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PRAIRIE PROVINCES WATER BOARD

Report #173

Basin Review
Calculation of Apportionable Flow for the Cold River at the Outlet of Cold Lake

Prepared by R. Halliday & Associates

Recommended by the PPWB Committee on Hydrology

Approved by the Prairie Provinces Water Board

December 2015

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Calculation of Apportionable Flow

for the

Cold River at the Outlet of Cold Lake

R. Halliday & Associates
Saskatoon, SK

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EXECUTIVE SUMMARY

Cold Lake is one of the bodies of water that is apportioned between Alberta and Saskatchewan under the terms of the *Master Agreement on Apportionment*, administered by the Prairie Provinces Water Board (PPWB). The basin is the second to be reviewed by the PPWB's Committee on Hydrology for the purpose of evaluating current apportionable flow calculation procedures and to recommend improvements as appropriate.

Determining apportionable flow in this basin is unusual as this is the only case for which the PPWB must apportion a transboundary lake. Because of the interprovincial nature of the lake the selected apportionment point is the Cold River at the outlet of Cold Lake. Based on PPWB procedures, and assuming a uniform water yield throughout the basin, Alberta is required to deliver 68.4 percent of the apportionable flow at the outlet of Cold Lake to Saskatchewan.

This review indicates that under typical flow conditions, and at the present level of development, Saskatchewan receives almost all of the natural flow of the Cold River at the Cold Lake outlet. The challenge for the administration of apportionment arises when the water level of Cold Lake nears the elevation of the natural outlet of the lake or, indeed, drops below the natural outlet. Consideration of low water level conditions led to a review of the consumptive use associated with each water licence in the basin.

At present the consumptive use from only two water users is included in the calculation of apportionable flow for this basin. While municipal use has often been excluded from apportionable flow calculations in the past, the use by the City of Cold Lake is included because the return flow from that city is to the Beaver River, not Cold Lake. The industrial use by Imperial Oil for *in situ* bitumen development is also included. The review of the water licences led to the conclusion that the consumptive use by CNRL in its bitumen operation should also be included in the calculation. On the other hand the very large withdrawal from Cold Lake by the Cold Lake Fish Hatchery is essentially non-consumptive and does not need to be considered in the apportionable flow calculation. It should be noted as well that the licences for Imperial Oil, CNRL and the fish hatchery all contain provisions that require the licensee to cease pumping when Cold Lake levels are low. The addition of water use by CNRL can easily be incorporated into the apportionable flow calculation procedure.

As part of the review of current water allocations, future water use was also considered. There are no proposed or anticipated water uses in Alberta that would lead to water consumption in excess of existing allocations. At present there is no water consumption in the Saskatchewan portion of the basin and it is anticipated that this situation will continue for the foreseeable future.

The apportionable flow computation is currently performed by a Fortran 77 program, COLD3.FOR. The program is based on the principle of conservation of mass and involves lake back-routing to compute inflow and then forward routing to compute natural outflow. The continuity equation is used to compute the net inflow into the lake, *i.e.* net inflow is computed as the change in storage plus recorded outflow plus consumptive use. The

resulting net inflow is then verified by routing through the lake on a daily basis in order to match the recorded lake levels and outflows. The calculation also uses a relation between Cold Lake elevations and outflow to calculate change in storage. This rating curve is known as ELOUT.

The input data to COLD3.FOR consist only of the recorded flow of the Cold River at the outlet of Cold Lake, the recorded elevation of Cold Lake itself, and water use reports pertaining to licences held by Imperial Oil and by the City of Cold Lake. Change in storage is determined using the water level gauge for the lake itself. Calculation of apportionable flow therefore requires solving a circular relationship between storage and outflow using a daily time step. Two hundred fifty iterations are performed by the program to achieve a steady state solution of the finite difference algorithm. There are no reservoirs in the basin therefore there is no need to consider evaporative losses.

This review confirmed that COLD3.FOR performs the computations as described. One requirement of this basin review was to develop an Excel spreadsheet to perform the apportionable flow calculations. Excel proved unable to handle the cascading iterations required for the calculation of apportionable flow. Varying the number of iterations or the precision did not have much effect on the result. In order to resolve this, the Excel spreadsheet was loaded into the LibreOffice spreadsheet program. LibreOffice is able to read most Excel-format spreadsheet files with no modifications. The LibreOffice spreadsheet performed the required calculations without difficulty. One can therefore conclude that there is an inherent problem in the Excel program. A spreadsheet program capable of performing the current apportionable flow calculation as well as a calculation including the CNRL water consumption has been delivered to the PPWB secretariat.

In addition to considering the apportionable flow calculation, this review considered a number of topics important to the administration of apportionment in the Cold Lake basin. One such matter was the uniform yield assumption. This required a recalculation of the gross and effective drainage areas of the basin and similar calculations for sub-basins using current topographic information. Land classification throughout the basin was also considered. In general the uniform yield assumption appears reasonable. In any case, there is insufficient hydrologic data for the basin to warrant modifying the assumption.

The review examined hydrogeological connections in and near the basin. The basin definition is, of course, based on surficial topography. Identifying basin boundaries in the context of groundwater resources is no more than an administrative convenience. A dominant feature of the basin's geology is the Helina/Hatfield paleovalley, which intersects Cold Lake itself. Scientists hold the view that the lake gains about as much water from Alberta as it loses to Saskatchewan. As well, the quantity of subterranean water movement is small compared to surface water flows.

When Cold Lake levels are lower than 534.55 m some water users are required to cease pumping from Cold Lake. The two industrial licensees, however, have standby licences that allow them to pump groundwater when surface water is unavailable. Based on currently available hydrogeological information it appears that there is no hydraulic connection between the sites of the standby licences and Cold Lake. It is possible that such pumping could affect the level of Marie Lake.

The data requirements for the calculation of apportionable flow for the Cold Lake basin are modest. The continued operation of hydrometric stations and reporting to Alberta's Water Use Reporting system is required. There are other monitoring needs that support the overall administration of apportionment. In particular, the continued operation of the Alberta and Saskatchewan groundwater observation wells in and near the basin is important.

As a result of this review several recommendations can be made. These are:

1. The PPWB should adopt the spreadsheet calculation of apportionable flow developed during this project. In addition to the water allocations currently considered, the calculations should incorporate the monthly water consumption reports from CNRL and could include average water consumption by other users.

2. To accommodate drought conditions the PPWB should consider quarterly reports on apportionable flow, for example, when Cold Lake drops below 534.62 m, the level at which industrial use from the lake may be curtailed, and monthly reports when the level drops below 534.55 m, the level at which industrial uses switch to groundwater pumping.

3. Based on a review of hydrological information, the drainage area ratios developed in PPWB (1995) should continue to be used in the administration of apportionment.

4. The shape files and related GIS information delivered under this project should be made available to PPWB member agencies and other interested parties.

5. The PPWB should consider a drought contingency plan to address the effects of groundwater pumping during times of drought.

6. Existing monitoring in and near the basin should be maintained.

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1. INTRODUCTION

1.1 Study Background

Cold Lake is one of the bodies of water that is apportioned between Alberta and Saskatchewan under the terms of the *Master Agreement on Apportionment* (MAA) (PPWB 2009). Because of the interprovincial nature of the lake the apportionment point is the Cold River at the outlet of Cold Lake. The MAA is an agreement among the three Prairie Provinces and the federal government setting out the rights and duties of the provinces concerning the equitable sharing of eastward flowing transboundary waters. The Prairie Provinces Water Board (PPWB) administers the agreement on behalf of the parties (Kellow 1989).

The MAA calls for the apportionment of the natural flow of streams and defines natural flow as the quantity of water that would occur in any watercourse had the flow not been affected by human interference or intervention, excluding any water that is part of the natural flow, but is not available for use because of the provisions of any international treaty. From the early days of the agreement, the difficulties of calculating a true natural flow were evident. The Board agreed in 1976 that, *"effects on runoff of changing land-use patterns are not considered in the computation of natural flow (changes in land use include land clearing for agriculture, drainage, forestry, industrial and urban development and other land uses). Changes in natural flow due to groundwater inflow or recharge are not considered in the computations."* In the present day, the natural flow of streams can also be affected by climate change and those effects also are not included in the PPWB's natural flow calculations. These and other simplifications agreed upon by the Board may be made as a result of data availability issues, data acquisition cost versus benefit to the calculation, or consideration of the desired level of accuracy for a given basin. For these reasons the PPWB identifies the result of natural flow computations for PPWB apportionment purposes as "apportionable flow" rather than a true natural flow.

The groundwork for the computation of apportionable flow for the Cold Lake basin lies in studies of apportionment of westward flowing tributaries of eastward flowing streams (PPWB 1986) and of interprovincial lakes (PPWB 1995). The latter study provided details specific to the Cold Lake basin. Current apportionable flow computation procedures are documented in a PPWB (2011) procedures manual.

This review is being conducted as part of the PPWB basin review process that was initiated in 2011 in order to ensure regular evaluation and improvement to the apportionable flow calculation procedures for all basins subject to apportionment. The target is that each basin will be reviewed approximately every ten years. The first such review was for the North Saskatchewan River. The PPWB retained R. Halliday & Associates Ltd. to assist them in the conduct of the review for the Cold Lake basin.

1.2 Basin Overview

The 6530.5 km^2 Cold Lake basin shown in Figure 1.1 straddles the Alberta-Saskatchewan boundary, as does Cold Lake itself. The 355.0-km^2 lake is very deep – about 100 m, hence its name, Cold Lake. According to PPWB (1995) the elevation of the lake outlet is 534.377 m.

The Cold River exits the lake eastward, joining the Beaver River in Saskatchewan, and ultimately the Churchill River. Much of the basin, including 437.3 km^2 Primrose Lake, lies in Saskatchewan. The headwaters consist of the Saskatchewan tributaries of Primrose Lake, including the Calder River and Brett Creek. The Martineau River flows from Primrose Lake into Cold Lake within Alberta. Other Saskatchewan tributaries, such as the Kesatasew and Muskeg rivers, join the Martineau River in Saskatchewan. The only significant tributary of Cold Lake entirely within Alberta is the Medley River, which originates in the Moostoos upland of the Cold Lake Air Weapons Range and flows south to Cold Lake.

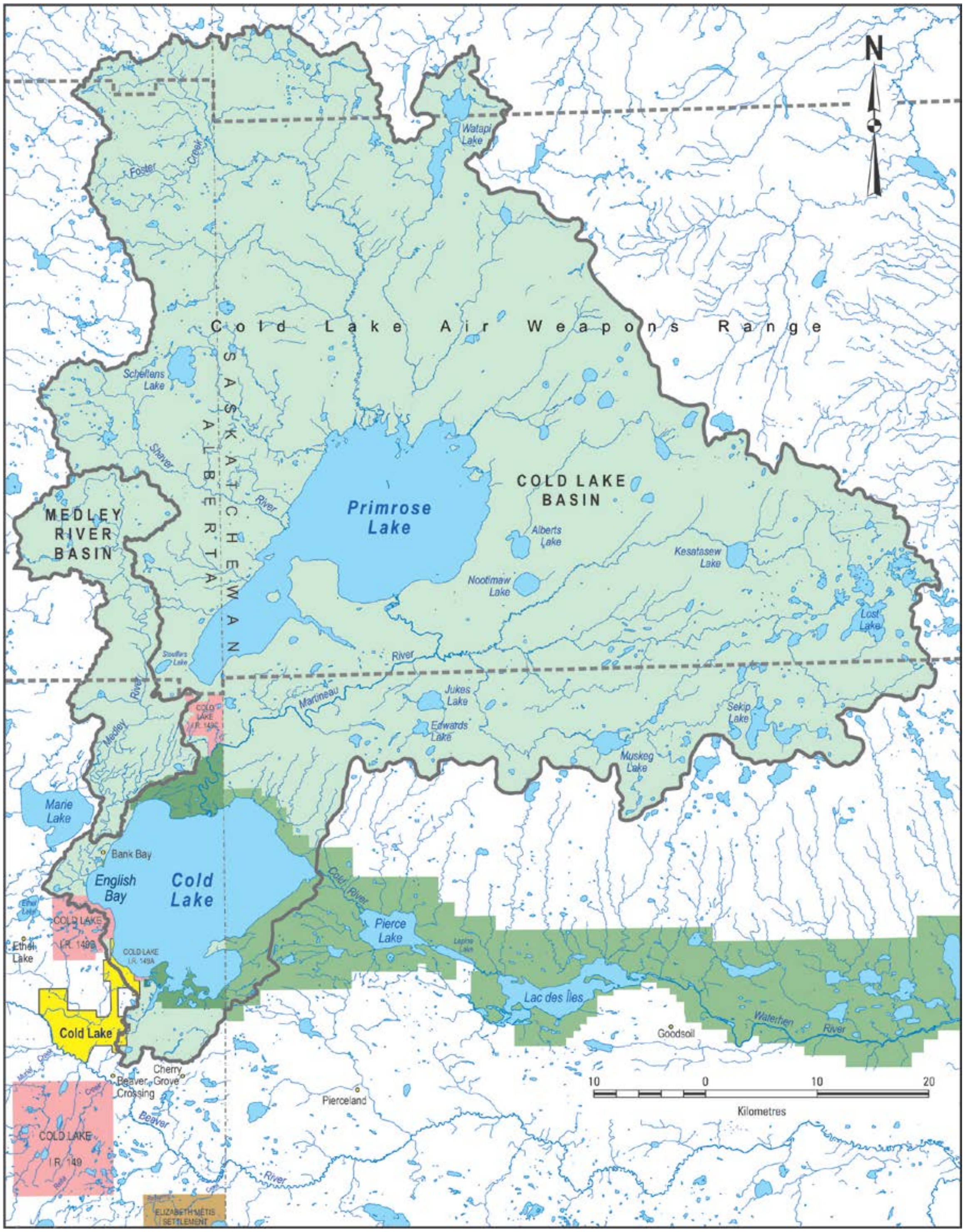

Figure 1.1 Cold Lake Basin.

South of English Bay on the west side of the lake at the Cold Lake First Nations Reserve, the basin boundary closely follows the shoreline of the lake. The basin on the lake's south side is a rolling morainal plain with undulating to gently rolling topography. There are some small ridges and knobs, as well as minor wetlands. The northern portion of the basin, extending through the Cold Lake Air Weapons Range, is a hummocky morainal plain with moderately rolling topography. The basin is underlain by the marine shales and ironstone concretions of the Lea Park Formation. The drift materials overlaying the bedrock, comprised of fluvioglacial deposits, range in depth from 50 to 100 m over much of the basin. These depths increase to 250 to 300 m in the northern part of the Moostoos Upland at the northern boundary of the Cold Lake Air Weapons Range.

