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Evaluation of Lake Evaporation in the North Saskatchewan River Basin

Technical Report to the
PPWB Committee on Hydrology

December 2014

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PPWB Committee on Hydrology

Anthony Liu[1], Neil Taylor[1], Ali Kiyani[1,3] and Curtis Mooney[2]

[1] Hydrometeorology and Arctic Lab, Meteorological Service of Canada
[2] Science Unit, Meteorological Service of Canada
[3] University of Alberta

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Executive Summary

The North Saskatchewan River Basin (NSRB) is one of the largest river basins on the Canadian prairies. An accurate estimation of evaporation from the river and other water bodies in the NSRB is critical for calculating the water balance in the basin. Evaporation estimates are also an important part of apportionment calculations used to ensure equitable distribution of water between the Prairie Provinces.

In this study, by investigating various evaporation methods and applying them to two large water bodies (Lake Abraham and Brazeau Reservoir) in the NSRB, we find that the lake evaporation estimates from methods previously used in this region generally produce similar results. A generic modeling approach is developed to make reasonable estimates of lake evaporation and water balance from the reservoirs, which considers both model accuracy and data availability. An Ensemble Estimation System (EES) is also developed in an attempt to address the uncertainties associated with the lack of actual measurements of annual lake evaporation, as well as offering a quantitative estimate of the potential error introduced by utilizing models with different physical assumptions and input data. The results from ensemble system and individual members indicate that although there is year-to-year variation in precipitation and gross evaporation, in general, the estimated annual evaporation exceeds the total precipitation for Lake Abraham and Brazeau Reservoir. The ensemble mean shows that the average annual gross evaporation is about 545 mm at Lake Abraham and 580 mm at Brazeau Reservoir, and the net evaporation is 46 mm and 94 mm respectively.

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1. Introduction

Evaporation is one of the major components in the hydrologic cycle. The balance between precipitation and evaporation in a watershed can significantly impact water availability. An accurate estimation of evaporation is important to fully quantify the hydrology of a watershed, and for the purposes of the Prairie Provinces Water Board (PPWB) – Committee on Hydrology (COH), to ensure accurate estimates of water apportionment between provinces.

The North Saskatchewan River Basin (NSRB) is one of the largest river basins on the Canadian prairies. There are a significant number of open water bodies, including lakes and reservoirs, in the NSRB where evaporation is not limited by available water supply. The hydrology of the NSRB has not been adequately studied due to a limited hydrometeorological observation network, especially for evaporation.

Previous studies on open water evaporation in Prairie Provinces have greatly improved our understanding of lake evaporation in a unique mountain-prairie environment, as well as explored some practical estimation methods for open water evaporation (McKay and Stichling, 1961; Buckler and Quinn, 1971; Hopkinson, 1999; Strong and Hyrnkiw, 2001). Yet there are still uncertainties existing in lake evaporation estimation, mainly because no direct measurements of evaporation are available for these basins, including the NSRB. Measurement of evaporation is more complex and expensive as compared with measurements of other hydrometeorological components. There is a great need to develop a generic model to estimate evaporation from the water bodies in the NSRB, as well as to provide quantitative estimates of the uncertainties.

One of the tasks of the PPWB-COH is to conduct calculations of apportionable flow at provincial boundaries to determine if conditions of apportionment, outlined in the Master Agreement on Apportionment, are met. Evaporation from reservoirs is one source of water loss considered in the calculations. However, current practice is to ignore losses attributed to reservoirs at higher elevations in the Alberta Foothills under the assumption that annual net evaporation at these sites is negligible. In the interest of completeness and transparency, the COH seeks to evaluate the validity of this assumption for future apportionment calculations. The first step in this process is to estimate annual gross and net evaporation from these water bodies. The resulting estimates can then be evaluated in the context of apportionable flow at provincial boundaries.

The aim of the present work is twofold: 1) to develop a generic approach for the PPWB-COH to evaluate lake evaporation by comparing various methods to calculate evaporation from open water; and 2) to estimate precipitation-evaporation balance over Lake Abraham and Brazeau Reservoir located in the Alberta Foothills within the NSRB.

The remainder of the report is organized as follows: In section 2, we describe the data and methodology used in this study. In section 3, we present the lake evaporation estimates and discuss the generic lake evaporation approach for the NSRB. In section 4, we present the results on precipitation-evaporation balance for Lake Abraham and Brazeau Reservoir. Finally, our results are summarized in section 5.

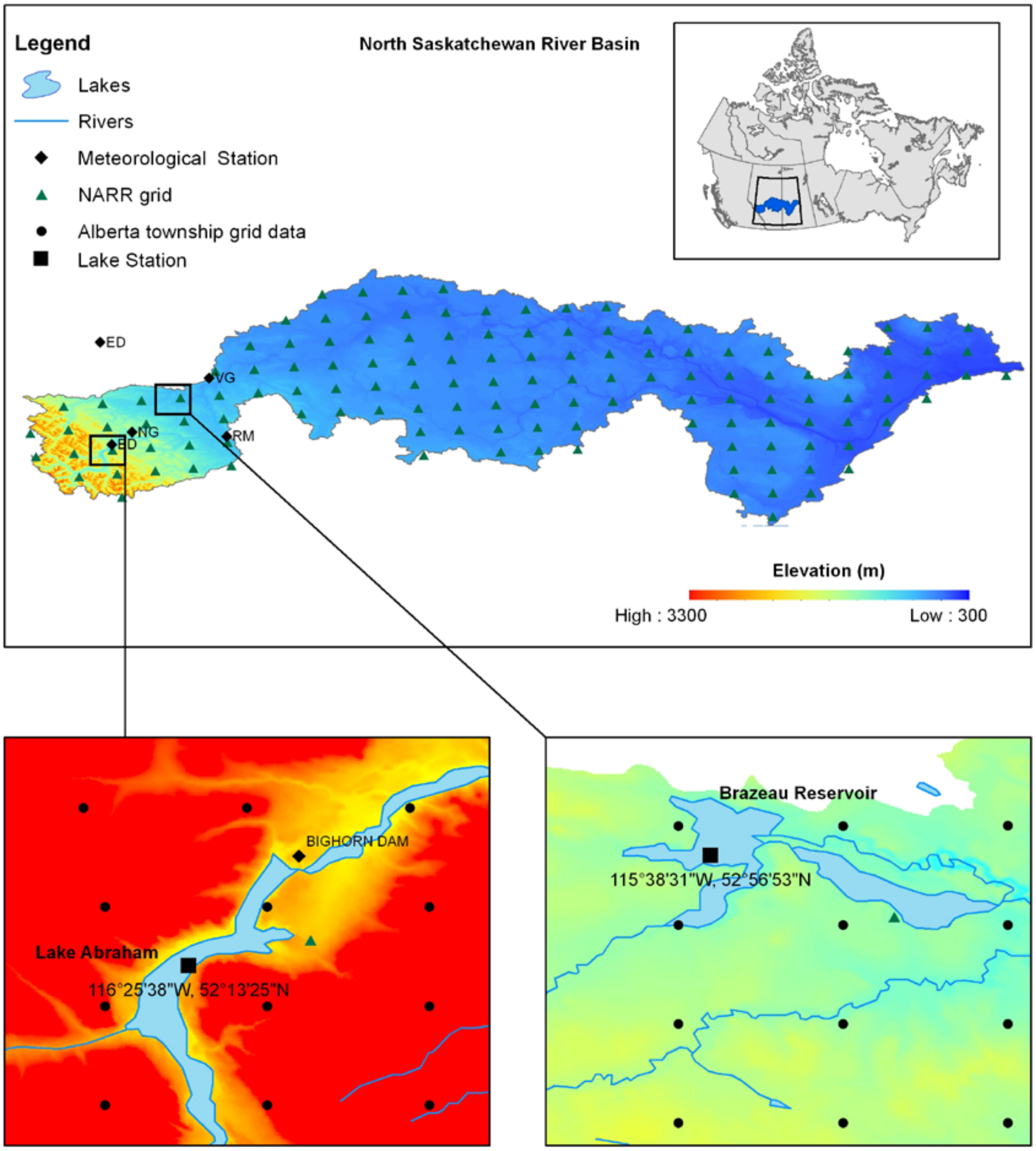

Figure 1: Locations of Lake Abraham and Brazeau Reservoir in the North Saskatchewan River Basin along with the locations of surface meteorological station data, Alberta township data and North American Reanalysis data (NARR). Bighorn Dam, Edson,

Nordegg, Rocky Mountain House, and Violet Grove stations are indicated as BD, ED, NG, RM and VG respectively.

2. Data and methodology

2.1 Data

The hydrometeorological data required to calculate lake evaporation varies between methods. In general, some or all of the following data are required: temperature, dewpoint temperature, relative humidity, wind speed, pressure, radiation and elevation.

Three datasets are used in this study: 1) Surface meteorological station observations, 2) the Alberta Environment township dataset, and 3) the North America Regional Reanalysis (NARR) dataset. These data provide a complete hydrometeorological dataset at the locations of interest, and allow calculation of evaporation using a number of methods.

Among these three datasets, the surface observations provide the most accurate meteorological conditions, but spatial coverage is coarse. There are no surface observations available at either Lake Abraham or Brazeau Reservoir. The surface observations from Nordegg, with precipitation data from Bighorn Dam, were used to represent the meteorological conditions at Lake Abraham; these data are available from 2001 to 2010. The conditions at Brazeau Reservoir were represented by the averaged observations from four nearby stations: Edson, Nordegg, Rocky Mountain House, and Violet Grove (Figure 1). The data period is from 1979 to 2010. There are no observational radiation data suitable for radiation based evaporation calculations available at any of these MSC met stations.

The Alberta Environment township dataset provides interpolated hydrometeorological conditions for major townships in Alberta based on available surface observations. This dataset includes daily maximum temperature, minimum temperature, relative humidity, precipitation, wind speed, wind direction, and incoming shortwave radiation. The data spatial resolution is 10 km and covers the period 1960 - 2008. However, minimum and maximum temperatures are the only parameters available for 1960 - 1971. Also, there are some data gaps in incoming radiation throughout the whole dataset. The surrounding township data were interpolated to Lake Abraham and Brazeau Reservoir (Figure 1) using inverse distance weighting (IDW) methods. This dataset is suitable for mass-transfer based evaporation calculations. The existence of incoming solar radiation data allows for some types of radiation-based evaporation calculations, but prohibits more complex methods which require both longwave and shortwave radiation.

The North American Regional Re-analysis (NARR) dataset from the National Centre for Environmental Prediction (NCEP) has a 32 km horizontal grid resolution and a temporal resolution of 3 hours for the North American domain for the period 1979-2010 (Mesinger et al., 2006). Previous studies have found that the NARR data provides reasonable historical weather conditions for climatological research (Bukovsky and Karoly 2007). Choi et al. (2009) found that NARR temperature and precipitation data agrees with observed data better than the global reanalysis products dataset for the northeastern Canadian Prairies. Other studies have found that NARR shortwave radiation data agree well with surface observations after applying some regression modifications to remove bias (Cohen et al. 2003; Schroeder et al. 2009). An ongoing University of Alberta (U of A) experiment validating NARR radiation data over central Alberta shows that NARR net radiation data correlates well with surface observations and can be used after applying bias correction techniques (see Appendix 2).

In this study, the original NARR net radiation data were bias-corrected based on the findings of the U of A research by applying Eq. 1a.

$$R_{nm} = R_n * A_1 + B_1 \qquad (1a)$$

where R_{nm} is modified net radiation, R_n is the original NARR net radiation, and A_1 and B_1 are regression coefficients valued at 1.0038 and -31.90.

Previous study by Schroeder et al. (2009) shows that the original NARR solar radiation data could be bias corrected by a linear applying Equation 1b,

$$R_{sn} = R_s * A_2 + B_2 \qquad (1b)$$

where R_{sn} is modified solar radiation, R_s is the original NARR solar radiation, and A_2 and B_2 are regression coefficients valued at 0.91 and -18.66.

The Alberta Agriculture and Rural Development (AARD) also developed a scheme to derive incoming solar radiation using temperature, latitude and date (AARD, 2013). In this study the AARD method was employed for incoming solar radiation estimation.

The modified NARR net radiation and AARD estimated incoming solar radiation data were then applied to Lake Abraham and Brazeau Reservoir for the evaporation calculations. One obvious advantage of the NARR dataset is that net radiation can be calculated from shortwave and longwave radiation data and therefore can be used to estimate evaporation using combined methods that require both radiation and mass-transfer components. NARR also provides the potential evaporation and precipitation distribution over the whole NSRB basin (Figure 1).

2.2 General Methodology

Evaporation can be described as a diffusive aerodynamic process that follows Fick's first law and can often be described by Dalton-type equations such as

$$E = f(K_e, v_a) \cdot (e_s - e_a) \qquad (2)$$

where E is the evaporation rate, e_s and e_a are the vapor pressure of the evaporating surface and the overlying air respectively; f is a function of v_a and K_e, where v_a is the wind speed, and K_e is an empirical coefficient for vertical vapour transport by the turbulent wind eddies.

The evaporation process is also controlled by energy conservation. The general energy balance for evaporation can be written as

$$E_v = R_n - H_s - E_w - \frac{\Delta Q}{\Delta t} \qquad (3)$$

Where E_v is the average energy flux for evaporation; R_n is the net radiation flux, including both shortwave and long wave; H_s is the sensible heat flux from the ground and atmosphere; E_w is the water-advected heat flux ; and $\frac{\Delta Q}{\Delta t}$ is the time rate of change of heat in the water body.

Based on the above relationships, a variety of methods have been developed to estimate lake evaporation, which can be divided into four categories: mass-transfer, energy balance, combined and complementary approaches (Dingman 1994).

Lake evaporation occurs over open water bodies where water supply is not limited so that the process mainly depends on regional hydrometeorological conditions. A variety of methods exist to estimate lake evaporation. For this study we have selected a few from each category that are either commonly used or which have been previously utilized in the region.

2.2.1 Mass-transfer approaches

The mass-transfer approaches are based on Eq. 2 and have been used extensively in previous studies to estimate lake evaporation (Meyer 1915, 1942; Penman 1948; Brutsaert 1982; PFRA 1988, 1994; Winter et al. 1995). Three methods using a mass-transfer approach were employed to estimate lake evaporation in this study. These are the Meyer method (MYR), the Prairie Farm Rehabilitation Administration (PFRA) modified Meyer method (MYR-PFRA), and the mass-transfer component from the Penman formula (PM-M). As compared with the original Meyer method, MYR-PFRA uses estimated water temperature. The MYR-PFRA equation has been used to calculate lake-evaporation for some lakes in the Prairie Provinces and these calculations provide a reference for water apportionment in the Prairie Provinces. Details of these methods are given in Appendix 1.

