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# PRAIRIE PROVINCES WATER BOARD

## Report #178

# Basin Review Calculation of Apportionable Flow for the Saskatchewan River at the Saskatchewan/Manitoba Boundary

Prepared by Optimal Solutions Ltd
Recommended by the PPWB Committee on Hydrology
Approved by the Prairie Provinces Water Board

November 2017

# BASIN REVIEW
# CALCULATION OF APPORTIONABLE FLOW
# FOR THE
# SASKATCHEWAN RIVER
# AT THE
# SASKATCHEWAN-MANITOBA BOUNDARY

**SUBMITTED TO:**

**THE PRAIRIE PROVINCES WATER BOARD**
**COMMITTEE ON HYDROLOGY**

**BY**
**OPTIMAL SOLUTIONS LTD.**
**CALGARY, ALBERTA**

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**Erin Zoski, Environment and Climate Change Canada, Regina**

**Ron Woodvine, Agriculture and Agri-Food Canada, Regina**

**Bart Oegema, Saskatchewan Watershed Authority, Moose Jaw**

**Megan Garner, Environment and Climate Change Canada, Regina**

**Jeff Hovdebo, Saskatchewan Watershed Authority, Moose Jaw**

**Mike Renouf, Environment and Climate Change Canada, Regina**

## EXECUTIVE SUMMARY

This study has been initiated and funded by the Prairie Provinces Water Board. Its goal is to critically examine the current procedure used for calculation of apportionable flows in the Saskatchewan River Basin. A short summary of the relevant findings includes the following:

a) The Project Depletion Method should continue to be used as the only viable calculation method in the Saskatchewan River Basin.
b) The existing water use components often do not adequately represent the current level of water use, and they should be updated where necessary based on the analyses and options provided in this report.
c) The existence of some large wildlife and unclassified water licenses which are currently excluded from calculation as mentioned in Section 4 should be re-evaluated by the COH based on the best available information related to the originally licensed purposes and the current water use practices.
d) COH should consider including the sum of numerous existing smaller water licenses listed in Section 4 that are located within the effective drainage area by assuming the current level of water use and by using the suggested monthly distributions and return flow factors related to various types of water use.
e) Storage changes and net evaporation on reservoirs should continue to be included in the calculation, but they should also be updated to include negative net evaporation and suggested corrections to the storage capacity curves as outlined in this report. Inclusion of net evaporation on Codette Lake should also be considered.
f) Time of Travel equations have been analyzed based on the available data. Options for updating travel time calculations are presented in Section 5 of this report.

All identified options for the apportionable flow calculation considered by the COH are summarized in Section 8 of this report and the options approved for use in the revised apportionable flow calculation are noted.

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# 1. INTRODUCTION

## 1.1 Study Background

On October 30, 1969, the governments of Canada, Alberta, Saskatchewan and Manitoba entered into the ***“Master Agreement on Apportionment”*** (MAA). Among other things, the Agreement:

- Provided a formula for the apportionment of the “natural flow” of eastward flowing interprovincial streams, and
- Reconstituted the Prairie Provinces Water Board (PPWB) to administer the Agreement.

The sharing of waters of eastward flowing streams between Saskatchewan and Manitoba is governed by “Schedule B” of the Agreement, a detailed discussion of which is carried out in Section 3 of this document. In order to facilitate collaboration on water sharing issues, the PPWB has created specialty committees to advise on various aspects of the Agreement (e.g. surface water, groundwater, water quality, etc.). One such committee is the Committee on Hydrology (COH) which has been given responsibility to directly oversee issues related to surface water quantity, including:

- Monitoring and reporting on the apportionable flows at the Alberta/Saskatchewan and Saskatchewan/Manitoba interprovincial boundaries, and
- Establishing the methods by which to determine the apportionable flow for each watercourse flowing across the interprovincial boundaries.

The Saskatchewan River, and specifically the Saskatchewan River at the Saskatchewan/Manitoba Boundary, is one of the rivers that are subject to sharing under Schedule B of the Master Agreement. In 1976, the PPWB COH issued the report “Natural Flow – Saskatchewan River at Saskatchewan Manitoba Boundary”. This report describes the procedures approved by the PPWB for the calculation of the apportionable flow for the Saskatchewan River at the Saskatchewan/Manitoba Boundary. Apportionment monitoring for the Saskatchewan River at the Saskatchewan/Manitoba Boundary subsequently began in 1977. While some minor modifications have been made to the procedures since that time, there has been no comprehensive review to ensure the procedures continue to meet the needs of the PPWB for monitoring apportionment under the MAA.

In 2011, the PPWB COH embarked on a process of reviewing the apportionable flow calculation procedures for each of the basins subject to apportionment under the MAA, including the Saskatchewan River at the Saskatchewan/Manitoba Boundary. The purpose of the reviews is to ensure regular evaluations and improvements to the apportionable flow computation procedures. Within the context of the foregoing discussion, the purpose of this report is to *review and update* *the apportionable flow calculation procedures used by the PPWB for the Saskatchewan River at the Saskatchewan/Manitoba interprovincial boundary.*

## 1.2 Report Overview

This report begins by describing PPWB's initiative to review the apportionable flow computation procedures for all streams covered under the *Master Agreement on Apportionment*, and the role of this report under this broader context (Section 1). The report then provides an overview of the basin geography, climate and hydrology in Section 2. Section 3 discusses details of the existing apportionment computation procedures for the Saskatchewan River at the Saskatchewan / Manitoba Boundary. The differences between current and documented procedures are discussed as well as other models that could be used for the computation of apportionable flow. Section 4 provides analyses of the current water use included in the calculation procedure and it also contains options for future modifications of this important component in the assessment of apportionable flows. Section 5 examines the existing travel time formulas that are used in the calculations and makes recommendations to additional future assessments based on the findings provided in this study. Section 6 explains why land use change and channel losses are not part of the evaluation of apportionable flows in the Saskatchewan River Basin, while Section 7 addresses net evaporation calculation options. Section 8 summarizes the options that were identified for updating the apportionable flow computation procedures, and Section 9 assesses the overall impact of the refinements selected by the COH on the calculation of apportionable flows at the interprovincial boundary. Section 10 identifies the hydrometric data, Section 11 the meteorological data and Section 12 other data that is required for the updated apportionable flow calculations. Section 13 comments on future action regarding review of apportionable flow computation procedures for the Saskatchewan River basin, and Section 13 summarizes the conclusions and recommendations from the current basin review. Finally, Appendix A contains tables which provide historic changes to the calculation procedure since it was originally established and the storage capacity curves for reservoirs that are currently included in the calculation of apportionable flows.

## 1.3 Terms and Definitions

Due to a number of terms often being used interchangeably, including *natural flow* and *apportionable flow*, *diversion, consumption*, and *water use*, there can be confusion related to their precise meanings. To provide clarity, the following definitions are used throughout this report:

Natural flow – as defined in Schedule B, natural flow means "*the quantity of water which would naturally flow in any water course had the flow not been affected by human interference or human intervention*".

Apportionable flow – refers to the flow that is subject to sharing between two provinces as defined in the MAA. In terms of the Saskatchewan River at the Saskatchewan/Manitoba Boundary, *apportionable flow* means the quantity of water entering Saskatchewan from Alberta via the Saskatchewan River and its tributaries plus the natural flow arising within the Saskatchewan portion of the Saskatchewan River Basin, which is estimated using methods and procedures approved by the PPWB.

Water allocation – refers to the maximum amount of water that can be diverted in a calendar year, as set out in water licenses and/or registrations.

Water diversion – refers to the actual amount of water being diverted from a surface or groundwater source, either permanently or temporarily, in a given time period, being generally a calendar year. The actual amount of water diverted during any one year may vary due to weather conditions, water availability and/or changes in operations.

Water consumption or consumptive use – refers to the amount of water that is, or is expected to be, used for the intended purpose.

Losses – refers to that portion of a diversion that is lost due to items such as evaporation, seepage, leakage, etc.

Return flow – refers to that portion of a diversion that is returned to a water body, be it the source water body or some other water body, and may be available for reuse.

Water use – refers to the sum of water consumption and losses or, alternatively, represents the difference between water diverted and returns.

Flow depletion – refers to the actual quantity of water removed from a water body or river reach. It is comprised of water consumption, water losses and return flow to another water body or river reach, and it represents the actual quantity of water that has been removed from a water body or a stream.

Gross drainage area is the land surface area that can be expected to contribute surface runoff to a given body of water under extremely wet conditions. It is defined by the topographic divide (height of land) between the water body under consideration and adjoining watersheds.

Effective/Contributing drainage area is that portion of the gross drainage area that can be expected to contribute surface runoff to a body of water during a flood with a return period of two years. The effective drainage area excludes portions of the gross drainage area that drain to peripheral marshes, sloughs and other natural depressions that do not contribute to runoff in an average year.

Non-effective/non-contributing drainage area is that portion of the gross drainage area which is expected to not contribute surface runoff to a body of water, in this case the Saskatchewan River, during a flood event with less or equal to the return period of two years. The non-contributing drainage area includes portions of the gross drainage area that drain to peripheral marshes, sloughs and other natural depressions that do not contribute to runoff in an average year.

This report uses metric units. Table 1.1 provides the conversion factors to Imperial units.

**Table 1.1 Unit Conversion Factors**

| | **Metric Units** | **Imperial Units** |
|---|---|---|
| Length | 1.0 millimeter (mm) | = 0.0394 inches (in) |
| | 1.0 meter (m) | = 3.28084 feet (ft) |
| | 1.0 kilometer (km) | = 0.6214 miles (mi) |
| Area | 1.0 hectare (ha) | = 2.4711 acres (ac) |
| | 1.0 square kilometer (km$^2$) | = 0.3861 square miles (mi$^2$) |
| Volume | 1.0 cubic meter (m$^3$) | = 35.3155 cubic feet (ft$^3$) |
| | 1.0 cubic decameter (dam$^3$) = 1000 (m$^3$) | = 0.8107 acre-feet (ac-ft) |

## 2. BASIN OVERVIEW

### 2.1 Basin Geography

The Saskatchewan River basin is a large basin that extends from the frontal ranges of the Alberta and Montana Rocky Mountains and flows across Alberta, Saskatchewan, and part of Manitoba (Figure 2.1) before entering Lake Winnipeg and draining into the Hudson Bay via the Nelson River system. From its source in the Rocky Mountains, where elevations can reach in excess of 3,500 m above sea level, the river travels a distance of about 1950 km before discharging emptying into Lake Winnipeg near Grand Rapids, at an elevation of about 220 m above sea level. At its entry into Lake Winnipeg, the Saskatchewan River has drained about 406,000 km$^2$ of terrain that includes high elevation glacial alpine, foothills, boreal forests, Canadian Shield, and prairie grassland ecozones.

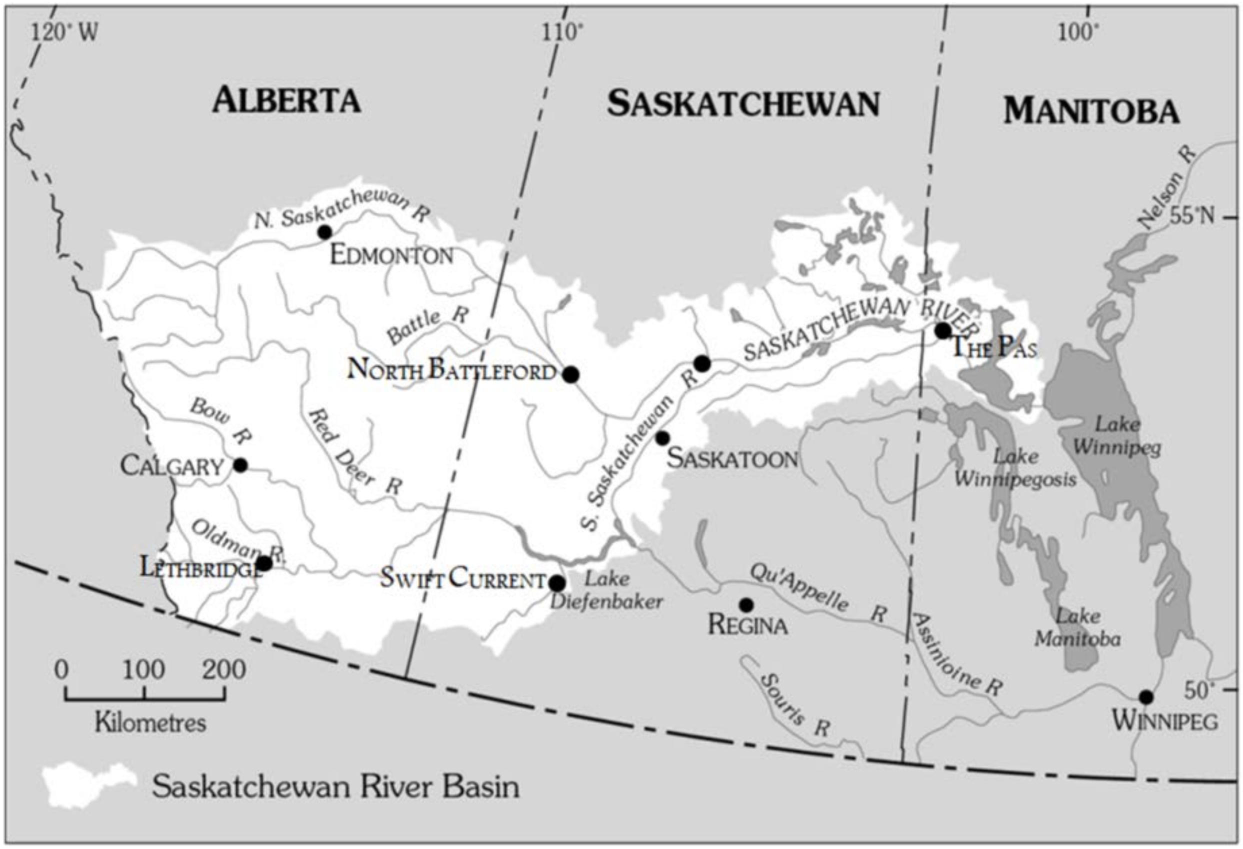

**Figure 2.1 Saskatchewan River Basin (source: http://seawa.ca/test/north-south-sask-river-basins/ )**

The basin is home to approximately 2.8 million people (2015 Statics Canada) in Alberta, of which about 2.3 million live in the greater Edmonton and Calgary areas, and to about 330,000 people live in Saskatchewan, of which about 230,000 live in the City of Saskatoon.

The Saskatchewan River basin experiences a cold continental climate with normal temperatures varying from about 5 to 6°C for areas in south eastern Alberta to about -1°C for areas in the extreme north-eastern parts of the basin (Figure 2.2). Winters are generally long and cold with mean monthly temperatures falling to below -15°C while summers are short and warm with mean monthly temperatures generally below 20°C (Figure 2.3).

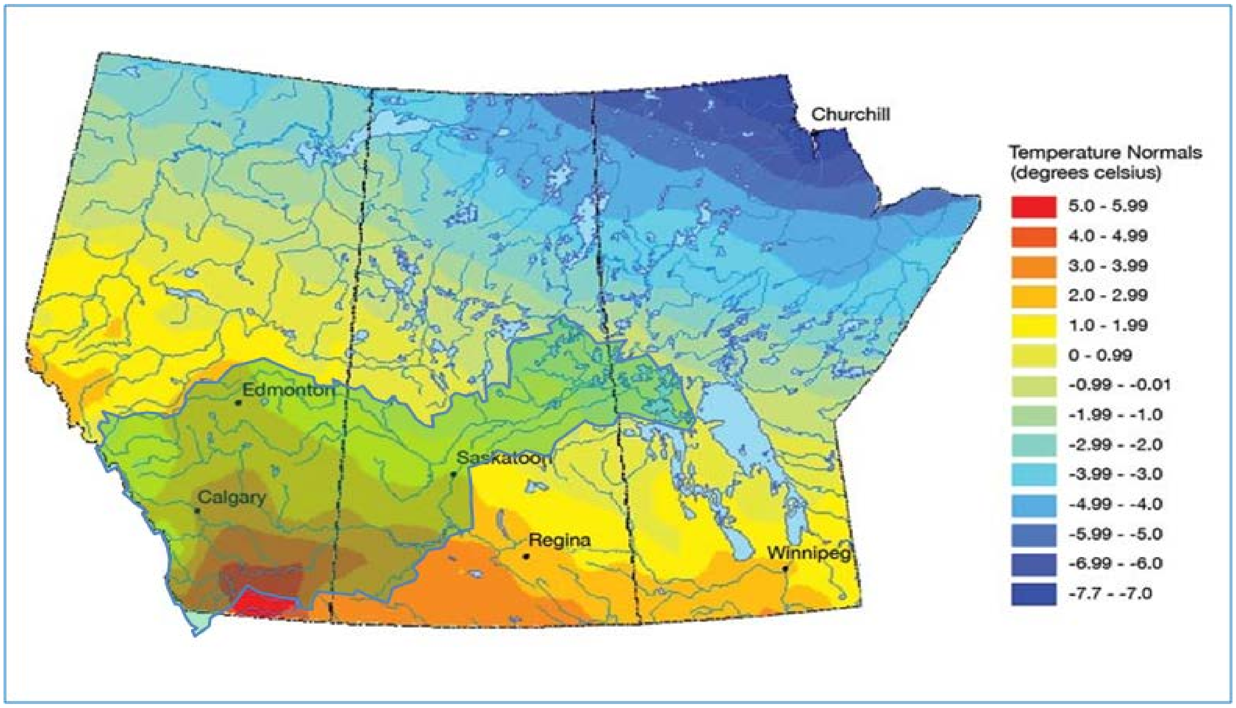

**Figure 2.2 Temperature Normals for the Canadian Prairies (adapted from map by NRCAN http://www.nrcan.gc.ca/sites/www.nrcan.gc.ca/files/earthsciences/jpg/assess/2007/ch7/images/fig4_a_e.jpg)**

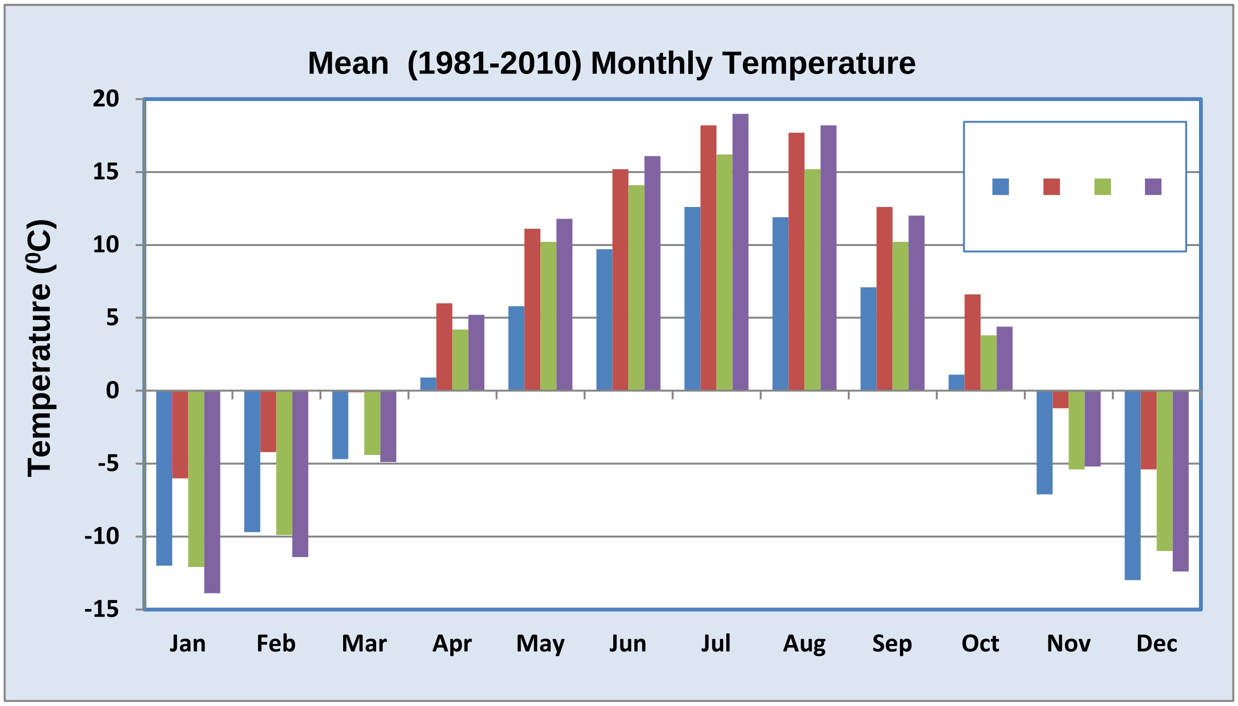

**Figure 2.3 Mean (1981-2010) Monthly Temperature (${}^{0}$C) for Key Sites in the Saskatchewan River Basin (Data source: Environment Canada, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html )**

## 2.2 Basin Hydrology

### 2.2.1 Basin Layout

The Saskatchewan River is formed in central Saskatchewan by the confluence of its two major tributaries, the North and South Saskatchewan Rivers, about 40 kilometers east of Prince Albert, at the Saskatchewan River Forks (Figure 2.1). The North Saskatchewan River originates at the toes of the Saskatchewan Glacier of the Columbia Ice fields, which straddle the Continental Divide of the Alberta Rockies, and flows in a northeasterly direction to the City of Edmonton. The North Saskatchewan River then flows east to the Alberta-Saskatchewan boundary and from where flows in a southeasterly direction to North Battleford where it is joined by the Battle River, a prairie stream originating in the western Alberta plains. The river continues in a southeasterly direction to its confluence with Eagle Creek, a tributary whose source is in Saskatchewan. It then swings into a northeast direction to Prince Albert and on to the "Forks" where it is joined by the South Saskatchewan River to form the Saskatchewan River (Figure 2.1). The flow of the North Saskatchewan River and its major tributary that originates in Alberta (the Battle River) are both gauged at the Alberta-Saskatchewan Boundary where they are, independently, subject to Schedule A of the MAA. Schedule A requires Alberta to allow 50% of the annual natural flow of each of the two rivers to flow into Saskatchewan.

The South Saskatchewan River is formed by the confluence of two main tributaries, the Oldman and Bow Rivers. The Oldman River, the southerly tributary, originates in the south west corner of the Alberta Rockies and flows in an easterly direction to Lethbridge. Prior to reaching Lethbridge, the Oldman River provides irrigation water to about 71,000 hectares of land within the Lethbridge Northern Irrigation District and is subsequently joined by three smaller tributaries, the Waterton, Belly and St Mary Rivers, which have their origin in the Glacier National Park in Montana. These three tributaries also provide irrigation water to about 150,000 hectares of land within the St Mary River Irrigation District. Because these streams have their source in Montana, they are subject to provisions of the 1909 Boundary Waters Treaty between Canada and the United States. From Lethbridge, the Oldman River flows east to its confluence with the Bow River to form the South Saskatchewan River. The Bow River has its source at the mouth of the Bow Glacier in the Alberta Rocky Mountains north-west of Banff. The river flows in a southeasterly direction to the City of Calgary. Downstream of the City of Calgary and prior to its confluence with the Oldman River, the Bow River provides irrigation water to about 39,000 hectares of land in the Western Irrigation District, to about 105,000 hectares of land in the Bow River Irrigation District and to about 121,000 hectares in the Eastern Irrigation District. After the confluence of the Bow and Oldman Rivers, the South Saskatchewan River flows east through the Palliser Triangle, one of the most arid areas in Canada, and past the City of Medicine Hat where it is joined by several small streams rising in the Cypress Hills. Past Medicine Hat, the South Saskatchewan River flows northeast into Saskatchewan. About 16 kilometers downstream of the

Alberta-Saskatchewan Boundary the South Saskatchewan River is joined by the Red Deer River, a major tributary which has its source in the Sawback Range of the Alberta Rockies. While the Red Deer and South Saskatchewan Rivers cross the Alberta-Saskatchewan Boundary independently, they are subject to the MAA as a single entity with the apportionment point being *"…at the option of Alberta, a point at or as near as reasonably may be below the confluence of the said two rivers [Red Deer and South Saskatchewan*]"[1]. Furthermore, in recognition of Alberta's allocations prior to the Agreement, the MAA provides that:

> "*Alberta shall be entitled in each year to consume, or divert, or store for its consumptive use a minimum of 2,100,000 acre-feet net depletion of flow of the … South Saskatchewan ... even though its share for the said year would be … more than one-half the natural [apportionable] flow … provided the actual flow at the said apportionment point does not fall to… less than 1,500 cubic feet per second*."

From its confluence with the Red Deer River, the South Saskatchewan River flows east to its confluence with Swift Current Creek, a small stream originating in the Saskatchewan portion of the Cypress Hills, before emptying into Lake Diefenbaker, a reservoir formed by the construction of the Qu'Appelle River Dam and the Gardiner Dam. Exiting Lake Diefenbaker, the South Saskatchewan flows north-east to Saskatoon and on to its confluence with the North Saskatchewan River to form the Saskatchewan River. The combined stream then flows north-east into Codette Lake, formed by the Francois Finley Hydroelectric Dam near Nipawin, and then into Tobin Lake, formed by the E.B. Campbell Hydroelectric Dam. It then flows northeast passing through a region of marshes, where it is joined by the Torch and the Mossy River. At the northern edge of the marshes it flows east between a series of small lakes and is joined by the Sturgeon-weir River, a westward flowing tributary having part of its source in Manitoba, prior to flowing into west central Manitoba. Downstream of the Saskatchewan-Manitoba Boundary the Saskatchewan River is joined by the Carrot River just prior to reaching The Pas, Manitoba. Southeast of The Pas, it forms several streams in a delta on the Northwest side of Cedar Lake, then exits the lake on the southeast end and flows into Lake Winnipeg.

### 2.2.2 Precipitation

Precipitation across the Saskatchewan River basin is highly variable, ranging from about 1,500 mm per year in some of the high elevation mountain areas to about 300 mm per year in the semi-arid prairie zone in the rain shadow of the mountains, which forms the Palliser Triangle. Within the rest of the basin, precipitation is generally in the order of 400-500 mm (Figure 2.4). As shown in Figure 2.5, with the exception of the extreme back ranges of the Rocky Mountains, throughout the basin most of the annual precipitation falls in the late spring and summer with the

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[1] Prairie Provinces Water Board, "The 1969 *Master Agreement on Apportionment*"

month of June generally experiencing the highest precipitation in the eastern and southern plains areas and July being the highest month in the Edmonton area. Throughout the prairie region, about 30% of the precipitation falls in the form of snow as shown in Figure 2.6 for Saskatoon.

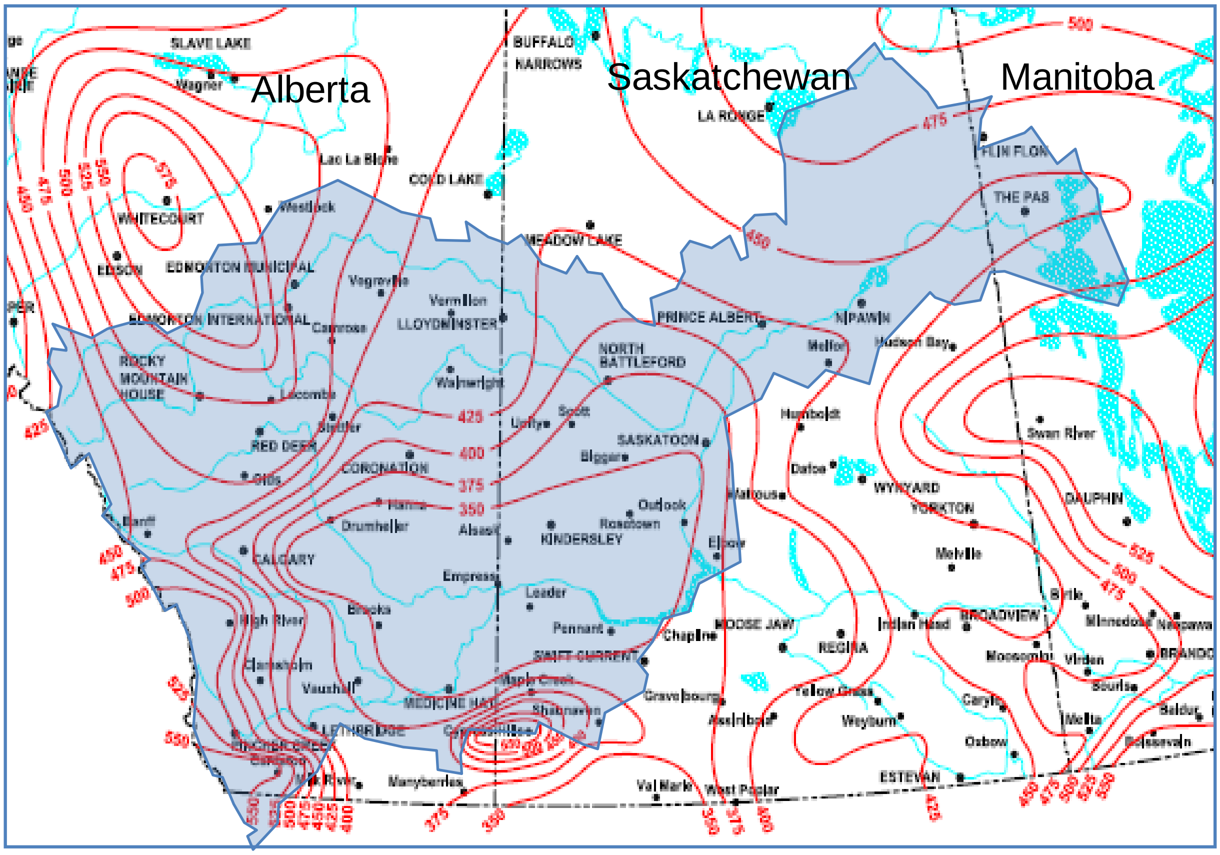

**Figure 2.4 Mean annual precipitation (mm) in the Saskatchewan River Basin (1971-2000) (Adapted from: AAFC Mean annual precipitation in Canadian Prairies)**

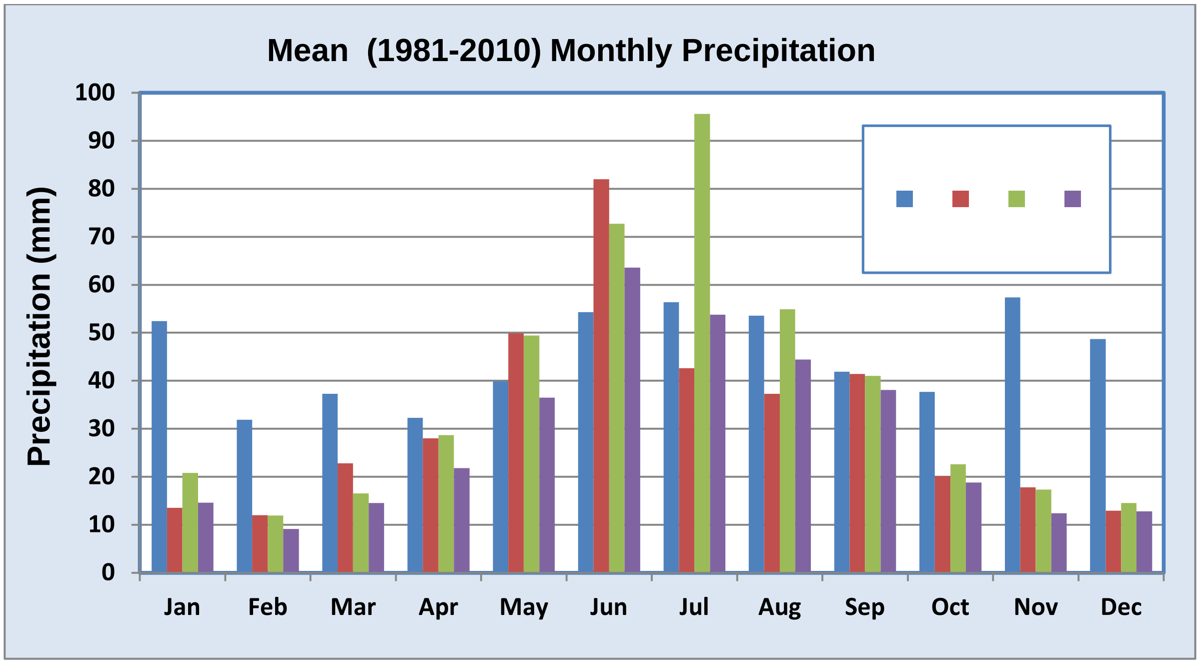

**Figure 2.5 Mean (1981-2010) monthly precipitation (mm) at sites in the Saskatchewan River Basin(Data source: Environment Canada, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html )**

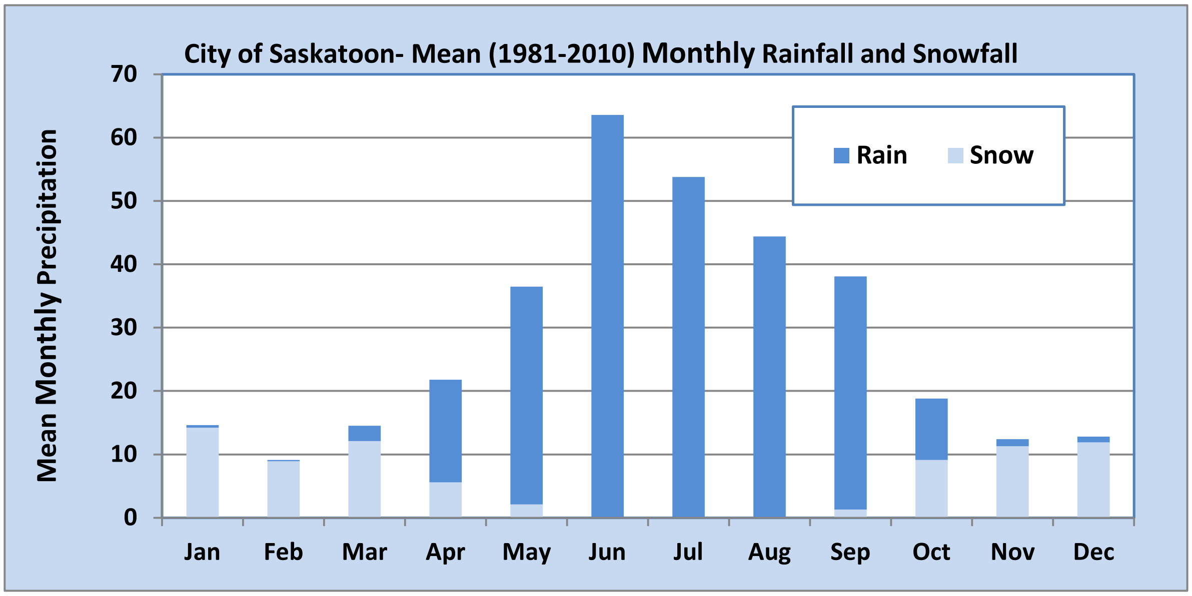

**Figure 2.6 City of Saskatoon - Mean (1981-2010) Monthly Rainfall and Snowfall. (Data source: Environment Canada, Canadian Climate Normals. http://climate.weather.gc.ca/climate_normals/index_e.html)**

### 2.2.3 Gross Evaporation

Mean annual gross evaporation within the Saskatchewan River Basin generally increases in a southerly direction from about 500 mm in the extreme northeast corner of the basin and mountain areas to about 1050 mm in the southwest parts of Saskatchewan and southeast Alberta (Figure 2.7). As shown in Figure 2.8, most of the evaporation occurs in the months of May to September.

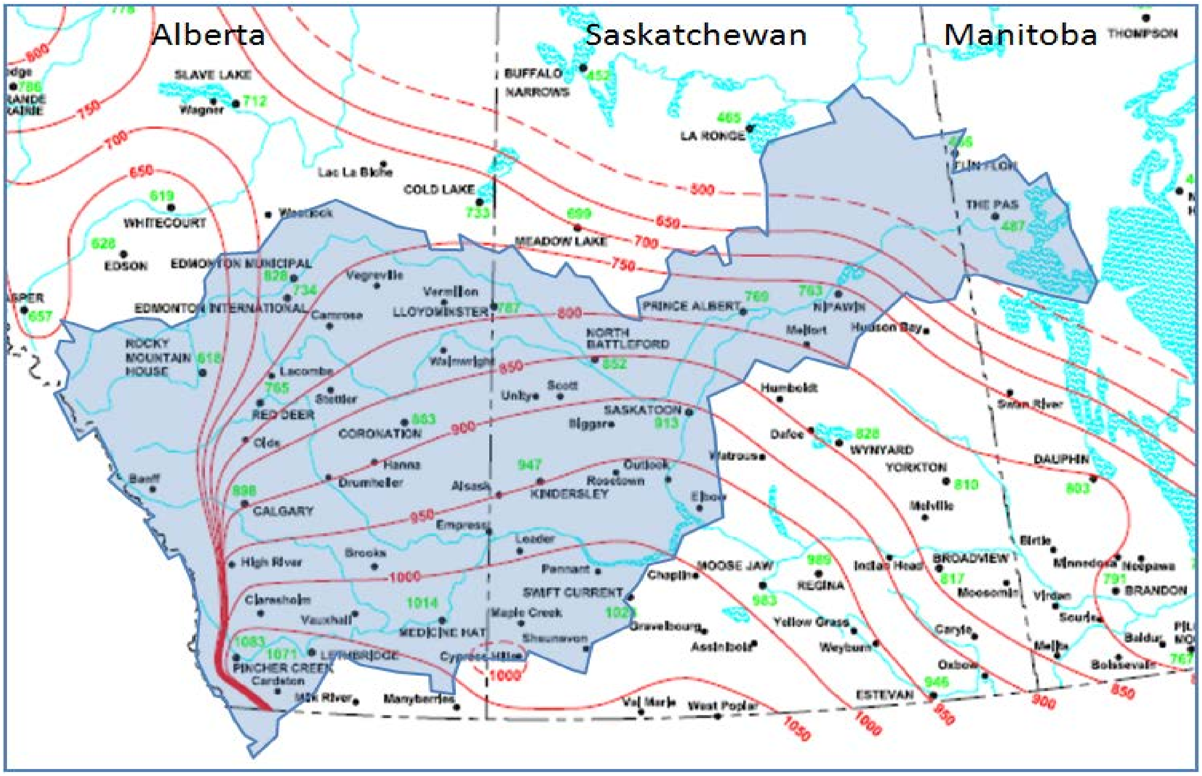

**Figure 2.7 Mean annual gross evaporation (mm) in Saskatchewan River Basin (1971-2000)**
**(Adapted from: AAFC map of Annual Gross Evaporation for Canadian Prairies)**

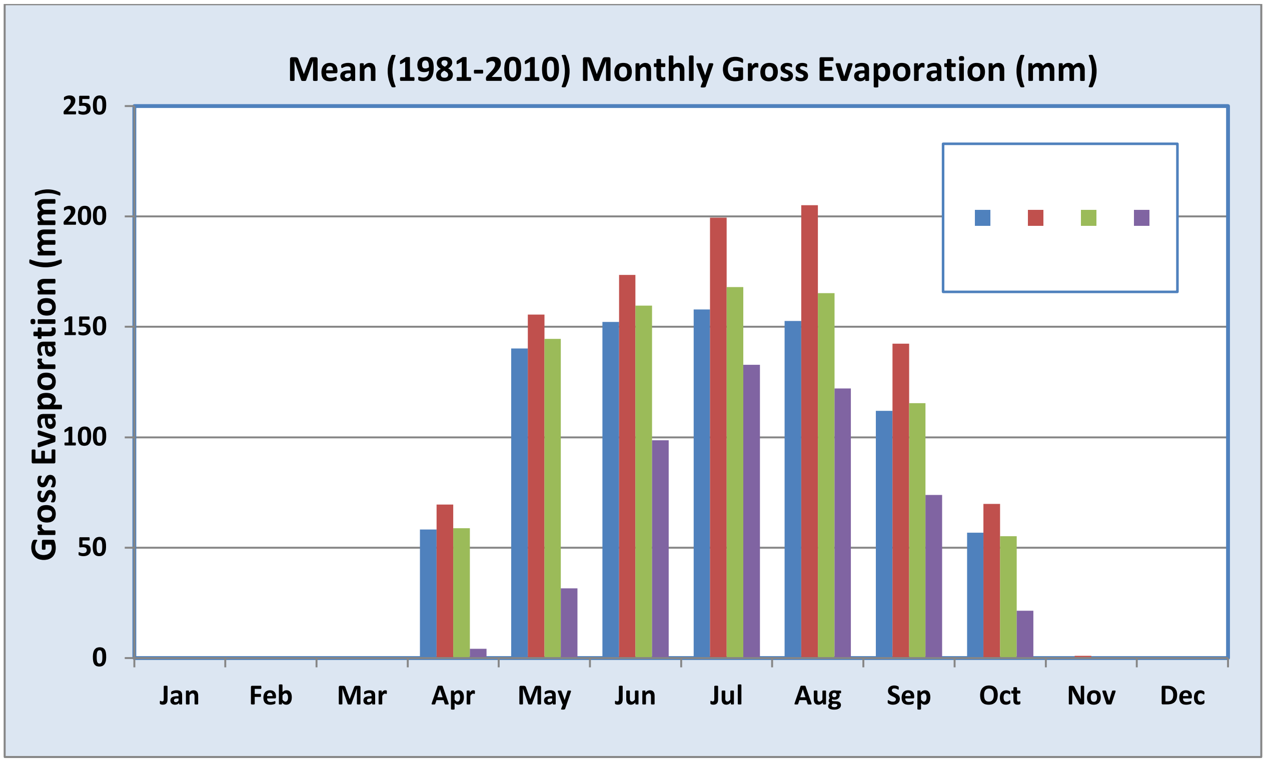

**Figure 2.8 Mean (1981-2010) Monthly Gross Evaporation (mm) in the Saskatchewan River Basin**

### 2.2.4 Runoff

The Saskatchewan River originates within the eastern slopes of the Alberta and Montana Rockies and flows roughly eastward across Alberta to the Alberta-Saskatchewan Boundary where it has a combined (North Saskatchewan, South Saskatchewan and Battle Rivers) gross and effective drainage areas of 215,085 km$^2$ and 126,648 km$^2$, respectively. From the Alberta-Saskatchewan Boundary, the Saskatchewan River flows across Saskatchewan to the Saskatchewan-Manitoba Boundary, its apportionment point as defined in Schedule B of the MAA, and on to The Pas, the point where streamflow is recorded. At the Saskatchewan-Manitoba Boundary, the Saskatchewan River has a gross drainage area of 366,535 km$^2$, a net increase of 151,450 km$^2$ from the gross drainage area upstream of the Alberta-Saskatchewan Boundary. However, because most of the area drained by the Saskatchewan River within Saskatchewan is comprised of the prairies, an area characterized by numerous sloughs, wetlands and dead drainage areas that capture runoff, a significant portion of the increased gross drainage area does not contribute to the flow of the Saskatchewan River in most years. Agriculture and Agri-Food Canada, AAFC has estimated the effective drainage area of the Saskatchewan River basin at the Saskatchewan-Manitoba Boundary to be about 195,820 km$^2$, an increase of about 69,172 km$^2$ from that at the Alberta-Saskatchewan Boundary, or about 45% of the gross drainage area of the Saskatchewan River within

Saskatchewan. Most of the additional contributing area in Saskatchewan is located downstream of the Forks (Figure 2.9).

