Kiggavik Project

Environmental Impact Statement

Tier 3 Technical Appendix 5K

Historical and Climate Change Water Balance for Pointer Lake and Judge Sissons Lake

December 2011

TECHNICAL MEMORANDUM

DATE October 5, 2011 **PROJECT No.** 09-1362-0610/8000

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HISTORICAL AND CLIMATE CHANGE WATER BALANCE FOR POINTER LAKE AND JUDGE SISSONS LAKE AT THE KIGGAVIK PROJECT SITE - VOLUME 5K

AREVA Resources Canada Inc. (AREVA) has requested that Golder Associates Ltd. (Golder) provide a water balance for the watersheds associated with Pointer Lake and Judge Sissons Lake at the Kiggavik Project site for historical conditions and under a climate change scenario of 5^{o}C warming over a period of 100 years. The water balance parameters presented in this study include five major inputs and outputs: precipitation, evaporation, evapotranspiration, sublimation and discharge and can be described by equation 1:

$$Q = P - E - ET - S \qquad (1)$$

Where Q = discharge

P = precipitation

E = evaporation

ET = evapotranspiration

S = sublimation

This assessment employs physically based models to predict the water balance components using climatic variables that are regularly measured at meteorological stations including precipitation, air temperature, relative humidity, solar radiation, and wind. The historical and existing and climate change scenario water balances involve three major steps:

1) generating climate datasets for historical and future conditions;

2) modeling water balance components using the generated climate datasets and physically based models; and

3) applying the water balance results to the Judge Sissons and Pointer Lake watersheds and validating historical model results with observed discharge data collected during baseline studies.

1.0 CLIMATE DATA

To calculate the components of a water balance, specific climatic data are required. Both historical and future climatic conditions are averaged over approximately 30 year periods to account for inter annual variation. The interface used to model climate in this study is limited to projections as far as 2099; therefore, the climate change scenarios assessed in this study apply to the period 2071-2099.

To estimate water balance components under climate change scenarios, five specific climate variables were required, i.e.:

1) air temperature
2) precipitation
3) solar radiation
4) relative humidity
5) wind speed

The five climatic variables were predicted for the Kiggavik site using models available from the Canadian Climate Change Scenarios Network (CCSN 2011). As these variables are interdependent, these parameters were explored simultaneously and outputs do not necessarily yield the 5°C temperature increase as requested, however, many models produce results close to this value.

To capture the inherent uncertainties involved in modeling climate for 2071-2099, and the variability of potential outputs, twenty three ensembles were run, as shown in Table 1. In this analysis, all available models and emission scenarios (SRA1B, SRA2, and/or SRB1) under the 2007 IPCC Fourth Assessment Report (AR4 [2007]) available from CCCSN (2011) that output all five parameters of interest were used. Information on the emission scenarios and models is available from CCCSN (CCCSN 2011).

Table 1: Climate models and emission scenarios

AR4 (2007) model	Emission Scenario		
	SR-A1B	SR-A2	SR-B1
BCM2.0-Run 1	✓	✓	✓
CGCM3T47-Mean	✓	✓	✓
CGCM3T63-Run 1	✓	✓	✓
CNRMCM3-Run 1	✓	✓	✓
ECHAM5OM- Mean	✓	✓	✓
FGOALS-g1.0(Mean)	✓		✓
HADCM3 – Run 1	✓	✓	✓
INMCM3.0 – Run 1	✓	✓	✓

The twenty three ensembles were run for the Kiggavik Project site (latitude 64.44, longitude 97.66) using 1971-2000 as baseline data. Figure 1 presents a summary of the average monthly temperature, precipitation, surface downwelling shortwave radiation (incoming shortwave radiation at the ground surface), relative humidity, and wind derived from the twenty three ensembles.

