This document includes the Cover Page, Table of Contents, Executive Summary, and study report for the document: *Future water Budget Projections in Mississippi Rideau Watershed Region*, completed in September, 2014.

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Future Water Budget Projections in Mississippi Rideau Watershed Region

November 2015

FUTURE WATER BUDGET PROJECTIONS IN MISSISSIPPI RIDEAU WATERSHED REGION

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RIDEAU VALLEY CONSERVATION AUTHORITY

Mississippi Valley Conservation Authority

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Executive Summary

Climate change studies show a rise in temperature and high variability, frequency and intensity of precipitation. But there always exist uncertainties in climate projections, sometimes resulting in less confidence of our knowledge on the likely effect of such change in climate on hydrological regimes and water resources. Water resources are one of the vulnerable sectors that face significant challenges with climate change. Change in precipitation patterns or changes in patterns of snow and ice melt alters hydrological systems and quality and quantity of water resources available.

The study area is the Mississippi-Rideau Watershed Region (the MR region or the Region) in eastern Ontario, which includes the boundaries of the Mississippi Valley Conservation Authority (MVCA) and the Rideau Valley Conservation Authority (RVCA).

The Region has many programs and activities in place that integrate existing water management with watershed and subwatershed plans, including protecting healthy watersheds and wetlands, storm water management as well as improving efficiency and sustainability of water infrastructure, reducing water pollution, and protecting drinking water sources. As seen in other climate change studies, the MR Region also sees impacts of climate change to a certain extend and might face significant challenges in the future, especially on water resources. This study is to elaborate on the Region's knowledge and understanding of climate impacts, vulnerability, and adaptation planning, that in the future, may be incorporated into the existing core programs.

This study, 'Future Water Budget Projections in Mississippi Rideau Watershed Region' is a subproject of 'the Mississippi Rideau Climate Change Vulnerability Assessment Project'.

The study compares future climate from the different Global Climate Model (GCM) scenarios and projects future water budget parameters in the Region. Multi-model, multi-scenario climate projections using change field method were analyzed to assess uncertainty in projected future hydrologic components. Similar to many climate change studies, the focus of this study is not to predict the future data, but to better understand uncertainties that could affect implementation in climate adaptation decisions under a wide range of possible future projections.

The GCM scenario climate data were obtained from the Ministry of Natural Resources and Forestry (MNRF). There are 76 different scenarios available from 28 GCMs and 3 emission scenarios. Daily climate data, generated using the change field or delta method, was used in the study. The data was downscaled to Drummond Center and the Ottawa Airport climate stations respectively, in the Mississippi and the Rideau watersheds in the Rideau.

The baseline period of 1970 to 2000 and future periods of 2010-2040, 2041-2070, and 2071-2100 were selected. These future periods are referred to in this report as 2020s, 2050s, and 2080s respectively. Ten scenarios were chosen for each 30-year periods using the percentile method. In this method, the scenarios were selected to correspond to different percentiles assigned to rank average annual change field values for precipitation and temperature separately.

The Thornthwaite water budget model, modified by Johnston and Louie (1983), from the Ontario Ministry of the Environment, was used to generate the water budget parameters for the future and baseline climate.

For both climate stations in the Region, the study shows good consistency within the selected GCM scenarios in projecting future climate for 2010-2100 periods.

The annual average temperature increases to 9.8^{0}C in the Mississippi from its baseline temperature of 5.7^{0}C and in the Rideau it increases to 10.2^{0}C from its baseline temperature of 6.1^{0}C. The results indicate a 1.3 to 4.1^{0}C increase the annual average temperature and 4-9% of the precipitation, by 2100.

Seasonally, the temperature increase is in a similar range, 1.2 to 4.50C. The largest increases in temperature and precipitation are observed in the winter months. Though the precipitation increases annually, on seasonal average, it decreases up to 2% during the summer (decreases up to 6% on monthly average).

The observed largest increase in temperature in the winter will shift the timing and increase the amount of runoff. This has the potential to reduce the capacity of the snow pack storage and its volume of water that could infiltrate and the soil for storage as soil moisture groundwater.

In the Region, the snow consistently is projected to decease between 26 and 75% and the water deficit is projected to increase between 22 and 177%. Annually, average runoff increases between 1 to 6%, but it consistently decreases in the spring and the summer months, and is crucial in water management during the low flow season.