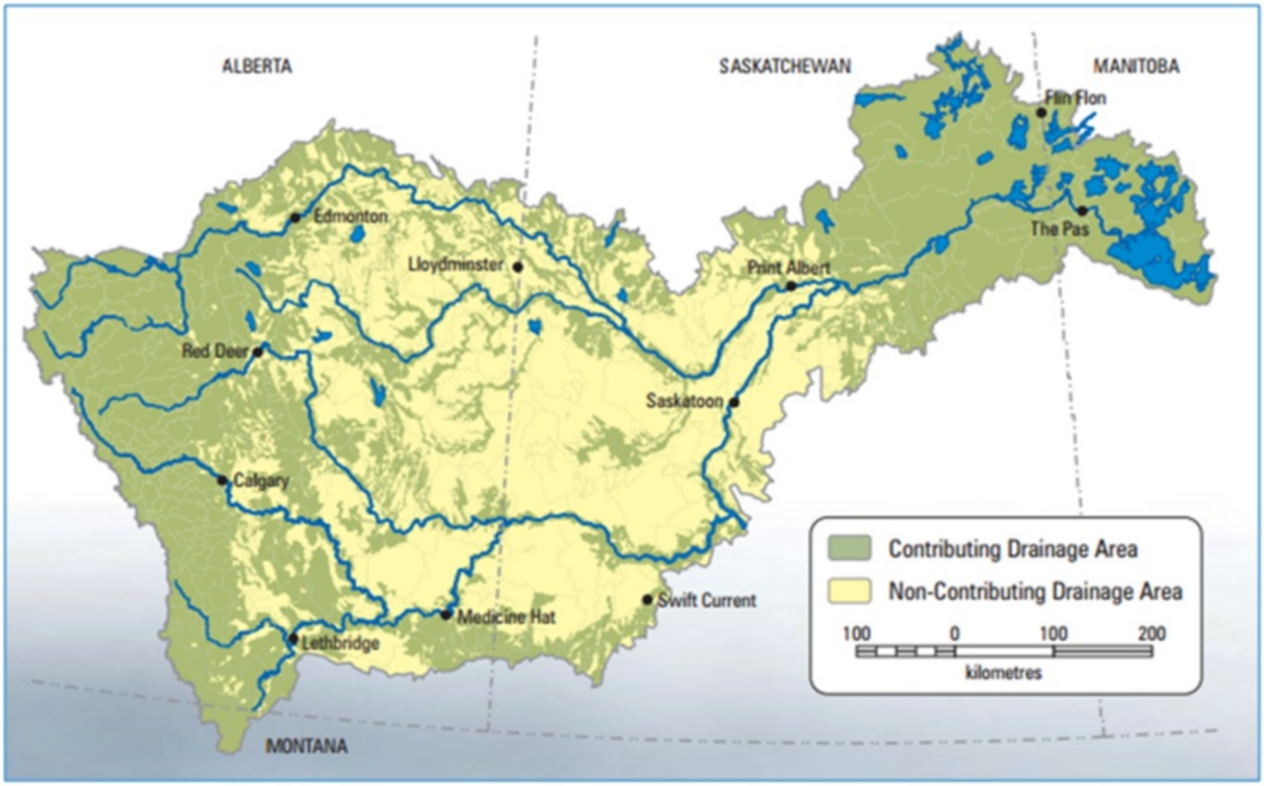

**Figure 2.9 Contributing and Non-Contributing Drainage**
**(Source: State of the Saskatchewan River Basin report)**

In addition, the mean monthly gross evaporation during the spring and summer period generally exceeds the mean monthly precipitation (as shown in Figure 2.10 for the example of Saskatoon) throughout the Prairies region, which results in a moisture deficit. As a result, in most years the Prairie region only contributes a relatively modest amount of runoff to the flow of the Saskatchewan River, occurring mostly during the March-May snowmelt period when soils are frozen and snowmelt exceeds the rate of infiltration. Therefore, most of the natural flow in the Saskatchewan River occurs during the mid-May to July period and is generated from snowmelt and summer precipitation in the Rocky Mountains. Figure 2.11 compares the mean monthly flow for the Castle River at Beaver Mines, a mountain stream in Alberta having a gross drainage area of 821 $km^2$, to the mean monthly flow of Eagle Creek near Environ, a prairie stream in Saskatchewan having a drainage area of 11,900 $km^2$. Figure 2.11 shows that Eagle Creek contributes only a fraction of the flow contribution of the Castle River even though it has a gross drainage area that is more than 14 times larger.

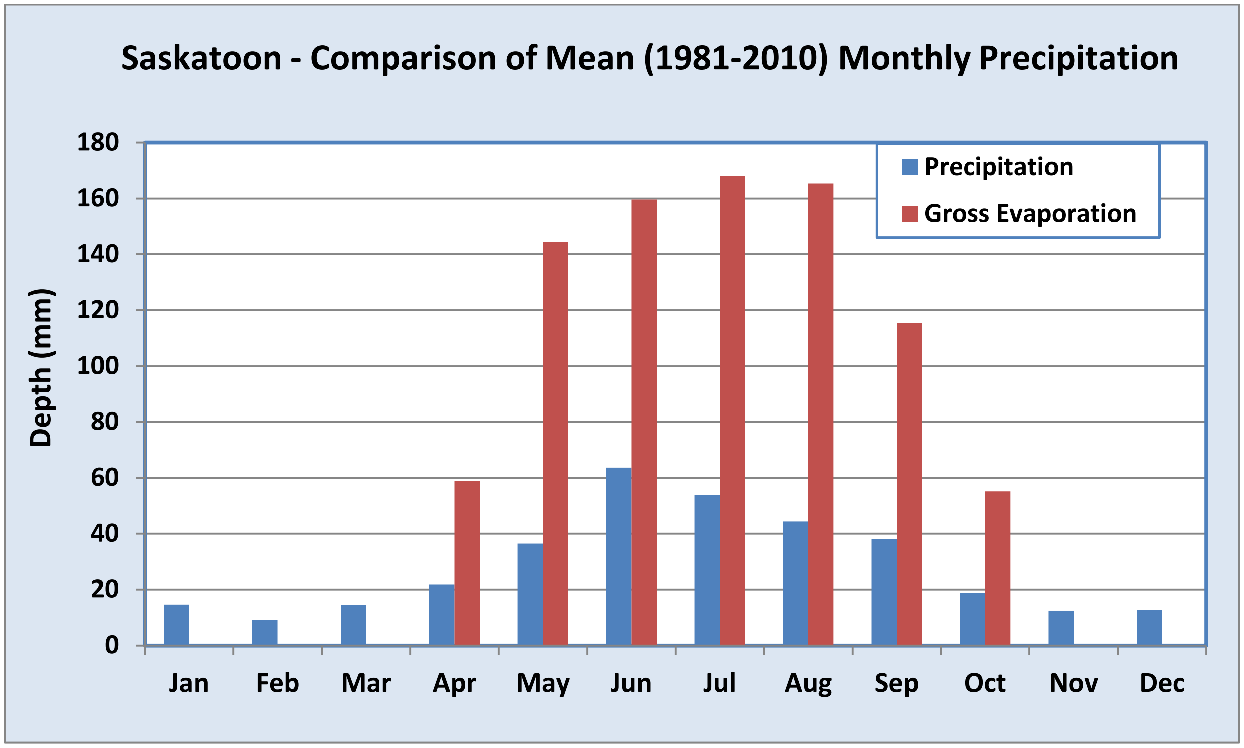

**Figure 2.10 Mean (1981-2010) Monthly Precipitation vs Gross Evaporation at Saskatoon.**

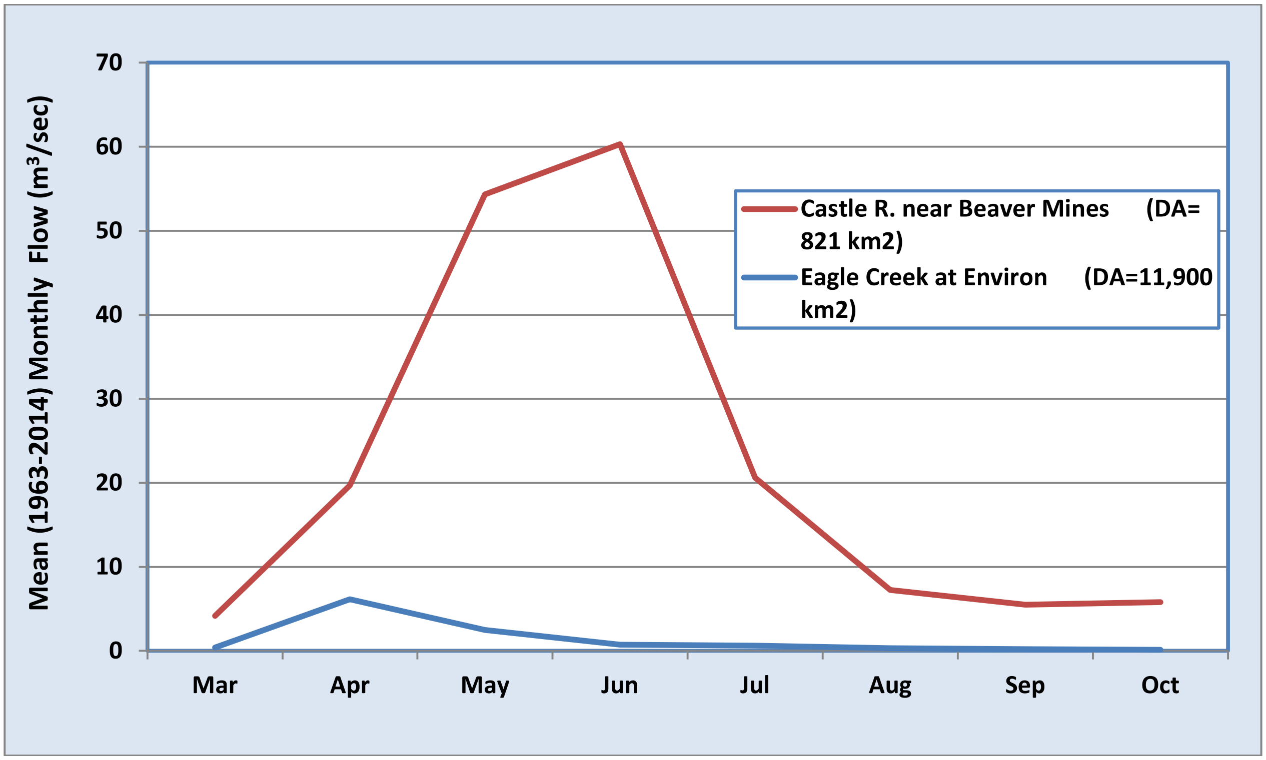

**Figure 2.11 Comparison of (1963-2014) Contribution to the flow of the Saskatchewan River by Mountain versus Prairie Streams**

### 2.2.5 Effects of Regulation and Water Use on Flows in the Saskatchewan River

The flow entering Saskatchewan via the North and South Saskatchewan Rivers is significantly altered from natural, both temporally and volumetrically, by a large number of reservoirs (Figure 2.12) and water use projects, including the previously noted irrigation districts in Alberta (Section 2.2.1). As shown in Figure 2.13, the flow entering Saskatchewan via the North Saskatchewan River has only been reduced by about 4%, however, its temporal distribution has been altered significantly by storage in the Bighorn and Brazeau Reservoirs, which store water during the summer high flow period and make releases for hydropower production during the winter months.

Figure 2.14 illustrates how the flow for the South Saskatchewan River below the confluence with the Red Deer River is significantly reduced during the May to October period, due to irrigation, consumptive use, and reservoir storage. As indicated in Figure 2.14, due to these modifications, on average Alberta has delivered to Saskatchewan approximately 80% of the apportionable flow of the South Saskatchewan River. Downstream of the Alberta-Saskatchewan Boundary, the flow of the South Saskatchewan River is further modified, both in volume and temporal distribution, by evaporation and storage in Lake Diefenbaker, as illustrated by the recorded flow at Saskatoon (Figure 2.14). Within Saskatchewan, the flow of the Saskatchewan River is also modified by storage in Reid Lake on Swift Current Creek, and by Codette Lake and Tobin Lake on the Saskatchewan River below the Forks, as well as a number of large diversions which have a significant influence on flows being delivered to Manitoba.

It is noted that as most of the reservoirs in Alberta are within the headwaters of the North and South Saskatchewan Rivers, an area in which annual precipitation is relatively the same as evaporation, evaporation losses within Alberta do not have a significant influence on flows in the Saskatchewan River. However, as the mean annual gross evaporation in the vicinity of reservoirs in Saskatchewan is in the order of 300-600 mm greater than the mean annual precipitation, evaporation losses from reservoirs in Saskatchewan have a significant influence on flow depletion in Saskatchewan and the volume of flow being passed from Saskatchewan to Manitoba.

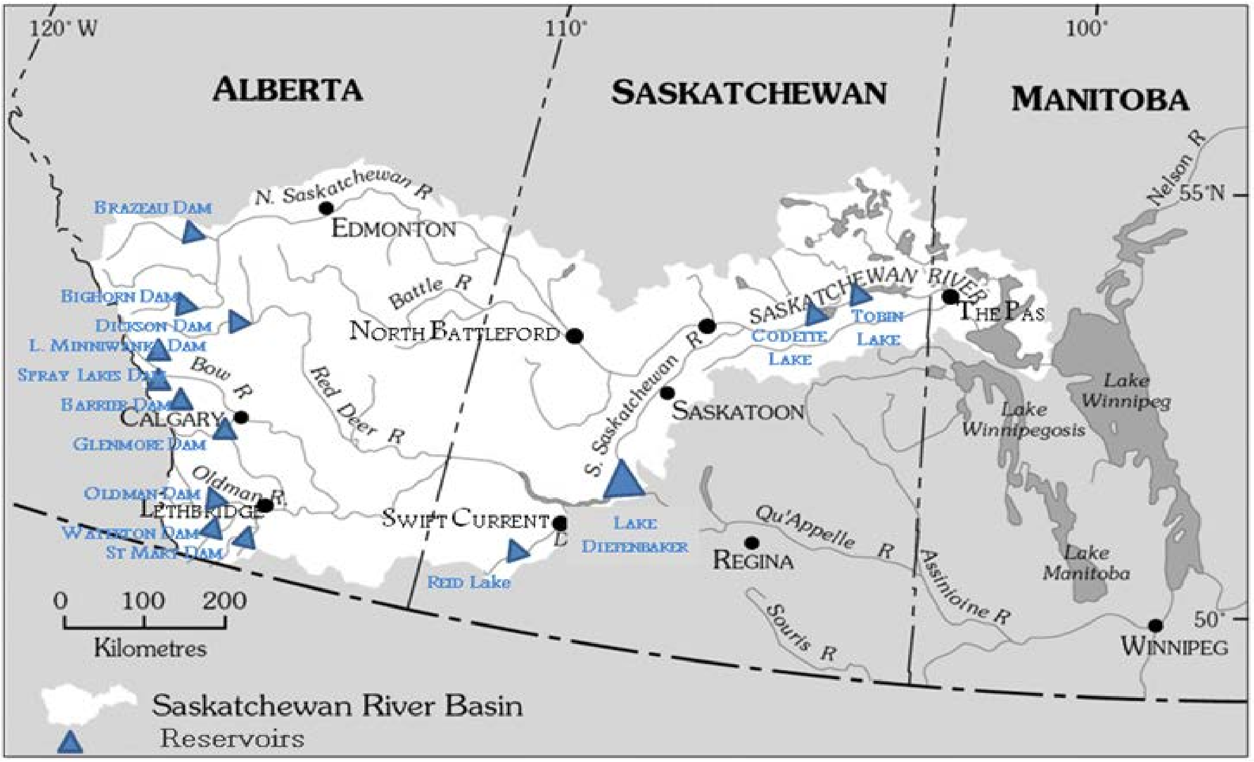

**Figure 2.12 Major On-stream Reservoirs in the Saskatchewan River Basin (Source of base map: http://seawa.ca/test/north-south-sask-river-basins/ )**

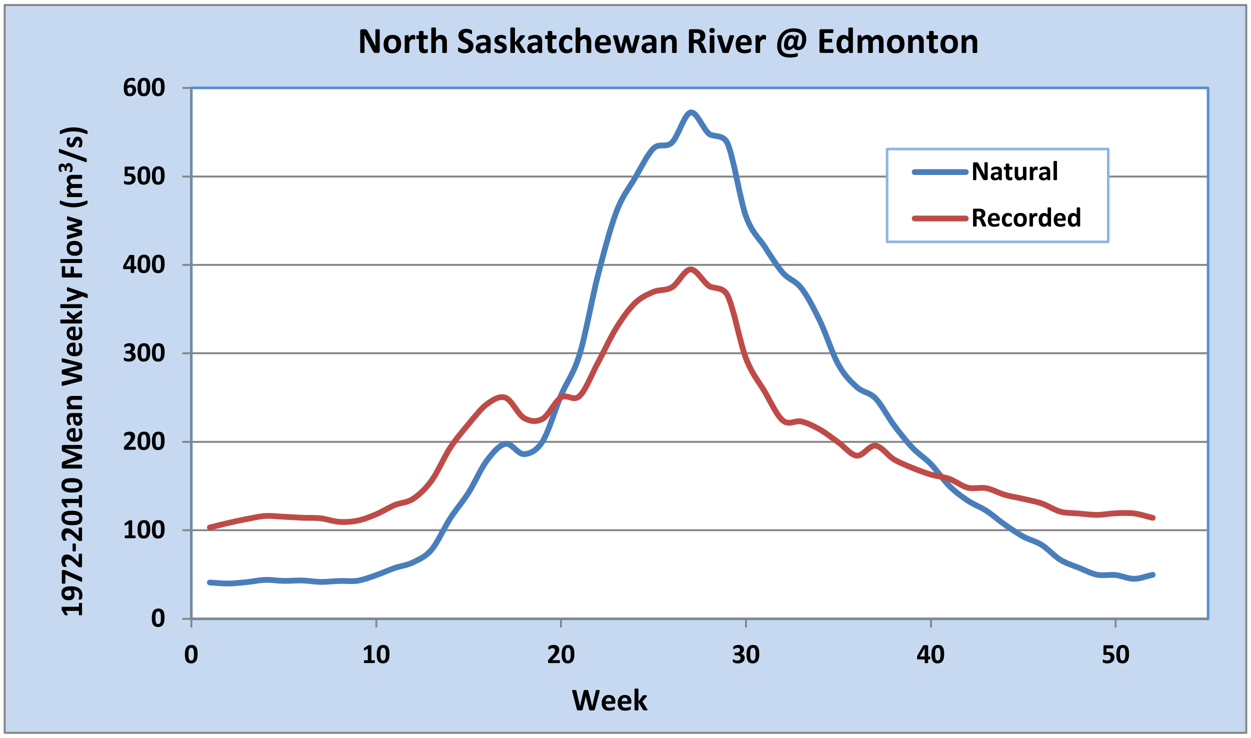

**Figure 2.13 North Sask. River at Edmonton, Natural and Recorded flow (1972-2010)**

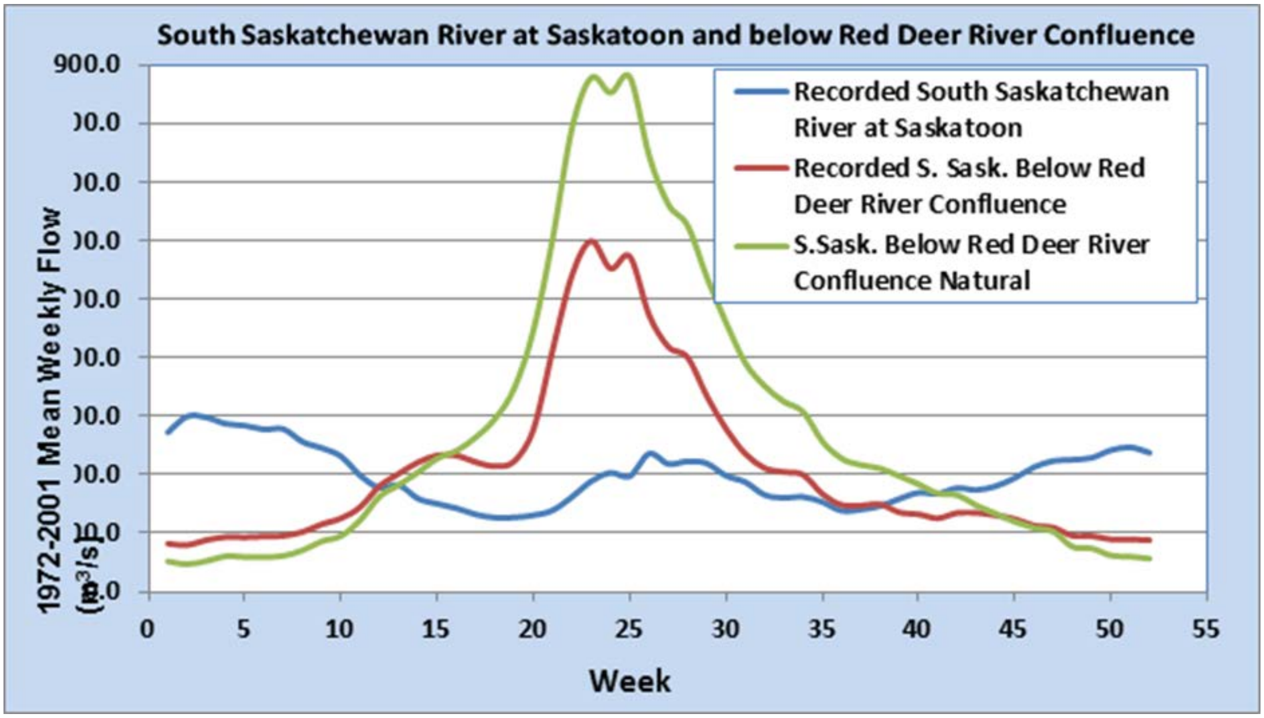

**Figure 2.14 South Saskatchewan River Natural and Recorded Flow below Red Deer River Confluence and Recorded Flow at Saskatoon (1972-2001)**

# 3. APPORTIONABLE FLOW CALCULATION

## 3.1 Apportionment Details

The sharing of waters of the Saskatchewan River between Saskatchewan and Manitoba is governed by "Schedule B" of the *Master Agreement on Apportionment* and in particular Section 2 and Section 3 of Schedule B, which state:

> *2.(a) The parties hereto shall mutually establish a method by which to determine the natural [apportionable] flow of each watercourse flowing across their said common boundary.*
>
> *2.(b) For the purpose of this agreement, the said natural flow shall be determined at a point as near as reasonably may be to their said common boundary.*

> *3. Saskatchewan shall permit in each watercourse the following quantity of water to flow into the Province of Manitoba during the period from January 1 of each year to the following December 31 of that year*[2]*, a quantity of water equal to the natural flow for that period …less*
>
> *(a) One-half the water flowing into Saskatchewan in that watercourse from the Province of Alberta,*
> *(b) Any water which would form part of the natural flow in that water course but does not flow into the Province of Saskatchewan because of the implementation of any provision of any subsisting water apportionment agreement made between Alberta and Saskatchewan and approved by Manitoba; and*
> *(c) One-half the natural flow arising in the Province of Saskatchewan.*

As there are no subsisting water apportionment agreements between Alberta and Saskatchewan outside of the MAA, the above terms and conditions can be summarized as follows:

i. *Saskatchewan and Manitoba shall mutually establish the method and procedures to be used in the computation of apportionable flow,*
ii. *Apportionment is to be based on the flow at their common boundary or a point as close as reasonably possible to the common boundary,*
iii. *The apportionment period is the calendar year (January 1 to December 31 of each year), and*
iv. *On an annual basis, Saskatchewan must permit the flow into Manitoba a volume of water equal to or greater than one-half of the apportionable flow, where the apportionable flow is comprised of the water flowing into Saskatchewan from Alberta, plus the natural flow arising in the Province of Saskatchewan.*

The apportionable flow, as identified in items "*i*" to "*iv*", can be represented by the following equation:

$$AAF_{SK/Man} = AREC_{AB/SK} + ANAT_{SK} \qquad (1)$$

Where:

$AAF_{SK/Man}$ = the annual (Jan 1 to Dec 31) apportionable flow at the Saskatchewan-Manitoba Boundary,
$AREC_{AB/SK}$ = the recorded annual (Jan 1 to Dec 31) quantity of water in the Saskatchewan River system flowing into Saskatchewan from Alberta, and
$ANAT_{SK}$ = the annual natural flow arising in the province of Saskatchewan.

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[2] It is noted that the apportionment period outlined in the 1969 Agreement was "*April 1 of each year to March 31 of the year following*" but that it was changed to the calendar year in 1999.

Alternatively, following the work of Bart Oegema of WSA as shown below, the apportionable water flowing into Manitoba would have been equal to the water flowing into Saskatchewan plus the natural flow arising in Saskatchewan, were it not for water uses within Saskatchewan. Therefore, the apportionable flow can be computed as the sum of water flowing into Manitoba plus water use in Saskatchewan, a procedure known as the "*project depletion method*", derived as follows (where AF is apportionable flow, REC is recorded flow and NAT is natural flow, and DEPL is depletions):

$AF_{SK/MB} = REC_{AB/SK} + NAT_{SK}$ (1)

Note that where the subscript indicates a single jurisdiction the volume is within that area, and where a subscript indicates two jurisdictions (e.g. $_{AB/SK}$) the volume is at the border between the two.

The natural flow arising in Saskatchewan can be estimated by equation (2):

$NAT_{SK} = REC_{SK/MB} + DEPL_{SK} + DEPL_{AB} - NAT_{AB/SK}$ (2)

Further, the natural flow at the Alberta-Saskatchewan boundary can be calculated by equation (3) as follows:

$NAT_{AB/SK} = REC_{AB/SK} + DEPL_{AB}$ (3)

Substituting equation (3) into equation (2) gives:

$NAT_{SK} = REC_{SK/MB} + DEPL_{SK} + DEPL_{AB} - REC_{AB/SK} - DEPL_{AB}$

Which can be simplified to equation (4):

$NAT_{SK} + REC_{AB/SK} = REC_{SK/MB} + DEPL_{SK}$ (4)

Considering equation (1) and equation (4) together then gives equation (5):

$AF_{SK/MB} = REC_{SK/MB} + DEPL_{SK}$ (5)

Equation (5) is the basis of the apportionable flow calculation applied by the PPWB for the Saskatchewan River Basin.

$$AAF_{SK/Man} = AREC_{SK/Man} + \sum_{k=1} AWU_k \qquad (2)$$

Where:

$AAF_{SK/Man}$ = was previously defined (apportionable flow at SK/MB Boundary),
$AREC_{SK/Man}$ = the recorded annual (Jan 1 to Dec 31) quantity of water flowing into Manitoba from Saskatchewan, and
$\Sigma AWU_k$ = the sum of annual water use in Saskatchewan for all projects k=(1,n)

In 1976 the PPWB issued the report "*Natural Flow – Saskatchewan River at Saskatchewan Manitoba Boundary*" (PPWB Report #45). The report, which describes methods and procedures approved by the PPWB for the calculation of apportionable flow, states that the annual apportionable flow is to be computed using a monthly time step and the above noted project depletion method. Apportionment monitoring for the Saskatchewan River at the Saskatchewan-Manitoba Boundary actively began in 1977. While over the years there have been some modifications to the procedures outlined in the 1976 report, the changes have generally been minor and aimed at accommodating changes in the level or location of hydroclimatic monitoring stations. The historical annual apportionable flow computed using these procedures, along with the actual water flowing into Manitoba from Saskatchewan are summarized in Table 3.1.

Table 3.1 shows that the Saskatchewan River at the Saskatchewan-Manitoba boundary has a mean annual apportionable flow of about 18,127,000 dam$^3$ but has varied from a low of 8,250,000 dam$^3$ to a high of 31,000,000 dam$^3$. Table 3.1 further shows that on average Saskatchewan has passed 17,552,000 dam$^3$, or 97% of the apportionable flow, to Manitoba, a mean annual surplus delivery of about 8,489,000 dam$^3$ above Manitoba's 50% share of 9,063,000 dam$^3$. Table 3.1 further shows that flow delivered by Saskatchewan to Manitoba has ranged from about 79% to 111% of the apportionable flow, with deliveries above 100% generally being the result of a drawdown in storage during dry years.

## 3.2 Documented Apportionable Flow Calculations

As indicated previously, in 1976 the PPWB issued the report "*Natural Flow – Saskatchewan River at Saskatchewan-Manitoba Boundary*" (PPWB Report #45) which was prepared for the PPWB-COH by Environment and Climate Change Canada's (ECCC), Water Survey of Canada (ECCC-WSC). ECCC-WSC prepared Report #45 because they had experience in the development and requirements of apportionment procedures through their involvement in the administration of the 1909 Boundary Waters Treaty. The report, which is one of seven similar reports prepared for other apportionment points around that time, describes the methods and procedures approved by the Board for the calculation of apportionable flow for the Saskatchewan River at the Saskatchewan-Manitoba Boundary. Since that time there have been at least three additional reports issued by the PPWB, each of which has altered one or more aspects of the proposed computational procedures. The sections that follow review these reports and provide a summary of the procedures and modifications approved in each report towards providing an understanding of the current methods and procedures and how they have evolved over time.

**Table 3.1 Computed Actual and Apportionable Annual Flow at SK/MB Boundary**

| Year | Computed Apportionable Flow | Computed Actual Flow At Sask/Man Boundary | % of Apportionable Flow Delivered to Man. | Manitoba's share of apportionable Flow | Surplus/(Deficit) Delivery to Man |
|---|---|---|---|---|---|
| | (dam$^3$) | (dam$^3$) | (%) | (dam$^3$) | (dam$^3$) |
| 1977 | 12,700,000 | 13,300,000 | 105 | 6,350,000 | 6,950,000 |
| 1978 | 19,200,000 | 17,100,000 | 89 | 9,600,000 | 7,500,000 |
| 1979 | 16,500,000 | 16,600,000 | 101 | 8,250,000 | 8,350,000 |
| 1980 | 16,600,000 | 15,800,000 | 95 | 8,300,000 | 7,500,000 |
| 1981 | 18,900,000 | 18,600,000 | 98 | 9,450,000 | 9,150,000 |
| 1982 | 16,200,000 | 15,300,000 | 94 | 8,100,000 | 7,200,000 |
| 1983 | 15,900,000 | 16,500,000 | 104 | 7,950,000 | 8,550,000 |
| 1984 | 13,700,000 | 13,200,000 | 96 | 6,850,000 | 6,350,000 |
| 1985 | 17,300,000 | 16,000,000 | 92 | 8,650,000 | 7,350,000 |
| 1986 | 20,700,000 | 19,200,000 | 93 | 10,350,000 | 8,850,000 |
| 1987 | 14,000,000 | 14,300,000 | 102 | 7,000,000 | 7,300,000 |
| 1988 | 8,250,000 | 9,180,000 | 111 | 4,125,000 | 5,055,000 |
| 1989 | 14,100,000 | 11,100,000 | 79 | 7,050,000 | 4,050,000 |
| 1990 | 20,900,000 | 20,500,000 | 98 | 10,450,000 | 10,050,000 |
| 1991 | 17,100,000 | 16,500,000 | 96 | 8,550,000 | 7,950,000 |
| 1992 | 11,700,000 | 11,200,000 | 96 | 5,850,000 | 5,350,000 |
| 1993 | 18,700,000 | 17,700,000 | 95 | 9,350,000 | 8,350,000 |
| 1994 | 15,100,000 | 15,100,000 | 100 | 7,550,000 | 7,550,000 |
| 1995 | 20,700,000 | 19,900,000 | 96 | 10,350,000 | 9,550,000 |
| 1996 | 21,100,000 | 21,200,000 | 100 | 10,550,000 | 10,650,000 |
| 1997 | 22,100,000 | 20,900,000 | 95 | 11,050,000 | 9,850,000 |
| 1998 | 18,000,000 | 17,500,000 | 97 | 9,000,000 | 8,500,000 |
| 1999 | 18,300,000 | 17,400,000 | 95 | 9,150,000 | 8,250,000 |
| 2000 | 12,400,000 | 13,000,000 | 105 | 6,200,000 | 6,800,000 |
| 2001 | 9,970,000 | 10,100,000 | 101 | 4,985,000 | 5,115,000 |
| 2002 | 12,600,000 | 10,100,000 | 80 | 6,300,000 | 3,800,000 |
| 2003 | 14,000,000 | 14,400,000 | 103 | 7,000,000 | 7,400,000 |
| 2004 | 15,000,000 | 13,400,000 | 89 | 7,500,000 | 5,900,000 |
| 2005 | 29,500,000 | 28,600,000 | 97 | 14,750,000 | 13,850,000 |
| 2006 | 22,200,000 | 22,300,000 | 100 | 11,100,000 | 11,200,000 |
| 2007 | 23,600,000 | 23,200,000 | 98 | 11,800,000 | 11,400,000 |
| 2008 | 18,400,000 | 17,200,000 | 93 | 9,200,000 | 8,000,000 |
| 2009 | 13,700,000 | 13,500,000 | 99 | 6,850,000 | 6,650,000 |
| 2010 | 21,600,000 | 20,400,000 | 94 | 10,800,000 | 9,600,000 |
| 2011 | 31,000,000 | 31,100,000 | 100 | 15,500,000 | 15,600,000 |
| 2012 | 23,400,000 | 23,000,000 | 98 | 11,700,000 | 11,300,000 |
| 2013 | 26,400,000 | 25,600,000 | 97 | 13,200,000 | 12,400,000 |
| 2014 | 27,300,000 | 27,000,000 | 99 | 13,650,000 | 13,350,000 |
| Average | 18,127,000 | 17,552,000 | 97 | 9,063,000 | 8,489,000 |
| Maximum | 31,000,000 | 31,100,000 | 111 | 15,500,000 | 15,600,000 |
| Minimum | 8,250,000 | 9,180,000 | 79 | 4,125,000 | 3,800,000 |

### 3.2.1 Methods and Procedures Proposed in the March 1976 Report, Natural Flow – Saskatchewan River at Saskatchewan-Manitoba Boundary”

As outlined in the previous section, in March 1976 the PPWB issued the report “*Natural Flow – Saskatchewan River at Saskatchewan-Manitoba Boundary*” (PPWB Report #45). This was the first report issued by the PPWB that provided a detailed outline of proposed methods and procedures for the Saskatchewan River. The methods and procedures proposed in this report are as follows:

i. The apportionable flow is to be computed annually using a monthly time step.

ii. The apportionable flow is to be computed using the “*project depletion method*”, that is where apportionable flow is computed as*“… recorded flow at the Boundary plus effects of storage and use within Saskatchewan …”*

iii. Water use adjustments, or “…*quantities [of water use] for storage increments, diversions and evaporation loss … are to be computed at the point of occurrence …*” with “*… adjustment items being routed to the Manitoba Boundary using travel periods…*”.

iv. Small storage and farm ponds, whose combined *“… depletions are insignificant in terms of total Saskatchewan River flow”, “ … not be included in the calculation of flow for apportionment between Saskatchewan and Manitoba*”, meaning that only projects considered by the PPWB to have a significant impact were to be included in the computations.

The computation of apportionable flow, as described in the above noted recommendations, can be represented as per equation (3) below.

$$AAF_{SK/Man}=\sum_{i=1}^{12}(MREC_{SK/Man} - MLFC_{Man} + (\sum_{k=1}^{n-m} MWUA_k))_i \qquad (3)$$

Where:

$AAF_{SK/Man}$ = annual apportionable flow at the Saskatchewan-Manitoba boundary,

$MREC_{SK/Man}$ = the recorded quantity of water flowing across the Manitoba boundary, or flowing across a point some distance upstream or downstream of the boundary, during months “i=1” to “12” of each year,

MLFC = the monthly flow contribution from the local area between the gauging site and the Saskatchewan-Manitoba boundary, and

$\Sigma MWUA_k$ = the sum of monthly water use adjustments by approved projects “k=1” to “n-m” in Saskatchewan. The projects included in the computation (n-m) are a small subset of all water use projects (n) in Saskatchewan whose water use impacts are deemed to be significant and have been approved by the PPWB for inclusion in the computation. The monthly water use adjustment for each approved project is computed as follows:

$$MWUA_{k,i} = TTA_{k(i-1)} + MWU_{k(i)} - TTA_{k(i)} \qquad (4)$$

Where:

$MWUA_{k,i}$ = the water use adjusted for time of travel for project “k” during month “i”,
$MWU_k$ = the monthly water use by project “k” during month “i”,
$TTA_k$ = the adjustment applied to the monthly water use by project “k” to account for the time of travel in months “i” and “i-1” respectively. It is calculated as

$$TTA_k = (TT_{k(i)}/\#\text{of days in month “i”}) * MWU_{k(i)\ k(i)} \qquad (5)$$

Where:

$TT_{k(i)}$ = the time of travel (days) from the project site to the Saskatchewan-Manitoba boundary.

While the time of travel (TT) is a function of the flow rate, in the current apportionment computation procedures TT is treated as a constant for all months and all years with TT being based on the time of travel for the mean annual flow from the project site to the Saskatchewan-Manitoba boundary. Because of this, the time of travel adjustment ($TT_k$/#of days in the month) is also a constant and equation (5) can be rewritten as follows:

$$TTA_{(k)} = af_{(k)} * MWU_{k(i)} \qquad (5a)$$

Where “af” is referred to as the “adjustment factor” for time of travel and is equal to (TTk/#of days in the month)’

Substituting equation (4) and (5a) into equation (3) yields:

$$AAF_{SK/Man}=\sum_{i=1}^{12}((MREC_{SK/Man(i)} - MLFC_{Man(i)}) + (\sum_{k=1}^{n-m}(af*MWU_{(i-1)} + MWU_{(i)} - af*MWU_{(i)})_k)) \qquad (6)$$

or as

$$AAF_{SK/Man}=\sum_{i=1}^{12}((MREC_{SK/Man(i)} - MLFC_{Man(i)}) + (\sum_{k=1}^{n-m}(af_{(k)}*MWU_{(i-1)} + (1 - af_{(k)}*MWU_{(i)})_k)) \qquad (6a)$$

The methods and procedures for computing each of the parameters in equation (6a), as well as approved water use projects to be included in the computation of apportionable flow is summarized in Table A.1 in Appendix A. The hydrometric and climatic stations required for the computation of apportionment flows with the proposed procedures are listed in Table 3.2.

**Table 3.2 Hydrometric and Climatic Stations Identified in PPWB Report #45 as Required for the Computation of the Apportionable Flow at the Saskatchewan-Manitoba Boundary**

| Hydrometric Stations | Purpose |
|---|---|
| Broderick (M1) Irrigation Main Canal below Pumping Station (WSC #05HF007) | Diversion |
| Dragline Ditch near Squaw Rapids (WSC #05KH011) | Diversion |
| Elbow Diversion Canal at Drop Structure (WSC #05JG006) | Diversion |
| Lake Diefenbaker at Gardiner Dam (WSC #05HF003) | Storage and Evaporation |
| N. Saskatchewan River at Prince Albert (WSC #05GG001) | Routing |
| Reid Lake near Duncairn (WSC #05HD033) | Storage and Evaporation |
| Saskatchewan River at The Pas (WSC #05KJ001) | Flow into Manitoba |
| S. Saskatchewan River at Saskatoon (WSC #05HG001) | Routing |
| S. Saskatchewan River at St Louis (WSC #05HH001) | Routing |
| Swift Current Canal at Swift Current (WSC #05HD034) | Diversion |
| Tobin Lake at Squaw Rapids Spillway (WSC #05KD004) | Storage and Evaporation |
| **Climatic Stations** | **Purpose** |
| Elbow Automatic Station | Air Temperature, dew point, precipitation, wind |
| Lake Diefenbaker (lower) | Surface water temperature |
| Lake Diefenbaker (upper) | Surface water temperature |
| Nipawin | Air temperature, dew point, precipitation |
| Swift Current | Air Temperature, dew point, precipitation, wind |
| Tobin Lake | Surface water temperature, wind speed. |

### 3.2.2 Methods and Procedures Approved in the May 1976 Report "Determination of Natural Flow for Apportionment Purposes" – PPWB Report #48

In May 1976 the PPWB-COH submitted PPWB Report #48, "*Determination of Natural Flow for Apportionment Purposes*" to the Board which outlined the recommended "*… procedures for the* *determination of natural [apportionment] flows in the South Saskatchewan, North Saskatchewan, Saskatchewan, Churchill and Qu'Appelle River Basins*". Among other things, this report confirmed that apportionment computations for the Saskatchewan River at the Saskatchewan-Manitoba Boundary were:

i. To be carried out using the previously outlined "*project depletion method*", and
ii. To have annual reporting based on monthly means.

The report also acknowledged that *"… little is known about the effects of land use changes and groundwater discharge and recharge on natural [apportionable] flow…"* and based on limited data which suggests that *"…these effects are minor compared to the magnitude of flows…"* and recommended "*…that these effects not be considered in the natural flow computations.*"

With respect to Saskatchewan River at the Saskatchewan-Manitoba Boundary, the report proposed the following changes to the procedures outlined in the March 1976 report (PPWB Report #45):

i. That the hydrometric station Saskatchewan River near Manitoba Boundary (WSC St. #05KH008) rather than Saskatchewan River at The Pas (WSC St. #05KJ001) be used for the computation of the recorded monthly quantity of water flowing across the Saskatchewan-Manitoba boundary ($MREC_{SK/Man}$). As this site is only 2 river miles upstream of the boundary local inflow between the gauging site and the boundary would be minimal, thus eliminating the need to estimate the monthly local area flow contribution ($MLFC_{Man}$) including the contribution by Carrot, Pasquia, and Birch-Saskeram Rivers which would be required if the station at The Pas were used.
ii. That net evaporation for Reid Lake be computed for the May to November period based on actual lake surface area (see Appendix A for elevation-area relation) multiplied by 1.1 times the unit [gross] evaporation for upper Lake Diefenbaker minus precipitation at Swift Current. This recommendation is based on the recognition that the ratio of the Meyer coefficient "c" for Reid Lake versus upper Lake Diefenbaker (10/9) is equal to 1.1 and that input data for all other parameters (air temperature, dew point temperature, and wind speed) are the same for both sites[3].
iii. PPWB Report #45 states that month-end elevations used in the computation of change in storage for Lake Diefenbaker and Tobin Lake are to be adjusted for wind effects. However, PPWB Report #48 is silent with respect to this adjustment. Further, as neither report identifies which stations or methods are to be used for the correction, it would seem to suggest that the wind correction of month-end elevations was eliminated from the approved procedures.

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[3] Personal communication with Ron Woodvine.

The hydrometric and climate data stations deemed necessary for the apportionment flow computation procedures recommended in PPWB Report #48 was essentially the same as that in Table 3.2 with the exception of the hydrometric station Saskatchewan River at The Pas (WSC St #05KJ001) being replaced by the station Saskatchewan River near Manitoba Boundary (WSC St. #05KH008).

The procedures recommended within this report were subsequently approved by the PPWB and apportionment computations were started in 1977. It is noted that while the PPWB-COH was responsible for carrying out the computation of apportionable flow, estimates of gross evaporation for each of the three lakes was provided by ECCC-AES.

### 3.2.3 Modifications Resulting from Water Survey of Canada’s August 1983 Report “Saskatchewan River Monitoring Study"

Based on the recommendation in PPWB Report #48, the hydrometric station Saskatchewan River near Manitoba Boundary (WSC St. #05KH008) was used from 1977 onwards to represent the flow entering Manitoba from Saskatchewan. However, as the station experienced many operational problems, including periods of missing data, ECCC operational staff at The Pas recommended to the PPWB that *“…the site near the Manitoba Boundary is hydrometrically unsuitable.”*

Following a detailed investigation as to the best procedure for estimating the flow crossing the Saskatchewan-Manitoba Boundary, ECCC recommended that water flowing from Saskatchewan into Manitoba ($MREC_{SK/Man} – MLFC_{Man}$ within equation (3)) be estimated based on the recorded flow at the hydrometric Saskatchewan River at The Pas (WSC St #05KJ001) minus 1.31 times the recorded flow for the hydrometric station Carrot River near Turnberry (WSC St. #05KH007). The 1.31 factor was estimated based on the difference in annual (1969-1979) flow between the Saskatchewan River at The Pas and the Saskatchewan River at the Boundary divided by the recorded flow for the Carrot River near Turnberry. The subtraction of 1.31 times the flow of Carrot River near Turnberry was applied to remove the estimated flow from the Carrot, Pasquia and Birch-Saskeram Rivers that cross the Manitoba Boundary independently but join the Saskatchewan River upstream of The Pas. This recommendation was approved by the PPWB and applied to all subsequent apportionable flow computations.

### 3.2.4 Method and Procedure Modifications Approved in the PPWB Report #141

Due to budgetary restraints in the early 1990s, ECCC experienced difficulties maintaining the existing level of monitoring and requested the PPWB to evaluate its monitoring requirements. This report, prepared by the PPWB-COH, examines alternative methods of computing the various components of the apportionable flow procedures and makes recommendations on modifications that could be made to the methods and procedures to reduce monitoring requirements[4], while maintaining an acceptable level of accuracy in the computation of apportionable flows at the Saskatchewan-Manitoba boundary.