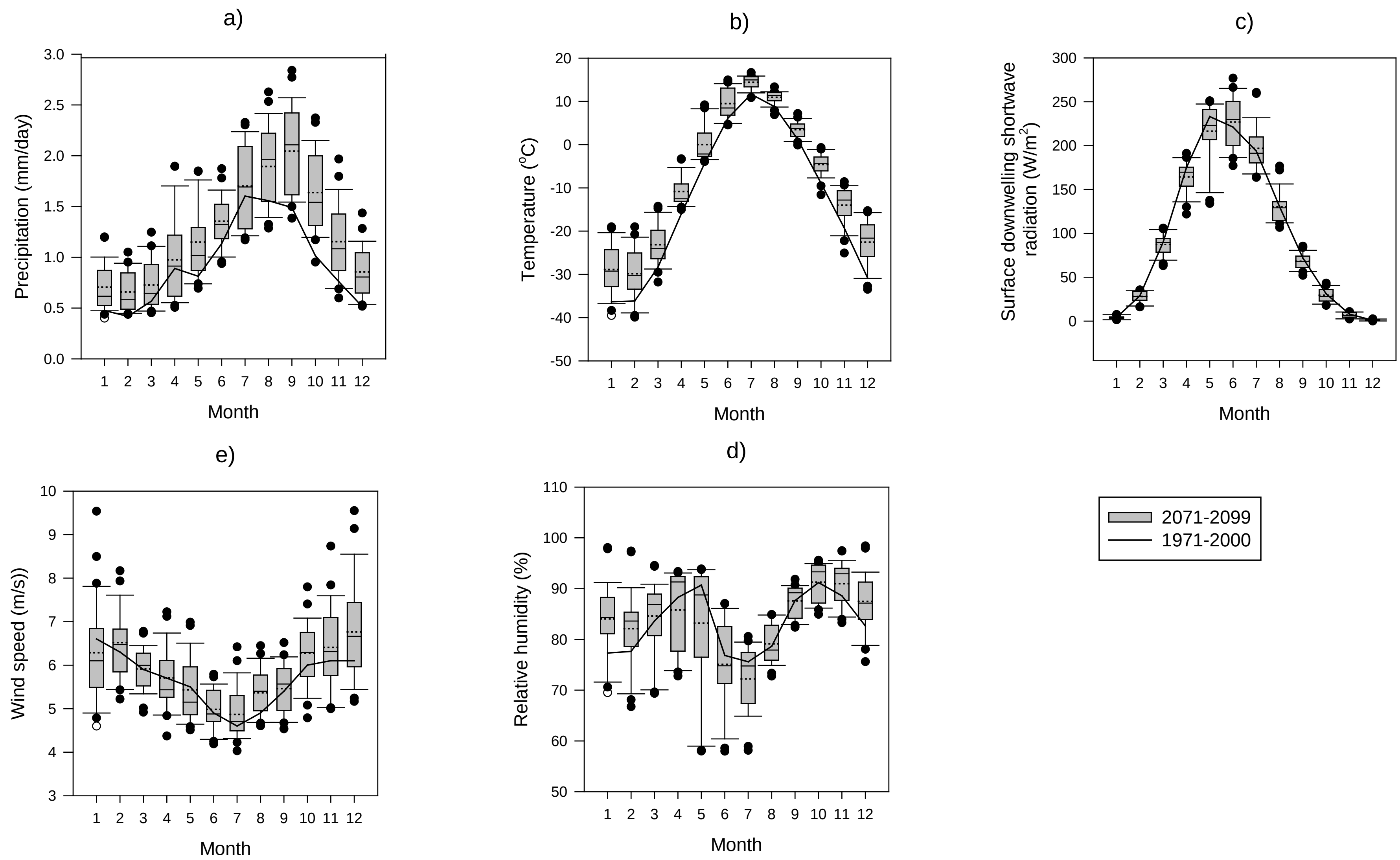

Figure 1: Average predicted a) precipitation, b) temperature, c) surface downwelling shortwave radiation, d) relative humidity, and e) wind speed for 2071-2099 and baseline conditions (1971-2000). The box plots indicate the 90th percentile, 75th percentile, median

Modeled baseline data were compared with archived climate normals (1971 - 2000) recorded at Baker Lake by Environment Canada (EC 2011). All climate parameters were in agreement with observed data with the exception of wind speed. The climate models output wind speeds between 0.67 m/s and 3.9 m/s for 1971-2000 and projections to 2071-2099 had similar results. Environment Canada observed mean monthly wind speeds during this same baseline period at Baker Lake between 4.6 m/s and 6.6 m/s. The discrepancy is likely because observed wind can be spatially variable while the model outputs are average wind speeds over the corresponding modeled grid (for example, an area of 200 x 200 km). To correct the modeled wind speed, the projected wind speed was normalized to Environment Canada Baker Lake normals according the following formula:

$$Corr_{2071-2099} = \left(\frac{\mathrm{CCCSN}_{2071-2099} - \mathrm{CCCSN}_{1971-2000}}{\mathrm{CCCSN}_{1971-2000}}\right) \times \mathrm{EC}_{1971-2000} + \mathrm{EC}_{1971-2000}$$

Where: $Corr_{2071-2099}$ is corrected wind speed for 2071-2099 (m/s)
$\mathrm{EC}_{1971-2000}$ is observed wind speed for 1971-2000 (m/s)
$\mathrm{CCCSN}_{1971-2000}$ is modeled wind speed for 1971-2000 (m/s)
$\mathrm{CCCSN}_{2071-2099}$ is modeled wind speed for 2071-2099 (m/s)

Historical air temperature, precipitation, humidity and wind data were compiled from Environment Canada observed data for the period 1971-2000. Because surface downwelling shortwave radiation data are not available for the Baker Lake station, these data were modeled for the baseline period 1971-2000 using the twenty-three climate ensembles and results were averaged to produce historical monthly data.

2.0 WATER BALANCE COMPONENTS

Air temperature, precipitation, solar radiation, relative humidity, and wind speed for each climate dataset were used to calculate the five components of the water balance: precipitation, evaporation, evapotranspiration, sublimation, and runoff.

2.1 Precipitation

Annual precipitation was calculated by summing the total monthly precipitation values for each approximately 30-year averaged climate dataset.

2.2 Lake Evaporation and Evapotranspiration

Lake evaporation and evapotranspiration rates were estimated using Program WREVAP (Morton et al. 1985). Program WREVAP is based on the complementary relationship between actual and potential evaporation where lake evaporation is limited only by the amount of available energy while evapotranspiration is additionally limited by the water availability on land.

Monthly mean air temperature, solar radiation, humidity and annual precipitation from the twenty three derived climate scenarios (Appendix A) and mean historical conditions were used as input values for Program WREVAP to determine corresponding evaporation from lakes and evapotranspiration from land surfaces. In addition to the climatic variables, this model incorporates the latitude, altitude, average depth of the lake, and total dissolved solids, the values for which are presented in Table 2. Two lake evaporation rates were determined, one for deep lakes (i.e., Judge Sissons) and one for shallow lakes (i.e., all other lakes), while evapotranspiration is assumed equal for all land surfaces.

The annual lake evaporation rates were calculated by summing the modeled monthly evaporation rates for July, August and September; modeled ice thicknesses presented in baseline studies suggest that these are the months in which the lakes are largely ice-free and therefore open to evaporation.

Evapotranspiration is a challenging component to calculate in the arctic due to the unique characteristics of terrestrial vegetation, permafrost, infiltration, solar radiation, and precipitation patterns. There is large uncertainty associated with measuring and calculating evapotranspiration in arctic environments (IASC 2010; Bergstrom et al. 2001), which is compounded when considering potential climate change scenarios. Program WREVAP is predicted to potentially overestimate evapotranspiration as the model has been validated with data from more temperate regions where evapotranspiration rates are typically higher; the model does not incorporate local optimization coefficients which would account for the limited vegetation and shallow active layer which limit evapotranspiration in the Arctic.

Evapotranspiration is predicted to occur near the Kiggavik Project primarily during July and August when plants are most productive, snow cover is absent, and water is available. Therefore, annual evapotranspiration consists of modeled rates from July and August exclusively.