2.2.2 Radiation-based approaches

Based on an energy balance, radiation approaches can be derived using Eq. 3 where the water-advected fluxes and change in heat storage are often neglected. A number of empirical equations have been developed to calculate lake evaporation at a variety of locations (Makkink 1957; Jensen and Haise 1963; Priestley and Taylor 1972; Hargreaves 1975; Hargreaves and Samani 1982; Abtew 1996). The data used for each method varies, and in general, some or all of the following variables are required: incoming shortwave radiation, net radiation, pressure, and temperature. Five methods using a radiation-based approach were employed to calculate lake evaporation in this study. These are the Priestley-Taylor method (PT), Alberta Irrigation modified Priestley-Taylor method (PT-AI), Abtew method (ABT), Hargreaves and Samani method (HS) and the radiation component from the Penman formula (PM-R). Details of these methods are given in Appendix 1.

2.2.3 Combined approaches

Penman combined the mass-transfer (Eq.2) and energy balance (Eq.3) methods, resulting in the so-called Penman formula (Penman 1948). The Penman method requires input data from both mass-transfer and radiation approaches, which include temperature, dewpoint temperature or relative humidity, wind speed, pressure and net radiation. In this study, both the original Penman method (PM) and a Water Survey of Canada (WSC)-modified Penman method (PM-WSC) were used to calculate lake evaporation. Previous studies show that the WSC-modified Penman method can produce reasonable evaporation amounts compared with pan-derived evaporation estimates over some lakes in the Canadian Prairies (Hyde and Woodward 2006; Wagner-Watchel and MacCulloch 2011). Details of these methods are given in Appendix 1.

2.2.4 Complementary approaches

Complementary approaches for evaporation estimation are generally used when there are only standard meteorological variables available. Different complementary formulas for lake-evaporation have been derived (Brutsaert and Stricker 1979; Morton 1983; Granger and Gray 1989). In this study, the Morton method (MOT) is employed, which has been previously used in the Canadian prairies. Details of the model are given in Appendix 1.

2.3 An ensemble approach

Although it is possible to identify a group of suitable approaches or equations to estimate lake evaporation, it remains a challenge to determine which one gives the best result for a given year. This may be due to a number of constraints: each method requires different input data and the quality of these data vary with time; no direct evaporation measurements are available for validation; model performance varies with time, with no consensus of which model is less biased for a given year. The challenge is similar to predicting streamflow for an ungauged basin which relies on both the predictability of the method and the quality and availability of input data. Building an ensemble of all the validated methods provides an approach for making a quantitative estimate of the uncertainties introduced by utilizing models with different physics assumptions.

The hope is that an Ensemble Estimation System (EES) will capture the spread of the potential deviation from the actual value (i.e., what would be observed if measurements were available) associated with the uncertainty in estimated evaporation. Therefore an ensemble approach is recommended for deriving a reasonable evaporation estimate with some indication of associated uncertainties. The ensemble mean, minimum and maximum are defined in Eq. 4, 5, and 6.

$$E_{eps} = \frac{1}{n}\sum_{i=1}^{n} E_i \qquad (4)$$

$$E_{\min} = Min(E_1, E_2, ..., E_n) \qquad (5)$$

$$E_{\max} = Max(E_1, E_2, ..., E_n) \qquad (6)$$

where E_{eps}, $E_{\min}$ and $E_{\max}$ are ensemble mean, minimum and maximum and E_i is the evaporation estimate from the *n* th member.

3. Results and Discussion

All the lake evaporation estimates shown in this section are calculated using monthly mean meteorological conditions from the above dataset. A comparison between station data and Alberta township data is discussed later in this report. Gross evaporation was assumed to be zero from January to March, as the lakes are typically fully ice covered during the period.

3.1 Evaporation comparison for Lake Abraham

Annual evaporation at Lake Abraham was calculated using various methods with the results plotted in Figure 2. There is a large spread among results from the different methods, especially for the radiation-based approaches. Compared with the main cluster of the results, it is obvious that the Abtew equation overestimates and the original Priestley-Taylor equation underestimates evaporation. These two methods likely need to be calibrated before application to evaporation calculations over prairie lakes. Among the results from the three mass transfer methods, the MYR-PFRA equation calculated slightly higher values. Results from the two combined approaches are similar with the PM-WSC equation giving slightly higher values than the original PM. The Morton method agrees reasonably well with the other methods, but estimates a slightly higher value. In general the variation in annual evaporation is slightly stronger in the mass-transfer and combined approaches than in the Morton and radiation-based approaches. The evaporation estimates from several methods that have been previously adopted in the region stay within the main cluster of results, which include MYR-PFRA, MOT, PM-WSC, and PT-AI. It is also noted that almost all the estimates indicate stronger evaporation in 2001 when significant drought occurred, and weak evaporation in 2010, when the prairies experienced a relatively cold and wet summer.

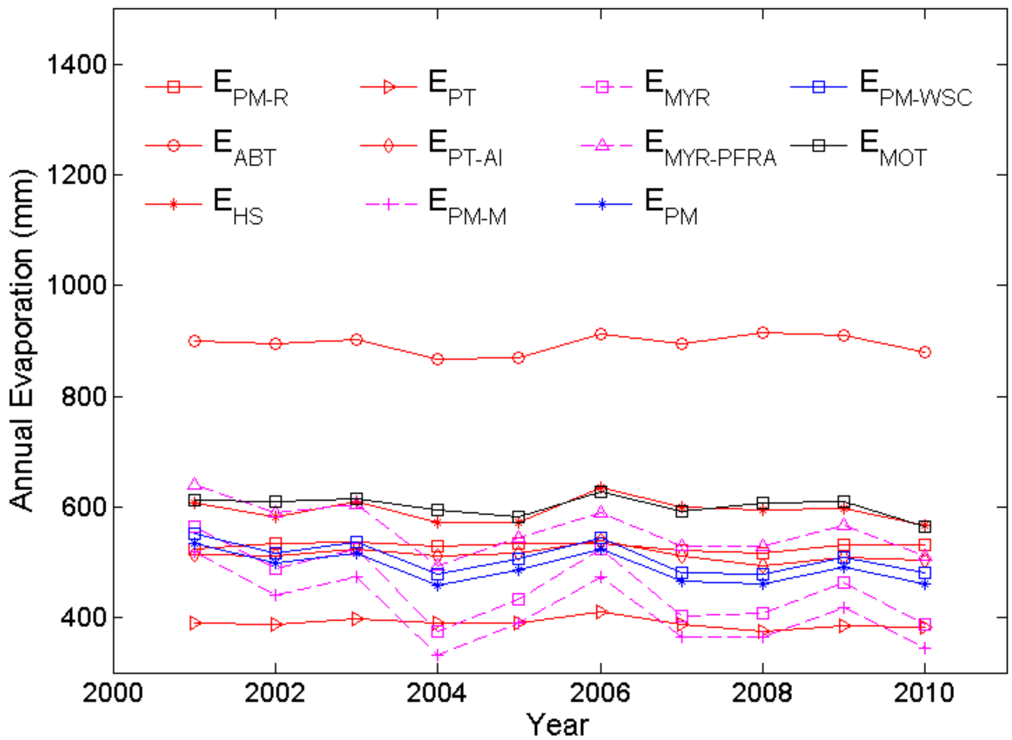

Figure 2: Comparison of estimates of annual lake evaporation over Lake Abraham.

Based on the results from the methods that have been validated in the region, we could eliminate the calculations that are likely out of range. Yet we cannot identify the method that can give the best estimate, because there is no direct evaporation measurement over Lake Abraham. Additional uncertainties in the input meteorological data also need to be considered, which makes model validation a real challenge.

Apportionment calculations in support of the PPWB require a reliable evaporation estimate based on available observations and methods. In this study, an EES is developed to derive a reasonable estimate as well as some associated uncertainty. The EES includes methods that have been previously verified in the region and those that were found to give reasonable estimates. The methods employed in the system come from four different groups as discussed in section 2. These are the PM, the PM-WSC, the MYR-PFRA, the PT-AI, the MOT, and the HS methods. The spread of the evaporation estimates from the EES is given in Figure 3. The estimates from MOT and HS are at the top of the envelope for most years. Results from the other methods vary from year to year.

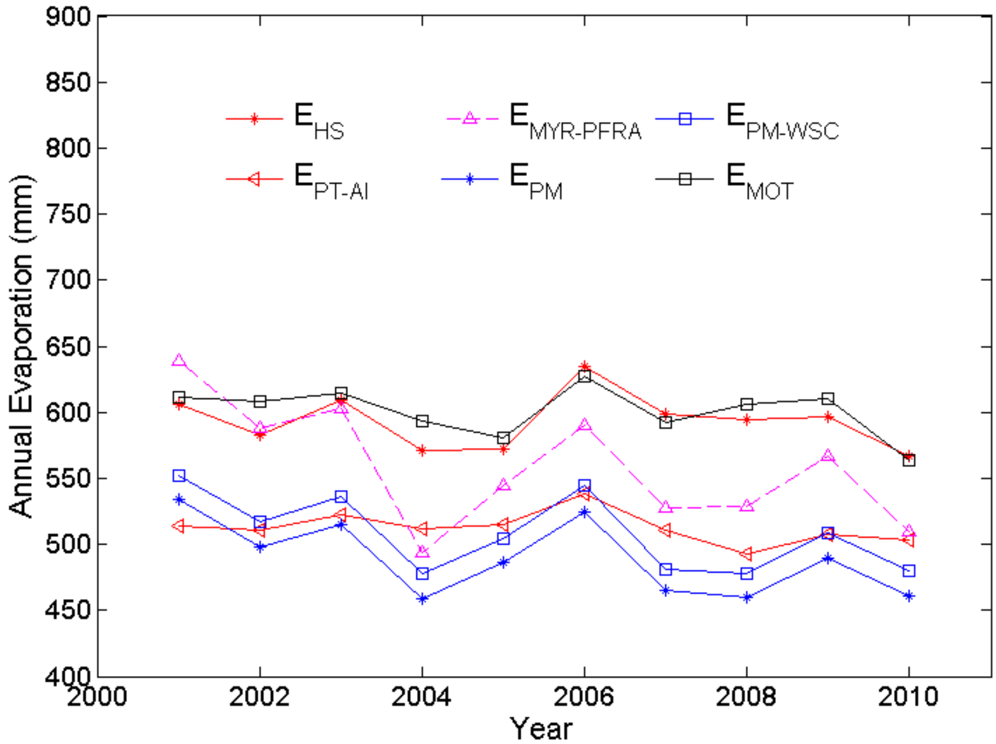

Figure 3: Spread of estimates of annual lake evaporation over Lake Abraham from the EES.

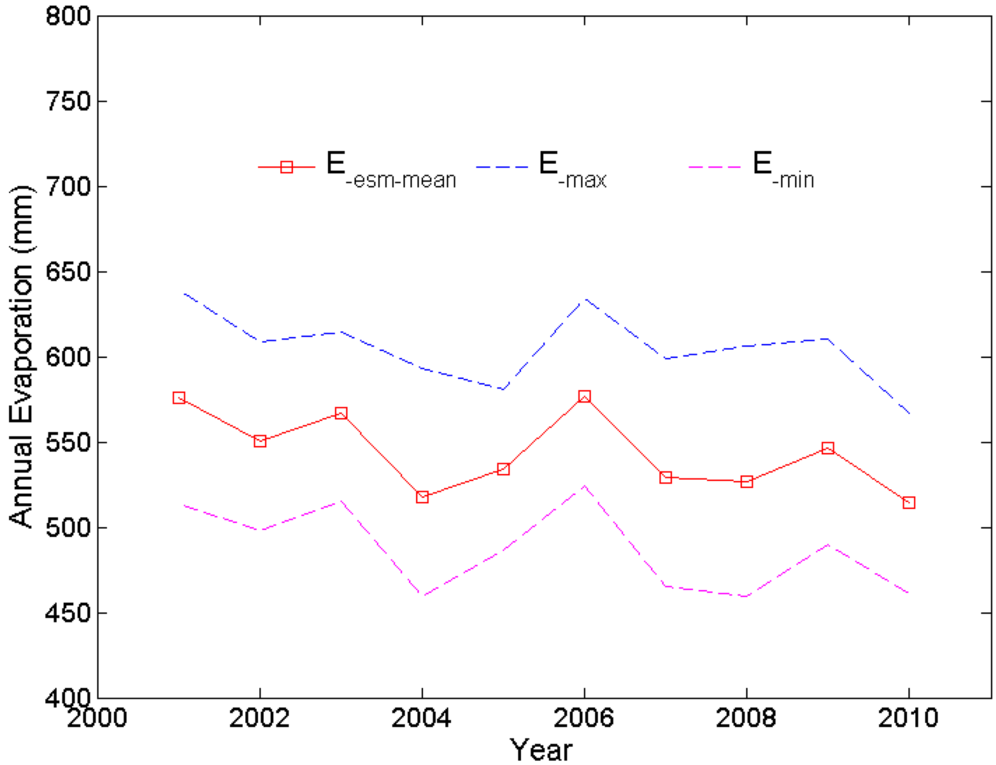

Figure 4: The minimum, maximum, and mean of annual lake evaporation of Lake Abraham (results from the EES).

The uncertainty of annual evaporation estimates at Lake Abraham was also calculated from the EES (Figure 4). There is evaporation uncertainty of about ±75 mm for a given year, which is within ±15% of the annual amount. The difference between ensemble mean and the methods (MOT, MYR-PFRA, and PM-WSC) that have been previously adopted in the region are relatively small, which is approximately within ±10% (Table 1). The EES shows that the 10-year mean lake evaporation at Lake Abraham is about 545 mm.

Table 1: Comparison of annual evaporation at Lake Abraham between EES mean and several methods being used.