The report acknowledges that at the time there was a total of 3,774 licensed water use projects in Saskatchewan with an annual diversion [allocation] of 1,312,648 dam$^3$. However, it points out that a great portion of the diversions [allocations] are for hydroelectric power generation purposes (eg., project #07592 which has a licensed diversion [allocation] of 427,108 dam$^3$) and that most of the water diverted for these purposes is returned to the river. It also acknowledges that a large number of projects are situated outside the effective drainage area and would have little or no effect on apportionable flows. The report suggests "*given the number of projects in the basin, it would be impractical to monitor every single project*". The report also suggests that given the low level of water use relative to the average annual apportionable flow it would be more cost-effective to ignore water use from small projects, including large urban centers, and to focus on water use by the eleven major water use projects already being considered in the apportionment computations. The report then examines historical water use by the noted eleven major water use projects included in the apportionment computation and notes the following:

i. Mean annual water use by the eleven projects is 601,879 dam$^3$ or 3.5% of the apportionable flow and has varied from -3.85% to 9.31% of apportionable flow.
ii. The maximum annual effect by each of seven of the items included in the apportionable flow computations was less than 1% of the apportionable flow. These were:
    a. Reid Lake net evaporation 0.09%,
    b. Swift Current Irrigation project 0.20%,
    c. Reid Lake change in storage 0.23%
    d. Luck Lake and Riverhurst Irrigation[5] project 0.24%,
    e. Tobin Lake net evaporation 0.70%,
    f. Dragline Channel 0.8%, and
    g. Broderick Irrigation project 0.99%.

The report then examines alternative ways of estimating the water use by the above noted projects. It concludes that using long-term mean monthly values for six of the projects (four estimated using hydrometric stations and two using pumping stations) would result in a mean annual deviation of -0.09% from that computed using gauged values with an annual range of -

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[4] It is noted that this report does not include the hydrometric stations required for the estimation of travel times (WSC #05GG001, 05HG001 and WSC #05HH001) in the list of PPWB stations required for the apportionable flow computations.

[5] None of the earlier reports had included the Luck Lake and Riverhurst Irrigation projects in the recommended apportionable flow computations. While the summary of apportionable flow computations carried out in Appendix A of PPWB Report #141 shows this item first being included in the 1990-91 computations, it is uncertain if and when the PPWB may have approved the addition of these projects.

0.81% to 0.67%. Based on the finding the report recommends that the following hydrometric stations be removed from the PPWB list of required monitoring sites and the water use by the three projects be based on their long-term mean monthly flow (or water level):

i. Swift Current Canal at Swift Current (WSC St #05HD034)
ii. Reid Lake near Duncairn (05HD033)
iii. Dragline Ditch near Squaw Rapids (05KH011)

### 3.2.5 Modifications Approved in the April 2003 Report "A Sensitivity Analysis of PPWB Apportionment Monitoring to Evaporation Calculations" – PPWB Report #161

As noted earlier in this report, monthly gross evaporation estimates for Lake Diefenbaker and Tobin Lake, which are required for the computation of apportionable flow at the Saskatchewan-Manitoba boundary, are calculated by ECCC-AES using the Meyer equation in which water temperatures and subsequently saturation vapor pressure are estimated from air temperatures. Up until 1994 actual water temperature measurements were used in the evaporation calculations. However, when the Government of Canada Program Review eliminated the resources required to support these measurement programs and the processing of the data, reservoir specific water temperature regression equations were developed for Lake Diefenbaker and Tobin Lake which have since been used in the estimation of gross evaporation for both lakes. Within this context, the 2003 report undertakes a critical review of these calculations and assesses other methods of estimating evaporation. The following provides a summary of the findings and recommendations in this report.

*Lake Diefenbaker*

The 2003 evaporation study notes that previously, "*Most water temperatures were measured with … recorders located in sheltered bays along the lake…*" and that "*It is questionable whether these data really represented the surface water temperature in a spatial sense.*" The report goes on to state that "*The best spatial data [of surface water temperatures] came from the Riverhurst Ferry operators who measured water temperature three times a day across the width of the lake near Riverhurst.*" As such, contrary to the PPWB approved methods, "*… this information was used in the estimation of water temperature for both the upper and lower sections of the lake.*" It continues that "*Starting in 1995, when staff and resources were eliminated in the Federal Government's Program Review, the water temperature has been estimated using regression equations developed specifically for the reservoir from water temperatures measured over the period 1972 to 1994.*" The report suggests that using this procedure can result in errors of +/-10% in the computed monthly gross evaporation. The report notes that an examination of historical net evaporation for Lake Diefenbaker suggests that the mean annual net evaporation from Lake Diefenbaker represents about 1.4% of the mean annual apportionable flow. The report also carries out an assessment of alternative methods for estimating net evaporation (e.g. using the long-term average of monthly net evaporation, using the long-term monthly average of gross evaporation and the actual monthly precipitation).

*Tobin Lake*

Until 1994, surface water temperature was measured adjacent to the concrete abutment that forms part of the spillway to the E.B Campbell Dam. Since the site was not representative of the whole lake, a more detailed program was considered necessary. Starting in 1995, monthly water temperatures were estimated based on a set of monthly regression equations that related water temperature to air temperature. The report suggests that the mean annual net evaporation from Tobin Lake represents about 0.5% of the mean annual apportionable flow and, given the level of surplus deliveries, could be ignored. The report goes on to examine the time saving and accuracy implication of estimating Tobin Lake net evaporation using simpler techniques.

*Reid Lake*

The report notes that: "*There is no explicit [gross] evaporation calculation for Reid Lake … Rather it has been arbitrarily set to 110% of the [upper] Lake Diefenbaker gross evaporation …*" and that "*the precipitation for Swift Current is used in conjunction with the prorated Lake Diefenbaker gross evaporation to determine the net evaporation at Reid Lake in any month*." The report goes on to state that the inclusion or exclusion of Reid Lake evaporation in the apportionable flow computations "*is inconsequential compared to either Tobin Lake or Lake Diefenbaker...*" as it represents "*… a mean annual volume of 7,700 dam$^3$ or 0.05% of average annual apportionment flow*."

With respect to Lake Diefenbaker, Tobin Lake and Reid Lake the report concludes:

> "*The savings generated by moving to a simpler estimation procedure are minimal; thus the existing procedures should continue for Lake Diefenbaker, Tobin Lake and Reid Lake.*"

## 3.3 Summary of Approved Apportionable Flow Computational Procedures

Table A.2 provides a summary of the apportionable flow computation procedures resulting after incorporating all of the modifications proposed in the previously discussed reports. The methods and procedures described in Table A.2 in Appendix A are believed to represent the most recent methods and procedures of the approved apportionable flow computation procedures.

### 3.3.1 Current Apportionable Flow Calculations

Currently the apportionable flow calculations for the Saskatchewan River at the Saskatchewan-Manitoba Boundary are carried using a FORTRAN program. However, for the purpose of this evaluation, the current apportionable flow calculation procedures were provided in an EXCEL Workbook created, by the PPWB, to replicate exactly the procedures within the FORTRAN program. Within the EXCEL Workbook, the computation of apportionable flow is carried out using the previously described project depletion method.

$$AAF_{SK/Man}=\sum_{i=1}^{12}((MREC_{SK/Man(i)} - MLFC_{Man(i)}) + (\sum_{k=1}^{n-m} (TTA_{(i-1)} + MWU_{(i)} - TTA_{(i)})_k)) \qquad (6)$$

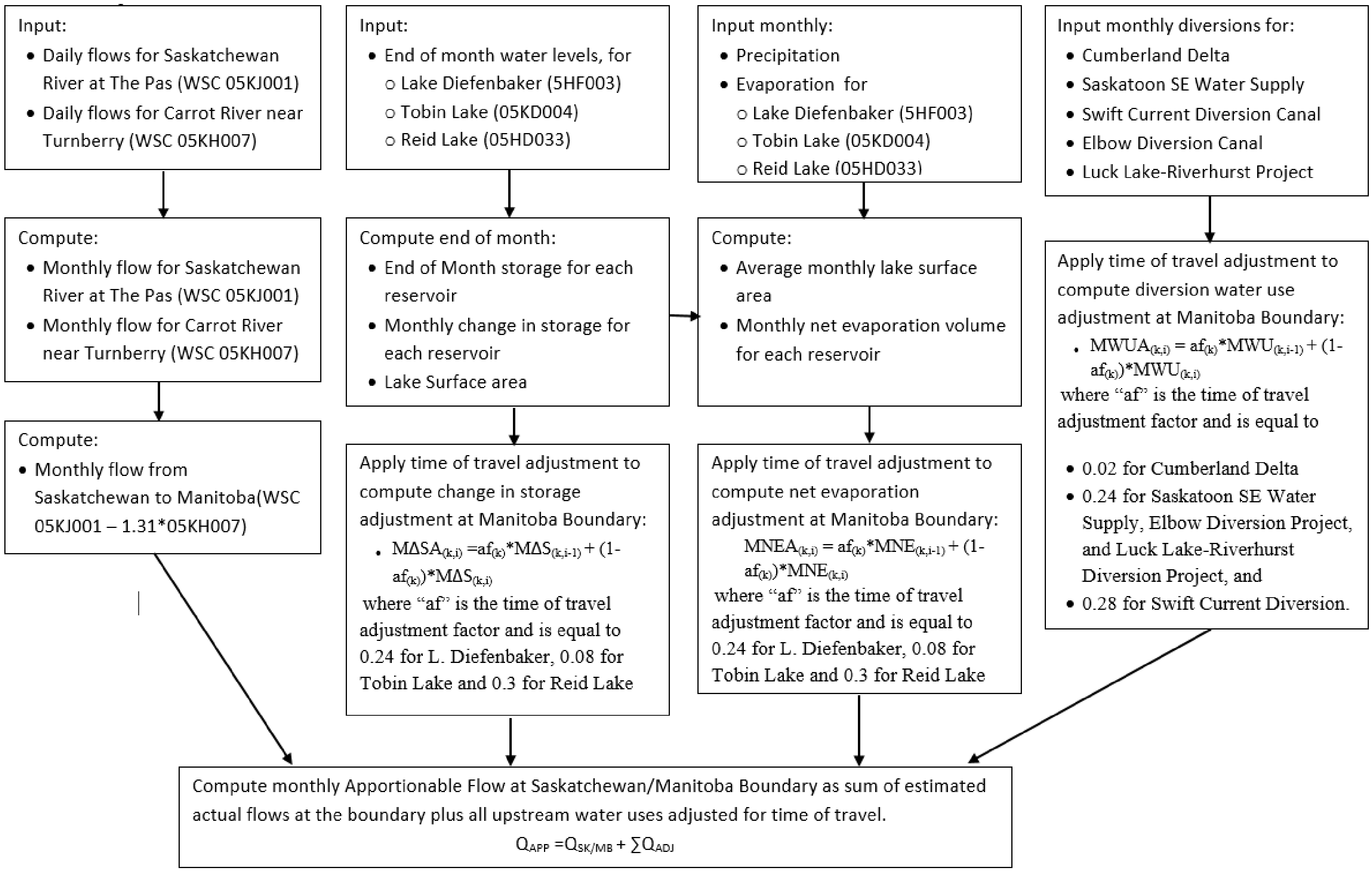
Within the EXCEL Workbook, the quantity of water flowing from Saskatchewan into Manitoba ($MREC_{SK/Man(i)} - MLFC_{Man(i)}$) is computed as follows:

i. The recorded daily flows, (January 1 to December 31) for the Saskatchewan River at The Pas (WSC station #05KJ001) and for Carrot River near Turnberry (WSC station #05KH007) are entered in the first sheet ("*Input*" sheet) of the workbook,
ii. The average monthly flow is computed from the daily flows for both stations ("*Interim Calculation*" sheet) and 1.31 times the average monthly flow from the Carrot River is subtracted from the average monthly flow at The Pas to estimate the average monthly flow at the Saskatchewan-Manitoba Boundary,
iii. The quantity of water flowing from Saskatchewan into Manitoba each month is then calculated ("*Interim Calculations Continued*" sheet) by multiplying the average monthly flow by the adjustment factor 86.4 and by the number of days in the month.

The EXCEL workbook also computes the monthly water use and associated time of travel adjustments ($TTA_{(i-1)} + MWU_{(i)} - TTA_{(i)}$) for the following 11 water use items associated with three reservoirs and five diversion projects:

1) Lake Diefenbaker change in storage,
2) Lake Diefenbaker evaporation,
3) Tobin Lake change in storage,
4) Tobin Lake evaporation,
5) Reid Lake change in storage,
6) Reid Lake evaporation,
7) Cumberland Delta diversion,
8) Saskatoon SE Water Supply,
9) Swift Current Diversion Canal,
10) Elbow Diversion Canal, and
11) Luck Lake-Riverhurst Diversion.

The procedures used within the EXCEL Workbook to compute each of these water use items is presented in a flowchart in Figure 3.1 and discussed in more details in the following.



Input:
- Daily flows for Saskatchewan River at The Pas (WSC 05KJ001)
- Daily flows for Carrot River near Turnberry (WSC 05KH007)

Compute:
- Monthly flow for Saskatchewan River at The Pas (WSC 05KJ001)
- Monthly flow for Carrot River near Turnberry (WSC 05KH007)

Compute:
- Monthly flow from Saskatchewan to Manitoba(WSC 05KJ001 – 1.31*05KH007)

Input:
- End of month water levels, for
    - Lake Diefenbaker (5HF003)
    - Tobin Lake (05KD004)
    - Reid Lake (05HD033)

Compute end of month:
- End of Month storage for each reservoir
- Monthly change in storage for each reservoir
- Lake Surface area

Apply time of travel adjustment to compute change in storage adjustment at Manitoba Boundary:
- $M\Delta SA_{(k,i)} = af_{(k)} * M\Delta S_{(k,i-1)} + (1-af_{(k)}) * M\Delta S_{(k,i)}$

where "af" is the time of travel adjustment factor and is equal to 0.24 for L. Diefenbaker, 0.08 for Tobin Lake and 0.3 for Reid Lake

Input monthly:
- Precipitation
- Evaporation for
    - Lake Diefenbaker (5HF003)
    - Tobin Lake (05KD004)
    - Reid Lake (05HD033)

Compute:
- Average monthly lake surface area
- Monthly net evaporation volume for each reservoir

Apply time of travel adjustment to compute net evaporation adjustment at Manitoba Boundary:

$MNEA_{(k,i)} = af_{(k)} * MNE_{(k,i-1)} + (1-af_{(k)}) * MNE_{(k,i)}$

where "af" is the time of travel adjustment factor and is equal to 0.24 for L. Diefenbaker, 0.08 for Tobin Lake and 0.3 for Reid Lake

Input monthly diversions for:
- Cumberland Delta
- Saskatoon SE Water Supply
- Swift Current Diversion Canal
- Elbow Diversion Canal
- Luck Lake-Riverhurst Project

Apply time of travel adjustment to compute diversion water use adjustment at Manitoba Boundary:
- $MWUA_{(k,i)} = af_{(k)} * MWU_{(k,i-1)} + (1-af_{(k)}) * MWU_{(k,i)}$

where "af" is the time of travel adjustment factor and is equal to

- 0.02 for Cumberland Delta
- 0.24 for Saskatoon SE Water Supply, Elbow Diversion Project, and Luck Lake-Riverhurst Diversion Project, and
- 0.28 for Swift Current Diversion.

Compute monthly Apportionable Flow at Saskatchewan/Manitoba Boundary as sum of estimated actual flows at the boundary plus all upstream water uses adjusted for time of travel.

$Q_{APP} = Q_{SK/MB} + \sum Q_{ADJ}$

**Figure 3.1 Computational Procedure for Calculating Apportionable Flows in the Saskatchewan River Basin**

## ***Lake Diefenbaker, Tobin Lake and Reid Lake Change in Storage***

i. The recorded end of month reservoir elevations (midnight November 30 to midnight December 31 of the year under consideration) for Lake Diefenbaker (WSC St. #05HF003) and Tobin Lake (WSC St. #05KD004) along with the historical mean end of month water levels for Reid Lake (WSC St. #05HD033) are entered in the first sheet ("*Input*" sheet) of the workbook,

ii. The end of month elevations are then applied to elevation-storage tables *("Stage-capacity-area"* sheet) using a "*forecast function*" to determine the end of month storage ("*Interim Calculation*" sheet) for each month in each reservoir.

iii. The end of month storage volume for the previous month (month i-1) is then subtracted from the current months (month i) storage volume to determine the water use resulting from the change in storage for each month in each of the three reservoirs ("*Interim Calculation Continued*" sheet).

iv. The monthly water use adjusted for time of travel is then computed by adding a fixed percentage of the previous month's change in storage to the current month's water use while reducing the current month's water use by a similar percentage ("*Routing adjustments*" sheet). The adjustments being: 24% for Lake Diefenbaker (i.e. $MWUA_{(k,i)} = 0.24*MWU_{(k,i-1)} + 0.76*MWU_{(k,i)}$ ), 8% for Tobin Lake, and 30% for Reid lake.

## ***Lake Diefenbaker Net Evaporation***

i. The computation of net lake evaporation for Lake Diefenbaker starts with the previous entry of end of month reservoir elevations and continues with the following additional entries:
   a. Monthly gross evaporation depth for December of the previous year to December of the current year, with the ice covered period of January-March being set at zero, *(Note -The gross evaporation is provided by ECCC, and is computed by ECCC for both the upper and lower sections of the reservoir. However, only a single, area weighted average, 0.70 * GE for the upper and 0.30 * GE for the lower section, is provided to the PPWB and entered into the workbook...)*
   b. Monthly precipitation for Lake Diefenbaker is provided to the PPWB by ECCC and is computed as the average of monthly precipitation at Elbow CS (4022359), Elbow 2 NE (4022363), Lucky lake (4024714), Swift Current (4028060) and Beechy (4020560)[6] in the first sheet ("*Input*" sheet) of the workbook.

ii. The previously entered end of month elevations are then applied to elevation-area tables *("Stage-capacity area"* sheet) using a "*forecast function*" to determine the end of month lake surface area ("*Interim Calculation*" sheet) for each month. The average lake surface area for each month is subsequently computed as the average of the month (i-1) and month (i) lake surface areas ("*Interim Calculation Continued*" sheet).

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[6] Provided to the PPWB by MSC - Anthony Liu, Environment Canada - March 1, 2016 e-mail.

iii. The net evaporation volume for each month is then calculated by subtracting the precipitation from the gross evaporation, setting any negative values (i.e. precipitation exceeds gross evaporation) to zero, and multiplying the result by the previously computed lake surface area ("*Interim Calculation*" sheet).

iv. The monthly water use adjusted for time of travel is then computed by adding 24 percent of the previous months net evaporation volume to the current months water use while reducing the current months water use by a similar percentage ("*Routing adjustments*" sheet) for time of travel associated with the current months net evaporation losses (i.e. $MWUA_{(k,i)} = 0.24*MWU_{(k,i-1)} + 0.76*MWU_{(k,i)}$ ).

## ***Tobin Lake Net Evaporation***

i. The computation of net lake evaporation for Tobin Lake starts with the previous entry of end of month reservoir elevations and continues with the following additional entries:
   a. Monthly precipitation at Nipawin (station #407N51G)
   b. Monthly gross evaporation depth for April to October, with the ice cover period of Jan–Mar and Nov-Dec being set at zero, in the first sheet ("*Input*" sheet) of the workbook. *(gross evaporation is provided by ECCC, is computed on the basis of mean monthly surface water temperatures, and subsequently saturation vapor pressure, that are estimated by regression which correlates surface water temperature to air temperature.)*

ii. The previously entered end of month elevations are then applied to elevation-area tables *("Stage-capacity area"* sheet) using a "*forecast function*" to determine the end of month lake surface area ("*Interim Calculation*" sheet) for each month. The average lake surface area for each month is subsequently computed as the average of the month (i-1) and month (i) lake surface areas ("*Interim Calculation continued*" sheet).

iii. The net evaporation volume for each month is then calculated by subtracting the precipitation from the gross evaporation, setting any negative values (i.e. precipitation exceeds gross evaporation) to zero, and multiplying the result by the previously computed lake surface area ("*Interim Calculation*" sheet).

***iv.*** Finally, the monthly water use adjusted for time of travel is computed by adding 8% of the previous months net evaporation volume to the current months water use while reducing the current months water use by a similar percentage ("*Routing adjustments*" sheet) (i.e. $MWUA_{(k,i)} = 0.08*MWU_{(k,i-1)} + 0.92*MWU_{(k,i)}$ ).

## ***Reid Lake Net Evaporation***

i. The computation of net lake evaporation for Reid Lake starts with the previous entry of historical average end of month reservoir elevations and with the following additional entries in the first sheet ("*Input*" sheet) of the workbook:
   a. Monthly precipitation at Swift Current CDA (station # 4028060), and

   b. Monthly gross evaporation for April to December (*which are calculated as 1.1 times the gross evaporation for Lake Diefenbaker*).

ii. The previously entered end of month elevations are then applied to elevation-area tables (“*Stage-capacity area*” sheet) using a “*forecast function*” to determine the end of month lake surface area (“*Interim Calculation*” sheet) for each month. The average lake surface area for each month is subsequently computed as the average of the month (i-1) and month (i) lake surface areas (“*Interim Calculation Continued*” sheet).

iii. The net evaporation volume for each month is then calculated by subtracting the precipitation from the gross evaporation, setting any negative values (i.e. precipitation exceeds gross evaporation) to zero, and multiplying the result by the previously computed lake surface area (“*Interim Calculation*” sheet).

iv. Finally, the monthly water use adjusted for time of travel is computed by adding 30% of the previous months net evaporation volume to the current months water use while reducing the current months water use by a similar percentage (“*Routing adjustments*” sheet) for time of travel associated with the current months net evaporation losses (i.e. $MWUA_{(k,i)} = 0.3*MWU_{(k,i-1)} + 0.7*MWU_{(k,i)}$).

## *Cumberland Delta Diversion*

i. The computation of water use by the Cumberland Delta Project starts with the entry of the recorded historical mean monthly flow for Dragline Ditch near Squaw Rapids (05KH011) in the first sheet (“*Input*” s*heet) of the workbo*ok. The mean monthly diversions flows entered are Jan 0.683, Feb 0.601, Mar 0.59, Apr 0.701, May 1.47, June 2.53, July 3.62, Aug. 3.16, Sept 2.44, Oct 1.66, Nov 0.466, Dec 0.734 all values being in $m^3/s$.

ii. The monthly volume (in $dam^3$) of diversions by Cumberland Delta Project are then calculated by multiplying the mean monthly flow rate by the volume conversion factor 86.4 times the number of days in the month (“*Interim Calculations Continued*” sheet).

iii. The monthly water use adjusted for time of travel is then computed by adding 2% of the previous months diversion to the current months water use while reducing the current months water use by a similar percentage (“*Routing adjustments*” sheet) for time of travel associated with the current months diversion (i.e. $MWUA_{(k,i)} = 0.02*MWU_{(k,i-1)} + 0.98*MWU_{(k,i)}$). It is noted that return flows are not considered in the computations of water use by the Cumberland Delta Project.

## *Saskatoon SE Water Supply*

i. The computation of water use by the Saskatoon SE Water Supply System (SSEWSS) starts with the entry of the recorded mean monthly flow, from December of the previous year to December of the current year, for the Broderick (M1) Irrigation Main Canal downstream of the East Side Pump Station (WSC St. #05HF007) in the first sheet (“*Input*” sheet) of the workbook.

ii. The monthly volume of water use by the SSEWSS is then calculated by multiplying the mean monthly flow by the adjustment factor 86.4 and by the number of days in the month ("*Interim Calculations Continued*" sheet).

iii. The monthly water use adjusted for time of travel is computed by adding 24 % of the previous months diversion to the current months water use while reducing the current months water use by a similar percentage ("*Routing adjustments*" sheet) for time of travel associated with the current months diversion (i.e. $MWUA_{(k,i)} = 0.24*MWU_{(k,i-1)} + 0.76*MWU_{(k,i)}$). It is noted that return flows are not considered in the computations of water use by the SSEWSS.

***Swift Current Diversion Project***

i. The computation of water use by the Swift Current Diversion Project starts with the entry of the recorded historical mean monthly flow for Swift Current Canal at Swift Current (WSC St. #05HD034) in the first sheet ("*Input*" sheet) of the workbook. The mean monthly diversions entered being Jan 0.00, Feb 0.09, Mar 0.263, Apr 1.14, May 1.08, June 0.509, July 0.835, Aug. 0.457, Sept 0.16, Oct 0.105, Nov 0.387, Dec 0.0; all values being in $m^3/s$.

ii. The monthly volume of water use by Swift Current Diversion Project is then calculated by multiplying the mean monthly flow by the adjustment factor 86.4 and by the number of days in the month ("*Interim Calculations Continued*" sheet).

iii. The monthly water use adjusted for time of travel is then computed by adding 28 percent of the previous months diversion to the current months water use while reducing the current months water use by a similar percentage ("*Routing adjustments*" sheet) for time of travel associated with the current months diversion (i.e. $MWUA_{(k,i)} = 0.28*MWU_{(k,i-1)} + 0.72*MWU_{(k,i)}$). It is noted that the Swift Current Diversion Project does not consider return flows in the computations of water use.

***Elbow Diversion Canal***

i. The Elbow Diversion Canal diverts water from Lake Diefenbaker to the Qu'Appelle system. The computation of water use by the Elbow Diversion Project starts with the entry of the recorded flow, December of the previous year to December of the current year, for the Elbow Diversion Canal at Drop Structure (WSC St. #05JG006) in the first sheet ("*Input*" sheet) of the workbook. It is noted that while there is a duplicate entry, consisting both the recorded daily flow and the recorded monthly flow, made in the "*input*" sheet, only the daily flows are used in subsequent calculations for this project.

ii. The recorded daily flows are then used to generate mean monthly diversions in the "Interim Calculation" sheet. The mean monthly flows are subsequently multiplied by the adjustment factor 86.4 and by the number of days in the month ("*Interim Calculations Continued*" sheet) to determine the monthly water use.

iii. The monthly water use is then adjusted for time of travel by adding 24 percent of the previous months diversion to the current months water use while reducing the current months water use by a similar percentage ("*Routing adjustments*" sheet) (i.e. $MWUA_{(k,i)} = 0.24*MWU_{(k,i-1)} + 0.76*MWU_{(k,i)}$ ). Water diverted by the Elbow Diversion Project goes to the Qu'Appelle system and there are no returns to Saskatchewan River system.

***Luck Lake-Riverhurst Diversion***

i. The Luck Lake-Riverhurst Diversion start by entering the annual volume of water pumped (in acre-feet) at each of the Luck Lake pumping station and the Riverhurst pumping station in the first sheet ("*Input*" sheet) of the workbook.
ii. The sum of the annual pumpage is then converted to a metric flow rate and distributed monthly as follows: May 7%, June 34%, July 31%, August 15%, and September 13% ("*Interim Calculations Continued*" sheet).
iii. The monthly flow rates are then converted to a volume of monthly water use by multiplying them by the adjustment factor 86.4 and the number of days in the month ("*Interim Calculations Continued*" sheet).
iv. The water use adjusted for time of travel is then computed by adding 24 percent of the previous months diversion to the current months water use while reducing the current months water use by a similar percentage ("*Routing adjustments*" sheet) for time of travel associated with the current months diversion (i.e. $MWUA_{(k,i)} = 0.24*MWU_{(k,i-1)} + 0.76*MWU_{(k,i)}$ ). Return flows are not considered from this project.

***Computation of Apportionable Flow***

The resulting flow at the Saskatchewan-Manitoba Boundary, along with the monthly water use adjustments computed for the 11 previously noted water use projects are summarized in the "*results*" sheet of the EXCEL Workbook. The flow at the boundary along with the water use by the 11 projects are then summed to generate the monthly apportionable flow. The "*results*" sheet also tracks the cumulative flow at the boundary and the cumulative apportionable flow for the year.

## 3.4 Comparison of Documented and Current Apportionable Flow Computation Methods and Procedures

This section provides a comparison between the "documented" (approved) and "current" apportionable flow computation methods and procedures and discusses the potential effect of deviations on the computed apportionable flow.

Table 3.3 provides a summary of the approved computational procedures and of the current computational procedures where the two differ.

**Table 3.3 Comparison of Approved and Current Apportionable Flow Computation Methods and Procedures**

**Approved versus Current Computational Procedure**

| ITEM | Approved Procedure | Current Calculations |
|---|---|---|
| Apportionable Flow Procedure | Apportionable flow calculated based on "*Project Depletion Method*"<br>$AAF_{SK/Man} = \sum_{i=1}^{12}((MREC_{SK/Man(i)} - MLFC_{Man(i)})$<br>$+ (\sum_{k=1}^{n-m} (TTA_{(i-1)} + MWU_{(i)} - TTA_{(i)})_k))$ | |

**Approved versus Current Computational Methods**

| Parameter | Approved Method | Current Calculations |
|---|---|---|
| $MREC_{SK/Man} - MLFC_{Man}$ monthly recorded flow at MB Boundary | Recorded flow for the Saskatchewan River at The Pas (WSC #05KJ001) minus 1.31 times the recorded flow at Carrot River near Turnberry (WSC # 05KH007) to account for local inflow between the Manitoba Boundary and The Pas by Carrot, Pasquia and Birch-Saskeram Rivers. | |

**Approved versus Current Water Use Projects ($MWU_k$) and Methods**

| Project | Parameter | Approved Projects and Method | Current Projects and Method |
|---|---|---|---|
| **Lake Diefenbaker** | Change in Storage | Based on change in storage between month-end elevation of the previous month to month-end elevation of current month at Gardiner Dam (WSC #05HF003) determined using elevation-capacity table in Appendix A. | |
| | Net Evaporation | Lake Diefenbaker net evaporation (NE) and gross evaporation (GE) to be computed for an upper (0.69 LSA) and lower (0.31 LSA) section for May-Nov. using the Meyer equation. P computed as average of Elbow, Swift Current, Tagaske and Beechy. $e_s$ = saturation vapor pressure estimated from mean monthly surface water temperature, which is estimated by ECCC-AES using regression. | Same as approved procedure with three exceptions;<br>1. GE and NE are computed for the April to December period rather than May to November.<br>2. AES computations based on upper and lower sections having a weighing of 0.70 and 0.30 of the Lake Surface Area (LSA) respectively.<br>3. Net evaporation is set to zero for months where P exceeds GE. |
| **Tobin Lake** | Change in Storage | Based on change in storage between month-end elevation of the previous month to the month-end elevation of current month at Tobin Lake (WSC #05KD004) determined using elevation-capacity curve in Appendix A. | |

| | | | |
|---|---|---|---|
| | Net Evaporation | Computed for May-Oct. using Meyer equation with “C” value of 10, water temperature estimated using regression equations, precipitation and dew point at Nipawin, and elevation-area curve in Appendix A, Table A7. | Same as approved procedure with two exceptions:<br>1. GE and NE are computed for April to October rather than May to October.<br>2. Net evaporation is set to zero for months where P exceeds GE. |
| **Reid Lake** | Change in Storage | To be based on historical average month-end elevation of the previous month to that of the current month at Reid Lake near Duncairn (WSC #05HD033) using elevation-capacity curve provided in Appendix A | |
| | Net Evaporation | Computed for May-Oct. as 1.1 times the gross evaporation for upper Lake Diefenbaker minus precipitation at Swift Current times the average historical monthly lake surface area. | Computed for April - December as 1.1 times the prorated gross evaporation for Lake Diefenbaker minus precipitation at Swift Current times the average historical monthly lake surface area. Net evaporation is set to zero for months where P exceeds GE. |

**Approved versus Current Water Use Diversion Projects ($MWU_k$) and Methods**

| **Project** | **Approved Projects and Methods** | **Current Projects and Methods** |
|---|---|---|
| Cumberland Delta | Diversions based on historical mean monthly flow at Dragline Ditch near Squaw Rapids (05KH011). Jan 0.683, Feb 0.601, Mar 0.59, Apr 0.701, May 1.47, June 2.53, July 3.62, Aug. 3.16, Sept 2.44, Oct 1.66, Nov 0.466, Dec 0.734 all values are in $m^3/s$. | |
| Saskatoon SE Water Supply | Diversion based on gauged flow at Broderick (M1) Irrigation Main Canal downstream of the East Side Pump (WSC St. # 05HF007). That return flow is to be ignored. | |
| Swift Current Canal | Diversions based on historical mean monthly flow gauged at Swift Current Canal at Swift Current (05HD034). Jan 0.00, Feb 0.09, Mar 0.263, Apr 1.14, May 1.08, June 0.509, July 0.835, Aug. 0.457, Sept 0.16, Oct 0.105, Nov 0.387, Dec 0.0 all values are in $m^3/s$. | |
| Elbow Diversion | Diversion equal to gauged flow at Elbow Diversion Canal at Drop Structure (WSC #05JG006). Water diverted to Qu’Appelle system and no return to Saskatchewan River. | |
| Luck Lake-Riverhurst | Diversion based on sum of Luck Lake and Riverhurst pumping stations with the following monthly distribution: May 7%, June 34%, July 31%, August 15%, September 13%. | |

**Approved versus Current Time of Travel Procedures**

| **Reach** | **Approved Travel Time Equation** | **Current Travel Time Equation** |
|---|---|---|
| S. Saskatchewan – Gardiner Dam to the Forks | $TT=0.63*10^{2.69-0.158 \log Q}$<br>Q= mean adjusted flow at Saskatoon in cfs | Time of Travel accounted for by shifting a fixed percentage of monthly water use into the next month. The |

| | | |
|---|---|---|
| Saskatchewan R. – the Forks to Tobin Lake | $TT=1.30*10^{3.52-0.47\ \log Q}$<br>Q= sum of mean adjusted flow at Prince Albert and St. Louis in cfs | percentages by project are as follows:<br>Reid Lake 30%,<br>Swift Current Canal Diversion 28%,<br>Lake Diefenbaker, Saskatoon SE Water Supply, Elbow Diversion, and Luck Lake-Riverhurst 24%.<br>Tobin Lake 8%, Dragline Ditch 2% |
| Saskatchewan River – Tobin L. to Manitoba Boundary | $TT=1.00*10^{3.05-0.30\ \log Q}$<br>Q= sum of mean adjusted flow at Manitoba Boundary in cfs | |
| *Note – The approved method requires that each project's total travel time is to be determined as the sum of the TT through the initial reach and all successive downstream reaches. The initial reach for all projects, except Tobin Lake and Dragline Ditch, is the Gardiner Dam to the Forks. The initial reach for Tobin lake is Tobin Lake to Manitoba Boundary and 0.7 of the Tobin L to Manitoba Boundary for the Dragline Ditch.* | | |

Table 3.3 shows the following differences between the approved and current apportionable flow computational procedures:

i. Lake Diefenbaker Net Evaporation
   a. The approved method calls for net evaporation to be computed for the May to November period. The current procedure computes net evaporation for the April to December period.
   b. Due to the upper section of Lake Diefenbaker being much shallower than the lower section, the approved procedure calls for gross evaporation to be computed for a larger and warmer upper section whose area is 0.69 of the lake surface area and a smaller and cooler lower section which has an area equal to 0.31 of the LSA. In comparison ECCC-AES in their computation of a prorated gross evaporation assign a weight of 0.70 to the upper section and 0.30 to the lower section.
   c. The current procedure incorrectly sets net evaporation to zero for months in which the precipitation (P) exceeds gross evaporation (GE).

ii. Tobin Lake Net Evaporation
   a. The approved method calls for net evaporation to be computed for the May to October period. The current procedure computes net evaporation for the April to October period.
   b. The current procedure incorrectly sets net evaporation to zero for months in which the precipitation (P) exceeds gross evaporation (GE).

iii. Reid Lake Net Evaporation
   a. The approved method calls for gross evaporation to be computed as 1.1 times the monthly gross evaporation for upper Lake Diefenbaker. The current procedures compute gross evaporation as 1.1 times the monthly prorated gross evaporation for Lake Diefenbaker.

   b. The current procedure incorrectly sets net evaporation to zero for months in which the precipitation (P) exceeds gross evaporation (GE).

iv. Time of Travel Adjustment

   a. The approved procedures call for the time of travel adjustment to be computed based on equations which relate time of travel to flow for reaches in the South Saskatchewan and Saskatchewan River. The current procedures compute the time of travel adjustment as a fixed percentage of the project water use, resulting in the same time of travel for all ranges of flow.

It is recommended that corrections be carried out to the apportionable flow computational procedures to ensure that it conforms with the approved procedures.

## 3.5 Potential Corrections and Updates to the Current Apportionable Flow Calculations

This section examines hydrologic parameters within the current computational procedures that conform with the documented (approved) procedures but which may be in need of correction or updating. They include:

- A review of the elevation-area-capacity tables for Lake Diefenbaker, Tobin Lake and Reid Lake,
- A review of the contribution by the local area between the gauging site (Saskatchewan River at the Pas) and the Saskatchewan-Manitoba Boundary, and
- A review of adjustments for the contribution by westward flowing tributaries to the Saskatchewan River upstream of the Saskatchewan-Manitoba Boundary

### 3.5.1 Review of Elevation-Area-Capacity Tables for Lake Diefenbaker, Tobin Lake, and Reid Lake

The elevation-area-capacity tables currently being used in the estimation of change in storage and evaporation for Lake Diefenbaker, Tobin Lake, and Reid Lake are provided in Appendix A, Tables A-3 to A-8. This section reviews these tables for each of the three reservoirs relative to updated tables/curves provided by the Water Security Agency (WSA) of Saskatchewan to ensure they continue to be representative and that the range within the computational spreadsheet adequately covers the range of recorded water level elevations in each reservoir.

*Lake Diefenbaker*

The elevation-capacity table and the elevation-area table currently being used for the estimation of change in storage and evaporation for Lake Diefenbaker are presented in Appendix A, Tables A-5 and A-8 respectively. The most up to date elevation-area-capacity curves and table for Lake Diefenbaker, provided by the WSA, are presented in Appendix A, Figure A-1. In order to assess if these tables need to be updated, a graphical comparison of the elevation-area and elevation-capacity tables currently used in the apportionable flow procedures to the most recent data provided by WSA was carried out. The results are shown in Figure 3.2 and Figure 3.3.

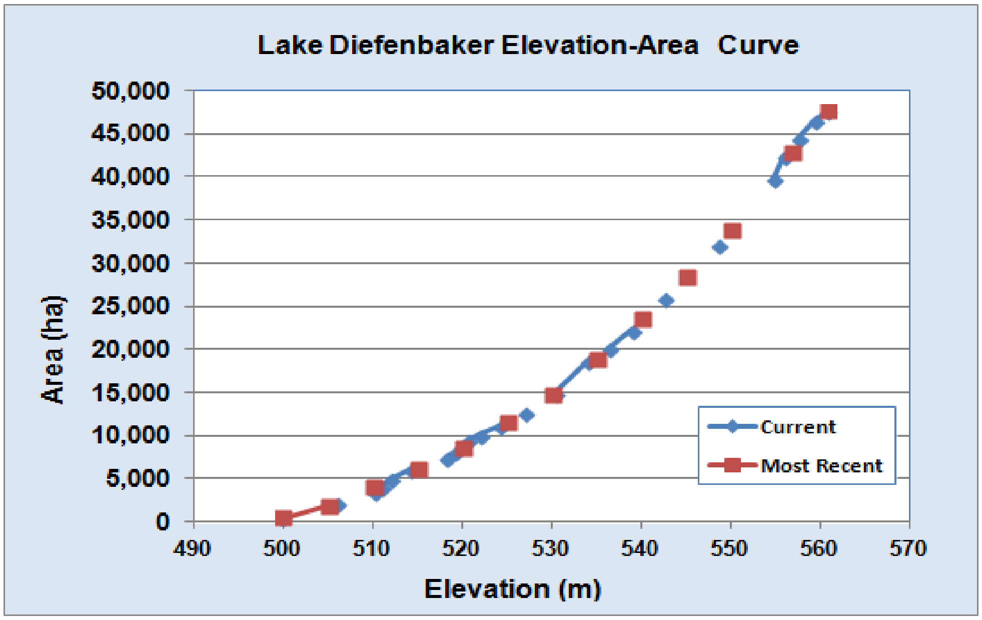


**Figure 3.2 Comparison of Current to Most Recent Elevation-Area Curves for Lake Diefenbaker**

Figures 3.2 and 3.3 show that the elevation-area and elevation-capacity tables currently being used in the estimation of change in storage and evaporation are nearly identical to the most recent tables therefore the they do not need updating.

The current elevation-area table for Lake Diefenbaker covers the elevation range of 499.9-560.8 m while the elevation-capacity table covers the range 545.59-556.87 m. In comparison, Water Survey of Canada records indicate that during the January 1, 1970 to December 31, 2015 period Lake Diefenbaker fluctuated between elevation 546.56 m and 556.9 m. It would therefore appear that the elevation-capacity table being used in the current procedures does not cover the full range of water levels experienced by Lake Diefenbaker and needs to be expanded. It is recommended that the range be expanded to include the last point provided in Figure A-1 this being 560.83 m and 11,150,000 dam$^3$.

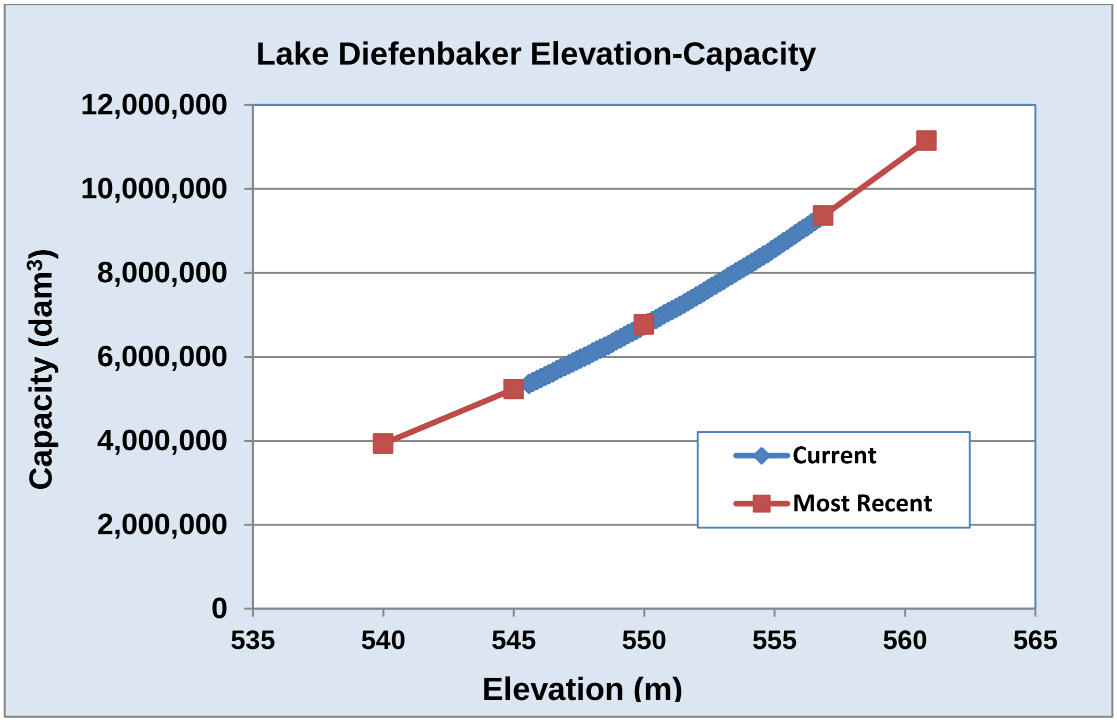


**Figure 3.3 Comparison of Current to Most Recent Elevation-Capacity Curves for Lake Diefenbaker**

*Tobin Lake*

The elevation-capacity table and the elevation-area table currently being used for the estimation of change in storage and evaporation for Tobin Lake are presented in Appendix A, Tables A-4 and A-7 respectively. The updated elevation-area-capacity tables provided by WSA are presented in Appendix A, Figure A-2. While these tables are based on the original stage-storage table provided by SaskPower, the updated tables show several potential errors:

- The surface area for elevation 313.3 m is smaller than the surface area for 312.9 m incorrectly implying the lake surface area get smaller with increase in elevation,
- Incremental increases in capacity appear to be computed on the basis of the surface area for the higher elevation rather than the average surface area thus resulting in an overestimation of capacity, and
- There is a significant deviation between the current and updated elevation-area relationship for elevations above 313.5 m (Figure 3.4).

