ Abraham\ change\ in\ storage\ for\ the\ previous\ month,$ and

$Routed\ \Delta SA = Lake\ Abraham\ change\ in\ storage\ routed\ to\ Deer\ Creek$

The ratio values in these equations are very close to those currently used (equations 2-3 and 2-4).

The benefits of this approach are that the routing adjustments are simple to calculate and no additional data beyond current requirements is necessary. The drawbacks to this option are that routing by this method does not take into account actual water use/release that occurs at the end of each month or the change in travel time with flow rate.

d) Develop New Regression Equations

As an alternative, a new method to estimate travel time from each of the reservoirs to Deer Creek was devised based predominantly on the findings of the instantaneous peak flow comparison between the stations at Edmonton and Deer Creek (Figure 5-4). For each travel time in that data set, additional time was added to account for the travel time from each reservoir to Edmonton, based on the findings of the mean daily flow analysis. In addition, several low flow points were also added. A reasonable fit regression equation was found for each of the two reservoirs as shown in Figure 5-5 and 5-6.

This resulted in the following equations to calculate travel time from the two reservoirs in the North Saskatchewan River Basin to the apportionment point at Deer Creek.

Brazeau Reservoir

$$T = -2.3 \times log Q_E + 10.2 \quad (5\text{-}3)$$

Lake Abraham

$$T = -2.9 \times log Q_E + 12.6 \quad (5\text{-}4)$$

where : Q_E = Daily Mean Flow at 05DF001 for the last five days of the month (cms), and

$T = travel\ time\ in\ days\ from\ the\ reservoir\ to\ the\ apportionment\ point$

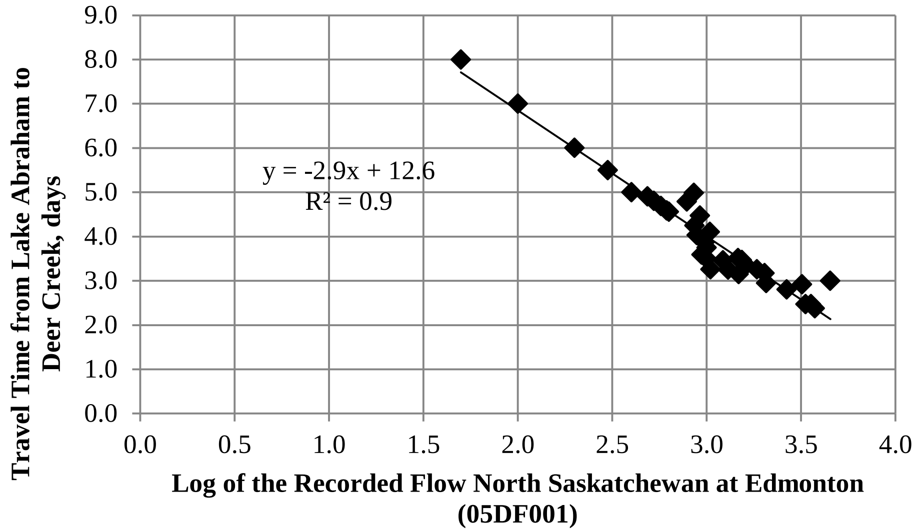

Figure 5-5: Estimated travel time from Lake Abraham to Deer Creek using flows at North Saskatchewan River at Edmonton (05DF001).

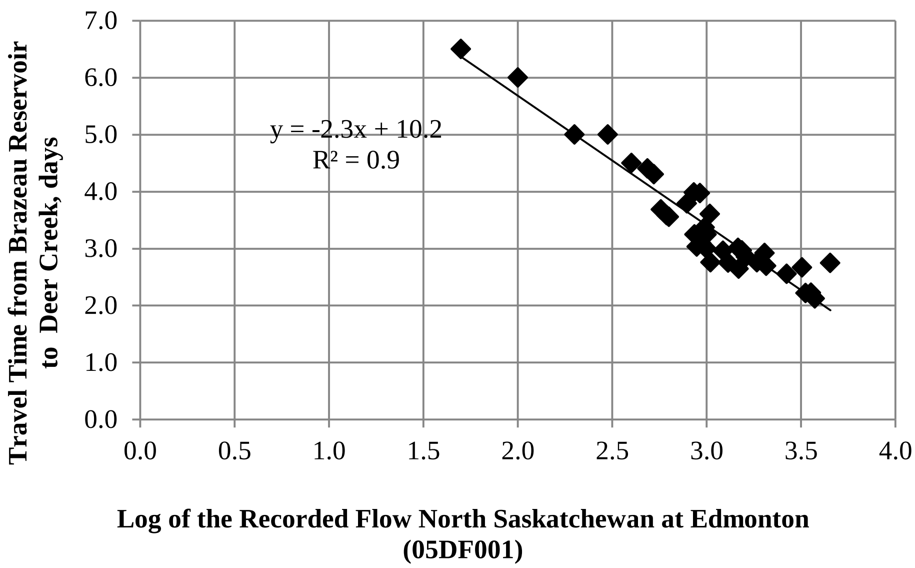

Figure 5-6: Estimated travel time from Brazeau Reservoir to Deer Creek using flows at North Saskatchewan River at Edmonton (05DF001).

The calculation steps would be as follows:

- Determine the average flow for the last five days of the month measured at the hydrometric station at Edmonton.
- Calculate the travel time to the apportionment point using either equation 5-3 or 5-4.
- Determine the monthly change in storage that occurred at the reservoir.
- Determine the carryover volume based on the calculated travel time.

- Subtract the carryover volume from that months change in storage and add it to the following month's change in storage.
- These steps are repeated for each month at each reservoir. The carryover volume from December is applied in the following year.

The benefits of adopting this method are that it accurately represents conditions at the end of each month and accounts for the change in travel time with flow rate. The drawbacks to this option are that the calculation requires multiple steps and that it adds an additional station to the PPWB monitoring requirements (Edmonton 05DF001).

5.5 Recommendation for Routing from Lake Abraham and Brazeau Reservoir

It is recommended that the new regression equations (5-3 and 5-4) be implemented as the routing method for apportionable flow calculations. At present the only routing options available in RBAT (the new PPWB apportionable flow software) are SSARR routing and an option called fixed percentage time lag. The fixed percentage option was built into the program based on the FORTRAN routing method for the North Saskatchewan River. In order to be able to apply the new routing equations they were transformed to the fixed percentage format based on calculated travel times from 1975 to 2012 using the procedure described under option c). The resulting equations are:

Brazeau Reservoir

$$Routed\ \Delta SB = 0.167 \times \Delta SB_{-1} + 0.833 \times \Delta SB \quad (5\text{-}5)$$

Lake Abraham

$$Routed\ \Delta SA = 0.202 \times \Delta SA_{-1} + 0.798 \times \Delta SA \quad (5\text{-}6)$$

where: $\Delta SB = Brazeau\ Reservoir\ change\ in\ storage\ for\ the\ calculation\ month,$

$\Delta SB_{-1} = Brazeau\ Reservoir\ change\ in\ storage\ for\ the\ previous\ month,$

$Routed\ \Delta S_B = Brazeau\ Reservoir\ change\ in\ storage\ \ routed\ to\ Deer\ Creek$

$\Delta SA = Lake\ Abraham\ change\ in\ storage\ for\ the\ calculation\ month,$

$\Delta SA_{-1} = Lake\ Abraham\ change\ in\ storage\ for\ the\ previous\ month,$ and

$Routed\ \Delta SA = Lake\ Abraham\ change\ in\ storage\ routed\ to\ Deer\ Creek$

In the long term, it is possible that other routing options may be added to the RBAT program and at that time the recommended routing, option b), could then be applied.

5.6 Recommendation for Routing of Other Consumptive Use Projects

As described in Section 3, it is recommended that other estimated consumptive uses be incorporated into the apportionable flow calculations. These withdrawals are located at various locations along the North Saskatchewan River in Alberta, with the majority concentrated in and around the Edmonton area, as shown in Figure 3-1.

Although as a group it has been determined that these consumptive uses should be included in the apportionable flow calculations, individually even the largest users account for only a tiny fraction of the flow in the river. Therefore, routing each consumptive use from its location of occurance to the apportionment point is unnecessarily complicated for the apportionable flow calculations. It is recommended that the consumptive uses be routed as a lump sum from Edmonton (as it is centrally located in the basin and a significant portion of the water use occurs in that area).

As part of the analysis in Section 5.3 travel times from Edmonton to Deer Creek were reviewed. Figure 5-7 shows the relationship between the log of the peak instantaneous flow record vs. the travel time for the peak to reach the station at Deer Creek. It is recommended that the resulting equation (equation 5-7) be used to determine the travel time for the purpose of calculating routing adjustment for consumptive uses other than the two reservoirs.

$$T = -1.7 \times log Q_E + 7.3 \tag{5-7}$$

where: Q_E = Daily Mean Flow at 05DF001 for the last five days of the month (cms), and

$T = travel\ time\ in\ days\ from\ Edmonton\ to\ the\ apportionment\ point$

The proposed calculation process would be as follows:

- Determine the average flow for the last five days of the month measured at the hydrometric station at Edmonton (also required for recommended routing for the two reservoirs).
- Calculate the travel time from Edmonton to the apportionment point using Equation 5-7.
- Calculate the portion of that months consumptive use volume that would have occurred during the travel time (i.e. assuming the use is equally distributed over the month).
- Subtract that volume from the consumptive use for that month and add it to the following months consumptive use volume.
- Repeat these steps for each month. Carryover December's routing adjustment volume to January of the following year.