In both watersheds, the low flow season appears to have little or no runoff occurring from July through September, and this low flow period appears to occur earlier and last progressively longer from 2020s to 2080s with decreases in its amounts. This situation along with low projected summer precipitation, high temperature and increasing evapotranspiration has the potential to be extremely important in managing flows and levels in the watershed.

The study confirms the limitation of the delta method in generating the climate data. Upon breaking down the 30-year periods it became evident that the 15-year trend analysis presumes that the future climate generated from GCMs, using the delta method for any climate stations, will follow the patterns of their baseline data while incorporating the future GHG emissions. Therefore the climate projections using the delta method are not recommended for studies where a potential change in inter arrival time, duration, or spatial extent of climatic extremes are concerned (e.g. droughts and floods). In any climate change and adaptation study both the selection of GCM and the downscaling method are crucially depend on the objective of the study.

Table of Contents

List of Figures

List of Tables

List of Appendices

List of Abbreviations

AET	Actual Evapotranspiration
AR	Assessment Report (IPCC reports 4 and 5 referred to)
ET	Evapotranspiration
GCM	Global Circulation Model
GHGE	Green House Gas Emission
IPCC	Intergovernmental Panel on Climate Change
MOE	Ontario Ministry of the Environment
MNR(F)	Ontario Ministry of Natural Resources (and Forestry)
MVCA	Mississippi Valley Conservation Authority
PET	Potential Evapotranspiration
RCPs	Representative Concentration Pathways
RVCA	Rideau Valley Conservation AUthority
MNRF	Ministry of Natural Resources and Forestry
SRES	Special Reports on Emissions Scenarios
WHC	Water Holding Capacity

1 Introduction

The Mississippi-Rideau Watershed Region (the MR region or the region), located in eastern Ontario, includes the boundaries of the Mississippi Valley Conservation Authority (MVCA) and the Rideau Valley Conservation Authority (RVCA). The Mississippi River and the Rideau River, the largest rivers in the region, discharge to the Ottawa River. A base map of the study region is given in Figure 1-1. In 2007 and 2008, the region completed a conceptual and Tier-I water budget reports in conjunction with the Technical Rules prepared by the Ministry of Environment (MOE 2008) for the preparation of Assessment Reports under the Clean water Act (2006).

In 2014, the region initiated ‘the Mississippi Rideau Climate Change Vulnerability Assessment Project’ to better understand the sustainable availability of terrestrial and aquatic resources in the future. This report, entitled the ‘Future Water Budget Projections in Mississippi Rideau Watershed Region (MR region)’ is a subproject of that. Other reports include in this project, which are completed and/or are ongoing:

1. Climate Change Vulnerability Assessment for Aquatic Ecosystems in the MR Region,
2. Mississippi Rideau Regional Characterization Report,
3. Impacts of Changing Hydrology on the Otter/Hutton Creek System,
4. Vulnerability of Fur Bearers,
5. Biodiversity – Using Nature Serve’s Rapid Assessment Index to Prioritize Species' Vulnerability to Climate Change, and
6. Organizational Readiness Assessment – A Pilot Project at Mississippi Valley Conservation Authority.

Objectives

The specific objectives of this study in the MR region area are:

- To compare the performance of the selected General Circulation Model (GCM) Scenarios in projecting the future climate to the Region.
- To project **water budget** components as a first step in understanding future water cycle as well as the climate for the Region.
- To identify **gaps** or **additional requirements** in pursuing the study includes extreme climates.
- To provide **data and study results** to assess reservoir operation strategies under climate change projection in the Mississippi.

Report Organization

This report documents climate model selection, data analysis, and the future climate and water budget projections for the Region. The report is divided into 5 sections:

1. Introduction
2. Methodology
3. Results and Discussion
4. Summary and Conclusion
5. Recommendations for future study

A description of the study area is not included in this report as it detailed in the MR Region Characterization Report (2015). Detailed watershed information can found in the Watershed Characterization report (Mississippi-Rideau Source Protection, 2008) for MR Source Protection Region prepared as part of the Source Protection Assessment Reports.