Given this uncertainty in the reliability of the updated elevation-area-capacity relation for Tobin Lake, it is recommended that the elevation-area and elevation-capacity relation being used currently continue to be used until more reliable estimates are available.

The current elevation-area table for Tobin Lake covers the elevation range of 286.51-318.82 m while the elevation-capacity table covers the range 310.9-313.94 m. In comparison, Water Survey of Canada records indicate that during the January 1, 1970 to December 31, 2015 period Tobin Lake fluctuated between elevation 311.759 m and 313.50 m. It would therefore appear that the elevation-capacity table being used in the current procedures adequately covers the full range of water levels experienced in Tobin Lake.

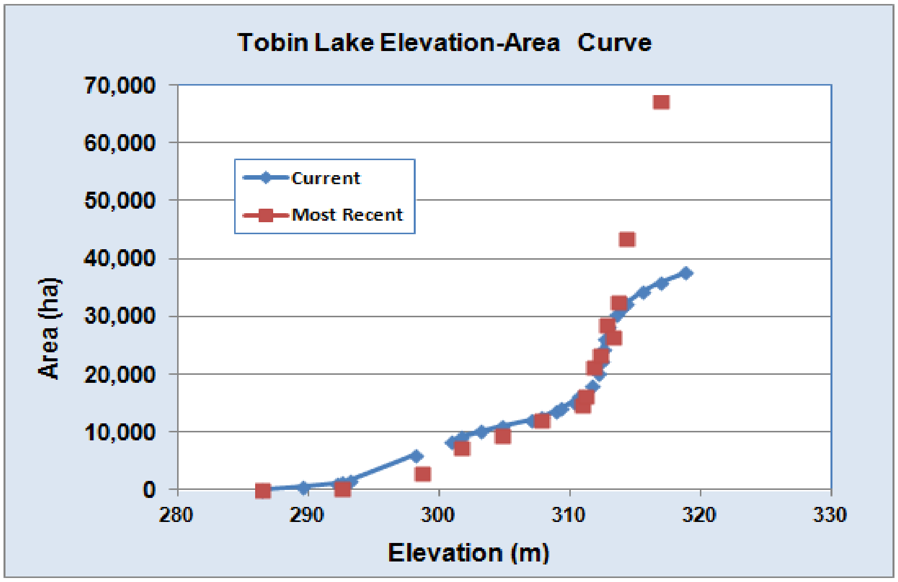


**Figure 3.4 Comparison of Current and Most Recent Update of Elevation-Area Curve for Tobin Lake**

*Reid Lake*

The elevation-capacity table and the elevation-area table currently being used for the estimation of change in storage and evaporation for Reid Lake are presented in Appendix A, Tables A-3 and A-6 respectively. The elevation-area table currently being used to estimate Reid Lake evaporation exhibits an error for elevation 797.81 m as it indicates a smaller surface area than for elevation 797.05 m, as shown in Table 3.4 below.

**Table 3.4 Reid Lake Elevation – Area**

| Elevation (m) | Area (ha) | Elevation (m) | Area (ha) |
|---:|---:|---:|---:|
| 792.48 | 0 | 800.10 | 738.6 |
| 794.00 | 12.1 | 800.86 | 854.3 |
| 794.77 | 33.2 | 801.62 | 951.0 |
| 795.53 | 70.8 | 802.39 | 1025.9 |
| 796.29 | 131.5 | 803.15 | 1082.6 |

| | | | |
|---|---|---|---|
| 797.05 | 222.6 | 804.67 | 1183.7 |
| 797.81 | 76.9 | 806.20 | 1295.0 |
| 798.58 | 465.4 | 807.72 | 1436.7 |
| 799.34 | 598.9 | 809.24 | 1578.4 |

Updated elevation-area-capacity tables and curves for Reid Lake were obtained from AAFC and are presented in Appendix A, Figure A-3. An examination of the tables being used currently to the updated tables indicates that, with the exception of the previously noted error, the two are relatively similar. As the change in storage and evaporation for Reid Lake are based on the average historical end of month elevations, which range from 804.6 to 806.1 m, this error likely has minimal impact on the computed change in storage and net evaporation. While the potential error is minimal, it is recommended that the current elevation-area-capacity tables in the computational procedures be replaced with the updated tables to eliminate the above noted error.

### 3.5.2 Review of Adjustment for Contribution by Local Area between the Saskatchewan-Manitoba Boundary and the Gauging Site (Saskatchewan River at The Pas)

Paragraph 2(b), Schedule B, of the *Master Agreement on Apportionment* states that the flow on which the division of water in each watercourse is based should be determined as near the common boundary as possible. To meet this requirement, the Prairie Provinces Water Board selected the hydrometric station Saskatchewan River near Manitoba Boundary (WSC #05KH008) in 1976 as the flow monitoring site for the Saskatchewan River at the Saskatchewan-Manitoba Boundary. Due to numerous operational problems in monitoring the flow at the Boundary, resulting in substantial loss of water level records, the hydrometric station Saskatchewan River at The Pas (WSC #05KJ001) began being used for apportionment monitoring in the mid-1980s. However, as the monitoring site at The Pas, which is located about 80 km downstream of the Boundary and includes the flow contribution from an additional 22,294 $km^2$ of effective local drainage area (Table 3.5); including the Carrot, Pasquia and Birch-Saskeram Rivers (Figure 3.5) that originate in Saskatchewan and flow independently into Manitoba, an adjustment to the recorded flow at the Pas was required to correct for this additional contribution. The procedure approved for this adjustment was one in which the recorded flow for the Saskatchewan River at The Pas was reduced by 1.31 times the recorded flow for the Carrot River near Turnberry (WSC #05KH007) as indicated below:

**Saskatchewan River @ Saskatchewan-Manitoba Boundary = Recorded Flow at The Pas (WSC #05KJ001) – 1.31 * Carrot River near Turnberry (WSC #05KH007)**

The adjustment factor of 1.31 was based on an assessment of 1969-1979 data that showed a difference in the mean flow of the Saskatchewan River at the Boundary and The Pas of 31 $m^3/s$ (611 $m^3/s$ − 580 $m^3/s$) or 1.31 times the 23.6 $m^3/s$ mean flow for Carrot Creek near Turnberry.

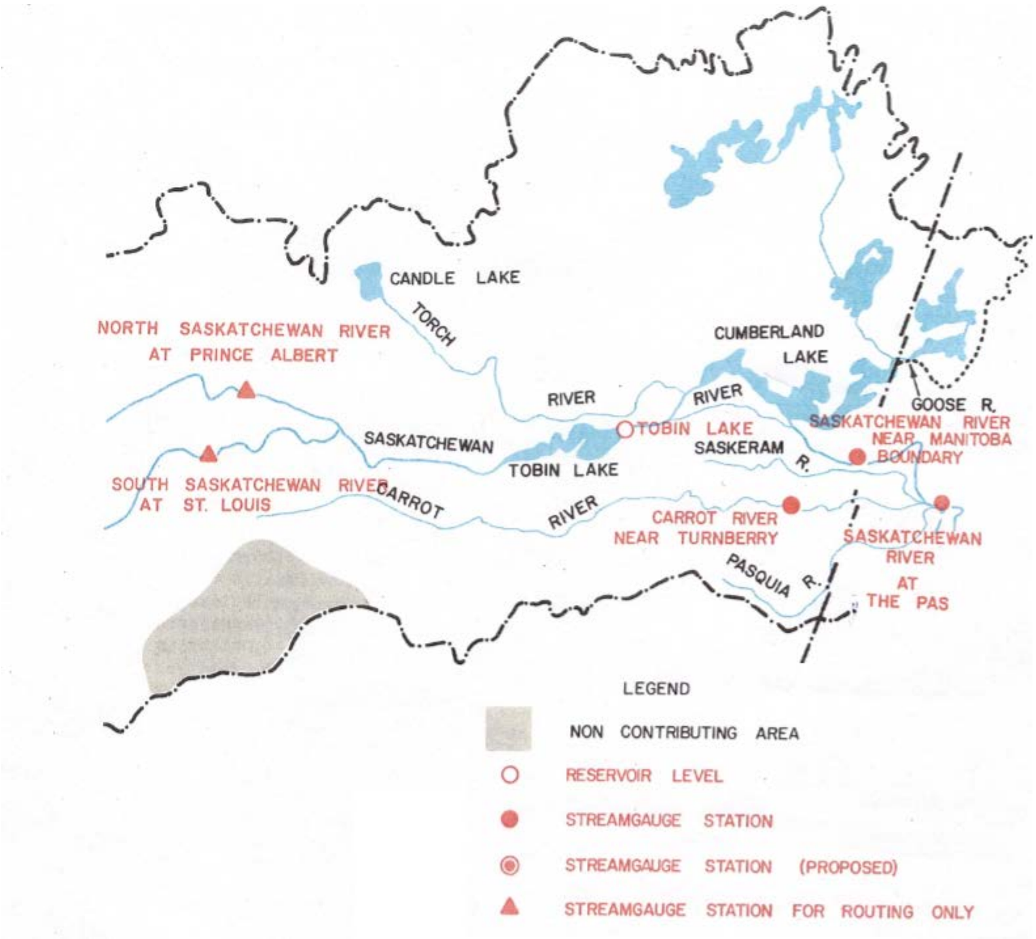


**Figure 3.5 Tributary Inflows Between the Boundary and the Pas as per PPWB Report #45**

**Table 3.5 Ratio of gross and effective local drainage areas between the Saskatchewan River at The Pas and the Manitoba Boundary to the Carrot River near Turnberry**

| PFRA Gross and Effective Drainage Areas | | | |
|---|---|---|---|
| Station # | Station Name | Gross Drainage Area ($km^2$) | Effective Drainage Area ($km^2$) |
| 05KJ001 | Saskatchewan River at The Pas | 388,839 | 213,684 |
| 05KH008 | Saskatchewan River near Manitoba Boundary | 366,545 | 195,966 |
| | Local drainage area between 05KH008 and 05KJ001 | 22,294 | 17,718 |
| 05KH007 | Carrot Creek near Turnberry | 15,304 | 10,737 |
| Ratio of local drainage area between 05KH008 and 05KJ001 to that of Carrot River near Turnberry | | 1.46 | 1.65 |

To verify if the 1.31 coefficient continues to be representative, the mean monthly flow values were assembled for the Saskatchewan River near Manitoba Boundary, the Saskatchewan River at The Pas, and Carrot River near Turnberry for months when data was available for all three sites (Table 3.6).

The annual flow volume was then computed for each year at each of the stations for years when all monthly flows were available, and the difference in annual flow volume between The Pas and the Boundary was computed. The exception was 1972 when only the data for January was missing for the station at the Boundary. This was filled by using the average of all other available January flows (425.2 $m^3/s$). The difference in flow volume was then divided by the annual flow for Carrot River at Turnberry to determine the ratio (adjustment factor) to be applied to the flow of the Carrot River to account for the local area contribution (Table 3.7). Three ratios are shown in Table 3.7. Ratio 1 has a mean value of 1.30 (this is close to the previously used ratio of 1.31), while the median value is 1.15, implying that high values weigh in more in the calculation of the mean than the low values. Ratio 2 was calculated the same way but without the highest outliers on both ends (the highest and the lowest values in Ratio 1), and Ratio 3 was calculated by excluding the highest values on both ends of Ratio 2. It is obvious that in this process the means are coming closer to the median, while the median remains the same.

### Table 3.6 Mean Monthly Flow for Saskatchewan River near Manitoba Boundary, Saskatchewan River at The Pas and Carrot River near Turnberry

| | Mean Monthly Flows of Saskatchewan River near Manitoba Boundary, Station 05KH008, ($m^3/s$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1969 | 432 | 476 | 415 | 911 | 966 | 648 | 1,280 | 928 | 583 | 513 | 314 | 287 |
| 1970 | | | | | | 686 | | | | 378 | | |
| 1971 | | 558 | | | 1,040 | 840 | 867 | 796 | 432 | 348 | 417 | 349 |
| 1972 | 425 | 423 | 491 | 822 | 1,350 | 915 | 1,250 | 1,010 | 562 | 520 | 341 | 290 |
| 1973 | 473 | 520 | 503 | 691 | 913 | | | | | 461 | 328 | 387 |
| 1974 | 493 | 545 | 614 | 946 | 2,230 | 1,650 | 1,220 | 868 | 783 | 665 | 517 | 434 |
| 1975 | 494 | 634 | 604 | 637 | 1,060 | 983 | 940 | 555 | 416 | 401 | 411 | 341 |
| 1976 | 442 | 544 | 543 | 768 | 431 | 333 | 383 | 447 | 466 | 460 | 298 | 316 |
| 1977 | 447 | 498 | 362 | 519 | 459 | 579 | 409 | 362 | 436 | 352 | 238 | 270 |
| 1978 | 389 | 374 | 353 | 499 | 872 | 699 | 740 | 526 | 559 | 642 | 368 | 323 |
| 1979 | | | | 531 | 1,360 | 891 | 461 | 377 | 337 | 307 | 274 | 227 |
| 1980 | 281 | 492 | 492 | 698 | 558 | 723 | 771 | 438 | 394 | 502 | 401 | 234 |
| 1981 | 413 | 448 | 416 | 752 | 545 | 886 | 750 | 1,070 | 673 | 486 | 412 | 238 |
| 1982 | 388 | 439 | 411 | 596 | 793 | 573 | 708 | 571 | 379 | 379 | 311 | 271 |
| Mean | 425 | 496 | 473 | 698 | 967 | 800 | 815 | 662 | 502 | 458 | 356 | 305 |

| | Mean Monthly Flows of Saskatchewan River at the Pas, Station 05KJ001, ($m^3/s$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1969 | 413 | 473 | 429 | 932 | 1,100 | 688 | 1,260 | 954 | 584 | 532 | 327 | 281 |
| 1970 | 424 | 522 | 390 | 441 | 1,170 | 775 | 1,150 | 900 | 501 | 408 | 410 | 333 |
| 1971 | 483 | 577 | 534 | 806 | 1,190 | 888 | 890 | 817 | 436 | 370 | 436 | 337 |
| 1972 | 459 | 403 | 486 | 673 | 1,550 | 1,080 | 1,330 | 1,050 | 563 | 536 | 352 | 253 |
| 1973 | 472 | 526 | 511 | 648 | 1,000 | 1,160 | 979 | 582 | 556 | 469 | 306 | 369 |
| 1974 | 454 | 537 | 600 | 966 | 2,330 | 1,860 | 1,390 | 946 | 837 | 712 | 546 | 430 |
| 1975 | 487 | 627 | 606 | 621 | 1,240 | 1,160 | 1,050 | 595 | 450 | 456 | 443 | 335 |
| 1976 | 413 | 541 | 577 | 786 | 513 | 388 | 493 | 498 | 493 | 473 | 284 | 292 |
| 1977 | 468 | 520 | 345 | 534 | 477 | 594 | 402 | 365 | 438 | 355 | 250 | 268 |

| | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1978 | 309 | 338 | 341 | 499 | 1,060 | 812 | 799 | 543 | 577 | 679 | 388 | 332 |
| 1979 | 451 | 513 | 564 | 543 | 1,570 | 1,120 | 538 | 388 | 344 | 313 | 295 | 245 |
| 1980 | 284 | 497 | 500 | 711 | 587 | 690 | 798 | 438 | 372 | 487 | 398 | 222 |
| 1981 | 401 | 464 | 418 | 751 | 558 | 872 | 742 | 1080 | 691 | 512 | 424 | 246 |
| 1982 | 378 | 481 | 433 | 588 | 886 | 618 | 689 | 545 | 384 | 412 | 327 | 268 |
| Mean | 421 | 501 | 481 | 679 | 1,088 | 908 | 894 | 693 | 516 | 480 | 370 | 301 |

| | Mean Monthly Flows of Carrot River near Turnberry, Station 05KH007, ($m^3/s$) | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec |
| 1969 | 1.59 | 1.15 | 1.15 | 47.10 | 55.30 | 13.70 | 4.39 | 3.30 | 2.77 | 14.20 | 4.40 | 1.76 |
| 1970 | 0.99 | 0.83 | 0.77 | 21.20 | 128.00 | 41.80 | 58.10 | 15.30 | 5.41 | 7.56 | 16.80 | 4.68 |
| 1971 | 1.92 | 1.24 | 1.23 | 53.50 | 97.80 | 16.40 | 12.80 | 11.20 | 9.13 | 25.00 | 18.40 | 5.85 |
| 1972 | 2.78 | 1.75 | 1.70 | 25.90 | 196.00 | 53.70 | 17.30 | 7.13 | 5.91 | 6.97 | 1.93 | 0.42 |
| 1973 | 0.63 | 0.66 | 1.27 | 18.30 | 36.60 | 86.20 | 78.30 | 30.10 | 12.20 | 10.20 | 7.67 | 5.00 |
| 1974 | 3.20 | 2.59 | 2.23 | 33.60 | 211.00 | 102.00 | 28.80 | 19.10 | 19.10 | 18.40 | 9.47 | 4.07 |
| 1975 | 2.69 | 2.12 | 1.90 | 19.90 | 113.00 | 84.00 | 43.40 | 11.70 | 11.10 | 15.40 | 7.18 | 1.92 |
| 1976 | 1.27 | 1.25 | 1.15 | 40.60 | 38.80 | 28.50 | 31.90 | 5.70 | 3.00 | 3.13 | 1.79 | 1.18 |
| 1977 | 0.93 | 0.87 | 1.64 | 20.80 | 20.60 | 12.90 | 2.64 | 10.60 | 9.81 | 8.98 | 13.20 | 3.39 |
| 1978 | 1.71 | 0.93 | 1.27 | 26.60 | 129.00 | 33.30 | 9.76 | 17.00 | 13.80 | 38.20 | 19.90 | 6.27 |
| 1979 | 2.33 | 1.48 | 1.37 | 20.90 | 226.00 | 137.00 | 33.90 | 6.46 | 6.42 | 8.28 | 6.84 | 2.12 |
| 1980 | 1.12 | 1.01 | 1.67 | 33.90 | 39.20 | 5.49 | 9.17 | 4.42 | 8.80 | 12.30 | 3.36 | 1.55 |
| 1981 | 0.64 | 0.78 | 3.12 | 16.60 | 19.10 | 7.51 | 9.95 | 5.25 | 2.97 | 16.00 | 8.09 | 2.26 |
| 1982 | 0.78 | 0.36 | 0.34 | 21.50 | 58.80 | 46.10 | 11.50 | 4.23 | 5.26 | 9.27 | 2.28 | 1.48 |
| Mean | 1.61 | 1.22 | 1.49 | 28.60 | 97.80 | 47.76 | 25.14 | 10.82 | 8.26 | 13.85 | 8.67 | 3.00 |

### Table 3.7 Ratio of Annual Contribution by Local Area between the Boundary and The Pas to Carrot River near Turnberry

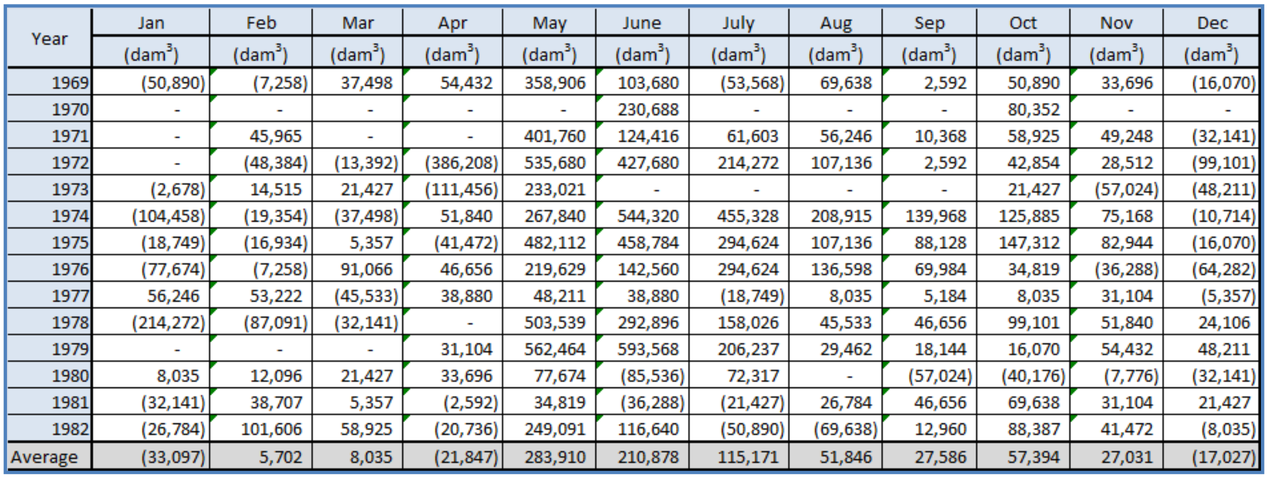
| | Annual Flow Volume ($Mm^3$) | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | 05KH008 | 05KJ001 | 05KJ001-05KH008 | 05KH007 | Ratio 1 | Ratio 2 | Ratio 3 |
| 1969 | 20,430 | 21,014 | 584 | 398 | 1.47 | 1.47 | 1.47 |
| 1970 | | | | | | | |
| 1971 | | | | | | | |
| 1972 | 22,159 | 2,3061 | 902 | 853 | 1.06 | 1.06 | 1.06 |
| 1973 | | | | 758 | | | |
| 1974 | 28,891 | 30,588 | 1,697 | 1,200 | 1.41 | 1.41 | 1.41 |
| 1975 | 19,648 | 21,221 | 1,573 | 831 | 1.89 | 1.89 | |
| 1976 | 14,244 | 15,095 | 850 | 417 | 2.04 | ▨ | ▨ |
| 1977 | 12,925 | 13,143 | 218 | 280 | 0.78 | 0.78 | ▨ |
| 1978 | 16,711 | 17,599 | 888 | 789 | 1.13 | 1.13 | 1.13 |
| 1979 | | | | | | | |
| 1980 | 15,709 | 15,711 | 3 | 322 | ▨ | ▨ | ▨ |
| 1981 | 18,636 | 18,818 | 182 | 244 | 0.75 | ▨ | ▨ |
| 1982 | 15,311 | 15,804 | 493 | 427 | 1.15 | 1.15 | 1.15 |
| | | | | | | | |
| | | | | Mean[1] | 1.30 | 1.27 | 1.24 |
| | | | | Median | 1.15 | 1.15 | 1.15 |
| Shaded areas indicate values omitted in the computation of the mean ratio | | | | | | | |

Table 3.7 shows that on an "annual" basis the flow contribution by the 22,294 km$^2$ effective local area between the Saskatchewan River at the Boundary and The Pas is in the order of 1.30 times the "annual"

flow of the Carrot River near Turnberry. However, as the ratio indicated a high level of variability from year to year, ranging from 0.75 in 1981 to 2.04 in 1976, a more detailed assessment, which examined the difference in monthly flows between the Saskatchewan River at The Pas and at the Boundary (Table 3.8), was carried out.

Table 3.8 shows that during most of the winter and early spring months (November to April), the flow for the Saskatchewan River at The Pas is smaller than the flow at the Boundary. The negative local inflow in nearly all years during the months of December and January would seem to suggest the loss of water to the formation of ice cover during this period and also, potentially, during the shoulder months of November, February, March and April, although less frequently. As these negative values introduce a bias in the estimation of the ratio to be applied to the Carrot River for the estimation of local flow contribution, it was decided to calculate the ratio solely on the basis of the open water (May-October) flows, a period when losses to ice formation are not an issue and the tributary streams are more likely to be flowing. The results are shown in Table 3.9.

**Table 3.8 Monthly Flow Difference Between the Saskatchewan River near the Boundary and at The Pas**



| Year | Jan | Feb | Mar | Apr | May | June | July | Aug | Sep | Oct | Nov | Dec |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) | (dam$^3$) |
| 1969 | (50,890) | (7,258) | 37,498 | 54,432 | 358,906 | 103,680 | (53,568) | 69,638 | 2,592 | 50,890 | 33,696 | (16,070) |
| 1970 | - | - | - | - | - | 230,688 | - | - | - | 80,352 | - | - |
| 1971 | - | 45,965 | - | - | 401,760 | 124,416 | 61,603 | 56,246 | 10,368 | 58,925 | 49,248 | (32,141) |
| 1972 | - | (48,384) | (13,392) | (386,208) | 535,680 | 427,680 | 214,272 | 107,136 | 2,592 | 42,854 | 28,512 | (99,101) |
| 1973 | (2,678) | 14,515 | 21,427 | (111,456) | 233,021 | - | - | - | - | 21,427 | (57,024) | (48,211) |
| 1974 | (104,458) | (19,354) | (37,498) | 51,840 | 267,840 | 544,320 | 455,328 | 208,915 | 139,968 | 125,885 | 75,168 | (10,714) |
| 1975 | (18,749) | (16,934) | 5,357 | (41,472) | 482,112 | 458,784 | 294,624 | 107,136 | 88,128 | 147,312 | 82,944 | (16,070) |
| 1976 | (77,674) | (7,258) | 91,066 | 46,656 | 219,629 | 142,560 | 294,624 | 136,598 | 69,984 | 34,819 | (36,288) | (64,282) |
| 1977 | 56,246 | 53,222 | (45,533) | 38,880 | 48,211 | 38,880 | (18,749) | 8,035 | 5,184 | 8,035 | 31,104 | (5,357) |
| 1978 | (214,272) | (87,091) | (32,141) | - | 503,539 | 292,896 | 158,026 | 45,533 | 46,656 | 99,101 | 51,840 | 24,106 |
| 1979 | - | - | - | 31,104 | 562,464 | 593,568 | 206,237 | 29,462 | 18,144 | 16,070 | 54,432 | 48,211 |
| 1980 | 8,035 | 12,096 | 21,427 | 33,696 | 77,674 | (85,536) | 72,317 | - | (57,024) | (40,176) | (7,776) | (32,141) |
| 1981 | (32,141) | 38,707 | 5,357 | (2,592) | 34,819 | (36,288) | (21,427) | 26,784 | 46,656 | 69,638 | 31,104 | 21,427 |
| 1982 | (26,784) | 101,606 | 58,925 | (20,736) | 249,091 | 116,640 | (50,890) | (69,638) | 12,960 | 88,387 | 41,472 | (8,035) |
| Average | (33,097) | 5,702 | 8,035 | (21,847) | 283,910 | 210,878 | 115,171 | 51,846 | 27,586 | 57,394 | 27,031 | (17,027) |

Table 3.9 indicates that, on average, the flow contribution by the local area between the Boundary and The Pas during the open water period is about 1.64 times the flow for the Carrot River near Turnberry, while the median values for all three Ratios is 1.74. The ratio of 1.64 is close to the ratio of the local effective drainage area (17,718 km$^2$) to the drainage area of Carrot River (10,737 km$^2$) at the gauging site which is 1.65, suggesting it likely is a more appropriate ratio to apply to Carrot River flows for the estimation of flow contributed by the local area between the Boundary and The Pas. However, this ratio should only be applied to open season (May-October) flows, while the winter flows would be exempt from the calculation.

## Table 3.9 Estimation of Adjustment Factor of the Carrot River near Turnberry based on Open Water Season Flows

| | May to October Flow Volume (Mm$^3$) | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | 05KH008 | 05KJ001 | 05KJ001– 05KH008 | 05KH007 | Ratio 1 | Ratio 2 | Ratio 3 |
| 1969 | 13,066 | 13,598 | 532 | 249 | 2.13 | 2.13 | 2.13 |
| 1970 | | | | | | | |
| 1971 | | | | | | | |
| 1972 | 14,890 | 16,220 | 1,330 | 764 | 1.74 | 1.74 | 1.74 |
| 1973 | | | | 671 | | | |
| 1974 | 19,653 | 21,395 | 1,742 | 1,057 | 1.65 | 1.65 | 1.65 |
| 1975 | 11,544 | 13,122 | 1,578 | 738 | 2.14 | 2.14 | |
| 1976 | 6,681 | 7,579 | 898 | 295 | 3.05 | | |
| 1977 | 6,868 | 6,958 | 90 | 174 | 0.52 | | |
| 1978 | 10,707 | 11,852 | 1,146 | 642 | 1.79 | 1.79 | 1.79 |
| 1979 | | | | | | | |
| 1980 | 8,973 | 8,940 | -33 | 211 | | | |
| 1981 | 11,677 | 11,797 | 120 | 162 | 0.74 | 0.74 | |
| 1982 | 9,032 | 9,379 | 347 | 358 | 0.97 | 0.97 | 0.97 |
| | | | | | | | |
| | | | | Average | 1.64 | 1.59 | 1.66 |
| | | | | Median | 1.74 | 1.74 | 1.74 |

There may be reluctance to separate the open water season and winter flows when calculating the adjustment coefficients for Carrot River near Turnberry, since the current procedure is applied to total annual flows. An equivalent coefficient for annual flows can be derived on the basis of the mean winter flow volumes, summer flow volumes, and the mean coefficient of 1.64 by using the following weighted average formula:

$$Cadj = \frac{\text{Vwinter} * 0 + \text{Vsummer} * 1.64}{\text{Vwinter} + \text{Vsummer}}$$

Replacing values of 113.22 million of m$^3$ for the winter flow volume (Vwinter) and 462.26 million m$^3$ for summer flow volume (Vsummer) for the Carrot River at Turnberry in the above equation gives the adjustment coefficient of 1.32, almost identical to 1.31 that has been used in the past.

It is up to the COH to decide whether the median (1.74) or the mean (1.64) should be used in the above equation. Another approach is to apply one of the coefficients (1.74 or 1.64) only to the open season flows and ignore the winter flows in the calculation. Option 2 should therefore be based on maintaining status quo, which is to use an adjustment factor of 1.31 for all months. There is no more hydrometric data available now than when the PPWB adopted the current methodology as recommended in the August 1983 Water Survey of Canada “Saskatchewan River Monitoring Study”, and consequently there is no evidence that the current practice should be revised.

Another Option (3) could be considered. Instead of basing the adjustment ratio solely on the Carrot River, the ratio could be based on the sum of the Carrot River and Pasquia River flow volumes and then multiplied by the ratio of the gross or effective drainage area of Carrot River and Pasquia River, i.e.

(Carrot River + Pasquia River) * (effective drainage area ratio)

The following table contains the gross and effective drainage areas for the four stations of concern, and the calculations below show the GDA and EDA ratios using the Carrot River alone, and using both the Carrot and Pasquia Rivers. It is evident there is little difference.

| Hydrometric Station | Drainage Area ($km^2$) | |
|---|---|---|
| | Gross | Effective |
| 05KH008 - Saskatchewan River near Manitoba Boundary | 366,545 | 195,966 |
| 05KJ001 - Saskatchewan River at The Pas | 388,839 | 213,684 |
| 05KH007 - Carrot River near Turnberry | 15,304 | 10,737 |
| 05KJ014 - Pasquia River at Highway No. 9 | 74 | 74 |

Drainage Area Ratios based on the Carrot River Data Alone

GDA Ratio: (388,839 – 366,545) / 15,304 = 1.46EDA Ratio: (213,684 – 195,966) / 10,737 = 1.65

Drainage Area Ratios based on the use of both Carrot and Pasquia River Data

GDA Ratio: (388,839 – 366,545) / (15,304 + 74.3) = 1.45

EDA Ratio = (213,684 – 195,966) / (10,737 + 74.3) = 1.64

Similar negligible effects are obtained if the annual ratio of May to October flows [(The Pas – Interprovincial Boundary) / (Carrot River + Pasquia River)] is determined. The differences between the adjustment coefficients with or without the Pasquia River are well within 1%.

The only active WSC hydrometric station on the Pasquia River (05KJ014) monitors runoff from a very small drainage area (74.3 $km^2$) and contributes relatively little flow to the Saskatchewan River (average annual flow of 15,200 $dam^3$ over the 1974 to 2015 period of record). There would appear to have once been provincial stations located closer to the mouth of the Pasquia River (for example, 05KJ802 - Pasquia River at PR 283 Pump Plant near The Pas, which has a gross and effective drainage area of 2480 $km^2$), but these stations are no longer active.

Water use within Manitoba downstream of the Saskatchewan-Manitoba Boundary but upstream of the Pas reduces the observed flow and should be included in the computation of local inflow. Currently, there are two water use allocations within Manitoba between the Saskatchewan-Manitoba Boundary and the hydrometric station Saskatchewan River at the Pas (WSC 05KJ001), these are:

**Table 3.10 Water Allocations between the Manitoba Boundary and the Pas Gauging Station**

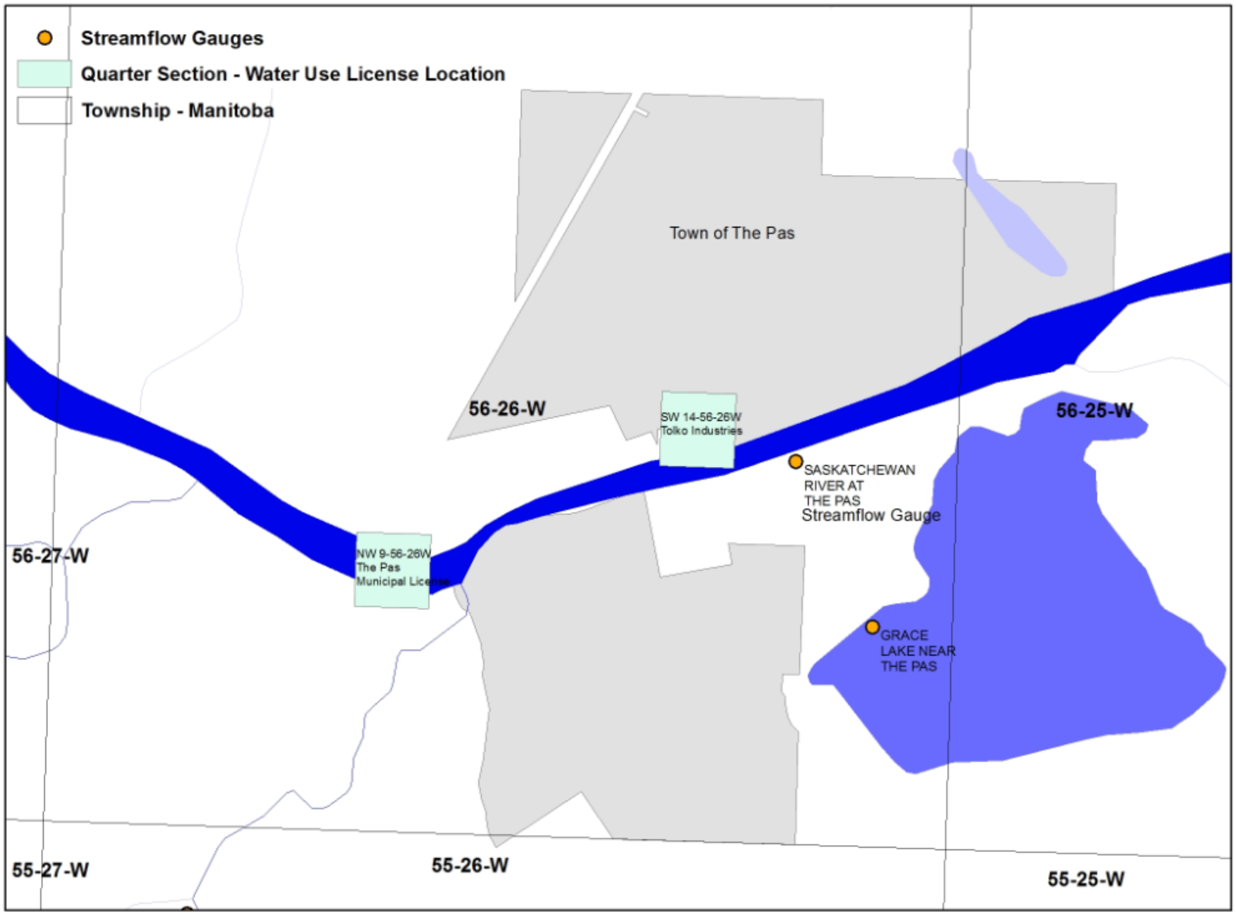
| Project ID | File # | Original Application Date | Company Name | Usage Category | License # | Mean Ann. Allocation (dam3) |
|---|---|---|---|---|---|---|
| 6747 | 1 | 1962-12-28 | The Pas | Municipal | 2008-012 | 4,810 |
| 9936 | 1 | 1996-01-22 | Tolko Industries | Industrial | 2013-024 | 15,000 |
| TOTAL ALLOCATIONS | | | | | | 19,810 |

The Town of The Pas diverts its water allocation of 4810 dam$^3$ from upstream of the gauging location on the Saskatchewan River at The Pas. This water is returned to Grace Lake and then to the Saskatchewan River. It should be included in the apportionment calculation as it is returned downstream of the gauging site. Although the volume of this license is relatively small compared to the flow, it should still be included for completeness and transparency. The location of the withdrawal point for the industrial water diverted by Tolko Industries is located upstream of The Pas gauging station and, as such, the water use should be included in the apportionment flow computation.

The 19, 810 dam$^3$ use between the interprovincial boundary and the hydrometric station at The Pas is equivalent to a mean annual flow of 0.63 m$^3$/s. Inclusion of these two uses would result in a revised adjustment coefficient of 1.34, calculated as:

$$(611 \text{ m}^3/\text{s} + 0.63 \text{ m}^3/\text{s} – 580 \text{ m}^3/\text{s}) / 23.6 \text{ m}^3/\text{s} = 1.34 \text{ m}^3/\text{s}$$

**Figure 3.6 Water Allocations between Manitoba Boundary and the Pas Gauging Station**



Summary of options are:

| | |
|---|---|
| OPTION 1: | Apply one of the coefficients (1.74 or 1.64) only to the open season flows and ignore the winter flows in the calculation. |
| OPTION 2: | Maintain status quo 1.31 for $Cadj$. |
| OPTION 3: | Sum the Carrot River and Pasquia River flow volumes then multiply by the ratio of the effective drainage area (1.64). |
| OPTION 4: | Include the Consumptive Uses Between the Manitoba Boundary and the Hydrometric Station Saskatchewan River at The Pas (Tolko Industries and the town of the Pas) which would change the adjustment factor of 1.31 to 1.34 |

### 3.5.3 Review of Contribution by Westward Flowing Tributaries (Goose River) of the Saskatchewan River upstream of the Saskatchewan-Manitoba Boundary

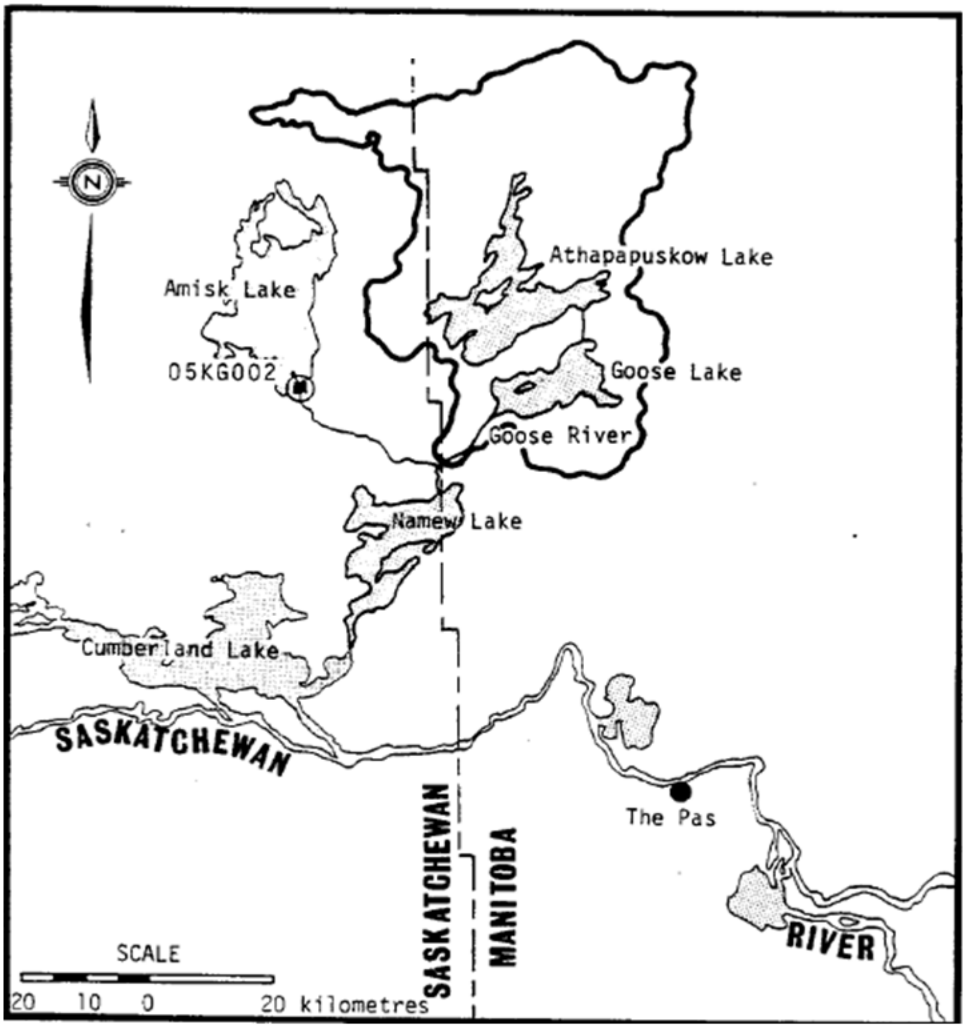
The Goose River is a tributary of the Saskatchewan River that originates in Manitoba and flows westward across the Saskatchewan-Manitoba Boundary (Figure 3.7). Within Manitoba, it receives westward flowing waters from Athapapuskow Lake and Goose Lake. Shortly after crossing into Saskatchewan, the Goose River joins the larger Sturgeon-weir system that rises in Saskatchewan and flows into Namew Lake, which straddles the Saskatchewan-Manitoba Boundary, and then flows into Cumberland Lake before joining the Saskatchewan River in Saskatchewan about 20 km upstream of the Boundary.

The flow of the Goose River has not been monitored. However, it is estimated at, on average, about 265,242 dam$^3$, assuming similar per unit area specific yield as for the Sturgeon-weir River at Outlet of Amisk Lake (WSC #05KG002) (Table 3.11).

**Table 3.11 Estimation of Flow for the Goose River at the Manitoba/Saskatchewan Boundary**

| | Gross Drainage Area (km$^2$) | Estimated/Recorded Mean Annual Yield (dam3) | Specific Mean Annual Yield (dam$^3$/km$^2$) |
|---|---|---|---|
| **Sturgeon-weir at Outlet of Amisk Lake (WSC #05KG002) (1965-1995)** | 14,600 | 1,480,890 | 101.43 |
| | | | |
| **Saskatchewan Portion of Goose River Basin** | 375 | 38,037 | assumed same as Sturgeon-weir |
| **Manitoba Portion of Goose River Basin** | 2240 | 227,205 | assumed same as Sturgeon-weir |
| **Total - Goose River @ Crossing into Saskatchewan** | 2615 | 265,242 | |

**Figure 3.7 Goose River Basin to the Saskatchewan-Manitoba Boundary (Source: PPWB Report #65)**



The 1976 report "*Natural Flow – Saskatchewan River at Saskatchewan-Manitoba Boundary*" recognized that, being a westward flowing tributary, the flow contribution of the Goose River may require some special consideration. However, the report recommended that the sharing of the Goose River not be taken into account as a separate item because *"… apportionment of westward-flowing tributaries of eastward flowing streams is under consideration, and an agreement [on how they are to be apportioned] has not been reached.*"

In April 1986, the PPWB approved the PPWB-COH report "*Westward Flowing Tributaries of Eastward Flowing Streams – Apportionment Study*". The report, after examining various potential interpretations as to the intent of the 1969 Master Agreement as it relates to westward flowing tributaries of eastward flowing streams, recommended that a procedure referred to as the "*Rational*

*Method*", be applied. The Rational Method essentially directs that the waters of westward flowing tributaries of eastward flowing streams are to be shared according to the following principles:

1. *"The province in which the water originates is entitled to 50% of that water and the rest of the water is divided equally between the downstream provinces."*
2. *"The apportionment is between provinces, not between the various regions, so a province is allowed to remove its apportionment entitlement wherever it is most convenient, provided that in so doing the depletion is equitable."*

With respect to the Goose River, the above implies that:
a) Since there is no second downstream province, Saskatchewan and Manitoba are each entitled to 50% of the flow originating upstream of the Goose River's crossing into Saskatchewan,
b) Each province is allowed to take its entitlement of the flow of the Goose River wherever it is most convenient, be it directly from the Goose River or from the Saskatchewan River.
c) Should Manitoba's water use directly from the Goose River approach its 50% entitlement, the PPWB would be required to apportion the flow of the Goose River independently to ensure that Manitoba's removal of its entitlement is equitable.