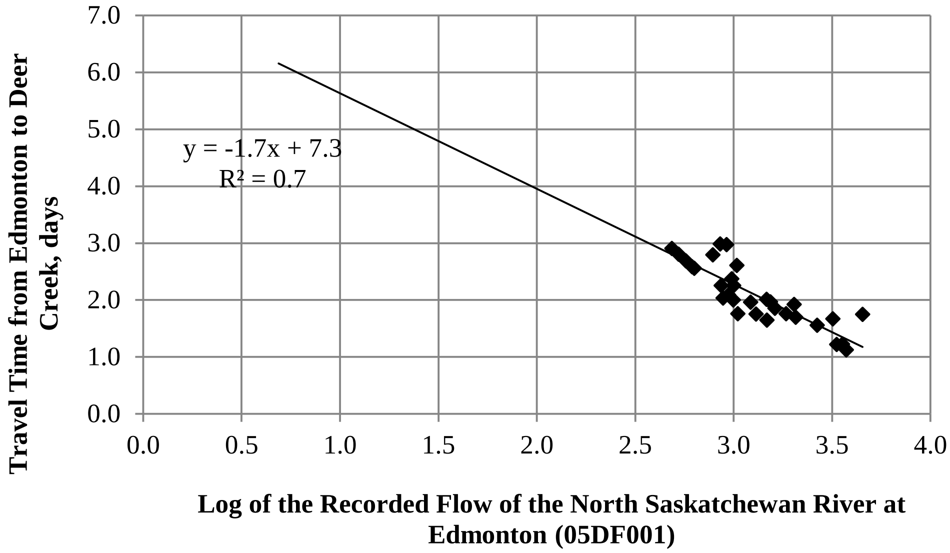

Figure 5-7: Estimated travel time from Edmonton to Deer Creek using flows at North Saskatchewan River at Edmonton (05DF001).

As mentioned in Section 5.5 the only routing option, other than SSARR routing, that is currently available in RBAT is the fixed percentage routing option. Until further routing options are available equation 5-7 can be simplified to:

$$Routed\ CU = 0.12\ CU_{-1} + 0.88\ CU \qquad (5\text{-}8)$$

where: $CU = total\ monthly\ consumptive\ use$

$CU_{-1} = total\ monthly\ consumptive\ use\ for\ the\ previous\ month$

This simplification was made based on calculated travel times from 1975 -2010, using the procedure described under routing option a).

In the future, options for routing of consumptive uses from various locations along the river can be explored based on the capabilities available in RBAT. For example, the AEP model divides the river into the following 25 reaches for use in SSARR routing:

1. Saskatchewan Crossing to Whirlpool Point
2. Whirlpool Point to Bighorn Dam
3. Bighorn Dam to Saunders
4. Saunders to Ram River
5. Ram River to Rocky Mountain House
6. Rocky Mountain House to Baptiste River
7. Baptiste River to Brazeau River
8. Brazeau River to Lodgepole
9. Lodgepole to Rose Creek

10. Rose Creek to Drayton Valley
11. Drayton Valley to Highway 759
12. Highway 759 to Genessee Bridge
13. Genessee Bridge to Strawberry Creek
14. Strawberry Creek to Devon
15. Devon to Edmonton
16. Edmonton to Fort Saskatchewan
17. Fort Saskatchewan to Sturgeon River
18. Sturgeon River to Vinca
19. Vinca to Waskatenau Creek
20. Waskatenau Creek to Pakan
21. Pakan to Duvernay
22. Duvernay to Elk Point
23. Elk Point to Lea Park
24. Lea Park to Saskatchewan Boundary
25. Saskatchewan Boundary to Deer Creek

The time of storage for the different reaches in the AEP model are grouped such that the times of storage for reaches 1-4, 6-7, 9-15, and 16-25 are the same. Only reach five has a distinct flow/time of storage relationship.

The following reaches are proposed as possible breakpoints for the purpose of grouping consumptive uses for calculation of travel time in the apportionable flow calculations (reach lengths are taken from the AEP model documentation). The approximate number of licences within the top 83 located in each reach are shown in brackets.

1. Headwaters to Lodgepole, 284 km (3)
2. Lodgepole to Strawberry Creek, 142 km (17)
3. Strawberry Creek to Edmonton, 66 km (19)
4. Edmonton to Waskatenau Creek, 91 km (32)
5. Waskatenau Creek to Elk Point, 164 km (3)
6. Elk Point to Deer Creek, 120 km (9)

One simple possibility would be to prorate the travel times for each reach based on their distance upstream or downstream from Edmonton. For example, for consumptive uses in the Lodgepole to Strawberry Creek reach the travel time would be the travel time from Edmonton (based on equation 5-7) multiplied by the ratio of the distance between Lodgepole and Deer Creek and the distance between Edmonton and Deer Creek (i.e. 583 km / 375 km = 1.55).

5.7 Summary of Recommendations for Routing

It is recommended that two new routing equations be used to calculate travel time adjustments for Lake Abraham and Brazeau Reservoir (Equations 5-5 and 5-6). The proposed method offers the advantage of accounting for variability in travel time with different flow, as well as accurately representing the actual activity at the reservoirs at the month's end.

For other consumptive uses it is recommended that a routing adjustment procedure similar to that proposed for the reservoirs be used. The majority of the consumptive uses occur in the middle portion of the basin surrounding Edmonton. For immediate application it is recommended that an appropriate simplification would be to route all consumptive uses from Edmonton using Equation 5-8. If desired in the future, the consumptive uses could be divided up into reaches and the routing time pro-rated based on the location of the reach relative to Edmonton. A reach breakdown and outline of this method has been suggested.

In both cases the preferred travel time equations cannot currently be implemented in RBAT. At this time, it is recommended that all routing be done using the fixed percentage method calculated based on the new routing equations, as has been described in the preceding sections.

6. Impact of Proposed Apportionable Flow Calculation Changes

In order to assess the cumulative impact of the calculation procedures recommended in this basin review, apportionable flow values calculated with the proposed changes were compared to the results from the FORTRAN program. As shown in Table 6-1, the resulting change in terms of delivery of apportionable flow was 5% or less in all years.

Table 6-1: Example of cumulative impact of proposed changes to apportionable flow calculation procedures for 1979-2013.

	Recorded Flow at Deer Creek, dam3	Estimated Flow at AB/SK Border, dam3	Old Method Apportionable Flow at Deer Creek, dam3	Proposed New Method Apportionable Flow at AB/SK Border, dam3	% Delivery Fortran	% Delivery New Method
1979	5,504,000	5,498,000	5,443,000	5,619,000	101%	98%
1980	8,337,000	8,331,000	8,233,000	8,395,000	101%	99%
1981	7,702,000	7,696,000	7,795,000	7,961,000	99%	97%
1982	7,287,000	7,281,000	7,471,000	7,635,000	98%	95%
1983	5,802,000	5,796,000	5,642,000	5,818,000	103%	100%
1984	4,998,000	4,992,000	4,960,000	5,128,000	101%	97%
1985	5,853,000	5,847,000	5,754,000	5,916,000	102%	99%
1986	8,909,000	8,903,000	8,933,000	9,096,000	100%	98%
1987	5,385,000	5,380,000	5,358,000	5,526,000	101%	97%
1988	4,779,000	4,773,000	4,708,000	4,883,000	102%	98%
1989	7,164,000	7,158,000	7,286,000	7,449,000	98%	96%
1990	8,922,000	8,916,000	8,955,000	9,118,000	100%	98%
1991	8,372,000	8,366,000	8,320,000	8,484,000	101%	99%
1992	5,571,000	5,565,000	5,485,000	5,653,000	102%	98%
1993	6,276,000	6,270,000	6,357,000	6,522,000	99%	96%
1994	5,967,000	5,961,000	5,931,000	6,105,000	101%	98%
1995	7,258,000	7,252,000	7,431,000	7,588,000	98%	96%
1996	7,010,000	7,004,000	6,912,000	7,089,000	101%	99%
1997	6,951,000	6,945,000	7,088,000	7,265,000	98%	96%
1998	7,639,000	7,633,000	7,648,000	7,815,000	100%	98%
1999	8,328,000	8,322,000	8,276,000	8,442,000	101%	99%
2000	5,688,000	5,682,000	5,751,000	5,925,000	99%	96%
2001	4,869,000	4,863,000	4,707,000	4,880,000	103%	100%
2002	4,823,000	4,817,000	4,842,000	5,012,000	100%	96%
2003	6,066,000	6,060,000	6,032,000	6,206,000	101%	98%
2004	5,607,000	5,602,000	5,779,000	5,943,000	97%	94%
2005	9,482,000	9,476,000	9,517,000	9,677,000	100%	98%
2006	5,605,000	5,599,000	5,489,000	5,656,000	102%	99%
2007	7,620,000	7,614,000	7,676,000	7,849,000	99%	97%
2008	7,002,000	6,996,000	6,907,000	7,081,000	101%	99%
2009	4,679,000	4,673,000	4,577,000	4,755,000	102%	98%
2010	5,809,000	5,803,000	5,987,000	6,161,000	97%	94%
2011	8,448,000	8,442,000	8,452,000	8,627,000	100%	98%
2012	7,955,000	7,949,000	7,864,000	8,041,000	101%	99%
2013	8,187,000	8,181,000	8,202,000	8,373,000	100%	98%

7. Data Needs

7.1 Hydrometric Data Required for Apportionable Flow Calculations

Records of mean daily flow and mean daily water level from the following hydrometric stations are currently required for the computation of the apportionable flow of the North Saskatchewan River at the Alberta/Saskatchewan border:

- North Saskatchewan River near Deer Creek (05EF001) (WSC)
- Lake Abraham near Nordegg (05DC009) (TransAlta)
- Brazeau Reservoir (05DD006) (TransAlta)

For immediate implementation of the recommended procedures in RBAT, no further data will be required. In the future, if the preferred routing equations are used, data from the station 05DF001 North Saskatchewan River at Edmonton will also be required. This station is operated by the Water Survey of Canada and has a continuous record dating back to 1911.

7.2 Meteorologic Data Required for Apportionable Flow Calculations

Currently, no meteorological data is required to complete the apportionable flow calculations for the North Saskatchewan River at the Alberta/Saskatchewan border. The revised computation procedures recommend including evaporative losses from reservoirs in the apportionable flow calculations based on long term average gross evaporation and recorded precipitation. This will require monthly precipitation data for Brazeau Reservoir and Lake Abraham on an annual basis, as well as occasional updates of the estimated long term average gross evaporation at the discretion of the COH.

For Lake Abraham the precipitation data used in the evaporation calculation will be from the Kootenay Plains Auto met station (AEP) with data from Nordegg met station (EC) used to fill in as necessary when data is missing. For Brazeau reservoir it is recommended that precipitation data from Edson, Nordegg, Rocky Mountain House and Violet Grove stations be averaged as the reservoir is located in the middle of these stations. On any day that data is not available from all four of these stations, the average will be from those stations that are available.