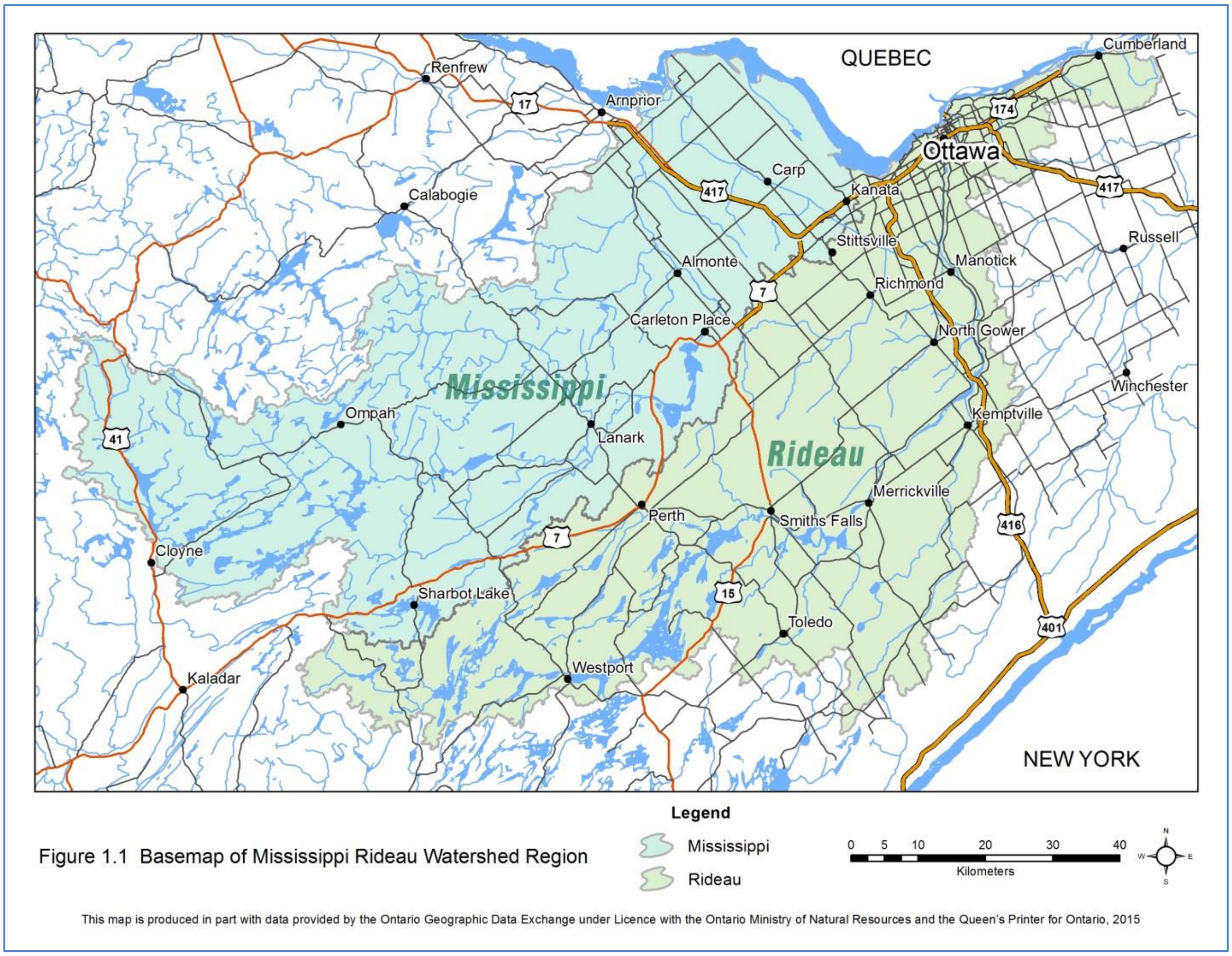

Figure 1-1. Basemap of Mississippi Rideau watershed region.

2 Methodology

2.1 Climate Data

General Circulation Models (GCMs) are the systems of mathematical equations that describe the climatic conditions evolving from atmospheric, oceanic, cryospheric and land processes. Though the GCMs represents our best science and use complex computational methods, they still under continued development and varying degrees of uncertainty persist. The GCMs use Greenhouse Gas (GHG) scenarios. As the actual quantity of future GHG emissions are variable or unknown, varying degrees of uncertainty exist in both the emission scenarios and GCMs and that translate into the future climate projections.

The Special Reports on Emissions Scenarios (SRES) are reports developed by the Intergovernmental Panel on Climate Change (IPCC). The Fourth Assessment Report (AR4) of the IPCC, developed in 2007, includes A2 (high GHG emissions), A1B (medium GHG emissions), and B1 (low GHG emissions) scenarios. IPCC'S Fifth Assessment Report (AR5), based on GHG driven Representative Concentration Pathway (RCPs), has recently been released. The RCPs span a large range of stabilization, mitigation, and non-mitigation pathways. Though AR5 data has been released, the AR4 climate projections that are already downscaled to every climate station in Ontario are used in this climate analysis study for the Mississippi and Rideau watersheds.