Year	EES_Mean	E_Morton Minus EES_Mean	E_Meyer_PFRA Minus EES_Mean	E_Penman_WSC Minus EES_Mean
2001	576	35	63	-24
2002	551	58	38	-34
2003	567	47	36	-31
2004	518	75	-24	-40
2005	534	47	11	-29
2006	577	51	13	-32
2007	529	63	-1	-48
2008	527	80	2	-49
2009	547	64	20	-38
2010	514	50	-4	-34
Mean	544	57	15	-36

3.2 Evaporation comparison for Brazeau Reservoir

Meteorological data for Brazeau Reservoir allow the evaporation to be estimated over a longer time period, from 1979-2010. The results are similar to Lake Abraham, with a large spread among different methods (Figure 5). The results from the two combined approaches agree well with each other, with the PM-WSC method giving slightly higher values. Among the three mass-transfer methods, the MYR-PFRA method gives higher values than the other two approaches. With respect to the radiation approaches, similar to the results from Lake Abraham, the ABT equation likely overestimates and the original PT equation likely underestimates the evaporation. The rest of the radiation-based methods are similar to the main cluster of results. The MOT method agrees well with other methods and stays within the main cluster. It is also evident, as expected, that more evaporation occurred in a drought year (2001) and less evaporation occurred in a wet and cold year (2010).

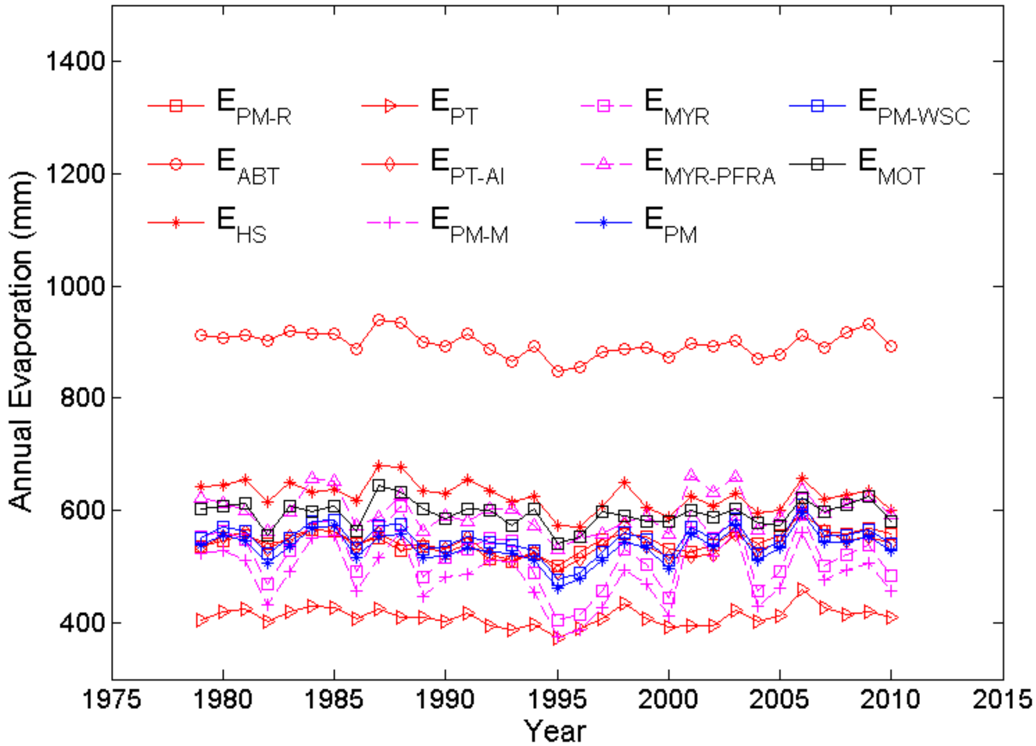

Figure 5: Comparison of annual lake evaporation calculated from various methods at Brazeau Reservoir.

The EES was applied to the Brazeau Reservoir results, and again the ensemble members capture the main variations of lake evaporation and the trends are similar to Lake Abraham (Figure 6). Individual results vary with time, with no consensus on which result consistently has high or low values. For some years, the model results are similar, while for other years the spread are larger. The uncertainty of annual evaporation estimates at Brazeau Reservoir is evaluated using the EES (Figure 7).

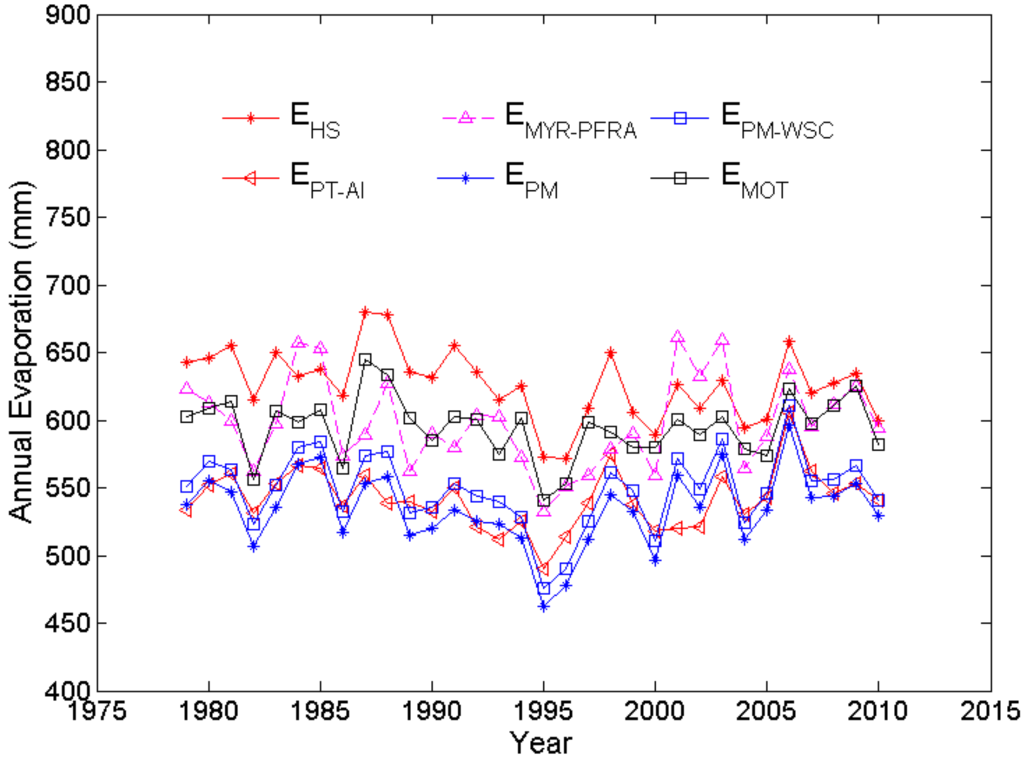

Figure 6: Spread of estimates of annual lake evaporation over Brazeau Reservoir from the EES.

It shows an evaporation uncertainty of less than ± 75 mm for a given year, within ± 15% of the annual amount. The EES shows that for 2001-2010, the same data period as Lake Abraham, the mean lake evaporation at Brazeau Reservoir is about 580 mm, which is higher than Lake Abraham (Table 2). This result agrees with findings from a previous PPWB COH study (R.F. Hopkinson, 1999), which shows that in general lake evaporation decreases with increasing elevation in the Canadian Prairies. The differences between EES mean and MOT, MYR-PFRA, PM-WSC methods are within 10% of the annual amount.

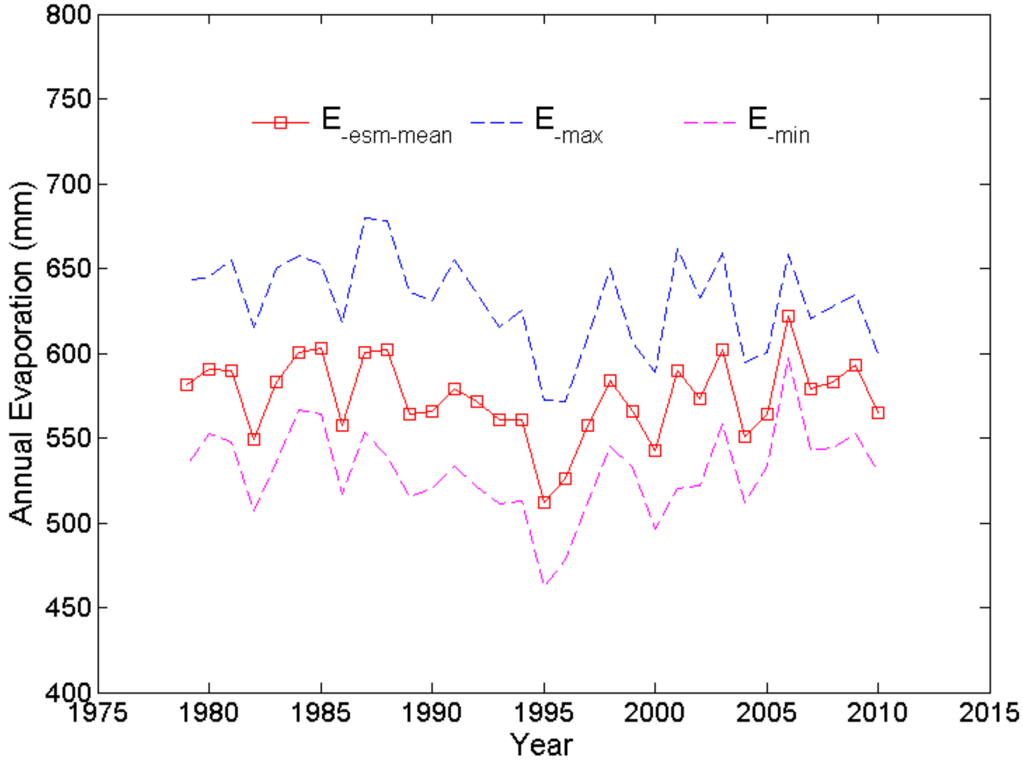

Figure 7: The minimum, maximum, and mean of annual lake evaporation of Brazeau Reservoir.

Table 2: Comparison of annual evaporation at Brazeau Reservoir between the EES mean and several methods being used (The value in bracket showing the average of 2001-2010, the same period as used in Lake Abraham).

Year	EES_Mean	E_Morton Minus EES_Mean	E_Meyer_PFRA Minus EES_Mean	E_Penman_WSC Minus EES_Mean
1979	582	21	42	-31
1980	591	18	22	-21
1981	590	24	10	-26
1982	549	7	13	-26
1983	583	24	15	-31
1984	600	-2	57	-21
1985	603	4	50	-19
1986	557	7	16	-24
1987	600	45	-11	-27
1988	602	32	25	-25
1989	564	38	-2	-33
1990	566	19	24	-30
1991	579	24	1	-26
1992	571	29	32	-28
1993	561	13	41	-22
1994	561	41	12	-33
1995	512	28	20	-37
1996	526	26	25	-36
1997	557	42	2	-31
1998	584	8	-5	-22
1999	566	15	24	-18
2000	542	38	17	-31
2001	590	11	72	-18
2002	573	16	60	-24
2003	602	1	57	-15
2004	551	28	14	-26
2005	564	9	24	-18
2006	622	1	15	-11
2007	579	18	16	-24
2008	583	28	29	-26
2009	593	32	32	-27
2010	565	17	29	-23
Mean	574 (582)	21(16)	24 (35)	-25 (-21)

3.3 A generic approach for estimating lake evaporation

In this section, we try to develop a generic approach for estimating lake evaporation over the Prairie water bodies for PPWB-COH basin review, which needs to consider both data availability and estimation uncertainties. As discussed earlier, the calculations of estimated lake evaporation demonstrate that there are a number of methods which give a reasonable evaporation estimate, especially those models which have been previously calibrated and validated at various lakes on the prairies. In general these models agree very well with each other and the differences between methods are approximately within 10% of the annual amount for any given year.

Most of the time, the data required for calculating evaporation from all the methods are not available. Therefore a generic model for calculating lake-evaporation must consider the data availability as well. Based on the results in this study, the following approach is recommended to be used in PPWB-COH basin review:

1) If all the required input data and the computing resources are available, the ensemble approach is recommended to determine the ensemble mean and uncertainty in evaporation estimates. The ensemble approach would be appropriate for detailed studies, such as basin reviews, but is not recommend for daily operations, due to data demands and complex calculations.

2) If both radiation and routine meteorological observation data are available, the PM-WSC method is recommended for a single model approach.

3) If only routine meteorological observation data are available, such as air temperature, wind speed, and dewpoint temperature, MYR-PFRA method is recommended.

4) If wind speed data are missing or cannot represent the station conditions, but if radiation data is available, the MOT method is recommended.

5) If only radiation data and air temperature data are available, the PT-AI method is recommended.

The PM-WSC method considers both mass-transfer and radiation information in evaporation estimates and stays close to the ensemble mean, therefore it is recommended for single model approach in PPWB-COH basin review.

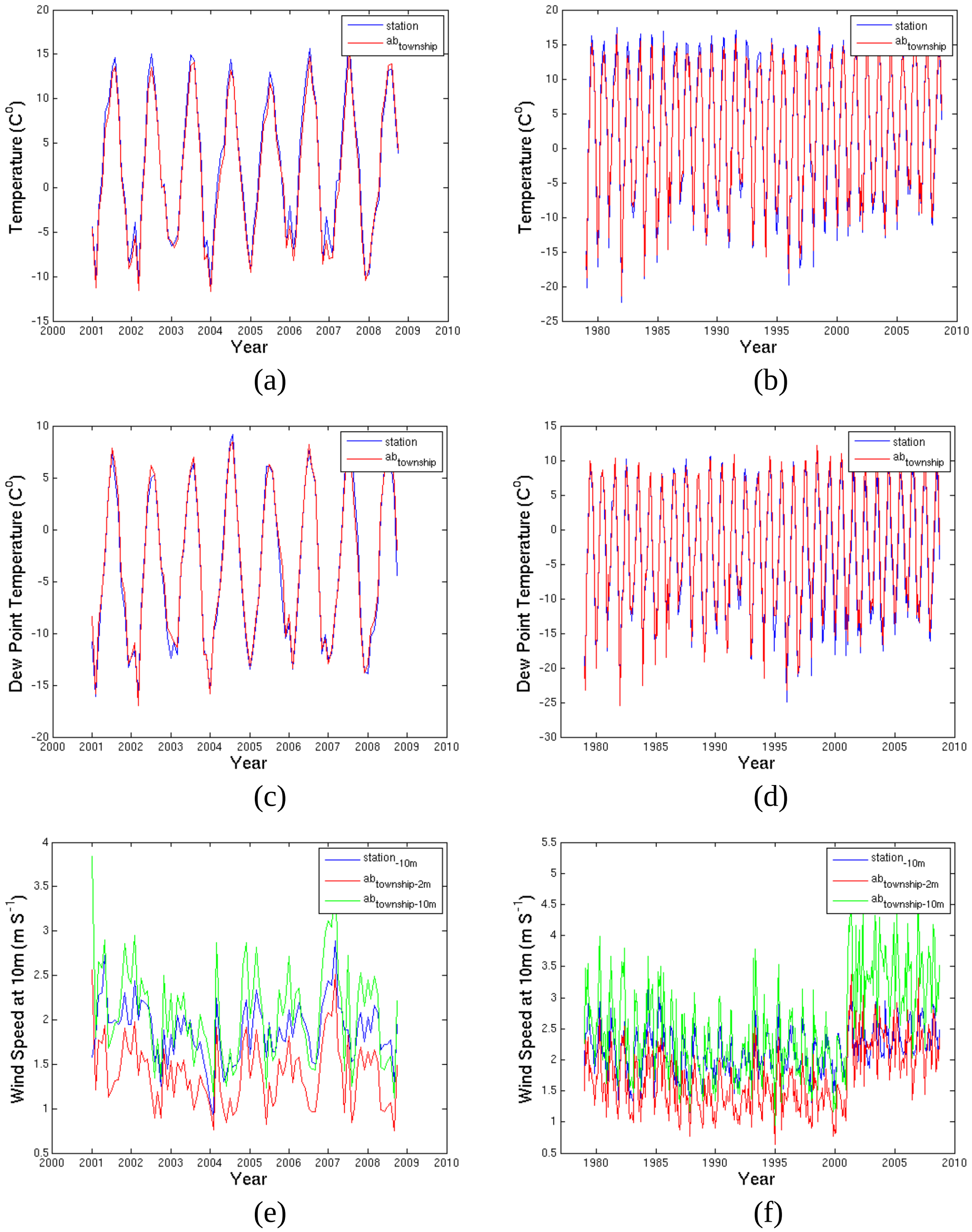

Figure 8: Comparison of temperature, dewpoint temperature and wind speed between the MSC station dataset and the Alberta township dataset at Lake Abraham (a,c,e) and Brazeau Reservoir (b,d,f).

