Future Water Budget Projections in Mississippi Rideau Watershed Region

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S. Kunjikutty[1], J. Oblak[1] and P. Lehman[1]

[1] Mississippi Valley Conservation Authority, Ontario, Canada

Abstract

The Future Water Budget Projections in Mississippi Rideau Watershed Region study is part of 'the Mississippi Rideau Climate Change Vulnerability Assessment Project'. The main purpose of the study was to compare outcomes of different GCM scenarios in projecting the future climate and generate water budget components. Using climate data from the Ministry of Natural Resources and Forestry the GCM scenarios were selected by percentile method. The Drummond Centre climate station in the Mississippi River watershed and the Ottawa Airport station in the Rideau River watershed were used in this study. The baseline period of 1970-2000 was selected to project climate data for the periods of 2011-2040, 2041-2070, and 2071-2100. The Thornthwaite water budget model from the Ontario Ministry of Environment and Climate Change was used to generate the water budget components. In both watersheds, the selected models show high consistency and good agreement in the future temperature and precipitation projections. The rates of change in the temperature projections per year increased consistently in the future. Though the precipitation projections show an average increase of 10%, the precipitation projections have high variability similar to the baseline data. However, the rain in the summer and fall months decreases in the range of 0.01mm/yr. to 0.13mm/yr. (0.5% to 4.5%). These decreases were observed to appear early and remain for a prolonged period towards 2100. In both watersheds, the spring freshets appear to decrease and peak runoff occurs early by two or more weeks towards 2100. The shift in the timing of the peak runoff and its decease in amount is crucial for water managers. This is very critical for the Mississippi watershed as water management is often a compromise between water users such as tourism, hydropower generation, fisheries, and low flow augmentation, and depends on storage and release from the reservoirs. In the future, the runoff appears to increase only in the winter months. In the summer and fall months there is a consistent increase in the deficit (-1mm to -27.3mm, >700%) and decrease in the runoff amount (>70%). This situation occurs early and exists for prolonged periods of time increasing the challenge for water managers to resolve conflicts over priorities among the water users and their needs.

Keywords: climate change, climate models, water balance, hydrology, water budget projections

Résumé

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Mots clés :

1. Introduction

Climate change impacts on water will affect many sectors, altering the hydrologic cycle as the atmosphere warms and altering the amount, extent, timing, and intensity of precipitation and streamflow. These changes will likely affect water management programs which are developed to protect and manage the water.

Changes to the hydrologic cycle will include a shift in the balance between precipitation, evaporation and associated processes. This new imbalance will increase the challenges water managers face in resolving the demand conflicts among water users and recently researchers determined that over the last 50 years rainfall amounts during the most intense 1% of storms increased by almost 20% [1].

In winter, warmer temperatures increase the likelihood of precipitation falling as rain rather than snow which in turn will alter the timing of streamflow, especially the peak spring freshet and this is shown in recent studies in both the Mississippi watershed and in other areas through reductions in the amount and duration of snowfall, increased winter mean discharge, and low summer and fall stream flows [2, 3, 4]. The 2001 Intergovernmental Panel on Climate Change (IPCC) [5] report states during this century, the inflow in North American Rivers will increase in the winter and will decrease in the summer. This finding is confirmed in another watershed scale study by Kunjikutty et al. [2] in eastern Ontario's Mississippi River watershed.

In 2006 a hydro-technical study was completed for the Mississippi River Water Management Plan which confirmed that using historic trends in the stream flow conditions to establish water management objectives, particularly in fish and aquatic habitat, could be very challenging for water managers. Warmer air temperatures could raise stream and lake temperatures. This in turn harm may the cold-water species such as lake trout. This is consistent with the findings from a recent study done in the Mississippi watershed on the impact of climate change on water resources [2]. There are many cold-water lakes and creeks in the watershed so lake trout protection is of particular relevance to the region. Since the changes in stream flow are due to climate change, water managers need to determine the extent of these changes, determine the capacity of the existing infrastructure to responding, and manage the associated risks in an integrated manner.

Historic conditions cannot be used in isolation to accurately predict the future and it is crucial that water managers have a good understanding of the watershed's hydrologic system and its response to potential changes in climate. This in turn will increase their ability to implement a viable water management plan. Several sources of uncertainty associated with climate change make its impact more difficult to understand [6], the key uncertainties being in climate data, downscaling methods, and simulated hydrology. Use of more than one climate projection from a combination of many global circulation models (GCMs) and greenhouse gas emission scenarios (GHGES) is recommended in a hydrologic climate impact study to assess the uncertainties [6,7]. Uncertainties are also carried from the downscaling methods which use many assumptions in their techniques.

The goal of this study is to determine the performance of the selected GCM and GHGES scenarios downscaled to the Mississippi-Rideau watershed region and to project the future water budget components and associated uncertainty. This is one of the six subprojects of a larger project aims to assess the climate change vulnerability in the Mississippi-Rideau region. This paper includes a description of the watershed region, method used in climate model selection and analysis, model performance and the future water budget projections.

2. Study Area

The Mississippi-Rideau Watershed Region (MR region) is located in Eastern Ontario. The region includes the boundaries of the Mississippi and the Rideau Valley Conservation Authorities (MVCA and RVCA). The major rivers in the watershed, the Mississippi, Rideau, and Carp discharge, along with some smaller tributaries, to the Ottawa River. The study area encompasses the western and central portions of the City of Ottawa as well as a number of smaller municipalities, rural townships, and counties.