2.2 Climate Data downscaling

The future climate projections downscaled to the regional climate stations in the MR region were downloaded from the Ontario Ministry of Natural Resources (MNR), recently renamed the Ontario Ministry of Natural Resources and Forestry (MNRF), web-application. This web-application provides hourly and daily climate projections using change field method, hourly precipitation from the Canadian Regional Climate Model (CRCM), and daily climate data using a LARS weather generator for all the climate stations in Ontario,. The daily climate data downscale with the delta/change field method was used in this study to assess the regional future water budget components. In a further study, a finer time scale hourly RCM data will be used in hydrologic and hydrodynamic modeling to assess flood forecasting and extreme event analysis.

Drummond Centre and Ottawa Airport are the two climate stations selected for the Mississippi and Rideau watersheds, respectively. There are 28 GCMs and 3 SRES scenarios (A1, A1B, and B1) available for each climate station. The built-in percentile method identifies and automatically highlights ten scenarios from these data sets that match the historical climate conditions of the chosen climate station, correspond to a range of percentile rankings. The baseline period chosen for this study is 1970-2000. Future climate data for both climate stations were generated for 2011-2040, 2041-2070, and 2071-2100 periods. These future periods are referred to in this report as periods 2020s, 2050s, and 2080s respectively.

2.2.1 *Climate Models*

The IPCC recommends that users should apply multiple climate change scenarios - as many as possible - in impacts and adaptation assessments (IPCC 2007).

Future climate data generated through the GCM delta/change field method is used in the MR Region water balance study. The change field method involves applying mean monthly changes in future climate from the baseline climate to the existing climate data (BENFLOW and MNR 2010). This method is widely used by water managers due to its ease of use with the advantage of producing the future data from numerous GCMs and associated emission scenarios (Wilby and Harris 2006, Jung et al 2011).

One of the major limitations of using the change field method in hydrological impact assessment is lack of good representation of the potential climate change impacts on inter-annual or day-to-day variability of climate parameters. Given that the changes in sequence of wet and dry days and peak precipitation events are not altered by this method, it is recognized that future floods, droughts, groundwater recharge, and snowmelt timing may be underestimated. The significance of the uncertainty in quantifying these changes has not been accurately accounted for in today's climate change science (Bates et al. 2008).

IPCC Third Assessment Report (Giorgi et al. 2001) also recommends combining the use of GCMs and different downscaling techniques may be a suitable approach in generating climate change scenarios for impacts and adaptation studies. Recent studies showed a simpler downscaling method performs comparably to the more sophisticated methods in generating mean values, while generating extreme values needs a more sophisticated method (Hayhoe et al. 2010). This study uses statically downscaled various GCM data using the delta method, however, as a next step in extreme analysis Mississippi will be using more sophisticated data from a GCM driven RCM data.

2.2.2 Percentile method

Scatter plot method and percentile method are the two approaches used to shortlist the best climate change scenarios that match with the baseline historic conditions. The scatter plot method is to 'bound the uncertainty', that is to select four future climates that reflect the extreme range of projected temperature and precipitation changes. The percentile method is a statistical-based, reproducible method of selecting GCM-GHG scenarios to provide a broader range of future climate for the climate impacts assessment process, with a maximum of 10 scenarios selected.

In the percentile method, each of the 28 GCMs and 3 SRES scenario combinations are first ranked in ascending order based on their mean annual temperature change field and mean annual precipitation delta values. A percentile is then assigned to each scenario, representing the order of the scenario divided by the total number of scenarios. A range of percentile rankings such as 90th, 75th, 50th, 25th, and 10th percentiles for both the mean annual temperature and mean annual precipitation delta values is selected. Thus, a total of ten climate scenarios, corresponding to these rankings, five each for the mean annual temperature change and mean annual precipitation change were selected by the this method. A detailed scenario projection analysis showed that the extreme percentiles such as 95th and 5th percentiles might be more appropriate than 90th and 10th percentiles (MNR, 2010). Therefore, the built-in auto selection option for the percentile method in the web application selected scenarios corresponding to 95th, 75th, 50th, 25th, and 5th percentiles and were further analyzed in the study.