7.3 Other Data Required for Apportionable Flow Calculations

Currently, no data beyond the hydrometric requirements listed in section 7.1 are required for the apportionable flow computations for the North Saskatchewan River. The recommended changes to the computation methods include consideration of consumptive uses in the basin. This will require AEP to provide annual updates of the net licenced volume and occasional updates regarding reported consumptive use.

8. Migration to RBAT

The revised apportionable flow calculation procedures will be moved into RBAT by the PPWB Secretariat. The capabilities of the program have been taken into consideration in developing the revised calculation procedures. Specifically, the recommended routing procedures have been simplified to accommodate the methods currently available in the program.

9. Future Action Regarding Apportionment Calculation Procedures

The apportionable flow computations for the North Saskatchewan River are currently completed annually. At the present level of development and water use in Alberta, and under normal flow conditions, there is no challenge in terms of the delivery of the required volume of water to Saskatchewan on an annual basis. Increase in water use in the basin is occurring gradually and there is no requirement foreseen to increase the level of monitoring in this basin in the near future. Despite this, should short term conditions in the basin be such that flow in the North Saskatchewan is reduced significantly below normal levels, an interim increase in apportionment monitoring may be required as it might be for other basins.

The effects of land development are currently not considered in the apportionable flow calculations for the North Saskatchewan River. Due to the complexity of this issue consideration of the changes of land development was outside the scope of this review. At some point in the future this issue may be studied in detail as it pertains not only to the NSRB, but also many of the other basins subject to apportionment under the MAA. Based on such a study, recommendations for assessing and quantifying the impact of various types of land development could then be made.

Under the PPWB's proposed basin review cycle it is anticipated that each basin will be reviewed approximately every 10 years. Based on the current and historical apportionment record and the anticipated growth rate in the North Saskatchewan basin this timeframe is acceptable for the next overall review. As part of the recommended changes to the apportionment computations, reported consumptive use data will require periodic update. This should be incorporated as part of the annual apportionment monitoring program.

10. Conclusions and Recommendations

The apportionable flow for the North Saskatchewan River at the Alberta/Saskatchewan boundary has been monitored on an annual basis since the late 1970's. Based on the apportionable flow calculation procedures that have been in place, during that time the lowest percentage of the annual apportionable flow that Saskatchewan has received is 97%. This level has been reached in 2 of the 35 years in the monitoring record.

The project depletion method is used by the PPWB for calculating apportionable flows. Following a review of the various considerations in the apportionable flow calculation procedure for the North Saskatchewan River the following recommendations have been made:

Location of Apportionment Point

It is recommended that the point of apportionment be adjusted from the hydrometric monitoring station at Deer Creek, Saskatchewan, to the Alberta/Saskatchewan border. This will be done by subtracting the median net inflow generated in the Saskatchewan between the border and Deer Creek. The adjustment will be static from year to year and will be based on hydrometric data collected at the station Monnery River near Paradise Hill (05EF004) for the period from 1968 to 1996 and 2010 to 2014. The adjustment may be updated from time to time at the discretion of the COH as more years of record become available.

Consumptive Use
The calculation procedures used to account for storage changes in Lake Abraham and Brazeau Reservoir will remain unchanged from the current practice. It is recommended that other consumptive use be included in the apportionable flow calculations. A subset of the largest licences will be included based on an estimated percent of the net licenced use being consumed. The remainder of the licences will be included based on the assumption that all of the net licenced volume is consumed. The resulting consumptive use volumes will be distributed throughout the year based on the activity categories associated with each licence. This will require AEP to provide an annual update of net licenced use from their licensing database, as well as occasional updates of reported consumptive use from their water use reporting database as deemed appropriate by the COH.

Evaporation
It is recommended that evaporation losses from Lake Abraham and Brazeau Reservoir be considered as part of the apportionable flow calculations. Evaporation calculations will be based on long term average gross evaporation values combined with recorded annual precipitation.

Routing Adjustments
It is recommended that new routing equations (Equations 5-5 and 5-6) be used to adjust for travel time to the apportionment point when accounting for change in storage at Lake Abraham and Brazeau Reservoir. The actual change in stored volume that occurs during the calculated travel

time at each month's end will then be determined and that volume will be carried forward to the following month.

In terms of routing for other consumptive uses, it is recommended that the total monthly consumed volume be routed from a single location at Edmonton using Equation 5-8 to account for travel time to the apportionment point. The portion of the consumptive use estimated to have occurred during the travel time, assuming the consumptive use is equally distributed through the month, will then be carried forward to the following month.

For immediate implementation in RBAT all routing equations have been converted to carryover ratios based on the average travel times calculated for the period from 1975 to 2010. In future, should further options be available in RBAT, the recommended routing equations will be used.

Data Requirements

The data required to complete the proposed calculations will be slightly increased from the current requirements. Licenced allocation and reported consumptive use data from the province of Alberta, which is already monitored as part of their licensing program, will be required to account for water use. Additionally, precipitation data as well as long term average evaporation estimates will be required for the calculation of reservoir evaporation. Should the recommended routing procedures be applied at some time, data from one additional hydrometric station (North Saskatchewan River at Edmonton), will be required for calculation of routing adjustments.

The next review of the apportionable flow calculation procedures for the North Saskatchewan River should be carried out as part of the normal basin review process, which is planned to be in approximately a ten year cycle. There is currently no foreseeable need for a comprehensive review of apportionable flow procedures for this basin before that time.

References

PPWB, 2014, Evaluation of Lake Evaporation in the North Saskatchewan River Basin, PPWB Report #171, December 2014.

North Saskatchewan Watershed Alliance, 2012: Atlas of the North Saskatchewan River Watershed in Alberta, June 2012. Accessed at: https://www.nswa.ab.ca/content/watershed-atlas

PFRA, 1980: Report on Determination of River Distances for the Saskatchewan-Nelson River Basin, Hydrology Report #95, Hydrology Division, Prairie Farm Rehabilitation Administration, September 1980.

PPWB, 1975: North Saskatchewan River at Alberta-Saskatchewan Boundary Natural Flow, Report #45, Prairie Provinces Water Board, March 1975.