Table 2: Pointer Lake and Judge Sissons Lake Characteristics

	Pointer Lake	Judge Sissons Lake
Average depth of lake (m)	1.39	4.6
Altitude (m)	141	133
Latitude (hddd.dd)	64.4	64.3
Total dissolved solids (mg/L)	0	0
Shallow lake surface area (km^2)	12.2	69.5
Deep lake surface area (km^2)	0	95.5
Watershed land surface area (km^2)	66.8	493
Watershed area (km^2)	79.0	705

2.3 Sublimation

Pomeroy et al. (1997) modeled blowing snow at a site 50 km north of Inuvik, NWT and found sublimation to be 28% of the total annual snowfall. Due to the similar environment at Kiggavik, Golder applied this value to the historical water balance for the site (Golder, 2010b). Because the driving forces of sublimation, such as wind speed, snow particle size, solar radiation, temperature, and humidity, may be considerably different under a climate change scenario, sublimation was instead estimated for the climate change scenarios using a physically based model. The vapour transfer sublimation model applied in this study was originally derived by Thrope and Mason (1966) and modified by Dery and Xiao (1998). This model estimates sublimation as a function of snow properties and atmospheric conditions. The snow properties used in this study are from MacDonald et al. (2009) while the atmospheric variables include precipitation, solar radiation, relative humidity, temperature and wind speed. Annual sublimation rates were calculated by summing the modeled monthly evaporation rates for December through May when substantial snow has accumulated and is available for sublimation.

2.4 Runoff

Runoff was set as the remaining annual volume of precipitation not predicted to be lost through sublimation, evaporation, or evapotranspiration according to equation (1).

3.0 POINTER LAKE AND JUDGE SISSONS LAKE WATER BALANCE RESULTS

Evaporation, evapotranspiration and sublimation rates for historical and climate change scenarios (2071-2099) were applied to the lake surface areas, watershed land surface area, and total watershed area, respectively, to yield mean annual discharges for the Pointer Lake and Judge Sissons Lake watersheds.

A summary of the results are presented in Table 3, Figure 2, and Figure 3 while the complete datasets for the climate change models are presented in Appendix B. The mean value for the climate change scenario in Table 3 reflects average results from all twenty-three ensembles while lower and upper values are plus or minus one standard deviation.

Table 3: Kiggavik water balance parameters for historical and climate change conditions.

		Historical conditions (1971-2000)	Climate change conditions (2071-2099)		
		Mean value	Lower value	Mean value	Upper value
Pointer Lake watershed (10^6 m^3/yr)	Precipitation	26.7	28.2	35.9	43.6
	Evaporation	2.60	2.31	2.67	3.03
	Evapotranspiration	6.69	6.18	7.51	8.83
	Sublimation	4.95	1.34	4.60	8.45
	Discharge	12.5	12.9	20.8	28.8
Judge Sissons Lake watershed (10^6 m^3/yr)	Total Precipitation	222	234	299	363
	Evaporation	39.5	37.6	42.2	46.7
	Evapotranspiration	49.3	45.6	55.4	65.1
	Sublimation	41.3	11.2	40.8	70.4
	Discharge	92.3	94.2	161	227

The historical modeled water balances corresponds well with observed discharge data from Pointer Lake and Judge Sissons Lake during baseline studies (Golder 2011). The mean annual discharge from Pointer Lake Outflow and Judge Sissons Lake Outflow during baseline studies was 15,900,000 m^3 and 89,000,000 m^3, respectively (Table 4). Modeled historical discharges (12,500,000 m^3 and 92,300,000 m^3, for Pointer Lake and Judge Sissons Lake Outflow, respectively) are 79% and 104% of the observed mean discharge during baseline studies and thereby help to validate the methods and models applied in this study and suggest that conditions are reasonably represented.

Table 4: Observed annual discharge at Pointer Lake Outflow and Judge Sissons Lake Outflow during baseline studies (2007-2010) (Golder, 2011)

	Pointer Lake Outflow (10^6 m^3/yr)	Judge Sissons Lake Outflow (10^6 m^3/yr)
2007	16.9	63.8
2008	13.0	85.5
2009	9.95	107
2010	23.9	100
mean	15.9	89.0