2.3 Thornthwaite Water Budget Program

The water balance parameters were tabulated from Thornthwaite and Mather calculations (Thornthwaite and Mather 1955, Johnstone and Louie 1983). The FORTRAN program developed by Johnston and Louie uses an empirical method to compute the changes in water storage as a function of monthly mean temperature, total precipitation, latitude, and soil water holding capacity (WHC). The program tabulates additions, losses, and changes in water storage at a location. Using daily climate data may better models snowmelt and improves the accounting of snow storage, which is of specific importance for Canadian climate. The latitude of the climate station location, and an estimate of the soil WHC (the maximum amount of water that can be held in the soil capillaries for use by vegetation), are the other input parameters needed for the model. Besides temperature and precipitation, the model outputs include rain, snow storage, potential evapotranspiration (PET), actual evapotranspiration (AET), water deficit, water surplus, snow storage, and soil moisture storage.

The accumulated precipitation on days with a daily mean temperature greater than the critical temperature (set at -1^{0}C) is accounted for as the rain and when the daily mean temperature is equal to or less than the critical temperature precipitation is accounted for as snow storage. Snow storage is the water equivalent of snow at the end of the period, which is depleted by the snowmelt routine. 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 and/or transpire from a vegetated surface, whereas the AET is the total evapotranspiration for the period. The soil deficit is the amount by which the available soil moisture fails to meet water demand, and is obtained by subtracting the PET from the AET.

The water surplus is the excess water after the surface evaporation has been met (AET = PET) and soil moisture storage has reached the WHC level. This climatic water budget program uses a number of assumptions about the physical processes involved in the water exchange within the soil-water-plant system. Therefore, the program warrants the use of the outputs from this program as indices of the main water balance components only. The outputs cannot be assumed to be the basin specific estimates of actual conditions.

3 Results and Discussion

3.1 Model Selection

Using the percentile method, for Drummond Centre climate station in the Mississippi watershed, nine models were selected for the 2020s (2011-2040) and ten models, each selected for 2050s (2041-2070) and 2080s (2071-2100). For the Ottawa Airport station in the Rideau watershed, ten models each were selected for all three periods. For the selected GCMs and SRES scenarios in all three periods, the annual mean precipitation and the annual mean temperature along with the corresponding rankings are given in tables 3.1 and 3.2, respectively for Drummond Centre and Ottawa Airport stations. Similar details on the entire suite of 57 GCMs and SRES combinations of both climate stations are given in Appendix A.

To illustrate the model selection, for Drummond Centre, HADCM3 SRB1 (5%), CSIROMk3.5 SRB1 (25%), NCARPCM SRA1B (50%), GISS-AOM SRB1 (75%), and CGCM3T47-Run2 SRA1B (95%), are the GCM-SRES combinations selected based on the annual mean precipitation for the 2020s. Similarly, NCARPCM SRA1B (5%), CNRMCM3 SRA2 (25%), CGCM3T47-Run1 SRA2 (50%), GFDLCM2.0 SRA1B (75%), and MIROC3.2medr SRB1 (95%) were selected based on the annual mean temperature. The NCARPCM model with the SRA1B emission scenario was chosen based on both annual mean precipitation (50%) and annual mean temperature (5%) rankings. Therefore, only nine models were selected for the 2020s for Drummond Centre station.

However, ten models, five each based on annual mean precipitation and annual mean temperature, were selected for 2050s and 2080s for Drummond Centre, and for all three periods for Ottawa Airport stations. This methodology is used only in the water budget analysis as the main objective is to compare the model projections and assess the uncertainty lies in the climate

Table 3-1. GCM Scenarios by the percentile method for the Drummond Centre station.

Drummond Centre 2011-2040					
Model Name	Emission Scenario	Precipitation Change (%)	Precipitation Rank (%)	Temperature Change (^{o}C)	Temperature Rank (%)
CGCM3T47-Run1	SRA2	3.5	47	1.3	51
CGCM3T47-Run2	SRA1B	8.1	95	1.4	64
CNRMCM3	SRA2	2.6	40	1	25
CSIROMk3.5	SRB1	1.0	25	1.1	28
GFDLCM2.0	SRA1B	-0.1	12	1.6	75
GISS-AOM	SRB1	5.8	75	1.2	44
HADCM3	SRB1	-1.9	5	0.8	8
MIROC3.2medr	SRB1	6.3	81	1.9	95
NCARPCM	SRA1B	3.8	51	0.7	5