1.3 Report Outline

This report begins with a review of hydrological and land use considerations (Section 2). Apportionable flow, including the apportionable flow calculation procedures, is then discussed (Section 3). Various aspects of the computations and particular features of the basin are then reviewed separately: consumptive use (Section 4), and hydrogeological connections (Section 5) and additional apportionment considerations (Section 6). The total impact of the proposed changes on apportionable flows is then evaluated as a whole (Section 7). Based on the existing and proposed calculation procedures, the data requirements are discussed (Section 8). Finally, the findings of the report are summarized along with recommendations related to apportionment, surface water hydrology, groundwater, and monitoring.

2. HYDROLOGY AND LAND USE

2.1 Hydrologic Considerations

In 1975, in response to a request from the PPWB, the Prairie Farm Rehabilitation Administration (PRFA) undertook to provide the gross and effective drainage areas for all active and discontinued gauging stations in the Prairie Provinces. The work was carried out over a period of years and was based on 1:50,000 National Topographic Series (NTS) maps having 25-foot contour intervals, aerial photographs and site visits. The findings are available as Mylar overlays to 1:250,000 NTS maps and were updated regularly for many years (Mowchenko and Meid 1983). The approximate drainage divides used to organize Water Survey of Canada data (Johnstone 1922) have also been digitized. In the case of the Cold Lake basin the boundaries of 06AF have previously been adjusted to coincide with the gross drainage area shown in Figure 1.1.

This baseline hydrologic information is used by the PPWB and its member agencies. The information is also shared with any other interested party. This service provided consistent, reliable information and avoided considerable duplication of effort. With the demise of PFRA, this information is not being routinely updated even though the need continues.

As part of the current project the PFRA databases were examined in light of new information and certain hydrologic features were calculated. The review was carried out using QGIS®, an open source Geographic Information System (GIS), a product of the Open Source Geospatial Foundation (OSGeo). It runs on Linux, Unix, Mac OSX, Windows and Android and supports numerous vector, raster, and database formats and functionalities. The program is available for download at http://www.qgis.org/en/site/.

Two baseline hydrologic characteristics of the basin were examined and compared to earlier work performed by the PFRA. First, the gross and effective drainage areas of the Cold Lake basin and its sub-basins were considered. The current Canadian Digital Elevation Data (CDED) model was used with a generation of one-metre contours over the entire watershed. As well, high resolution orthophotos of the region were also used. Recalculating the gross drainage area led to a change from 6520 km^2 to 6530.5 km^2. In general the changes in gross drainage areas are subtle. There are no changes that would have a bearing on the administration of apportionment, nor on provincial water licensing. There is as well little change in the non-contributing drainage.

In addition to considering the overall basin boundary, previously determined drainage areas for Primrose Lake and for the Martineau River at the Water Survey of Canada (WSC) gauging station were re-examined and the drainage area of the Medley River at the mouth was determined. Drainage area results are shown in Table 2.1 and the sub-basins are illustrated in Figure 2.1.

Table 2.1 Drainage Areas in Cold Lake Basin

Location	WSC Station No.	Drainage Type	Area (km^2)
Cold River at Outlet of Cold Lake	06AF001	Gross	6,530.5
Cold River at Outlet of Cold Lake	06AF001	Effective	6,272.5
Cold Lake at Cold Lake	06AF002	Gross	6,530.5
Cold Lake at Cold Lake	06AF002	Effective	6,272.5
Cold Lake Basin – Alberta	n/a	Gross	1,716.7
Cold Lake Basin – Alberta	n/a	Effective	1,653.8
Cold Lake Basin – Saskatchewan	n/a	Gross	4,813.8
Cold Lake Basin – Saskatchewan	n/a	Effective	4,618.7
Primrose Lake at RCAF Testing Station	06AF003	Gross	3,416.4
Primrose Lake at RCAF Testing Station	06AF003	Effective	3,393.0
Martineau River above Cold Lake	06AF008	Gross	5,391.3
Martineau River above Cold Lake	06AF008	Effective	5,179.0
Martineau River at Cold Lake	n/a	Gross	5,451.0
Martineau River at Cold Lake	n/a	Effective	5,238.7
Medley River at Cold Lake	n/a	Gross/Effective	411.5

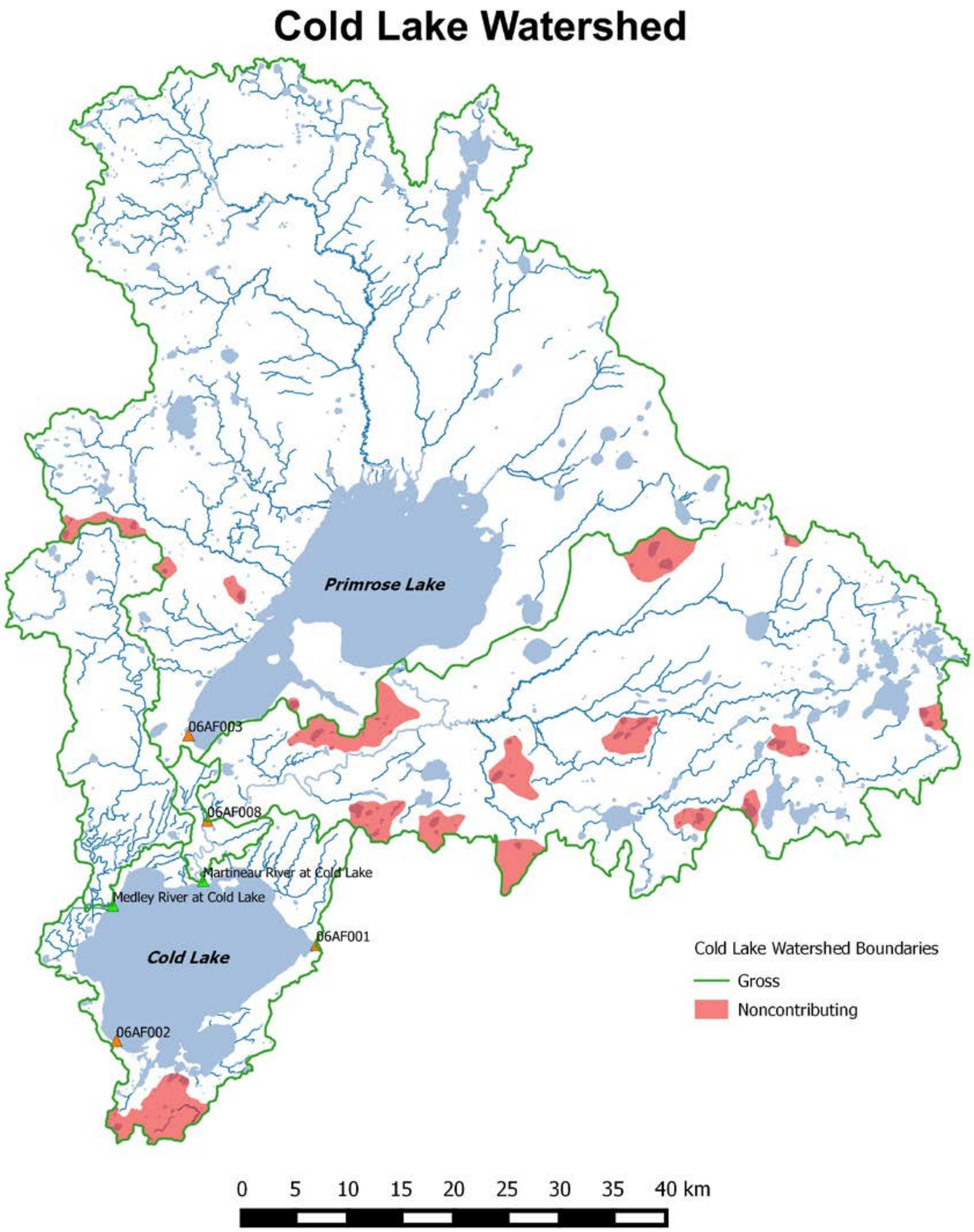

Figure 2.1 Sub-basins of the Cold Lake Basin.

Secondly, the areas of the two major lakes were examined. Depending on the source, the published surface area for both lakes varies. For this project two sources of information were used, the National Hydro Network (NHN), a standard officially adopted by the Canadian Council on Geomatics (CCOG) in August 2004 and the Shuttle Radar

Topographic Mission (SRTM). Results obtained, as shown in Table 2.2, are very similar. In this report the NHN results are used as this dataset is deemed to be a Canadian standard. Also the SRTM data were obtained in the winter and in north latitudes could be subject to snow effects.

Table 2.2. Surface Areas of Major Lakes.

Lake	Province	NHN Area km^2	SRTM Area km^2
Cold	Alberta/Saskatchewan	355.0	353.5
Cold	Alberta	252.5	258.7
Cold	Saskatchewan	102.5	94.9
Primrose	Alberta/Saskatchewan	437.3	437.0
Primrose	Alberta	19.5	21.4
Primrose	Saskatchewan	417.8	415.5

2.2 Land Use

Within Alberta the southern part of the sub-watershed lies in the dry mixedwood natural region and the northern part in the central mixedwood natural region. Within Saskatchewan, the entire basin falls within the mid-boreal upland. The thin, sandy grey luvisolic soils of the well-drained uplands sustain aspen forests with balsam poplar occurring in moister sites in low-lying areas and along streams. White spruce stands occur infrequently and jackpine grows in well-drained sandy locations. Both black spruce and tamarack are common in poorly drained areas of the basin. During the normal process of vegetation succession, white spruce and eventually balsam fir can be expected to replace the deciduous forest. Land cover is fairly stable with some increase in cleared land south of Cold Lake in recent decades. Influences include bitumen development in the lower Medley River basin and urbanization in the vicinity of the City of Cold Lake.

Cold Lake Provincial Park occupies several parcels of land on the shores of the lake. Frenchman's Bay Provincial Recreation Area and English Bay Provincial Recreation Area lie on the south and west shores, respectively. Saskatchewan's Meadow Lake Provincial Park occupies the entire Cold Lake shoreline in that province.

2.2.1 Agriculture

Agricultural water use in the basin is very modest, consisting of one small licence and nine registrations in Alberta. Furthermore, most of the registrations lie in areas of non-contributing drainage. Changes in agricultural land use are unlikely to play a significant role in determining apportionable flow in the Cold Lake basin.

Some information pertaining to land use changes in the Alberta and part of the Saskatchewan portion of the basin is available in Komex (2004). Landsat images for the years 1976, 1984 and 2002 were interpreted using vegetation difference indexing to examine land use trends in the Beaver River basin, including the Cold Lake basin. (The Medley River sub-basin was assessed separately from the remainder of the Cold Lake basin and is discussed in section 2.2.3.) The analysis distinguished only between forested areas and cleared areas. Through this period the percent of cleared land increased from about three percent to about eight percent in the Cold Lake basin, exclusive of the Medley basin. This cleared land could be the result of both agricultural activity and urban development, especially in the area south of Cold Lake.

This apparent expansion in cleared area must be used with caution as it may not represent directly comparable landscapes. The portion of the basin that was unclassified due to cloud cover and other reasons is much larger than that identified as cleared. In fact, in 1984 almost half the basin was unclassified. As well, there was no ground-truthing associated with this work although aerial photographs were used to support the classification of the satellite images.

2.2.2 Urban Development

Urban development in the basin is modest, the only significant development being that in the portion of the City of Cold Lake that lies in the Cold Lake basin. As indicated in the previous section some of the identified cleared land identified in Komex could relate to urban expansion.

In general, runoff from an urban landscape exceeds that from agricultural or natural landscapes. There are five to ten storm sewer outfalls that do return water to Cold Lake. None of these is measured so no urban runoff figures are available (Simms 2015).

2.2.3 Industrial Development

The Medley River basin is the focus for much of the industrial activity in the Cold Lake basin. The land use information produced by the Komex study may offer some insights into development of roads, cut lines and other linear features associated with oil development. The classified cleared land ranged from two percent of the Medley basin in 1976 to one-half percent in 1984 to three percent in 2002. There was comparatively little unclassified land associated with the Medley River basin so the figures given should be more defensible than those for the remainder of the Cold Lake basin. The observations concerning lack of ground-truthing would still apply.

Based on this information it is unlikely that land use changes associated with industrial development would have a bearing on the calculation of apportionable flow.

2.3 Summary

Almost the entire Cold Lake basin is covered by natural forests and there is very little forest harvesting in the basin. While there has been some apparent increase in cleared land since 1976 due to agriculture, urban expansion and industry, this increase is relatively small. There does not appear to be reason to attempt to include land use change in the calculation of apportionable flow at this time.

3. APPORTIONABLE FLOW COMPUTATION PROCEDURES

3.1 Apportionment Considerations

As indicated in section 1.1, the calculation of apportionable flow under the terms of the MAA represents a simplification over the much more rigorous determination of a true natural flow. Schedule A identifies the terms of the apportionment agreement between Alberta and Saskatchewan. Under the agreement Saskatchewan is entitled to receive at least 50 percent of the water that would have naturally flowed into the province from Alberta. The Cold Lake basin is rather more complicated since the basin features westward flowing tributaries of eastward flowing streams and two large interprovincial lakes. In considering this problem, the PPWB agreed to apportion the flow between Alberta and Saskatchewan based on the percentage of the gross drainage area within each province – 26.4 percent in Alberta and 73.6 percent in Saskatchewan. The procedure is known as the Rational Method PPWB (1995). The general principle is that the province in which the water originates is entitled to 50 percent of the flow with the rest of the flow being divided equally between the downstream provinces. Application of the Rational Method to these drainage areas leads to an apportionment of 31.6 percent of the Cold River at the outlet of Cold Lake flow to Alberta, 43.4 percent to Saskatchewan and 25 percent to Manitoba. This results in Alberta being required to deliver 68.4 percent of the apportionable flow at the outlet of Cold Lake to Saskatchewan. Table 3.1 illustrates the calculation.

Table 3.1. Cold Lake Apportionment (from PPWB 1995).