We also investigated the applicability of using the Alberta township data at locations where the meteorological station data were not available. A comparison between these two datasets shows that temperature and dewpoint temperature data from the Alberta township dataset agree very well with the station observations, and therefore can be used in evaporation calculations (Figure 8). However there is some disagreement in the wind speed data. Wind speed records from the Alberta township dataset were observed at a height of 2 meters before being interpolated using a log wind profile to 10 meters to compare with the meteorological station data. The interpolated data show good agreement (albeit with a generally positive bias, especially at higher windspeeds) with MSC data at Lake Abraham but there is a big difference at Brazeau Reservoir. It is also noted that in 2002 an abrupt change to higher average wind speeds occurred in the Brazeau Reservoir Alberta township dataset, which requires further investigation (see Figure 8f). Also, the Alberta Township radiation record has a large number of missing data, which limits its usability.

4. Precipitation-evaporation balance

In this section, we present the results of net evaporation (evaporation minus precipitation) calculations to investigate the balance between precipitation and evaporation at Lake Abraham and Brazeau Reservoir.

4.1 Precipitation-evaporation balance at Lake Abraham

Precipitation data for Lake Abraham is available from all three datasets. A comparison between these datasets is given in Figure 9 showing that the Alberta township and NARR precipitation data agree well with the meteorological observations for most years. The precipitation trend in these three dataset is similar, with NARR slightly overestimating precipitation at Lake Abraham after 2006. All three datasets show a clear signal of precipitation deficit during the prairie drought period, 2001-2004, and precipitation surplus in 2005. There are some missing data in 2007 (the month of December) and 2010 (from October to December) in the meteorological station dataset, which may introduce errors into the results for these two years. The observed precipitation data are used in all net evaporation calculations.

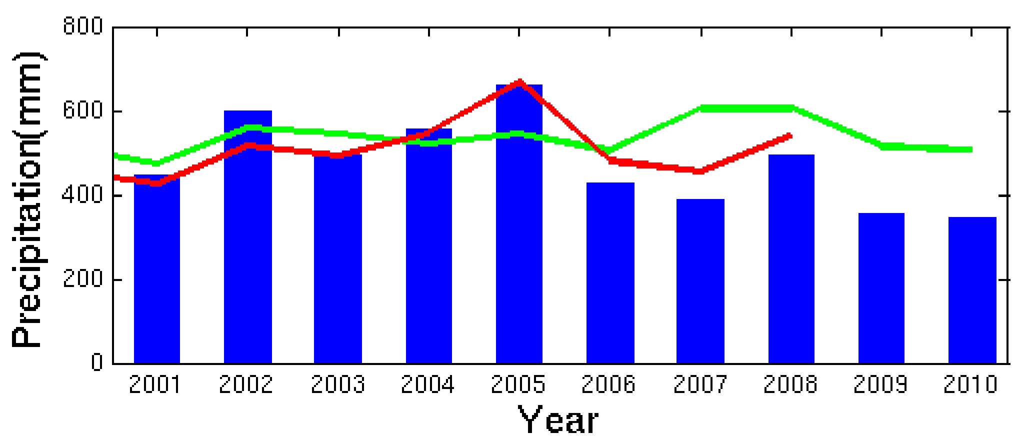

Figure 9: Comparison of annual precipitation data at Lake Abraham with surface station data (blue bars), Alberta township data (red line), and NARR data (green line). There are missing data in 2007 and 2010 in the MSC station dataset; the Alberta township data is only available till 2008.

The range in net evaporation calculated from the ensemble members shows that evaporation and precipitation are not always balanced at Lake Abraham, but vary from year to year (Figure 10). The results suggest that for most years which allowed a full-year calculation (2007 and 2010 had missing precipitation data) the estimated evaporation generally exceeds the total precipitation on an annual basis, except with water surplus in 2002, 2004 and 2005.

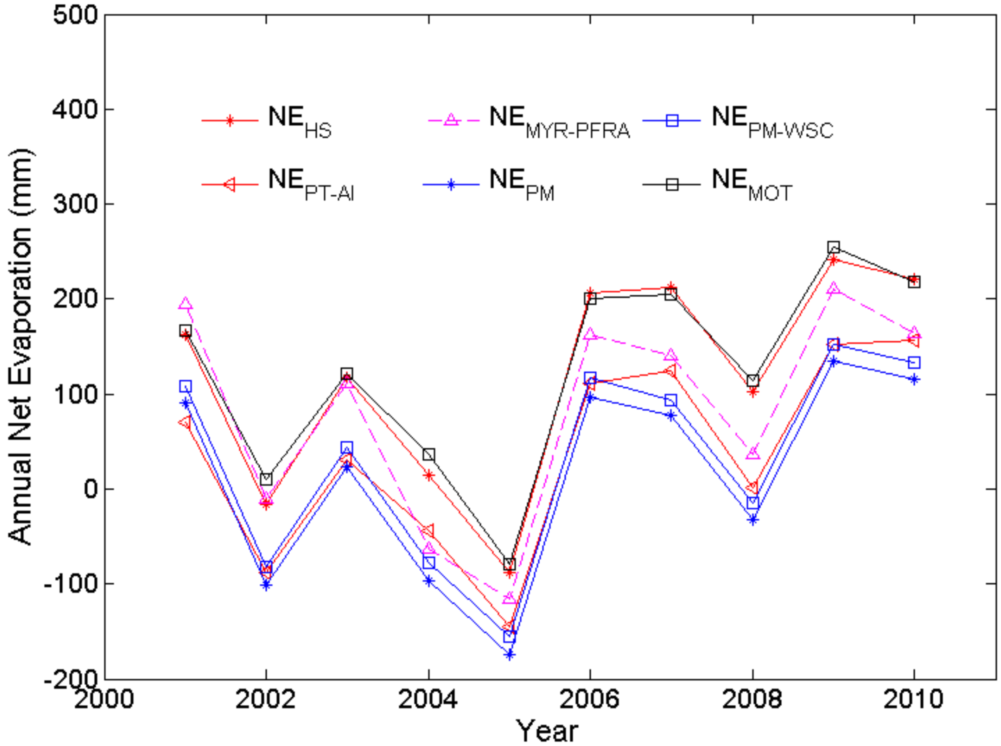

Figure 10: Net evaporation comparison at Lake Abraham. (The amount for 2007 and 2010 is not accurate due to missing precipitation data)

The ensemble mean and uncertainty chart (Figure 11) shows that for a typical dry year the water deficit is about 150-200mm, (e.g., 2006 and 2009), and for a wet year, such as 2005, the water surplus can reach 125mm. There are some years, such as 2004 and 2008, where precipitation and evaporation are roughly balanced (net evaporation near zero). It is noted that the range in the calculations varies with time. For most years the range in annual net evaporation exceeds 100mm. There is more confidence in the calculation for the years when the ensemble members agree well and the range is small. For the years with a relatively large range in values, users should be aware of estimation uncertainties and consider this information in risk management. A more detailed comparison between the ensemble mean and spread and several major methods is given in Table 3.

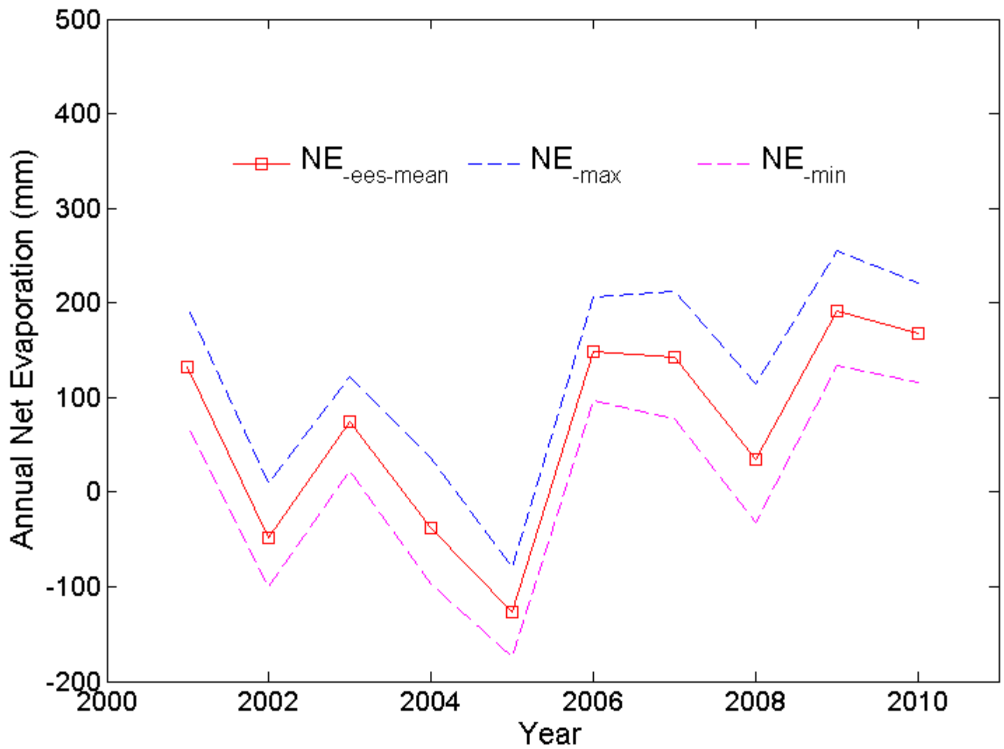

Figure 11: The minimum, maximum, and mean of annual net lake evaporation for Lake Abraham

Table 3. Comparison of annual net evaporation at Lake Abraham between the EES mean and several calculation methods (mm). The numbers in bracket are calculated with 2007 and 2010 data excluded.

Year	NE _Mean	NE _Max	NE _Min	NE_Morton	NE_Meyer_ PFRA	NE_Penman_ WSC
2001	132	195	70	167	195	108
2002	-48	10	-101	10	-10	-82
2003	75	122	23	122	111	44
2004	-39	37	-97	37	-62	-78
2005	-126	-79	-174	-79	-115	-156
2006	149	207	97	200	162	117
2007	142	212	78	205	141	94
2008	34	114	-33	114	37	-14
2009	191	255	134	255	211	153
2010	168	221	115	218	164	134
Mean	68 (46)	129 (108)	11(-10)	125 (103)	83 (66)	32 (11)

4.2 Precipitation-evaporation balance at Brazeau Reservoir

A comparison between precipitation data from the three datasets shows that the Alberta township data agree well with the meteorological observations at Brazeau Reservoir

(Figure 12). The NARR precipitation data agree well with observations until 2001 but then have a significant positive bias afterward, especially after 2005, where it exceeds 250mm. It is noted that the NARR dataset also shows some positive bias for Lake Abraham after 2005. This might be due to changes in the NARR model physics or data assimilation procedures after 2005, thereby affecting NARR's ability to reflect observed precipitation variation in this area. The observed precipitation data is used in net evaporation calculations for Brazeau Reservoir.

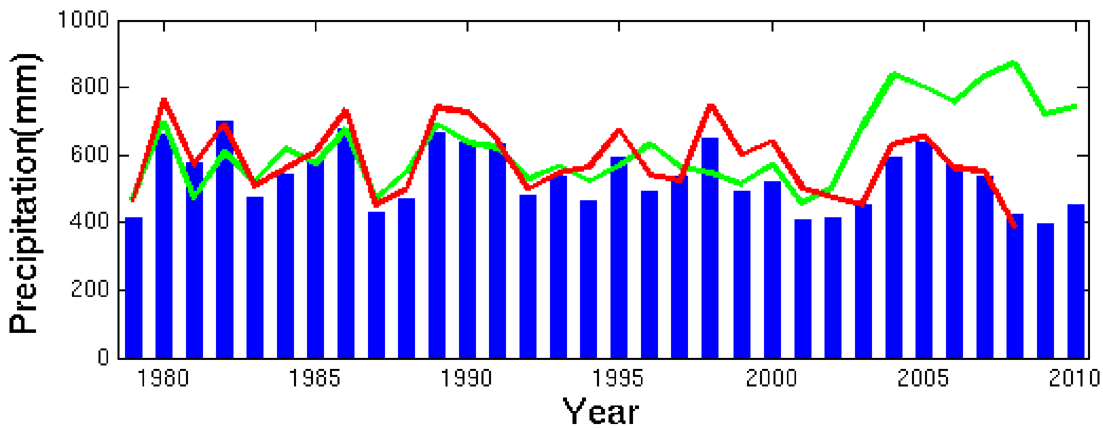

Figure 12: Comparison of annual precipitation data at Brazeau Reservoir. MSC data (blue bars); Alberta township data (red line); and NARR data (green line). (The Alberta township data is only available until 2008).