Appendix 1: FORTRAN Program Code

```
C     PROGRAM NNFM - CALCULATION OF MONTHLY APPORTIONMENT FLOWS ON THE
C     NORTH SASKATCHEWAN RIVER AT ALTA-SASK BOUNDARY
C     PROGRAM WRITTEN JUNE/77 BY PPWB SYSTEMS STAFF
C     METRIC REVISION : JUN.1981
C     UPDATED TO FORTRAN77 LEVEL BY PPWB SYSTEMS STAFF 1984-11-30
      REAL*8 ADJ(12,99,2),BRAZ(12,99),LABR(12,99),RADJ(12,99,2),
     + RFLOW(12,99),TOTAL(12,99),BC2(2,80),AC2(2,80),AFLOW(12),
     + BFLOW(12),PCT(12),RCUM(12),ACUM(12),PCUM(12)
C     WHERE:
C     ADJ(N,M,1)=BRAZEAU STORAGE
C     ADJ(N,M,2)=L ABRAHAM STORAGE
C     BRAZ(N,M)=END-OF-MONTH LEVEL
C     LABR(N,M)=END-OF-MONTH LEVEL
C     N = MONTH
C     M = YEAR
      INTEGER NMPD/80/,NMT/12/,NOTES(10,18)
      CHARACTER*3  MONTH(12),AAA*4
      CHARACTER*12  NAME1,NAME2
      CHARACTER*4  DESC(3,1),KD
      DATA  MONTH/'JAN','FEB','MAR','APR','MAY','JUN','JUL','AUG',
     +'SEP','OCT','NOV','DEC'/
      DATA  DESC/'DD6 ','DC9 ','EF1 '/
C***********************************************************************
90     FORMAT (/,'       NORTH SASKATCHEWAN RIVER NATURAL FLOW   ')
91     FORMAT (/,'           COMPUTATION COMPUTER PROGRAM',// )
92     FORMAT (/,'     *************************************************')
93     FORMAT ( '     *  FORTRAN PROGRAM TO COMPUTE MONTHLY NATURAL *')
94     FORMAT ( '     *  FLOW FOR THE NORTH SASKATCHEWAN RIVER AT   *')
95     FORMAT ( '     *  THE ALBERTA-SASKATCHEWAN BOUNDARY.         *')
96     FORMAT ( '     *************************************************')
102    FORMAT (//)
105    FORMAT ('NORTH SASKATCHEWAN RIVER AT THE ALBERTA-',
     +  'SASKATCHEWAN BOUNDARY')
106    FORMAT ('MONTHLY NATURAL FLOW')
107    FORMAT ('DATA FROM NATURAL FLOW COMPUTER PRINTOUT ')
108    FORMAT ('DATA IN DAM3 UNIT')
201   FORMAT (I2,1X,I4,1X,I2,1X,I4,1X,I2,54X,A4,I4)
202   FORMAT (12F8.3,A4,I4)
203   FORMAT (1H1,////,55X,'BASIC HYDROMETRIC DATA')
204   FORMAT (1H1,////,52X,'INTERIM COMPUTATION RESULTS')
205   FORMAT (1H1,////,38X,'SUMMARY OF ADJUSTMENTS WHEN ROUTED TO ALTA',
     + '-SASK BOUNDARY')
206   FORMAT (1H1,////,47X,'APPORTIONMENT FLOW CALCULATION RESULTS')
207   FORMAT (1H ,///,3X,'LEVEL VALUES IN METRES, AND FLOW VALUES IN',
     + ' DAM3')
208   FORMAT (1H ,///,3X,'ALL VALUES IN DAM3')
209   FORMAT (1H1,////,41X,'NORTH SASKATCHEWAN RIVER NATURAL FLOW',
     + ' COMPUTATIONS')
210   FORMAT (1H ,///,48X,'NATURAL FLOW COMPUTATION PARAMETERS')
```

```
211   FORMAT (1H ,///,44X,'COMPUTATION PERIOD',I4,' - ',I4,'  TO  ',I2,
     + ' - ',I4)
212   FORMAT (1H ,2X,'VALUES OF -99999. OR -99.99 DENOTE MISSING DATA')
213   FORMAT (18A4,A4,I4)
214   FORMAT (1H+,10X,18A4/)
215   FORMAT (1H ,/,03X,'NOTES:')
216   FORMAT (1H ,1X,'BRAZ. MONTH END LEVEL',02X,12(F8.2,1X))
217   FORMAT (1H ,1X,'L ABRM MONTH END LEVEL',01X,12(F8.2,1X))
218   FORMAT (1H ,1X,'BRAZEAU STORAGE CHANGE',01X,12(F8.0,1X))
219   FORMAT (1H ,1X,'L ABRM STORAGE CHANGE',02X,12(F8.0,1X))
220   FORMAT (1H ,1X,'REC - N.SASK @ DEER CK',01X,12(F8.0,1X))
221   FORMAT (1H ,1X,'TOTAL',18X,12(F8.0,1X))
222   FORMAT (1H ,1X,'TOTAL ADJUSTMENTS',06X,12(F8.0,1X))
223   FORMAT (1H ,1X,'NATURAL FLOWS',10X,12(F8.0,1X))
224   FORMAT (1H ,1X,'50%',20X,12(F8.0,1X))
225   FORMAT (1H ,1X,'PERCENT DELIVERED',05X,12(F8.2,1X)/)
226   FORMAT (1H //,2X,I4,16X,12(06X,A3)/)
227   FORMAT (1H ,/,117X,'......CONTINUED',/,1H1,//////)
231   FORMAT (1H ,1X,'CUMULATIVE RECORDED',03X,12(F9.0))
232   FORMAT (1H ,1X,'CUMULATIVE NATURAL',04X,12(F9.0))
233   FORMAT (1H ,1X,'CUMULATIVE PERCENT',04X,12(F8.2,1X))
234   FORMAT (1H1,////,25X,'BASIC HYDROMETRIC DATA - FLOW VALUES IN',
     +  ' MEAN CMS FOR MONTH')
235   FORMAT (1H ,1X,'REC - N.SASK @ DEER CK',01X,12(F8.1,1X))
238   FORMAT (12F10.0,A4,I4)
239   FORMAT ('==============================================')
240   FORMAT ('**  A NATURAL FLOW SUMMARY TABLE IS CREATED  **')
241   FORMAT ('**  AND LOADED IN THE CURRENT DRIVE UNDER    **')
242   FORMAT ('**  THE NAME  NSNF.DAT                       **')
243   FORMAT ('==============================================')
C       INPUT THE INPUT FILE NAME:
      WRITE (*,90)
      WRITE (*,91)
      WRITE (*,92)
      WRITE (*,93)
      WRITE (*,94)
      WRITE (*,95)
      WRITE (*,96)
      WRITE (*,102)
      WRITE (*,' (A\)') '... ENTER INPUT FILE NAME:'
      READ (*,' (A)) ')  NAME1
      WRITE (*,102)
      WRITE (*,' (A\)') '... ENTER OUTPUT FILE NAME:'
      READ (*,' (A)) ')  NAME2
      OPEN(1,FILE= NAME1 , ACCESS = 'SEQUENTIAL')
      OPEN(2,FILE= NAME2)
      OPEN(3,FILE= 'NSNF.DAT')
C######################################################################
      WRITE (3,105)
      WRITE (3,106)
      WRITE (3,107)
      WRITE (3,108)
C######################################################################
```

```
C
      READ(1,201) MONF,IYRF,MONL,IYRL,IP,ID,IC
      NMYR =IYRL-IYRF+1
      WRITE(2,209)
      WRITE(2,210)
      WRITE(2,211) MONF,IYRF,MONL,IYRL
      IF (NMYR.GT.99.OR.MONF.GT.12.OR.MONL.GT.12)     CALL STP (AAA,1)
C
C     READ BASIC DATA
      DO 301 NYR = 1,NMYR
      IYR = IYRF + NYR -1
      READ (1,202) (BRAZ(NT,NYR),NT=1,12),KD,IC
      IF(KD.NE.DESC(1,1))                      CALL STP (AAA,2)
      IF(IYR.NE.IC)                         CALL STP (AAA,3)
301   CONTINUE
      DO 302 NYR = 1,NMYR
      IYR = IYRF + NYR -1
      READ (1,202) (LABR(NT,NYR),NT=1,12),KD,IC
      IF(KD.NE.DESC(2,1))                      CALL STP (AAA,4)
      IF(IYR.NE.IC)                         CALL STP (AAA,5)
302   CONTINUE
      DO 304 NYR=1,NMYR
      IYR=IYRF+NYR-1
      READ (1,202) (RFLOW(NT,NYR),NT=1,12),KD,IC
      IF (KD.NE.DESC(3,1))                     CALL STP (AAA,6)
      IF (IYR.NE.IC)                        CALL STP (AAA,7)
304   CONTINUE
C     CORRECT DATA UNITS AND SCREEN DATA FOR MISSING VALUES
      DO 305 NYR =1,NMYR
      DO 305 NT =1,NMT
      IF (BRAZ(NT,NYR).LE.0.0)  BRAZ(NT,NYR)= -9999.99
      IF (LABR(NT,NYR).LE.0.0)  LABR(NT,NYR)= -9999.99
      IF (RFLOW(NT,NYR).LT.0.0) RFLOW(NT,NYR)= -99999.
305   CONTINUE
C
C     READ NOTES
      DO 306 N= 1,10
      READ (1,213) (NOTES(N,K),K=1,18),KD,IC
306   IF (IC.NE.N)                          CALL STP (AAA,8)
C
C     PRINT AND CONVERT INPUT DATA
      WRITE (2,234)
      DO 330 NYR = 1,NMYR
      IYR = IYRF + NYR - 1
      ML = 12
      IF (IYR .EQ. IYRL) ML = MONL
      WRITE (2,226) IYR,MONTH
      WRITE (2,235) (RFLOW(NT,NYR),NT=1,ML)
330   CONTINUE
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@
      CALL UNA (IYRF,4,5,RFLOW,12,NMYR,1,12,10,1)
C
```

```
C     WRITE BASIC DATA
      WRITE(2,203)
      DO 401 NYR= 1,NMYR
      IYR = IYRF +NYR -1
      ML = 12
      IF (IYR.EQ.IYRL) ML = MONL
      WRITE (2,226) IYR,MONTH
      WRITE (2,216) (BRAZ(NT,NYR),NT=1,ML)
      WRITE (2,217) (LABR(NT,NYR),NT=1,ML)
      WRITE (2,220) (RFLOW(NT,NYR),NT=1,ML)
      KYR = NYR/7
      IF (NYR.EQ.KYR*7.AND.NYR.NE.NMYR) WRITE (2,227)
401   CONTINUE
      WRITE(2,207)
      WRITE(2,212)
C
C     START COMPUTATIONS
C     INITIALIZE COMPUTED PARAMETERS
      DO 501 NYR = 1,NMYR
      DO 501 NT = 1,NMT
      DO 502 J = 1,2
502   ADJ(NT,NYR,J)= -99999.
      DO 503 J= 1,2
503   RADJ (NT,NYR,J)= -99999.
      TOTAL (NT,NYR) = -99999.
501   CONTINUE
C     READ ALL REQUIRED CURVE COORDINATES
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@
      CALL CRD (BC2,NMPBC,IP,NMPD)
      CALL CRD (AC2,NMPAC,IP,NMPD)
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@
      WRITE (2,204)
C     DETERMINE CHANGE IN STORAGE
      DO 504 NYR = 1,NMYR
      MF = 1
      ML = 12
      IF (NYR.EQ.1)MF=MONF
      IF (NYR.EQ.NMYR)ML=MONL
      DO 505 NT= MF,ML
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@@@
      CALL SC4 (NMPBC,BC2,BRAZ(NT,NYR),VOUT,1,NMPD)
      IF (NYR.EQ.1.AND.NT.EQ.MF) GO TO 506
      ADJ(NT,NYR,1)=(VOUT-VSSB)* 1000.
506   VSSB = VOUT
C@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@@@@@@@@@@@@@@@@@@@@@@@@@@
      CALL SC4 (NMPAC,AC2,LABR(NT,NYR),VOUT,1,NMPD)
      IF (NYR.EQ.1.AND.NT.EQ.MF) GO TO 507
      ADJ(NT,NYR,2)=(VOUT-VSSA) * 1000.
507   VSSA = VOUT
```

```
505   CONTINUE
C     PRINT RESULTS OF INTERIM COMPUTATIONS
      IYR = IYRF + NYR -1
      WRITE (2,226) IYR,MONTH
      WRITE (2,218) (ADJ(NT,NYR,1),NT = 1,ML)
      WRITE (2,219) (ADJ(NT,NYR,2),NT = 1,ML)
      KYR = NYR/8
      IF(NYR.EQ.KYR*8.AND.NYR.NE.NMYR) WRITE(2,227)
504   CONTINUE
      WRITE (2,208)
      WRITE (2,212)
C
C     ROUTE ADJUSTMENTS TO ALTA-SASK BOUNDARY
      WRITE (2,205)
      DO 601 NYR =1,NMYR
      MF=1
      ML=12
      IF (NYR.EQ.1) MF = MONF +2
      IF (MF.GT.12) GO TO 601
      IF (NYR.EQ.2.AND.MONF.EQ.12) MF = 2
      IF (NYR.EQ.NMYR) ML = MONL
      DO 602 NT = MF,ML
      KT = NT -1
      KYR = NYR
      IF (NT.EQ.1)KT =12
      IF (NT.EQ.1)KYR = NYR - 1
      TOTAL (NT,NYR) = 0.0
      RADJ(NT,NYR,1) = 0.136 * ADJ(KT,KYR,1) + 0.864 * ADJ(NT,NYR,1)
      RADJ(NT,NYR,2) = 0.172 * ADJ(KT,KYR,2) + 0.828 * ADJ(NT,NYR,2)
      DO 603 J=1,2
      IF (ADJ(KT,KYR,J).EQ. -99999.) RADJ(NT,NYR,J) = -99999.
      IF (ADJ(NT,NYR,J).EQ. -99999.) RADJ(NT,NYR,J) = -99999.
603   CONTINUE
      DO 604 J = 1,2
      IF (RADJ(NT,NYR,J).EQ. -99999.) GO TO 605
      TOTAL (NT,NYR) = TOTAL (NT,NYR) + RADJ(NT,NYR,J)
      GO TO 604
605   TOTAL (NT,NYR) = -99999.
      GO TO 602
604   CONTINUE
602   CONTINUE
C     PRINT ROUTED RESULTS
      IYR = IYRF + NYR -1
      WRITE (2,226) IYR,MONTH
      WRITE (2,218) (RADJ(NT,NYR,1),NT=1,ML)
      WRITE (2,219) (RADJ(NT,NYR,2),NT=1,ML)
      WRITE (2,221) (TOTAL(NT,NYR),NT=1,ML)
      KYR = NYR/7
      IF (NYR.EQ.KYR*7.AND.NYR.NE.NMYR) WRITE (2,227)
601   CONTINUE
      WRITE (2,208)
      WRITE (2,212)
C
```

```
C     PERFORM FINAL COMPUTATIONS
      WRITE (2,206)
      DO 701 NYR = 1,NMYR
      DO 702 NT = 1,NMT
      AFLOW(NT) = -99999.
      BFLOW(NT) = -99999.
      PCT(NT) = -99.99
      RCUM(NT) = 0.0
      ACUM(NT) = 0.0
702   PCUM(NT) = -99.99
      MF = 1
      ML = 12
      IF(NYR.EQ.1)MF = MONF + 2
      IF(MF.GT.12)GO TO 701
      IF (NYR.EQ.2.AND.MONF.EQ.12) MF = 2
      IF(NYR.EQ.NMYR) ML=MONL
      TEMPR = 0.0
      TEMPA = 0.0
      DO 703 NT = MF,ML
      IF(RFLOW(NT,NYR).EQ.-99999..OR.TOTAL(NT,NYR).EQ.-99999.)GO TO 703
      AFLOW(NT) = RFLOW(NT,NYR) + TOTAL(NT,NYR)
C CORRECTION FOR UNUSUAL ICE CONDITIONS IN JAN. 1974
      IF (NT .EQ. 1 .AND. NYR .EQ. 5) AFLOW(NT) = 49340.
      BFLOW(NT) = AFLOW(NT) * 0.50
      PCT(NT) = RFLOW(NT,NYR)/ AFLOW(NT)* 100.
      TEMPR = TEMPR + RFLOW(NT,NYR)
      RCUM(NT) = TEMPR
      TEMPA = TEMPA + AFLOW(NT)
      ACUM(NT) = TEMPA
      PCUM(NT) = RCUM(NT) / ACUM(NT) * 100.
703   CONTINUE
C     PRINT RESULTS
      IYR = IYRF +NYR -1
      WRITE (2,226) IYR,MONTH
      WRITE (2,220) (RFLOW(NT,NYR),NT=1,ML)
      WRITE (2,222) (TOTAL(NT,NYR),NT=1,ML)
      WRITE (2,223) (AFLOW(NT),NT=1,ML)
C#####################################################################
C     PRINTING THE NATURAL FLOW SUMMARY TABLE
      WRITE (3,238) (AFLOW(NT),NT=1,12),'NSNF',IYR
C######################################################################
      WRITE (2,224) (BFLOW(NT),NT=1,ML)
      WRITE (2,225) (PCT(NT),NT=1,ML)
      WRITE (2,231) (RCUM(NT),NT=1,ML)
      WRITE (2,232) (ACUM(NT),NT=1,ML)
      WRITE (2,233) (PCUM(NT),NT=1,ML)
      KYR = NYR/4
      IF (NYR.EQ.KYR * 4.AND.NYR.NE.NMYR) WRITE (2,227)
701   CONTINUE
      WRITE (2,208)
      WRITE (2,212)
C     WRITE NOTES
      WRITE (2,215)
```

```
      DO 801 N=1,10