Drummond Centre 2041-2070					
Model Name	Emission Scenario	Precipitation Change (%)	Precipitation Rank (%)	Temperature Change (^{o}C)	Temperature Rank (%)
CGCM3T47-Run1	SRA2	12.8	95	2.8	68
CGCM3T47-Run3	SRA1B	6.6	51	2.6	64
CGCM3T47-Run4	SRA1B	3.5	25	2.6	63
CGCM3T47-Run5	SRB1	9	75	2.2	35
CGCM3T47-Run5	SRA1B	7.6	61	3	75
FGOALS-g1.0	SRB1	0	9	1.5	5
GFDLCM2.1	SRA1B	8.3	68	2.5	51
GISS-ER	SRA2	14.2	99	2.1	25
HadGEM1	SRA2	3.8	27	3.8	95
INMCM3.0	SRB1	-1.1	5	2	23

Drummond Centre 2071-2100					
Model Name	Emission Scenario	Precipitation Change (%)	Precipitation Rank (%)	Temperature Change (^{o}C)	Temperature Rank (%)
CGCM3T47-Run1	SRA2	17.4	95	4.8	83
CGCM3T47-Run2	SRB1	13.2	72	2.8	25
CGCM3T63	SRB1	9.6	51	2.8	24
ECHO-G	SRA2	5.6	25	5.4	91
FGOALS-g1.0	SRA1B	3	12	3.6	51
GFDLCM2.1	SRA1B	13.3	75	3.6	48
GISS-AOM	SRB1	10	52	2.3	5
HadGEM1	SRA1B	6.5	32	5.7	95
INMCM3.0	SRA2	2.9	11	4.4	75
IPSLCM4	SRA2	2.5	5	6	97

Table 3-2. GCM Scenarios by the percentile method for the Ottawa Airport station.

Ottawa Airport 2011-2040					
Model Name	Emission Scenario	Precipitation Change (%)	Precipitation Rank (%)	Temperature Change (^{o}C)	Temperature Rank (%)
BCM2.0	SRA2	3.6	51	0.9	15
CGCM3T47-Run1	SRA1B	5.3	75	1.3	57
CGCM3T47-Run1	SRA2	3.5	49	1.3	51
CGCM3T47-Run4	SRA1B	-1.9	5	1.3	59
CSIROMk3.0	SRA1B	8.2	95	1.1	27
ECHAM5OM	SRA2	1.9	29	0.8	5
GFDLCM2.0	SRA1B	-0.1	12	1.6	75
GISS-AOM	SRA1B	4.3	59	1.1	25
INMCM3.0	SRA1B	1.0	25	1.6	77
MIROC3.2medr	SRB1	6.3	84	1.9	95

Ottawa Airport 2041-2070					
Model Name	Emission Scenario	Precipitation Change (%)	Precipitation Rank (%)	Temperature Change (^{o}C)	Temperature Rank (%)
CGCM3T47-Run1	SRA2	12.8	95	2.8	68
ECHO-G	SRA2	3.4	25	3.4	89
FGOALS-g1.0	SRB1	0	9	1.5	5
GFDLCM2.0	SRA2	1.8	19	3	75
GFDLCM2.1	SRA1B	8.3	68	2.5	51
GISS-EH	SRA1B	9	75	1.7	9
GISS-ER	SRA2	14.2	99	2.1	25
INMCM3.0	SRB1	-1.1	5	2	23
IPSLCM4	SRA2	-0.2	8	3.7	95
NCARCCSM3	SRB1	6.6	51	2.5	49

Ottawa Airport 2071-2100					
Model Name	Emission Scenario	Precipitation Change (%)	Precipitation Rank (%)	Temperature Change (^{o}C)	Temperature Rank (%)
CGCM3T47-Run1	SRA2	17.4	95	4.8	83
CGCM3T47-Run2	SRB1	13.2	73	2.8	25
CGCM3T47-Run5	SRA1B	9.6	51	3.7	55
FGOALS-g1.0	SRA1B	3	12	3.6	51
GFDLCM2.1	SRA1B	13.3	75	3.6	48
INMCM3.0	SRA2	2.9	11	4.4	75
IPSLCM4	SRB1	5.4	25	4.1	67
IPSLCM4	SRA2	2.5	5	6	96
MIROC3.2medr	SRA1B	5.3	23	5.6	95
NCARCCSM3	SRB1	8.3	43	2.3	5

projections from these models. In further modeling studies the same GCM and scenario projections are used for average, warm, and cold climatic conditions for the future 100-year period, though the percentiles are different in the three 30-year periods.