The net evaporation calculations for Brazeau Reservoir show a pattern similar to that of Lake Abraham, with the evaporation and precipitation balance varying with time (Figure 13). The members generally agree well with a range of about 100 mm for most years. However there are also years, such as 2001, with a relatively large spread of 142 mm.

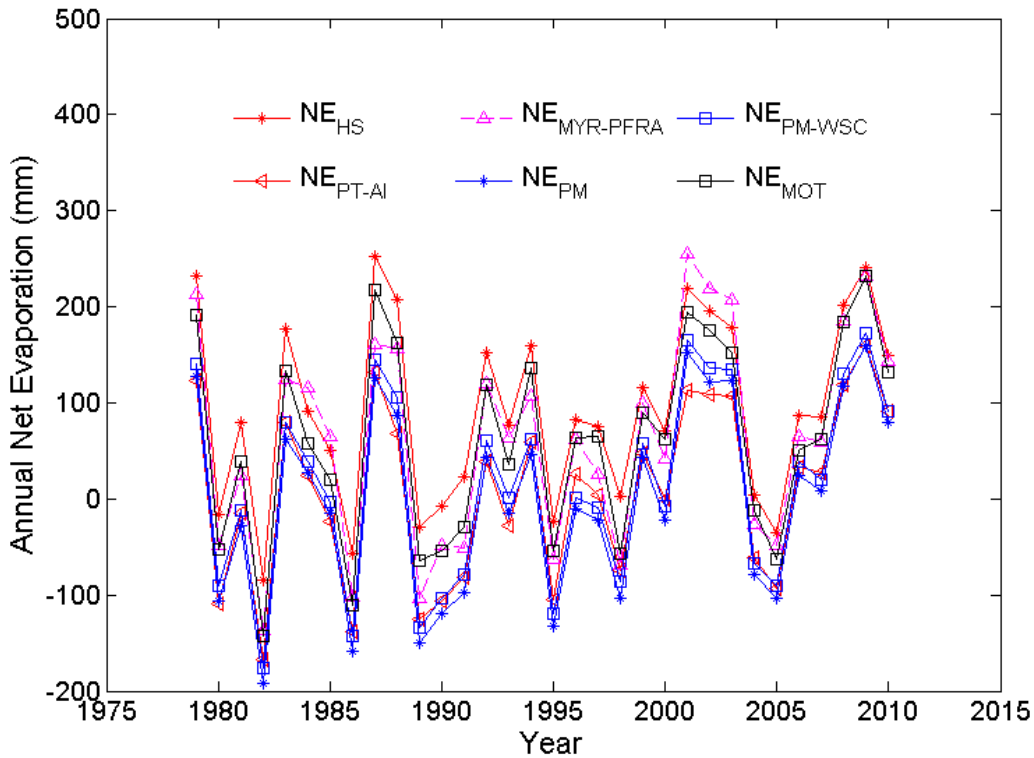

Figure 13: Net evaporation comparison at Brazeau Reservoir.

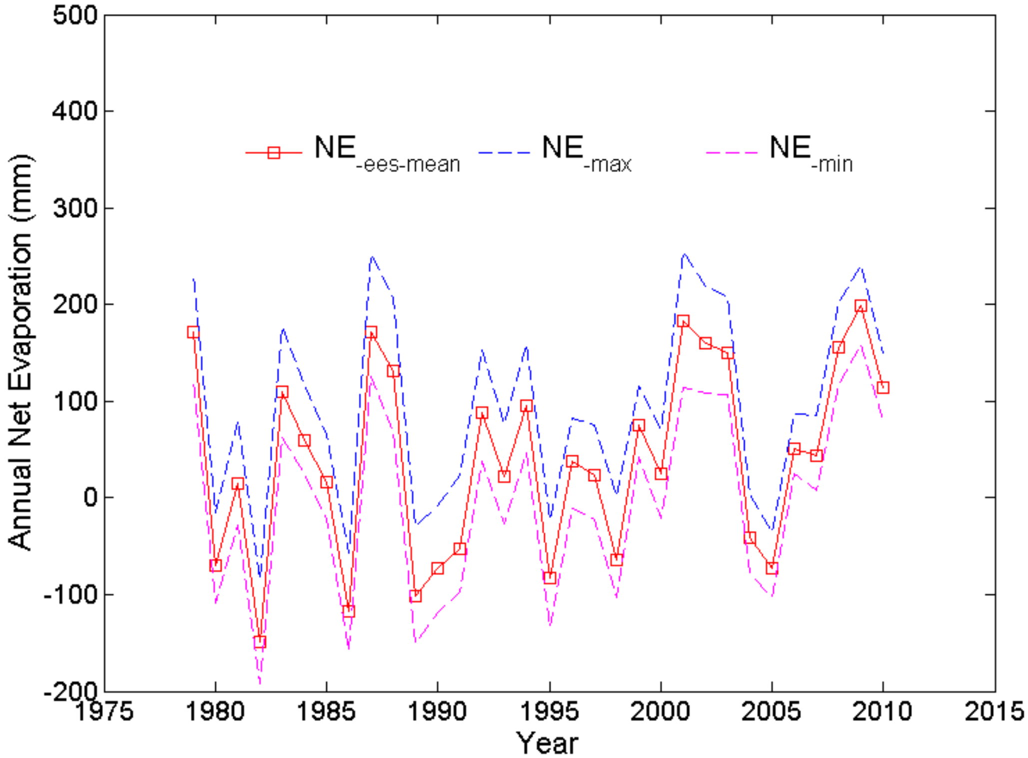

Figure 14: The minimum, maximum, and mean of annual net lake evaporation of Brazeau Reservoir.

The ensemble mean and uncertainty chart indicates that although a clear signal of precipitation surplus exists in some years, such as 1982, there are more years that the estimated annual evaporation exceeds the total precipitation (Figure 14). Similar to Lake Abraham, for a typical dry year, the water deficit is about 150-200 mm, and for a wet year, the water surplus can reaches 150 mm. There are also years when precipitation and evaporation are roughly balanced. The uncertainty in the calculations varies with time, which can be less than 100 mm (e.g. 2000), but jump to nearly 150 mm in the subsequent year (e.g. 2001). This requires further studies. A detailed comparison of net evaporation at Brazeau Reservoir between ensemble mean and spread for several major methods is given in Table 4.

Table 4. Comparison of annual net evaporation at Brazeau Reservoir between the EES mean and several calculation methods (mm). (The value in bracket showing the average of 2001-2010, the same period as used in Lake Abraham).

Year	NE_EES Mean	NE_EES Max	NE_EES Min	NE_ Morton	NE_Meyer _PFRA	NE_Penman _WSC
1979	171	232	123	192	213	140
1980	-70	-16	-109	-52	-49	-91
1981	15	80	-28	39	25	-11
1982	-150	-84	-192	-142	-137	-176
1983	109	177	63	134	124	79
1984	59	116	25	57	116	39
1985	16	66	-23	20	66	-3
1986	-118	-57	-158	-111	-102	-142
1987	172	252	125	217	161	145
1988	131	207	68	163	156	106
1989	-101	-30	-150	-64	-103	-134
1990	-73	-8	-119	-54	-49	-103
1991	-52	23	-98	-29	-51	-79
1992	89	152	38	118	121	61
1993	22	76	-27	36	64	1
1994	95	159	47	136	107	62
1995	-83	-23	-133	-54	-63	-119
1996	37	83	-11	64	62	2
1997	23	75	-22	65	25	-8
1998	-64	2	-103	-56	-69	-86
1999	76	116	43	90	100	58
2000	24	71	-22	62	42	-7
2001	183	255	113	194	255	165
2002	159	219	108	176	219	136
2003	151	208	107	152	208	135
2004	-40	3	-79	-12	-27	-67
2005	-73	-36	-103	-63	-49	-91
2006	50	87	25	51	66	39
2007	44	85	8	62	60	20
2008	156	201	118	184	185	130
2009	199	241	159	232	232	173
2010	114	149	80	132	144	91
Mean	40 (94)	96 (141)	-4 (54)	61 (111)	64 (129)	14 (73)

5. Summary and Conclusions

By investigating various evaporation methods and applying them to two large water bodies in the Alberta foothills, we try to develop a method for PPWB-COH to estimate gross and net lake evaporation over prairie water bodies with inadequate observations and validation for an accurate evaporation estimation. A number of general conclusions can be drawn from this study.

Three datasets were employed in this study, including a meteorological station dataset, an Alberta township dataset, and a NARR dataset. The temperature and dewpoint temperature data from the Alberta township dataset agree well with MSC station observations, but there was some bias in wind speed data, especially for Brazeau Reservoir. The Alberta township data should be used for areas where no direct meteorological observations are available. The NARR net radiation data can be used to estimate evaporation in the Canadian Prairies after applying some simple bias correction techniques.

The lake evaporation estimates from methods that have been previously used in this region generally agree well with each other for Lake Abraham and Brazeau Reservoir. These include the WSC-modified Penman (PM-WSC), the PFRA-modified Meyer (MYR-PFRA), the Alberta Irrigation-modified Priestley-Taylor (PT-AI) and the Morton (MOT) methods. An EES, which is developed based on these methods and several others, appears to give reasonable results. This system not only provides an estimate of the annual lake evaporation amount, but also offers a quantitative estimate of the uncertainty introduced by utilizing models with different physics assumptions and input data.

The results from ensemble system and individual members indicate that for most years, the estimated annual evaporation exceeds the total precipitation for Lake Abraham and Brazeau Reservoir. The ensemble mean shows that the average annual gross evaporation is about 545 mm at Lake Abraham and 580 mm at Brazeau Reservoir, and the net evaporation is 46 mm and 94 mm respectively.

Although evaporation exceeds precipitation at both sites on average, the net evaporation can vary significantly from year to year. For example, the water deficit can reach 200 mm for a dry year, while the water surplus can be close to 150 mm for a wet year.

Estimating lake evaporation in this region presents challenges due to limitations in observations of standard meteorological variables and radiation data. Uncertainty is compounded by a lack of direct evaporation measurements in this region, and over much of the Canadian prairies. A generic modeling approach is recommended that considers both model accuracy and data availability. Use of an ensemble estimation system allows estimates of lake evaporation, as well as associated uncertainty, with consideration of multiple physical approaches, therefore is recommended to be used in the PPWB-COH basin review process where the requisite data are available.

A pilot project on a lake that has standard hydrometeorological observations, as well as radiation and eddy covariance evaporation observations could be used to determine which method will provide the best calibrated results for evaporation estimate, and would help to narrow down the uncertainties in evaporation estimate. We recommend that the PPWB–COH consider forming a subgroup with members from COH as well as experts from three provinces to start working on such a pilot project, and to explore the ways to standardize evaporation estimated for all reservoirs of interest to the PPWB-COH apportionment calculation.

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Appendix 1 Methodologies for lake-evaporation calculations

Meyer equation (Meyer 1915, 1942)

This is the metric conversion of the Meyer equation. The original was in Imperial units, and evaporation was in inches.

$$E = 10.1 * (e_a - e_d)(1 + 0.062139 u_{7.6})(1 + .0000328084(el))$$

where

E = the bulk aerodynamic evaporation (mm)
e_a = saturation vapor pressure (mb)
e_d = vapor pressure (mb)
$u_{7.6}$ = wind velocity at 7.62 m above the ground (km/hr)
el = elevation of the station (m).

Vapor pressure can be calculated using the following equation. To calculate e_a the dewpoint temperature would be used. To calculate e_d the actual air temperature would be used:

$$e = 6.108 * \exp^{\frac{17.27T}{(T+237.3)}}$$

where

e = the vapor pressure (mb)
T = temperature (ºC)

To determine dew point temperature, the air actual air temperature and relative humidity are measured and dew point temperature is calculated using the following equation[1]:

$$T_d = \frac{bf(Rh,T)}{a - f(Rh,T)}$$

where

T_d = Dew Point Temperature (°C)

$$f(Rh,t) = \frac{aT}{b+T} + \ln(Rh/100)$$

a = 17.27

[1] For our calculations, dewpoint data were readily available from archived meteorological data.

b = 237.7 °C
Rh = relative humidity (%)
T = air temperature (°C)

The wind velocity at the appropriate elevation can be calculated using the following equations:

$$u_{7.6} = u_d (7.62/d)^{0.25}$$

where
$u_{7.6}$ = wind velocity at 7.62m above the ground (km/hr)
u_d = measured wind velocity at height d above ground (km/hr)
d = distance above ground (m)

PFRA –Meyer equation (Martin 2002)

Meyers Gross Evaporation (produced by PFRA for small to moderate-sized water bodies on the Prairies)

Data requirements:	saturated vapour pressure related to estimated water temperature, actual monthly vapour pressure, mean monthly windspeed
Time step:	monthly values
Spatial resolution:	Calculated at meteorological stations

$$E = CK(e_w - e_a)(1+6.2139 * 10^{-2}\, u_{7.6})(1+3.28084 * 10^{-5}\, Z)$$

E = evaporation (mm)
C – coefficient dependant on saturated vapour pressure reading interval per day. Range of values from 10.1 to 11, for observations of 1 to 24 readings per day. A value of 9.0 was used for the calculations in this report.

K – metric conversion factor (0.750062)

e_w – saturated vapour pressure at the estimated monthly mean water temperature (see PFRA 2002) at the surface of a hypothetical open body of water at the station site (mb).[2]

e_a – actual monthly mean vapour pressure in the atmosphere at 7.62 m above the ground level of the station (mb).

$u_{7.6}$ – monthly mean wind speed at 7.62 m above ground level of the station (km/hr)

Z – elevation of the station (m).

[2] Note that the PFRA document recommends determination of saturation vapour pressure using a formulation from Goff and Gratch (1946) whereas in our calculations we use the formulation from Alduchov and Eskridge (1996). The two methods were first compared to ensure consistency in results.

Priestley Taylor equation - original version and modified version by Alberta Irrigation (Priestley and Taylor 1972)

$$E = \alpha \frac{\Delta}{\Delta + \gamma} * \frac{R_n}{\lambda}$$

where:

E is evaporation, α is an empirical coefficient valued at 1.26, with α = 1.66 for Alberta Irrigation modified version. R_n is net radiation, Δ is slope of the saturated vapour pressure curve, e_s is saturated vapour pressure at temperature T (ºC).

$$\Delta = \frac{4098 * e_s}{(237.3 + T)^2}$$

$$e_s = 6.108 * \exp^{(\frac{17.27*T}{237.3+T})}$$

γ – psychrometric constant, P – atmospheric pressure (mb), λ – the latent heat of vapourization.

$$\gamma = 0.0016286 \frac{P}{\lambda}$$

$$\lambda = 2.501 - 0.002361 * T$$

Hargreaves and Samani equation (Hargreaves 1975; Hargreaves and Samani 1982)

$$E = 0.00135 * (T + 17.8) R_s$$

where E is evaporation (mm); T is air temperature (ºC); R_s is solar radiation (W m^{-2}).