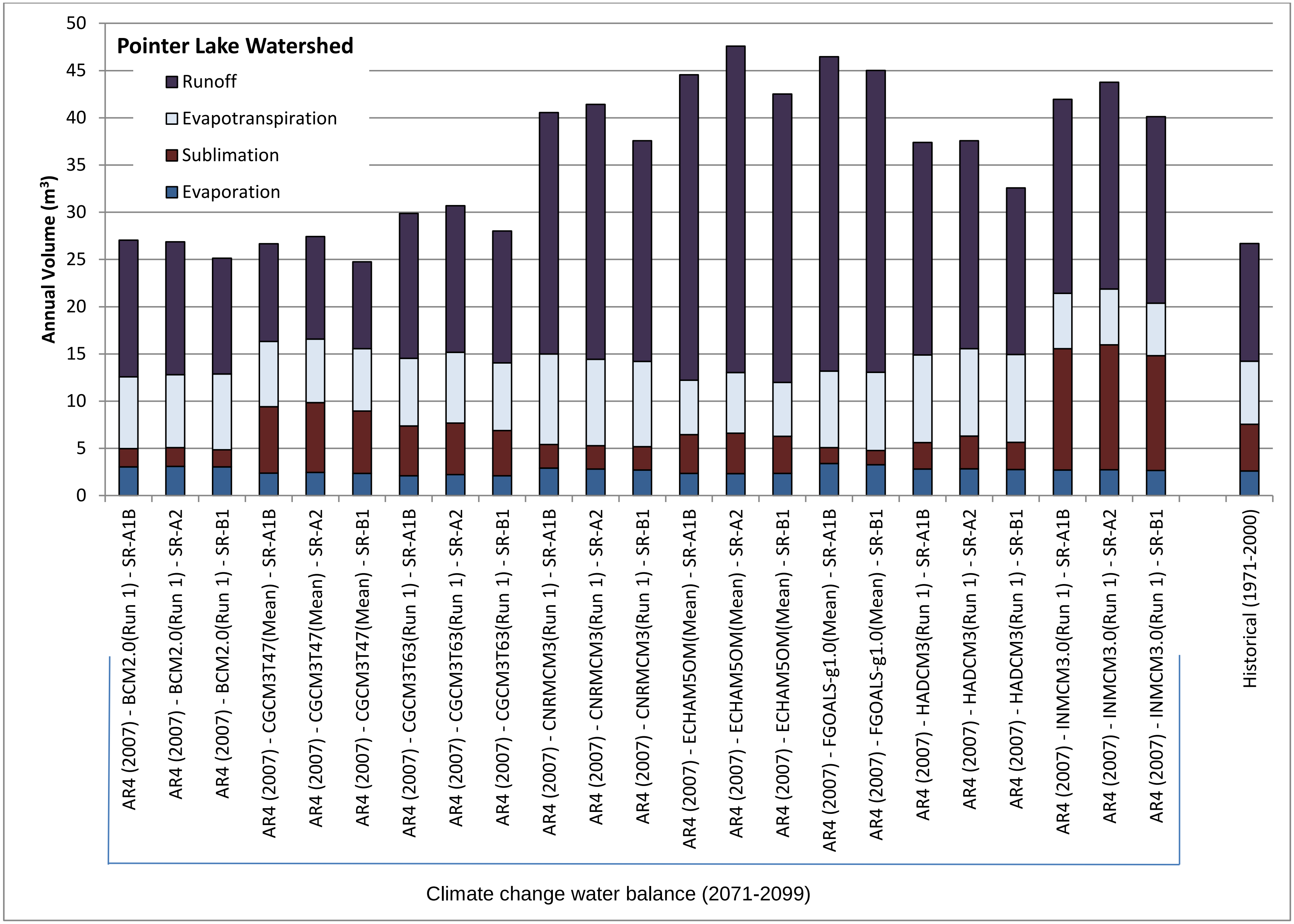

Figure 2: Historical and climate change water balances for Pointer Lake watershed

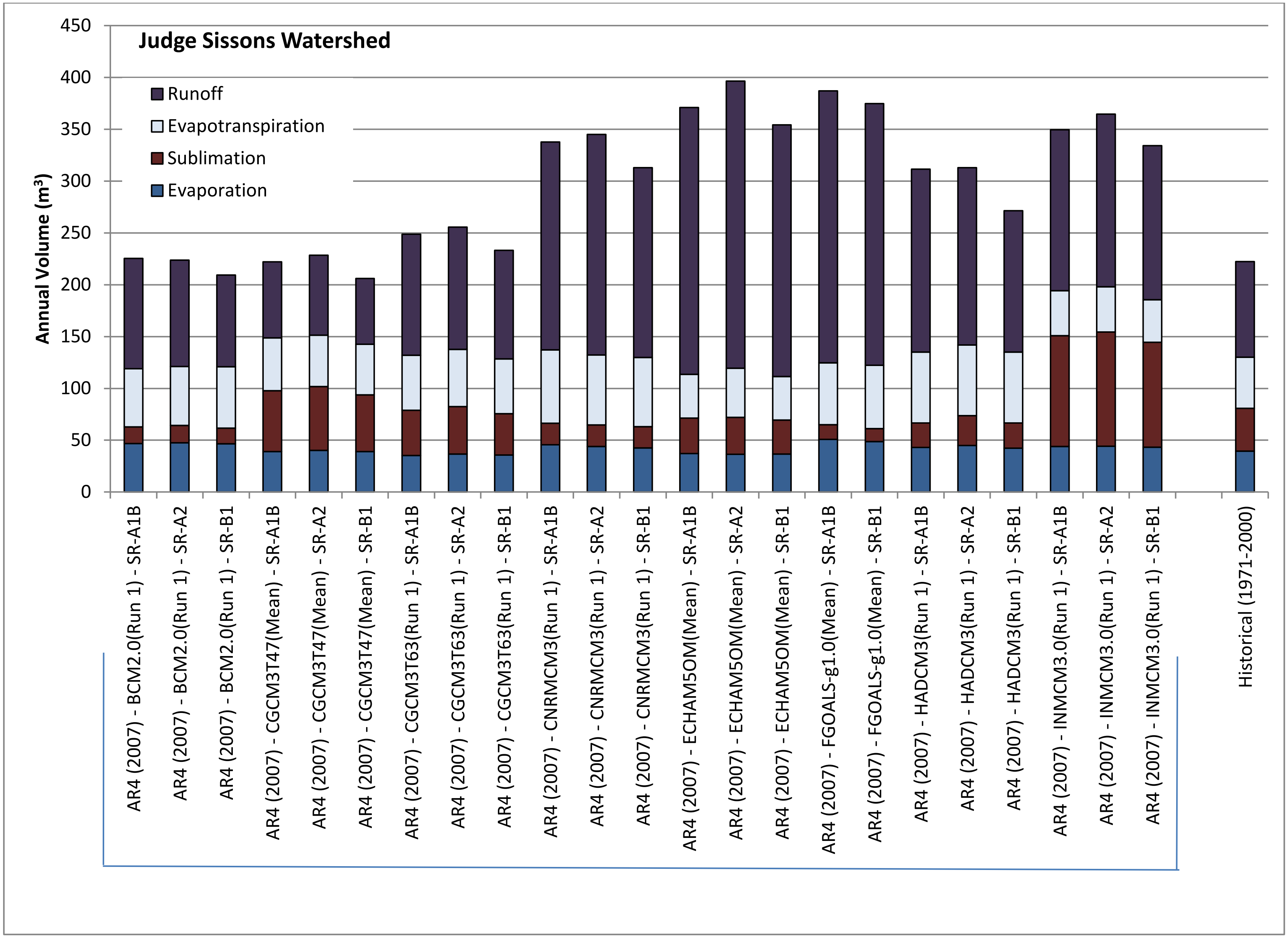

Figure 3: Historical and climate change water balances for Judge Sissons Lake watershed

Three of the twenty three modeled climate scenarios predict a decrease in annual precipitation for 2071-2099. AR4 (2007)-ECHAM5OM(Mean)-SR-A2 estimated the greatest increase in precipitation at 78% historical rates. On average, the models predict a 34% increase in precipitation; this increase is typically distributed throughout the year, however most dramatic increases occur in the autumn (Figure 1a).