Province	Gross Drainage Area km^2	Percent of Gross Area	Percent of Water Yield*	Percent of Share Based on Rational Method**		
				Alberta	Sask.	Manitoba
Alberta	1722	26.4	26.4	13.2	6.6	6.6
Sask.	4798	73.6	73.6	18.4	36.8	18.4
Total	6520	100.0	100.0	31.6	43.4	25.0

* Assuming uniform yield throughout the Cold Lake watershed

** 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

Schedule A of the MAA is silent on the audit period associated with the apportionment computation while Schedule B relating to Saskatchewan-Manitoba specifies that the audit period is the calendar year. Instead Schedule A states that the *"... actual flow shall be adjusted from time to time on an equitable basis during each calendar year ..."* . The apportionable flow computation is based on a daily time step and reported as monthly volumes on a semi-annual basis. The calendar year is used to evaluate apportionment performance. The apportionable flow calculation procedures are agreed upon by the member agencies of the PPWB and must be adhered to, unless modifications are formally approved.

Apportionable flow calculations for the Cold Lake basin have been computed since 1993. The apportionment point is the WSC hydrometric station on the Cold River at Outlet of Cold Lake (06AF001). The water levels of Cold Lake at Cold Lake (06AF002) for the period of record are shown in Figure 3.1. It can be seen that the water level has dropped below the natural outlet elevation within the period of instrumental record.

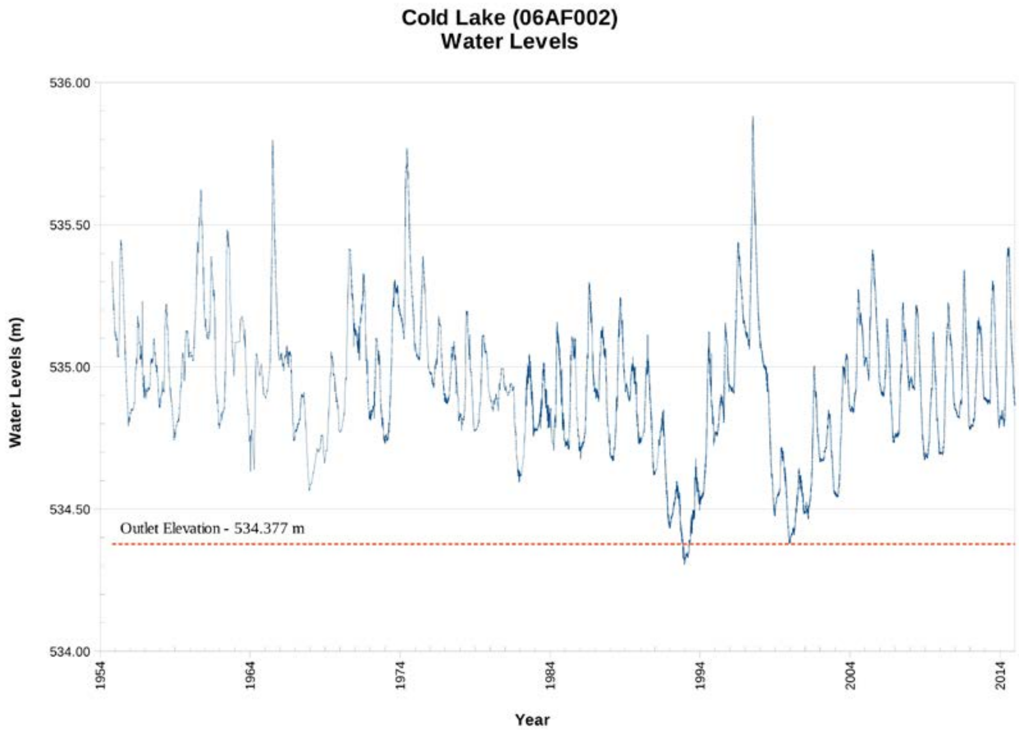

Figure 3.1. Cold Lake Water Levels for the Period of Record.

Table 3.2 shows the historic recorded annual flows for the Cold River at the outlet of Cold Lake along with the calculated apportionable flow as determined by the PPWB. The years 1992 and 1993 are included from PPWB (1995) as they represent the lowest apportionable flows in the period 1968 to 2014. (For the purpose of this report calculated values have been rounded to three significant figures.) It can be seen that at no time has Alberta not met its obligations under the MAA. The table does indicate, not surprisingly, that when Cold Lake levels are low, as in 1993 and 2000, Alberta uses more of its allotted share of the flow. Values in the percentage of apportionable flow delivered have been recalculated in cases where the published apportionable flow record did not seem to be correctly calculated.

Table 3.2. Historical Annual Recorded Flows and Apportionable Flows for Cold River at Outlet of Cold Lake (06AF001).

Year	Recorded Annual Flow (dam^3)	Apportionable Flow (dam^3)	Apportionable Flow Delivered (percent)
1992		19,600[1]	
1993	12,700	14,800[1]	86
1994	194,000	195,000[2]	99
1995	340,000	345,000	98
1996	800,000	808,000	99
1997	1,410,000	1,420,00	99
1998	421,000	426,000	99
1999	94,300	97,600	97
2000	51,000	56,700	90
2001	204,000	209,000	97
2002	187,000	197,000	96
2003	300,000	304,000[2]	99
2004	652,000	660,000	99
2005	897,000	902,000	99
2006	528,000	537,000	98
2007	589,000	598,000	98
2008	585,000	591,000	99
2009	402,000	408,000	99
2010	567,000	574,000	99
2011	595,000	600,000	99
2012	599,000[2]	603,000[2]	99
2013	674,000	679,000	99
2014	751,000	758,000	99

Notes:
1. Data from PPWB (1995)
2. Corrected values.

3.2 Current Calculation Procedures

The procedures used by the PPWB to calculate apportionable flow for the basin are documented in an interprovincial lakes apportionment study and an internal procedures manual (PPWB 1995, PPWB 2011). The procedure is based on the project depletion method, which is described in PPWB (1976) and other reports of the PPWB. In general this calculation involves adjusting the recorded flow at the point of apportionment to take into account diversions into and out of the basin, water uses, net evaporation from constructed storage works, and routing factors. The project depletion method is highly dependent on hydrometric and other direct measurements and is less dependent on meteorological, topographic and land use information than other methods.

For Cold Lake the apportionable flow computation is performed by a Fortran 77 program, COLD3.FOR. The program is based on the principle of conservation of mass and involves lake back-routing to compute inflow and then forward routing to compute natural outflow.

The continuity equation is used to compute the net inflow into the lake, *i.e.* net inflow is computed as the change in storage plus recorded outflow plus consumptive use. The resulting net inflow is then verified by routing through the lake on a daily basis in order to match the recorded lake levels and outflows. The calculation also uses a relation between Cold Lake elevations and storage to calculate change in storage. This rating curve is known as ELOUT.

The input data consist only of the recorded flow of the Cold River at the outlet of Cold Lake, the recorded elevation of Cold Lake itself, and water use reports pertaining to licences held by Imperial Oil and by the City of Cold Lake. Water use reports pertaining to other water licences in the basin are not at present included in the calculation.

Cold Lake dropped below its natural outlet elevation for 157 consecutive days from November 4, 1992 to April 9, 1993. The lowest level attained was 534.306 on December 19, 1992. This was about 70 mm lower than the natural outlet elevation.

Change in storage is determined using the water level gauge for the lake itself. Calculation of apportionable flow therefore requires solving a circular relationship between storage and outflow using a daily time step. Two-hundred fifty iterations are performed to achieve a steady state solution of the finite difference algorithm.

3.3 Apportionable Flow Calculation Using COLD3.FOR

When calculations of apportionable flow were initiated in 1993 they were performed in a Lotus 1-2-3 spreadsheet. This proved difficult to use and the spreadsheet was re-written in 1996 as a Fortran program known as COLDAPP. Bothe (1996) describes the program in some detail. The program calculates apportionable flow one day at a time for an entire year. The calculated apportionable flow from the last day of the previous year is used to initiate the process. The circular relationship between storage and outflow is described by the following two equations:

$$\mathbf{S_t = S_{t-1} + I_t - O_t - W_t}$$

and

$$\mathbf{O_t = f(S_t)}$$

where, **S** is storage in m^3 during day *t,*
I is the inflow in m^3 during day *t,*
O is the outflow in m^3 during day *t,*
W is the diversion out of Cold Lake in m^3**,**
$\mathbf{f(S_t)}$ is the storage-outflow relation

The daily storage is calculated using a stage-storage relation based on the water level gauge at the City of Cold Lake:

$$\mathbf{\log (S) = a\log(H) + b}$$

where, **S** is the storage in m^3,
H is the stage in m,

a is a constant equal to 63.25591,
b is a constant equal to -164.0844266

The flowchart in Figure 3.2 illustrates the steps in the operation of the Fortran program.

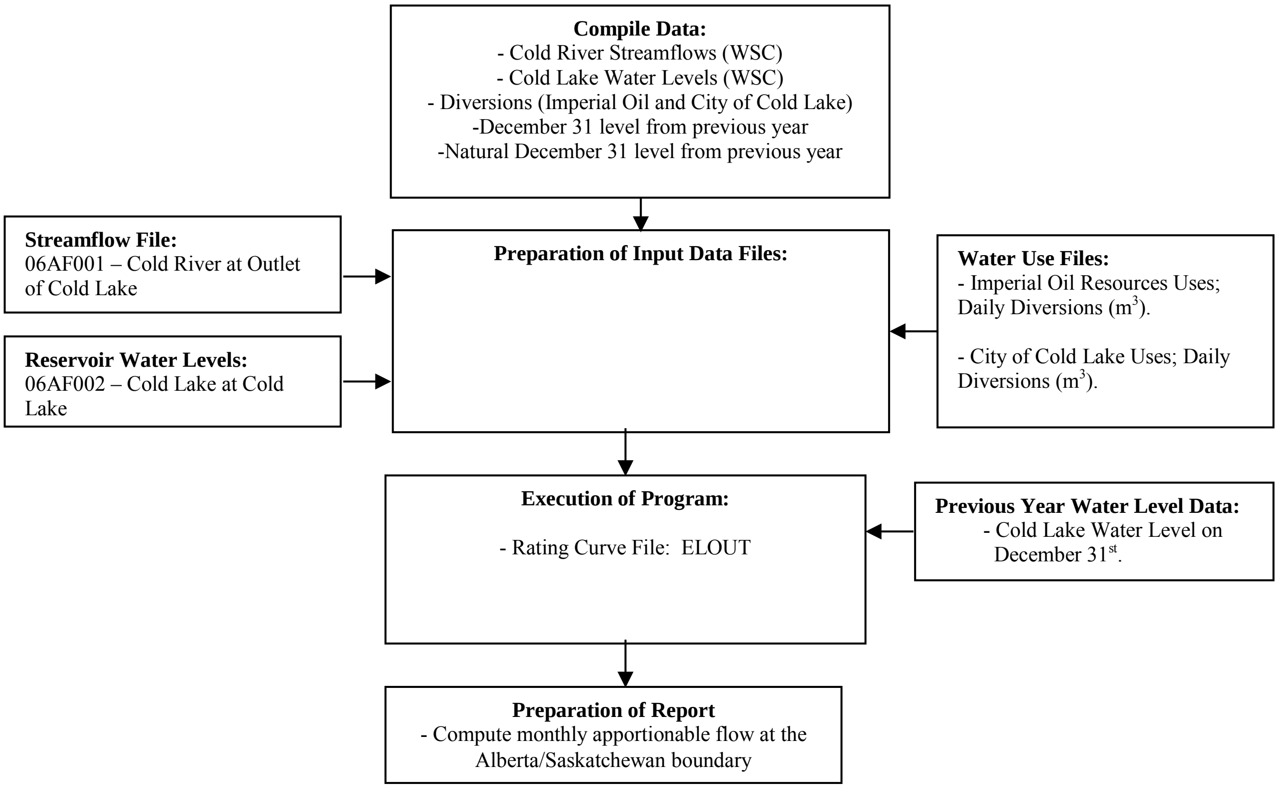

Figure 3.2. Apportionable Flow Computation at Cold Lake (PPWB 2011).

Continued use of COLDAPP over a number of years revealed two problems: it produced erratic swings in the flow of Cold River when outflow should have been steady and it produced an erroneously high simulated natural water level at the start of each calendar year. These problems were overcome by implementing a new smoothed version of the ELOUT rating curve and by inputting initial conditions for a year's run manually. The current program is known as COLD3.FOR (Kerkhoven 2011). The revised version of ELOUT, ELOUT2, uses elevation 534.366 m as zero flow, almost identical to the outlet elevation given in PPWB (1995).

The present COLD3.FOR program has a few features that could be improved on if it were to be used in the future. A very old dialect of Fortran is being used. The program resembles Fortran 77 with a few non-standard extensions supported by the PC compiler that is being used. Free, open source compilers are available that implement modern Fortran standards (e.g. GNU Fortran). The COLD3 program could be modified to work with these newer compilers with a few small changes.

Within the program there is not a good separation between input and output and the actual calculations. If the calculation functions were in a separate module, it would make them more easily reusable in other programs and with different sources of input data. Some of the calculations are mixing single-precision floating-point numbers (32 bits) with double-precision floating-point numbers (64 bits). This has the potential to introduce small rounding errors in the calculations. Finally, the storage calculation is performed a fixed number of times (250) regardless of whether the calculation has converged on an accurate result. It would be better to define the acceptable error and then iterate the calculation until the error is below the acceptable range.

With the transition to an Excel-based computation procedure and the implementation of RBAT, the need to improve COLD3.FOR is moot. Improvements to the program are likely not needed.

3.4 Verification of Fortran Program Apportionable Flow Calculation Procedures

COLD3.FOR performs the computations as described in Sections 3.2 and 3.3. As part of this basin review an Excel spreadsheet was developed to perform the apportionable flow calculations as described earlier in this section. The Excel spreadsheet approach proved unable to handle the cascading iterations required for the calculation of apportionable flow in both Windows and Mac OS X versions. Varying the number of iterations or the precision did not have much effect on the result. The Excel results start to diverge from the Fortran calculation at about day 40 and the calculation ultimately fails at around day 200.

In order to resolve the Excel problem, the Excel spreadsheet file was loaded into the LibreOffice spreadsheet program. LibreOffice is able to read most Excel-format spreadsheet files with no modifications. The LibreOffice spreadsheet performed the required calculations without difficulty. One can therefore conclude that there is an inherent problem in the Excel program. It is possible that the Excel problem could be resolved by inserting a Visual Basic macro that performs the calculation. This approach was rejected as it would add complexity to the calculation.

LibreOffice is a free open source office suite that is available on-line at www.libreoffice.org. The community driven software is a product of a not-for-profit organization, The Document Foundation (TDF). The software is available in Windows, Mac OS X and Linux versions.