3. Methodology

3.1 Selection of Climate Models

The Fourth Assessment Report (AR4) of the IPCC includes A2 (high GHG emissions), A1B (medium GHG emissions), and B1 (low GHG emissions) scenarios. Ministry of Natural Resources and Forestry (MNRF) has downscaled AR4 data to every climate station in Ontario [8]and these AR4 projections are available through the Aquamapper web portal. There are 28 Global Circulation Models (GCMs) and three Special Reports on Emission Scenarios (SRES) available for each climate station. Drummond Centre in Mississippi and Ottawa Airport in the Rideau watersheds were the climate stations selected.

This study used the daily climate data from the GCM change field method. he changes in the mean monthly future climate from the baseline climate will apply to the existing climate [9]. Water managers use this method widely because it is easy to use and has the advantage of using data from many GCMs and associated emission scenarios. One of the major limitations of this method in the hydrological impact assessment is the lack of good representation of potential climate change impacts on inter-annual or day-to-day variability of climate parameters. So the changes in sequence of wet days, dry days and peak precipitation events are not altered. The method may underestimate future floods, droughts, groundwater recharge, and snowmelt timing [10]. The degree of uncertainty when quantifying these changes has not yet been correctly considered in climate change science.

The web-application uses the percentile method to shortlist climate scenarios that match with the historical conditions. The percentile method is a statistical method of selecting a broader range of future climate scenarios for the climate impacts assessment. Based on the mean annual temperature change field and mean annual precipitation change field values, each of the 28 GCMs and 3 SRES scenario combinations are ranked in ascending order. A percentile is then assigned to each scenario, representing the order of the scenario divided by the total number of scenarios. The method will select 90th, 75th, 50th, 25th, and 10th percentiles for both the mean annual temperature and mean annual precipitation change fields. Thus, a total of ten scenarios corresponds to these rankings. A pilot study showed the extreme percentiles such as 95th and 5th percentiles might be more appropriate than 90th and 10th percentiles [9, 10] so the built-in percentile method will select scenarios corresponding to 95th, 75th, 50th, 25th, and 5th percentiles for further use in this study.

The base line period chosen is 1970-2000. The future climate projections were generated for 2011-2040, 2041-2071, and 2071-2100 periods.

3.2 Water Budget Model

In this study, the hydrologic water balance model uses the Thornthwaite and Mather (1995) method. Air temperature and precipitation data are the main inputs to the model. Latitude of the climate station and estimated soil water holding capacity (WHC) are the other input parameters needed in the model.

The model computes water budget components by tabulating additions, losses, and changes in water storage. Daily climate data is better at modeling the snowmelt and in improving snow storage calculation. It is of specific importance for Canadian climate. The WHC is the maximum amount of water that the soil capillaries can hold for use by vegetation.

The model outputs include rain, snow storage, potential evapotranspiration (PET), actual evapotranspiration (AET), moisture deficit, and moisture surplus. The accumulated precipitation on days when the daily mean temperature is greater than the critical temperature (set at -1^{0}C) is accounted for as rain. When the daily mean temperature is equal to or less than the critical temperature, the accumulated precipitation is accounted for as snow storage. Snow storage is the water equivalent of snow at the end of the period. The daily snowmelt is computed when there is snow on the ground and the daily temperature is greater than 0^{0}C.

The PET is the amount of water that could evaporate from a vegetated surface, but the AET is the total evapotranspiration which occurs in the period. The soil deficit is the amount that the available soil moisture fails to meet water demand, and is the difference between the PET and AET. The soil surplus is the excess water after the surface evaporation has met (AET = PET) and soil storage has reached the WHC level. This simple water budget procedure uses many assumptions on the physical processes in the water exchange in the soil-water-plant system. So, outcomes from this procedure should use only as indices of the main water balance components and it should not be assumed that the model provides specific estimates of actual conditions in the basin.

4. Results and Discussion

4.1 Model Selection and Performance

By applying the percentile method nine scenarios in 2040 and ten scenarios each in 2070 and 2100 were selected for Drummond Center station. Ten models were selected for all the three future periods for the Ottawa Airport station. The details of the selected models and their corresponding percentiles are illustrated in table 1. The NCARPCM model with the SRA1B emission scenario was selected based on both annual mean precipitation (50%) and annual mean temperature (5%) rankings. Therefore, there were only nine models selected for 2040 for Drummond Centre station. The precipitation and temperature projections from the selected models were assessed for consistency or variability. The models correspond to a wide range of percentiles (5% to 95%). The comparison of the model projections is crucial in water management decision-making, especially for the extreme conditions like wet/dry or flood/drought.

The average monthly temperature projections from the selected models for Drummond Centre station were consistent across the months. Similar results were observed with the Ottawa Airport station with the exception of two models that over-projected the temperature in 2040. However in both watersheds a high degree of variability was observed in the monthly average precipitation across the months. This variability is the same variability observed in the baseline data. From 2040 to 2100 the models show an increasing trend in the monthly temperature and precipitation projections.