As summers become warmer and wetter, lake evaporation and evapotranspiration conditions are typically predicted increase, however under nine ensembles lake evaporation is predicted to decrease and seven ensembles evapotranspiration is predicted to decrease. Fifteen ensembles result in a predicted decrease in sublimation while eight result in a predicted increase. Although water losses typically increase, under many ensembles, the magnitude does not compensate for the dramatic increases in precipitation. Twenty of the twenty three climate change ensembles predict an increase in runoff at Judge Sisson and Pointer Lake outflows. On average, runoff is estimated to increase 67% and 74% for Pointer Lake and Judge Sissons Lake watersheds, respectively. The maximum increase in runoff is observed under the AF4 (2007) – ECHAM50M(Mean) – SR-A2 scenario at 177% and 200% of historical discharge for the two watersheds.

4.0 UNCERTAINTY

There is considerable uncertainty in an assessment of this nature; there is uncertainty associated with the climate change models, which is further compounded when integrating these data into water balance calculations. Although historical modeled discharge values correspond well with observed data from baseline studies, no measured sublimation, evaporation, or evapotranspiration data exist near the Kiggavik Project site for further validation; therefore, these predicted rates remain hypothetical.

Evapotranspiration is a component of particular uncertainty in this study. Evapotranspiration is not only sensitive to climatic conditions, but also to vegetative characteristics which are also likely to change under climate change scenarios. Evapotranspiration is expected to increase in many arctic environments under a warmer climate as vegetative species become more established, and potentially shift from non-transpiring lichens and mosses to transpiring vascular plants (Rouse et al. 1997). A potentially deepened active layer may also increase soil moisture potential and thereby increase the water source for transpiring plants.

Evaporation, evapotranspiration, and sublimation are also sensitive to physical terrestrial changes such as a potentially lengthened ice-free (Buermann et al. 2003) and snow-free season. Changes in the temporal distribution of snow and ice will alter the length of the season in which these processes are active.

Although annual runoff volumes in the Pointer Lake and Judge Sissons watersheds are predicted to increase by 2099, the seasonal flow patterns may also change. As the active layer thickens and soil storage capacity increases, flow rates are likely to become more consistent over the open water period (Rouse et al. 1997). Therefore, in a warmer Arctic climate, the annual flow volume may be more uniformly distributed during the open water period. This means that although precipitation is predicted to increase, it is unlikely that the magnitude of the peak floods will increase proportionally.

5.0 CONCLUSIONS

Results from this water balance assessment for historical and climate change conditions suggest that Pointer Lake and Judge Sissons Lake watersheds will experience an increase in precipitation and runoff while under different climate change ensembles, evapotranspiration, evaporation, and sublimation present less consistent and typically more moderate changes. Although there is considerable uncertainty associated with modeling climate for 2071-2099 and in deriving the associated water balance parameters, the results presented in this assessment provide a reasonable estimate for potential changes at the Kiggavik Project site. The mean, upper and lower values provided in this assessment can help account for the inherent uncertainties and incorporate a degree of conservatism to further applications.