801   WRITE (2,214) (NOTES(N,K),K=1,18)
      WRITE (*,102)
      WRITE (*,239)
      WRITE (*,240)
      WRITE (*,241)
      WRITE (*,242)
      WRITE (*,243)
      CLOSE (1)
      CLOSE (2)
      CLOSE (3)
      STOP
      END
C######################################################################
      SUBROUTINE CRD (C2,NMP,IP,NMPD)
C     SUBPROGRAM CRD - READING CURVE COORDINATES
C     SUBPROGRAM WRITTEN JULY/76 BY PPWB SYSTEMS STAFF
C     SUBPROGRAM UPDATED NOV/84 TO 77LEVEL FORTRAN
      REAL*8  C2(2,NMPD)
      CHARACTER*72 CTL
220   FORMAT (A72)
221   FORMAT (19X,I2)
222   FORMAT (12F6.0)
223   FORMAT (1H1,////,08X,A72//)
224   FORMAT (1H ,30X,I2,'.',F9.2,F16.5)
      READ  (1,220) CTL
      READ  (1,221) NMP
      READ  (1,222) ((C2(J,N),J=1,2),N=1,NMP)
      IF (IP.EQ.0) RETURN
C     PRINT CURVE COORDINATES IF SPECIFIED
      WRITE (2,223) CTL
      DO 501 N = 1,NMP
501   WRITE (2,224) N,(C2(J,N),J=1,2)
      RETURN
      END
C######################################################################
      FUNCTION ITA (NT,IYR,NMMT)
C     SUBPROGRAM SPECIFYING DAYS IN TIME PERIOD
C     SUBPROGRAM WRITTEN AUG /70 BY SNBB SYSTEMS STAFF
      INTEGER NMD1(12)
      DATA NMD1/31,99,31,30,31,30,31,31,30,31,30,31/
      ITA = 0
      DO 501  N = 1,NMMT
      MO = NMMT*(NT - 1) + N
      IF (MO.NE.2) GO TO 501
      IYRD4 = IYR/4
      NMD1(2) = 28
      IF (IYR.EQ.IYRD4*4) NMD1(2) = 29
501   ITA = ITA + NMD1(MO)
      RETURN
      END
C#########################################################################
      SUBROUTINE SC4 (NMP,C2,VIN,VOUT,IND,NMPD)
```

```
C     SUBPROGRAM SC4 - DETERMINATION OF VALUES FROM RATING TABLE
C                   INCLUDING LINEAR INTERPOLATION BETWEEN POINTS
C     SUBPROGRAM WRITTEN JULY/76 BY PPWB SYSTEMS STAFF
C     ARRAY OF TABLE VALUES MUST GO FROM SMALLEST TO LARGEST
C     SUBPROGRAM UPDATED NOV/84 TO LEVEL77 FORTRAN
      REAL*8  C2(2,NMPD),VIN
      CHARACTER*3  AAA
      DATA AAA/'SC4'/
C     DETERMINE IF RESULT IS TO BE ORDINATE OR ABSCISSA
      IF (IND.EQ.2) GO TO 303
      J = 1
      K = 2
      GO TO 305
303   J = 2
      K = 1
305   CONTINUE
C     DETERMINE IF INPUT WITHIN RANGE OF TABLE
      IF (VIN.LT.C2(J,1))                 CALL STP (AAA,1)
      IF (VIN.GT.C2(J,NMP))                 CALL STP (AAA,2)
C     DETERMINE OUTPUT GIVEN INPUT
      DO 407 NP = 1,NMP
      IF (VIN.GT.C2(J,NP)) GO TO 407
      IF (VIN.EQ.C2(J,NP)) GO TO 505
C     INTERPOLATION REQUIRED
      VOUT = (((C2(K,NP)-C2(K,NP-1))/(C2(J,NP)-C2(J,NP-1)))*
     +  (VIN-C2(J,NP-1))) + C2(K,NP-1)
      GO TO 801
407   CONTINUE
                                    CALL STP (AAA,3)
505   VOUT = C2(K,NP)
801   RETURN
      END
C#######################################################################
      SUBROUTINE UNA (IYRA,I1A,I1C,V2,NMT,NMYR,NR,IX,IY,IZ)
C     SUBROUTINE UNA - CONVERSION OF ENGLISH UNITS TO METRIC UNITS
C                   AND VICE VERSA
C     SUBROUTINE WRITTEN BY PPWB SYSTEMS STAFF - MAR/77 AND JAN/80
C     UPDATED BY PPWB SYSTEMS STAFF - NOV/84
C     INPUT ACCEPTED AND OUTPUT PRODUCED
C     1. CFS                  -CFS
C     2. ACRE-FEET               -AF
C     3. ACRES                  -AC.
C     4. CMS                   -M3S
C     5. CUDAMS                  -DAM
C     6. HECTARES                -HA.
C     7. INCHES                 -IN
C     8. FEET                  -FT
C     9. MILLIMETERS              -MM
C     10.METERS                 -M
      REAL*8  V2(IX,IY,IZ)
       CHARACTER*3 AAA
       DATA  AAA/'UNA'/
      GO TO (401,451,501,551,601,651,701,751,801,851),I1A
```

```
C
C**** CONVERT FROM CFS ***********************************************
401   GO TO (999,402,901,422,432,901,901,901,901,901),I1C
C
C     CONVERT TO ACRE-FEET
402   DO 403 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 403 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 403
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 1.983471074D0 * ITA(NT,IYR,1)
403   CONTINUE
      GO TO 999
C
C     CONVERT TO CMS
422   DO 423 NYR = 1,NMYR
      DO 423 NT = 1,NMT
      IF (V2(NT,NYR,NR) .EQ. (-99999.0D0)) GO TO 423
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 35.31466673D0
423   CONTINUE
      GO TO 999
C
C     CONVERT TO CUDAMS
432   DO 433 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 433 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 433
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 2.446575543D0 * ITA(NT,IYR,1)
433   CONTINUE
      GO TO 999
C
C**** CONVERT FROM ACRE-FEET *****************************************
451   GO TO (452,999,901,472,482,901,901,901,901,901),I1C
C
C     CONVERT TO CFS
452   DO 453 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 453 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 453
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 1.983471074D0 / ITA(NT,IYR,1)
453   CONTINUE
      GO TO 999
C
C     CONVERT TO CMS
472   DO 473 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 473 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 473
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 70.04561995D0 / ITA(NT,IYR,1)
473   CONTINUE
      GO TO 999
C
C     CONVERT TO CUDAMS
482   DO 483 NYR = 1,NMYR
```

```
      DO 483 NT = 1,NMT
      IF (V2(NT,NYR,NR) .EQ. (-99999.0D0)) GO TO 483
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 1.233481837D0
483   CONTINUE
      GO TO 999
C
C**** CONVERT FROM ACRES *********************************************
501   GO TO (901,901,999,901,901,502,901,901,901,901),I1C
C
C     CONVERT TO HECTARES
502   DO 503 NYR = 1,NMYR
      DO 503 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 503
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 0.404686D0
503   CONTINUE
      GO TO 999
C
C**** CONVERT FROM CMS ***********************************************
551   GO TO (552,562,901,999,582,901,901,901,901,901),I1C
C
C     CONVERT TO CFS
552   DO 553 NYR = 1,NMYR
      DO 553 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 553
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 35.31466673D0
553   CONTINUE
      GO TO 999
C
C     CONVERT TO ACRE-FEET
562   DO 563 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 563 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 563
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 70.04561995D0 * ITA(NT,IYR,1)
563   CONTINUE
      GO TO 999
C
C     CONVERT TO CUDAMS
582   DO 583 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 583 NT = 1,NMT
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 86.4D0 * ITA (NT,IYR,1)
583   CONTINUE
      GO TO 999
C
C**** CONVERT FROM CUDAMS ********************************************
601   GO TO (602,612,901,632,999,901,901,901,901,901),I1C
C
C     CONVERT TO CFS
602   DO 603 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 603 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 603
```

```
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 2.446575543D0 / ITA(NT,IYR,1)
603   CONTINUE
      GO TO 999
C
C     CONVERT TO ACRE-FEET
612   DO 613 NYR = 1,NMYR
      DO 613 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 613
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 1.233481837D0
613   CONTINUE
      GO TO 999
C
C     CONVERT TO CMS
632   DO 633 NYR = 1,NMYR
      IYR = IYRA + NYR - 1
      DO 633 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 633
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 86.4D0 / ITA(NT,IYR,1)
633   CONTINUE
      GO TO 999
C
C**** CONVERT FROM HECTARES ******************************************
651   GO TO (901,901,652,901,901,999,901,901,901,901),I1C
C
C     CONVERT TO ACRES
652   DO 653 NYR = 1,NMYR
      DO 653 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 653
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 2.471052D0
653   CONTINUE
      GO TO 999
C
C**** CONVERT FROM INCHES ********************************************
701   GO TO (901,901,901,901,901,901,999,702,712,722),I1C
C
C     CONVERT TO FEET
702   DO 703 NYR = 1,NMYR
      DO 703 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 703
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 12.0D0
703   CONTINUE
      GO TO 999
C
C     CONVERT TO MILLIMETERS
712   DO 713 NYR = 1,NMYR
      DO 713 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 713
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 25.4D0
713   CONTINUE
      GO TO 999
C
C     CONVERT TO METERS
722   DO 723 NYR = 1,NMYR
```

```
      DO 723 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 723
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 25.4D0 / 1000.0D0
723   CONTINUE
      GO TO 999
C
C**** CONVERT FROM FEET **********************************************
751   GO TO (901,901,901,901,901,901,752,999,762,772),I1C
C
C     CONVERT TO INCHES
752   DO 753 NYR = 1,NMYR
      DO 753 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 753
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 12.0D0
753   CONTINUE
      GO TO 999
C
C     CONVERT TO MILLIMETERS
762   DO 763 NYR = 1,NMYR
      DO 763 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 763
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 304.8D0
763   CONTINUE
      GO TO 999
C
C     CONVERT TO METERS
772   DO 773 NYR = 1,NMYR
      DO 773 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 773
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 0.3048D0
773   CONTINUE
      GO TO 999
C
C**** CONVERT FROM MILLIMETRES ****************************************
801   GO TO (901,901,901,901,901,901,802,812,999,822),I1C
C
C     CONVERT TO INCHES
802   DO 803 NYR = 1,NMYR
      DO 803 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 803
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 25.4D0
803   CONTINUE
      GO TO 999
C
C     CONVERT TO FEET
812   DO 813 NYR = 1,NMYR
      DO 813 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 813
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 304.8D0
813   CONTINUE
      GO TO 999
C
C     CONVERT TO METERS
```

```
822   DO 823 NYR = 1,NMYR
      DO 823 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 823
      V2(NT,NYR,NR) = V2(NT,NYR,NR) / 1000.0D0
823   CONTINUE
      GO TO 999
C
C**** CONVERT FROM METRES *********************************************
851   GO TO (901,901,901,901,901,901,852,862,872,999),I1C
C
C     CONVERT TO INCHES
852   DO 853 NYR = 1,NMYR
      DO 853 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 853
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 3.280839895D0 * 12D0
853   CONTINUE
      GO TO 999
C
C     CONVERT TO FEET
862   DO 863 NYR = 1,NMYR
      DO 863 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 863
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 3.280839895D0
863   CONTINUE
      GO TO 999
C
C     CONVERT TO MILLIMETERS
872   DO 873 NYR = 1,NMYR
      DO 873 NT = 1,NMT
      IF (V2(NT,NYR,NR).LT.0.0) GO TO 873
      V2(NT,NYR,NR) = V2(NT,NYR,NR) * 1000.0D0
873   CONTINUE
      GO TO 999
901                                   CALL STP (AAA,1)
999   RETURN
      END
C##########################################################################
      SUBROUTINE STP (AAA,NSTP)
C     SUBPROGRAM STP - DOCUMENTATION OF ABNORMAL END OF JOB
C     SUBPROGRAM WRITTEN OCT/74 BY PPWB STAFF
      CHARACTER*4 AAA
201   FORMAT (1H /////,' ABNORMAL END OF JOB - STOP NO.',I3,
     + ' IN PROGRAM ',A3)
      WRITE (2,201) NSTP,AAA
      STOP
      END
C##########################################################################
```