In 2040, GFDLCM2.0 SRA1B and CGCM3T47-Run1 SRA2 seem to over predict the temperature compared to other models. These models correspond to 50th and 75th percentiles of temperature ranking. However, the projections from these models are similar across the months. It should be noted that while GFDLCM2.0 SRA1B projected the lowest, CGCM3T47-Run1 SRA2 projected the highest precipitation in 2040 (Figure 2), so treating these models as outliers is questionable.

Table 1. Selected GCM-GHG model for Drummond Centre and Ottawa Airport Stations

Drummond Centre

GCM	Emission Scenario	Precip. Rank (%)	Temp. Rank (%)	GCM	Emission Scenario	Precip. Rank (%)	Temp. Rank (%)	GCM	Emission Scenario	Precip. Rank (%)	Temp. Rank (%)
2040 (2011-2040)				**2070 (2041-2070)**				**2100 (2071-2100)**			
CGCM3T47-Run2	SRA1B	95		CGCM3T47-Run1	SRA2	95		CGCM3T47-Run1	SRA2	95	
GISS-AOM	SRB1	75		CGCM3T47-Run5	SRB1	75		GFDLCM2.1	SRA1B	75	
NCARPCM	SRA1B	51	5	CGCM3T47-Run3	SRA1B	51		CGCM3T63	SRB1	51	
CSIROMk3.5	SRB1	25		CGCM3T47-Run4	SRA1B	25		ECHO-G	SRA2	25	
HADCM3	SRB1	5		INMCM3.0	SRB1	5		IPSLCM4	SRA2	5	
MIROC3.2medr	SRB1		95	HadGEM1	SRA2		95	HadGEM1	SRA1B		95
GFDLCM2.0	SRA1B		75	CGCM3T47-Run5	SRA1B		75	INMCM3.0	SRA2		75
CGCM3T47-Run1	SRA2		51	GFDLCM2.1	SRA1B		51	FGOALS-g1.0	SRA1B		51
CNRMCM3	SRA2		25	GISS-ER	SRA2		25	CGCM3T47-Run2	SRB1		25
				FGOALS-g1.0	SRB1		5	GISS-AOM	SRB1		5

Ottawa Airport

2040 (2011-2040)				**2070 (2041-2070)**				**2100 (2071-2100)**			
CSIROMk3.0	SRA1B	95		CGCM3T47-Run1	SRA2	95		CGCM3T47-Run1	SRA2	95	
CGCM3T47-Run1	SRA1B	75		GISS-EH	SRA1B	75		GFDLCM2.1	SRA1B	75	
BCM2.0	SRA2	51		NCARCCSM3	SRB1	51		CGCM3T47-Run5	SRA1B	51	
INMCM3.0	SRA1B	25		ECHO-G	SRA2	25		IPSLCM4	SRB1	25	
CGCM3T47-Run4	SRA1B	5		INMCM3.0	SRB1	5		IPSLCM4	SRA2	5	
MIROC3.2medr	SRB1		95	IPSLCM4	SRA2		95	MIROC3.2medr	SRA1B		95
GFDLCM2.0	SRA1B		75	GFDLCM2.0	SRA2		75	INMCM3.0	SRA2		75
CGCM3T47-Run1	SRA2		51	GFDLCM2.1	SRA1B		51	FGOALS-g1.0	SRA1B		51
GISS-AOM	SRA1B		25	GISS-ER	SRA2		25	CGCM3T47-Run2	SRB1		25
ECHAM5OM	SRA2		5	FGOALS-g1.0	SRB1		5	NCARCCSM3	SRB1		5

For the Mississippi watershed, the variation in the temperature projections ranges from 1 to 9^{0}C, with the highest variation occurring in February. The standard deviation and the standard error in the temperature range from 0.4^{0}C to 1.7^{0}C and 0.1^{0}C to 0.6^{0}C. The average monthly temperature varied from 2 to 7^{0}C at Ottawa Airport for the Rideau watershed. Similar to the Mississippi, the standard deviation and the standard error in the temperature projections are very low (0.6^{0}C to 2^{0}C and 0.2^{0}C to 0.6^{0}C) and could indicate a better agreement between the model projections.

The variability in the average precipitation projections in the Mississippi watershed ranges from 11mm to 54mm. The variability was higher (45-54mm) in the months of April, August, and September. The standard deviation and the standard error in precipitation ranges from 3.6mm to 16.7mm and 1.1mm to 5.3mm respectively. However, though the projections have a high variability, their statistical results show a better agreement within the scenarios. Compared to the Mississippi station, the variability in the precipitation is higher with the Rideau station; it varies from 21mm to 87mm. The standard deviation and the standard error in the precipitation range from 6.1mm to 24.5mm and 1.4mm to 7.2mm. Even with high variability associated with historic or future precipitation, the low standard deviation and error indicates a relatively good agreement among the model projections.

As seen in Figure 1, the majority of the models at both climate stations projected a consistent increase in the temperature from 2040 to 2100. The models projected 10-30% of the increase in the temperature in 2040, 20-50% in 2070, and 40-100% in 2100. In the case of precipitation projection, the majority of the models in all three future periods with Mississippi and 2040 and 2070 with Ottawa Airport station projected 0-10% increase (Figure 2). However in 2100 while half of the models still projected increases of 0-10%, the other half-projected a 10-20% increase.