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APPENDIX A

Predicted Mean Monthly Climate Data for 2071-2099 for Twenty Three Ensembles

Ensemble	Variable	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
	Precipitation (mm/d)	0.51	0.44	0.5	0.65	1.1	1	1.2	1.6	1.7	1.2	0.69	0.53
	Surface downwelling shortwave radiation (W/m^2)	4.2	31	90	180	240	260	220	150	72	28	7.1	0.84
BCM2.0(Run 1) - SR-A1B	Relative humidity (%)	84	82	89	93	94	87	67	76	90	94	93	87
	Temperature (^{o}C)	-36	-39	-27	-13	-2.8	4.9	15	12	4.4	-4.3	-18	-29
	Wind speed (m/s)	5.7	7.5	6.1	6.1	6.4	5.1	4.5	4.7	5.6	7.8	6.5	5.2
	Precipitation (mm/d)	0.48	0.6	0.56	0.71	0.88	0.96	1.2	1.7	1.7	1.2	0.69	0.52
	Surface downwelling shortwave radiation (W/m^2)	4.2	30	89	170	250	270	220	140	69	28	6.8	0.83
BCM2.0(Run 1) - SR-A2	Relative humidity (%)	84	84	90	93	94	85	67	76	91	94	95	87
	Temperature (^{o}C)	-35	-36	-26	-13	-2.8	6.3	16	13	4.5	-3.4	-15	-27
	Wind speed (m/s)	6.2	6.4	5.4	7.2	5.5	4.8	4.3	4.7	4.7	6.8	7.2	6.1
	Precipitation (mm/d)	0.4	0.44	0.55	0.67	0.9	0.94	1.2	1.5	1.7	0.95	0.6	0.54
	Surface downwelling shortwave radiation (W/m^2)	4.4	31	91	170	250	280	220	150	74	32	7.3	0.84
BCM2.0(Run 1) - SR-B1	Relative humidity (%)	82	81	88	93	94	87	70	76	90	93	90	83
	Temperature (^{o}C)	-40	-40	-29	-13	-3.7	4.7	14	12	3.4	-6.2	-21	-33
	Wind speed (m/s)	6.4	6.4	5.4	6.6	5.9	4.7	5.3	5.4	4.7	6.9	7.2	5.2
	Precipitation (mm/d)	0.55	0.48	0.45	0.53	0.74	1.1	1.4	1.4	1.5	1.3	0.9	0.64
	Surface downwelling shortwave radiation (W/m^2)	2.4	22	79	160	220	210	180	130	65	22	3.8	0.33
CGCM3T47(Mean) - SR-A1B	Relative humidity (%)	71	68	70	74	75	76	76	78	84	86	84	78
	Temperature (^{o}C)	-28	-29	-24	-13	-1.3	8.2	13	9.5	2.1	-4.3	-12	-21
	Wind speed (m/s)	7.3	5.7	5.5	6	5.1	4.9	4.6	5	5.2	5.7	5.6	6.5
	Precipitation (mm/d)	0.57	0.47	0.5	0.57	0.74	1.2	1.4	1.3	1.6	1.4	0.94	0.69
	Surface downwelling shortwave radiation (W/m^2)	2.3	22	77	160	220	200	180	130	65	21	3.6	0.33
CGCM3T47(Mean) - SR-A2	Relative humidity (%)	72	70	70	74	76	76	75	77	84	87	85	79
	Temperature (^{o}C)	-26	-28	-22	-13	-0.023	9.3	14	11	2.9	-3.1	-11	-19
	Wind speed (m/s)	6.8	5.7	5.6	5.8	4.8	4.4	5.3	5	5.1	6.2	5.4	6.8
	Precipitation (mm/d)	0.49	0.45	0.47	0.51	0.69	1.1	1.2	1.3	1.4	1.2	0.83	0.6
	Surface downwelling shortwave radiation (W/m^2)	2.6	23	78	170	220	210	190	130	67	23	3.9	0.36
CGCM3T47(Mean) - SR-B1	Relative humidity (%)	70	67	69	73	75	75	75	77	83	85	83	76
	Temperature (^{o}C)	-31	-32	-26	-14	-2.2	7.4	12	8.9	1.1	-5.4	-14	-24
	Wind speed (m/s)	7.2	5.5	6	5.9	5.7	4.6	4.7	4.9	4.9	6.3	5.8	6.7
	Precipitation (mm/d)	0.56	0.5	0.53	0.61	0.97	1.3	1.7	1.7	1.6	1.3	0.87	0.68
	Surface downwelling shortwave radiation (W/m^2)	1.5	16	65	140	200	190	160	110	58	18	2.5	0.12
CGCM3T63(Run 1) - SR-A1B	Relative humidity (%)	81	79	79	80	79	77	79	82	85	88	88	84
	Temperature (^{o}C)	-28	-28	-23	-13	-1.4	7.2	11	7.9	0.74	-5	-13	-21
	Wind speed (m/s)	5	7.9	5.7	5.4	4.6	5.7	6.4	6.1	4.7	5.1	7.8	6

Ensemble	Variable	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
CGCM3T63(Run 1) - SR-A2	Precipitation (mm/d)	0.62	0.54	0.61	0.59	0.8	1.3	1.8	1.6	1.6	1.5	1	0.66
	Surface downwelling shortwave radiation (W/m^2)	1.5	16	63	150	210	190	170	110	56	18	2.4	0.13
	Relative humidity (%)	81	78	79	79	79	77	79	82	85	88	88	84
	Temperature (^{o}C)	-27	-27	-23	-12	-1.4	8	12	8.9	1	-5.1	-12	-20
	Wind speed (m/s)	6	5.4	5.5	5.2	4.7	5.2	6.1	6.4	5.9	6	7.5	6.8
CGCM3T63(Run 1) - SR-B1	Precipitation (mm/d)	0.44	0.49	0.47	0.56	0.82	1.3	1.6	1.7	1.6	1.2	0.87	0.63
	Surface downwelling shortwave radiation (W/m^2)	1.6	17	70	150	210	200	160	110	59	20	2.6	0.15
	Relative humidity (%)	81	78	77	79	79	77	79	82	85	86	85	83
	Temperature (^{o}C)	-31	-31	-27	-14	-2.2	7.2	11	6.9	-0.13	-7.3	-16	-24
	Wind speed (m/s)	6.4	5.2	5	4.9	4.9	4.8	5.4	5.5	5.7	6.6	7.5	6
CNRMCM3(Run 1) - SR-A1B	Precipitation (mm/d)	0.75	0.59	0.75	0.98	1.3	1.5	2.1	2.5	2.3	1.7	1.2	0.98
	Surface downwelling shortwave radiation (W/m^2)	3.9	28	89	170	240	250	200	120	65	27	6.1	0.82
	Relative humidity (%)	85	80	86	93	93	84	78	85	90	94	94	91
	Temperature (^{o}C)	-29	-32	-24	-9.4	-2.4	6	15	12	5.8	-1.1	-9.6	-22
	Wind speed (m/s)	6	6.2	6.3	5.3	4.5	5.8	4	4.6	5.2	6.7	6.9	5.6
CNRMCM3(Run 1) - SR-A2	Precipitation (mm/d)	0.77	0.69	0.64	0.93	1.3	1.5	2.3	2.6	2.5	1.7	1.2	0.93
	Surface downwelling shortwave radiation (W/m^2)	3.8	27	90	170	240	240	190	110	64	28	6	0.81
	Relative humidity (%)	86	84	88	93	93	84	80	85	89	93	94	92
	Temperature (^{o}C)	-28	-29	-22	-9.7	-2.5	6.7	15	12	6.3	-1.2	-8.6	-19
	Wind speed (m/s)	5.4	6.6	6.7	5.3	5	5	4.6	5.1	6.5	6.8	8.7	6.4
CNRMCM3(Run 1) - SR-B1	Precipitation (mm/d)	0.62	0.54	0.68	0.9	1.3	1.4	2.3	2.3	2	1.6	1.1	0.8
	Surface downwelling shortwave radiation (W/m^2)	4	28	91	170	240	250	180	120	68	28	6.4	0.85
	Relative humidity (%)	80	79	85	92	93	86	81	85	89	92	93	89
	Temperature (^{o}C)	-33	-33	-25	-10	-3	4.5	13	11	4.8	-2.4	-14	-24
	Wind speed (m/s)	4.8	6.7	5.9	6.1	6	5.5	4.4	5.6	6.2	6.2	6.8	5.5
ECHAM5OM(Mean) - SR-A1B	Precipitation (mm/d)	0.92	0.9	0.94	1.3	1.8	1.5	1.7	2.2	2.4	2.1	1.4	1.1
	Surface downwelling shortwave radiation (W/m^2)	4.2	26	80	130	140	190	170	110	57	24	6.1	0.98
	Relative humidity (%)	90	88	88	92	89	71	69	78	90	95	93	91
	Temperature (^{o}C)	-21	-22	-17	-7.5	4.8	14	16	12	4.4	-3.2	-10	-16
	Wind speed (m/s)	7.8	6.8	6.3	5.3	4.8	5.5	4.7	5.9	5.6	6.3	5	7.5
ECHAM5OM(Mean) - SR-A2	Precipitation (mm/d)	0.93	0.9	1	1.7	1.8	1.9	1.9	2.4	2.5	2.1	1.6	1.1
	Surface downwelling shortwave radiation (W/m^2)	4.2	26	78	120	130	180	170	110	52	23	6	0.95
	Relative humidity (%)	89	88	89	92	89	73	71	80	92	95	94	92
	Temperature (^{o}C)	-21	-22	-17	-6.2	4.6	13	16	12	4.7	-2.8	-10	-15
	Wind speed (m/s)	7.5	7.1	6.8	5.4	6.1	5.4	4.7	5.5	5.5	6.4	6.3	7.7