Appendix 2: List of Water Use Projects in NSR Basin Between Alberta Border and Deer Creek, SK

License	EDA/Non - EDA	OnStream	Source	Client	Project	Status	Allocation D	Purpose	Avg Use Dam3		
Projects outside of Effective Drainage Area											
05714	Non-EDA		Surface	PERKINS FREEMAN H		CATO	0				
07997	Non-EDA		Surface	DUSTOW HERBERT A		ATO	3	Domestic			
09669	Non-EDA		Surface	BROWN DOROTHY A		ATO	2	Domestic			
13800	Non-EDA		Surface	611206 SASKATCHEWAN LTD		ATO	2	Domestic			
										7	Allocations outside Effective Area
Projects in Effective drainage area but not from North Sask River											
00510	EDA	N	Surface	FRENCHMAN BUTTE RM OF	HAMLET OF FRENCHMAN BUTTE MUNICIPAL	ATO	4	Municipal	1.5		
05910	EDA	N	Surface	BUCKINGHAM MARGUERITE		ATO	3	Domestic			
06427	EDA	N	Surface	SYMES LIONEL A		ATO	4	Domestic			
06925	EDA	N	Surface	DUCKS UNLIMITED CANADA	ONION LAKE	ATC	0	Wildlife			
07246	EDA	N	Surface	DUCKS UNLIMITED CANADA	LONG LAKE PROJ	CATO	0				
12364	EDA	N	Surface	MUDGE MELVILLE R		ATO	2	Domestic			
14434	EDA	N	Surface	EATON LYNN M		ATC	110	Irrigation			
14441	EDA	N	Surface	FORT PITT HUTTERIAN BRETHREN		CATO	0				
14925	EDA	N	Surface	MAPLETOFT VEREDIANNA	MAPLETOFT A AND B PROJECTS	ATO	5	Domestic			
										126	Use or allocation if use not reported in EDA but not from NSR
Surface water projects directly from North Sask River											
13572	EDA	y	Surface	FORT PITT HUTTERIAN BRETHREN		CATO	0				
14566	EDA	Y	Surface	FORT PITT HUTTERIAN BRETHREN		CATO	0				
14612	EDA	Y	Surface	EATON DOUG H		APP	0	Irrigation			
16760	EDA	Y	Surface	FORT PITT HUTTERIAN BRETHREN		ATO	231	Intensive Livestock			
16761	EDA	Y	Surface	FORT PITT HUTTERIAN BRETHREN		ATO	2579	Irrigation			
16814	EDA	Y	Surface	GADSBY RANDY NORMAN		ATO	61	Irrigation			
										2871	Surface allocations directly from NSR
Groundwater Projects influenced by North Sask River.											
2797	EDA	Y	Ground	ONION LAKE FIRST NATION		ATO	610	Municipal	265		
4842	EDA	Y	Ground	BLACK PEARL RESOURCES INC	ONION LAKE FN SAGD	ATO	20	Oil Recovery			
4869	EDA		Ground	LAIDLER DOUG	(requested allocation)	APP	0.17	Domestic			
										285	GW Total (Use or allocation if no reported use)
										3282	