4.2 Hydrological impacts

4.2.1 Temperature and Precipitation

In both watersheds the average monthly temperature consistently increased from the baseline to 2100. The rate of increase was observed to be high in the winter and the summer months. Similar to the baseline precipitation data, high variability is associated with future precipitation projections. In contrast to temperature projections, precipitation is projected to increase in the winter months compared to the baseline condition and decrease during the traditional summer and fall low flow season.

The percent change rate in the future maximum and minimum temperatures, the precipitation, the snow, and the rain from their baseline conditions are given in tables 2 and 3 for Mississippi and Rideau watersheds respectively. The rates of changes in the maximum and the minimum temperatures per year increased in the range of 0.03^{0}C/yr. to 0.05^{0}C/yr. in Mississippi and 0.03^{0}C/yr. to 0.06^{0}C/yr. in Rideau (Table 2 and 3). The monthly precipitation rate changes were highly variable and ranged from -0.05mm to 0.24 mm/yr. in the Mississippi and -0.08mm/yr. to 0.35mm/yr. in the Rideau. However, in both watersheds the precipitation (rain) in the summer and fall months decreases in the range of 0.01 mm to 0.15mm. As well, these decreases are observed to appear earlier and remain for a prolonged period from 2040 to 2100. In the summer and fall months, the decrease in the amount of precipitation, its early onset and prolonged existence, along with the increase in both minimum and maximum temperatures is crucial in water management. The change rate in snow in majority of the months in the future will decrease in the range of -0.01mm/yr. to 0.11mm/yr. in Mississippi and 0.01mm to 0.22mm in Rideau (Table 2 and 3).

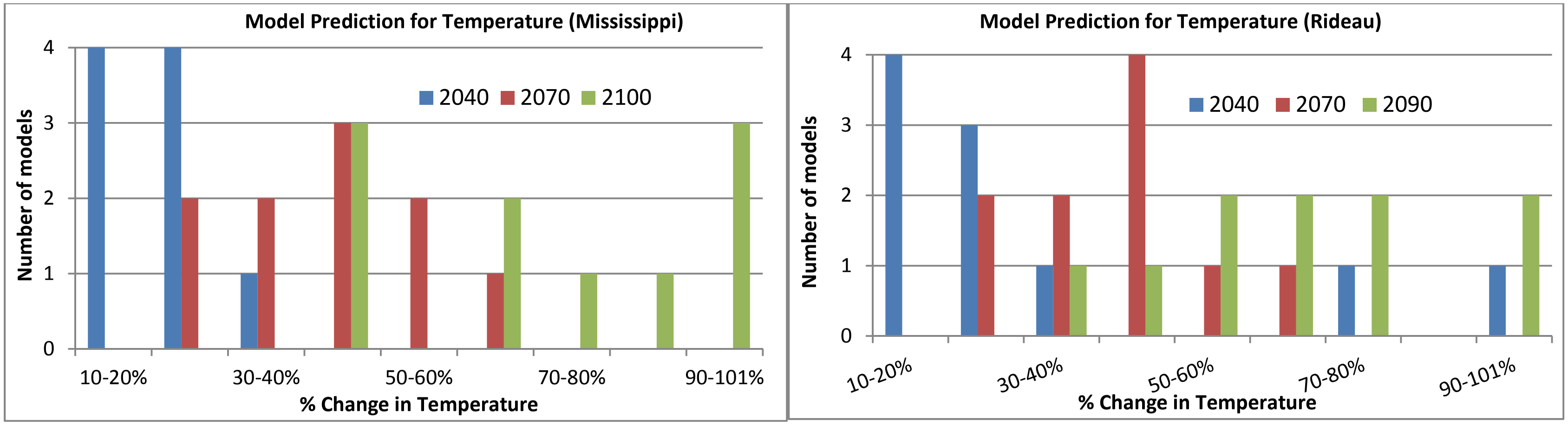

Figure 1: Performance of the selected models in the Temperature projections (Mississippi and Rideau)