Currently there are no water use allocations within the Manitoba portion of the Goose River basin. Given that:
a. There are currently no water uses within the Manitoba portion of the Goose River basin
b. There is no third downstream jurisdiction, Manitoba and Saskatchewan are each entitled to 50% of the flow originating in the Manitoba portion of the Goose River basin; the same as for water originating in Saskatchewan, and
c. Manitoba is permitted to take its share of the Goose River "*…wherever it is most convenient";* including downstream of the Manitoba boundary,

there is currently no need to apportion the flow of the Goose River separately, rather it can be apportioned as an integral part of the Saskatchewan River apportionment without any special consideration.

### 3.6 Discussion of Other Models Available for the Basin

PPWB has embarked on the development of a new model for calculation of apportionable flows, which gave birth to the River Basin Assessment Tools (RBAT) software platform. RBAT uses SQL Server database and provides numerous utilities. It was developed to replace the existing Fortran program and to calculate natural flows with a monthly time step and the same time lagging coefficients for PPWB Routing Method 1, but it can also be used with a daily time step, provided sufficient information exists to enable the SSARR routing equations. This information is currently unavailable, and it is not clear when it would be available in a timely manner to enable calculation of apportionable flows at the Saskatchewan-Manitoba Boundary on a daily basis. The daily time step would also utilize the Project

Depletion method (this is the only natural flow calculation method built into RBAT), although it would require that all water uses be also converted to daily time steps. There seem to be no other models suitable for calculation of natural flows on the scale required in the Saskatchewan River Basin other than the existing Fortran program, the existing Excel spreadsheet, or RBAT.

# 4. WATER USE IN THE SASKATCHEWAN RIVER BASIN

## 4.1 Water Use Currently Included in the Calculation of Apportionable Flows

Water licenses issued by the Province of Saskatchewan identify solely the maximum allowable annual water use, which includes the consumptive use and losses. The licenses do not include return flows, whether they are returned instantly, such as in gravel washing operations, or over a period of many months. The actual water use currently accounted for differs from year to year, as discussed later in this chapter.

As of November 2015, there are 4,054 water use licenses, which have a licensed water use of 1,481,192 dam$^3$ within the Saskatchewan portion of the Saskatchewan River basin. Of this total, 2,509 licenses, with a licensed water use of 1,481,192 dam$^3$, are located within the effective drainage area of the Saskatchewan River basin (Table 4.1). Of the aforementioned 2,509 water use licenses, 1,155,405 dam$^3$, or 83.6% of the licensed water use within the effective area is assigned to the 14 largest water licenses (Table 4.2). This implies that a relatively accurate estimate of apportionable flow can be obtained by including the water use by a relatively small number of the licensed water use projects in the apportionable flow computation.

**Table 4.1 Licensed Water Use Within Saskatchewan Portion of Saskatchewan River Basin**

| | # of Licences | Losses (dam$^3$) | Consumptive Use (dam$^3$) | Water use (dam$^3$) |
|---|---|---|---|---|
| Effective Area | 2,509 | 711,466 | 886,434 | 1,442,900 |
| Non-Effective Area | 1,545 | 13,009 | 25,283 | 38,292 |
| Total | 4,054 | 724,475 | 911,717 | 1,481,192 |

The Swift Current Diversion is a sum of twenty licenses, of which two of the largest licenses represent 91% of the total. Percentages in the last column represent percentage of the cumulative diversion in the previous column with respect to the total water use within the effective drainage area (1,442,900 dam$^3$) listed in Table 4.1. It should be noted again that the 15 licenses listed in Table 4.2 account for 75% of all water licenses in the basin in terms of the volume of licensed diversions.

**Table 4.2 Cumulative Water Use by Largest Licensed Water Uses Within Saskatchewan Portion of Saskatchewan River Basin**

| User | License Number | Project | Type | Diversion (dam$^3$) | Losses (dam$^3$) | License (dam$^3$) | Cumulative Diversion (dam$^3$) | Percent of Total (%) |
|---|---|---|---|---|---|---|---|---|
| SASKPOWER | 07592 | QUEEN ELIZABETH THERMAL | Cooling | 427108 | 0 | 427108 | 427108 | 26.7 |
| **WATER SEC. AGENCY** | **05334** | **LAKE DIEFENBAKER** | Unclassified | 0 | 184143 | 184143 | 611251 | 38.3 |
| **SASK AGRICULTURE** | **11722** | **EAST SIDE CANAL SSRID (Broderick)** | Agriculture | 106079 | 8634 | 114713 | 725964 | 45.4 |
| **SASK WATER** | **10647** | **SSEWS** | Unclassified | 70907 | 37004 | 107911 | 833875 | 52.2 |
| WATER SEC. AGENCY | 06740 | CANDLE LAKE DAM | Recreation | 0 | 92000 | 92000 | 925875 | 57.9 |
| **DUCKS UNLIMITED** | **12790** | **CUMBERLAND MARSHES** | Wildlife | 0 | 69000 | 69000 | 994875 | 62.3 |
| SASKATOON | 16914 | SASKATOON MUNICIPAL | Urban | 61650 | 0 | 61650 | 1056525 | 66.1 |
| PRINCE ALBERT PULP* | 10691 | PRINCE ALBERT PULP | Manufacturing | 28000 | 0 | 28000 | 1084525 | 67.9 |
| JACKFISH LAKE WSA | 00531 | JACKFISH/MURRAY LAKE | Unclassified | 0 | 27630 | 27630 | 1112155 | 69.6 |
| JACKFISH LAKE WSA | 11818 | N/A | Wildlife | 0 | 22250 | 22250 | 1134405 | 71.0 |
| RED EARTH LAND | 03837 | JAM CREEK DAM | Rural | 0 | 21000 | 21000 | 1155405 | 72.3 |
| PRINCE ALBERT | 14236 | | Municipal | 16245 | 0 | 16245 | 1171650 | 73.3 |
| **AAFC, WSA, & other users** | **4012, 198, et al.** | **SWIFT CURRENT DIVERSION** | Irrigation, Domestic | 15748 | 262 | 16010 | 1187660 | 74.3 |
| DUCKS UNLIMITED | 15803 | LUCK LAKE WILDLIFE PROJECT | Wildlife | 0 | 9250 | 9250 | 1196910 | 74.9 |
| OTHER | - | ALL OTHERS | All types | | | 245990 | **1442900** | 100.0 |

*Prince Albert Pulp Mill is closed now but it will reopen in 2020.

The entries marked with **bold font** in Table 4.2 represent the licenses that are currently included in the calculation procedure. Water use in the Saskatchewan River Basin represents the sum of all anthropogenic consumptive water uses and water losses from the Saskatchewan River and its tributaries that are not returned to the main watercourse. There are five diversions from the Saskatchewan River that have been included in the current procedures used for the calculation of apportionable flows:

- Broderick Irrigation Diversion (M1) which diverts water from Lake Diefenbaker in a northerly direction into the South Saskatchewan River Irrigation District, and then through the SSEWSS canal to meet other agricultural, municipal and industrial uses;
- Elbow Diversion, which diverts water from Lake Diefenbaker to augment flows in the Qu'Appelle River Basin;
- Swift Current Diversion, located on Swift Current Creek upstream of Lake Diefenbaker which diverts water to Highfield Reservoir

- Dragline Ditch (also known as Cumberland Marsh) diversion, which diverts water into a dam built on the Birch river to provide water supply for numerous wildlife restoration projects operated by Ducks Unlimited, and located close to the SK / MB boundary; and,
- Annual estimates for Riverhurst and Luck Lake diversions are summed up and applied in monthly calculations using fixed monthly percentages.

Storage change and net evaporation losses on Lake Diefenbaker, Tobin Lake and Reid Lake are also included due to the significant effect they have on the monthly apportionable flow calculations. It should be noticed that water licenses for net evaporation on Tobin and Reid Lakes cannot be found in the existing database. Net evaporation loss was only licensed on Lake Diefenbaker. Water uses included in the current apportionment flow computation procedures are listed in Table 4.3.

**Table 4.3 Water Use Included in the Current Calculation Procedure (all units in dam$^3$)**

| WATER USE PROJECT | License Number | Type of Water Use | Consumptive Use | Losses | Licensed Water Use | Actual Use |
|---|---|---|---|---|---|---|
| SSEWS | 10647 | Multipurpose | 70,907 | 37,004 | 107,911 | 102,219 |
| East Side SSRID (Broderick Canal) | 11722 | Irrigation | 106,079 | 8,634 | 114,713 | 73,500 |
| Swift Current Diversion | 4012 & 198 | Irrigation | 15,748 | 262 | 16,010 | 13,249 |
| Cumberland Marshes | 12790 | Wildlife | 0 | 69,000 | 69,000 | 49,280 |
| Luck Lake and Riverhurst Diversion | 15782/16000 | Irrigation | 7,333 | | | 7,333 |
| Lake Diefenbaker (includes Elbow Diversion/Qu'Appelle Dam) | 05334 | Unclassified | | 184,143 | 184,143 | |
| Total | | | 200,067 | 299,043 | 491,777 | 245,581 |

Each entry in Table 4.3 is discussed in more detail in a separate sub-section of this chapter. Note that the Luck Lake and Riverhurst diversions cannot be located in the water license database. The Swift Current diversion is a sum of 20 licenses, of which two are the most significant -- license number 4012 with the diversion limit of 8600 dam$^3$ and license number 198 with the diversion limit of 5953 dam$^3$, and they account for 91% of the total. The other licensed annual volumes in Table 4.3 were obtained directly from the WSA Water License database. No return flows are taken into account in the current calculation procedure. The annual consumptive water use (excluding evaporation and storage change) taken into account for 2014 in the current calculation spreadsheet provided by PPWB is 126,168 dam$^3$. In comparison, the total amount of consumptive use associated with water licenses that fall within the effective drainage area for the Saskatchewan River Basin in Saskatchewan is in the order of 1,442,900 dam$^3$. There exists a significant volume of licensed water use that is currently not included in the calculation of apportionable flows. This is addressed later in this section.

## 4.2 Availability of the Water Use Data for the Computation of Apportionable Flow

While water diversions for all projects were monitored in 1976, the monitoring was discontinued for several projects in Table 4.3 in the 1980s due to budgetary constraints. These projects are still taken into account in the calculation procedure by using the monthly or annual averages over all historic years with data records even though, in some cases they continue to be monitored by a third party. In particular:

- Broderick Irrigation Diversion - WSC Station 05HF007 is no longer active, however the Provincial Government of Saskatchewan has continued to conduct its own monitoring. It may also be possible to use pump records from the ESPS to reconstruct the flows since deactivation of the WSC station, but this option needs to be investigated further.
- Elbow Diversion – WSC Station 05JG006 is still active providing daily recorded flows
- Swift Current Diversion Station 05HD034 is no longer active
- Dragline Ditch – WSC Station 05KH011 is no longer active, and
- The Luck Lake irrigation and Riverhurst irrigation are currently included in the calculation as a sum of their annual water use (4783 ac-ft for Riverhurst and 3169 ac-ft for Luck Lake for 2014) which amounts to the total of 9809 dam3. This is broken respectively into monthly fractions of 7, 34, 31, 15 and 13 percent, inclusive from May to September.
- Changes in monitoring regarding Net Evaporation -- due to the discontinuation of water temperature measurements, evaporation is now computed using indirect methods which correlate water temperature to air temperature. Net evaporation on Reid Lake and Tobin Lake is also estimated and included in the calculation of apportionable flows.

## 4.3 Analysis of Water Use Data Used in Current Apportionable Flow Computations

This section examines the diversions that are currently used in the calculation of apportionable flows.

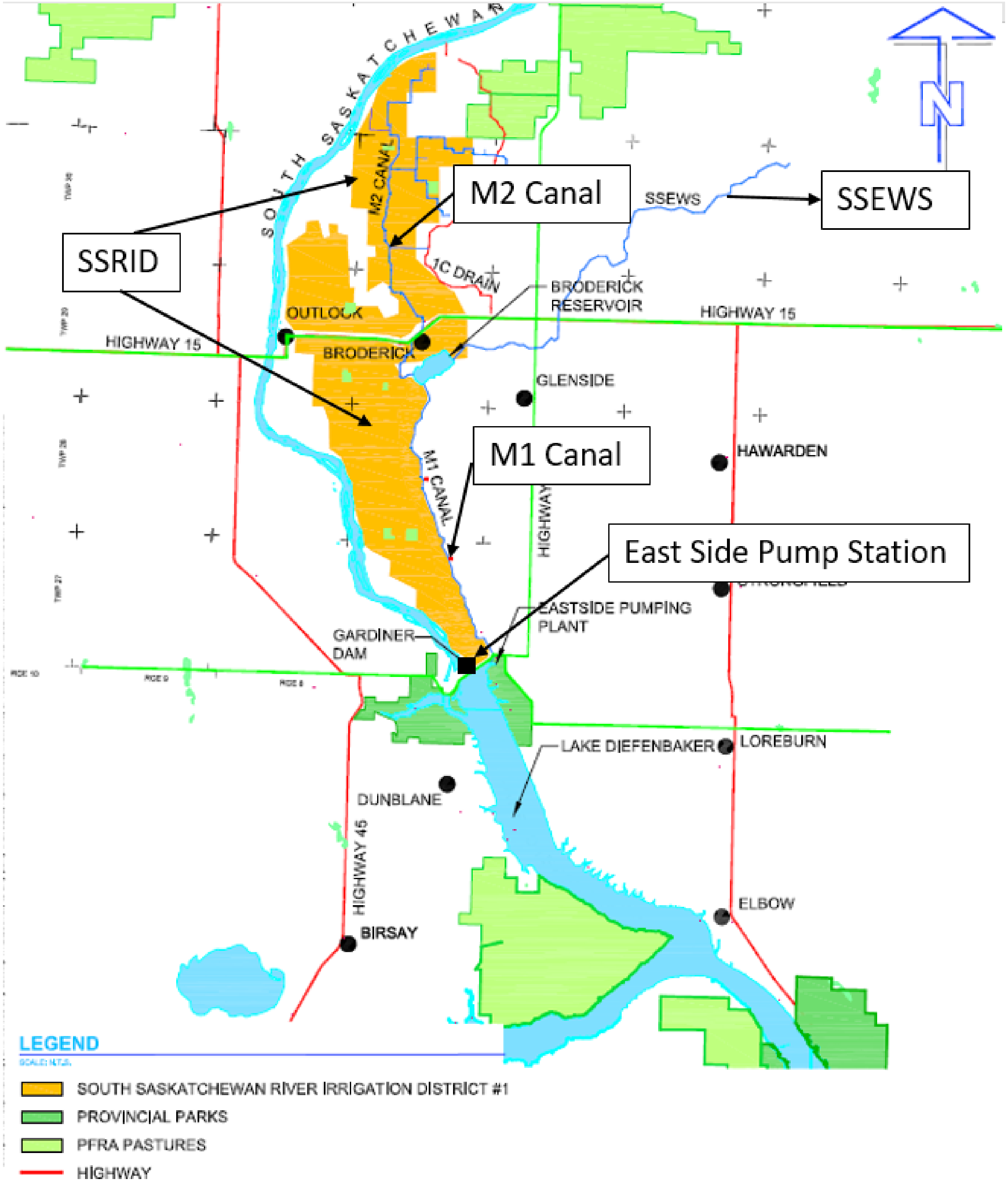
### 4.3.1 Broderick (M1) Irrigation Canal

Broderick Irrigation Canal supplies the Saskatoon Southeast Water Supply System (SSEWSS), as well as the South Saskatchewan River Irrigation District (SSRID), from Lake Diefenbaker, as shown in Figure 4.1. Broderick Irrigation Canal diversions are currently estimated using the long term monthly averages of historical data. However, the data that are currently used do not represent the total diversion into the canal from Lake Diefenbaker, as attested by the discrepancy between the monthly averages calculated from the available WSC station data and the annual values provided by the Provincial Government of Saskatchewan (Table 4.4).

The mean annual diversion volume (1977-2015) based on the WSA records is 58,548 dam$^3$ with a significant variation from year to year. The actual use in the PPWB's apportionable flow calculation spreadsheet of 17,115 dam$^3$ refers to year 2014 given as 27,174 dam$^3$ in Table 4.4. The Provincial Government of Saskatchewan (Water Security Agency) maintains their records of diversions from Lake Diefenbaker into the M1 Canal and the SSRID. The historical data were provided by the Provincial

Government of Saskatchewan. The data provided by the Sask. Ministry of Agriculture is significantly below the total diversion that is on the historic record at the WSC gauge 05HF007 records for the 1968 to 1995 period, as shown in Table 4.4 below. It should be apparent that the total withdrawal into Broderick canal serves other purposes in addition to the SSRID irrigation, however the current account of this diversion in the PPWB's calculation spreadsheet only reflects the portion of the total diversion that is used by SSRID. Based on the total recorded flow volumes for the 1968-1995 period, the diversion at the 05HF007 WSC gauge is roughly 1.55 times the SSRID diversion over the same period. In fact, the mean value of the ratio calculated based on the diverted volumes for each year other than 1968 is 1.57. In this calculation, the first year (1968) has not been taken into account since it appears to be a statistical outlier with a ratio of over 10. It was suggested that it may be possible to retrieve pumped flow data for East Side Pump Station from the Water Security Agency, which might help explain this discrepancy, since the pumped data should be higher than the water use for irrigation in SSRID. Pumped flow supplies other water users and it also includes the losses to leakage and evaporation. This is one option that should be considered by PPWB.

**Figure 4.1 South Saskatchewan River Irrigation District with Broderick Canal**



Source: AECOM

The water license for SSRID information is available in Table 4.3. The actual water use as a percentage of the existing license limit can be obtained as a ratio of the total diverted volumes and the licensed allocation (73,500 / 106,079 = 0.69), to give an estimate of about 69% on average over the 1977 − 2015 period of record, although the variation from year to year can be significant.

**Table 4.4 Annual Diversions into SSRID (dam$^3$)**

| Year | East Side Pump Station (ESPS) | Sask. Gov. SSRID Diversion | WSC Gauge 05HF007 | Ratio |
|---|---|---|---|---|
| 1968 | 22,541 | 2,200 | 22,541 | 10.15 |
| 1969 | 26,628 | 9,498 | 26,618 | 2.80 |
| 1970 | 12,490 | 10,423 | 12,490 | 1.20 |
| 1971 | 25,031 | 20,661 | 25,031 | 1.21 |
| 1972 | 51,660 | 32,983 | 51,660 | 1.57 |
| 1973 | 66,457 | 33,495 | 66,457 | 1.98 |
| 1974 | 27,368 | 27,391 | 27,368 | 1.00 |
| 1975 | 52,639 | 33,955 | 52,639 | 1.55 |
| 1976 | 43,426 | 42,678 | 43,426 | 1.02 |
| 1977 | 87,395 | 53,290 | 87,483 | 1.64 |
| 1978 | 88,564 | 56,709 | 88,513 | 1.56 |
| 1979 | 63,660 | 53,878 | 63,820 | 1.18 |
| 1980 | 110,828 | 78,405 | 110,840 | 1.41 |
| 1981 | 106,832 | 68,205 | 106,815 | 1.57 |
| 1982 | 70,574 | 47,125 | 70,618 | 1.50 |
| 1983 | 67,502 | 41,414 | 67,522 | 1.63 |
| 1984 | 133,327 | 75,477 | 133,351 | 1.77 |
| 1985 | 96,668 | 72,109 | 96,733 | 1.34 |
| 1986 | 79,189 | 47,674 | 79,336 | 1.66 |
| 1987 | 88,175 | 54,609 | 88,185 | 1.61 |
| 1988 | 155,641 | 91,634 | 155,282 | 1.69 |
| 1989 | 115,861 | 69,383 | 115,836 | 1.67 |
| 1990 | 83,889 | 49,549 | 83,901 | 1.69 |
| 1991 | 68,520 | 26,557 | 68,520 | 2.58 |
| 1992 | 85,961 | 53,379 | 85,895 | 1.61 |
| 1993 | 53,718 | 27,815 | 53,741 | 1.93 |
| 1994 | 61,033 | 42,049 | 61,057 | 1.45 |
| 1995 | 90,500 | 52,784 | 90,591 | 1.72 |
| 1996 | 47,452 | 31,176 | | |
| 1997 | 65,633 | 42,421 | | |
| 1998 | 98,253 | 52,448 | | |
| 1999 | 32,502 | 20,631 | | |
| 2000 | 65,467 | 36,549 | | |
| 2001 | 122,782 | 61,514 | | |
| 2002 | 105,500 | 51,431 | | |
| 2003 | 91,931 | 58,490 | | |
| 2004 | 72,307 | 36,446 | | |
| 2005 | 29,962 | 19,831 | | |
| 2006 | 48,599 | 24,165 | | |
| 2007 | 43,669 | 22,618 | | |
| 2008 | 67,982 | 37,914 | | |
| 2009 | 59,131 | 33,880 | | |
| 2010 | 15,548 | 12,538 | | |

| | | | | |
|---|---|---|---|---|
| 2011 | 40,964 | 25,893 | | |
| 2012 | 34,941 | 14,729 | | |
| 2013 | 46,873 | 28,959 | | |
| 2014 | 27,174 | 22,776 | | |
| Average to 1996 | 73,607 | 45,052 | | 1.57 |
| Average from 1996 | 58,550 | 33,264 | | 1.00 |

Based on the above analyses, it would appear that the use of 17,079 dam$^3$ for 2014 in the calculation of apportionable flows is an underestimate. According to the historic volumes in Table 4.4, it should be at least 1.55 times higher on average. It should also be noted that this ratio has a sizeable variation from year to year, with a standard deviation of 0.39, implying that the use of a single factor such as 1.55 for all years involves significant level of uncertainty. The following options for inclusion of Broderick Canal diversion data into future calculations of apportionable flows by PPWB are:

a) Increase the existing SSIRD diversion data by 1.55 and use the result in the calculation of apportionable flows;
b) Continue the WSC flow monitoring station 05HF007 and use the data recorded each year; or,
c) Use East Side pump station data from 1996 onward.

Option b) is more reliable in terms of the accuracy of the final results, but it is also more expensive to implement. Option c) depends on the availability and accuracy of the East Side Pump station data.

### 4.3.2 Swift Current Diversion

The Swift Current Main Canal was constructed by PFRA in 1945 to convey diversions from the Swift Current Creek eastward to supply the AAFC Swift Current Research Station, the provincial Waldeck Irrigation Project, various private irrigation projects along the canal, and to supplement the water supply in Highfield Reservoir located on Rushlake Creek (Figure 4.2). Based on the information provided by AAFC, all diversions through this canal can be considered lost to the Saskatchewan River system, except return flows of 35% from the Waldeck Irrigation Project (Clifton Associates) which flow back to Swift Current Creek.

Station 05HD034 (Swift Current Canal at Swift Current) was discontinued as a WSC gauge in 1995, but the monitoring continued by the AAFC with diversions being calculated based on the gate openings rather than being monitored directly. Due to a change in operating policy in the late 1990s, the most relevant Swift Current diversion data are from data collected by AAFC during the 1998-2008 period. Table 4.5 contains the summary of average monthly diversions available from AAFC for this period, along with a comparison with the diversion estimates currently used by PPWB. Although the mean monthly values for the 1999-2008 period are different from the mean monthly values used in the PPWB calculation spreadsheet, the mean annual volumes are very close (13,249 dam$^3$ in the calculation spreadsheet provided by PPWB compared to 13,795 dam$^3$ based on the 1998 - 2008 measurements).

### Table 4.5 Recent Swift Current Diversion Data ( Source: AAFC & WSA)

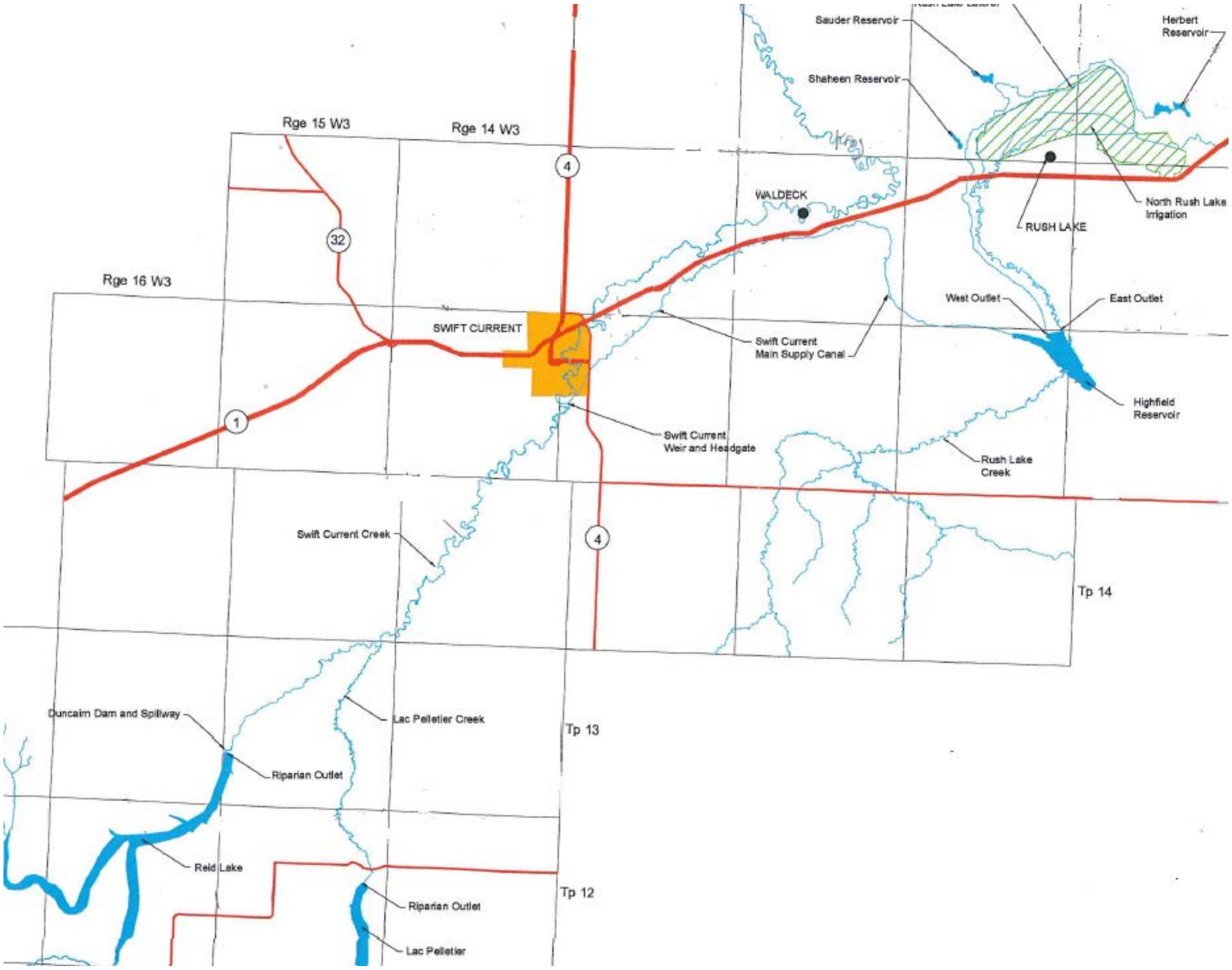
| Year | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sept | Oct | Nov | Dec | Annual |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1998 | 0 | 0 | 0 | 0 | 2,992 | 2,280 | 7,206 | 1,944 | 1,068 | 0 | 0 | 0 | 15,490 |
| 1999 | 0 | 0 | 1,131 | 0 | 136 | 1,519 | 1,334 | 2,502 | 1,112 | 0 | 0 | 0 | 7,734 |
| 2000 | 0 | 0 | 0 | 0 | 5,897 | 3,873 | 1,003 | 3,171 | 694 | 0 | 0 | 0 | 14,638 |
| 2001 | 0 | 0 | 1,214 | 876 | 9,330 | 1,537 | 9,644 | 1,939 | 0 | 0 | 0 | 0 | 24,540 |
| 2002 | 0 | 0 | 9 | 1,299 | 8,434 | 1,930 | 2,321 | 2,761 | 94 | 0 | 0 | 0 | 16,848 |
| 2003 | 0 | 0 | 534 | 0 | 1,064 | 1,926 | 3,366 | 2,019 | 662 | 0 | 0 | 0 | 9,571 |
| 2004 | 0 | 0 | 1,057 | 1,693 | 3,745 | 4,246 | 546 | 2,733 | 322 | 0 | 0 | 0 | 14,342 |
| 2005 | 0 | 0 | 1,493 | 633 | 2,711 | 1,663 | 1,826 | 2,899 | 955 | 0 | 0 | 0 | 12,180 |
| 2006 | 0 | 0 | 1,195 | 0 | 3,546 | 215 | 1,826 | 3,329 | 0 | 0 | 0 | 0 | 10,111 |
| 2007 | 0 | 0 | 0 | 0 | 2,789 | 676 | 2,434 | 4,440 | 632 | 0 | 0 | 0 | 10,971 |
| 2008 | 0 | 0 | 0 | 165 | 8,165 | 1,587 | 1,276 | 3,367 | 769 | 0 | 0 | 0 | 15,329 |

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Average | 0 | 0 | 603 | 424 | 4,437 | 1,950 | 2,980 | 2,828 | 573 | 0 | 0 | 0 | 13,795 |
| PPWB Estimates* | 0 | 218 | 704 | 2,955 | 2,893 | 1,319 | 2,236 | 1,224 | 415 | 281 | 1,003 | 0 | 13,249 |
| Waldeck Diversion | 0 | 0 | 0 | 0 | 1,380 | 187 | 0 | 1,436 | 0 | 0 | 0 | 0 | 3,003 |
| 35% Return Flow | 0 | 0 | 0 | 0 | 483 | 65 | 0 | 503 | 0 | 0 | 0 | 0 | 1,051 |
| Proposed Net Water Use (dam$^3$) | 0 | 0 | 603 | 424 | 3,954 | 1,885 | 2,980 | 2,325 | 573 | 0 | 0 | 0 | 12,744 |
| Proposed Net Water Use (m$^3$/s) | 0.000 | 0.000 | 0.225 | 0.164 | 1.476 | 0.727 | 1.113 | 0.868 | 0.221 | 0.000 | 0.000 | 0.000 | |

*Provided in PPWB's spreadsheet that calculates apportionable flows for 2014

There are indications that AAFC has data after 2008 but that the data had not been processed since no requests were made by any agency so far. The data after 2008 could not be obtained for the purposes of this project.

**Figure 4.2 Swift Current Diversion Layout (source: Clifton Associates)**



The options related to the diversion flows into the Swift Current Canal are:

a) Change the existing monthly distribution in the PPWB calculation spreadsheet to reflect the monthly averages obtained from the 1998-2008 data series as shown in Table 4.5;
b) Do not update Table 4.5 and from 2009 and on, use diversion flows calculated from headgate operation records maintained by AAFC, using the AAFC supplied data in place of historic monthly mean data going forward. This option is based on the assumption that AFFC would commit to processing and supplying the diversions to the Secretariat in time to complete apportionable flow computations each year.
c) Ignore the 35% return flow from Waldeck Irrigation (as is the case now); or,
d) Reduce the net water use by 35% of the diversion into Waldeck Irrigation to account for its return flows. The net impact of this is small, but it is relatively easy to apply based on the data in Table 4.5.

### 4.3.3 Elbow Diversion Canal into Qu'Appelle River Basin

Station 05JG006 provides daily records of diversions to the Elbow Diversion Canal. This diversion is used to augment flows in the Qu'Appelle River for multiple downstream water uses, as stated in its water license which is labelled as *multipurpose* and of *unclassified* type, although most of the water is used for potable water supply for the cities of Moose Jaw and Regina. There are no return flows into the South Saskatchewan River associated with this diversion. Return flows from this diversion remain within the Qu'Appelle River Basin. The estimates currently used in the apportionable flow computation are based on recorded diversions, and this situation is expected to continue.

### 4.3.4 Dragline Ditch / Cumberland Marsh Diversion

The flow gauge for this diversion (Station 05KH011) was discontinued in 1996. The mean monthly records between 1976 and 1996 available from WSC were summarized and checked against the values that are used in the PPWB's Calculation Spreadsheet. The comparison shows a slight overestimate by about 2000 dam$^3$ in the PPWB estimates, as seen in Table 4.6 below.

**Table 4.6 Dragline Ditch Diversions (m$^3$/s)**

| | WSC Record | PPWB |
|---|---|---|
| Jan | 0.665 | 0.683 |
| Feb | 0.578 | 0.601 |
| Mar | 0.589 | 0.590 |
| Apr | 0.736 | 0.701 |
| May | 1.342 | 1.470 |
| Jun | 2.358 | 2.530 |
| Jul | 3.682 | 3.620 |
| Aug | 3.006 | 3.160 |
| Sep | 2.225 | 2.440 |
| Oct | 1.504 | 1.660 |
| Nov | 0.436 | 0.466 |
| Dec | 0.679 | 0.734 |
| Total (dam$^3$) | 47028 | 49280 |

An important issue is related to the calculation of the return flows, which are currently ignored. Based on the information that Optimal Solutions Ltd. received from WSA in 2014 as part of a modeling study of the operation of Lake Diefenbaker, the return flow estimate for the Cumberland Marsh diversion was set to 85% (Optimal Solutions Ltd, 2014). This implies that only 15% of the 49,280 dam$^3$ should actually be applied as the water use within Saskatchewan, since the remaining 85% flow into Manitoba. Upon further analysis, the COH contacted Ducks Unlimited, which resulted in the following analyses that is briefly summarized below:

According to COH, the Cumberland Marsh and CRT require on average a total flow of 2.5 m$^3$/s from May to September to supplement runoff to replace evaporative losses based upon the entire marsh being at FSL. This works out to about 33,000 dam$^3$. The flooded area for Cumberland Marsh is 30,693 ha and CRT is 20,483 ha. Based on a proportion by area, the water volume required by Cumberland Marsh is 19,800 dam$^3$ and CRT is 13,200 dam$^3$. Based on table 4.6, PPWB calculates the average diversion is 49,280 dam$^3$. This implies that the average return flow is about 60%.

It is important to note that only the incremental increase in the lake surface area should be used as a basis for calculating adjustments that should be used in the calculation of natural flows. The sheer size this and other recreation and wildlife (Candle Lake, Jackfish/Murray Lake, Luck Lake) licenses brings into question the notion that they were issued to represent evaporation losses. It is unlikely that the incremental increase in water surface area on all recreational and wildlife projects could be so large. It seems more likely that they represent diversions aimed to stabilize the lake levels during the open flow season, most of which are returned to the stream through return flows via natural drains, as explained on page 9 of the PPWB report #45 (March 1976).

The following options are available to PPWB:

a) The status quo option (i.e. continue to ignore return flows from Cumberland Marshes);
b) Adopt the 85% return flow rate and use only 15% of the diversion instead; or,
c) Adopt the 60% return flow rate and use 40% of the diversion
d) Ignore this project as the project diversions are used to maintain a portion of the marsh which under natural conditions could have been maintained by “natural” overflows from the Saskatchewan River.

### 4.3.5 Luck Lake and Riverhurst Irrigation

The Luck Lake Irrigation District has been in operation since 1989. The district irrigates 10,600 ha. It is located just west of Lake Diefenbaker. The Riverhurst Irrigation District currently covers about 12,300 ha in two zones (northern and southern). Both districts are supplied by pumped diversions from Lake Diefenbaker. Return flows are zero since Luck Lake is a closed basin, and they are ignored in the current calculation of apportionable flows, which is conducted by assuming fixed monthly distributions and applying them to the sum of both diversions provided as the annual total water use. The Luck Lake and Riverhurst Irrigation Districts account for a small percentage of total water use. The options for PPWB are:

a) Obtain and use the actual monthly diversions from month to month in each year instead of assuming a fixed monthly distribution of annual totals; or,
b) Continue to treat the water use in those districts without making any changes.

## 4.4 Water Use Excluded from the Current Apportionment Flow Calculations

This section discusses water use licenses that are not currently used in the calculation of apportionable flows. The total of all combined water licenses that are currently not used in the calculation of apportionable flows is 1,054,365 dam$^3$. This amount was obtained by subtracting the existing water use licenses indicated in bold font in Table 4.2 and the Wood Lake Marsh water license of 155,000 dam$^3$ (since it has never been built) from the total of 1,597,900 dam$^3$ obtained by summing all water licenses within the effective drainage area. The major water licenses in this group are shown in Table 4.7 below.

**Table 4.7 Major Water Licenses Excluded from Calculation of Apportionable Flows**

| User | License Number | Project | Type | Diversion (dam$^3$) | Losses (dam$^3$) | License (dam$^3$) | Cumulative Diversion (dam$^3$) | Percent of Total (%) |
|---|---|---|---|---|---|---|---|---|
| SASKPOWER | 7592 | QUEEN ELIZABETH THERMAL | Cooling | 427,108 | 0 | 427,108 | 427,108 | 40.51 |
| WATER SEC. AGENCY | 6740 | CANDLE LAKE DAM | Recreation | 0 | 92,000 | 92,000 | 519,108 | 49.23 |
| SASKATOON | 16914 | SASKATOON MUNICIPAL | Urban | 61,650 | 0 | 61,650 | 580,758 | 55.08 |
| PRINCE ALBERT PULP* | 10691 | PRINCE ALBERT PULP | Manufacturing | 28,000 | 0 | 28,000 | 608,758 | 57.74 |
| JACKFISH LAKE WSA | 531 | JACKFISH/MURRAY LAKE | Unclassified | 0 | 27,630 | 27,630 | 636,388 | 60.36 |
| JACKFISH LAKE WSA | 11818 | N/A | Wildlife | 0 | 22,250 | 22,250 | 658,638 | 62.47 |
| RED EARTH LAND | 3837 | JAM CREEK DAM | Rural | 0 | 21,000 | 21,000 | 679,638 | 64.46 |
| PRINCE ALBERT | 14236 |  | Municipal | 16,245 | 0 | 16,245 | 695,883 | 66.00 |
| DUCKS UNLIMITED | 15803 | LUCK LAKE WILDLIFE PROJECT | Wildlife | 0 | 9,250 | 9,250 | 705,133 | 66.88 |
| SASK. WATER UTIL. | Multiple | SASK. MUNICIPAL LICENSES | Municipal | 14,179 | 0 | 14,179 | 719,312 | 68.22 |
| OTHER | - | ALL OTHERS | All types |  |  | 335,053 | 1,054,365 | 100.00 |

## Queen Elizabeth Thermal Power Plant

The largest license is related to use of water for cooling of a thermal power plant. The large diversion volume shown in the license is almost entirely returned to the stream. The only losses are associated with evaporation, and yet they are considered negligible based on the entry in the losses column. Hence, this license has no impact on the calculation of apportionable flows, and it should continue to be excluded from the calculation of apportionable flows. It can be assumed that all diverted flows are returned to the stream.

## Candle Lake Dam

The recreational license on the Candle Lake Dam, which has a consumptive use license for 92,000 dam$^3$, has also been excluded in the calculation of apportionable flows. The level in Candle Lake is regulated by a four-bay 3.1 m concrete dam, constructed in 1978−1979 and operated by the Saskatchewan Watershed Authority. The dam discharges into the Torch River. An operation study was conducted in 2008 by the Department of Fisheries and Oceans Canada. Based on this study, the average difference in evaporation between Natural and Controlled is 1239 dam$^3$ on an annual basis or 1535 dam$^3$ during the open water period. Evaporation losses for natural and regulated conditions on the Candle Lake Dam are shown in Table 4.8.

**Table 4.8 Average Evaporation Loss for the Open Water Period from 1968-2006 (April-Oct)**

| Candle Lake | 0.25 m$^3$/s RIPARIAN RELEASE CONDITIONS (Elevation m) | Evaporation (dam$^3$) | NATURAL CONDITIONS MONTH END LEVEL (m) | Evaporation (dam$^3$) | Controlled – Natural (dam$^3$) |
|---|---|---|---|---|---|
| January | 494.34 | -1,665 | 494.04 | -1,606 | -59 |
| February | 494.35 | -1,374 | 494.03 | -1,322 | -52 |
| March | 494.36 | -1,916 | 494.04 | -1,844 | -72 |
| April | 494.37 | 2,553 | 494.03 | 2,451 | 102 |
| May | 494.37 | 8,928 | 494.03 | 8,571 | 357 |
| June | 494.37 | 7,922 | 494.07 | 7,643 | 279 |
| July | 494.35 | 8,552 | 494.09 | 8,290 | 262 |
| August | 494.31 | 8,680 | 494.04 | 8,403 | 277 |
| September | 494.30 | 5,755 | 494.04 | 5,577 | 177 |
| October | 494.30 | 2,532 | 494.03 | 2,451 | 81 |
| November | 494.30 | -1,688 | 494.05 | -1,638 | -50 |
| December | 494.33 | -2,002 | 494.06 | -1,938 | -64 |
| Difference Total (dam$^3$) | | | | | 1,239 |
| Difference Open water Total (dam$^3$) | | | | | 1,535 |

Source: Candle Lake Operation Study, Prepared For: Fisheries and Oceans Canada, prepared by R.S. Pentland, Water Resource Consultants Ltd., March, 2008.

Evaporation on the Candle Lake Dam should therefore be included in the apportionment calculation with a loss of 1535 dam$^3$ distributed monthly.

## City of Saskatoon/City of Prince Albert

Municipal water use for the City of Saskatoon and City of Prince Albert have large water licenses, but like most large municipalities, it also has a large return flow portion which has been estimated by WSA at 71% of gross diversion. However, a 30% consumption equals a large volume of water. Therefore, these diversions should be included in the calculation.

## Prince Albert Pulp Mill

The Prince Albert Pulp Mill is currently closed but is set to reopen in 2020. The Prince Albert Pulp Mill should have a high return flow factor (WSA estimated return flow as 95% of gross diversion). This estimate was provided by WSA as part of a 2014 project aimed to model the operation of Lake Diefenbaker under the current and future conditions. Although only a 5% consumption, the Prince Albert mill should be included in the apportionment calculations upon re-opening.

## Jackfish/Murray Lake

Flow through Jackfish Lake is extremely limited and the gross drainage area is small. The latter has been estimated at only 3.8 to 6.9 times the lake area. There is no permanent surface inflow and evaporation rates are high, thus precipitation and groundwater are evidently important for maintaining water levels. A single surface outlet is restricted by a weir installed in 1983 at an elevation of 729.72 m (Mitchell et al.,1990). Only when lake levels are above the weir will water exit the lake. There are no diversions into the lakes and the flow direction is unaffected. The outflow structure increases summer lake levels compared to natural, but spring levels can be lower than natural due to increase downstream channel capacity.

Natural outlet elevation of Jackfish Lake was 528.79 m. Simulations of the lake with a natural outlet over the period 1954 to 1990 show the monthly average lake levels would have a 1.9 m range, while with the structure in place (FSL=529.44m) the simulations indicate a range of 1.35 m. The effects of channelization are reflected in the rated outflow capacity of the lake control structure. For instance, when Jackfish Lake is at elevation 529.5 m, the maximum outflow from the lake is 5.3 $m^3/s$, compared to 1.0 $m^3/s$ under natural conditions. Simulated month end elevations for the FSL of 529.44 m or current scenario were given, but simulated month end elevations for the natural condition simulations were not given. Therefore, estimate the maximum and minimum elevations from Figure 4.3 and assign them to April and September, then interpolate May, June, July, August elevations and set them from October to September to estimate the simulated average area of Jackfish Lake. Based on these results, the average increase in evaporation due to the control structure at Jackfish Lake are 107 $dam^3$ during the open water season.