Appendix 3: List of Largest 83 Consumptive Use Projects in NSR Basin in Alberta

	Water Allocation ID	Stakeholder Name	Industrial Activity	Specific Activity	Net Licenced, dam^3	2008-2011 Average Reported Annual Diversion, dam^3	2008-2011 Average Reported Annual Return, dam^3	2008-2011 Average Reported Annual Consumptive Use, dam^3
1	1938	EPCOR POWER DEVELOPMENT CORPORATION	Commercial	COOLING	42,574	0	0	0
2	30262	CITY OF EDMONTON	Municipal	URBAN	30,696	0	0	0
3	18503	TRANSALTA CORPORATION	Commercial	COOLING	22,716	15,951	5,972	9,979
4	15186	DOW CHEMICAL CANADA ULC	Commercial	OTHR	21,493	5,613	0	5,613
5	30266	EPCOR POWER DEVELOPMENT CORPORATION	Commercial	COOLING	15,110	48,983	40,227	8,756
6	165665	CAPITAL POWER GENERATION SERVICES INC.	Commercial	COOLING	11,718	0	0	0
7	15061	CAPITAL POWER GP HOLDINGS INC.	Commercial	COOLING	11,064	18,720	9,137	9,583
8	34660	TRANSALTA CORPORATION	Commercial	COOLING	10,797	2,927	692	2,236
9	18489	CAPITAL POWER GENERATION SERVICES INC.	Commercial	COOLING	10,793	13,804	0	13,804
10	30265	EPCOR POWER DEVELOPMENT CORPORATION	Commercial	COOLING	10,223	0	0	0
11	34659	TRANSALTA CORPORATION	Commercial	COOLING	10,181	2,760	878	1,882
12	165619	AGRIUM PRODUCTS INC.	Commercial	OTHR	7,163	4,628	890	3,738
13	18453	AGRIUM PRODUCTS INC.	Commercial	OTHR	6,919	4,545	880	3,665

	Water Allocation ID	Stakeholder Name	Industrial Activity	Specific Activity	Net Licenced, dam^3	2008-2011 Average Reported Annual Diversion, dam^3	2008-2011 Average Reported Annual Return, dam^3	2008-2011 Average Reported Annual Consumptive Use, dam^3
14	103209	HUSKY OIL OPERATIONS LIMITED	Industrial	GAS/PTRO	6,753	4,604	0	4,604
15	183853	SHELL CANADA LIMITED |	Industrial	GAS/PTRO	6,564	5,116	0	5,116
16	30261	CITY OF EDMONTON	Municipal	URBAN	6,337	97,965	93,863	4,102
17	32194	SHELL CANADA LIMITED	Industrial	GAS/PTRO	6,202	5,479	2,193	3,286
18	28525	SHELL CANADA PRODUCTS LIMITED	Industrial	GAS/PTRO	5,059	1,936	0	1,936
19	16361	SHELL CHEMICALS CANADA LTD.	Commercial	OTHR	4,479	3,046	1,777	1,269
20	37317	TRANSALTA CORPORATION	Commercial	COOLING	4,441	5,554	3,230	2,324
21	21427	ECO-INDUSTRIAL BUSINESS PARK INC.	Commercial	OTHR	3,879	50	31	19
22	10857	ATCO GAS AND PIPELINES LTD.	Commercial	OTHR	3,700	0	0	0
23	28456	ECO-INDUSTRIAL BUSINESS PARK INC.	Commercial	OTHR	3,609	36	1	35
24	17961	IMPERIAL OIL RESOURCES LIMITED	Industrial	INJECTN	3,441	0	0	0
25	21997	IMPERIAL OIL RESOURCES LIMITED	Industrial	GAS/PTRO	3,369	3,948	1,545	2,403
26	103397	TERVITA CORPORATION	Commercial	OTHR	2,990	710	0	710
27	10296	CANADIAN NATURAL RESOURCES LIMITED	Industrial	INJECTN	2,985	65	0	65
28	9522	PENGROWTH ENERGY CORPORATION	Industrial	INJECTN	2,802	1	0	1
29	165608	SUNCOR ENERGY INC.	Industrial	GAS/PTRO	2,659	0	0	0
30	143616	TOWN OF DRAYTON VALLEY	Municipal	URBAN	2,430	1,127	0	1,127

	Water Allocation ID	Stakeholder Name	Industrial Activity	Specific Activity	Net Licenced, dam^3	2008-2011 Average Reported Annual Diversion, dam^3	2008-2011 Average Reported Annual Return, dam^3	2008-2011 Average Reported Annual Consumptive Use, dam^3
31	21017	PENN WEST PETROLEUM LTD.	Industrial	INJECTN	2,270	0	0	0
32	183134	PROVIDENT ENERGY LTD.	Commercial	OTHR	2,250	747	0	747
33	165736	IMPERIAL OIL RESOURCES LIMITED	Industrial	GAS/PTRO	2,130	2,566	1,078	1,488
34	166324	BP CANADA ENERGY COMPANY	Commercial	OTHR	2,048	19	0	19
35	13179	DEVON CANADA CORPORATION	Industrial	INJECTN	1,975	311	0	311
36	21548	SUNCOR ENERGY INC.	Industrial	GAS/PTRO	1,691	1,769	776	993
37	29058	ARC RESOURCES LTD.	Industrial	INJECTN	1,542	114	0	114
38	29789	SINOPEC DAYLIGHT ENERGY LTD.	Industrial	INJECTN	1,523	0	0	0
39	165617	PENN WEST PETROLEUM LTD.	Industrial	INJECTN	1,357	0	0	0
40	30270	SHERRITT INTERNATIONAL CORPORATION	Commercial	OTHR	1,341	822	401	421
41	30272	SHERRITT INTERNATIONAL CORPORATION	Commercial	OTHR	1,320	816	393	423
42	11723	CITY OF LLOYDMINSTER	Municipal	URBAN	1,122	4,071	3,649	422
43	9642	CANADIAN NATURAL RESOURCES LIMITED	Industrial	INJECTN	1,103	41	0	41
44	18769	UNIVERSITY OF ALTA	Commercial	COOLING	1,079	10,829	8,154	2,675
45	165647	UNIVERSITY OF ALTA	Commercial	COOLING	1,079	10,830	10,288	541
46	17486	KEYERA CORP.	Commercial	OTHR	995	472	0	472
47	30269	AGRIUM PRODUCTS INC.	Commercial	OTHR	987	1,542	307	1,234
48	21378	AGRIUM PRODUCTS INC.	Commercial	OTHR	975	1,523	304	1,219

	Water Allocation ID	Stakeholder Name	Industrial Activity	Specific Activity	Net Licenced, dam^3	2008-2011 Average Reported Annual Diversion, dam^3	2008-2011 Average Reported Annual Return, dam^3	2008-2011 Average Reported Annual Consumptive Use, dam^3
49	9670	CANADIAN NATURAL RESOURCES LIMITED	Industrial	INJECTN	968	39	0	39
50	18947	PENN WEST PETROLEUM LTD.	Industrial	INJECTN	900	62	0	62
51	22011	CANADIAN SALT COMPANY LIMITED, THE	Commercial	OTHR	871	3,751	3,398	353
52	165615	PENN WEST PETROLEUM LTD.	Industrial	INJECTN	867	0	0	0
53	137488	SINOPEC DAYLIGHT ENERGY LTD.	Industrial	INJECTN	852	284	0	284
54	116778	MANDERLEY TURF PRODUCTS INC.	Commercial	GRDN	755	251	0	251
55	30271	SHERRITT INTERNATIONAL CORPORATION	Commercial	OTHR	690	608	205	402
56	17347	PENN WEST PETROLEUM LTD.	Industrial	INJECTN	678	20	0	20
57	180659	PRAXAIR CANADA INC.	Commercial	COOLING	644	143	0	143
58	16256	MANDERLEY TURF PRODUCTS INC.	Commercial	GRDN	639	143	0	143
59	13779	TRANSALTA CORPORATION	Commercial	COOLING	617	214	54	160
60	13432	PRAXAIR CANADA INC.	Commercial	COOLING	609	348	197	151
61	13946	GULF CHEMICAL & METALLURGICAL CANADA CORPORATION	Commercial	OTHR	598	59	16	44
62	168183	PENN WEST PETROLEUM LTD.	Industrial	INJECTN	573	142	0	142
63	123485	ARC RESOURCES LTD.	Industrial	INJECTN	555	0	0	0

	Water Allocation ID	Stakeholder Name	Industrial Activity	Specific Activity	Net Licenced, dam^3	2008-2011 Average Reported Annual Diversion, dam^3	2008-2011 Average Reported Annual Return, dam^3	2008-2011 Average Reported Annual Consumptive Use, dam^3
64	137487	SINOPEC DAYLIGHT ENERGY LTD.	Industrial	INJECTN	543	275	0	275
65	21379	AGRIUM PRODUCTS INC.	Commercial	OTHR	514	802	160	642
66	19705	ARC RESOURCES LTD.	Industrial	INJECTN	416	5	0	5
67	13232	MANDERLEY TURF PRODUCTS INC.	Irrigation	CROP	406	497	0	497
68	29859	MANDERLEY TURF PRODUCTS INC.	Commercial	GRDN	389	243	0	243
69	17981	SUNCOR ENERGY	Industrial	INJECTN	383	124	0	124
70	9675	CANADIAN NATURAL RESOURCES LIMITED	Industrial	INJECTN	370	32	0	32
71	21510	TOWN OF ST. PAUL	Municipal	URBAN	370	862	0	862
72	202434	MANDERLEY SOD	Commercial	GRDN	370	106	0	106
73	20969	LAFARGE CANADA INC.	Commercial	AGGWSH	358	263	184	79
74	10317	MANDERLEY TURF PRODUCTS INC.	Commercial	GRDN	347	45	0	45
75	165735	CANADIAN SALT COMPANY LIMITED, THE	Commercial	OTHR	333	612	561	51
76	165616	PENN WEST PETROLEUM LTD.	Industrial	INJECTN	313	0	0	0
77	20979	ENERPLUS CORPORATION	Industrial	INJECTN	308	139	0	139
78	113337	MANDERLEY TURF PRODUCTS INC.	Commercial	GRDN	265	138	0	138
79	166268	MANDERLEY TURF PRODUCTS INC.	Commercial	GRDN	243	143	0	143
80	166267	MANDERLEY TURF PRODUCTS INC.	Commercial	GRDN	215	0	0	0

	Water Allocation ID	Stakeholder Name	Industrial Activity	Specific Activity	Net Licenced, dam^3	2008-2011 Average Reported Annual Diversion, dam^3	2008-2011 Average Reported Annual Return, dam^3	2008-2011 Average Reported Annual Consumptive Use, dam^3
81	20971	ARC RESOURCES LTD.	Industrial	INJECTN	123	221	0	221
82	15732	BP CANADA ENERGY COMPANY	Commercial	OTHR	49	19	0	19
83	166325	BP CANADA ENERGY COMPANY	Commercial	OTHR	49	33	0	33

Appendix 3: Estimation of Travel Times from Lake Abraham and Brazeau Reservoir to Deer Creek

In order to estimate the actual travel times from the two reservoirs to the apportionment point, the daily mean flow records along the North Saskatchewan River were examined to estimate how long various flows at each station take to reach the downstream station. The following were the findings from the analysis for each section of the river.