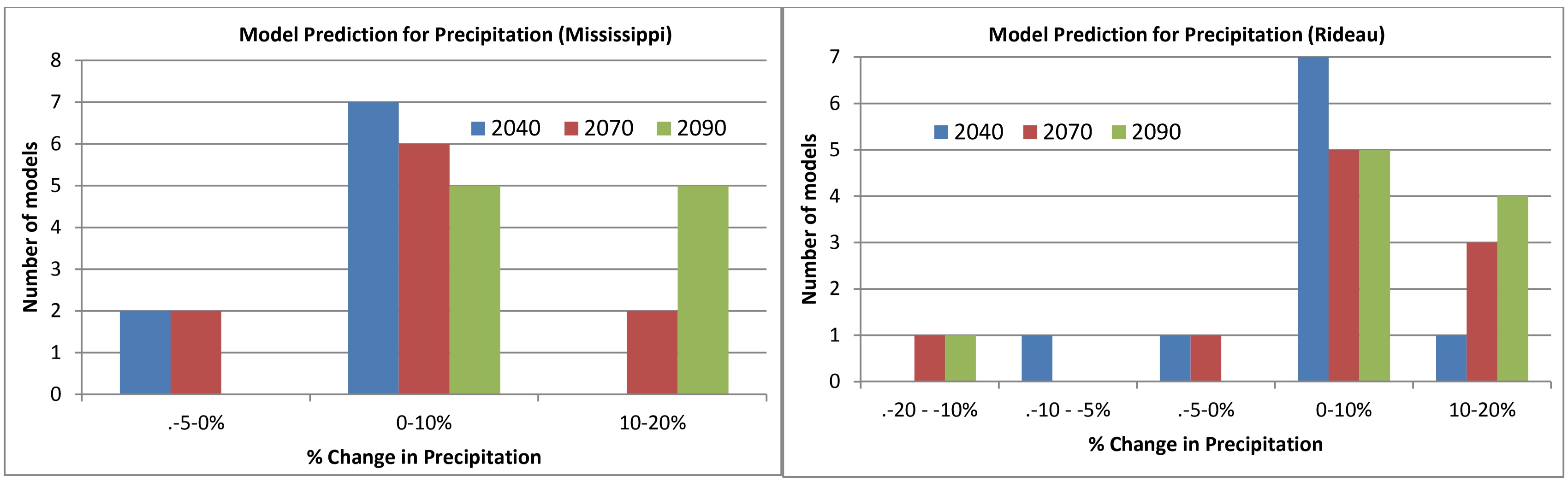

Figure 2: Performance of the selected models in the Precipitation projections (Mississippi and Rideau)

Table 2. Temperature, Precipitation, Snow, and Rain Change Rates from the Baseline Period (MVCA)

Months	Min. / Max. Temp. Change Rate (^{0}C/yr.)			Precipitation Change Rate (mm/yr.)			Snow Change Rate (mm/yr.)			Rain Change Rate (mm/yr.)		
	2040	*2070*	*2100*	*2040*	*2070*	*2100*	*2040*	*2070*	*2100*	*2040*	*2070*	*2100*
Jan	0.05	0.05	0.05	0.16	0.21	0.15	0.03	0.05	0.01	0.13	0.16	0.14
Feb	0.04	0.04	0.05	0.10	0.06	0.10	0.00	-0.01	0.01	0.10	0.07	0.09
Mar	0.04	0.04	0.05	0.10	0.15	0.10	-0.06	-0.02	-0.05	0.16	0.17	0.15
Apr	0.04	0.05	0.05	0.19	0.18	0.19	-0.11	-0.08	-0.06	0.30	0.25	0.25
May	0.04	0.04	0.04	0.14	0.12	0.10	0	0	0	0.14	0.12	0.10
Jun	0.04	0.03	0.04	0.08	-0.03	-0.01	0	0	0	0.08	-0.03	-0.01
Jul	0.04	0.04	0.04	0.05	-0.05	-0.04	0	0	0	0.05	-0.05	-0.04
Aug	0.05	0.04	0.05	-0.02	0.01	-0.04	0	0	0	-0.02	0.01	-0.04
Sep	0.04	0.04	0.04	-0.02	-0.03	0.02	0	0	0	-0.02	-0.03	0.02
Oct	0.04	0.04	0.05	0.01	0.12	0.04	-0.03	-0.02	-0.01	0.04	0.14	0.05
Nov	0.04	0.03	0.04	0.00	0.14	0.11	-0.13	-0.07	-0.08	0.12	0.20	0.19
Dec	0.04	0.05	0.05	0.24	0.22	0.18	0.02	0.03	-0.02	0.21	0.19	0.21

Table 3. Temperature, Precipitation, Snow, and Rain Change Rates from the Baseline Period (RVCA)

Months	Min. / Max. Temp. Change Rate (^{0}C/yr.)			Precipitation Change Rate (mm/yr.)			Snow Change Rate (mm/yr.)			Rain Change Rate (mm/yr.)		
	2040	*2070*	*2100*	*2040*	*2070*	*2100*	*2040*	*2070*	*2100*	*2040*	*2070*	*2100*
Jan	0.06	0.04	0.05	0.15	0.18	0.18	0.02	0.05	0.02	0.13	0.13	0.16
Feb	0.04	0.04	0.05	0.07	0.11	0.1	-0.03	0.02	-0.02	0.1	0.09	0.11
Mar	0.05	0.04	0.05	0.09	0.16	0.12	-0.13	-0.07	-0.11	0.23	0.23	0.23
Apr	0.05	0.05	0.05	0.22	0.17	0.23	-0.15	-0.11	-0.09	0.37	0.28	0.32
May	0.04	0.04	0.04	0.15	0.04	0.11	0	0	0	0.15	0.04	0.11
Jun	0.03	0.04	0.03	0.01	0.03	0.00	0	0	0	0.01	0.03	0.00
Jul	0.04	0.04	0.04	0.08	-0.03	-0.04	0	0	0	0.08	-0.03	-0.04
Aug	0.04	0.04	0.04	0.15	-0.05	-0.01	0	0	0	0.15	-0.05	-0.01
Sep	0.03	0.04	0.04	-0.13	0.00	0.01	0	0	0	-0.13	0.00	0.01
Oct	0.03	0.04	0.05	-0.08	0.03	0.02	-0.11	-0.06	-0.04	0.03	0.09	0.07
Nov	0.04	0.04	0.04	0.06	0.15	0.08	-0.22	-0.14	-0.13	0.28	0.29	0.21
Dec	0.06	0.05	0.05	0.35	0.27	0.16	0.01	-0.01	-0.08	0.34	0.29	0.24