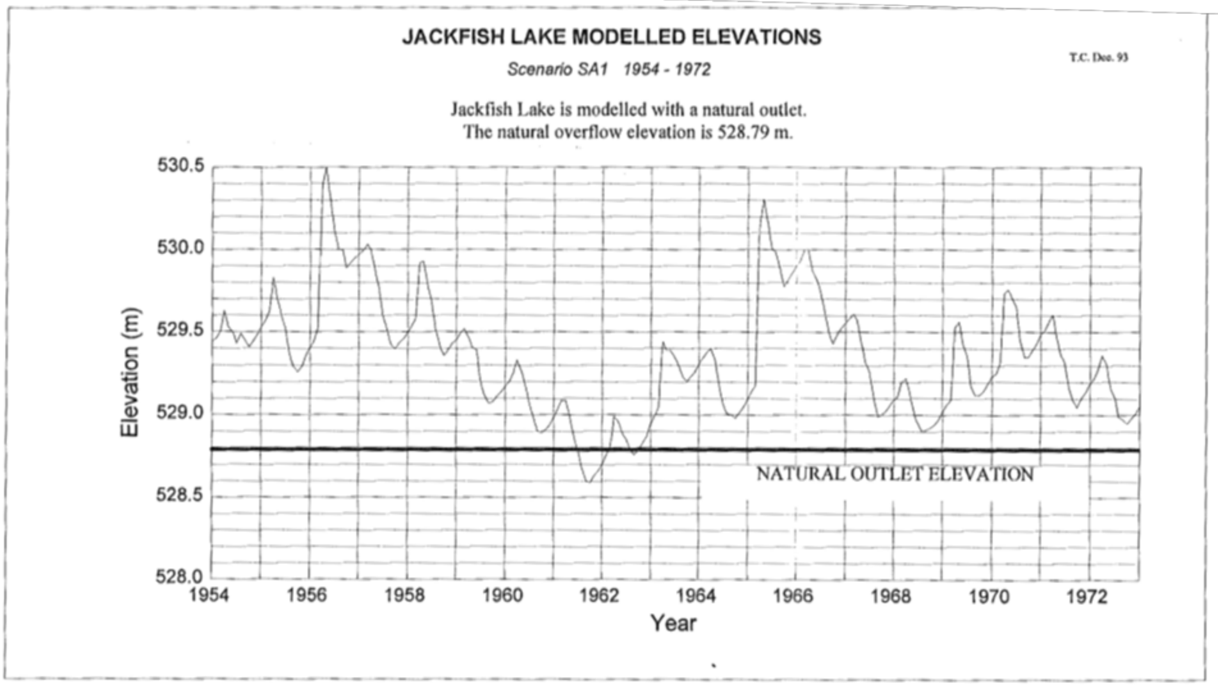
**Table 4.9 Average evaporation losses for natural and controlled conditions from 1954 to 1990**

| | | Natural | | | FSL = 529.44 m | | |
|---|---|---|---|---|---|---|---|
| | Evap (mm) | Elev. (m) | Area (ha) | Evap (dam$^3$) | Elev. (m) | Area (ha) | Evap (dam$^3$) |
| Apr | 30.6 | 529.52 | 8,322 | 2,548 | 529.51 | 8,311 | 2,544 |
| May | 109.3 | 529.45 | 8,260 | 9,028 | 529.45 | 8,264 | 9,032 |
| June | 98.0 | 529.37 | 8,199 | 8,038 | 529.38 | 8,208 | 8,047 |
| July | 100.4 | 529.29 | 8,137 | 8,171 | 529.32 | 8,161 | 8,194 |
| Aug | 106.4 | 529.21 | 8,076 | 8,592 | 529.24 | 8,097 | 8,615 |
| Sept | 79.3 | 529.14 | 8,014 | 6,353 | 529.19 | 8,058 | 6,387 |
| Oct | 42.2 | 529.14 | 8,014 | 3,384 | 529.18 | 8,050 | 3,399 |
| | | | | | | | |
| Total (dam3) | | | | 46,113 | | | 46,219 |
| | | | | | | | |
| Difference (dam3) | 107 | | | | | | |

Ref: Jackfish Basin Management Plan, Aug. 23, 1996, prepared by Bart Oegema, WSA

While 107 dam$^3$ is a relatively small annual depletion, this is still a significant project. Therefore, Jackfish/Murray Lake should be included with an annual net depletion 107 dam$^3$, distributed monthly as shown in Table 4.9 based on the water levels shown in Figure 4.3.

**Figure 4.3 Jackfish Lake Modelled Elevations (Source: WSA)**

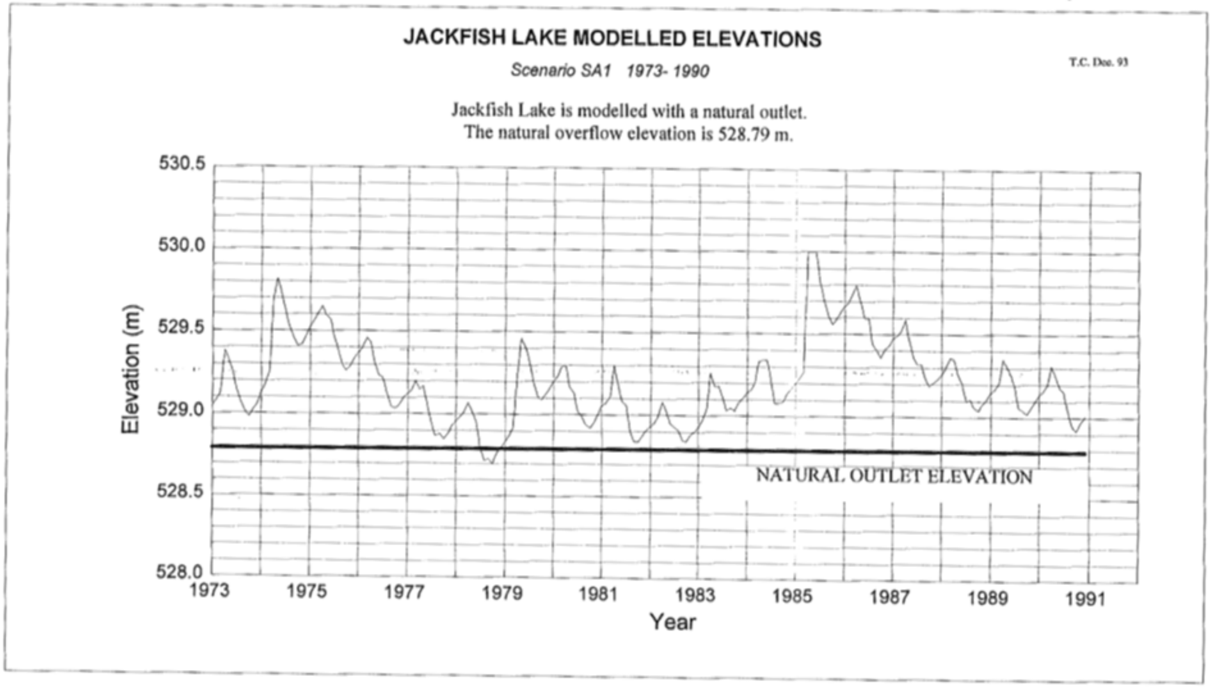


JACKFISH LAKE MODELLED ELEVATIONS

*Scenario SA1 1954 - 1972*

T.C. Dec. 93

Jackfish Lake is modelled with a natural outlet.
The natural overflow elevation is 528.79 m.



JACKFISH LAKE MODELLED ELEVATIONS

*Scenario SA1 1973- 1990*

T.C. Dec. 93

Jackfish Lake is modelled with a natural outlet.
The natural overflow elevation is 528.79 m.

## Jam Creek Dam

Jam Creek Dam is a Ducks Unlimited Project. Jam Creek Dam is a marshy area with lots of spill points along the natural river levy.

In 1978, DUC had looked into the potential of developing a project (Jam Creek). It never went forward as no options were feasible. Further discussions in 1983 with DUC, DPRR, Redearth Band, and Indian Affairs also went nowhere. DUC was involved in upgrades to an existing dyke at Jam Creek in 1999. DUC supervised the construction but the project was to be in the name of “Red Earth Land Use Development Corporation”.

There is no further information on the licensing and regulatory matters, nor on the condition of the project in the years following the dyke upgrade (1999). DU has commented that as far as we know this project has been non-operable for some time. There has been insufficient information about this project and all efforts to obtain information have been exhausted. However, because of the magnitude of the license and the existing dyke, it should still be included in Table 4.11 with other wildlife projects with a 90% return flow.

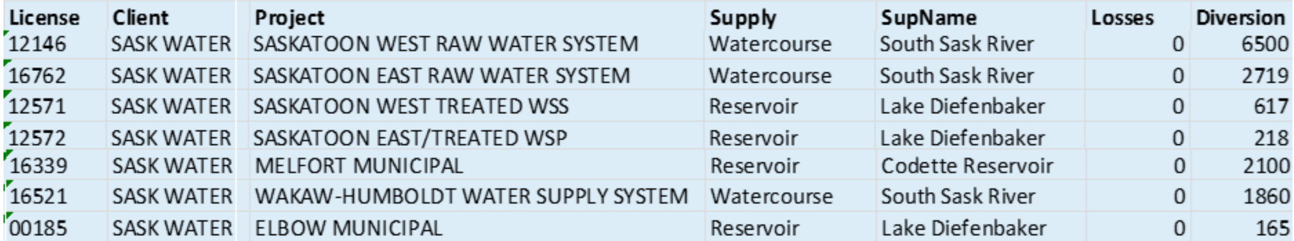
## Luck Lake

Luck Lake is a Ducks Unlimited Canada project. DU will not renew the project license as the infrastructure needs replacing. The project will not be operated going forward and no water will be pumped specifically to maintain Luck Lake water levels. As the Luck Lake wildlife project is located within a closed basin, and water is pumped in via the Luck Lake Irrigation Project, no need to include this project as all depletions are captured in the pumped diversions to the Luck Lake Irrigation Project.

## SaskWater Utilities

There are two non-potable utilities at Saskatoon – one on east side and one on west. SaskWater operates their own intakes for the west side and east side raw water utilities, but purchases treated water from the City for their treated water utilities. The other two potable utilities are supplied by Saskatoon and bought by SaskWater for potable water for the Melfort area and Wakaw Humboldt area. It is therefore recommended to include Saskatoon West raw water, Saskatoon east raw water, Melfort, Wakaw-Humboldt since all these diversions will have close to zero return flows. While these four licenses are the most significant, a total of seven municipal licenses were included as the SaskWater Utility entry in Table 4.7 above. These licenses are listed in more detail in Table 4.10.

**Table 4.10 SaskWater Utilities Licenses**



| License | Client | Project | Supply | SupName | Losses | Diversion |
|---|---|---|---|---|---|---|
| 12146 | SASK WATER | SASKATOON WEST RAW WATER SYSTEM | Watercourse | South Sask River | 0 | 6500 |
| 16762 | SASK WATER | SASKATOON EAST RAW WATER SYSTEM | Watercourse | South Sask River | 0 | 2719 |
| 12571 | SASK WATER | SASKATOON WEST TREATED WSS | Reservoir | Lake Diefenbaker | 0 | 617 |
| 12572 | SASK WATER | SASKATOON EAST/TREATED WSP | Reservoir | Lake Diefenbaker | 0 | 218 |
| 16339 | SASK WATER | MELFORT MUNICIPAL | Reservoir | Codette Reservoir | 0 | 2100 |
| 16521 | SASK WATER | WAKAW-HUMBOLDT WATER SUPPLY SYSTEM | Watercourse | South Sask River | 0 | 1860 |
| 00185 | SASK WATER | ELBOW MUNICIPAL | Reservoir | Lake Diefenbaker | 0 | 165 |

## Other Licences

All other water licenses in the database that have been unaccounted for in the past calculations of apportionable flows have been compiled and analyzed. They are summarized in Table 4.11. The following considerations are relevant:

a) Only licenses within the effective drainage area were considered as relevant;
b) Licenses related to the water use discussed in sections 4.3.1 through 4.3.5 were excluded from the analyses;
c) The actual water use should be set conservatively to half of the license limit based on the previous experience gained on studies that relate the actual water use to the licensed water use for small license holders in Alberta. A different estimate (fraction of the total license) may be used for various types of water demands if the COH feels that 50% of the license is not a realistic target.
d) Breakdown of monthly water use patterns can be distinguished between agricultural and non-agricultural water use. Agricultural water use includes crop irrigation as well as watering of parks and other vegetated public areas.

Table 4.11 includes all licenses excluded from the apportionment calculations related to consumptive water use. Also, return flow factors are estimates from WSA since the exact values are not known. The final column in Table 4.11 contains the estimate of net water use after taking into account return flows from irrigation, municipal and industrial water uses. This is the upper limit of water use equal to the licensed amount. A more realistic value that could be included in the calculation of the apportionable flow could be closer to 30% of this license limit, based on the experience from the previous study on the Battle River basin in Alberta (PPWB Report #168). Monthly distributions for irrigation and municipal demands is provided in Table 4.10, while all other types of water use can have a uniform distribution throughout the year.

### Table 4.11 Existing Water Licenses Excluded from the PPWB's Computation Procedure

| Type of Water Use | | Diversion ($dam^3$) | Ret. Flow Fraction | Return Flow ($dam^3$) | Net Water Use ($dam^3$) |
|---|---|---|---|---|---|
| Domestic | Agriculture / Rural | 646 | 0.15 | 97 | 549 |
| | Unclassified | 7,237 | 0.20 | 1,447 | 5,790 |
| Industrial | Thermal Cooling (Sask. Power) | 427,108 | 1.0 | 427,108 | 0 |
| | Oil Recovery | 6,982 | 0.00 | 0 | 6,982 |
| | Manufacturing | 1,079 | 0.80 | 863 | 216 |
| | Mining / Gravel | 8,286 | 0.90 | 7,457 | 829 |
| Agriculture | Livestock | 408 | 0.10 | 41 | 367 |
| | Irrigation | 121,315 | 0.30 | 36,395 | 84,921 |
| | Parks/Commercial/Unclassified | 4,141 | 0.30 | 1,242 | 2,899 |
| Municipal | Unclassified | 2,458 | 0.70 | 1,740 | 746 |
| | Commercial / Institutional | 70 | 0.85 | 60 | 11 |
| | Recreation | 247 | 0.90 | 222 | 25 |
| | Rural (including City of Prince Albert) | 17,012 | 0.70 | 11,908 | 5,104 |
| | Tankload | 1,364 | 0.90 | 1,228 | 136 |
| | Urban (excl. 61650 $dam^3$, for City of Saskatoon) | 15,050 | 0.85 | 12,793 | 2,258 |
| Other | Aquaculture | 138 | 0.90 | 124 | 14 |
| | Flood Control | 12,102 | 0.90 | 10,892 | 1,210 |
| | Recreation (incl. Candle Lake & Jackfish) | 120,114 | 0.90 | 108,103 | 12,011 |
| | Unclassified | 26,405 | 0.90 | 23,765 | 2,641 |
| | Wildlife (incl. Jan Creek Dam) | 69,247 | 0.90 | 62,322 | 6,925 |
| | Total: | 841,436 | | 707,806 | 133,630 |

Inclusion of additional consumptive water use based on the monthly breakdown in Table 4.12 is an option to be considered when updating the existing calculation procedure.

### Table 4.12 Monthly Distribution of Annual Water Use

| Month | Irrigation | Municipal |
|---|---|---|
| Jan | 0.000 | 0.07 |
| Feb | 0.000 | 0.07 |
| Mar | 0.000 | 0.07 |
| Apr | 0.000 | 0.07 |
| May | 0.070 | 0.09 |
| Jun | 0.340 | 0.10 |
| Jul | 0.310 | 0.11 |
| Aug | 0.150 | 0.12 |
| Sep | 0.130 | 0.09 |
| Oct | 0.000 | 0.07 |
| Nov | 0.000 | 0.07 |
| Dec | 0.000 | 0.07 |

Source: WSA

The following options can be identified for COH:

a) Add water use estimates from the Net Water Use column in Table 4.11 with monthly distribution as specified in Table 4.12.
b) Select a percentage of the values in the Net Water Use in column in Table 4.11 that is deemed appropriate to represent the actual water use as opposed to the licensed water use. A reasonable range for COH's consideration should be between 30% and 50% of the licenses listed in Table 4.11. Use monthly distribution as specified in Table 4.12.
c) Continue to ignore small water licenses that have so far been excluded from the calculation procedure.

## 5. ASSESSMENT OF TRAVEL TIMES

The current apportionable flow procedures use a time lagging approach to adjust the monthly project water use for time of travel. The adjustments, which assume the adjustment to be a fixed percentage of each month's water use, are based on the assumption of a fixed travel time from their locations to the boundary. In essence, this solution can be viewed as a modification of the time of travel approach in the approved procedures, where monthly flow adjustments are modified based on the percentage of adjustment volumes that would actually reach the boundary within a month. Although the travel times calculated using the approved method in the 1976 report are a function of flow, the simplified method currently used essentially uses mean annual flow and results in the use of travel times that do not change from month to month. While the use of a fixed travel time can have a significant effect on the computed monthly flows, it is believed that it has relatively minor effect on the annual apportionable flow estimate.

The travel time versus flow equations that were originally approved by the PPWB are outlined in the March 1976 report (PPWB report #45) entitled *Natural Flow - Saskatchewan River at Saskatchewan-Manitoba Boundary*. The following equations evaluate travel times for the river reaches listed below:

River Reach from Gardiner Dam to the Forks

$T = 0.63 \cdot 10^{(2.69 - 0.158 \log Q)}$ where Q is the recorded flow at Saskatoon in cfs

River Reach from the Forks to Tobin Lake

$T = 1.30 \cdot 10^{(3.52 - 0.47 \log Q)}$ where Q is the sum of Q at Prince Albert and Q at St. Louis in cfs

River Reach from Tobin Lake to Saskatchewan-Manitoba boundary

$T = 1.0 \cdot 10^{(3.05 - 0.3 \log Q)}$ where Q is the flow at the boundary in cfs

While none of the reviewed documents propose a change in the computation of time of travel adjustments from that approved in PPWB Report #45, the procedures used within the EXCEL apportionment calculations workbook to account for time of travel is a simple shifting of a fixed percentage of monthly water use adjustment into the next month. The percent by which each project's adjustments are shifted are: Reid Lake –30%, Swift Current Canal diversion –28%, Lake Diefenbaker, Saskatoon SE Water Supply, Elbow Diversion, and Luck Lake-Riverhurst – 24%, Tobin Lake – 8%, Dragline Ditch – 2%. Table 5.1 shows the calculated travel times from Gardiner Dam to the Boundary using the time of travel approved within PPWB Report #45 for three flow conditions extracted from WSC stations for the selected locations. The travel times are shown for three representative flow rates, with the average annual flow rate, being used in current computations, shown in the last row of the table. The calculated times show as 24.7% of the length of an entire month (assuming a 30-day month) from Lake Diefenbaker to the boundary. Likewise, the travel time from Tobin Lake to the boundary is 57 hours for average flow conditions, which corresponds to about 8% of a 30-day month. This would imply that the percentages that are currently used in the calculation (which are also listed in the bottom section of Table A.2 in Appendix A) do correspond to travel times calculated on the basis of the equations listed in the PPWB Report # 45 but specifically to the travel time for average flow conditions. The accuracy of the equations is evaluated below. Based on the assessment discussed later in this Section, they appear to significantly underestimate the total travel times in the Saskatchewan River.

**Table 5.1 Assessment of Travel Time from Gardiner Dam to SK/MB Boundary based on Equations in PPWB Report #45**

| Flow Condition | Flow at S. Sask. River @ Saskatoon | Time of Travel Gardiner Dam to the Forks | N. Sask. @ Prince Albert + S. Sask. @ St Louis | Time of Travel Forks to Tobin Lake | Sask. River @ The Pas | Time of Travel Tobin Lake to Boundary | Total Time of Travel from Lake Diefenbaker to the Boundary | Total Travel Time as a % of month assuming a 30-day month |
|---|---|---|---|---|---|---|---|---|
| | ($m^3/s$) | (hrs) | ($m^3/s$) | (hrs) | ($m^3/s$) | (hrs) | (hrs) | (%) |
| Maximum | 1080 | 58 | 2400 | 20.8 | 2330 | 38 | 116 | 16.1 |
| Minimum | 32 | 101 | 86 | 99 | 78 | 104 | 304 | 42.3 |
| Average | 213 | 75 | 444 | 46 | 569 | 57 | 178 | 24.7 |

It is noted that PPWB Report # 45 proposes almost the same time of travel equation for the river reach from Medicine Hat to the Gardiner Dam as it does from Gardiner Dam to the Forks, i.e. the total travel times differ by only 8% when calculated by the two formulas:

Medicine Hat to Gardiner Dam: $TT=0.58 \cdot 10^{2.69-0.158 \log Q}$

Downstream of Gardiner Dam: $TT=0.63 \cdot 10^{2.69-0.158 \log Q}$

Due to the closer proximity of Gardiner Dam to Saskatoon than to Medicine Hat, the formula between Medicine Hat and the Gardiner Dam was assumed to represent the travel time between Medicine Hat and Saskatoon. A relatively small increase in travel time due to the distance between the Gardiner Dam and Saskatoon does not introduce a material change in the analyses presented below. In order to assess the adequacy of the time of travel equations proposed in PPWB Report #45, a comparison was carried out between the time of travel estimated from the time of occurrence of recorded peak flows versus the travel times that were calculated using the formula provided in PPWB Report #45. Two WSC stations were used in this analysis, one at Medicine Hat (05AJ001) and the other at Saskatoon (05HG001). Table 5.2 presents the results. The constraints used in this analysis are as follows:

a) Only years prior to 1967 were included, since that is the year when Lake Diefenbaker filling began and the flows downstream of the dam were regulated thereafter; and,
b) Where the annual peaks did not originate from the same hydrologic event, a manual search was conducted to find the matching peak at Saskatoon. This meant a loss of accuracy of the timing of the arrival peak at Saskatoon, to +/− 12 hours, but given that the travel time varies between 4 and 6 days, this is not considered critical to the conclusion of this analysis.

**Table 5.2 Travel Times between Medicine Hat and Saskatoon**

| | Medicine Hat | | | Saskatoon | | | | |
|---|---|---|---|---|---|---|---|---|
| Year | HH:MM | MM--DD | Peak Flow | HH:MM | MM--DD | Peak Flow | Travel Time based on PPWB #45 formula (hrs) | Recorded Travel Times between Peaks (hrs) |
| 1915 | 21:00 | 06--28 | 2550 | 0:00 | 07--03 | 3230 | 49 | 99 |
| 1923 | 22:00 | 06--03 | 4110 | 3:00 | 06--07 | 3650 | 47 | 79 |
| 1929 | 22:00 | 06--05 | 3450 | 14:30 | 06--09 | 3260 | 48 | 90 |
| 1932 | 0:00 | 06--05 | 2940 | 0:00 | 06--08 | 3200 | 49 | 96 |
| 1947 | 16:40 | 05--13 | 1050 | 12:00 | 05--19 | 1320 | 57 | 127.5 |

It can be seen from Table 5.2 that the observed travel times are on average two times longer than those calculated using the formula within PPWB Report #45 for the Saskatchewan River upstream of the Forks (which extends all the way to Medicine Hat). This discrepancy should be addressed.

The total length of the South Saskatchewan River from Medicine Hat to Saskatoon is given in PFRA Report #95 as being 662.6 km. Based on the formula from PPWB, high flows above 3000 $m^3/s$ would travel this distance in about two days. This would require an average stream velocity of 3.84 m/s. Implicit in this consideration is the fact that the maximum stream velocity in the middle section of the channel should be higher than average, possibly close to 5 m/s. This appears to be unlikely given the low slopes of the South Saskatchewan River that are around 0.033% on average between Medicine Hat (690 m altitude) and Saskatoon (482 m altitude). Recorded travel times are close to double this estimate, which would reduce the average stream velocity to 1.8 m/s, with a maximum channel velocity in its middle section of just over 3 m/s. This seems to be more reasonable, given the size of the river and the channel slopes. Field measurements of the historic flow surveys at Saskatoon, Nipawin and the Boundary should be obtained to better assess mean surveyed channel velocity for various flow rates. Given the known distances between these locations, it would be possible to assess travel times for selected flow rates.

Similarly, for recorded flows that are around 1300 $m^3/s$ the corresponding travel times are between 5 and 6 days. Using 5.5 days as a typical recorded travel time would result in the average channel velocity of 1.3 m/s, which seems reasonable. This should be compared to the results obtained from a formula provided by PPWB that results in the travel time of only 55 hours, which translates to the mean channel velocity of 3.16 m/s, a relatively small drop from 3.62 m/s that would correspond to three times as much flow.

A similar approach can be used to comment on the total travel time from Lake Diefenbaker to the SK/MB boundary for average flow conditions, which are in the vicinity of 450 $m^3/s$ for the entire year. At this flow rate, it takes 178 hours (7.4 days) to travel through the entire province. The distance between Gardiner Dam and the SK/MB boundary given in PFRA Report #95 is 697.4 km, which would result in a mean cross sectional velocity of 1.08 m/s. Having cross sectional flow areas and average velocities that were surveyed during site visits would be one way to verify if this assessment is reasonable. Flow surveys conducted by WSC should contain both the flow areas and mean velocities obtained on the survey dates. Until more information on flow surveys is obtained to address this assessment, only rough speculation is possible. For example, assuming a conservative cross sectional width of 280 m (obtained from Google Earth maps) and a conservative mean flow depth of 2.5 m, the resulting mean channel velocity of 0.58 m/s is obtained for average annual flow rate (based on the average of the three flow rates given in the last row of Table 5.1). This renders 332 hours of total travel time from Lake Diefenbaker to the boundary, as opposed to 178 hours calculated using the formulas adopted by PPWB. This difference is very close to being twice the estimate shown in Table 512.

It has determined that the travel times calculated by the current equations are about half of what they should be. The options to be considered are:

a) Status Quo – use current fixed percentages
b) Adopt the current findings based on the work done so far (i.e. double the travel times);
c) Initiate a separate study which will deal with this issue in much more detail; and,
d) If option c) is selected, re-introduce the calculation of travel times on a monthly basis, rather than using the fixed long term mean annual flows as is currently done.

An accurate assessment of travel times is a sizeable undertaking which was not foreseen as part of this project. The current project goal is to evaluate the current calculation procedure and provide recommendations for future improvements. If the PPWB decides to re-visit the development of empirical equations, all available flow surveys at key WSC stations on the Saskatchewan River between Saskatoon and SK/MB Boundary should be used in this assessment. Other methods such as the use of tracers should also be considered in the future as part of this assessment to further confirm and verify the results. The scope of such a study is well beyond the scope of this project.

# 6. IMPACT OF LAND USE CHANGES AND CHANNEL LOSSES

Evaluation of the impacts of land use changes and the potential inclusion of channel loss calculations are both parts of the Terms of Reference for this project.

## 6.1 Land Use Changes

Land use changes caused by deforestation, urbanization and agricultural developments affect the runoff patterns, such as for example increasing the runoff coefficient from urban areas or changing the return flow fraction for urban or agricultural water use. The following should be taken into account when evaluating the land use changes:

a) There is no data that can relate changes in recorded flows in Saskatchewan River at the SK/MB boundary as a result of the land use changes;
b) The Project Depletion Method inherently includes all impacts of land use changes as it relies on the use of the most recent estimates of recorded flows and adjustments; and,
c) Areas affected by land use changes is very small compared to the total size of the Saskatchewan River basin.

Based on the above, the impacts of land use changes on the calculation of apportionable flows was not evaluated.

## 6.2 Channel Loss

The current calculation procedure does not take into account any channel losses or return flows from urban or agricultural water use. There are no known data sources related to channel loss that could be used to improve the existing calculation procedure. Also, there are no dry channels in this basin, and therefore no priming periods, channels have water throughout the open flow season. The water surface area has not changed significantly as a result of regulation, so any attempt to quantify the changes in channel evaporation due to the change in surface area would result in negligible differences between the natural and regulated conditions. Due to all of the above, channel losses are excluded from further consideration.

# 7. EFFECTS OF STORAGE CHANGE AND RESERVOIR EVAPORATION LOSSES

This section provides a review of the effects of storage change and net evaporation on the calculation of apportionable flows.

## 7.1 Storage Change

Storage change is a significant component in the calculations of apportionable flows on a monthly basis. There are three reservoirs that are included in the apportionable flows calculation procedure by taking into account:

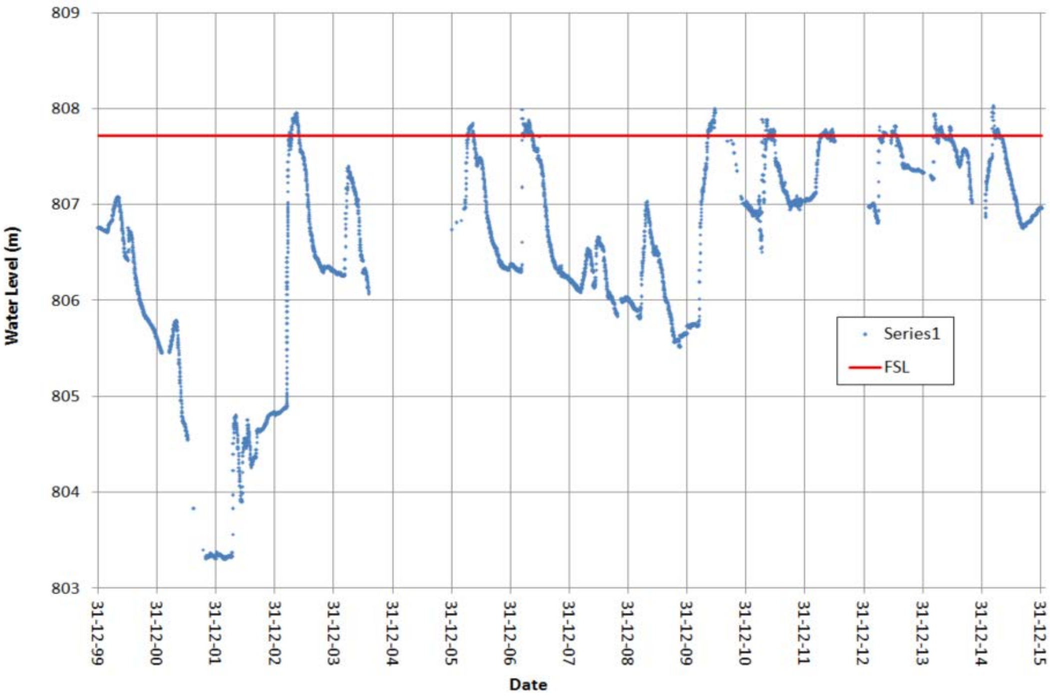
a) Lake Diefenbaker;
b) Tobin Lake; and,
c) Reid Lake.

Of those, unique historic water levels are used for Lake Diefenbaker and Tobin Lake. Storage change on Reid Lake has also been evaluated in each year historically, since it is necessary to remove its effects on the regulation of flows. However, the current PPWB calculation procedure assumes fixed monthly storage changes for Reid Lake based on the average historic end of month levels, because the WSC monitoring station on Reid Lake, which was a Federal funded station, was to be discontinued in 1995. However, as AAFC continued to collect water levels, end of month water levels are available although they are not used in the calculation of apportionable flow. The use of the average historical end of month elevations is acceptable if the storage change is similar from year to year. However, a plot of reservoir levels from 1999 to 2015 (Figure 7.1), shows that there are significant variations of the annual storage change from year to year

Available records of water levels on Reid Lake are shown for the 1999 - 2015 period in Figure 7.1. The vertical grid lines coincide with the calendar year end, so it is possible to see how much the annual storage change varies from year to year. Monthly water levels are needed to properly calculate net evaporation, however the year-end levels show the total storage change, which can be both positive and negative, and which can differ significantly from year to year. The following options for future updates of the calculation of apportionable flows can be identified:

a) Continue using the average historical end-of-monthly storage levels of Reid Lake as they are used now; or,
b) Use AAFC supplied hourly reservoir levels for Reid Lake in place of historic monthly mean data
c) Use the available storage records from the current year which should be surveyed on dates close to the end of each month, so as to prevent the need to calculate end of month elevations using interpolation

**Figure 7.1 Historic Elevations of Reid Lake (Source: AAFC / WSA*)**



*Historic Duncairn Reservoir levels were received from Imteaz.Bhuiyan@wsask.ca

## 7.2 Net Evaporation

The creation of reservoirs greatly increases the surface area of the natural watercourse, leading to a significant increase in water losses due to evaporation. While these losses are somewhat offset by precipitation over the reservoirs, evaporation losses from reservoirs can be significant within the Saskatchewan portion of the Saskatchewan River Basin. The following sub-sections examine how reservoir evaporation is taken into account in the current apportionable flow computation procedures, their significance in the overall computation of apportionable flow, potential refinements in the computation of evaporation losses, and alternatives for the estimation of evaporation.

### 7.2.1 Evaporation in the Current Apportionable Flow Computation Procedures

The current apportionable flow computation procedures include the “net” evaporation from three major reservoirs -- Lake Diefenbaker, Tobin Lake and Reid Lake. The methods and procedures initially approved (PPWB Report #45) for the computation of evaporation losses for each of three major reservoirs are outlined in Appendix A, Table A1. As noted in Table A1, the initial procedures called for gross evaporation for each of the three lakes to be computed using the Meyer equation with the lake surface saturation vapor pressure being computed using the observed mean monthly surface water temperatures. These procedures were used up to 1994, when the Government of Canada Program Review eliminated the resources required to support these measurement programs and the associated data processing. Subsequent to 1994, gross reservoir evaporation has been estimated using reservoir specific water temperature regression equations that were developed for Lake Diefenbaker and Tobin Lake. A detailed description of the procedures currently being used for the computation of gross and net evaporation for each of the three reservoirs is provided in Section 3.4 and Table 3.3 and are summarized below.

### *Lake Diefenbaker Net Evaporation*

Evaporation for Lake Diefenbaker is computed only for the April to December period with other months being set at “0”. Monthly gross evaporation from Lake Diefenbaker is calculated annually, using the PFRA Meyer equation for the upper (upstream of Riverhurst) and lower (downstream of Riverhurst) portions of the lake. The lake surface area weighted (0.7 for the upper and 0.3 for the lower) evaporation are then summed together and multiplied by the lake surface area to determine the total gross evaporation. This calculation is completed by ECCC and provided to PPWB in an EXCEL workbook. MSC also computes the monthly precipitation and provides it to the PPWB based on the recorded average precipitation at: Elbow CS (4022359), Elbow 2 NE (4022363), Beechy (4020560), Lucky Lake (4024714) and Swift Current (4028060).

### *Tobin Lake Net Evaporation*

Evaporation for Tobin Lake is computed only for the April to October period with all other months being set to “0”. Monthly gross evaporation for Tobin Lake is computed annually by ECCC, using the PFRA Meyer equation and is provided to the PPWB. As reservoir water temperatures are no longer measured, the surface water temperature is estimated using regression equations developed on the basis of 1978-2002 data. Net evaporation is computed by subtracting the recorded monthly precipitation at Nipawin (Station 407N51G), which is also provided by ECCC, from the gross evaporation and multiplying the resulting net evaporation by the lake surface area to obtain the total net evaporation.

### *Reid Lake Net Evaporation*

Evaporation for Reid Lake is computed for the April to December period with all other months being set to “0”. Gross evaporation for Reid Lake is computed as the gross evaporation for Lake Diefenbaker multiplied by a factor of 1.1. Net evaporation is computed by subtracting from the gross evaporation the monthly recorded precipitation at the meteorologic station at Swift Current (4028060) and by multiplying the resulting net evaporation by the historical average monthly lake surface area to obtain the total net evaporation.

The above noted net evaporation computation procedures can result in a positive (evaporation exceeds precipitation) or negative (precipitation exceeds evaporation) net evaporation. However, the evaporation methodology incorporated into the current apportionable flow calculations is to set all negative evaporation values to zero (i.e. the net evaporation for any month where precipitation exceeds gross evaporation is set to zero). There is no documentation on why this practice was adopted. A discussion on the potential effect of zeroing negative evaporation is provided in Section 7.4.

### 7.2.2 Significance of Reservoir Evaporation Relative to Apportionable Flow

Table 7.1 shows the 2014 monthly and annual adjustments for projects currently included in the computation of apportionable flow for the Saskatchewan River at the Saskatchewan-Manitoba Boundary.

**Table 7.1 2014 Monthly and Annual Water Use Adjustments (dam$^3$)**

| Project | Jan | Feb | Mar | Apr | May | Jun | Jul | Aug | Sep | Oct | Nov | Dec | Ann. |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **CHANGE IN STORAGE ADJUSTMENTS (dam$^3$)** | | | | | | | | | | | | | |
| Lake Diefenbaker | -333822 | -378575 | -58635 | 701980 | -103196 | 1049439 | -19688 | -189235 | 87472 | -98688 | -358016 | -262405 | 36631 |
| Tobin Lake | -111396 | 17280 | -29088 | 31104 | 101400 | -39694 | -5906 | -103320 | 9216 | 41760 | -81155 | 155099 | -14700 |
| Reid Lake | -1290 | 394 | 6862 | 11261 | -787 | -3199 | -2889 | -6579 | 2722 | -1483 | -439 | 838 | 5411 |
| **Total Change in Storage** | -446508 | -360901 | -80861 | 744345 | -2583 | 1006546 | -28483 | -299134 | 99410 | -58411 | -439610 | -106468 | 27342 |
| **DIVERSION ADJUSTMENTS (dam$^3$)** | | | | | | | | | | | | | |
| Broderick Canal | 0 | 0 | 0 | 0 | 1205 | 5806 | 5303 | 2571 | 2229 | 0 | 0 | 0 | 17114 |
| Elbow Diversion | 6857 | 5346 | 5169 | 1420 | 163 | 119 | 2786 | 4848 | 337 | 11115 | 1003 | 0 | 39163 |
| Swift Current Canal | 0 | 218 | 704 | 2955 | 2893 | 1319 | 2236 | 1224 | 415 | 281 | 1003 | 0 | 13248 |
| Dragline Channel | 1829 | 1454 | 1580 | 1817 | 3937 | 6558 | 9696 | 8464 | 6324 | 4446 | 1208 | 1966 | 49279 |
| Luck Lake Project | 0 | 0 | 0 | 0 | 686 | 3336 | 3040 | 1470 | 1275 | 0 | 0 | 0 | 9807 |
| **Total Diversions** | 8686 | 7018 | 7453 | 6192 | 8884 | 17138 | 23061 | 18577 | 10580 | 15842 | 3214 | 1966 | 128611 |
| **RESERVOIR NET EVAPORATION ADJUSTMENTS (dam$^3$)** | | | | | | | | | | | | | |
| Lake Diefenbaker | 0 | 0 | 0 | 0 | 6079 | 0 | 38212 | 21738 | 3658 | 39214 | 28725 | 10063 | 147689 |
| Tobin Lake | 0 | 0 | 0 | 0 | 0 | 0 | 15494 | 36048 | 28672 | 14697 | 0 | 0 | 94911 |
| Reid Lake | 0 | 0 | 0 | 0 | 534 | 0 | 1179 | 389 | 1137 | 1227 | 1015 | 379 | 5860 |
| **Total Net Evaporation** | 0 | 0 | 0 | 0 | 6613 | 0 | 54885 | 58175 | 33467 | 55138 | 29740 | 10442 | 248460 |
| | | | | | | | | | | | | | |
| **Total Adjustments** | | | | | | | | | | | | | 404413 |
| | | | | | | | | | | | | | |
| **Evaporation as a % of Total Adjustments** | | | | | | | | | | | | | 61 |

Table 7.1 shows that the change in storage adjustments, and in particular change in storage for Lake Diefenbaker, generally tends to be the largest adjustment component in the computation of monthly apportionable flows. However, as change in storage is a non-depletive water use that has negative and positive values which tend to balance out by the end of year, reservoir evaporation, and in particular lake evaporation from Lake Diefenbaker, is the single most significant adjustment factor, accounting for 61.4% of all adjustments in the 2014 apportionable flow calculations. However, the 2014 net

evaporation loss of 248,460 dam$^3$ only represent 0.91% of the 27,300,000 dam$^3$ apportionable flow in 2014 and only 1.37% of the 18,127,000 dam$^3$ long-term (1977-2014) mean annual apportionable flow.

### 7.2.3 Incorporation of Reservoir Evaporation in the Apportionable Flow Calculations

As noted previously, the current apportionable flow computation procedures include the “net” evaporation from three major reservoirs; Lake Diefenbaker, Tobin Lake and Reid Lake. In the mid 1970’s, measurement programs were developed by EC-AES, which carries out the gross evaporation calculations on behalf of the PPWB for Tobin Lake and Lake Diefenbaker to collect the water temperatures and precipitation data required to estimate evaporation as prescribed in PPWB Report #45. However, as noted in PPWB Report #161:

> *“… most water temperatures were measured with … recorders located in sheltered bays along the lake. It is questionable whether these data really represented the surface water temperature in a spatial sense. The best spatial data came from the Riverhurst ferry operators who measured water temperature three times each day across the width of lake near Riverhurst. This information [along with water temperature data collected by EC-AES] was used in the estimation of water temperature for both the upper and lower sections of the lake.*

PPWB Report #161 further notes that:

> *Considerable effort (one to two person months …) was required to install and operate the water temperature recorders and then to assemble and process the data from the recorders and the ferry operators.”*[7]

In 1994 the water temperature measurement program was discontinued when the Government of Canada Program Review eliminated the resources needed to support these programs and process the data. Since 1995 water temperatures for Tobin Lake and Lake Diefenbaker have been estimated using reservoir specific water temperature equations developed from the 1972 to 1994 measurements.

In about 2002 the PPWB-COH requested EC-AES to review the evaporation calculations and to assess the sensitivity of apportionment monitoring to the evaporation calculations and to potential errors from other, more simplified and time saving evaporation estimates. The following is noted in the 2003 PPWB Report (#161) based on 1973-2000 data:

*Lake Diefenbaker*

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[7] PPWB Report #161 –“A Sensitivity Analysis of PPWB Apportionment Monitoring to Evaporation Calculations.”

- The median annual net evaporation is 224,000 dam$^3$ or 1.4% of the median annual apportionment flow of 17,640,000 dam$^3$, but has varied from about 150,000 to 300,000 dam$^3$ (Figure 7.2)
- The annual net evaporation is generally in the range of 1-2% of the annual apportionable flow, the exception being 1988 when it accounted for 3.03% of the apportionment flow and 1996 when it accounted for about 0.7% of the apportionment flow (Figure 7.3)
- Applying the mean monthly net evaporation depth to the actual lake levels results in an annual difference of between -92,000 dam$^3$ and +74,000 dam$^3$ from actual evaporation volume (Figure 7.4) or an absolute error of about 0.96% of the apportionment flow.
- Estimating the annual net evaporation volume based on the mean monthly gross evaporation depth and the actual precipitation and lake surface area results in a difference of between -60,000 and +45,000 dam$^3$ with a bias of about -6,000 dam$^3$ or an absolute error of about 0.63% of the apportionable flow.