Bighorn Dam to Rocky Mountain House

For this segment of the river the flows measured at the station Clearwater River near Dovercourt (05DB006) were also used in order to isolate fluctuations at the North Saskatchewan River near Rocky Mountain House due to changes in flow at the dam. Generally, the flow from the Clearwater River is a small fraction of the flow in the main stem; however, there are instances in the record where flow equals or exceeds the flow coming out of Lake Abraham. Specifically, events on the North Saskatchewan that had a distinct peak or low flow day during which flow at the Clearwater station was either steady or trending opposite to the flow at the station below Bighorn were sought out in the record. The comparison found that most changes in flow at the dam are reflected at the station near Rocky Mountain House the following day, this includes days of very low flow. It was also apparent that there is a threshold above which the change in flow at the Bighorn station shows up on the same day. This appears to occur at a flow rate of about 150 m^3/s, although there is some overlap. Figure A10-1 illustrates the results of the comparison.

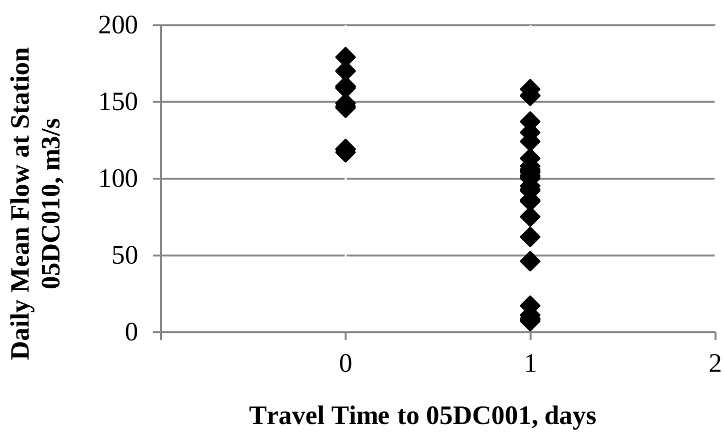

Figure A10-1: Number of days travel time for various flows from the station North Saskatchewan River below Bighorn Dam (05DC010) to be reflected at downstream station North Saskatchewan River near Rocky Mountain House (05DC001).

Rocky Mountain House to Lodgepole and Brazeau Dam to Lodgepole

In a similar process, the flow record measured in the main stem near Rocky Mountain House (05DC001) was compared to the record from the station North Saskatchewan River near Lodgepole (05DE006). In between these two stations the Brazeau River and the Nordegg River flow into the North Saskatchewan. The flow recorded at the station Brazeau River below Brazeau Plant (05DD005) and Nordegg River at Sunchild Road (05DD009) were reviewed alongside the two stations in question in order to take into consideration their effect on the flow at Lodgepole. The flow in the Nordegg River is very small compared to the main stem and therefore creates little interference in identifying the impact of flows from further upstream. Although generally lower, inflow from the Brazeau can also frequently be on par with flow coming through the North Saskatchewan River near Rocky Mountain House. The results are shown in Figure A10-2. Similar to the section upstream, flows were reflected either the same day or the following day with the distinction occurring at around 100 m^3/s.

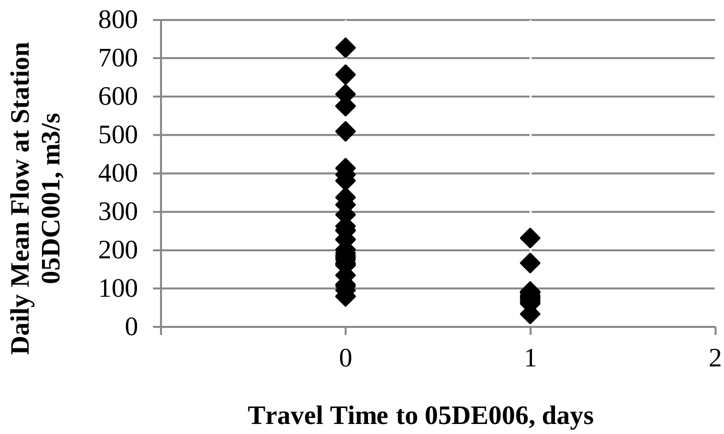

Figure A10-2: Number of days travel time for various flows from the station North Saskatchewan River near Rocky Mountain House (05DC001) to be reflected at downstream station North Saskatchewan River near Lodgepole (05DE006).

In addition to trying to isolate the effects of changes in flow at Rocky Mountain House on the flow at Lodgepole, the same was done for changes in flow measured at the Brazeau River station. In that case, the record was explored for instances where the flow out of the Brazeau Dam was adjusted while flow at the other two stations were stationary enough so as not to drown out the change in flow from the Brazeau River. Fifty six such events were selected from the record with flows on the Brazeau ranging from a maximum of 337 m^3/s to a minimum of zero. In all but two cases the associated high or low flow at the Lodgepole station was recorded on the same day; the distance between the two stations is only approximately 34 km.

Lodgepole to Edmonton

Between the station near Lodgepole (05DE006) and the station at Edmonton (05DF001) there are several gauged tributaries that add flow to the North Saskatchewan; the station names are as follows:

- Rose Creek near Alder Flats (05DE007)
- Tomahawk Creek near Tomahawk (05DE009)
- Strawberry Creek near the Mouth (05DF004)
- Week Creek at Thorsby (05DF008)
- Whitemud Creek near Ellerslie(05DF006)
- Blackmud Creek near Ellerslie (05DF003)

Generally speaking, the flows measured at these stations are small enough that they are drowned out by the flow coming from upstream on the North Saskatchewan River, with maximum mean daily flows on these tributaries of less than 20 m^3/s. However, Rose Creek and Strawberry Creek can produce flows in the 50-100 m^3/s and even up to 200 m^3/s. Whitemud and Blackmud Creek only register flow in a handful of days each year and rarely greater than 10 m^3/s. Comparing the recorded mean daily levels at Lodgepole to the mean daily flows recorded at Edmonton a pattern of travel times is evident. Figure A10-3 shows the results and can be summarized that water levels of less than about 2.7 m at Lodgepole (a level station) are reflected at Edmonton approximately 2 days later, whereas flows associated with levels greater than that show up in the record the following day.

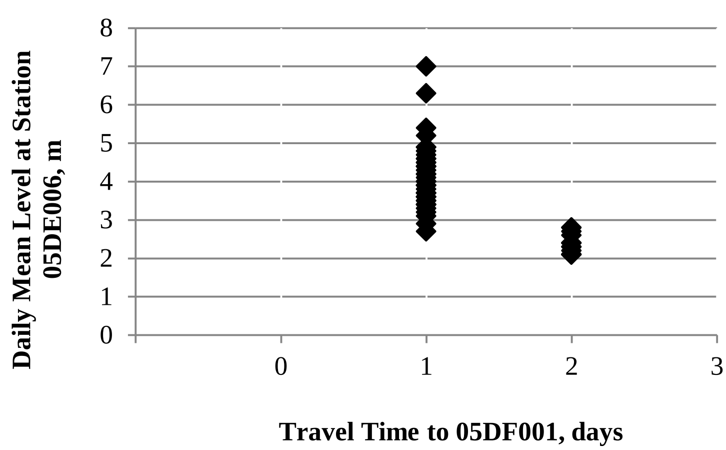

Figure A10-3: Number of days travel time for various levels from the station North Saskatchewan River near Lodgepole (05DE006) to be reflected at downstream station North Saskatchewan River at Edmonton (05DF001).

Edmonton to Deer Creek

Between the station at Edmonton (05DF001) and the station North Saskatchewan River near Deer Creek (05EF001) there are again several tributaries that contribute flow to the North Saskatchewan River. Some of the available gauged inflows include:

- Sturgeon River near Fort Saskatchewan (05EA001)
- Vermilion River at Lea Park (05EE002)

Flows at both these stations are relatively small compared to the flow from upstream on the main stem. The recorded maximum mean daily flows at each station are 115 m^3/s and 77 m^3/s, however, their respective mean daily flows are only 4 m^3/s and 2 m^3/s. When comparing the flows recorded at Edmonton and at Deer Creek, the flows recorded at these stations, and at the station Atimoswe Creek near Elk Point (05ED002), were useful in getting a general sense of local runoff conditions. Figure A10-4 shows the results of the travel time analysis between Edmonton and Deer Creek. Comparing mean daily flows it was found that flows of greater than approximately 500 m^3/s at Edmonton are reflected at Deer Creek in about 2 days, flows of between approximately 200 and 500 m^3/s appear in about 3 days, and flows of less than approximately 200 m^3/s can take 4+ days.

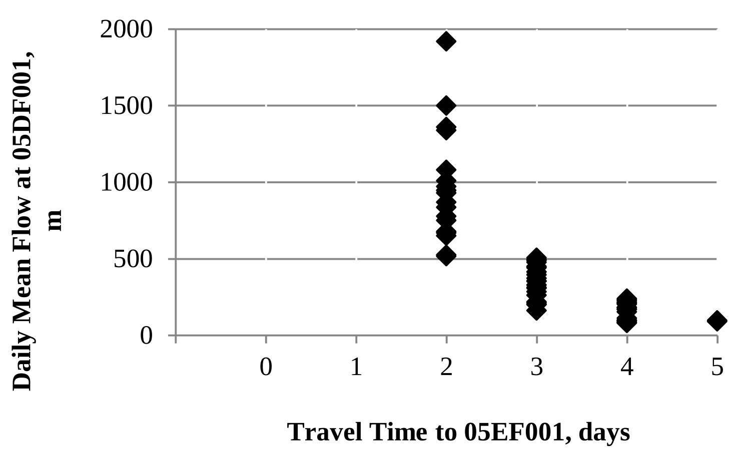

Figure A10-4: Number of days travel time for various flows at station North Saskatchewan River at Edmonton (05DF001) to be reflected at downstream station North Saskatchewan River near Deer Creek (05EF001).

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