The average annual baseline temperature in the Mississippi watershed was 5.7^{0}C, which increases to 7.0^{0}C in 2040, to 8.2^{0}C in 2070 and to 9.8^{0}C in 2100, with percent increases of 21%, 43%, and 71%, respectively (Figure 3). Like the average annual baseline temperature of 6.1^{0}C in Rideau increases to 8.1^{0}C in 2040, 8.6^{0}C in 2070 and 10.2^{0}C in 2100. The corresponding increases in the temperature are 34%, 42%, and 67%, respectively (Figure 3). The annual average total precipitation in Mississippi was 887mm in the baseline, which increases to 918mm (4%), 952mm (7%), and 968mm (9%) in 2040, 2070, and 2100, respectively (Figure 3). Similar increases were observed in Rideau when we omitted two underpredicted model projections. In Rideau, the baseline precipitation of 951mm increases to 985mm (4%) in 2040, 1020mm (7%) in 2070, and 1031mm (8%) in 2100.

4.2.2 Annual and seasonal Runoff

The average monthly runoff in the Mississippi and Rideau watersheds is shown in Figure 4. Along with the runoff in the baseline and the future periods, the runoff in the current period (2011-2013) also included in Mississippi watershed. In both watersheds, the spring peak

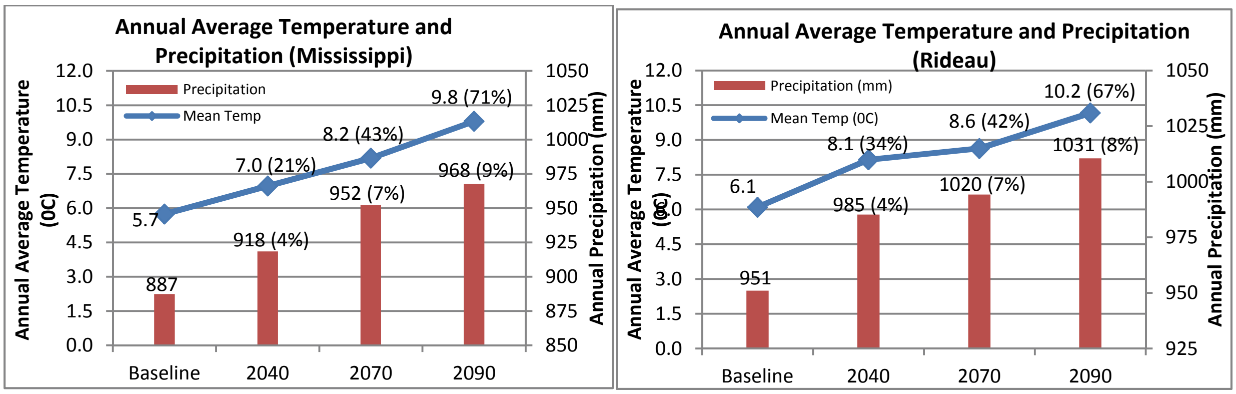

Figure 3. Annual average temperature and precipitation in the baseline and future periods (Mississippi and Rideau)

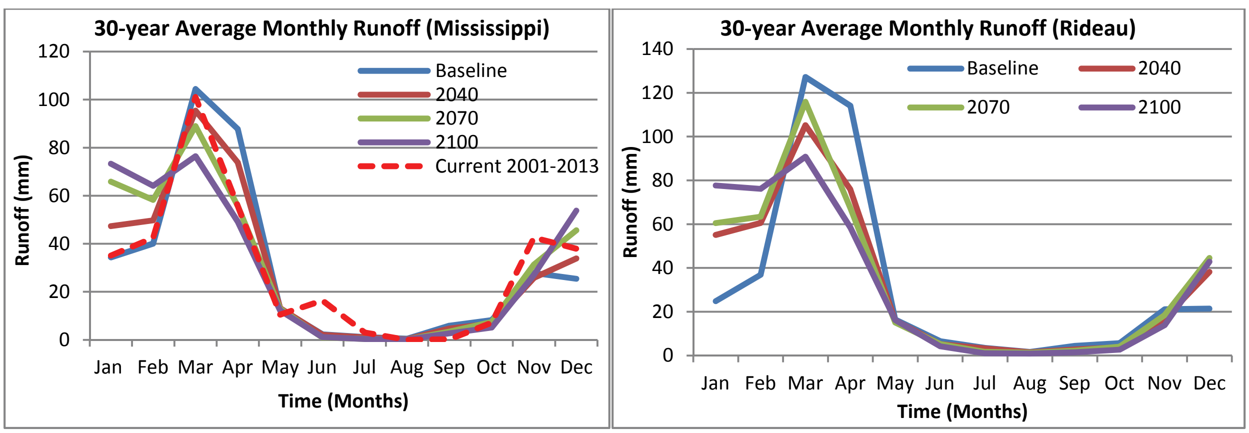

Figure 4. Annual average monthly runoff in the baseline and future periods (Mississippi and Rideau)

freshets appear to decrease from the baseline to the future period. This may be observed in the current conditions in the Mississippi watershed as well (Figure 4). During the summer and fall seasons (from June to October), runoff projections are observed to consistently decrease from the baseline in the future periods. As mentioned earlier, this information is crucial for water management in the low flow season.