The monthly results for 2013 using the Fortran program and the two spreadsheets are shown in Table 3.3. It can be seen that the total annual apportionable flow as calculated by LibreOffice replicates the Fortran calculation even at the fifth significant figure. Monthly values are identical at four significant figures. Interestingly, the LibreOffice results are identical to the Excel results for the first five months of the year then Excel diverges in June and ultimately fails in July.

Table 3.3. Apportionable Flow Using COLD3.FOR, Excel and LibreOffice.

	Fortran Output		Excel Output		LibreOffice Output	
Month	Recorded Flow dam^3	Apportion -able Flow dam^3	Recorded Flow dam^3	Apportion- able Flow dam^3	Recorded Flow dam^3	Apportion -able Flow dam^3
January	41126	41505	41126	41496	41126	41496
February	39131	39500	39131	39500	39131	39500
March	39511	39937	39511	39938	39511	39938
April	36150	36588	36150	36588	36150	36588
May	55365	55884	55365	55884	55365	55884
June	89398	89815	89398	89827	89398	89818
July	111793	112238	111793	n/a	111793	112240
August	92569	92991	92569	n/a	92569	92993
September	62605	63036	62605	n/a	62605	63037
October	43908	44313	43908	n/a	43908	44315
November	32988	33376	32988	n/a	32988	33377
December	29065	29468	29065	n/a	29065	29469
Totals	673609	678651	673609	n/a	673609	678655

3.5 Summary

The COLD3.FOR program performs the apportionable flow calculations as described in Sections 3.2 and 3.3. The program, if it were to be used in the future would benefit from a number of improvements.

An Excel spreadsheet was developed to perform the calculations performed by the Fortran program. The spreadsheet proved unable to handle the cascading iterations performed by COLD3.FOR. The same spreadsheet executed in LibreOffice was able to perform the calculations without difficulty. Monthly apportionable flow results are identical to those using the Fortran program at four significant figures and the annual total is identical at five significant figures.

4. CONSUMPTIVE USE

4.1 Water Use

Water use is a broad term that includes any use of water for any activity, economic or otherwise. Water use can include withdrawal or diversion of water from a source, or water used in place. Water uses may be considered consumptive or non-consumptive. Summing up the quantities of water allocated by water licences will overestimate water consumption in a river basin as many licensees do not consume their entire entitlement in a given year. The calculation of apportionable flow therefore requires the determination of water consumption.

The terminology related to consumptive use varies from one agency or practitioner to another. In this report, the term water allocation is used to identify the quantity of water set aside under provincial law for a particular user. The allocation may include a consumptive use component and a return flow that would be available to downstream users. Water withdrawal or water diversion is the quantity of surface or groundwater that a water user removes from the aquatic system. Water consumption is water diverted by a user that does not return to the aquatic system. Water consumption includes losses to seepage or evaporation. Return flow is the difference between water withdrawal and water consumption. These concepts are illustrated in Figure 4.1.

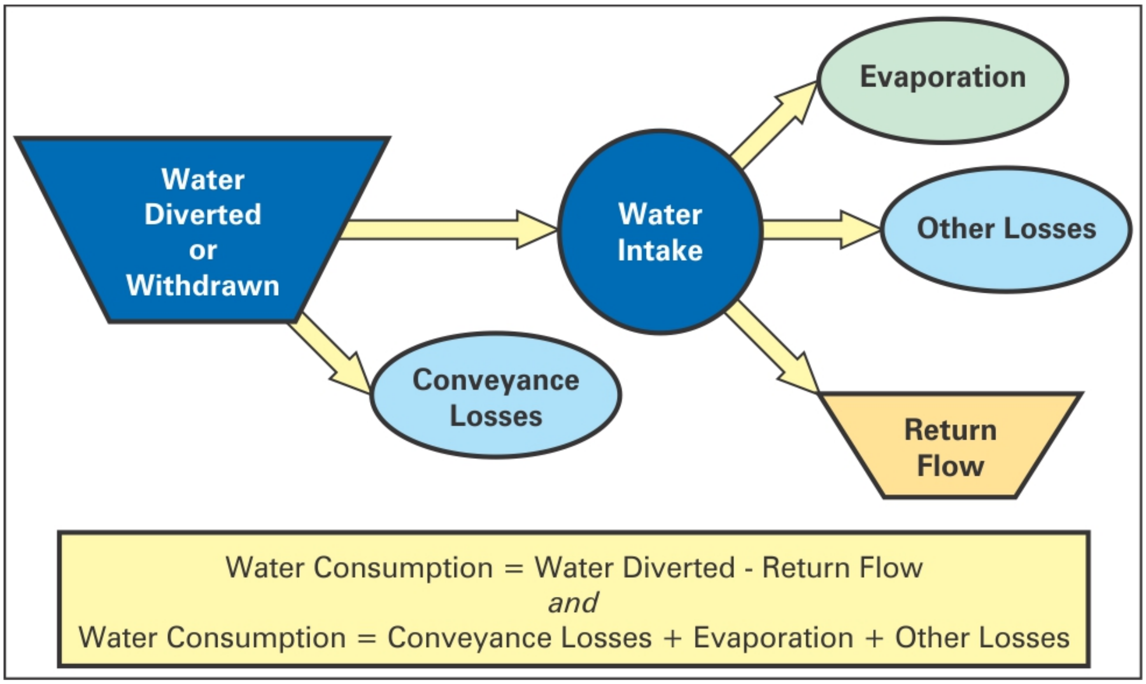

Figure 4.1. Water Use Concepts (PFSRB 2009).

Because the Cold Lake basin lies in both Alberta and Saskatchewan, determination of consumptive use requires consideration of water use in both provinces. The provinces operate robust water licensing systems, which are described in the following section. It should be noted that water use reporting data is dependent on licensees being in compliance with the terms of their licences. Provincial enforcement activities are subject to resource constraints so accurate and timely water use data are not always available. Consumptive use is discussed later in this section.

4.2 Water Allocation and Consumption

4.2.1 Alberta

In Alberta, licences are issued under the *Water Act,* which came into force in 1999. Previously, licences were issued under the *Water Resources Act* and other earlier legislation. The act provides for a statutory right to 1250 m^3/year without licence for household purposes, and for registration of traditional agricultural uses, primarily household use and livestock watering, of up to 6250 m^3/y. (Applications for registering traditional agriculture use had to be completed by the end of 2001.) All other withdrawals must be licensed.

The *Water Act* requires that new licences must be for a specified period, rather than in perpetuity as was the case under earlier legislation. It also provides for transfer of water rights (where enabled), with the province retaining up to 10 percent of the water transferred for environmental uses. The quantity of water allocated under a licence includes the amount expected to be consumed or lost, plus a return flow. Licences for municipal purposes may assume that 10 percent of the withdrawal will be consumed; those for irrigated agriculture may assume 75 percent will be consumed, for example.

One estimate of actual water usage under the 1250 m^3/year statutory right indicates that, on average, only 365 m^3/year is used. All Alberta licences may be examined using an on-line viewer on the Alberta Environment and Parks (AEP, formerly AESRD) website at https://avw.alberta.ca/ApprovalViewer.aspx.

Water licences are recorded in an AEP database by various purposes specified in Section 11 of the *Water (Ministerial) Regulation*. The purposes relevant to the Cold Lake basin include municipal, irrigation, commercial, industrial, and management of fish.

There are 18 registrations within the Alberta portion of the watershed, allocating 8,967 m^3. Nine of these registrations are for surface water, with a total allocation of 2,389 m^3 and the remaining nine allocate 6,578 m^3 from groundwater. Groundwater use will be further discussed in Section 5.2 of this report but such use is not a factor in determining apportionable flow. Groundwater licences are linked with the surface water basin for administrative purposes.

There are 13 surface water licences allocating some 24,500,000 m^3 within the Alberta portion of the Cold Lake basin. Table 4.1 summarizes the surface water allocations in the basin on November 18, 2014. The large number of significant figures in the table is the result of summing both small and large allocations. These licensed allocations can be considered in light of the median annual flow volume of the Cold River at the outlet of Cold Lake being approximately 354,000,000 m^3. Appendix 2 contains summaries of the key licences in the basin.

Table 4.1. Surface Water Allocation in Cold Lake Basin, Alberta.

Water Use Sector	Total Allocation m^3	Consumptive Use m^3	Return m^3	Losses m^3	Number
Registrations:	2,389	2,389	0	0	9
Licences:					
Municipal	7,400,890	740,090	6,660,800*	0	3
Irrigation	7,400	7,400	0	0	1
Commercial	119,870	5,160	0	114,710	3
Management of Fish	9,206,171	2,915,420	6,290,751	0	3
Industrial	7,808,404	7,771,404	37,000	0	3
Licence Totals	24,542,735	11,439,474	12,988,551	114,710	13

* The return flow is to the Beaver River, not to Cold Lake

There are three municipal licences for about 7,400,000 m^3 related to the Cold Lake Regional Utility Services Commission (RUSC). The licences assume that 90 percent of the water allocated to urban water supply returns to the aquatic system. However, the return flow that passes through the wastewater treatment systems at Cold Lake is discharged to the Beaver River, not Cold Lake. The entire diversion from Cold Lake must therefore be taken into account in the calculation of apportionable flow.

The small licence for irrigation purposes assumes that all the water diverted is consumed. This is a reasonable assumption especially taking into account the small quantity of water involved.

There are three commercial licences that will expire in the next 10 years. One is for a golf course at the City of Cold Lake. Two are for the Municipal District of Bonnyville, one for a ski hill and the other for dust control. Only about 120,000 m^3 is allocated under these licences, all of which is deemed consumed or lost. That said, most of this water is used for snow-making for a ski hill and therefore likely does return to Cold Lake.

There are three fish management licences, totalling about 9,200,000 m^3, a relatively large quantity of water. There is a small fishery operation on the Medley River, but the main project is the Cold Lake Fish Hatchery on the west shore of Cold Lake. The hatchery produces walleye and trout used in stocking Alberta lakes. The hatchery operates on a flow through basis and about a third of the water pumped is assigned as consumptive use in the licences; actual consumption is much lower. The second of two licences for the Cold Lake Fish Hatchery contains a provision that permits pumping only when Cold Lake is at or above 534.55 m.

There are three industrial licences totalling about 7,800,000 m^3. The first is an allocation of 5,110,000 m^3 to Imperial Oil Resources, pertaining to a Cyclical Steam Stimulation (CSS) operation west of Cold Lake. The licence uses Cold Lake Water under normal conditions but, when the lake level is low, groundwater is used. The stand-by groundwater licences are not within the Cold Lake surface water basin. The surface water licence term ends October 3, 2016. It is likely that Imperial would apply to renew its licence at that time, and go through a licence renewal process. The second licence is an allocation of 2,629,654 m^3 to CNRL's Burnt Lake Steam-Assisted Gravity Drainage (SAGD) facility. This licence has the same conditions with respect to Cold Lake levels. The headworks for the fish hatchery are used to provide water to this facility. This licence was issued in perpetuity (it does not have a set term). The third is a small 43,750 m^3 licence issued to Cenovus Energy for exploration purposes, whose term ends September 17, 2022. (Temporary exploration licences in the Medley River basin issued to CNRL expired in early 2015.)

4.2.2 Saskatchewan

Under the *Water Security Agency Act* of 2005, domestic users (household or on-farm) do not require a licence for uses less than 5000 m^3/y provided there are no constructed diversion works. The 5000 m^3/y figure implies both human uses and some use by livestock. Livestock uses in excess of 5000 m^3/y must be licensed. New licences for all purposes are issued for specified periods, usually 20 years. There is no provision in Saskatchewan law for licence holders to transfer licences to other water users.

Saskatchewan identifies licences as water coming from sub-basins within one of 14 major basins. Licenses pertaining to the Cold Lake basin are identified as pertaining to Major Basin 9 (Churchill River), sub-basin 61 (Beaver River). Groundwater licences are also filed by major basin, but indicate the aquifer from which the water supply is obtained. Industrial water users are required to report withdrawals monthly.

Water licences are registered by various sectors and sub-sectors. The principal water use sectors are municipal, agriculture, commercial, industrial, and 'other.' At present Saskatchewan has not issued any water licences pertaining to the Cold Lake basin.

4.2.3 Locations of Consumptive Uses

The surface water licences in the basin can be grouped in three categories: direct withdrawals from Cold Lake, withdrawals from or near the lower Medley River between Marie Lake and Cold Lake, and withdrawals from within the upper Medley basin. All licensed surface water withdrawals are from the effective drainage area. Three of the nine registrations, some 2550 m^3, are from the effective drainage area. The locations of the larger licences and a representative number of the smaller ones are shown in Figure 4.2.