Ensemble	Variable	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
ECHAM5OM(Mean) - SR-B1	Precipitation (mm/d)	0.85	0.82	0.85	1.2	1.6	1.6	1.6	2.1	2.4	2	1.5	1
	Surface downwelling shortwave radiation (W/m^2)	4.3	28	84	140	150	190	180	120	60	26	6.4	1
	Relative humidity (%)	89	87	87	91	89	73	67	78	90	94	93	91
	Temperature (^oC)	-24	-24	-19	-9	3.6	12	15	11	3.7	-4.4	-12	-18
	Wind speed (m/s)	6.7	6.6	6.1	5.4	5.7	5.5	4.6	5.5	5.3	6.6	5.7	7
FGOALS-g1.0(Mean) - SR-A1B	Precipitation (mm/d)	1.2	1.1	1.2	1.9	1.7	1.6	1.2	1.5	2.1	2.3	2	1.4
	Surface downwelling shortwave radiation (W/m^2)	4.7	33	98	180	230	260	260	180	84	39	9.3	0.8
	Relative humidity (%)	98	97	94	92	90	69	58	73	91	95	97	98
	Temperature (^oC)	-36	-38	-30	-14	-2.3	10	17	12	2	-9.6	-22	-30
	Wind speed (m/s)	7.2	6.8	6.3	6.3	4.7	4.7	4.9	6.1	5.6	5.3	6.1	6
FGOALS-g1.0(Mean) - SR-B1	Precipitation (mm/d)	1.2	0.95	1.1	1.9	1.7	1.5	1.3	1.5	2.1	2.4	1.8	1.3
	Surface downwelling shortwave radiation (W/m^2)	4.8	33	100	180	240	270	260	170	85	40	9.7	0.82
	Relative humidity (%)	98	97	95	91	91	70	59	76	91	96	97	98
	Temperature (^oC)	-38	-40	-32	-15	-3.9	8.5	15	11	0.57	-12	-25	-33
	Wind speed (m/s)	6.9	6.5	6.3	6	5.5	4.8	5.3	5.4	6.2	6.2	6.1	7.3
HADCM3(Run 1) - SR-A1B	Precipitation (mm/d)	0.66	0.59	0.66	1.1	1	1.8	2.1	2.1	2.3	1.5	0.99	0.74
	Surface downwelling shortwave radiation (W/m^2)	4.9	34	100	190	250	230	210	130	69	41	11	1.4
	Relative humidity (%)	86	84	88	91	90	74	77	83	90	95	94	90
	Temperature (^oC)	-29	-32	-24	-13	-2.6	12	16	12	3.1	-6.5	-17	-24
	Wind speed (m/s)	9.5	7.5	5.8	5.4	6.9	4.2	4.5	5.8	5.8	4.8	5	8.4
HADCM3(Run 1) - SR-A2	Precipitation (mm/d)	0.59	0.58	0.57	1.2	1.3	1.5	2.2	2	2.3	1.5	1.1	0.76
	Surface downwelling shortwave radiation (W/m^2)	5	34	110	190	230	240	200	130	71	40	10	1.3
	Relative humidity (%)	84	84	90	90	88	72	77	83	89	95	95	92
	Temperature (^oC)	-30	-30	-24	-12	-0.82	14	16	11	4.1	-5.8	-14	-22
	Wind speed (m/s)	7.9	8.2	6.4	7.1	7	4.2	5.8	6.3	5.9	5.6	6.7	9.1
HADCM3(Run 1) - SR-B1	Precipitation (mm/d)	0.52	0.49	0.62	0.91	1	1.4	1.7	2	1.8	1.4	0.87	0.83
	Surface downwelling shortwave radiation (W/m^2)	5.1	34	110	190	250	240	210	130	73	43	11	1.3
	Relative humidity (%)	81	80	87	90	90	75	76	84	89	94	94	86
	Temperature (^oC)	-32	-34	-27	-14	-3.4	11	14	10	1.8	-7	-17	-26
	Wind speed (m/s)	8.5	6.4	6.1	5.3	6.1	5.4	4.7	4.8	5.9	5.9	5.9	9.5
INMCM3.0(Run 1) - SR-A1B	Precipitation (mm/d)	0.88	0.85	0.91	1.3	0.96	1.3	2	2.2	2.8	1.9	1.3	1
	Surface downwelling shortwave radiation (W/m^2)	7.3	35	94	160	210	220	190	130	78	36	9.8	2.4
	Relative humidity (%)	88	84	85	75	58	59	67	75	83	87	88	87
	Temperature (^oC)	-19	-21	-15	-3.4	8.5	14	15	12	5.9	-2.6	-11	-16
	Wind speed (m/s)	5.5	6.8	4.9	4.4	5	4.3	4.2	4.8	6	7.4	6.5	7.8