Abtew equation (Abtew 1996)

$$E = K \frac{R_s}{\lambda}$$

where E is evaporation (mm); K is a dimensionless coefficient (0.53); R_s is solar radiation (MJ m^{-2}); λ is the latent heat of vapourization (MJ kg^{-1}).

Penman Equation (Maidment 1993)

$$E = \frac{1}{\lambda}\left[\frac{\Delta R_n + \rho_a c_p \, D/r_a}{\Delta + \gamma\left(1 + r_s/r_a\right)}\right]$$

where

Δ = gradient of saturated vapour pressure (kPa °C^{-1})
R_n= Net Radiation (MJ m^{-2} day^{-1})
ρ_a= density of air (kg m^{-3})
c_p= specific heat of moist air (=1013 J kg^{-1} °C^{-1})
D = vapor pressure deficit (e_s - e_a) in kPa
e_s= saturated vapor pressure (kPa)
e_a= actual vapor pressure (kPa)
r_a= aerodynamic resistance (s m^{-1})
r_s= surface resistance (s m^{-1})
γ = psychrometric constant (kPa °C^{-1})
λ = latent heat of vaporization of water (J kg^{-1})

Saturated vapour pressure is defined as a function of temperature (°C):

$$e_s = 0.6108 * \exp\left(\frac{17.27\ T}{237.3 + T}\right)$$

$e_a = RH \times e_s$

where RH is relative humidity. Alternatively e_a can be calculated using e_s equation if dew temperature (T_d) is used as T

The gradient of e_s, de_s/dT, is given by

$$\Delta = \frac{4098\ e_s}{(237.3 + T)^2}$$

Psychrometric constant is defined by the equation

$$\gamma = \frac{c_p P}{\varepsilon \lambda} \times 10^{-3}$$

where ε is the ratio of the molecular weight of water vapour to that of dry air (= 0.622), c_p is the specific heat of moist air (=1.013 kJ kg^{-1} °C^{-1}), P is the atmospheric pressure (kPa), and λ is the latent heat of vaporization of water (MJ kg^{-1}).

If T_s is the surface temperature of the water in °C, the latent heat of vaporization of water is given by

$$\lambda = 2.501 - 0.002361\ T_s$$

The density of air can be adequately estimated from

$$\rho_a = 3.486 \frac{P}{275 + T}$$

where P is the atmospheric pressure (kPa) and T is air temperature (°C).

The aerodynamic resistance r_a for open water can be estimated from

$$r_a = \frac{4.72 \left[\ln \left(z_m / z_o \right) \right]^2}{1 + 0.536\ U_2}$$

where z_m (m) is the height at which meteorological variables are measured, z_o (m) is the aerodynamic roughness of the surface, and U_2 is wind velocity in m s^{-1} measured at 2 m.

For a standard measurement height of 2 m for wind speed, air temperature, and humidity measurement and assuming the value z_o = 0.00137 m, and assuming r_s = 0, the Penman equation can be simplified and rearranged for calculating potential evaporation from open surface water as:

$$E_{Penman} = \left[\frac{\Delta}{\Delta + \gamma} \left(R_n / \lambda \right) + \frac{\gamma}{\Delta + \gamma} \frac{6.43\ (1 + 0.536\ U_2)}{\lambda} D \right]$$

where R_n (MJ m^{-2} day^{-1}) is net radiation, U_2 (m s^{-1}) is the wind speed at 2 m, D (kPa) is the vapor pressure deficit.

WSC Modified Penman (WSC report 2006, 2011)

$$E = \frac{\Delta Qn + \gamma Ea}{\Delta + \gamma}$$

where

E = daily evaporation from a water surface (mm)
Δ = rate of change of vapor pressure at the air temperature (mb)
Qn = net radiation in evaporation units (mm)
γ = psychrometric constant
Ea = bulk aerodynamic estimate of evaporation (mm)

The rate of change of vapor pressure at the air temperature, Δ, can be stated as:

$$\Delta = \frac{m_v L_e e_s}{RT^2}$$

where

m_v = molecular weight of water vapor (18.02 g/mol)
L_e = latent heat of vaporization (597.3-0.566T) cal/g where T is in ºC
e_s = vapor pressure at the air temperature (mb)
R = universal gas constant (1.9872 cal/mol/ºK)
T = temperature (K)
The psychrometric constant, γ, can be stated as:

$$\gamma = \frac{c_p p}{\varepsilon L_e}$$

where

c_p = heat capacity of dry air (0.240 cal/g/ºK)
p = atmospheric pressure (mb)
ε = 0.622, the ratio of the molecular weight of water vapor to the molecular weight of dry air.

The atmospheric pressure is a function of elevation and can be calculated using:

$$p = 1013.25 * (1 - 0.0000225577 * el)^{5.25588}$$

where

el = elevation (m)

The net radiation in terms of evaporation units is a conversion of the sensed net radiation in MJ/m^2 to mm using the following conversion:

$$Qn = \frac{238.95}{L_e} Rn$$

where

Qn = net radiation (mm)
Rn = measured net radiation (MJ m^{-2})

Ea is the bulk aerodynamic evaporation and can be estimated using Meyer equation:

$$Ea = \frac{10.1}{30.4}(e_a - e_d)(1 + 0.062139u_{7.6})(1 + .0000328084(el))$$

where

Ea = the bulk aerodynamic evaporation (mm/day)
e_a = saturation vapor pressure (mb)
e_d = vapor pressure (mb)
$u_{7.6}$ = wind velocity at 7.62 m above the ground (km/hr)

Vapor pressure can be calculated using the following equation. To calculate e_a the dewpoint temperature would be used. To calculate e_d the actual temperature would be used:

$$e = 6.11 * \exp^{\frac{17.26T}{(T+237.3)}}$$

where
e = the vapor pressure (mb)
T = temperature (ºC)

To determine dew point temperature, the actual air temperature and relative humidity are measured and dew point temperature is calculated using the following equation:

$$T_d = \frac{bf(Rh,T)}{a - f(Rh,T)}$$

where

T_d = Dew Point Temperature (ºC)
$f(Rh,t) = \frac{aT}{b+T} + \ln(Rh/100)$
a = 17.27
b = 237.3 ºC

Rh = relative humidity (%)
T = air temperature (ºC)

The wind velocity at the appropriate elevation can be calculated using the following equations:

$$u_{7.6} = u_d (7.62/d)^{0.25}$$

where
$u_{7.6}$ = wind velocity at 7.62m above the ground (km/hr)
u_d = measured wind velocity at height above ground (km/hr)
d = distance above ground (m)

Morton's CRAE method: (Morton 1983)

$E_W = b_1 + b_2 (1 + \gamma p / \Delta_p)^{-1} R_{TP}$
$R_{TP} = E_{TP} + \gamma p^* f_T^*(T_p - T))$
$E_{TP} = Rn - \lambda f_T(T_p - T)$

where E_W is lake evaporation , b_1 = 13.0Wm^{-2} and b_2 = 1.12; R_n is net radiation in Wm^{-2}, which is calculated as described in Morton (1983); E_{TP} is potential evapotranspiration; R_{TP} is potential evaporation at equilibrium temperature.

Estimate λ, the heat transfer coefficient
$\lambda = \gamma p + 4 \varepsilon\sigma (T + 273)^3 / f_T$
where $\gamma p = (\gamma p_s)(p/p_s)$
γp_s = 0.66 mbar ºC^{-1} for T =0ºC, for T < 0ºC γp_s = 0.66/1.15 mbar ºC^{-1}

Estimate the vapour transfer coefficient, f_T
$f_T = (p_s/p)^{0.5} f_z/\xi$
where f_z = 25.0 Wm^{-2} mbar^{-1} for T =0ºC, for T < 0ºC f_z = 25.0 x 1.15 Wm^{-2} mb^{-1}
ξ = the stability factor
$1/\xi = 0.28(1 + v_D/v) + \Delta R_{TC}\, \gamma p(p_s/p)^{0.5} b_o f_z (v - v_D)]$
Δ = the slope of the saturation vapour pressure curve at T
$\Delta = dv/dT = \alpha \beta v/(T + \beta)^2$
note for T => 0ºC, α = 17.27 and β = 237.3 and for T < 0ºC, α = 21.88 and β= 265.5
b_o = 1.0
$R_{TC} = R_T$

Estimate T_p, the potential evapotranspiration equilibrium temperature, an iterative solution of the vapour transfer and energy balance equations for a moist surface:

$[\delta T_p] = [R_T / f_T + v_D - v'_P + \lambda(T - T'_P] / (\Delta'_P + \lambda)$

solve iteratively until $[\delta T_p] = 0.01$ºC by setting initial values of T'_P, v'_P, and Δ'_P equal to T, v, and Δ

where T = average of maximum and minimum air temperature (ºC)

$v_p = 6.11 \exp [\alpha T_p/(T_p + \beta)]$ mb

$\Delta_p = \alpha \beta v_p/(T_p + \beta)^2$

and $T_p = T'_P + [\delta T_p]$

Appendix II. NARR radiation validation over Central Alberta

An ongoing University of Alberta experiment validating NARR radiation data over central Alberta shows that NARR net radiation data correlates well with surface observations and can be used after applying bias correction techniques.

NARR net radiation is calculated as follows:

R_n (W m^{-2})=*DSWRF* + *DLWRF* – *USWRF* - *ULWRF*
where *DSWRF* is the downward shortwave radiation flux, *DLWRF* is the downward longwave radiation flux, *USWRF* is the upward shortwave radiation flux, and *ULWRF* is the upward longwave radiation flux. The 3-hr NARR radiation fluxes were interpolated to create an hourly timeseries.

The correlation between observed R_n and NARR is 0.84, which implies that NARR follows the diurnal trend very well. The observed R_n is measured at a point in the field while the NARR R_n is averaged over a 32 by 32 km square. This difference in scales between the datasets, especially in a highly heterogeneous forested environment, will create some discrepency between the observed and NARR R_n. It is expected that in locations where heterogeneity is small (e.g. for lakes) the relationship between NARR and observed R_n will improve.

The original NARR net radiation data were bias-corrected by applying the following equation.

$$R_{nm} = R_n A_1 + B_1$$

where R_{nm} is modified net radiation, R_n is the original NARR net radiation, and A_1 and B_1 are regression coefficients valued at 1.0038 and -31.9.

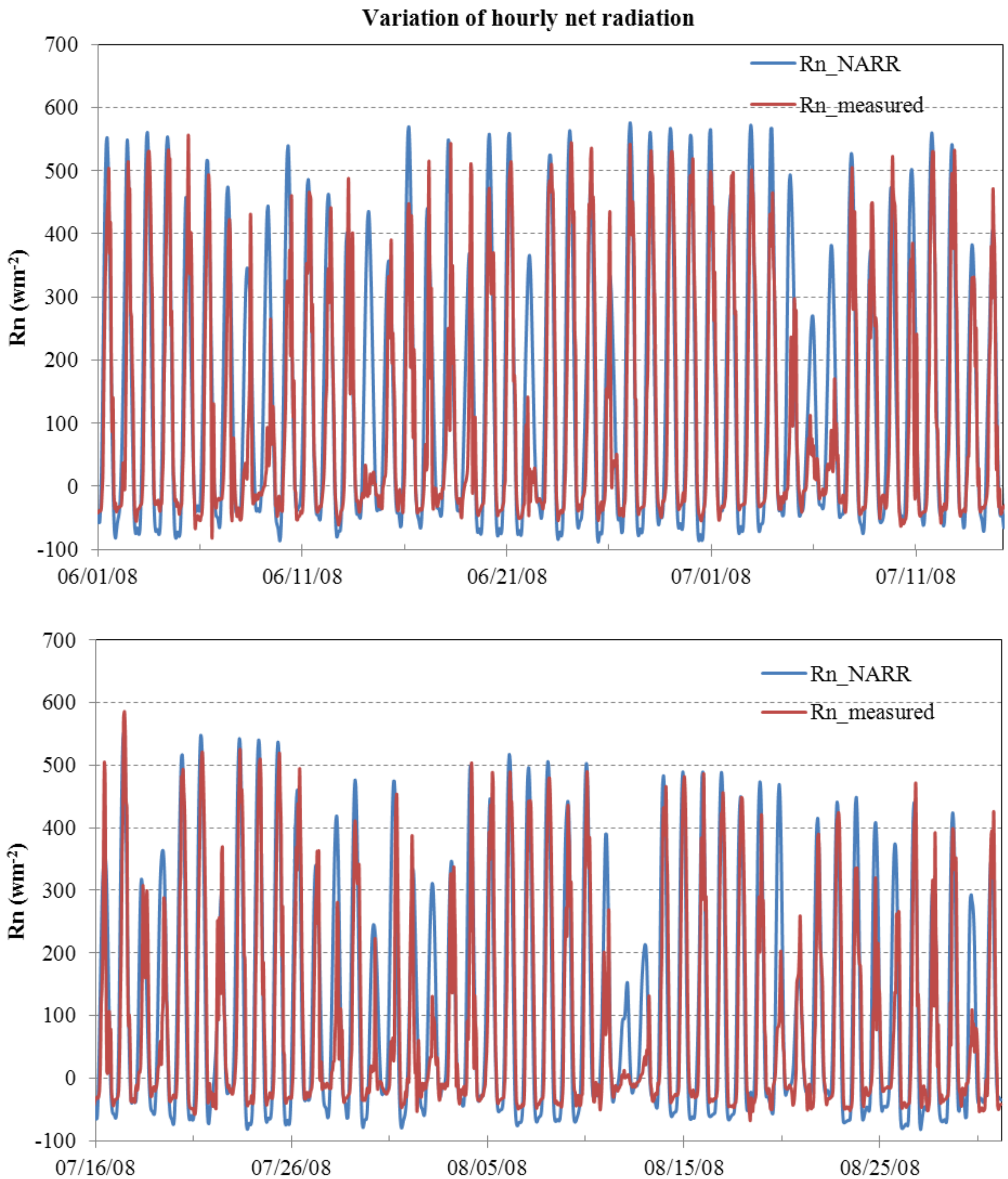

Figure II.1 Variation of hourly net radiation (R_n) measured by net radiometer instrument during summer 2008 for a research study site located in northeastern Alberta (55N, 112W). R_n of NARR data (32 km resolution) was interpolated at the field measurement location (Kiyani A. et al., unpublished data from PhD research at the University of Alberta).