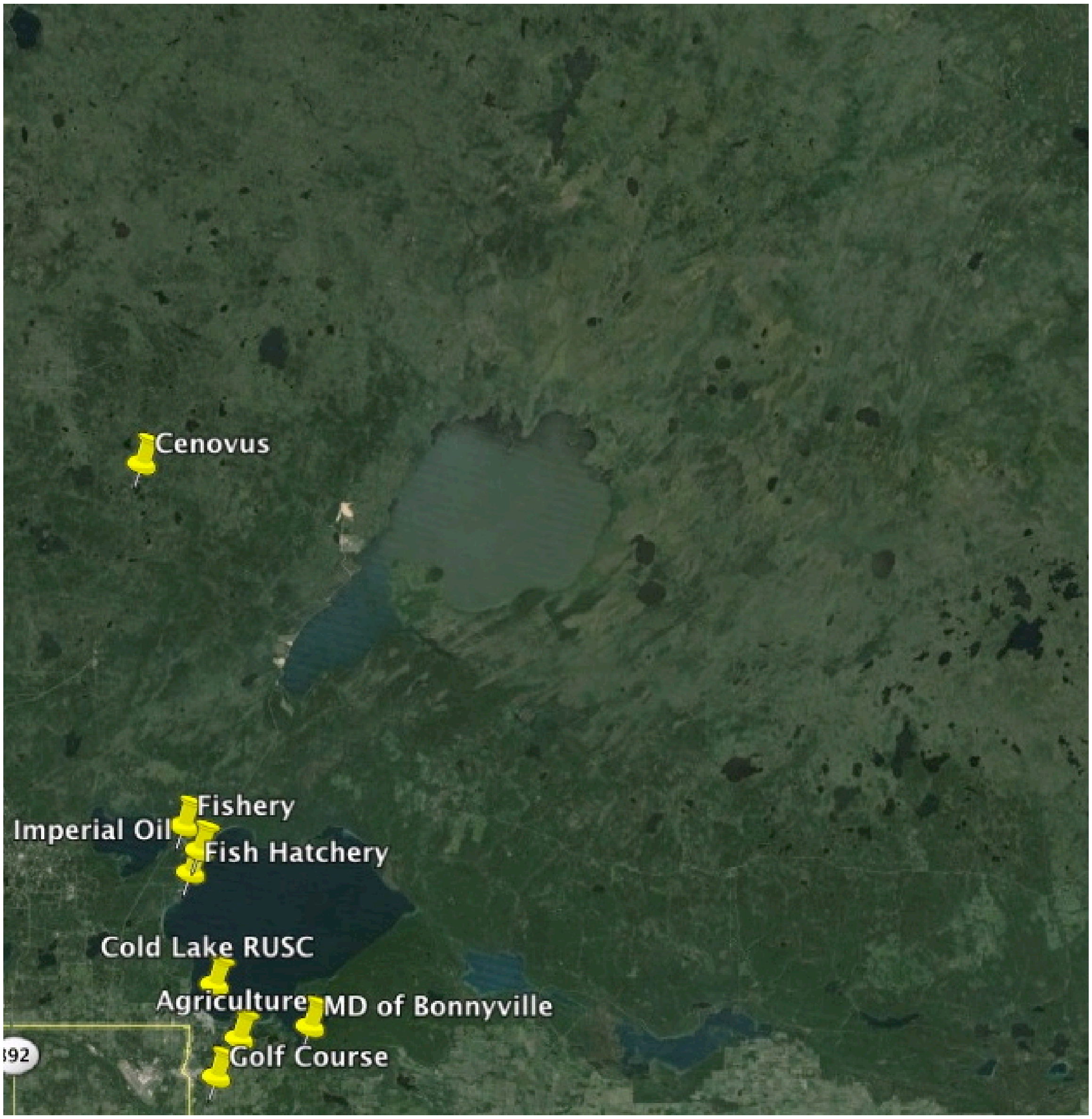

Figure 4.2. Surface Water Licences in the Cold Lake Basin.

4.2.4 Consumptive Use

Alberta includes provisions related to water use reporting in its water licences. Depending on the nature and extent of the use the report may be simply an annual volume diverted. On the other hand, more significant uses will require more detailed reporting. Typically this could involve reporting of monthly water diversions and consumption once a year or reporting daily diversions and consumption once a month. Alberta has an on-line Water Use Reporting (WUR) system through which water use reports can be submitted at http://esrd.alberta.ca/water/reports-data/water-use-reporting-system/default.aspx. The water use reports submitted by licence-holders can be obtained through database search requests performed by AEP staff.

On the basis of total allocation, there are three significant licensed water uses in the basin: municipal by the Cold Lake RUSC (three licences), fish management by the Cold Lake Fish Hatchery (two licences), and industrial by Imperial Oil and CNRL (two licences). Based on contents of the relevant licences, these uses account for almost all of the licensed water allocation in the basin.

As stated earlier in this chapter, licensed allocation is a poor estimate of actual water consumption. As well, licensed consumption rarely is equivalent to actual consumption. In the Cold Lake basin the licensees of the three major water allocations all report monthly water use to AEP. Water consumption values are shown in Table 4.2. As explained earlier in this report, the reason for reported consumption by the City of Cold Lake being so high is that none of the water diverted returns to the Cold Lake basin. The return flows from the city are to the Beaver River.

Table 4.2. Water Consumption in the Cold Lake Basin.

Water Use Sector	**Total Allocation m^3**	**Licensed Consumption – Cold Lake-Beaver River Basin* m^3**	**Reported Consumption – Cold Lake Basin m^3**	**Comments**
Municipal	7,400,890	740,090	2,550,000**	Average annual diversion (recent 10 years)
Irrigation	7,400	7,400	no data	Assume 7400 m^3 from licence
Commercial	119,870	119,870	no data	Assume 5160 m^3 from licence ***
Management of Fish	9,206,171	2,915,420	30,000	Based on four years data
Industrial	7,808,404	7,728,654	3,150,000	Average annual diversion (recent 10 years)
Totals	24,542,735	11,511,434	5,700,000	Including agriculture

* Return flows from the City of Cold Lake are to the Beaver River.
** This is the average quantity of water withdrawn from Cold Lake annually.
*** Likely an overestimate. See discussion concerning snow-making in text.

Using the contents of Table 4.2 scenarios for inclusion of various water consumption figures for the significant licences in the calculation of apportionable flow can be identified. The calculations are based on the median annual flow of the Cold River the outlet of Cold Lake being 354,000,000 m^3. Table 4.3 illustrates that including water consumption by the City of Cold Lake and by Imperial Oil in the apportionable flow calculation – the present case – accounts for much of the water consumption. Adding annual consumption by CNRL (281,000 m^3) would account for almost all of the remaining consumption.

Table 4.3. Comparison of Annual Water Consumption to Median Flow.

Scenario	**Present Case**	**+ CNRL**	**+ all others**
Percentage of Median Flow	1.52	1.67	1.68

For the three largest users, within-year distribution of water consumption is fairly level, particularly for municipal use. In the case of the industrial uses by Imperial Oil and CNRL, water consumption varies with bitumen production and there is no seasonal pattern to the use. There is, however, an increasing trend in municipal consumption and a declining trend in industrial consumption. The fish hatchery had increased its water withdrawals but actual water consumption is minor.

4.3 Modified Procedures for Incorporating Consumptive Use

Reported annual consumption by the three major users, City of Cold Lake, Imperial Oil and CNRL, should be used as the basis for the calculation of apportionable flow. The consumption related to the smaller licences is negligible. This consumption could be disregarded in the calculation or simply entered as a constant.

Although water consumption in a typical year represents a small percentage of the flow of the Cold River, it is important that procedures are in place to calculate apportionable flow when flows are low. The real challenge in this basin lies in administering apportionment when the level of Cold Lake is low say, below 534.6 m, or when flows of the Cold River are in the lower decile. If low lake measures were developed, they undoubtedly would require the inclusion of water consumed by the major users, that is, the City of Cold Lake and the industrial steam injection operations.

4.4 Changes to Consumptive Use Over Time

In 2007 AEP reported on current and future water use in the province, including use in the Beaver River basin (Alberta Environment 2007). The report forecast future water demand for 2025 in various water use sectors for the entire Beaver River basin, including Cold Lake. The report generally took a business as usual approach to forecasting demand. Alberta's Water for Life Strategy does, however, call for increased water use efficiency therefore the forecast water demand can be tempered not only by the strategy but also by more recent information.

4.4.1 Municipal Use

In 2007, municipal water demand was forecast to continue unchanged on a *per capita* basis. Even under a high population growth scenario, water demand would not exceed the present licensed withdrawal before 2025. More recently, studies related to supplying Bonnyville from the Cold Lake RUSC have assumed that the current *per capita* water use of 441 L/c/d would decline to 310 L/c/d by 2037. Cold Lake is now considered the source of municipal water for the City of Cold Lake, Bonnyville and other communities. As such, water demand could be expected to increase, even as *per capita* use decreases. That said, the water licences for the City of Cold Lake are three times larger than the current water diversion. A future need for an increase in the licensed quantity of water is extremely unlikely, even if overall water use increases.

4.4.2 Fish Management

The Cold Lake Fish Hatchery is the only significant fish management water use in the basin. The hatchery operates on a flow through basis with evaporation from ponds being the only consumptive use. Even if the hatchery were to be significantly expanded, the additional water consumption would be negligible.

4.4.3 Industrial Use

In 2007 the transition from the use of fresh water to saline water in steam injection bitumen development was well underway. At that time no increase in freshwater use was anticipated. The current industrial licences direct the companies to continue freshwater conservation measures. This is in keeping with Alberta's Oilfield Injection Policy – a policy that is currently being updated. It is probable that the existing operations that depend on licensed water supplies will continue to improve water efficiency. Imperial Oil does not use the quantity of water allocated under its licence and is unlikely to do so in the future. As well, CNRL's typical water consumption is about 12 percent of its licence. The company's maximum usage in any year thus far has been 20 percent of the licensed quantity. At present, there are no announced plans for increased bitumen production dependent on surface water supplies from the Cold Lake basin, nor from groundwater supplies in the general area.

4.5 Summary

Under typical runoff conditions there does not appear to be a reason to modify the way in which consumptive water uses are incorporated into the apportionable flow calculation. The need to consider how apportionable flow may be calculated during periods of drought does indicate some procedural changes, however. The following could be considered:

- The apportionable flow computation could be revised to include the water consumption by the City of Cold Lake and the two steam injection operations. That is, the annual water use by CNRL should be included in the apportionable flow calculation. Smaller consumptive uses, including that of the fish hatchery, could be ignored or included simply by an annual constant based on estimated average water consumption.

- There is a need to develop criteria that indicate when the low lake level computation is necessary. This should include modifications to water use reporting requirements under drought conditions.

At present there are no indications of developments in Alberta that would lead to a need to increase the allocation under current licences. As well, there are no indications that licences may be issued in Saskatchewan in the foreseeable future.

5. HYDROGEOLOGICAL CONNECTIONS

5.1 Basin Hydrogeology

The bedrock beneath the Cold Lake basin consists of a succession of sedimentary deposits, mainly sandstones, shales and limestone, underlain by the Pre-Cambrian shield. The McMurray Formation, at a depth of about 600 m, is variously water saturated, and a source of brackish water, or bitumen saturated. The heavy oil recovered in the watershed originates mainly in the Clearwater Formation, which overlies the McMurray Formation. The Grand Rapids Formation lies above the Clearwater Formation. These Lower Cretaceous formations range in age from 144 to 97.5 million years.

The uppermost bedrock of the basin is composed of dark grey marine shales known as the Lea Park Formation, underlain by Colorado shales. The Lea Park Formation is a silty marine shale with ironstone concretions. These formations date from the Upper Cretaceous period, some 97.5 to 66.4 million years in age. Cold Lake is incised into the Lea Park Formation.

Prior to glaciation, the bedrock surface was eroded by predominantly eastward flowing rivers. This produced broad paleovalleys with shallow side slopes and low gradients. The dominant valley in the basin is the Helina Valley, referred to as the Hatfield Valley in Saskatchewan. As shown in Figure 5.1 this valley passes beneath both Marie Lake and Cold Lake (Judd-Henrey and Simpson 2005). Bedrock valleys and depressions show little surface expressions as they are filled with thick accumulations of glacial sediments consisting of well-mapped clay tills, sands and gravels.

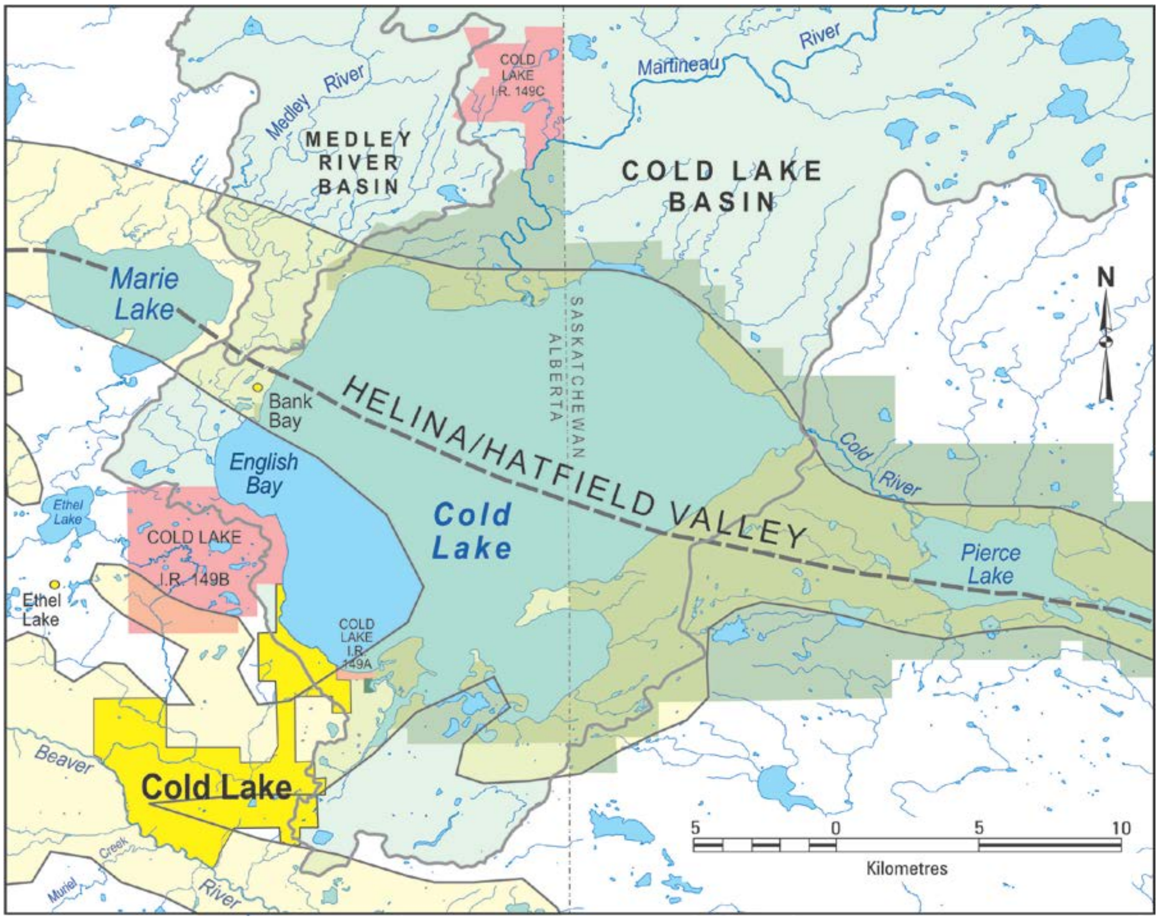

Figure 5.1. The Helina/Hatfield Paleovalley.

Glacier meltwater also scoured new channels in the bedrock surface during the earliest interglacial times. These scoured channels tend to have concave longitudinal profiles and steep side slopes. Their original sediments tend to be derived from the Pre-Cambrian Shield. It is essential to recognize that the pre-glacial and glacial paleovalleys are independent of present-day surface topography (Parks *et al.* 2005).