Ensemble	Variable	Month											
		1	2	3	4	5	6	7	8	9	10	11	12
INMCM3.0(Run 1) - SR-A2	Precipitation (mm/d)	0.95	0.94	1.1	0.98	1	1.3	2.2	2.4	2.4	2	1.6	1.1
	Surface downwelling shortwave radiation (W/m^2)	7.5	35	93	160	200	220	190	130	78	35	9.3	2.4
	Relative humidity (%)	88	86	86	75	59	61	68	75	83	87	88	87
	Temperature (^oC)	-19	-19	-14	-3.3	9.2	15	16	12	7.2	-0.7	-9.4	-16
	Wind speed (m/s)	6.1	5.4	6.2	4.8	5.1	5	4.4	5.1	4.7	7	5.9	7
INMCM3.0(Run 1) - SR-B1	Precipitation (mm/d)	0.79	0.84	0.99	0.79	0.86	1.2	1.8	2	2.8	2	1.4	1
	Surface downwelling shortwave radiation (W/m^2)	7.5	36	95	170	210	230	190	140	80	36	9.7	2.4
	Relative humidity (%)	86	84	86	77	58	58	66	73	82	86	88	86
	Temperature (^oC)	-22	-23	-16	-5.8	8.2	14	15	11	5	-3	-11	-18
	Wind speed (m/s)	5.1	6.4	5.5	6.2	4.9	4.9	4.5	5.2	4.5	5.7	5	5.5

APPENDIX B

Predicted Water Balance Values for 2071-2099 for Climate Change Scenarios

Water Balance Parameter Values for Data from Twenty Three Climate Models

AR4 (2007) Model-Emission Scenario	Pointer Lake Watershed					Judge Sissons Lake Watershed				
	Precipitation (10^6 m^3)	Evaporation (10^6 m^3)	Evapotranspiration (10^6 m^3)	Sublimation (10^6 m^3)	Runoff (10^6 m^3)	Precipitation (10^6 m^3)	E vaporation (10^6 m^3)	Evapotranspiration (10^6 m^3)	Sublimation (10^6 m^3)	Runoff (10^6 m^3)
BCM2.0(Run 1) - SR-A1B	27.0	3.1	7.6	1.9	14.5	225	46.9	56.1	16.1	106
BCM2.0(Run 1) - SR-A2	26.9	3.1	7.7	2.0	14.1	224	47.6	57.0	16.6	103
BCM2.0(Run 1) - SR-B1	25.1	3.0	8.0	1.8	12.3	209	46.6	59.3	15.1	88
CGCM3T47(Mean) - SR-A1B	26.7	2.4	6.9	7.0	10.3	222	39.0	51.0	58.6	73
CGCM3T47(Mean) - SR-A2	27.4	2.5	6.7	7.4	10.8	228	40.1	49.6	61.6	77
CGCM3T47(Mean) - SR-B1	24.7	2.4	6.6	6.6	9.2	206	39.0	48.7	54.8	64
CGCM3T63(Run 1) - SR-A1B	29.9	2.1	7.2	5.3	15.3	249	35.1	53.0	43.8	117
CGCM3T63(Run 1) - SR-A2	30.7	2.2	7.5	5.5	15.5	256	36.7	55.3	45.6	118
CGCM3T63(Run 1) - SR-B1	28.0	2.1	7.2	4.8	13.9	233	35.6	52.9	39.9	105
CNRMCM3(Run 1) - SR-A1B	40.6	2.9	9.6	2.5	25.6	338	45.6	70.7	20.7	201
CNRMCM3(Run 1) - SR-A2	41.4	2.8	9.1	2.5	27.0	345	44.0	67.5	20.7	213
CNRMCM3(Run 1) - SR-B1	37.6	2.7	9.0	2.5	23.4	313	42.5	66.7	20.6	183
ECHAM5OM(Mean) - SR-A1B	44.5	2.4	5.7	4.1	32.3	371	37.0	42.4	34.3	257
ECHAM5OM(Mean) - SR-A2	47.6	2.3	6.4	4.3	34.6	396	36.4	47.4	35.6	277
ECHAM5OM(Mean) - SR-B1	42.5	2.4	5.7	3.9	30.5	354	36.7	42.1	32.7	243
FGOALS-g1.0(Mean) - SR-A1B	46.5	3.4	8.1	1.7	33.3	387	50.7	59.7	14.1	262
FGOALS-g1.0(Mean) - SR-B1	45.0	3.3	8.3	1.5	31.9	375	48.6	61.2	12.6	252
HADCM3(Run 1) - SR-A1B	37.4	2.8	9.3	2.8	22.5	311	43.1	68.4	23.5	176
HADCM3(Run 1) - SR-A2	37.6	2.8	9.3	3.5	22.0	313	44.9	68.3	28.8	171
HADCM3(Run 1) - SR-B1	32.6	2.7	9.3	2.9	17.6	271	42.4	68.6	24.1	136
INMCM3.0(Run 1) - SR-A1B	42.0	2.7	5.9	12.8	20.5	349	43.9	43.2	107.0	155
INMCM3.0(Run 1) - SR-A2	43.8	2.7	5.9	13.2	21.9	365	44.2	43.7	110.1	167
INMCM3.0(Run 1) - SR-B1	40.1	2.7	5.6	12.1	19.7	334	43.2	41.1	101.2	149