Appendix III. Monthly average meteorological data used for evaporation calculations in this study.

Wind Speed (km/h) at Lake Abraham

Station	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
3054843	2001	5.7	6.5	8.2	8.3	9.8	7.1	7.1	7.2	7	7.2	8.3	7
3054843	2002	7	8.8	7.2	8	7.9	7.8	7.3	5.5	6	4.5	6.8	5.2
3054843	2003	6.6	5.8	7.4	6.6	7.4	6.7	7.2	6.2	6	6.3	5.5	5
3054843	2004	3.9	3.3	8.1	6.1	4.7	5	5.7	5.3	5.4	5.7	7.3	8
3054843	2005	5.8	7.1	8.4	7.7	7.2	5.7	7.1	5.9	5.9	6.9	6.4	6.3
3054843	2006	7.6	6.5	7.2	7.9	7.4	7	6.5	5.5	5.4	5.8	7.7	8.3
3054843	2007	8.8	8.6	10.4	7.7	7.6	6.8	6.8	5.5	5.6	7.1	7.5	6.3
3054843	2008	7.3	6.7	7.8	7.5	6	6.2	6.2	6.4	4.7	7	7.1	5.1
3054843	2009	8.6	7	8.9	6.8	7.8	6.8	5.6	5.4	7.2	5.5	10.7	5.5
3054843	2010	6.2	4.4	8.2	7.8	6.6	6.6	5	4.6	4.7	6.6	6.6	5.3

Dewpoint Temperature (°C) at Lake Abraham

Station	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
3054843	2001	-10.8	-16.1	-10.9	-5.8	-3	3.6	7.3	5.1	1.9	-5.3	-7.8	-13.3
3054843	2002	-12.3	-11.7	-16.1	-7.7	-2.1	2.3	5	5.3	1.9	-3.3	-5.7	-10.4
3054843	2003	-12.4	-10.9	-12.1	-3.5	-2	3.2	5.4	6.4	2.1	-2.5	-11.5	-12.2
3054843	2004	-15.5	-9.8	-8.7	-5.3	-0.5	4.3	8.4	9.2	3.1	-3	-6.8	-11
3054843	2005	-13.5	-11.8	-8.6	-6	0.2	6.1	6.1	5.5	1.8	-2.2	-7.5	-10.5
3054843	2006	-9.1	-13.5	-10.5	-5	-0.5	5	7.6	6	4.4	-2.4	-12	-10.1
3054843	2007	-12.5	-12	-7.9	-5.3	-0.5	5	8.7	8.5	3.8	-1.2	-8.8	-13.7
3054843	2008	-13.9	-10.4	-9.6	-6.9	1.8	5.8	6.9	6.6	3.2	-4.4	-6.4	-16.2
3054843	2009	-13.9	-12.4	-11.7	-6.3	-2.4	2.4	8	7.3	3	-4.5	-7.7	-15.6
3054843	2010	-9.2	-7.7	-7.7	-6.9	-1.4	3.8	6.5	7.4	3.4	-1.2	-6.7	-12.1

Air Temperature (°C) at Lake Abraham

Station	Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
3054843	2001	-4.4	-10.3	-2.3	1.6	8.5	9.7	13.6	14.6	9.3	1.5	-1.4	-8.7
3054843	2002	-7.3	-3.9	-10.9	-1.4	4.3	12.3	15.0	11.3	6.9	0.0	0.4	-5.3
3054843	2003	-6.6	-6.2	-5.2	1.7	5.8	11.2	14.9	14.3	7.8	4.6	-6.9	-5.9
3054843	2004	-11.1	-3.7	0.2	3.8	4.9	11.0	14.4	12.2	6.1	1.9	-0.9	-5.9
3054843	2005	-9.4	-4.5	-1.3	3.5	8.1	9.8	13.0	11.1	6.3	3.8	-1.6	-6.2
3054843	2006	-2.1	-6.9	-4.3	4.8	8.8	12.8	15.7	11.9	9.3	1.5	-8.5	-3.3
3054843	2007	-5.6	-7.6	0.7	0.9	7.2	11.5	16.9	10.5	6.8	3.4	-4.0	-10.1
3054843	2008	-9.7	-5.7	-2.8	-1.3	7.1	10.0	13.1	13.4	7.6	3.9	0.5	-13.5
3054843	2009	-7.8	-7.1	-5.2	0.5	6.0	10.0	13.9	12.6	11.1	-1.0	0.2	-13.8
3054843	2010	-5.8	-3.0	1.2	3.1	4.9	9.8	12.9	11.4	6.2	5.3	-1.3	-9.0

Net radiation ($W\ m^{-2}$) from NARR at Lake Abraham

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	-44.6	-12.4	35.5	97.3	141.5	143.4	135.8	106.7	55.9	12.1	-28.2	-50.0
2002	-33.4	-12.0	38.8	96.9	131.2	152.5	141.7	107.6	59.7	2.7	-29.6	-51.5
2003	-37.8	-10.2	44.8	97.6	137.6	149.8	138.9	105.4	61.6	10.1	-28.5	-53.5
2004	-24.0	-21.7	37.5	99.4	132.0	147.0	140.4	107.4	59.3	5.9	-32.8	-42.1
2005	-32.6	-16.0	42.1	103.7	140.2	145.0	139.6	102.2	59.5	9.1	-28.3	-46.9
2006	-32.9	-5.8	28.8	94.2	138.9	150.0	140.9	103.5	61.1	7.9	-22.5	-44.1
2007	-37.6	-2.9	43.2	89.0	133.8	146.9	142.3	104.1	60.1	13.5	-31.7	-39.3
2008	-35.6	-1.0	45.6	96.6	135.7	147.8	136.0	103.1	54.3	5.4	-29.2	-33.0
2009	-42.7	-10.6	39.8	102.3	142.3	143.4	140.6	105.8	51.9	13.9	-30.9	-41.7
2010	-38.4	-16.8	36.7	101.8	134.6	147.8	135.8	107.4	60.6	6.5	-24.2	-50.9

Incoming shortwave radiation ($W\ m^{-2}$) at Lake Abraham (with AARD method)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
2001	47.7	90.8	140.0	189.8	262.0	270.0	264.0	248.7	171.2	97.7	52.4	37.9
2002	46.2	80.5	150.7	189.3	241.5	292.2	288.6	232.1	159.1	96.5	50.5	35.9
2003	48.5	82.9	138.1	182.1	234.3	278.3	292.4	248.9	162.8	106.2	54.1	37.6
2004	47.1	88.9	138.4	208.3	233.4	288.7	264.0	206.7	151.4	97.7	53.2	36.6
2005	48.0	88.7	132.6	203.5	261.5	241.2	274.2	220.7	156.9	97.2	52.0	35.7
2006	44.5	84.8	138.1	208.4	263.2	277.5	285.6	232.3	166.8	95.3	51.7	35.0
2007	47.0	76.6	134.8	188.5	246.6	278.6	292.7	223.0	167.1	99.5	52.0	36.2
2008	50.1	90.6	141.5	198.0	252.0	284.4	280.8	235.1	173.7	105.4	53.9	38.9
2009	47.8	83.9	138.5	208.5	263.7	289.3	270.2	229.5	184.4	85.7	50.5	35.3
2010	42.0	89.1	134.3	205.0	233.0	281.7	283.1	218.2	140.7	99.5	63.2	36.7

Wind Speed (km/h) at Brazeau Reservoir

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1979	6.8	8.7	8.7	9.0	10.5	9.4	9.2	8.2	8.1	7.6	6.4	7.3
1980	7.5	7.8	8.5	10.0	10.6	8.6	7.2	7.6	7.6	7.0	6.3	7.1
1981	6.0	9.5	7.7	10.2	9.1	8.7	8.2	7.4	6.2	6.6	4.9	5.4
1982	6.7	7.8	8.6	8.4	9.4	6.4	6.2	7.1	7.0	5.9	5.0	5.4
1983	5.1	4.7	7.7	8.3	9.1	8.6	8.0	6.4	7.3	5.0	6.3	7.0
1984	8.5	7.4	9.0	8.6	11.6	9.3	8.9	8.7	8.1	8.9	5.1	6.8
1985	7.8	8.9	9.2	10.9	10.2	10.9	7.9	7.7	9.3	7.6	7.0	7.6
1986	6.7	5.8	8.0	9.3	9.0	8.9	6.7	5.8	7.1	5.6	6.1	5.8
1987	5.8	5.6	7.4	9.4	7.5	8.4	6.2	6.5	5.5	6.2	4.2	6.0
1988	6.3	8.6	7.3	9.3	8.3	7.8	7.1	6.7	6.4	6.3	5.3	5.3
1989	7.0	7.9	6.6	6.8	8.9	8.6	8.0	7.3	7.4	6.0	6.4	7.2
1990	5.8	7.3	7.2	8.6	9.1	9.2	7.7	6.8	6.7	7.4	6.3	7.3
1991	6.9	6.7	6.3	7.9	8.5	7.6	6.7	5.3	6.5	6.7	5.5	6.7
1992	5.7	6.7	6.7	7.9	7.9	7.8	7.3	6.5	7.3	7.6	6.5	6.6
1993	5.6	7.6	8.6	7.4	10.1	9.6	7.5	6.1	7.1	6.7	7.4	6.8
1994	7.0	7.3	8.0	8.0	9.2	8.6	7.8	6.9	6.5	6.9	6.6	5.9
1995	4.0	7.6	7.7	10.4	7.8	8.7	6.6	7.0	5.5	7.3	7.3	6.7
1996	6.6	6.9	8.8	9.2	8.2	9.3	8.6	7.8	7.8	6.7	6.7	6.4
1997	6.9	6.5	8.0	9.6	9.0	9.3	8.3	6.6	7.7	7.0	5.3	6.8
1998	4.7	5.1	8.8	7.8	8.5	8.1	8.3	6.4	7.0	6.3	6.1	7.4
1999	6.5	6.3	7.3	8.4	9.1	8.1	8.1	7.0	6.9	7.2	4.8	6.6
2000	5.4	5.6	8.0	8.7	8.7	8.3	7.4	7.0	6.8	6.5	6.0	5.9
2001	6.8	7.9	9.8	9.6	11.9	9.4	8.8	7.5	7.7	8.8	7.1	7.1
2002	7.2	9.1	7.9	9.6	10.2	8.3	8.9	7.8	7.8	6.9	7.1	6.7
2003	8.2	8.4	9.2	9.5	10.2	10.6	8.8	8.0	8.3	9.3	7.9	7.4
2004	7.6	7.3	10.6	9.8	8.6	8.6	9.0	7.3	7.8	7.6	8.5	9.6
2005	7.0	8.1	10.5	10.0	9.9	8.3	8.5	8.0	7.5	7.7	7.6	7.8
2006	7.2	9.4	9.3	9.7	10.0	9.6	7.8	7.5	7.7	7.9	8.3	8.9
2007	10.4	8.4	9.9	9.8	10.2	9.4	8.1	7.7	7.7	8.5	9.1	7.7
2008	8.4	8.0	8.8	10.4	10.2	8.7	8.4	8.5	7.2	8.9	8.3	7.7
2009	10.1	7.4	9.5	9.0	10.1	8.8	8.1	7.2	9.2	8.6	9.1	7.4
2010	6.4	5.9	9.1	12.4	9.7	8.5	8.6	7.8	7.0	7.5	7.2	5.9

Dewpoint Temperature (°C) at Brazeau Reservoir

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1979	-18.3	-22.9	-7.5	-5.1	-0.5	5.3	9.2	8.9	5.2	0.1	-8.7	-13.3
1980	-20.0	-12.4	-10.4	-2.4	0.6	7.6	8.4	6.9	3.9	-1.0	-6.7	-17.5
1981	-8.8	-10.3	-6.1	-5.1	4.0	4.3	9.1	10.1	4.5	-1.5	-4.8	-14.4
1982	-24.5	-16.9	-10.3	-8.1	-1.1	7.0	10.3	8.0	4.6	-2.0	-11.6	-11.4
1983	-13.3	-9.6	-6.5	-3.3	1.2	6.1	9.1	9.2	1.7	-2.5	-6.9	-21.6
1984	-10.0	-7.7	-7.0	-4.8	0.0	5.1	7.2	7.9	1.7	-5.0	-12.3	-19.5
1985	-12.1	-15.0	-7.9	-4.1	0.0	4.3	8.1	7.6	1.5	-3.2	-17.4	-9.3
1986	-9.0	-14.5	-4.9	-4.1	1.8	5.7	8.9	8.0	3.4	-0.2	-12.3	-11.5
1987	-10.3	-8.7	-7.9	-3.0	1.1	6.7	10.2	7.4	4.9	-2.7	-5.0	-11.3
1988	-17.1	-13.9	-5.7	-4.9	0.1	7.2	7.7	8.1	3.6	-1.1	-8.1	-12.4
1989	-14.8	-18.4	-14.0	-4.1	1.0	6.9	10.5	10.6	4.3	-2.1	-7.0	-9.8
1990	-12.4	-15.0	-7.5	-3.0	3.0	7.0	9.6	9.7	4.5	-4.7	-11.6	-17.5
1991	-16.9	-5.5	-11.3	-2.8	2.2	6.4	8.5	10.9	4.1	-5.2	-9.0	-11.6
1992	-8.9	-11.1	-5.0	-2.3	0.8	7.8	8.8	7.1	1.6	-2.6	-6.2	-18.5
1993	-18.8	-14.1	-7.7	-2.3	2.9	5.6	8.2	8.3	3.0	-2.2	-9.0	-9.7
1994	-17.0	-17.5	-7.1	-4.0	1.0	6.3	10.4	9.7	5.2	-2.7	-11.6	-17.6
1995	-13.8	-13.5	-9.6	-3.4	1.6	7.5	9.8	7.4	4.6	-3.2	-11.9	-19.4
1996	-24.9	-14.6	-12.2	-2.9	1.3	5.8	9.8	9.0	3.8	-3.6	-15.3	-21.2
1997	-19.6	-10.7	-12.1	-7.3	0.9	6.9	9.7	9.8	5.7	-1.9	-7.1	-11.0
1998	-21.1	-10.1	-8.6	-3.7	3.7	7.3	11.6	9.7	4.6	-0.5	-8.5	-16.4
1999	-15.8	-13.0	-10.3	-4.8	-0.6	5.2	7.0	9.9	2.7	-4.2	-7.4	-11.5
2000	-18.1	-14.0	-8.8	-5.7	0.7	5.3	10.3	8.6	3.0	-2.8	-10.7	-18.3
2001	-10.7	-16.7	-9.9	-5.7	-2.3	4.6	9.4	7.7	3.2	-5.2	-7.9	-15.3
2002	-13.9	-11.5	-17.8	-7.5	-1.9	4.1	7.1	6.6	2.9	-2.9	-5.8	-10.4
2003	-13.7	-11.1	-12.2	-2.6	-1.0	4.9	7.5	7.6	2.9	-2.2	-12.3	-14.0
2004	-17.6	-10.5	-7.3	-4.4	-0.1	5.9	10.2	9.5	3.5	-3.2	-6.8	-12.2
2005	-15.2	-11.7	-8.6	-5.4	1.2	7.5	8.0	7.0	2.3	-2.1	-6.6	-10.6
2006	-8.7	-12.7	-9.9	-3.6	1.3	6.6	9.3	6.9	4.8	-2.3	-12.9	-10.8
2007	-13.0	-13.4	-8.8	-5.2	0.9	7.0	10.5	8.3	3.3	-1.8	-9.2	-15.3
2008	-16.1	-12.5	-8.9	-6.6	1.7	6.3	8.2	8.0	3.5	-4.3	-6.1	-17.7
2009	-15.6	-13.8	-12.7	-5.6	-2.2	3.1	8.8	8.2	4.0	-4.1	-7.8	-17.6
2010	-11.8	-9.6	-7.1	-5.9	-1.1	4.6	7.8	8.1	3.4	-1.3	-10.1	-16.0