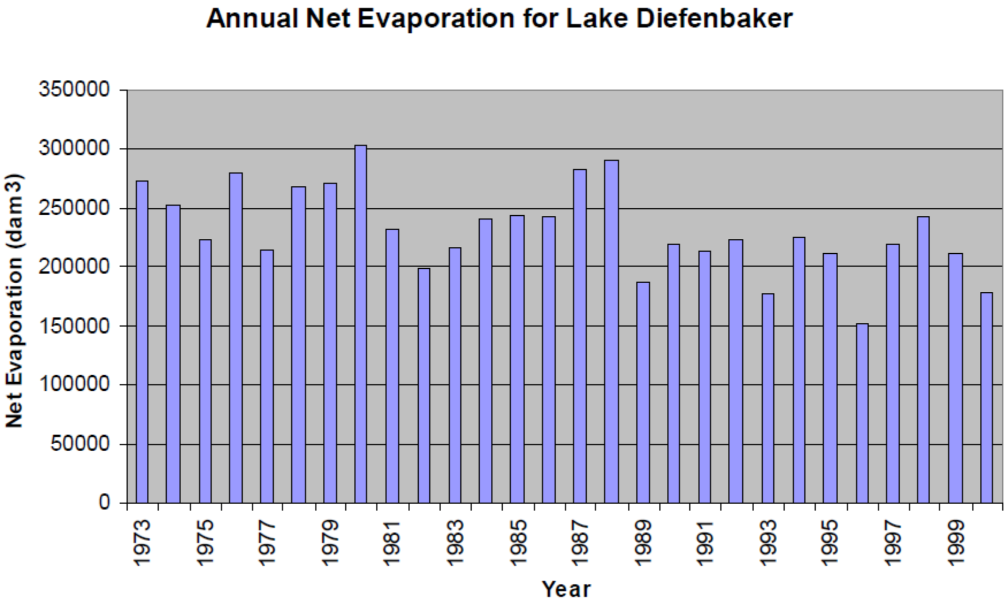

**Figure 7.2 Lake Diefenbaker Annual Net Evaporation (PPWB Report #161)**

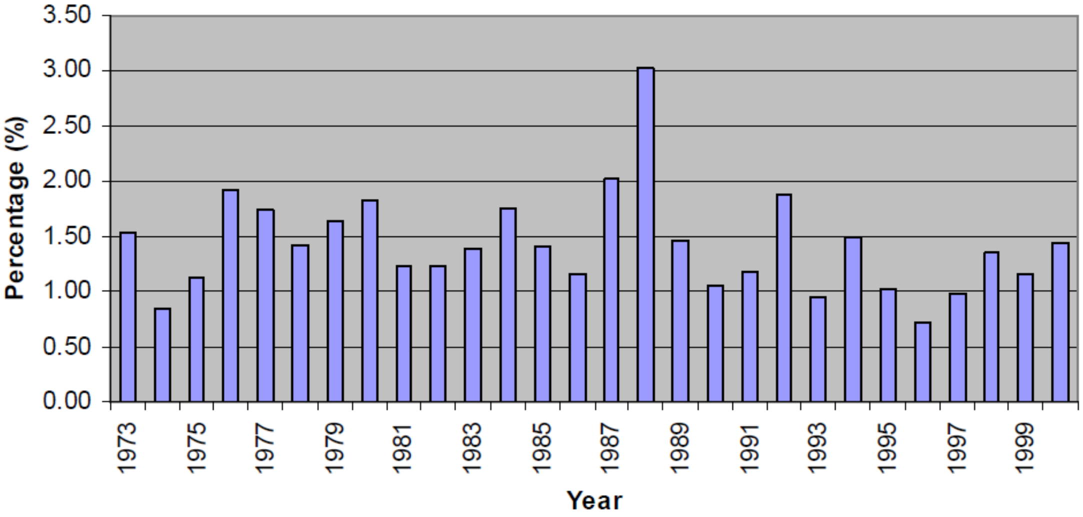

**Figure 7.3 Lake Diefenbaker Net Evaporation as a percentage of Apportionment Flow (source – PPWB Report #161)**

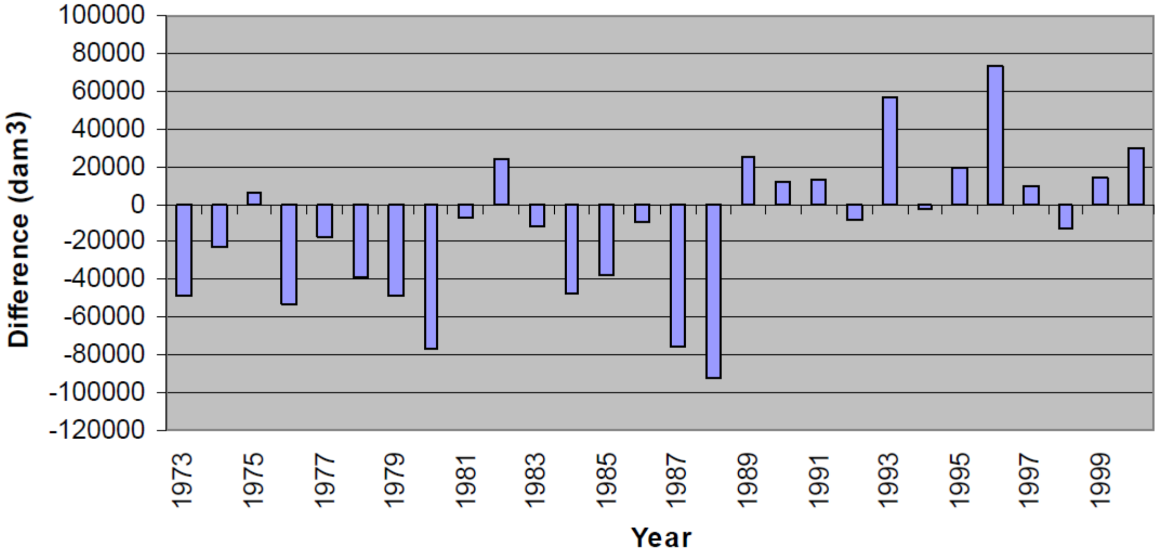

**Figure 7.4 Lake Diefenbaker – Annual difference in net evaporation between average and calculated values (source – PPWB Report #161)**

*Tobin Lake*

- The average annual net evaporation is 84,800 dam$^3$ or about 0.5% of the median annual apportionment flow of 17,640,000 dam$^3$, but it has varied from about 38,000 to 130,000 dam$^3$ (Figure 7.5).

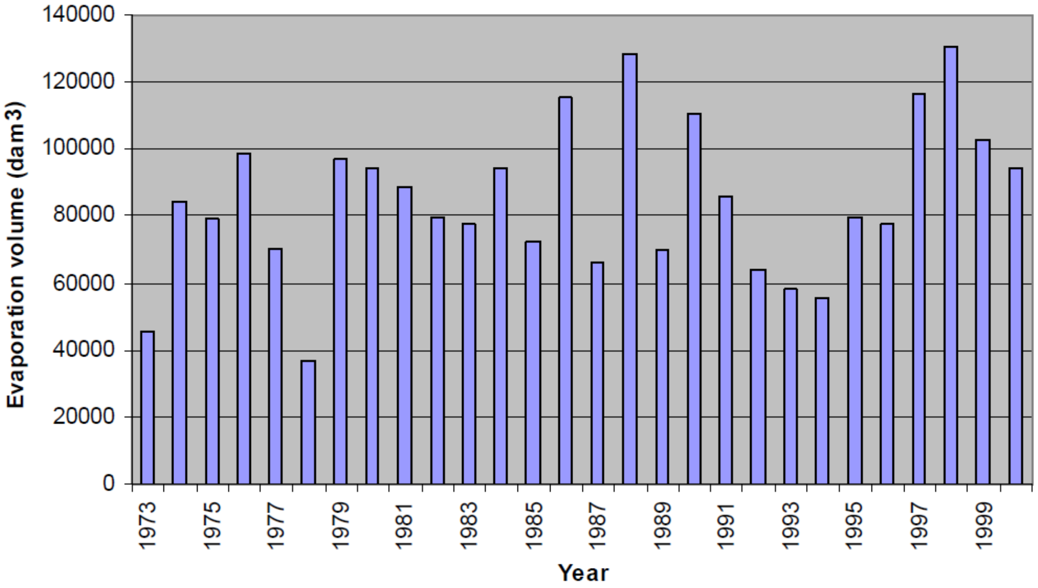

**Figure 7.5 Tobin Lake Annual Net Evaporation (source – PPWB Report #161)**

- The annual net evaporation is generally in the range of 0.3-0.7% of the annual apportionable flow, the exception being 1988 when it accounted for 1.35% of the apportionment flow.
- Estimating the monthly evaporation using the historical mean monthly net evaporation depth and actual lake surface area results in a bias of about -10,000 dam$^3$ and an annual deviation of between -65,000 and +35,000 dam$^3$.
- Estimating the monthly evaporation using the historical mean monthly gross evaporation depth and the actual precipitation and lake surface area reduces the bias to about -6,300 dam$^3$ and annual deviations of less than 44,000 dam$^3$ or about 0.3% of apportionment flow.

The report also notes that PFRA routinely computes monthly gross evaporation estimates for Nipawin using a modified model with simpler data requirements. However, it also notes that PFRAs gross evaporation estimates at Nipawin are, on average, 157 mm higher than the Tobin Lake gross evaporation using current PPWB procedures, which translates into about 50,000 dam$^3$.

### *Reid Lake*

- Net evaporation for Reid Lake which is calculated as 1.1 time the pro-rated gross evaporation for Lake Diefenbaker minus precipitation for Swift Current and the actual lake surface area is in the order of 7,700 dam$^3$ per year or about 0.05% of the median annual apportionment flow.
- Using the historical net gross evaporation depth minus actual precipitation would result in a negative bias of less than 200 dam$^3$ per year or about 0.002% of the apportionment flow.

- Net evaporation from Reid lake is inconsequential compared to either Tobin Lake or Lake Diefenbaker. Even ignoring net evaporation from Reid Lake would result in negligible error in the apportionment flow calculation

Based on the above noted analysis, PPWB Report #161 offers a number of options for calculating the net evaporation from Lake Diefenbaker and Tobin Lake. Given that no additional water temperature data has been collected since the time of that report, it is felt that these options are still valid and are presented, with some minor updates, in Tables 7.2 and 7.3.

**Table 7.2 Summary of Options for Lake Diefenbaker Evaporation**

| Option # | Option | Impact on Apportionment |
|---|---|---|
| 1 | Ignore evaporation | Underestimates apportionment flow by 1-2% and up to 3% in low flow years |
| 2 | Use the historical mean monthly net evaporation of past years | Underestimates mean annual net evaporation, and apportionable flow by about 11,000 $dam^3$ and annual errors can be as high as 96000 $dam^3$ resulting in potential errors of up to +/- 1% in the estimate of apportionable flow. |
| 3 | Use mean gross evaporation minus actual precipitation | Underestimates mean annual net evaporation, and apportionable flow by about 6,000 $dam^3$ and annual errors can be as high as 60,000 $dam^3$ or up to +/- 0.6% in the estimate of apportionable flow |
| 4 | Use current procedure - calculate monthly gross evaporation based on estimated water temperature | No known bias, but errors in estimating water temperature may cause monthly gross evaporation errors of up to 10%. |
| 5 | Use current procedure but install data loggers and water temperature sensors at previous sites and Riverhurst Ferry. | This reduces the potential error in surface water temperature but does not address the basic uncertainty associated with using Meyer equation on large reservoirs. |
| 6 | Use Morton lake evaporation model | Magnitude of annual gross evaporation much reduced relative to current procedure with little annual variability. |

| | | |
|---|---|---|
| 7 | Other possible methods – Penman, remote sensing, evaporation pan, energy budget | All other methods have either much greater data requirements or have operational difficulties. None of these have demonstrated scientific advantage over the Meyer equation. |

**Table 7.3 Summary of Options for Tobin Lake Evaporation**

| Option # | Option | Impact on Apportionment |
|---|---|---|
| 1 | Ignore evaporation | Underestimates evaporation and therefore apportionment flow by 85,000 dam$^3$ or 0.5% and up to 1.35% in low flow years |
| 2 | Use the historical mean monthly net evaporation of past years | Underestimates mean annual net evaporation, and apportionable flow by about 10,000 dam$^3$ and annual errors can be as high as 56,000 dam$^3$ or up to +/- 0.5% in the estimate of apportionable flow. |
| 3 | Use mean gross evaporation minus actual precipitation and actual water levels | Underestimates mean annual net evaporation, and apportionable flow by about 6,300 dam$^3$ and annual errors can be as high as 44,000 dam$^3$ resulting in potential errors of up to +/- 0.3% in the estimate of apportionable flow |
| 4 | Use PFRA gross evaporation for Nipawin less actual Nipawin precipitation | Overestimates evaporation by about 157 mm or about 50,000 dam$^3$ resulting in overestimate of apportionable flow by 50,000 dam$^3$ or 0.2% on average and up to 1.0% |
| 5 | Use current procedure- calculate monthly gross evaporation based on estimated water temperature | No known bias but errors in estimating water temperature may cause monthly gross evaporation errors of up to 10%. |
| 6 | Use current procedure but install data loggers and water temperature sensors. | Would reduce the potential error in surface water temperature but does not address basic uncertainty associated with using Meyer equation on large reservoirs. |
| 7 | Use Morton lake evaporation model | Magnitude of annual gross evaporation much reduced relative to current procedure with little |

| | | |
|---|---|---|
| | | annual variability. |
| 8 | Other possible methods – Penman, remote sensing, evaporation pan, energy budget | All other methods have either much greater data requirements or have operational difficulties. None of these have demonstrated scientific advantage over the Meyer equation. |

Given that even ignoring the net evaporation from Reid Lake would result in negligible error in the apportionment flow calculation, the report concludes that a more detailed analysis of options is not warranted and recommend that Reid Lake net evaporation *"… be calculated from average historical monthly gross evaporation based on 110% of Lake Diefenbaker mean gross evaporation less actual precipitation at Swift Current."*

While offering the above noted options for the estimation of net evaporation losses from the three reservoirs, the report cautions that:

> *"The current practice of estimating water temperature from regression provides the illusion of better estimates of evaporation than any of the cruder ways of dealing with evaporation. [However] Given the sensitivity of the Meyer equation estimate of monthly evaporation to errors in surface water temperature [~10% per $1^0$C], it is questionable whether the current methodology (commencing in 1995) is scientifically defensible …."*

Further, while the report offered a number of potential options for the calculation of reservoir evaporation and while it noted a number of concerns relating to the reliability of current procedures, the report concludes:

*"…simpler methods of estimating net evaporation could be implemented with very little loss of precision and negligible impact on apportionment monitoring. However, the savings in time and effort using simpler methods are minimal, so the existing procedure for estimating evaporation at Lake Diefenbaker, Tobin Lake and Reid lake should be continued."*

### 7.2.4 Reservoir Net Evaporation on Codette Lake

The inclusion of net evaporation loss on Codette Lake should be considered for inclusion into the calculation procedure. With roughly 3600 ha of surface water area and net evaporation that typically ranges above 200 mm per year, the estimated net evaporation loss should be expected to reach above 7,500 dam$^3$. This loss is of the same order of magnitude as the loss on Reid Lake which is currently included in the calculation of apportionable flows. Due to its proximity to Tobin Lake, the net evaporation rate estimates for Tobin Lake could be applied to Codette Lake on a monthly basis. Saskatchewan Power Corporation indicated that they maintain historic lake levels and that they could provide them to PPWB once a year upon request. Capacity – Area – Elevation curve for Codette Lake listed in Appendix A was obtained from Saskatchewan Watershed Authority.

### 7.2.5 Negative Net Evaporation

Negative net evaporation occurs when precipitation exceeds gross evaporation, thereby resulting in a negative value. This situation generally arises during the winter months when evaporation is at or close to zero and during wet summer months when precipitation exceeds gross evaporation. Under the current procedure for estimating apportionable flow, the net evaporation for Lake Diefenbaker, Tobin Lake and Reid Lake is set to zero for months outside their open water period (January to March for Lake Diefenbaker and Reid Lake and November to March for Reid Lake) and for months when net evaporation is negative. This practice is hydrologically erroneous as it fails to recognize precipitation in a consistent manner for all months and fails to recognize that water which is created by precipitation in excess of gross evaporation falling on the reservoir would not have been realized at the boundary and therefore is not part of the apportionable flow. This practice results in an overestimation of the annual net evaporation losses and apportionable flow. In order to assess the potential impact of zeroing negative net evaporation values, Lake Diefenbaker net evaporation volumes were calculated for the 1973-2007 period for both conditions; a) zeroing negative net evaporation values as per the current practice and b) including negative net evaporation values in the computation of annual net evaporation. Including the negative net evaporation values resulted in a mean annual net evaporation for Lake Diefenbaker of 182,550 dam$^3$ versus 213,200 dam$^3$ when negative net evaporation values were set to zero, a mean annual reduction in of 30,650 dam$^3$ per year or about 15% of the computed evaporation. The range of the annual reduction, from including negative monthly net evaporation in the computation of annual net evaporation for Lake Diefenbaker, varied from a low of 6,800 dam$^3$ to a high of 95,900 dam$^3$. As this error is larger than most of the diversion related water uses currently incorporated in the apportionable flow computations, it is recommended that the practice of zeroing net evaporation for months outside the open water period and for months when net evaporation is negative be discontinued.

## 8. SUMMARY OF IDENTIFIED OPTIONS

All of the recommendations and options identified in this report for updating the current apportionable flow computation procedure for the Saskatchewan River at the Saskatchewan-Manitoba are listed. Those that have been approved for further use by the PPWB Committee on Hydrology are also singled out by using the “APPROVED” identifier.

### 8.1 Elevation-Area-Capacity Tables

*Lake Diefenbaker*

| | |
|---|---|
| RECOMMENDATION | It is recommended that the range for Lake Diefenbaker elevation capacity table be expanded to include the last point provided in |

Figure A-1, this being 560.83 m and 11,150,000 dam$^3$. APPROVED

*Tobin Lake*

RECOMMENDATION The elevation-area and elevation-capacity relationships in Tables A-7 and A-3, respectively that are being used currently continue to be used until more reliable estimates are available. APPROVED

*Reid Lake*

RECOMMENDATION The current elevation-area-capacity tables in the computational procedures be replaced with the updated tables provided in Figure A-3.A3. APPROVED

## 8.2 Review of Adjustment for Contribution by Local Area between the Saskatchewan-Manitoba Boundary and the Gauging Site (Saskatchewan River at The Pas)

OPTION 1: Apply one of the coefficients (1.74 or 1.64) only to the open season flows and ignore the winter flows in the calculation.

OPTION 2: Maintain status quo by using 1.31 for $Cadj$

OPTION 3: Sum the Carrot River and Pasquia River flow volumes then multiply by the ratio of the effective drainage areas

OPTION 4: Maintain status quo of 1.31 but adjust for the Consumptive Uses between the Manitoba Boundary and the Hydrometric Station Saskatchewan River at The Pas (Tolko Industries and the Town of the Pas) which would change the current adjustment factor from 1.31 in Option 2 to 1.34. APPROVED

## 8.3 Review of Adjustment for Contribution by Westward Flowing Tributaries (Goose River) of the Saskatchewan River upstream of the Saskatchewan-Manitoba Boundary

There are currently no water use allocations within the Manitoba portion of the Goose River basin.

RECOMMENDATION If there are no approved water use projects within the Manitoba portion of the Goose River Basin, The Goose River can be treated as part of the apportionable flow of Saskatchewan River at the Saskatchewan-Manitoba boundary and the apportionable flow can be computed using the current procedures. There is currently no need to apportion the flow of the Goose

River separately, rather it can be apportioned as an integral part of the Saskatchewan River apportionment without any special consideration. APPROVED

### 8.4 Existing Water Use Currently Included in the Calculation of Apportionable Flows

Broderick Irrigation Canal

a) Increase the existing SSIRD diversion data by 1.55 and use the result in the calculation of apportionable flows for the Saskatchewan River;
b) Re-activate the WSC flow monitoring station 05HF007 and use the data recorded each year; or,
c) Use WSC 05HF007 data for the period 1968-1995 and East Side pump station data from 1996 onward. APPROVED

Swift Current Diversion

a) Change the existing monthly distribution in the PPWB calculation spreadsheet to reflect the monthly averages obtained from the 1998-2008 data series as shown in Table 4.5;
b) Do not update Table 4.5 and from 2009 and on, use diversion flows calculated from headgate operation records maintained by AAFC, using the AAFC supplied data in place of historic monthly mean data going forward. This option is based on the assumption that AAFC would commit to processing and supplying the diversions to the Secretariat in time to complete apportionable flow computations each year. APPROVED
c) Ignore the 35% return flow from Waldeck Irrigation (as is the case now); or,
d) Reduce the net water use by 35% of the diversion into Waldeck Irrigation to account for its return flows. The net impact of this is small, but it is relatively easy to apply based on the data in Table 4.5. APPROVED

Elbow Diversion Canal into Qu'Appelle River Basin

a) The only viable option that could be identified is to continue using Station 05JG006 which provides daily records of diversions to the Elbow Diversion Canal. APPROVED

Dragline Ditch / Cumberland Marsh Diversion

a) The status quo option (i.e. continue to ignore return flows from Cumberland Marshes);
b) Adopt the 85% return flow rate and use only 15% of the diversion instead; or,
c) Assume a different percentage of return flows that is based on collective judgement of the COH members and communication with project operator Ducks Unlimited Canada. Adopt 60% return flow rate and use 40% of the diversion. APPROVED

d) Ignore this project as the project diversions are used to maintain a portion of the marsh which under natural conditions could have been maintained by “natural” overflows from the Saskatchewan River.

Luck Lake and Riverhurst Irrigation

a) Obtain and use the actual monthly diversions from month to month in each year instead of assuming a fixed monthly distribution of annual totals; or,
b) Assume a certain percentage of return flow based on the studies done for similar districts and include the return flow percentage in the calculation of apportionable flows; or,
c) Continue to treat the water use in those districts without making any changes. APPROVED

## 8.5 Water Use Excluded from the Current Apportionment Flow Calculations

The decisions related to inclusion or exclusion of water use in the calculation of apportionable flows made by the Committee on Hydrology are as follows:

| Type of Included Water Use | | Diversion (dam$^3$) | Ret. Flow Fraction | Return Flow (dam$^3$) | Net Water Use (dam$^3$) |
|---|---|---|---|---|---|
| **Domestic** | **Agriculture / Rural** | **646** | **0.15** | **97** | **549** |
| | **Unclassified** | **7,237** | **0.20** | **1,447** | **5,790** |
| **Industrial** | **Thermal Cooling (SaskPower)** | **427,108** | **1.0** | **427,108** | **0** |
| | **Oil Recovery** | **6,982** | **0.00** | **0** | **6,982** |
| | **Manufacturing** | **1,079** | **0.80** | **863** | **216** |
| | **Mining / Gravel** | **8,286** | **0.90** | **7,457** | **829** |
| *Agriculture* | *Livestock* | *408* | *0.10* | *41* | *367* |
| | *Irrigation* | *121,315* | *0.30* | *36,395* | *84,921* |
| | *Parks/Commercial/Unclassified* | *4,141* | *0.30* | *1,242* | *2,899* |
| **Municipal** | **Unclassified** | **2,458** | **0.70** | **1,740** | **746** |
| | **Commercial / Institutional** | **70** | **0.85** | **60** | **11** |
| | **Recreation** | **247** | **0.90** | **222** | **25** |
| | **Rural** | **17,012** | **0.70** | **11,908** | **5,104** |
| | **Tankload** | **1,364** | **0.90** | **1,228** | **136** |
| | **Urban (excl. 61650 dam$^3$, for City of Saskatoon)** | **15,050** | **0.85** | **12,793** | **2,258** |
| *Other* | *Aquaculture* | *138* | *0.90* | *124* | *14* |
| | Flood Control | 12,102 | 0.90 | 10,892 | 1,210 |
| | Recreation (incl. Candle Lake & Jackfish) | 120,114 | 0.90 | 108,103 | 12,011 |
| | *Unclassified* | *26,405* | *0.90* | *23,765* | *2,641* |
| | *Wildlife (incl. Jam Creek Dam)* | *69,247* | *0.90* | *62,322* | *6,925* |
| | Total: | 841,436 | | 707,806 | 133,630 |

| **Water Use** | **COH Approved Decision** |
|---|---|
| QUEEN ELIZABETH THERMAL | Do Not include |
| CANDLE LAKE DAM | Include |
| SASKATOON MUNICIPAL | Include |
| PRINCE ALBERT PULP | Do Not Include |
| JACKFISH/MURRAY LAKE | Include |
| JAM CREEK DAM | Include |
| LUCK LAKE WILDLIFE PROJECT | Do Not Include |
| SASK. MUNICIPAL LICENSES | Include |

- Add water use estimates from the Net Water Use column in Table 4.11 and 4.7 with monthly distribution as specified in Table 4.12; APPROVED

Hence, that COH agreed to include all entries in Table 4.11 except:

- Flood Control and Recreation (in Other), as these are implicitly included in the existing procedure as part of reservoir net depletions, and explicitly in the case of Candle Lake and Jackfish Lake
- Municipal Urban with City of Saskatoon and Municipal Rural for City of PA as these are accounted for already via Table 4.7
- Municipal Unclassified SaskWater Utilities as these are already accounted for in Table 4.7
- Any item already accounted for in Table 4.7 or otherwise included

In the above reprint of Table 4.11, domestic, industrial and municipal water use (=22619 dam$^3$) are shown in **bold** font with monthly distributions for municipal water use as outlined in Table 12, while all others *(agriculture, aquaculture, unclassified and wildlife = 97765 dam$^3$), have irrigation monthly distributions also identified in Table 4.12.*

## 8.6 Assessment of Travel Times

a) Status Quo – use current fixed percentages; APPROVED
b) Adopt the current findings based on the work done so far (i.e. double the travel times);
c) Initiate a separate study which will deal with this issue in much more detail; and,

d) If option c) is selected, re-introduce the calculation of travel times on a monthly basis, rather than using the fixed long term mean annual flows as is currently done.

## 8.7 Land Use Change and Channel Losses

a) The only identified option is to retain the status quo for reasons that are listed in Section 6. APPROVED

## 8.8 Reservoir Evaporation

### Lake Diefenbaker

| | |
|---|---|
| RECOMMENDATIONS | The approved method calls for net evaporation to be computed for the May to November period. The current procedure computes net evaporation for the April to December period. It is recommended that net evaporation be computed for all months. APPROVED |

Due to the upper section of Lake Diefenbaker being much shallower than the lower section, the approved procedure calls for gross evaporation to be computed for a larger and warmer upper section whose area is 0.69 of the lake surface area and a smaller and cooler lower section which has an area equal to 0.31 of the LSA. In comparison ECCC-AES in their computation of a prorated gross evaporation assign a weight of 0.70 to the upper section and 0.30 to the lower section, and it is recommended that this practice be continued. APPROVED

The current procedure sets net evaporation to zero for months in which the precipitation (P) exceeds gross evaporation (GE). It is recommended that the practice of zeroing net evaporation for months outside the open water period and for months when net evaporation is negative be discontinued. NOT APPROVED

For open water periods include negative net evaporation. For winter or non-open water periods zero negative net evaporation. During summer, negative net evaporation affects flow and apportionment calculations. However, in the winter sublimation of snow over the ice cover will not change the flow in that month. APPROVED

Options for Lake Diefenbaker Net Evaporation

a) Ignore evaporation
b) Use the historical mean monthly net evaporation of past years
c) Use mean gross evaporation minus actual precipitation
d) Use current procedure - calculate monthly gross evaporation based on estimated water temperature and wind speed APPROVED
e) Use current procedure but install data loggers and water temperature sensors at previous sites and Riverhurst Ferry
f) Use Morton lake evaporation model
g) Consider other possible methods – Penman, remote sensing, evaporation pan, energy budget

## Tobin Lake

RECOMMENDATIONS

The approved method calls for net evaporation to be computed for the May to October period. The current procedure computes net evaporation for the April to October period. The recommendation is to compute net evaporation for all months. APPROVED

The current procedure sets net evaporation to zero for months in which the precipitation (P) exceeds gross evaporation (GE). It is recommended that the practice of zeroing net evaporation for months outside the open water period and for months when net evaporation is negative be discontinued. NOT APPROVED

For open water periods include negative net evaporation (April to October). For winter or non-open water periods (November to March) zero negative net evaporation. During summers, negative net evaporation affects flow and apportionment calculations, however in the winter sublimation of snow over the ice cover will not change the flow in that month. APPROVED

Options for Tobin Lake Net Evaporation

a) Ignore evaporation
b) Use the historical mean monthly net evaporation of past years
c) Use mean gross evaporation minus actual precipitation and actual water levels
d) Use PFRA gross evaporation for Nipawin less actual Nipawin precipitation
e) Use current procedure - calculate monthly gross evaporation based on estimated water temperature APPROVED
f) Use current procedure but install data loggers and water temperature sensors.
g) Use Morton lake evaporation model

h) Other possible methods – Penman, remote sensing, evaporation pan, energy budget

**Reid Lake Storage Change**

OPTION 1: Continue using the mean monthly storage levels of Reid Lake as they are used now; or,

OPTION 2: Use the available AAFC hourly storage records from the current year in place of historic monthly mean data, which should be surveyed on dates close to the end of each month, so as to prevent the need to calculate end of month elevations using interpolation. APPROVED

RECOMMENDATIONS

The approved method calls for gross evaporation to be computed as 1.1 times the monthly gross evaporation for upper Lake Diefenbaker. The current procedures compute gross evaporation as 1.1 times the monthly prorated gross evaporation for Lake Diefenbaker. Compute gross evaporation using actual month end lake elevations and corresponding surface areas for Reid Lake. APPROVED

The current procedure sets net evaporation to zero for months in which the precipitation (P) exceeds gross evaporation (GE). It is recommended that the practice of zeroing net evaporation for months outside the open water period and for months when net evaporation is negative be discontinued. NOT APPROVED

For open water periods include negative net evaporation. For winter or non-open water periods (November – March) zero negative net evaporation. During open water season negative net evaporation affects flow and apportionment calculations, however in the winter sublimation of snow over the ice cover will not change the flow in that month. APPROVED

**Options for Codette Reservoir Net Evaporation**

The inclusion of net evaporation loss on Codette Lake obtained from Saskatchewan's Water Security Agency (Table A.5) should be included in the calculation procedure. APPROVED

a) Use the same net evaporation rate estimates for Tobin Lake at Codette Lake on a monthly basis based on the existing storage capacity curve and the historic elevations monitored by SaskPower. APPROVED
b) Continue ignoring net evaporation on Codette Lake

Options related to Negative Net Evaporation

a) Adjust calculations so as to include negative net evaporation for all months,
b) Continue setting the negative net evaporation to zero as has been the case so far,
c) For open water periods (April to October) include negative net evaporation. For winter or non-open water (November to March) periods zero negative net evaporation. During summer, negative net evaporation affects flow and apportionment calculations, however in the winter sublimation of snow over ice cover will not change the flow in that month. APPROVED.

Table 8.1 lists all final decisions related to the changes that were considered to the calculation procedure.

**Table 8.1 Summary of Decisions related to Constituents in the Calculation Procedure**

| SK River Basin Apportionment | Component | COH APPROVED Changes |
|---|---|---|
| Lake Diefenbaker | Elevation-Area-Capacity Tables | Use updated capacity curve Figure A1 |
| Lake Diefenbaker | Net Evaporation Computation | Compute net evaporation for all months (not just Apr-Dec) |
| Lake Diefenbaker | Net Evaporation Computation | Use ECCC-AES computation of prorated gross evaporation weighting of 0.69 to the upper section and 0.31 to the lower section (instead of 0.7 and 03 that are currently used) |
| Lake Diefenbaker<br>Tobin Lake | Net Evaporation Method | NO CHANGE. (calculate monthly gross evaporation based on estimated water temperature) |
| Tobin Lake | Elevation-Area-Capacity Tables | NO CHANGE |
| Codette Lake | Net Evaporation | Include in calculation |
| Codette Lake | Net Evaporation | Apply Tobin Lake evaporation rate estimates for Codette Lake on a |

| | | |
|---|---|---|
| | | monthly basis |
| Reid Lake | Elevation-Area-Capacity Tables | Use updated table Figure A-3. |
| Reid Lake | Storage Change | Use the available AAFC hourly storage records in place of historic monthly mean data |
| Reid Lake | Net Evaporation | Compute gross evaporation using average monthly net evaporation for Lake Diefenbaker and the actual surface area for Reid Lake |
| All Lakes, Reservoirs | Negative Net Evaporation | For open water periods (April to October) include negative net evaporation and for winter or non-open water periods (November to March) zero negative net evaporation |
| Adjustment for Contribution by Local Area between the Saskatchewan-Manitoba Boundary and the Gauging Site (Saskatchewan River at The Pas) | Adjustment Ratio | No change but include City of the Pas and Tolko Paper Mill diversions which converts 1.31 to 1.34. Use 1.34 for all months. |
| Consumptive Uses Between the Saskatchewan-Manitoba Boundary and the Hydrometric Station Saskatchewan River at The Pas | Water Use | Include the City of the Pas and Tolko Paper Mill uses |
| Adjustment for Contribution by Westward Flowing Tributaries (Goose River) of the Saskatchewan River upstream of the Saskatchewan-Manitoba Boundary | Water Use | NO CHANGE |
| Swift Current Diversion | Water Use | Use AAFC head gate operations data from 2009 and on. |

| | | |
|---|---|---|
| Broderick Irrigation Canal | Water Use | Use WCS 05H007 (1968-1995) and East Side pump station data (1996 on) |
| Swift Current Diversion | Water Use | Reduce the net water use by 35% of the diversion into Waldeck Irrigation to account for its return flows |
| Elbow Diversion Canal into Qu'Appelle River Basin | Water Use | NO CHANGE (continue using daily records from Station 05JG006) |
| Dragline Ditch / Cumberland Marsh Diversion | Return Flow/Diversion | Use return flow of 60% and diversion of 40% = 19,712 dam3 consumption |
| Luck Lake and Riverhurst Irrigation | Water Use | NO CHANGE |
| Candle Lake Dam | Water Use | Include Candle Lake Dam with an annual net depletion of 1535 dam$^3$, distributed monthly |
| Saskatoon Municipal | Water Use | Include with a return flow of 70%. |
| Prince Albert Municipal | Water Use | Include with a return flow of 70%. |
| Jam Creek Dam | Water Use | Include in General Wildlife category (Table 4.11) |
| Jackfish Lake | Water Use | Include as an annual net depletion of 107 dam$^3$, distributed monthly |
| Luck Lake Wildlife Project | Water Use | NO CHANGE (not include) |
| SaskWater - Utilities | Water Use | Include with 0% return flow |

| | | |
|---|---|---|
| Flood Control | Water Use | NO CHANGE (not included as flood diversions would be accounted for in reservoir net depletions) |
| All other Water Licenses Excluded from the Computation (Table 4.11) | Water Use | Include all on Table 4.11 not already accounted for in Table 4.7 (except flood control and recreation)<br>Domestic, Industrial and Municipal = 22,619 dam$^3$ with municipal monthly distributions and (agriculture, aquaculture, unclassified and wildlife) = 97,765 dam$^3$, with irrigation monthly distributions |
| Travel Times | Routing | NO CHANGE |
| Land Use Changes | Water Use | No Recommendations / NO CHANGE |
| Channel Loss | Water Use | No Recommendations / NO CHANGE |
| Project Depletion | Apportionable Flow Calculation Method for the SK River at the SK/MB Boundary | NO CHANGE |

New demands that were added to the system required their routing coefficients in the same format that the routing coefficients were determined for other adjustments used in the earlier calculation. To achieved this, PPWB (Ron Woodvine) has assisted by developing a regression equation using the existing routing coefficients for the existing water uses and their distances from the SK/MB border. This regression has the following form:

Proposed Routing Factor = .000364 * (Distance from S/M Boundary in km) − 0.02592

The regression fit ($R^2$) obtained using the existing travel times was 0.946 which provided reasonable confidence that the new water use that was added to the calculation procedure as part of this project is in close agreement with the other water use for which the routing coefficients remained unchanged. The result of the application of the above regression equation is given in Table 8.2 below.

**Table 8.2 Routing Coefficients for New Water Demands and Codette Lake**

| Project | Routing Factors | Distance from Saskatchewan-Manitoba Boundary (km) |
|---|---|---|
| | | |
| **Currently Considered** | **Existing** | |
| Duncairn Dam (Reid Lake) | .30 LMV + 0.70 PMV | 950 |
| Swift Current Main Canal | .28 LMV + 0.72 PMV | 900 |
| Lake Diefenbaker | .24 LMV + 0.76 PMV | 660 |
| Broderick Irrigation Project | .24 LMV + 0.76 PMV | 660 |
| Elbow Diversion Canal | .24 LMV + 0.76 PMV | 660 |
| Luck Lake and Riverhurst Diversions | .24 LMV + 0.76 PMV | 660 |
| Tobin Lake | .08 LMV + 0.92 PMV | 460 |
| Dragline Channel | .02 LMV + 0.98 PMV | 120 |
| | | |
| **New** | **Proposed** | |
| Saskatoon | .17 LVM + .94 PMV | 530 |
| Prince Albert | .11 LMV + .89 PMV | 360 |
| Candle Lake | .11 LMV + .89 PMV | 360 |
| Codette Lake | .06 LMV + .94 PMV | 230 |
| Jackfish Lake | .21 LMV + .79 PMV | 640 |
| The Pas / Tolkin Pulp Mill | 1.00 PMV | 100 (in Manitoba) |
| Other Unspecified Water Uses | .20 LMV + .80 PMV | 600 |

This report is accompanied by an updated version of the calculation spreadsheet which takes into account Codette Lake storage change and Net Evaporation, as well as all other water demands listed in Table 8.1, where the last entry (Other Unspecified Water Uses) is broken down in more detail in Table 4.11. The updated calculation spreadsheet also takes into account the routing adjustment coefficients listed in Table 8.2 above.

## 9. OVERALL IMPACT OF PROPOSED CALCULATION CHANGES

In general, the overall impact of the proposed calculation changes is small. The relative difference between the previous apportionable flows and the updated values for 2014 is 0.16%; the previous apportionable flows were estimated at 27,345 mil. $m^3$, while the updated amount shows 27,390 mil. $m^3$. The changes are mainly due to taking into account significant return flows which had previously been ignored, such as for example 60% return flow from the Cumberland Marsh Diversion, as well as taking into account additional water use that has not been accounted in previous calculations.

## 10. HYDROMETRIC DATA REQURIED FOR APPORTOINABLE FLOW CALCULATIONS

Hydrometric data include all records of historic flows and water levels that are required for calculation of apportionable flows. Required hydrometric data at stations 05HD034 (Swift Current Diversion), 05HF007 (Broderick Diversion) and 05HD034 (Reid Lake water levels) were used as long term historic averages in earlier calculations. This study determined that data records can be retrieved for those stations at the end of each year. This will consequently improve the accuracy of calculations in future years. Table 10.1 shows the required hydrometric data each updated calculation of apportionable flows in the Saskatchewan River Basin.

**Table 10.1 Hydrometric Data used in the calculation of apportionable flows**

| Hydrometric Station Name | Station Number | Additional Comment |
|---|---|---|
| **Flow Stations ($m^3/s$)** | | |
| SASKATCHEWAN RIVER AT THE PAS | 05KJ001 | |
| CARROT RIVER NEAR TURNBERRY | 05KH007 | Adjustment ratio modified in this study |
| ELBOW DIVERSION CANAL AT DROP STRUCTURE | 05JG006 | |
| BRODERICK IRRIGATION CANAL * | 05HF007 | Use East Side pump station data 1996 and on |
| SWIFT CURRENT CANAL * | 05HD034 | AAFC data will be used and will be reduced by estimated return flows from Waldeck Irrigation component |
| **Water Levels Stations (m)** | | |
| LAKE DIEFENBAKER AT GARDINER DAM | 05HF003 | |
| TOBIN LAKE AT THE SPILLWAY | 05KD004 | |
| CODETTE LAKE | 05KD006 | |
| REID LAKE NEAR DUNCAIRN * | 05HD033 | AAFC data to be used |

Note: * indicates instances where genuine data records are now used instead of the long-term estimates based on historic means

## 11. METEOROLOGICAL DATA REQURIED FOR APPORTIONABLE FLOW CALCULATIONS

Meteorological data required for calculating apportionable flows involve precipitation and evaporation on all major water bodies (Lake Diefenbaker, Tobin Lake, Reid Lake and Codette Lake). Precipitation data is recorded. Evaporation is calculated based on the wind speed, water temperature and dew point temperature. There are no changes to the meteorological data that have been used before. All meteorological data used in the calculations are listed in Table 11.1 below.

**Table 11.1 Meteorological Data used in the calculation of apportionable flows**

| Climate Station | Type of Data Collected |
|---|---|
| ELBOW | Precipitation, Wind Speed, Air and Dew Point Temperature |
| SWIFT CURRENT | Precipitation, Wind Speed, Air and Dew Point Temperature |
| NIPAWIN | Precipitation, Wind Speed, Air and Dew Point Temperature |

Stations at Elbow and Swift Current are used for calculation of net evaporation on Lake Diefenbaker. The station at Nipawin provides data to calculate net evaporation on Tobin Lake. Codette Lake uses the same precipitation and evaporation estimates as Lake Tobin, which are applied to mean monthly lake areas, while Reid Lake uses the Swift Current precipitation and Lake Diefenbaker evaporation adjusted by a factor of 1.1. Air temperatures of Lake Diefenbaker and Tobin Lake are determined using regression equations which relate historic water temperature data to the air temperature.

## 12. OTHER DATA USED IN THE CALCULATIONS OF APPORTIONABLE FLOW

In addition to hydrometric and meteorological data listed in sections 11 and 12, other data required for calculation of natural flows are listed in Table 12.1. Those include the storage capacity tables as well as various water use estimates.

**Table 12.1 Other Data used in the calculation of apportionable flows**

| Reservoir Data | Data Type |
|---|---|
| LAKE DIEFENBAKER | Elevation – Area – Volume<br>(m – ha – dam$^3$) |
| TOBIN LAKE AT THE SPILLWAY | |
| CODETTE LAKE * | |
| REID LAKE NEAR DUNCAIRN | |
| **Gross Evaporation** | |
| LAKE DIEFENBAKER ** | Calculated estimates (mm), 0.69 and 0.31 upper and lower lake division instead of 0.7 and 0.3 as in earlier calculations |
| TOBIN LAKE AT THE SPILLWAY | Calculated estimates (mm) |
| CODETTE LAKE * | Same as Tobin Lake estimates (mm) |
| REID LAKE NEAR DUNCAIRN | Same as Lake Diefenbaker estimates x 1.1 |
| **Water Use Estimates** | |
| Luck Lake Irrigation | No change from earlier calculation |
| Riverhurst Irrigation | No changes from earlier calculation |
| Cumberland Marsh ** | Previously used values with assumed 60% return flow |
| Saskatoon Municipal * | Assumed 70% return flow |
| SaskWater - Utilities * | No return flow |

| | |
|---|---|
| Prince Albert Pulp Mill * | Currently set to zero, to reopen in 2020. Assumed 70% return flow |
| Candle Lake * | Table 4.8 |
| Jackfish Lake * | Table 4.9 |
| The Pas / Tolkin Pulp Mill * | No return flow |
| Other Unspecified Water Uses * | Industrial, Municipal and Domestic from Table 4.11 |
| Other Unspecified Water Uses * | Agricultural and other water use from Table 4.11 |

Note: * indicates new water use added to the calculations as part of this study
** indicates previous water use that was modified in the new calculation

Water use related to Prince Alberta Pulp Mill has been kept in the calculation spreadsheet with zero values, since the plant is not currently in use. It may be reactivated in 2020, at which point there will be no need to change the spreadsheet, but rather paste the monthly estimates of net water use.

## 13. FUTURE ACTION REGARDING APPORTIONMENT CALCULATION PROCEDURES

The computation of apportionable flow for the Saskatchewan River at the Saskatchewan-Manitoba boundary has been carried out annually since 1977 using a monthly time step and what is termed the *project depletion* method. The apportionable flow computations for the past 38 years show that:

a) the mean annual apportionable flow has averaged 18,127,000 dam$^3$;
b) the lowest computed annual apportionable flow was 8,250,000 dam$^3$ in 1988;
c) annual flow deliveries to Manitoba have averaged 97% of apportionable flow; and,
d) the lowest percentage of apportionable flow delivered to Manitoba has been 79% in 1989.

Given the above results, it may be concluded that at the present level of development and water use in Saskatchewan there is no concern in terms of Saskatchewan being unable to deliver Manitoba's water entitlements on an annual basis even during years with below average runoff. Similarly, at the current level of water use and the rate of increase in water use, there is no indication that an increase in the level of monitoring or the frequency of computations will be required in the near future. Despite this, should short term conditions in the basin be such that flow in the Saskatchewan River is significantly below normal levels, an interim increase in the frequency of apportionment computations may be advised to ensure apportionment obligations continue to be met.

Evaporation from storage reservoirs is the single largest water use within the Saskatchewan portion of the Saskatchewan River basin. Currently, gross evaporation from reservoirs, and more specifically evaporation from Lake Diefenbaker, is computed using previously developed regression equations that estimate water temperature, and subsequently gross lake evaporation, based on air temperature. As these methods are not highly reliable, consideration should be given to exploring current remote sensing technology as a means of obtaining more reliable estimates of water temperatures and subsequently gross evaporation in Lake Diefenbaker.

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 Saskatchewan portion of the Saskatchewan River basin, this timeframe appears to be a reasonable period of time for the next overall review.