A graphical representation of the mean annual change in precipitation versus the mean annual change in temperature from the baseline (1971-2000) conditions at Drummond Centre and projections in 2020s are shown in figure 3.1. The yellow points are the climate scenarios selected by the percentile method and the blue circles are those of that were not selected. Similar charts for periods 2050s and 2080s for Drummond Centre and periods 2020s, 2050s, and 2080s for the Ottawa Airport station are given in Appendix B.

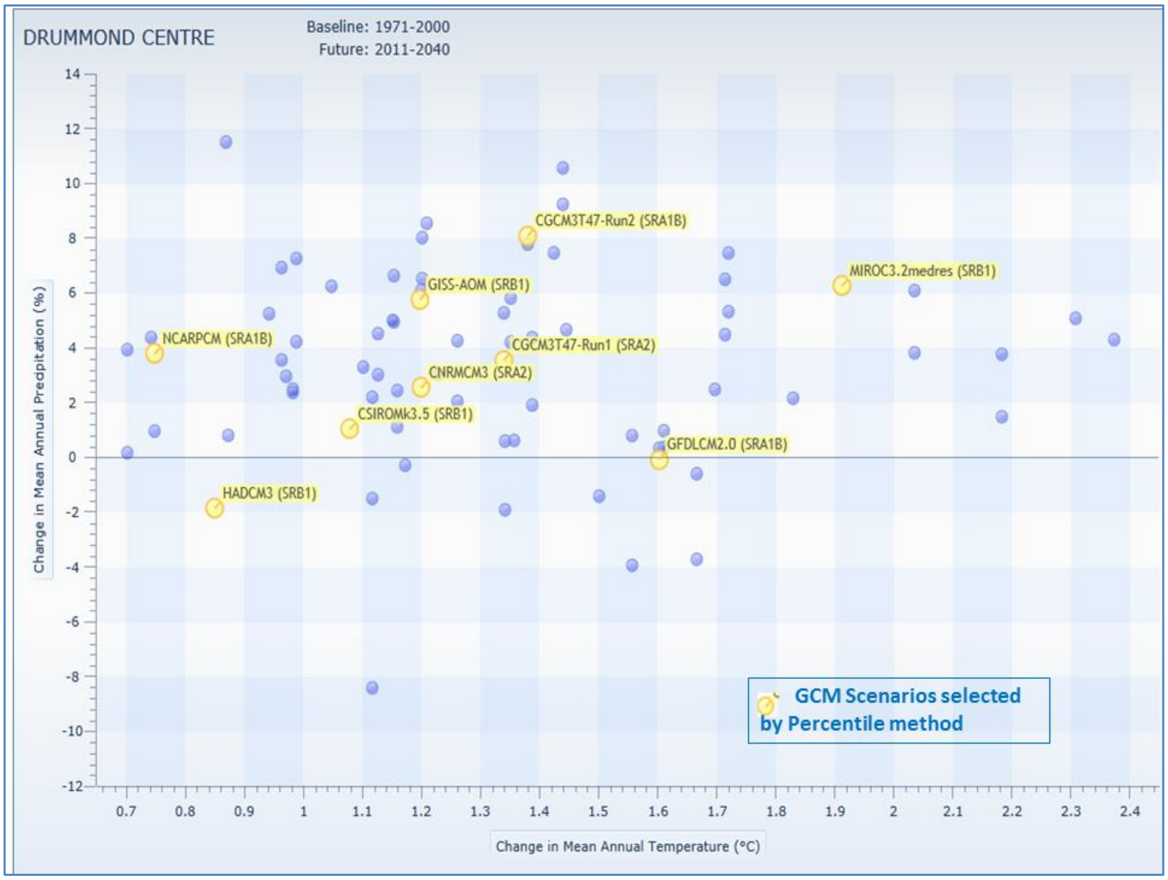

Figure 3-1. Mean annual change in precipitation vs. mean annual change in temperature from the baseline (Drummond Centre).