Air Temperature (°C) at Brazeau Reservoir

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1979	-14.9	-20.2	-0.9	0.7	7.5	13.4	16.3	15.2	11.4	4.9	-3.6	-10.6
1980	-17.2	-8.8	-5.7	7.5	10.9	13.7	15.5	11.8	8.8	5.6	-1.8	-14.4
1981	-5.6	-4.9	0.1	4.2	10.1	12.0	15.4	17.5	10.5	3.2	-1.4	-10.8
1982	-22.3	-13.8	-6.8	-0.1	9.0	14.3	15.3	12.8	9.9	4.2	-8.3	-8.5
1983	-10.1	-6.4	-3.7	4.5	10.3	13.0	15.5	16.5	7.4	3.3	-4.2	-18.9
1984	-6.1	-2.3	-2.3	4.7	8.1	13.0	16.4	15.8	6.1	0.3	-9.5	-16.5
1985	-8.5	-10.6	-2.1	4.0	11.4	12.2	16.9	13.0	6.1	2.8	-14.7	-5.2
1986	-5.2	-10.9	0.5	2.9	10.2	14.0	13.6	15.2	6.7	5.8	-8.2	-7.3
1987	-5.3	-4.4	-3.9	6.7	10.6	15.3	15.0	11.8	12.0	4.7	-1.1	-6.4
1988	-12.0	-7.2	0.3	6.0	11.8	14.6	15.2	14.1	9.2	5.6	-3.8	-7.9
1989	-10.4	-14.0	-8.8	3.8	9.1	14.1	16.2	13.8	9.7	3.4	-3.2	-5.7
1990	-8.3	-9.2	-0.5	3.6	9.0	13.6	16.1	15.8	11.6	2.5	-7.9	-14.5
1991	-12.7	-0.6	-5.0	5.4	9.9	12.5	16.0	17.0	10.9	0.5	-5.1	-7.2
1992	-5.0	-5.6	2.6	5.6	9.1	15.6	15.2	14.7	8.1	3.6	-3.0	-14.4
1993	-13.9	-8.2	-1.8	5.3	12.2	13.4	13.9	13.7	9.3	3.6	-4.0	-5.9
1994	-13.7	-12.9	0.5	4.9	9.4	12.2	15.9	14.2	11.0	2.4	-6.4	-11.5
1995	-12.4	-9.0	-4.0	2.5	9.3	13.2	14.4	11.1	10.2	2.4	-8.3	-15.0
1996	-19.8	-8.2	-7.1	4.1	5.7	12.1	15.0	14.9	7.6	2.1	-11.5	-17.3
1997	-15.8	-5.6	-6.3	0.7	8.8	13.0	14.8	14.4	10.4	2.1	-3.2	-4.5
1998	-17.2	-5.8	-3.8	5.3	12.3	12.5	17.4	16.5	10.5	3.7	-5.8	-12.0
1999	-12.3	-7.5	-4.7	4.0	7.7	11.6	13.4	15.0	8.7	3.5	-4.0	-4.6
2000	-13.4	-9.2	-2.0	2.5	7.4	12.1	15.7	13.0	8.3	3.1	-5.3	-12.8
2001	-4.5	-11.2	-2.0	3.2	9.9	11.3	14.7	15.5	10.1	2.1	-2.6	-10.6
2002	-8.9	-4.5	-12.1	-1.0	6.3	14.0	16.1	12.9	8.0	0.9	-0.1	-6.3
2003	-9.4	-7.3	-6.4	2.6	7.5	12.7	16.0	15.2	8.7	5.0	-7.6	-8.1
2004	-13.0	-5.3	-0.6	5.0	6.6	12.6	15.4	13.3	7.3	1.8	-0.8	-7.5
2005	-11.8	-5.1	-1.4	4.7	9.4	11.6	14.3	12.4	7.5	3.7	-1.5	-6.7
2006	-4.2	-6.7	-5.2	6.0	10.1	14.3	16.9	13.5	10.3	2.1	-9.7	-5.1
2007	-6.6	-9.4	-1.0	1.8	8.7	13.1	18.1	12.0	8.1	4.1	-4.0	-10.7
2008	-11.1	-6.9	-1.9	0.3	9.4	11.9	14.6	14.5	8.9	4.1	-0.2	-14.3
2009	-9.4	-8.6	-6.7	1.7	7.5	11.6	15.0	13.6	11.8	0.0	-1.0	-15.2
2010	-8.7	-5.8	0.6	4.4	6.6	12.0	14.4	12.8	7.0	4.4	-5.3	-12.6

Net radiation (W m^{-2}) from NARR at Brazeau Reservoir

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1979	-22.7	26.9	43.0	100.1	121.6	147.2	147.3	114.6	60.7	15.8	-27.9	-27.4
1980	-20.3	5.5	49.6	110.6	130.0	149.8	148.8	102.8	58.6	23.4	-23.6	-12.5
1981	-28.9	0.0	50.9	109.8	125.8	154.2	140.2	117.2	62.3	23.4	-25.7	-34.6
1982	3.1	8.6	41.4	99.4	140.8	150.5	136.0	104.3	65.4	17.2	-15.1	-34.3
1983	-20.3	6.4	44.4	102.0	130.0	141.3	148.6	120.6	57.7	22.0	-8.3	-21.1
1984	-16.7	4.1	57.9	107.2	122.5	151.8	157.7	113.1	66.0	24.2	-13.5	-21.4
1985	-25.2	7.4	50.5	110.1	130.2	154.1	155.2	105.0	62.5	18.1	-3.5	-30.0
1986	-22.8	10.0	56.8	103.4	130.4	150.4	131.1	121.1	58.3	13.9	-14.7	-40.9
1987	-31.5	2.7	54.1	100.2	136.5	155.5	142.2	99.4	70.1	18.1	-16.4	-35.7
1988	-30.5	10.5	56.1	102.3	129.0	148.8	135.2	107.7	60.4	14.3	-17.6	-32.8
1989	-23.6	-0.7	51.0	104.9	120.8	152.9	151.4	102.5	59.2	16.0	-9.6	-23.9
1990	-20.7	13.2	48.3	89.0	120.8	147.0	147.7	109.3	65.3	19.5	-11.8	-24.0
1991	-23.7	11.1	54.9	102.5	126.2	145.9	144.8	112.2	63.3	21.3	-17.0	-36.8
1992	-20.8	5.3	49.6	97.4	124.2	143.7	133.3	110.2	61.4	16.6	-13.8	-27.5
1993	-26.7	1.4	47.7	101.3	130.5	138.8	128.3	108.8	57.2	16.6	-15.3	-29.7
1994	1.8	13.1	53.7	94.9	124.5	142.4	144.1	108.0	65.1	15.6	-17.3	-30.5
1995	-23.3	9.1	57.2	94.8	132.1	139.9	133.9	98.3	60.3	19.4	-1.2	-27.3
1996	-18.5	0.9	45.0	105.9	123.4	139.6	148.8	109.7	55.5	20.3	-3.4	-25.3
1997	-16.5	-0.5	53.9	103.7	129.4	150.3	150.6	109.6	58.3	24.9	-21.6	-43.2
1998	-9.9	-1.1	56.5	108.3	137.1	136.2	149.6	113.3	65.5	16.2	-17.4	-26.3
1999	-10.4	-2.2	51.5	108.1	135.4	148.6	139.1	112.0	64.5	14.2	-17.5	-38.2
2000	-19.5	1.2	56.6	97.2	127.7	147.6	142.7	110.4	60.0	17.9	-22.3	-27.7
2001	-32.2	4.5	52.4	106.5	132.2	141.7	130.6	115.0	56.3	18.5	-16.3	-37.0
2002	-17.8	4.1	48.9	99.7	134.6	152.9	146.4	102.4	57.3	17.2	-12.6	-41.2
2003	-15.1	11.3	55.1	100.8	134.5	149.4	147.4	119.7	65.1	19.0	-17.7	-39.3
2004	-1.2	0.2	56.2	100.8	127.3	153.8	144.0	110.3	58.7	15.9	-16.1	-22.7
2005	-13.0	2.1	52.0	112.1	139.5	137.7	150.1	106.1	65.2	16.5	-14.9	-31.3
2006	-22.1	5.0	54.8	110.6	143.5	153.8	153.5	116.8	66.9	22.4	-7.2	-33.8
2007	-24.5	14.2	54.4	96.9	127.3	154.6	160.5	110.1	67.7	23.2	-16.9	-24.0
2008	-21.3	13.5	62.3	101.9	129.9	154.9	147.1	112.8	65.9	14.8	-14.5	-16.9
2009	-23.1	3.4	50.1	102.0	140.0	154.2	150.0	112.5	62.5	23.6	-22.6	-21.5
2010	-18.4	4.5	49.1	109.1	130.7	153.1	145.5	114.9	60.2	24.0	-11.9	-28.7

Incoming shortwave radiation (W m^{-2}) at Brazeau Reservoir (with AARD method)

Year	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
1979	50.5	71.9	144.6	186.4	243.1	285.6	284.5	233.4	178.0	99.6	61.7	44.5
1980	55.0	90.0	148.3	234.5	269.8	255.8	269.6	216.2	153.2	107.7	61.2	38.6
1981	49.5	85.6	144.6	217.6	248.5	281.4	259.8	242.9	174.6	95.5	54.2	40.7
1982	50.1	85.8	142.6	218.1	274.8	282.3	246.2	204.9	169.3	109.4	57.8	38.9
1983	52.4	78.7	115.2	212.8	272.6	271.3	266.7	248.8	163.5	104.3	49.4	40.2
1984	48.9	89.6	136.7	212.5	251.2	279.3	292.6	244.1	147.3	94.0	56.6	41.6
1985	54.3	90.9	141.6	199.6	280.5	286.0	288.9	223.3	148.7	96.9	53.8	39.6
1986	47.1	88.1	135.1	197.2	264.1	283.6	239.0	242.9	134.8	107.4	57.9	44.8
1987	53.9	84.5	130.6	231.6	285.3	293.9	252.1	205.0	184.2	109.9	58.4	41.0
1988	51.0	94.6	140.6	223.7	288.6	273.9	271.3	222.0	165.2	112.1	55.1	41.1
1989	56.7	94.1	146.7	218.4	263.2	282.5	264.8	194.0	170.1	107.7	54.9	38.8
1990	50.0	92.1	149.7	196.4	247.9	266.2	260.6	225.9	186.7	99.5	55.6	43.3
1991	52.6	82.5	150.9	209.8	256.5	257.7	280.0	230.4	173.4	106.7	61.6	41.0
1992	49.2	88.5	146.4	206.9	253.1	265.0	265.3	238.1	159.7	97.8	50.3	35.0
1993	56.7	81.4	130.2	197.0	260.9	260.8	242.1	214.8	162.5	101.2	52.3	39.3
1994	41.9	77.0	135.1	204.3	238.5	256.1	260.1	233.9	186.0	104.4	49.8	46.4
1995	56.4	78.4	131.5	185.9	261.9	254.9	237.6	199.2	180.3	99.1	48.2	37.9
1996	52.7	94.0	138.0	202.7	227.4	261.4	253.1	239.1	143.7	100.6	47.2	40.4
1997	53.3	93.8	144.2	209.7	250.9	258.0	269.0	226.2	163.7	89.5	55.3	41.4
1998	47.6	87.7	124.6	221.8	271.5	256.3	249.4	228.0	163.2	92.5	48.0	40.0
1999	49.3	94.9	139.3	199.6	262.0	270.2	253.1	218.3	173.1	105.2	53.0	40.9
2000	52.3	100.0	134.5	211.5	240.5	271.0	259.2	215.1	162.0	99.9	52.4	37.7
2001	49.8	89.7	135.1	199.4	264.6	260.6	252.9	246.1	172.5	100.5	54.6	39.1
2002	49.7	84.7	149.3	185.9	247.8	298.7	280.9	225.6	158.3	92.4	53.6	39.7
2003	49.3	81.8	142.7	185.9	243.5	272.1	286.8	243.5	160.7	107.1	57.2	40.4
2004	44.3	90.1	137.2	214.7	242.7	281.4	256.1	209.6	149.6	98.2	52.9	38.0
2005	49.3	91.3	136.0	211.5	263.8	246.3	267.9	219.3	156.2	98.0	53.2	36.8
2006	47.4	82.4	129.7	216.6	267.1	275.1	274.0	234.2	166.0	93.0	47.7	39.8
2007	51.4	77.9	139.5	187.5	250.2	273.8	286.0	215.5	167.2	102.2	53.8	38.6
2008	52.3	90.6	145.4	202.0	257.7	279.6	274.8	234.6	175.5	109.5	52.8	38.2
2009	52.2	87.9	146.3	209.8	275.0	294.7	276.6	231.4	186.6	84.6	57.0	38.0
2010	44.6	88.8	143.4	213.4	244.7	284.5	279.7	218.3	146.8	102.9	57.4	36.0

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