The bedrock topography of the watershed is covered by pre-glacial and glacial deposits, known as drift, laid down over the last 2.5 million years. By definition, in Alberta the materials that overlie the bedrock and underlie glacial till comprise Unit One (the lowermost unit) of the Empress Group, a layer of sand and sandy gravel, typically quartzite and chert. The regional geologic units in the watershed and their basic composition are shown in Figure 5.2. The Empress Group, Bronson and Muriel Lake formations lie within the buried valleys and channels of the watershed. The Bonnyville Formation is notable as it is the first formation that extends beyond the buried valleys. Formations above the Bonnyville Formation, from oldest to youngest, include the Ethel Lake, Marie Creek, Sand River and Grand Centre formations.

Period	Glacial Event	Stratigraphy		Lithology
Quaternary	Late Wisconsin	Surficial Stratified Sediment		Sand, gravel, silt
		Grand Centre Formation		Till
	Middle Wisconsin	Sand River FM		Sand, till
	Early Wisconsin	Marie Creek FM		Till
	Sangamon	Ethel Lake FM		Silt, clay, sand, gravel
	Illinoian	Bonnyville Formation	Unit 2	Till
			Unit 1	Sand, gravel
			Unit 1	Till
	Pre-Illinoian	Muriel Lake FM		Sand, gravel, silt, clay
		Bronson Lake FM		Diamict, clay
		Empress Group	Unit 3	Sand, gravel, till
	Preglacial		Unit 2	Clay, silt
Tertiary			Unit 1	Sand, gravel
Upper Cretaceous	n/a	Bedrock (Lea Park Formation)		

Figure 5.2. Regional Geologic Units of the Cold Lake Basin (adapted from Judd-Henrey and Simpson 2005 and BRWA 2013).

Drift formations govern the presence and characteristics of groundwater. An aquifer can be defined as a water-bearing formation sufficiently porous and permeable to yield water to a well in useful amounts. Aquifers can be either bedrock (typically consolidated) aquifers or drift aquifers (typically unconsolidated). It is tempting to consider the sand-dominated layers shown in Figure 5.2 as aquifers and the till-dominated layers as barriers to groundwater movement, or aquitards. This tends to oversimplify the true situation as there are various degrees of vertical or horizontal connectivity between formations. To simplify, drift aquifers may be classified as buried valley aquifers, intertill aquifers and surficial aquifers. Buried valley aquifers are capable of very high water yields. Because of this, petroleum companies have used the Empress and Muriel Lake aquifers as sources of water. In addition, brackish or saline groundwater from much deeper bedrock sources is widely used in the petroleum industry.

The water yield from intertill aquifers varies considerably. Some intertill aquifers have only sufficient sustainable water to supply domestic needs, while others may yield sufficient sustainable supply to meet some commercial needs. The sands comprising a surficial aquifer may be at or just a few metres below the surface. These aquifers vary in size (thickness and spatial extent) but, in general, do not typically yield significant water supplies. The surficial aquifers tend to be very responsive to climate conditions. Wells in surficial aquifers are often critically important to on-farm water users and in the Cold Lake Basin there are no potable water bedrock aquifers except along the southeast edge.

In general, buried valley aquifers can be considered as fairly isolated due to thick layers of till between aquifers. Water withdrawals are unlikely to affect other aquifers or surface water supplies. Nonetheless, monitoring of large-scale pumping in Alberta shows that drawing down the Muriel Lake aquifer induces draw down in shallower aquifers. For that reason Imperial oil is encouraged to pump from the Empress 1 formation rather than the Muriel Lake formation. Sustainable yields from the Empress aquifers are several thousand cubic metres a day: one case of a yield of 22,300 m^3/day has been reported (Judd-Henrey and Simpson 2005). Park *et al.* (2005) report that Cold Lake is hydraulically well connected to some of the aquifers in the area. Fluctuations in some observation wells tend to reflect water levels of the lake.

Other lakes in the basin may intersect surficial aquifers and some shallow intertill aquifers. Some lakes and wetlands of the basin, therefore, may gain water from or lose water to the groundwater system. Surveys such as those conducted by Welsh *et al.* (2012) elsewhere in the Beaver River basin have not been carried out in the Cold Lake basin. Depending on the permeability of the sub-surface, volumes of groundwater movement may be reported over days, years or millennia. In general, in comparison with surface water runoff, groundwater flows play a relatively small role in influencing lake levels.

Groundwater assessment must take into account the generalized movement of groundwater in the basin. In general, the groundwater flow is from the Moostoos Upland in the northern part of the Alberta basin southeast towards Cold Lake and thence to Saskatchewan. There is a strong hydraulic connection between the Helina/Hatfield valley and Cold Lake. Seasonal fluctuations and long term water levels of Cold Lake are therefore highly correlated with some groundwater levels of the Empress and Muriel Lake aquifers in the area. There is an estimated flow of about 18,000 m^3/d towards the lake from Alberta. At the same time, there is also a flow gradient from the lake to the Hatfield aquifer in Saskatchewan (Parks *et al.* 2005). It is generally accepted that the lake gains water from the Alberta aquifers but that it loses water to Saskatchewan aquifers. On balance therefore, the lake may neither gain nor lose surface water to the groundwater system (PPWB 1996). The estimated groundwater flow gradient into and out of Cold Lake represents about two percent of the median surface water flow in the Cold River.

Primrose Lake, on the other hand, is quite shallow and lies atop the Marie Creek Formation. This formation is composed of glacial till characterized by a very coarse sand fraction rich in calcareous fragments (Parks *et al.* 2005). It tends to contain low yielding surficial aquifers. Interactions between such aquifers and the lake have not been studied but could be assumed to be much less significant than those for Cold Lake.

One other aspect of groundwater in the basin is the use of deep well disposal of water used in or arising from bitumen recovery operations. This water is known as "produced water." It is generally highly saline and contains oil and soluble organic compounds. Thus, it cannot be disposed of in such a manner as to threaten the environment. The general approach is to recycle the water for further bitumen recovery or, in some cases, return it to deep isolated formations below the bedrock surface. Deep well disposal is regulated by Alberta's Energy Regulator (AER) and Saskatchewan's Ministry of Economy.

5.2 Groundwater Use

The aquifers contained in the buried valleys and channels can yield considerable supplies of water. On the other hand, the shallow aquifers tend to be suitable only for domestic water supply and livestock watering. Groundwater use within the surface water basin is very small and is related only to domestic and agricultural purposes. Groundwater used by the bitumen industry as standby licences when Cold Lake levels are low is drawn from sources outside the basin's surface water boundary. An examination of hydrographs from groundwater wells immediately east of Marie Lake indicates no reduction in lake levels when Imperial Oil is pumping (PPWB 1996). Since that time, there is some indication that the pumping may affect the levels of Marie Lake (Parks *et al.* 2005)

Although licences allocating groundwater include a reference to surface water basin boundaries, this is an administrative convenience. It does not necessarily imply any connectivity between the groundwater source and the surface waters of the basin. There are no groundwater licences in the Saskatchewan part of the Cold Lake basin and three groundwater licences allocating 5197 m^3 for livestock watering in the basin in Alberta. The three licences are all in non-contributing drainage south of Cold Lake, between the City of Cold Lake and the interprovincial boundary. There are also nine registrations allocating 6578 m^3 in the same general area. Only one of these lies within the contributing drainage area. Based on the very small water use and the locations of the use, there does not appear to be any need to take return flows to surface water from pumped groundwater into consideration in determining apportionable flow.

The use of saline (brackish) groundwater, defined in Alberta as water exceeding 4000 mg/L total dissolved solids, does not require a water licence under the Alberta *Water Act*. (Such use would require a licence in Saskatchewan.) Currently, saline groundwater is widely used in bitumen recovery operations instead of freshwater. Although a licence in not required under the *Water Act*, anyone drilling a well deeper that 150 m for any purpose must obtain a licence from the AER. This provision relates primarily to well safety and aquifer protection. The quantity of water or other substance withdrawn from such wells must be reported to the Petroleum Registry of Alberta.

5.3 Groundwater Monitoring

AEP monitors groundwater in the area as part of its Groundwater Observation Well Network (GOWN). Most of the wells monitoring water levels and water quality are north of the Beaver River and east of the Sand River. The wells tend to be concentrated around major industrial developments. Well 946 is a deep well in Cold Lake Provincial Park on the south shore of Cold Lake that has been in operation since 2007. The record is too short to determine trends but the elevations appear to track those of Cold Lake.

There are two GOWN wells in the Marie Creek basin on the east side of Marie Lake. These wells were installed in the mid-1980s. Well 192 is in the Empress Formation Unit 1 and Well 193 is in the Muriel Lake Formation. Elevations from both of these wells tend to track the Marie Lake hydrograph, not the Cold Lake hydrograph (Parks *et al.* 2005).

Saskatchewan operates three groundwater wells, known as Pierce 1, 2, and 3, in the Cold Lake-Waterhen area. These wells were installed west of Pierce Lake near the point where the Cold River enters the lake in 1992, when Cold Lake levels were low. Pierce 1 is in the Empress Formation within the Hatfield Valley aquifer. Pierce 2 is of medium depth and terminates in intertill sands, while Pierce 3 terminates in shallower intertill sands.

5.4 Summary

It is conceivable that routine or standby groundwater pumping to support bitumen operations in the Marie Lake area west of Cold Lake could ultimately affect groundwater flows into Cold Lake. This could be the case if the groundwater "footprint" of Cold Lake extended further west than the surface water basin boundary. The continued operation of the GOWN wells between Cold Lake and Marie Lake is an essential response to that potential issue.

One challenge associated with groundwater in the Cold Lake basin relates to whether the hydrogeological connections to Cold Lake results in it being either a gaining lake or a losing lake. The hypothesis that Cold Lake gains from Alberta and loses in equal measure to Saskatchewan is the current consensus. The groundwater flows related to Cold Lake represent a very small percentage of the surface water flows.

Licensed water uses from groundwater are very small and tend to lie in non-contributing portions of the basin. Withdrawals from groundwater and return flows, if any, to surface water are therefore insignificant to the determination of apportionable flow.

6. OTHER FACTORS IN DETERMINING APPORTIONABLE FLOW

6.1 Channel Loss and Routing Adjustments

Channel losses become a factor in calculation of apportionable flow when there may be a requirement to release water from an upstream reservoir to make up a flow deficit at the apportionment point. Channel losses also come into play when considering the effect of an upstream withdrawal or other consumptive use on flows at the apportionment point.

Channel losses are not taken into account in the current calculation of apportionable flow for two reasons. First, there are no reservoirs in the basin from which releases could be made to make up a flow deficit. Second, all of the water uses used in the existing and proposed apportionable flow calculations are from Cold Lake.

Even if there were a consumptive use far upstream on the Medley River, for example, this stream and other tributary streams are unregulated and tend to maintain a live stream year round. The potential for channel losses is therefore much lower than for the case of an ephemeral prairie stream.

Given the current situation with respect to licensed water consumption in the Cold Lake basin, there is no need to route water uses downstream to the apportionment point and therefore no need to perform routing adjustments. The quantity of water withdrawn from the Medley River is small in comparison to the natural flow. Further, the licence calls for decreased withdrawals during periods of low flow. As well, the point of withdrawal is very close to Cold Lake so travel times to the lake are short.

6.2 Reservoir Evaporation

There are no known water impoundments in the Cold Lake basin, certainly none of sufficient size to have a bearing on the calculation of apportionable flow. There is therefore no current need to develop a procedure for handling reservoir evaporation in this basin. In theory the difference in evaporation from the surface of Cold Lake itself could be considered. The natural level of the lake is decreased on account of water withdrawals; therefore the lake area and, hence, the evaporative loss would decrease. Total water withdrawals from the lake, however, change the levels of this relatively steep-sided lake by less than one-tenth of a metre so any effect on evaporative loss would be imperceptible.

PPWB (2015) contains an excellent review of methods of calculating evaporation in a prairie setting. Eleven methods of calculation were tested and a suite of seven models was found to provide similar results. The report recommends that, should complete data be available, an ensemble approach to calculating evaporation be used. The report notes that if just standard meteorological observations are available the modified Myer model as used by the former PFRA could be used.

As will be discussed later in this report, there are currently no meteorological observing stations in the Cold Lake basin. Any meteorological calculations related to the basin would have to be based on regional analyses supplemented by observed data from MSC stations such as the one at the City of Cold Lake. Based on AEP analyses, in a median year the Cold Lake basin annual evaporation exceeds annual precipitation by about 150-200 mm in the south and 50-100 mm in the north. The relevant gross (potential) evaporation calculations were performed using Morton's model (Alberta 2013). Agriculture and Agri-Food Canada produces a somewhat higher figure for average net evaporation at the City of Cold Lake for 1981-2010 using gross evaporation of 746 mm calculated from the Meyer formula and 421 mm precipitation from Environment Canada.

6.3 Watershed Heterogeneity

The apportionment of flow between Alberta and Saskatchewan is based on a uniform yield assumption for the entire Cold Lake basin. That is, the apportionment is based on the ratio of drainage areas in each jurisdiction. This assumption may not be correct as there are pronounced north to south gradients in various hydrological parameters related to the basin. The identified gradients, however, are based on averages developed over a relatively large surface area; data for the Cold Lake basin are scarce to non-existent. Even if the assumption of uniform yield is changed, a question remains. Would a different treatment of water yield from the Cold Lake basin lead to a significant difference in the determination of apportionment entitlements?

Another aspect of the uniform yield assumption is the land cover of the watershed. Differences in land cover could lead to differences in runoff. The only source of consistent land cover information for the entire watershed is the analysis performed by PFRA in 2000.

This land cover is shown in Figure 6.1. (Ducks Unlimited Canada has carried out detailed analyses of wetland features of the Alberta portion of the watershed.)