## 14. CONCLUSIONS AND RECOMMENDATIONS

Apportionable flow computations for the Saskatchewan River at the Saskatchewan-Manitoba boundary have been carried out on an annual basis since 1977 using the project depletion method. The current report represents the first comprehensive assessment of the apportionment computation procedures. Following the review of the various considerations in the calculation procedures for the Saskatchewan River at the Saskatchewan-Manitoba boundary, the following recommendations have been made:

## Apportionment Computation Procedures

It is recommended that apportionable flows continue to be calculated using the project depletion method.

## Location of Apportionment Point

It is recommended that the apportionment point continue to be at the Saskatchewan-Manitoba Boundary and that it be based on the hydrometric station for the Saskatchewan River at The Pas (05KJ001) minus 1.34 times the recorded flow for Carrot River near Turnberry (05KH007).

## Evaporation

It is recommended that gross evaporation for Lake Diefenbaker, Tobin Lake, and Reid Lake continue to be estimated for the April to December period using water temperatures estimated from previously developed regression equations which correlate water temperature to air temperature. It is recommended that the practice of zeroing negative net evaporation (i.e. occurrences in which the monthly precipitation exceeds gross evaporation) be discontinued. It is also recommended that net evaporation be set to zero for winter months (January-March) when reservoirs have an ice cover. Finally, it is recommended that storage change and net evaporation losses from Codette Reservoir be included in the apportionable flow computations.

## Consumptive Use from Licensed Projects

It is recommended that the water use by larger projects, (e.g. City of Saskatoon, Prince Albert, Candle Lake, Jackfish lake, etc.) be included independently in the apportionable flow computations based on an assumed percentage of licensed allocation being used and an assumed temporal distribution. It is recommended that the consumptive water use from all small licensed water use projects (excluding flood control and recreation) be included as an integrated value based on an estimate of the percentage of all licensed allocation actually being used and based on an assumed temporal distribution.

## Routing Adjustments

It is recommended that time of travel adjustments continue to be accounted for by reducing the consumptive use adjustment by a fixed percentage, based on the average travel time from the project site to the Saskatchewan-Manitoba boundary and carrying the time of travel adjustment volume forward to the following month.

## Westward Flowing Tributaries

The Goose River is a westward flowing tributary of the Saskatchewan River. Within the Goose River basin, Manitoba is considered the upstream province that, under the *Master Agreement of Apportionment* is required to ensure that 50% of the flow is passed to the downstream province, in this case Saskatchewan. At present, there are no water use projects within Manitoba's portion of the Goose River basin. Given that there is no water use within the Manitoba portion of the Goose River basin there are no concerns with Manitoba delivering Saskatchewan's share of the Goose River flow and therefore there is currently no need for apportionment monitoring on the Goose River.

## Data Requirements

In addition to the data that were previously required, the proposed calculations will also require the use of the existing monitoring of Codette Lake water levels and Reid Lake water levels, as well as monitoring of flows at Broderick Canal and Swift Current Canal, where previous calculations utilized long term historic monthly averages. Other water use included in the calculation are estimates based on water licenses, assumed level of water use, and assumed return flows. These estimates will be subject to further review in future updates.

## Next Review

The next review of apportionment flow computation procedures for the Saskatchewan River at the Saskatchewan-Manitoba boundary 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 computation procedures prior to that time.

# 15. REFERENCES

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Agriculture and Agri-Food Canada, Prairie Farm Rehabilitation Administration; *Gross and Effective Drainage Areas for Hydrometric Gauging Stations (2010).*

# APPENDIX A – CURRENT AND UPDATED CALCULATION PROCEDURES AND ELEVATION-AREA-CAPACITY TABLES / CURVES

## Table A.1 Summary of Methods and Procedures Documented in PPWB Report #45 for the Computation of Apportionable Flow at the Saskatchewan-Manitoba Boundary

| **Proposed Procedure** |
|---|
| $AAF_{SK/Man}=\sum_{i=1}^{12}((MREC_{SK/Man(i)} - MLFC_{Man(i)}) + (\sum_{k=1}^{n-m} (TTA_{(i-1)} + MWU_{(i)} - TTA_{(i)})_k))$ (6) |

| **Proposed Methods** | |
|---|---|
| **Parameter** | **Proposed Method** |
| $MREC_{SK/Man}$ – monthly recorded flow at MB Boundary | Recorded flow for the Saskatchewan River at The Pas (WSC Station #05KJ001) |
| $MLFC_{Man}$ monthly local area flow contribution | Carrot, Pasquia and Birch-Saskeram Rivers, which originate in Saskatchewan and flow into Manitoba prior to joining the Saskatchewan River upstream of The Pas, is not to be included in the calculations until such time as "…*flow at The Pas nears 50% of the natural [apportionable] flow or Manitoba's share of the Carrot, Pasquia or Birch-Saskeram Rivers nears obviously inequitable levels*".<br>Goose River, which originates in Manitoba and flows westward into Saskatchewan before joining the Saskatchewan River, is not to be included until an agreement is reached on the sharing of westward flowing tributaries of eastward flowing streams. |

| Approved Water Use Projects ($MWU_k$) - Reservoirs | | |
|---|---|---|
| **Project** | **Parameter** | **Proposed Method** |
| Lake Diefenbaker | Change in Storage | To be based on month-end elevation of the previous month to the current month for Lake Diefenbaker at Gardiner Dam (WSC #05HF003), corrected for wind effect, using the elevation-capacity table in Appendix A, Table A-5. |
| | Net Evaporation | Lake Diefenbaker to be treated as two separate sections, a shallow upper section occupying 0.69 of the lake surface area (LSA) and a deeper lower section comprised of 0.31 of LSA. Net evaporation (NE) and gross evaporation (GE) for each of the two sections is computed for May-Nov. using the Meyer equation and P as indicated below and the elevation-area table in Appendix A, Table A-8 .<br>$NE=LSA*(GE-P) = LSA*(C*(e_s-e_a)*(1+0.1*V)-P)$<br>Where: C= a constant which is 9.0 for both sections, |

| | | |
|---|---|---|
| | | $e_s$ and $e_a$ = the saturation vapor pressure and actual vapor pressure respectively in inches Hg. corresponding to the mean monthly surface water temperature and to the air temperature and humidity 25 ft. above ground,<br>V = mean monthly wind speed at 25 ft. elevation in miles/hr, and P = the monthly precipitation. $e_a$, V, and P for the lower section is based on Elbow station and Swift Current for the upper section. |
| Tobin Lake | Change in Storage | To be based on month-end elevation of the previous month to that of the current month on Tobin Lake at the Spillway (WSC #05KD004), corrected for wind effect, using elevation-capacity table in Appendix A, Table A-4 |
| | Net Evaporation | Computed for May-November using same Meyer equation as for Lake Diefenbaker but with “C” value of 10, water temperature from representative point on lake that is to be determined, precipitation and dew point at Nipawin, and elevation-area Table in Appendix A, Table A-7. |
| Reid Lake | Change in Storage | Calculated based on month-end elevation of the previous month to that of the current month for Reid Lake near Duncairn (WSC #05HD033) using elevation-capacity table provided in Appendix A, Table A-3. |
| | Net Evaporation | Computed for May-November period as monthly average lake surface area times the unit gross evaporation for upper Lake Diefenbaker minus Swift Current precipitation using elevation-area table provided in Appendix A, Table A-6. |

| Approved Water Use Projects ($MWU_k$) - Diversions | |
|---|---|
| **Project** | **Proposed Method** |
| Cumberland Delta | Diversion is equal to gauged flow at Dragline Ditch near Squaw Rapids (WSC St. #05KH011). Getting exact figures as to Saskatchewan’s water use is difficult because: a) the diversion is carried out to maintain a delta which, prior to regulation, was maintained by natural overflows, and b) return flows to the Saskatchewan River, which are downstream of the Saskatchewan-Manitoba Boundary and upstream of The Pas, via the Birch and Saskeram Rivers, are difficult to measure. Based on the foregoing and recognizing return flows from the Dragline Ditch have little effect on apportionment flow PPWB Report #45 recommends “*only the diversions through Dragline Ditch, unadjusted for return flow, be considered*”. |
| Saskatoon SE Water Supply | Diversion estimated as gauged flow at Broderick Irrigation Main Canal below Pumping Station (WSC St. # 05HF007). Measurements conducted in 1974 suggested that return flows were less than 10,000 ac-ft of the 54,000 ac-ft diverted |

| | |
|---|---|
| | and were an insignificant component of the 5.7 million ac-ft flowing in the South Saskatchewan River during the May-October period. Based on the foregoing, PPWB Report #45 recommends that "…*only the measured diversions be included in the computations*". |
| Swift Current Canal | Diversion estimated as gauged flow at Swift Current Canal at Swift Current (WSC St. #05HD034). Only an insignificant amount of diverted flow is returned, hence the return flow can be ignored. |
| Elbow Diversion Canal | Diversion estimated as gauged flow at Elbow Diversion Canal at Drop Structure (WSC St. #05JG006). Water diverted to Qu'Appelle system and no return to Saskatchewan River. |

| Proposed Time of Travel Procedures | |
|---|---|
| **Reach** | **Proposed Travel Time Equation** |
| S. Saskatchewan – Mouth of Red Deer R to Gardiner Dam | $TT=0.58*10^{2.69-0.158 \log Q}$<br>Where Q=the mean adjusted flow at Medicine Hat (in cfs) over the approximate travel period. |
| S. Saskatchewan – Gardiner Dam to the Forks | $TT=0.63*10^{2.69-0.158 \log Q}$<br>Where Q=the mean adjusted flow at Saskatoon (in cfs) over the approximate travel period. |
| N. Saskatchewan-Alberta Boundary to North Battleford | $TT=1.00*10^{2.63-0.236 \log Q}$<br>Where Q=the mean adjusted flow at Deer Creek (in cfs) over the approximate travel period. |
| N. Saskatchewan – North Battleford to the Forks | $TT=1.24*10^{3.22-0.328 \log Q}$<br>Where Q=the mean adjusted flow at Prince Albert (in cfs) over the approximate travel period. |
| Saskatchewan River – the Forks to Tobin L. | $TT=1.30*10^{3.52-0.47 \log Q}$<br>Where Q=the sum of mean adjusted flow at Prince Albert and St. Louis (in cfs) over the approximate travel period. |
| Saskatchewan River – Tobin L. to Manitoba Boundary | $TT=1.00*10^{3.05-0.30 \log Q}$<br>Where Q=the sum of mean adjusted flow at Manitoba Boundary (in cfs) over the approximate travel period. |
| *Note – Each project's total travel time is to be determine as the sum of the TT through the initial reach and all successive downstream reaches. The initial reach for all projects, except Tobin Lake and Dragline Ditch, is the Gardiner Dam to the Forks. The initial reach for Tobin Lake is Tobin Lake to Manitoba Boundary and 0.7 of the Tobin L to Manitoba Boundary for the Dragline Ditch.* | |

**Table A.2 Summary of Methods and Procedures Proposed in PPWB Report #45 with Modifications introduced in PPWB Reports #48, #141, #161 and EC Monitoring Report**

| **Approved Procedure** |
|---|
| $AAF_{SK/Man}=\sum_{i=1}^{12}((MREC_{SK/Man(i)} - MLFC_{Man(i)}) + (\sum_{k=1}^{n-m} (TTA_{(i-1)} + MWU_{(i)} - TTA_{(i)})_k))$ (6) |

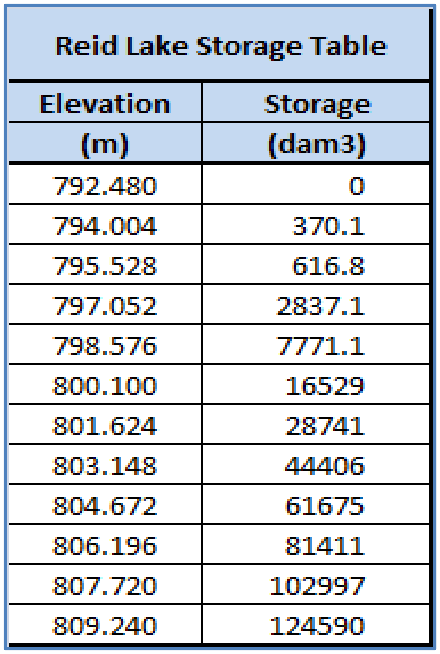
| **Approved Methods** | |
|---|---|
| **Parameter** | **Approved Method** |
| $MREC_{SK/Man}$ – monthly recorded flow at MB Boundary | Recorded flow for the Saskatchewan River at The Pas (WSC Station #05KJ001) |
| $MLFC_{Man}$ - monthly local area flow contribution | 1.31 times recorded flow at Carrot River near Turnberry (WSC St. # 05KH007) to account for local inflow between the Manitoba Boundary and The Pas by Carrot, Pasquia and Birch-Saskeram Rivers. |

| Approved Water Use Projects ($MWU_k$) - Reservoirs | | |
|---|---|---|
| **Project** | **Parameter** | **Approved Method** |
| Lake Diefenbaker | Change in Storage | To be based on month-end elevation of the previous and month-end elevation of the current month at Gardiner Dam (WSC #05HF003) using elevation-capacity table, Appendix A, Table A-5. |
| | Net Evaporation | Lake Diefenbaker net evaporation (NE) and gross evaporation (GE) to be computed for May-November using the Meyer equation and P as indicated below with lake surface area (LSA) computed from elevation-area curves in Appendix A, Table A-8.<br>$NE=LSA*(GE-P) = LSA*(C*(e_s-e_a)*(1+0.1*V)-P)$<br>Where: C= a constant which is 9.0 for both sections;<br>$e_s$ = the saturation vapor pressure and $e_a$ is the actual vapor pressure in inches Hg corresponding to the mean monthly surface water temperature, estimated by ECCC from regression equation, and humidity 25 ft. above ground, estimated from Elbow and Swift Current stations. V=mean monthly wind speed at 25 ft. elevation in miles/hr, estimated from Elbow and Swift Current. P = the average monthly precipitation at Elbow, Swift Current, Tagaske and Beechy. |
| Tobin Lake | Change in Storage | Based on month-end elevation of previous month to month-end elevation of the current month on Tobin Lake (WSC #05KD004) using elevation-capacity table in Appendix A, Table A-4. |
| | Net | Computed for May-November using same Meyer equation as for |

<table>
<tr><td></td><td>Evaporation</td><td colspan="2">Lake Diefenbaker but with “C” value of 10, water temperature is estimated using regression equations, precipitation and dew point and wind speed at Nipawin, and elevation-area curve in Appendix A, TableA-7.</td></tr>
<tr><td rowspan="2">Reid Lake</td><td>Change in Storage</td><td colspan="2">To be based on historical average month-end elevation of the previous month to that of the current month at Reid Lake near Duncairn (WSC #05HD033) using elevation-capacity curve provided in Appendix A, Table A-3.</td></tr>
<tr><td>Net Evaporation</td><td colspan="2">Computed for May-November period as historical mean monthly lake surface area times 1.1 the unit gross evaporation for upper Lake Diefenbaker minus Swift Current precipitation.</td></tr>
<tr><th colspan="4">Approved Water Use Projects ($MWU_k$) - Diversions</th></tr>
<tr><th>Project</th><th colspan="3">Approved Method</th></tr>
<tr><td>Cumberland Delta</td><td colspan="3">Diversions equal to historical mean monthly flow (in $m^3/s$) at Dragline Ditch near Squaw Rapids (05KH011) as follows: Jan 0.683, Feb 0.601, Mar 0.59, Apr 0.701, May 1.47, June 2.53, July 3.62, Aug. 3.16, Sept 2.44, Oct 1.66, Nov 0.466, Dec 0.734</td></tr>
<tr><td>Saskatoon SE Water Supply</td><td colspan="3">Diversions based on gauged flow at Broderick Irrigation Main Canal below Pumping Station (WSC St. # 05HF007). That return flow be ignored as most of the diversion is for industrial and municipal use and is lost forever.</td></tr>
<tr><td>Swift Current Canal</td><td colspan="3">Diversions to be based on historical mean monthly flow (in $m^3/s$) gauged at Swift Current Canal at Swift Current (05HD034). Jan 0.00, Feb 0.09, Mar 0.263, Apr 1.14, May 1.08, June 0.509, July 0.835, Aug. 0.457, Sept 0.16, Oct 0.105, Nov 0.387, Dec 0.0</td></tr>
<tr><td>Elbow Diversion Canal</td><td colspan="3">Diversions estimated as gauged flow at Elbow Diversion Canal at the Drop Structure (WSC St. #05JG006). Water is diverted to Qu’Appelle system and there is no return to Saskatchewan River.</td></tr>
<tr><td>Luck Lake-Riverhurst Diversion</td><td colspan="3">Diversions to be based on Luck Lake pumping station and Riverhurst pumping station.</td></tr>
<tr><th colspan="4">Approved Time of Travel Procedures</th></tr>
<tr><th colspan="2">Reach</th><th colspan="2">Travel Time Equation</th></tr>
<tr><td colspan="2">S. Saskatchewan – Gardiner Dam to the Forks</td><td colspan="2">$TT=0.63*10^{2.69-0.158 \log Q}$<br>Where Q=the mean adjusted flow at Saskatoon in cfs</td></tr>
<tr><td colspan="2">Saskatchewan River – the Forks to Tobin L.</td><td colspan="2">$TT=1.30*10^{3.52-0.47 \log Q}$<br>Where Q=the sum of mean adjusted flow at Prince Albert and St. Louis in cfs</td></tr>
</table>

| | |
|---|---|
| Saskatchewan River – Tobin L. to Manitoba Boundary | $TT=1.00*10^{3.05-0.30\ \log Q}$<br>Where Q=the sum of mean adjusted flow at Manitoba Boundary in cfs |
| *Note 1 – The number of reaches for which time of travel equations are presented have been reduced from six to three because other reaches (South Saskatchewan River - Mouth of Red Deer River confluence to Gardiner Dam, North Saskatchewan-Alberta Boundary to North Battleford, and North Saskatchewan River – North Battleford to the Forks) are not required due to there not being any approved water use projects on the reaches.*<br>*Note 2 – Each project's total travel time is to be determined as the sum of the TT through the initial reach and all successive downstream reaches. The initial reach for all projects, except Tobin Lake and Dragline Ditch, is the Gardiner Dam to the Forks. The initial reach for Tobin lake is Tobin Lake to Manitoba Boundary and 0.7 of the Tobin L to Manitoba Boundary for the Dragline Ditch.* | |

## Table A.3 Reid Lake Elevation-Capacity Table[8]



**Reid Lake Storage Table**

| Elevation (m) | Storage (dam3) |
|---|---|
| 792.480 | 0 |
| 794.004 | 370.1 |
| 795.528 | 616.8 |
| 797.052 | 2837.1 |
| 798.576 | 7771.1 |
| 800.100 | 16529 |
| 801.624 | 28741 |
| 803.148 | 44406 |
| 804.672 | 61675 |
| 806.196 | 81411 |
| 807.720 | 102997 |
| 809.240 | 124590 |

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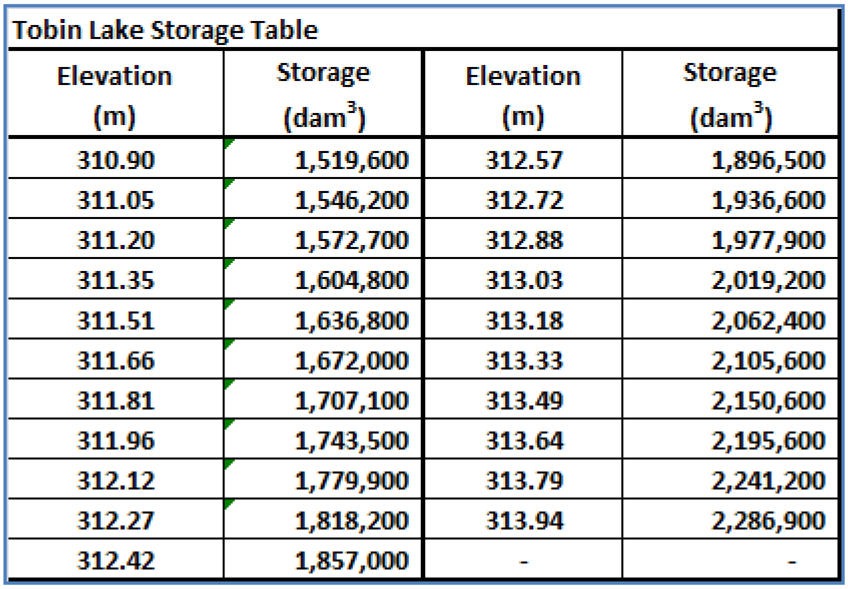
[8] Table A-3 provides a metric conversion of the values presented in table format within PPWB Report #45. The Table actually used within the EXCEL Workbook for the computation of apportionable flow was expanded to include the capacity for several additional elevations.

**Table A.4 Tobin Lake Elevation-Capacity Table used in the current calculations**



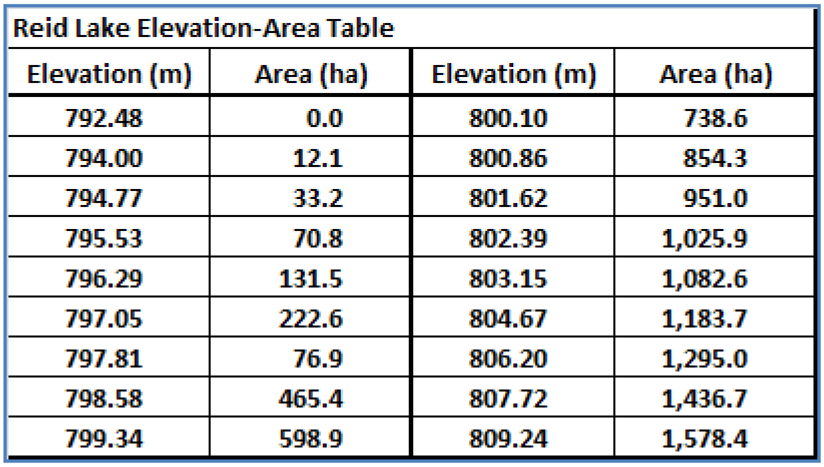
**Tobin Lake Storage Table**

| Elevation (m) | Storage ($dam^3$) | Elevation (m) | Storage ($dam^3$) |
|---|---|---|---|
| 310.90 | 1,519,600 | 312.57 | 1,896,500 |
| 311.05 | 1,546,200 | 312.72 | 1,936,600 |
| 311.20 | 1,572,700 | 312.88 | 1,977,900 |
| 311.35 | 1,604,800 | 313.03 | 2,019,200 |
| 311.51 | 1,636,800 | 313.18 | 2,062,400 |
| 311.66 | 1,672,000 | 313.33 | 2,105,600 |
| 311.81 | 1,707,100 | 313.49 | 2,150,600 |
| 311.96 | 1,743,500 | 313.64 | 2,195,600 |
| 312.12 | 1,779,900 | 313.79 | 2,241,200 |
| 312.27 | 1,818,200 | 313.94 | 2,286,900 |
| 312.42 | 1,857,000 | - | - |

**Table A.5 Codette Lake Elevation-Area-Volume Table used in the current calculations**

| Elevation (m) | Area (ha) | Volume ($dam^3$) |
|---|---|---|
| 313 | 0.0 | 0 |
| 314 | 58.6 | 440 |
| 318 | 162.1 | 4,853 |
| 322 | 331.0 | 14,716 |
| 326 | 594.8 | 33,233 |
| 330 | 970.7 | 64,543 |
| 334 | 1,482.8 | 113,612 |
| 338 | 2,117.2 | 185,612 |
| 342 | 2,827.6 | 284,509 |
| 346 | 3,637.9 | 413,819 |
| 348 | 4,000.0 | 490,198 |
| 350 | 4,465.5 | 574,853 |

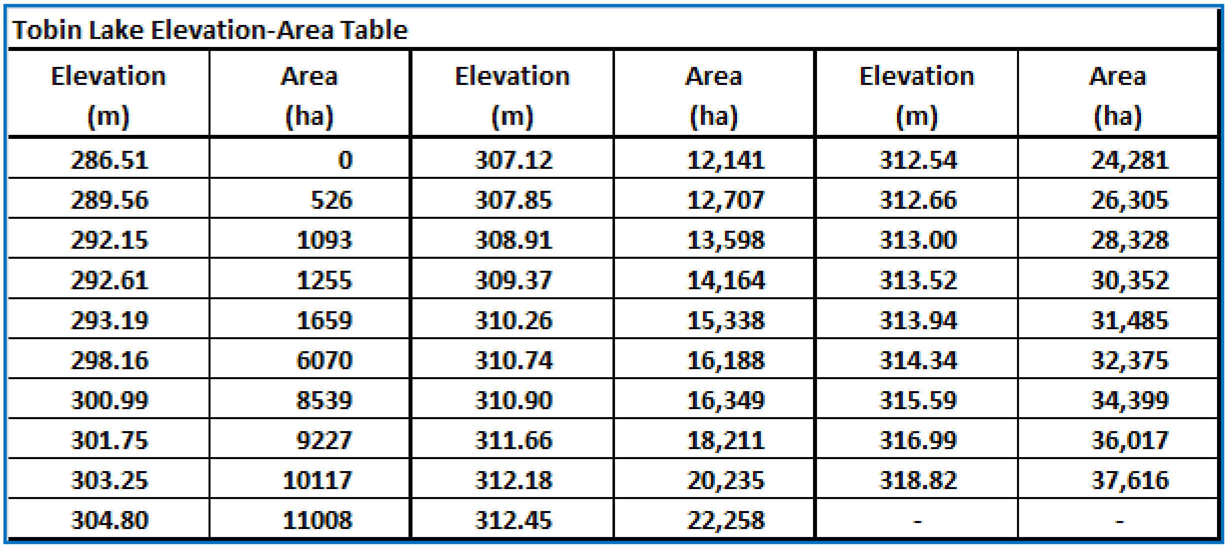
**Table A.6 Reid Lake Elevation-Area Table used in the current calculations**



Reid Lake Elevation-Area Table

| Elevation (m) | Area (ha) | Elevation (m) | Area (ha) |
|---|---|---|---|
| 792.48 | 0.0 | 800.10 | 738.6 |
| 794.00 | 12.1 | 800.86 | 854.3 |
| 794.77 | 33.2 | 801.62 | 951.0 |
| 795.53 | 70.8 | 802.39 | 1,025.9 |
| 796.29 | 131.5 | 803.15 | 1,082.6 |
| 797.05 | 222.6 | 804.67 | 1,183.7 |
| 797.81 | 76.9 | 806.20 | 1,295.0 |
| 798.58 | 465.4 | 807.72 | 1,436.7 |
| 799.34 | 598.9 | 809.24 | 1,578.4 |

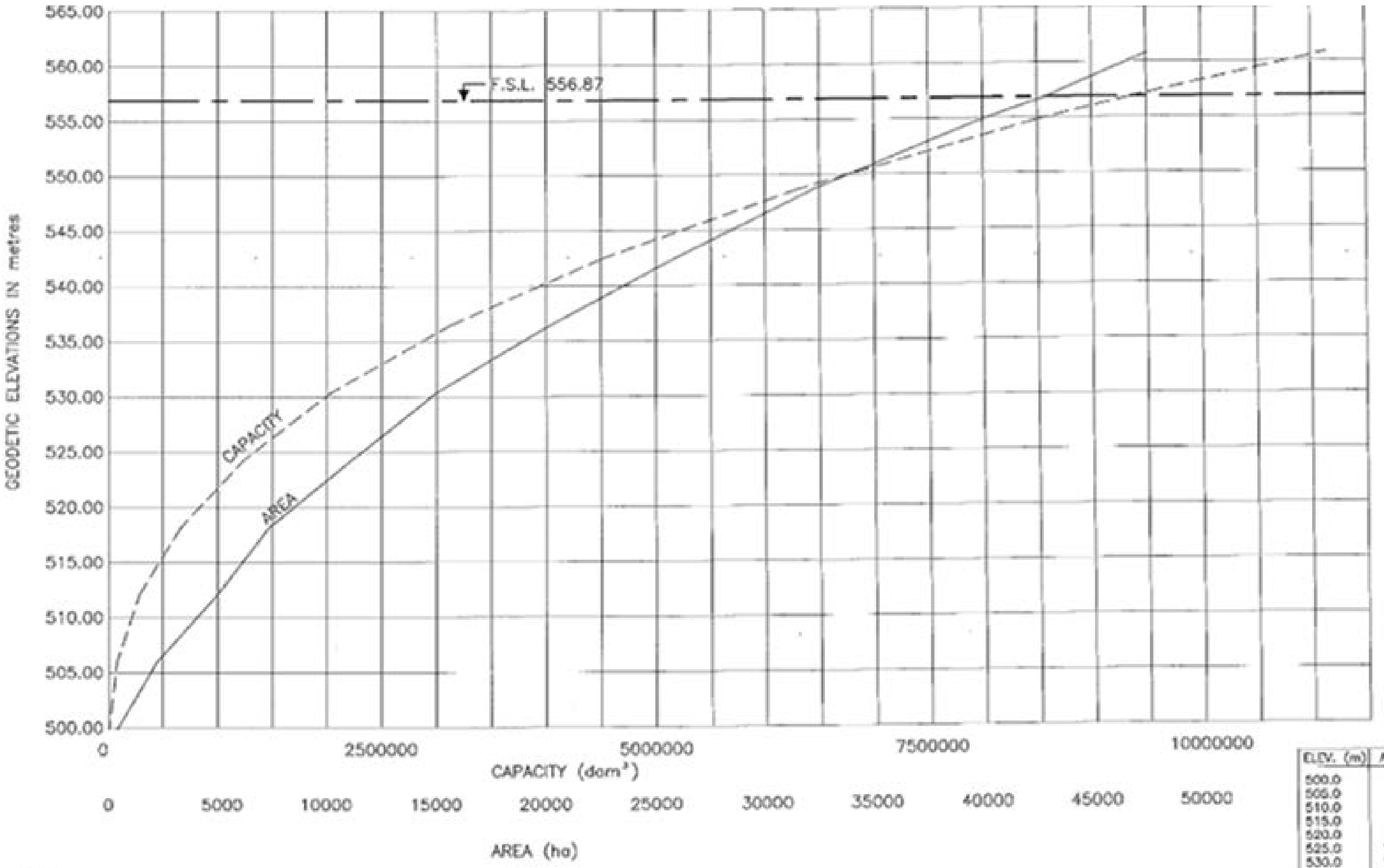
**Table A.7 Tobin Lake Elevation-Area Table**



Tobin Lake Elevation-Area Table

| Elevation (m) | Area (ha) | Elevation (m) | Area (ha) | Elevation (m) | Area (ha) |
|---|---|---|---|---|---|
| 286.51 | 0 | 307.12 | 12,141 | 312.54 | 24,281 |
| 289.56 | 526 | 307.85 | 12,707 | 312.66 | 26,305 |
| 292.15 | 1093 | 308.91 | 13,598 | 313.00 | 28,328 |
| 292.61 | 1255 | 309.37 | 14,164 | 313.52 | 30,352 |
| 293.19 | 1659 | 310.26 | 15,338 | 313.94 | 31,485 |
| 298.16 | 6070 | 310.74 | 16,188 | 314.34 | 32,375 |
| 300.99 | 8539 | 310.90 | 16,349 | 315.59 | 34,399 |
| 301.75 | 9227 | 311.66 | 18,211 | 316.99 | 36,017 |
| 303.25 | 10117 | 312.18 | 20,235 | 318.82 | 37,616 |
| 304.80 | 11008 | 312.45 | 22,258 | - | - |

**Figure A.1 Lake Diefenbaker Updated Elevation-Area-Capacity Curve and Table**



| ELEV. (m) | AREA (ha) | CAPACITY (dam³) |
|---|---|---|
| 500.0 | 450 | 6500 |
| 505.0 | 1900 | 65100 |
| 510.0 | 4100 | 212000 |
| 515.0 | 6100 | 463000 |
| 520.0 | 8500 | 833000 |
| 525.0 | 11600 | 1330000 |
| 530.0 | 14800 | 1990000 |
| 535.0 | 18900 | 2860000 |
| 540.0 | 23500 | 3930000 |
| 545.0 | 28400 | 5230000 |
| 550.0 | 33900 | 6770000 |
| 556.87 | 42900 | 9360000 |
| 560.83 | 47600 | 11150000 |

NOTES:

1) STRUCTURE COMPLETED IN 1964
2) STRUCTURE LOCATION S.E. 1 & 2-28-7-W3M
3) F.S.L. = 556.87 m
4) ORIGINAL IMPERIAL UNIT DATA FROM PFRA TABLES, DATED AUGUST 1965.
5) CURVES PREPARED USING HARD CONVERSION OF EXISTING DATA

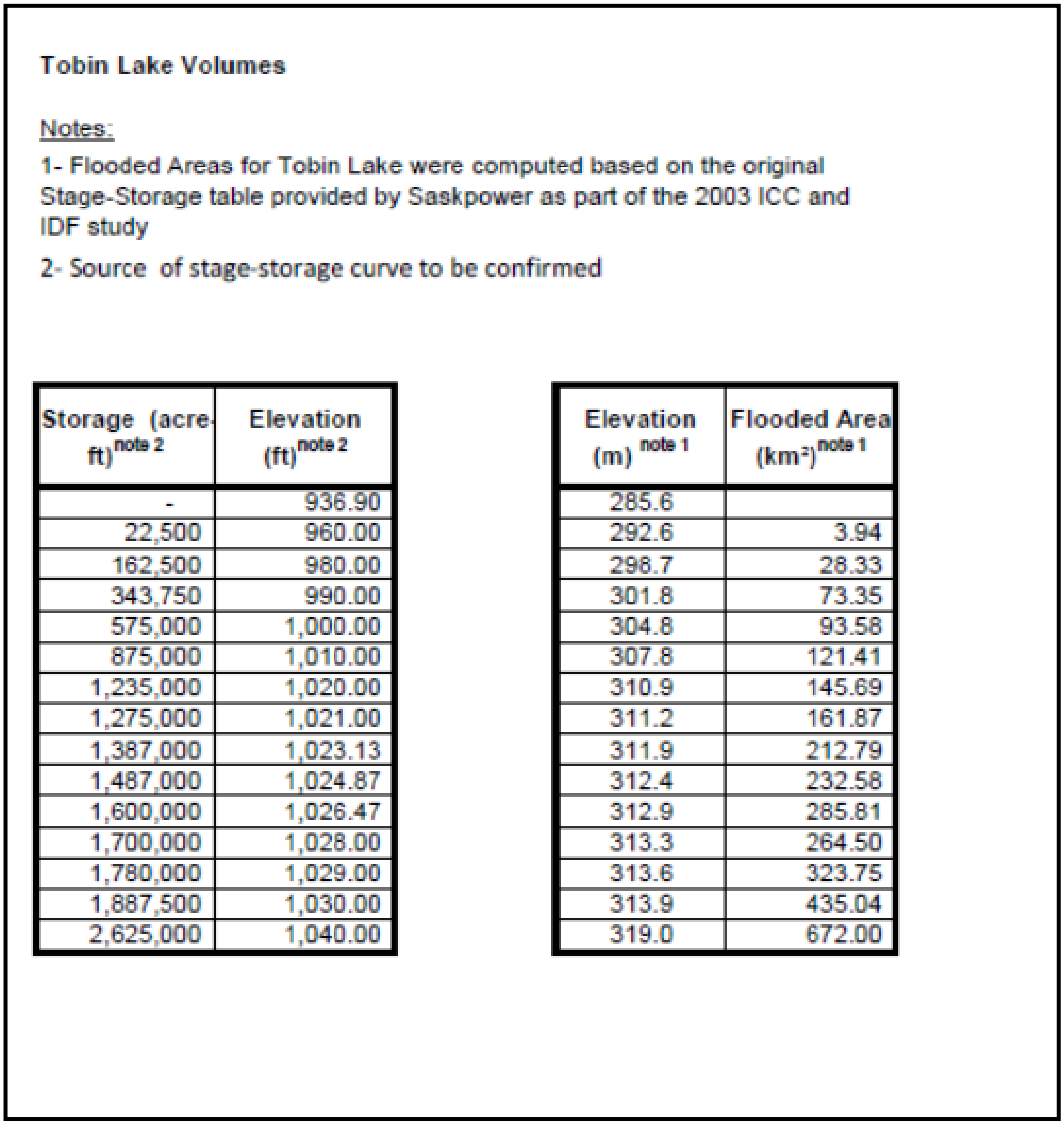
Saskatchewan
Watershed
Authority

AREA AND CAPACITY CURVES
FOR
LAKE DIEFENBAKER

Submitted RKR
Drawn KGBA
Date April 26, 2012

PLAN No. J5-1 (33)
Sheet of
ACAD. J5-1-33_2012
FIGURE

**Figure A.2 Tobin Lake Elevation-Area-Capacity Curves**



**Tobin Lake Volumes**

Notes:

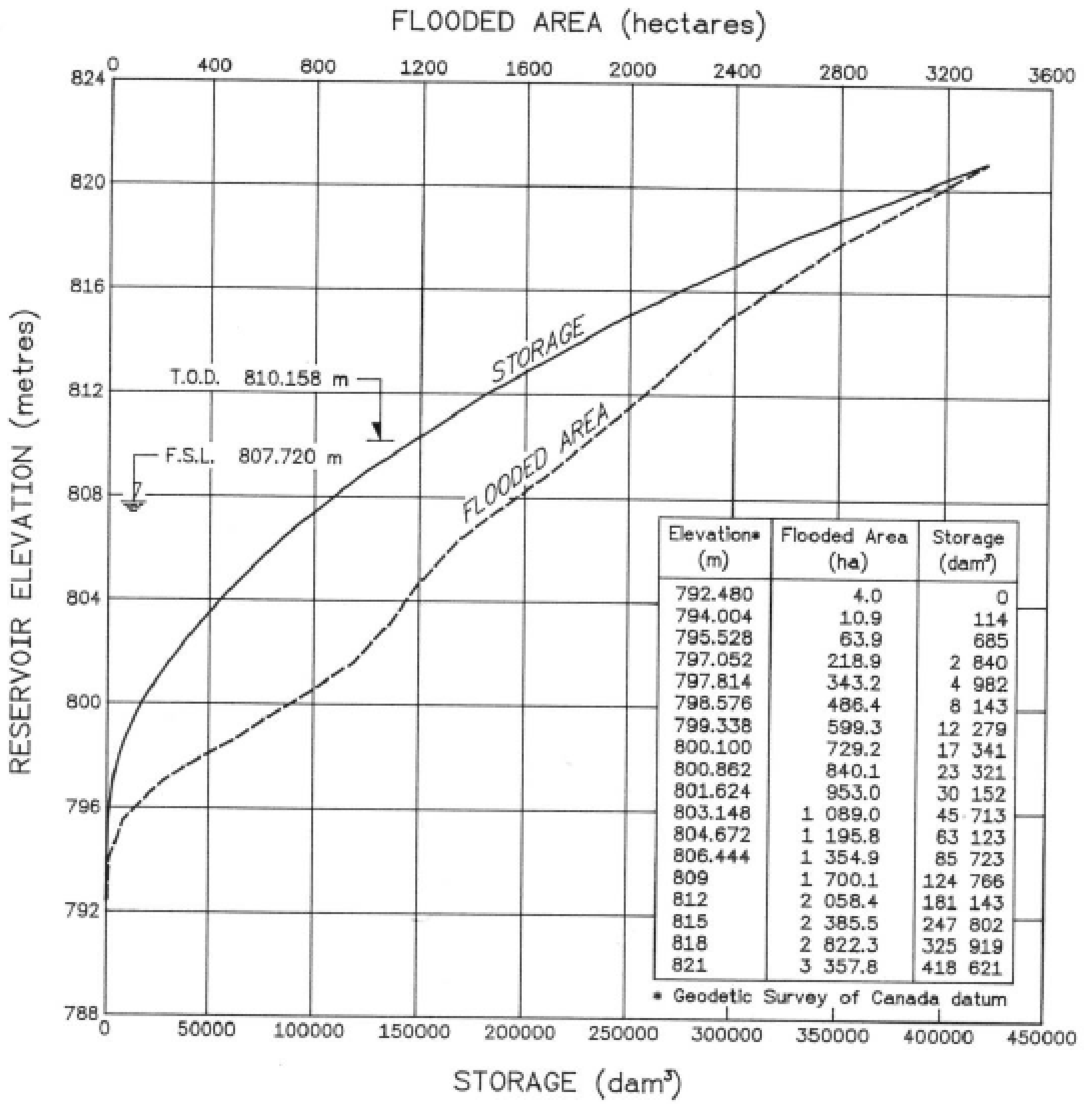
1- Flooded Areas for Tobin Lake were computed based on the original Stage-Storage table provided by Saskpower as part of the 2003 ICC and IDF study

2- Source of stage-storage curve to be confirmed

| Storage (acre-ft)$^{\text{note 2}}$ | Elevation (ft)$^{\text{note 2}}$ |
|---|---|
| - | 936.90 |
| 22,500 | 960.00 |
| 162,500 | 980.00 |
| 343,750 | 990.00 |
| 575,000 | 1,000.00 |
| 875,000 | 1,010.00 |
| 1,235,000 | 1,020.00 |
| 1,275,000 | 1,021.00 |
| 1,387,000 | 1,023.13 |
| 1,487,000 | 1,024.87 |
| 1,600,000 | 1,026.47 |
| 1,700,000 | 1,028.00 |
| 1,780,000 | 1,029.00 |
| 1,887,500 | 1,030.00 |
| 2,625,000 | 1,040.00 |

| Elevation (m) $^{\text{note 1}}$ | Flooded Area (km$^2$)$^{\text{note 1}}$ |
|---|---|
| 285.6 | |
| 292.6 | 3.94 |
| 298.7 | 28.33 |
| 301.8 | 73.35 |
| 304.8 | 93.58 |
| 307.8 | 121.41 |
| 310.9 | 145.69 |
| 311.2 | 161.87 |
| 311.9 | 212.79 |
| 312.4 | 232.58 |
| 312.9 | 285.81 |
| 313.3 | 264.50 |
| 313.6 | 323.75 |
| 313.9 | 435.04 |
| 319.0 | 672.00 |

# Figure A.3 Lake Reid Elevation-Area-Capacity Curves



| Elevation* (m) | Flooded Area (ha) | Storage (dam³) |
|---|---|---|
| 792.480 | 4.0 | 0 |
| 794.004 | 10.9 | 114 |
| 795.528 | 63.9 | 685 |
| 797.052 | 218.9 | 2 840 |
| 797.814 | 343.2 | 4 982 |
| 798.576 | 486.4 | 8 143 |
| 799.338 | 599.3 | 12 279 |
| 800.100 | 729.2 | 17 341 |
| 800.862 | 840.1 | 23 321 |
| 801.624 | 953.0 | 30 152 |
| 803.148 | 1 089.0 | 45 713 |
| 804.672 | 1 195.8 | 63 123 |
| 806.444 | 1 354.9 | 85 723 |
| 809 | 1 700.1 | 124 766 |
| 812 | 2 058.4 | 181 143 |
| 815 | 2 385.5 | 247 802 |
| 818 | 2 822.3 | 325 919 |
| 821 | 3 357.8 | 418 621 |

* Geodetic Survey of Canada datum

Note: The tabulated values on this plan up to elevation 804.672 m are direct metric conversions of the corresponding values on Plan No. 44690, with the calculated elevations rounded to the nearest 0.001 m, flooded areas to the nearest 0.1 ha and storages to the nearest dam³. The tabulated values above elevation 804.672 m were determined from Plan Nos. 114693 and 114695. The flooded area and storage curves are each drawn as a series of straight line segments between the plotted coordinates tabulated on this plan. Intermediate values of storage or flooded area should be determined by linear interpolation between the appropriate tabulated values.

| | | | |
|---|---|---|---|
| Designed<br>BJB | Submitted | Agriculture Canada<br>Prairie Farm Rehabilitation Administration<br>Administration du Rétablissement agricole des Prairies<br>Policy and Analysis Service | DUNCAIRN DAM RESERVOIR (REID LAKE) |
| Drawn<br>M.J.H. | Date May 9, 1990 | | STORAGE AND FLOODED AREA CURVES (METRIC UNITS) |
| Checked<br>R.J.W. | Approved Fred R.J. Martin<br>Manager, Hydrology Division<br>Date May 9/90 | | Scale<br>Date 02 MAY 90<br>PFRA No. 44891 |

Prairie Provinces Water Board
2365 Albert Street, Room 300
Regina, Saskatchewan
S4P 4K1
www.ppwb.ca