A weekly water budget analysis shows an early onset of the peak runoff by two or more weeks in the future periods. Similar results were also obtained in a hydrological modelling study done in 2008 for the Mississippi watershed [2]. The shift in the timing of the peak runoff and its decease is crucial for water managers. This situation is critical for the Mississippi watershed as the watershed management is a compromise between the needs of the water users such as tourism, hydro power generation, fisheries, and low flow augmentation; and completely depends on the storage and release from the reservoirs.

The differences in the future monthly runoff from their baseline condition are shown in Figures 5 and 6 for the Mississippi and Rideau watersheds respectively. In both watersheds, the increase in the runoff was observed only in the winter months. This is due to the observed increase in the minimum and the maximum temperatures in the winter.

In the spring/summer and summer/fall season, the runoff in every month appears to decrease as compared to their baseline condition (Figure 5 and 6). In both watersheds, the decrease observed is higher in the spring, especially in the months of March and April. In Rideau watershed, the decrease was much higher than that observed in the Mississippi. This might be due to the higher projected temperature in Rideau as compared to that in the Mississippi. The baseline temperature in March and April were -2.2^{0}C and 5.5^{0}C in Mississippi and -1.7^{0}C and 6.6^{0}C in Rideau. These temperatures were projected to increase in the range of -2.2^{0}C to 5.5^{0}C in Mississippi and 0.4^{0}C to 11^{0}C in Rideau. Similar to the spring, in both watersheds, the decrease in the runoff was highest in two months in the fall months of September and October. The consistent decrease in the spring and fall runoff increases the difficulty in managing water, especially in the Mississippi River where the water is closely managed through the operation of a series of storage reservoirs.

4.2.3 Annual Water Budget

The average monthly potential evapotranspiration, runoff and the deficit amounts in the baseline and the future periods are given in Figure 7 for Mississippi and Rideau watersheds. In both watersheds, the PET consistently increases from the baseline to the future periods. This increase is corresponding to the consistent increase in the temperature projections. In both watersheds, the deficit is increasing from the baseline to the future. The deficit starts early and persists for more time towards the future as compared to the baseline (Figure 7).

As previously noted, in both watersheds, the runoff in the summer and fall months will decrease in the future compared to their baseline conditions. As with the deficit, the amount of runoff also decreases in these months. Like the deficit, the zero point and/or the decrease in the runoff will occur early and last for a longer period in the future (Figure 7). The increase in the deficit, decrease in the runoff, and their earliest occurrence and prolonged existence during the summer and fall months is very crucial for water managers.

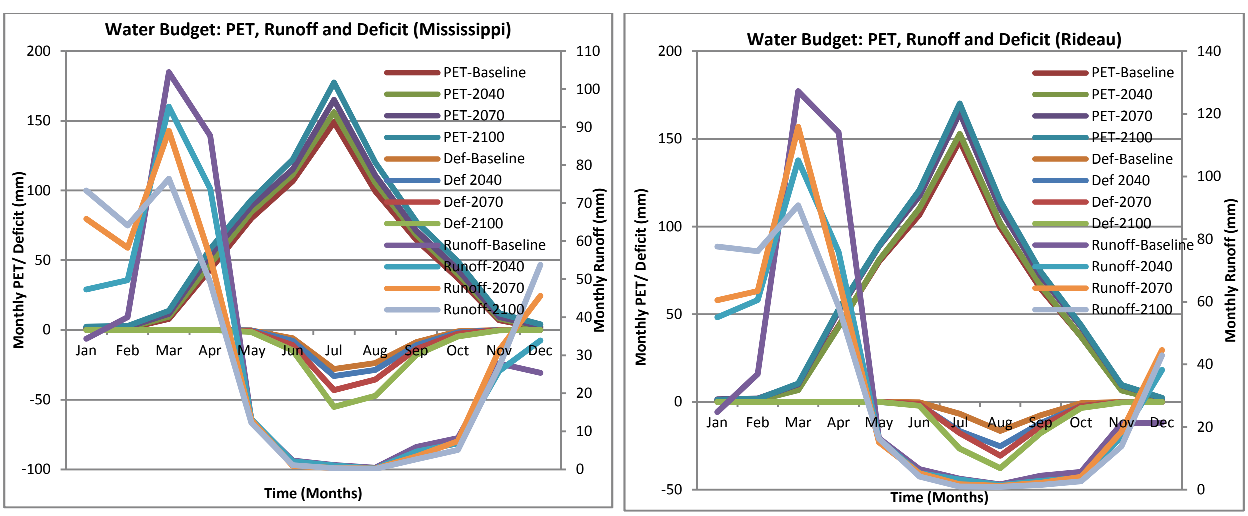

Figure 7. Monthly PET, Runoff, and Deficit in the baseline and future periods (Mississippi and Rideau)