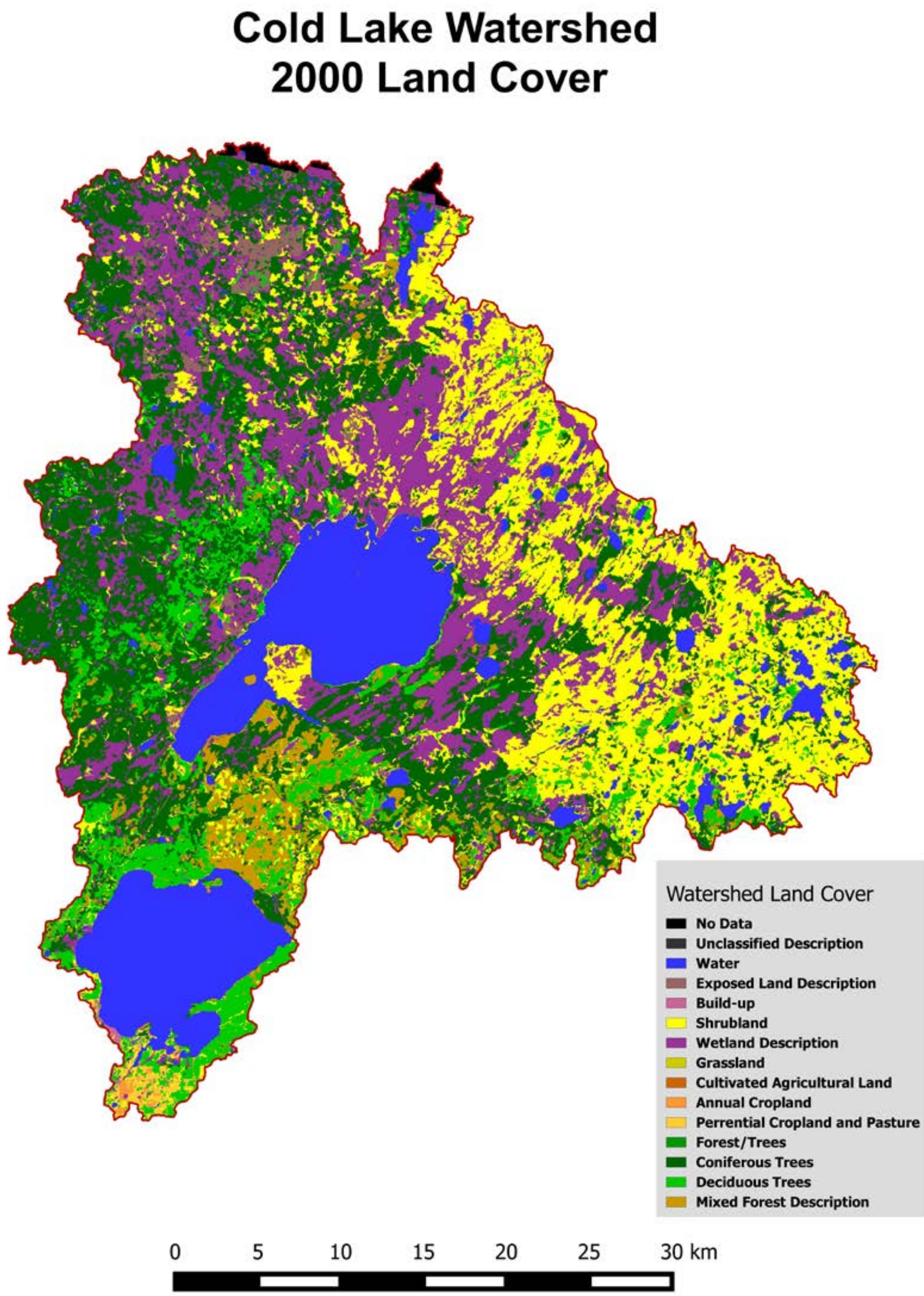

Figure 6.1. Landcover of the Cold Lake Basin (PFRA 2000).

Using the gross drainage areas for the sub-basins described in section 2, the landcover classification distribution for these three sub-basins can thus be compared to that of the entire Cold River basin. This was accomplished using QGIS®. The comparison based on gross basin boundaries is shown in Table 6.1. (Columns may not total 100 percent due to rounding.) Only the land cover classifications identified in the basin are listed. The table indicates that the land cover in the Primrose Lake sub-basin mirrors that of the entire Cold Lake basin. The most significant difference within the basin is that the Martineau River sub-basin features much more shrub land than the basin as a whole while the Medley River sub-basin features much more coniferous forest.

Table 6.1 also presents the landcover classification by province. The percentage of each classification tends to be similar in each province for the most part. Shrub land is much more prevalent in Saskatchewan while coniferous forest is very significant in Alberta. If runoff from shrub land in this basin could be demonstrated to be significantly different to runoff from conifer forest, this would be a reason to reconsider the uniform yield assumption.

Table 6.1. Landcover Classification Distribution.

Class	Description	Sub-basin or Jurisdiction (percent of gross area).					
		Cold Lake	Primrose Lake	Martineau River	Medley River	Alberta	Sask.
Water	All water bodies	14.8	14.9	4.6	1.0	17.6	13.8
Exposed Land	Naturally occurring non-vegetated surfaces	1.9	3.2	0.6	0.7	2.0	1.9
Built-up	Developed land, roads	0.1	0.0	0.0	0.0	0.4	0.0
Shrub land	Low woody vegetation	21.4	16.8	38.2	3.2	4.3	27.6
Wetland	Fens, bogs, swamps, etc.	21.2	29.7	14.9	14.4	18.2	22.3
Annual Cropland		0.1	0.0	0.0	0.0	0.5	0.0
Perennial Cropland	Periodically cultivated cropland, tame grasses, alfalfa	0.4	0.0	0.0	0.0	1.4	0.0
Coniferous Forest	Predominantly coniferous forest or treed areas	27.3	28.4	26.1	61.1	40.7	22.5
Deciduous Forest	Predominantly broadleaf forest or treed areas	8.6	5.6	8.4	15.8	13.2	7.0
Mixed Forest	Mixed forest or treed areas	4.1	1.5	7.2	3.9	1.7	4.9

The relatively flat landscape of the basin with its variations in precipitation and runoff along with the land cover could be modelled to test the uniform yield assumption. There are numerous examples of such modelling in the literature (Jiang *et al.* 2004, Pomeroy *et al.* 2013). In the absence of any precipitation data and scarce streamflow data, this would be a major challenge and it's not evident that the uniform yield assumption is a bad assumption.

As stated earlier in this chapter the current apportionment of flow between Alberta and Saskatchewan is based on the ratio of gross drainage area. Another approach may be to consider whether the apportionment of flow should vary in accordance with the effective drainage area. If the ratio of contributing areas in Alberta and Saskatchewan varied with moisture conditions, this would indicate a need to examine the entitlements of each province under varying moisture conditions. In the specific case of the Cold Lake basin non-contributing drainage in a median year is less that four percent of the basin. That is, virtually the entire basin can be deemed to contribute to flow in half of all years. There does not appear, therefore, to be much merit in considering varying the apportionment ratio based on moisture conditions.

An exception would be if the outlet elevation of Primrose Lake were high enough that flow from the lake would be effectively cut off while the Cold River continued to flow from Alberta into Saskatchewan. Under those conditions, a very significant portion of the basin would become non-contributing. No information concerning the natural outlet elevation of Primrose Lake has been located. As well, there is no anecdotal evidence indicating that flows from Primrose Lake ceased prior to those from Cold Lake when Cold Lake dropped below its outlet elevation in 1992-93.

Figure 6.2 displays a scatter plot of monthly water levels of Cold Lake versus Primrose Lake for the period from 1992 to 2012 (Kerkhoven, 2015). There are no inflections or break points that would indicate changes in basin yield under different flow conditions.

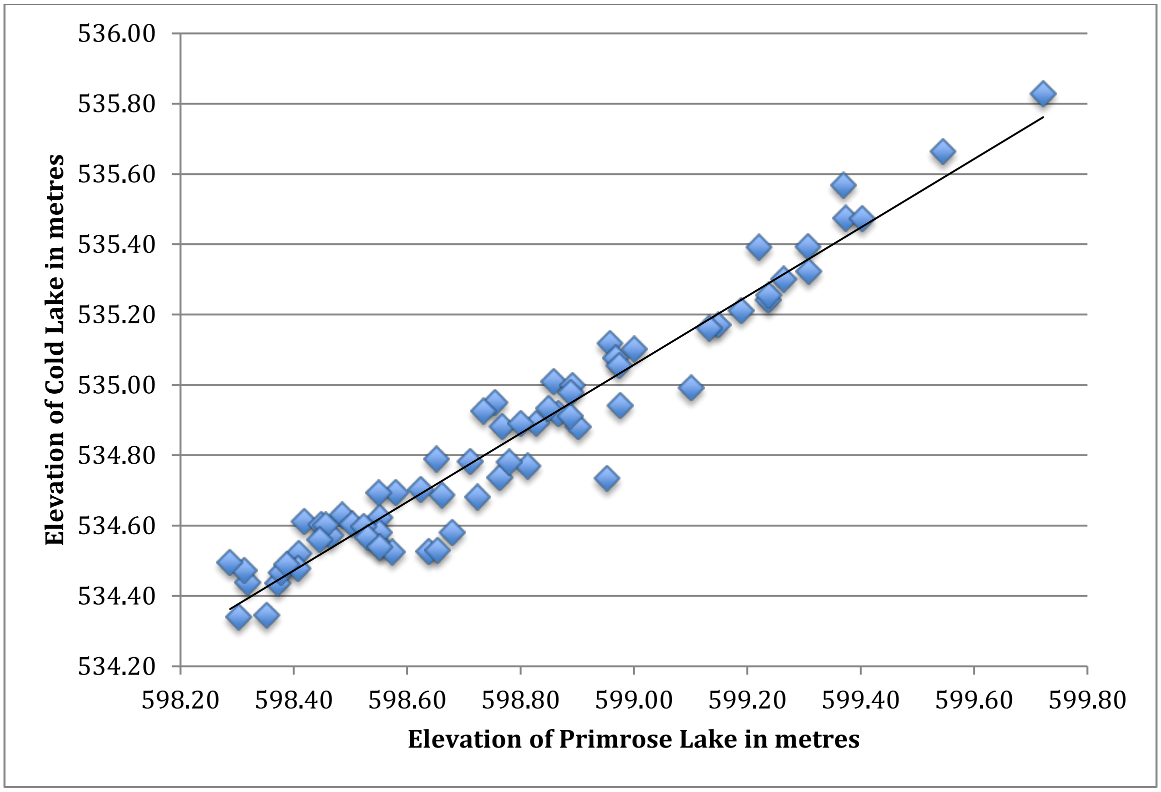

Figure 6.2. Monthly Water Levels of Cold Lake *versus* those of Primrose Lake.

The response of a land surface to precipitation and evaporation is distinctly different to that of a lake surface. For the purposes of administering apportionment the surface areas of Cold and Primrose lakes could be considered hydrologically distinct as compared to other parts of the basin. These two lakes comprise about 12 percent of the surface area of the basin. Removing the surface areas of these two lakes in both jurisdictions from the drainage areas considered in determining shares of apportionable flow would lead to a minor increase in the proportion of flow that Alberta is required to deliver to Saskatchewan. The percentage would increase from 68.4 to 68.7 if the assumption of uniform yield for the remainder of the basin is maintained. Table 6.2 shows the calculation.

Table 6.2. Effect on Apportionment Share Considering Cold and Primrose Lakes.

Province	Gross Drainage Area km^2	Adjusted Drainage Area km^2	Percent of Adj. Area	Percent of Water Yield	Percent of Share		
					Alberta	Sask.	Manitoba
Alberta	1716.7	1444.7	25.2	25.2	12.6	6.3	6.3
Sask.	4813.8	4293.5	74.8	74.8	18.7	37.4	18.7
Total	6530.5	5738.2	100.0	100.0	31.3	43.7	25.0

6.4 Low Cold Lake Levels

The industrial water use licences held by Imperial Oil and CNRL are subject to a low flow condition. When the Cold Lake water level is less than 534.62 m (1754.0 ft.) the two licence holders must reduce their pumping from Cold Lake. In the case of Imperial Oil, pumping must be reduced to 9.8 dam^3/day. (At present, the average daily rate over a ten-year period is only 7.9 dam^3/day.) CNRL's licence indicates that the company *may* be required to reduce pumping by 30 percent. When Cold Lake levels drop to 534.55 m for 48 hours industrial water pumping must cease. (Standby groundwater licences are in place for this contingency.) Within the instrumental record Cold Lake has dropped below the cut-off threshold for several months in 1992-93 and again in 1998-2001.

The effect of low Cold Lake water levels can be seen in Table 3.2, which shows that the percent of apportionable flow delivered drops from the usual 98 or 99 percent to about 90 percent when the lake is low. This is still a very high percentage but there would be merit in considering the calculation of apportionable flow on a quarterly or even monthly basis during periods of low lake level. This would allow PPWB members to keep senior officials and the public informed.

7. OVERALL IMPACT OF PROPOSED CHANGES

As discussed earlier in this report the calculation of apportionable flow for the Cold Lake basin is conceptually simple and straightforward. Although not absolutely necessary for the administration of apportionment under normal water supply conditions, the calculation could be improved by including water use reports from CNRL, the other significant water consumer. The calculation could be further modified, if deemed necessary, by incorporating annual consumption by smaller users as a constant.

Assuming that the calculation is performed in a LibreOffice spreadsheet, options for future calculations in a normal year include no change concerning inclusion of water use reports, addition of reports from one more major user, and addition of assumed consumption by the fish hatchery and other small users. Although not absolutely needed under normal conditions, inclusion of water consumption by CNRL could be justified on the basis of equal treatment of such users. It would also be beneficial to include CNRL data regularly so that when low levels prevail, the reporting structure is in place.

The existing drainage boundaries produced by PFRA have been examined and re-calculated using QGIS™. The changes are modest but it would be useful if those revised boundaries were adopted for future use by PPWB members.

During periods of low level on Cold Lake and resulting low flows of the Cold River it would be useful to consider calculating apportionable flow periodically during the year. This could be done quarterly, or even monthly, as conditions warrant. Such procedures could be part of an overall drought contingency plan for the basin.

8. DATA NEEDS

Data needs for the determination of apportionable flow are modest, consisting only of hydrometric data for a small number of sites and water use data for a few users. The administration of apportionment requires that administrators be equipped to respond to questions and concerns from various interests. Making such responses leads to other data needs. This section deals with data needs related to both the calculation of apportionable flow and to the administration of apportionment. Monitoring locations are shown in Figure 8.1.

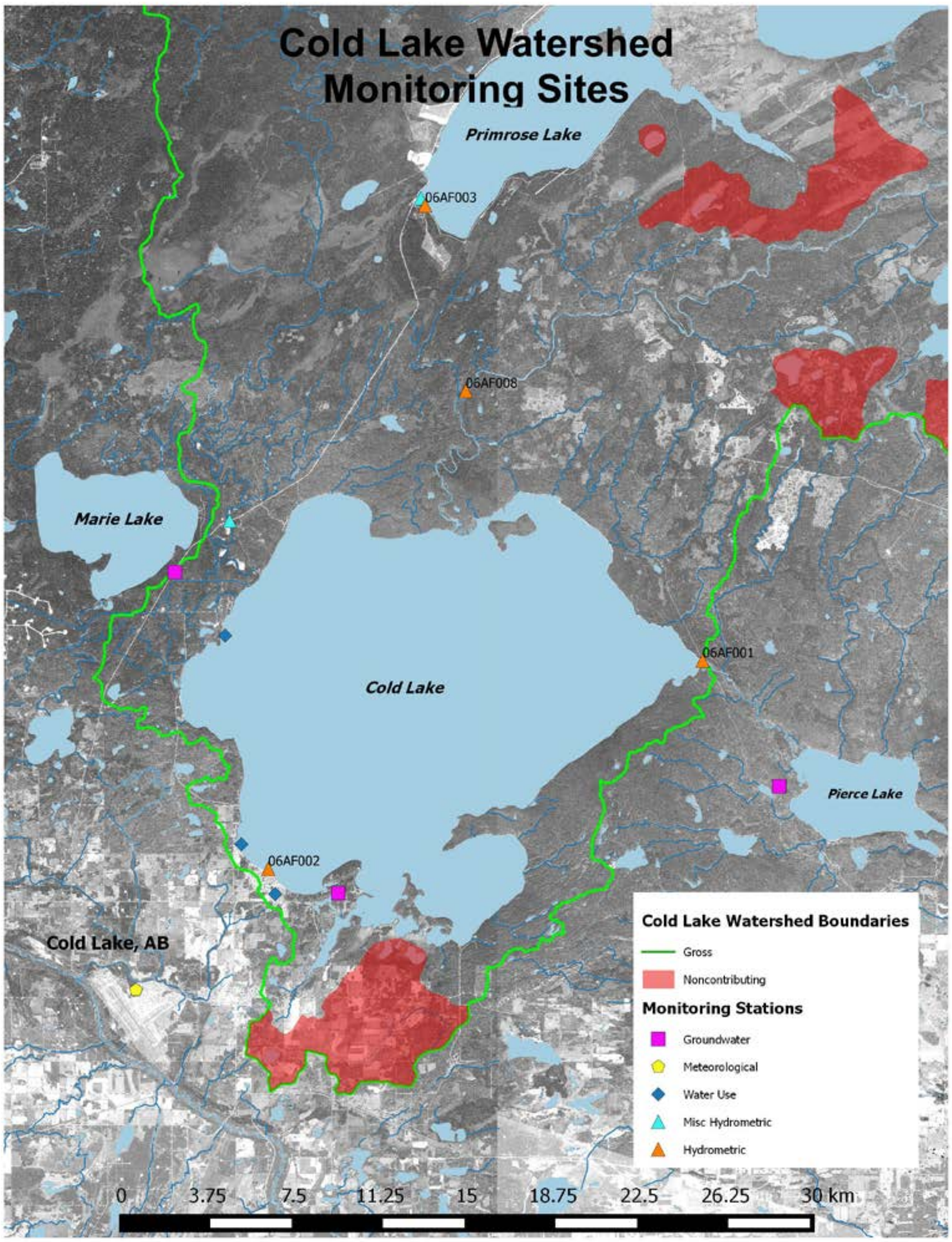

Figure 8.1 Monitoring Locations Pertaining to the Cold Lake Basin.

8.1 Hydrometric Data

Hydrometric data from two gauging stations are used in the current computation of apportionable flow using COLD3.FOR. The stations are the Cold River at the outlet of Cold Lake and Cold Lake itself. Both stations are operated by the Water Survey of Canada in cooperation with AEP. The station on Cold Lake has been in operation since 1954 and was equipped with a water level recorder in 1981.

The Cold River station has been in operation since 1993. The stage-discharge relation for the Cold River is stable although ice-affected. Water levels from the Cold Lake gauge can be used to fill in missing record in the event of a recorder failure at the Cold River site. The record quality is considered generally good.

A WSC manual gauge was installed on Primrose Lake (06AF003) from 1954 to 1958. Daily readings for a few summer months and occasional readings for other months are available. AEP has operated a staff gauge on Primrose Lake from 1992 to the present. The record is fragmentary, but could be of value should there be a need to evaluate the use of Primrose Lake water levels in any revised computation of apportionable flow.

The WSC also operated a station on the Martineau River above Cold Lake from 1981 to 1995. This record is hydrologically important as it covers the period when Cold Lake levels were very low in 1992 and 1993.

The only other hydrometric data available in the basin are miscellaneous measurements obtained by consultants assisting Imperial Oil in preparing operations reports required by Alberta. Measurements have been made on the Medley River near the Hwy 897 crossing twice a year during open water for several years (Amec 2011). Should a gauging station be required on the Medley River for apportionment purposes, this site could be considered.

8.2 Meteorological Data

There are no meteorological stations operated by the Meteorological Service of Canada in the Cold Lake basin. There is, however, a synoptic forecast station at Cold Lake Airport just south of the basin boundary. Temperature and precipitation information from this site is discussed in BRWA (2013). As might be expected, the data show increasing temperatures, particularly winter temperatures, and decreasing precipitation, especially in precipitation falling as snow.

Alberta's Agroclimate Information Service operates climate stations in the area, but none are in the Cold Lake basin. One, however, is within the Cold Lake Air Weapons Range west of Primrose Lake.

8.3 Groundwater Data

AEP monitors groundwater in the area as part of its Groundwater Observation Well Network (GOWN). One well is located immediately south of Cold Lake and two are to the east of Marie Lake, that is, between Marie Lake and Cold Lake. AEP makes these data available at http://esrd.alberta.ca/water/programs-and-services/groundwater/groundwater-observation-well-network/default.aspx

Saskatchewan operates three groundwater wells, known as Pierce 1, 2, and 3, in the Cold Lake-Waterhen area. These wells were installed west of Pierce Lake near the point where the Cold River enters the lake. The Water Security Agency makes these data available at https://www.wsask.ca/Water-Info/Ground-Water/Observation-Wells/

The continued operation of these wells is important to improving understanding of potential interactions between groundwater pumping and groundwater inflows and outflows of Cold Lake.

8.4 Water Use Reporting Data

At present water use reports from two licensees are used in the calculation of apportionable flow, namely, those from the City of Cold Lake and Imperial Oil. The findings of this report indicate that water use reports from CNRL should also be incorporated into the calculation. Such reports are a requirement of Alberta's water allocation system and these water users are required to provide their data to the province's WUR system as a condition of their licences.

9. FURTHER ACTIONS REGARDING APPORTIONMENT CALCULATION PROCEDURES

The apportionable flow computations for the Cold Lake Basin are currently completed annually using a Fortran program. At the present level of development and water use in Alberta, and under normal flow conditions, there is no challenge in terms of the delivery of the required volume of water to Saskatchewan on an annual basis. There is no current indication that water use in the basin, by either Alberta or Saskatchewan, would increase sufficiently to raise concerns about apportionment. Projected consumption in Alberta would not exceed the current licensed quantities. Despite this, there is a concern related to low lake levels on Cold Lake. The concern relates to the fact that there is no means of making up a flow deficit should one occur. A low flow contingency reporting plan is needed.

Given the minor level of current water consumption in the basin there does not appear to be any need to visit the uniform yield assumption used in the apportionment of flow between Alberta and Saskatchewan. If there were a need to consider this, the installation of gauging stations on the Medley River and on Primrose Lake plus a small number of meteorological stations would be required.

The most significant public concern with regard to water apportionment in this basin relates to the effects of groundwater pumping on the level of Cold Lake. Under present conditions the effect, if any, is minor. Nevertheless, investigations into groundwater-surface water interactions in the Helina/Hatfield Valley could be helpful in allaying public concern.

10. SUMMARY AND RECOMMENDATIONS

The apportionable flow for Cold Lake at the Alberta-Saskatchewan boundary has been determined on an annual basis since 1993. Based on the apportionable flow calculation procedures that have been in place, during that time the lowest percentages of the annual apportionable flow that Saskatchewan has received is 86 percent in 1993 and 90 percent in 2000. These years coincide with low water levels on Cold Lake. In all other years the percentage of annual apportionable flow delivered was 96 to 99 percent.

The project depletion method is used by the PPWB for calculating apportionable flows. The calculation is unusual, however, on account of the transboundary nature of Cold Lake. In accordance with the Rational Method used by the PPWB, Alberta is required to deliver 68.4 percent of the apportionable flow to Saskatchewan.

10.1 Calculation of Apportionable Flow

When calculation of apportionable flow was first instituted a spreadsheet program based on Lotus 1-2-3 was used but proved difficult at times. As a result, a Fortran 77 program, COLD3.FOR, that used an iterative process to determine daily apportionable flow was developed. The program used only the water uses of the City of Cold Lake and of Imperial Oil in its calculation. One of the deliverables of this project was a requirement to convert the Fortran program into a spreadsheet calculation. This was accomplished but, because of the inability of Microsoft Excel to handle cascading iterations, an open source spreadsheet program, LibreOffice, is required to run the program.

Based on a review of the present and future water uses in the basin, there does not appear to be any compelling reason to change the apportionable flow calculation methodology. The main concern regarding the calculation is that a procedure be in place to administer apportionment during drought conditions, that is, when Cold Lake levels are low. Under those circumstances it would be preferable to use a fuller accounting of water consumption.

Apportionment Recommendations

1. The PPWB should adopt the spreadsheet calculation of apportionable flow developed during this project. In addition to the water allocations currently considered, the calculations should incorporate the monthly water consumption reports from CNRL and could include average water consumption by other users.

2. To accommodate drought conditions the PPWB should consider quarterly reports on apportionable flow, for example, when Cold Lake drops below 534.62 m, the level at which industrial use from the lake may be curtailed and monthly reports when the level drops below 534.55 m, the level at which industrial uses switch to groundwater pumping.

10.2 Surface Water Hydrology

During this project the former PFRA determinations of gross and effective drainage areas as well as land cover information were reviewed using an open source program known as QGIS. New topographic information was used to revisit the drainage area calculations and to verify the surface areas of Cold and Primrose lakes. Drainage areas for sub-basins of the Cold Lake basin were also calculated. These values appear in this report, but they do not lead to any suggested changes in the apportionment of flow between provinces.

Most of the Cold Lake basin has been undisturbed by human activity. Agriculture and forestry uses of the basin are minor, as is urban development. The most significant land use change relates to bitumen exploration and development. The uniform yield assumption was considered by examining land cover information for the basin as a whole and for various sub-basins. Consideration of land use and land cover did not lead to any need to change the drainage area ratios used in the administration of apportionment.

Hydrological Recommendations

1. Based on a review of hydrological information, the drainage area ratios developed in PPWB (1995) should continue to be used in the administration of apportionment.

2. The shape files and related GIS information delivered under this project should be made available to PPWB member agencies and other interested parties.

10.3 Groundwater

Although water consumption in the basin is modest, the effects of groundwater pumping on Cold Lake is a public concern. It would be useful to achieve a better understanding of how the aquifers of the Helina/Hatfield Valley interact with Cold Lake and the extent, if any, to which standby pumping in the Marie Lake area may affect the quantity of groundwater entering Cold Lake. This issue would come to the fore in the event of a protracted drought in the basin.

Groundwater Recommendations

1. The PPWB should consider a drought contingency plan to address the effects of groundwater pumping during times of drought.

10.4 Monitoring

The monitoring needs required to calculate apportionable flow in the Cold Lake basin are modest and there does not appear to be any compelling reason to change them in the foreseeable future. That said, there is no meteorological data for the basin and hydrometric data are limited. If there were a need to carry out any hydrological modeling in the basin, there is insufficient data to do so.

As for surface water, there is limited groundwater monitoring in or near the basin. There is insufficient information to examine groundwater-surface water interactions in any detail.

Monitoring Recommendations

1. Existing monitoring in and near the basin should be maintained.

ACKNOWLEDGEMENTS

This report was produced by R. A. Halliday, R. Rickwood and D. R. Halliday on behalf of R. Halliday & Associates Ltd. for the Prairie Provinces Water Board. The authors wish to thank the following persons for their contributions to the work: Naba Adhikari, Darrell Corkel, Carmen de la Chevrotière, Tony Cowen, Brent Eberle, Megan Garner, Dennis Lazowski, Mark Lee, Anthony Liu, Kei Lo, Bart Oegema, Joe Prusak, Sangeeta Guha, Dave Simms, Cheryl Tweten, Garth van der Kamp, and Ron Woodvine. Thanks also to Harry Keess of the Beaver River Watershed Alliance and to Lis Mack of the Partners FOR the Saskatchewan River Basin for permission to use illustrations appearing in their state of the basin reports. These illustrations were prepared by Philip Gregory.

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APPENDIX ONE – ACRONYMS AND ABBREVIATIONS

AEP – Alberta Environment and Parks (formerly AESRD)

AER – Alberta Energy Regulator (formerly ERCB)

AERSD – Alberta Environment and Sustainable Resource Development

BRWA – Beaver River Watershed Alliance

CCOG – Canadian Council on Geomatics

CDED – Canadian Digital Elevation Data

CNRL – Canadian Natural Resources Ltd

CSS – Cyclical Steam Stimulation

dam^3 – cubic decametre, one thousand cubic metres

DUC – Ducks Unlimited Canada

ERCB – Energy Resources Conservation Board (Alberta)

GOWN – Groundwater Observation Well Network (Alberta)

MAA – Master Agreement on Apportionment

NHN – National Hydro Network

NTS – National Topographic Series

PFSRB – Partners FOR the Saskatchewan River Basin

PFRA – Prairie Farm Rehabilitation Administration, a former agency of Agriculture Canada

PPWB – Prairie Provinces Water Board

SAGD – Steam Assisted Gravity Drainage

SRTM – Shuttle Radar Topographic Mission

TDF – The Document Foundation

WSC – Water Survey of Canada

APPENDIX TWO – KEY WATER LICENCES IN THE COLD LAKE BASIN

Licensee	Purpose	Approv. ID	Annual Maximum	Consump-tive Use	Return	Pumping Condition
Cold Lake RUSC	Municipal	31772	2,115,420	425,550	1,689,870*	no
Cold Lake RUSC	Municipal	31772	4,132,170	197,360	3,934,810*	no
Cold Lake RUSC	Municipal	31772	1,153,300	117,180	1,036,120*	no
Imperial Oil	Industrial	79923	5,110,000	5,073,000	37,000	yes
CNRL	Industrial	78374	2,629,654	2,629,654	0	yes
AEP	Fish Management	294739	2,200,001	2,200,000	1	yes
AEP	Fish Management	30710	6,996,300	705,550	6,290,750	yes

* Return flow is to Beaver River

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