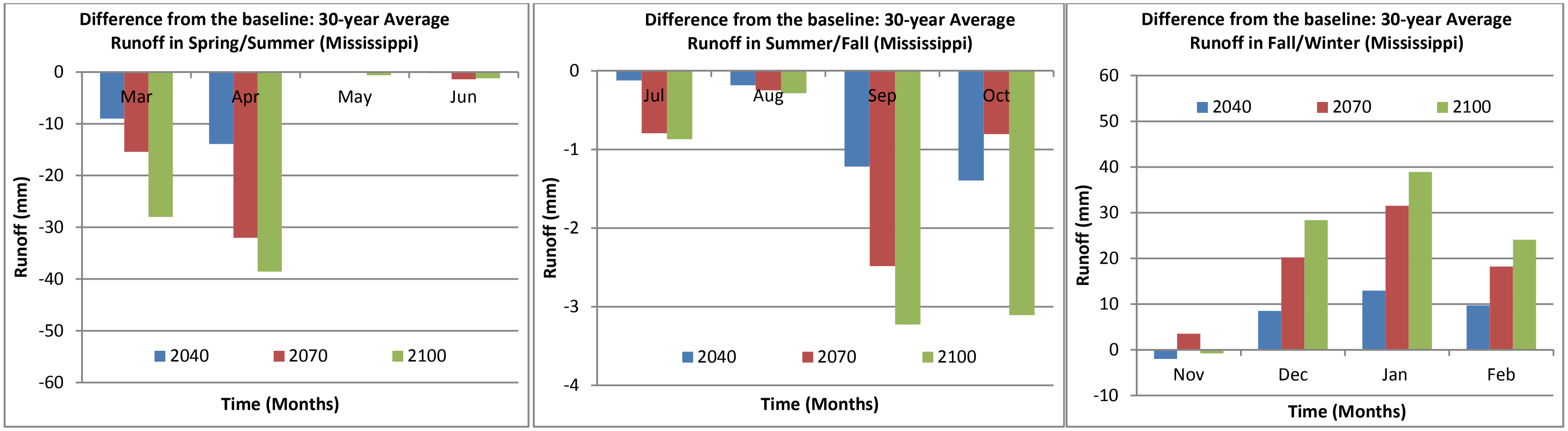

Figure 5. Average summer, fall and winter runoff difference from the baseline in Mississippi

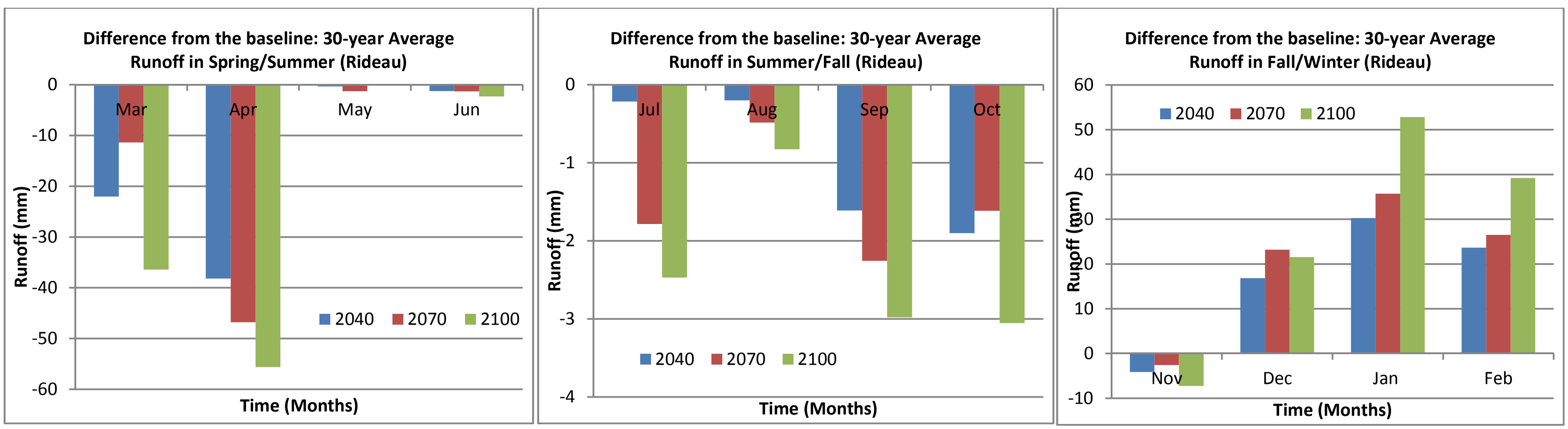

Figure 6. Average spring, summer, fall and winter runoff difference from the baseline in Rideau

5. Conclusion

In the Mississippi and Rideau watersheds, the selected GCM-GHG models for Drummond Centre (Mississippi) and Ottawa Airport (Rideau) climate stations show high consistency and good agreement in the temperature and the precipitation projections for the 2011-2100 periods. In the Mississippi, the average annual temperature in the baseline was 5.7^{0}C, which increases to 7.0^{0}C in 2040, 8.2^{0}C in 2070 and 9.8^{0}C in 2100. In the Rideau watershed, the baseline 6.1^{0}C increases to 8.1^{0}C in 2040, 8.6^{0}C in 2070 and 10.2^{0}C in 2100. The annual precipitation in the Mississippi watershed increases from 887mm in the baseline period to 918mm in 2040, 952mm in 2070, and 968mm in 2100. In the Rideau, it increases from 951mm to 985mm in 2040, 1020mm in 2070, and 1031mm in 2100. The spring freshets are observed to decrease in the future and peak runoff occurs earlier by more than two weeks in the future. The runoff shows increases only in the winter months, it might be due to the increase in the temperature. Like the runoff, the deficit increases consistently in the future and lasts for a longer period. The low flow season appears to have little or no runoff in the months of June to September. It appears to occur early and last progressively longer towards 2100 with decreases in its amounts. This is extremely important data for water managers in managing flows and levels in the river system.

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7. Acknowledgements

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