3.2 Comparison of Model Results

3.2.1 Mississippi (Drummond Centre Climate Station)

For each 30-year period, the mean precipitation and temperature projections from the selected models were compared to assess the consistency and variability in their projected values. The models selected correspond to percentiles ranging from fifth to 95th percentiles of the mean annual precipitation and temperature rankings. Therefore, the comparison of the projected outputs from these models will be crucial in the decision-making process in water management, especially in extreme conditions such as wet vs. dry or flood vs. drought analysis. The following results on the model performance (Section 3.2) and the temperature and precipitation projections (Section 3.3) use the daily future climate data from the selected scenarios.

Figure 3-2 shows the monthly average temperature from the nine GCM scenario projections for the 2020s period in comparison with the baseline condition. The temperature projections from these models were relatively consistent across the months with the exception of a small hike observed in July projected by the GFDLCM2.0_SRA1B scenario.

However, as seen in figure 3-3 the monthly average precipitation projections from these models showed a high degree of variability throughout the year. Similar results were also obtained in the periods 2050s and 2080s for both monthly temperature and precipitation projections (Appendix C)

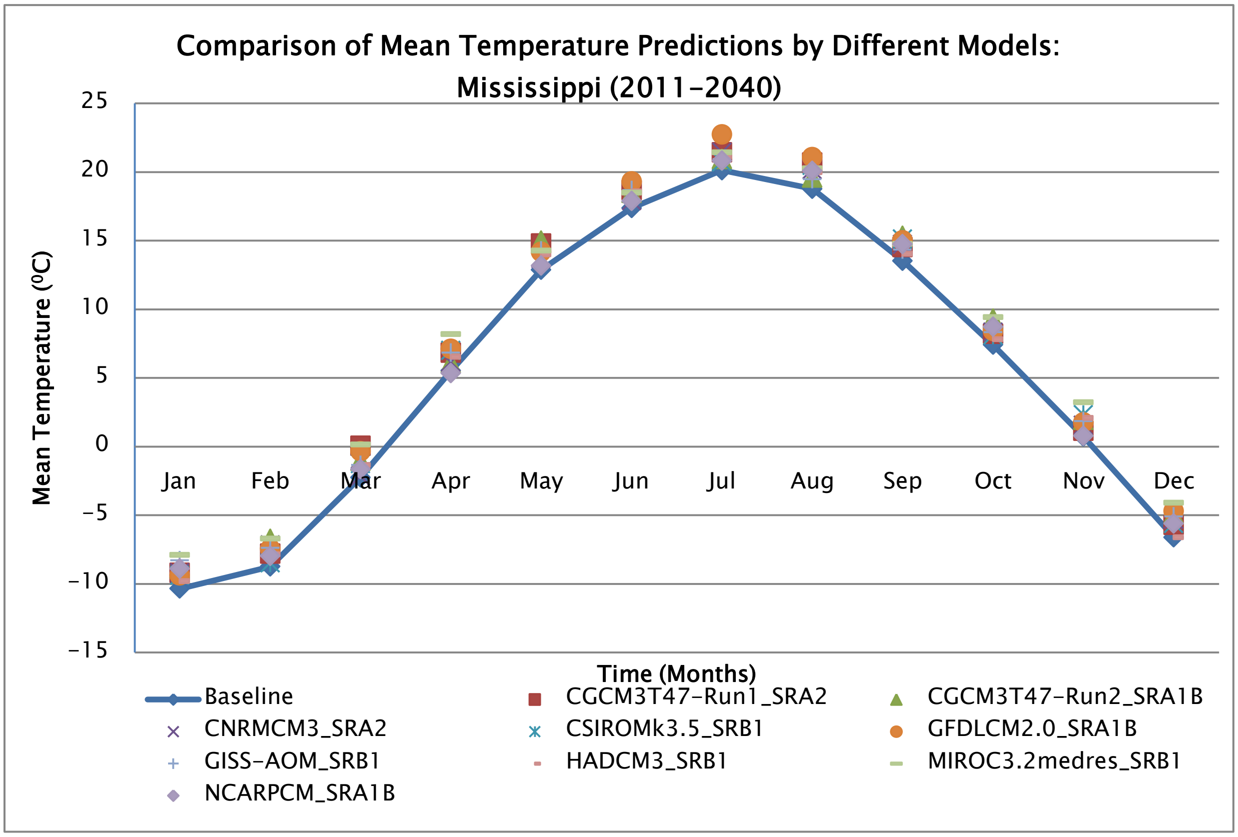

Figure 3-2. Monthly average temperature (2011-2040, Mississippi watershed).

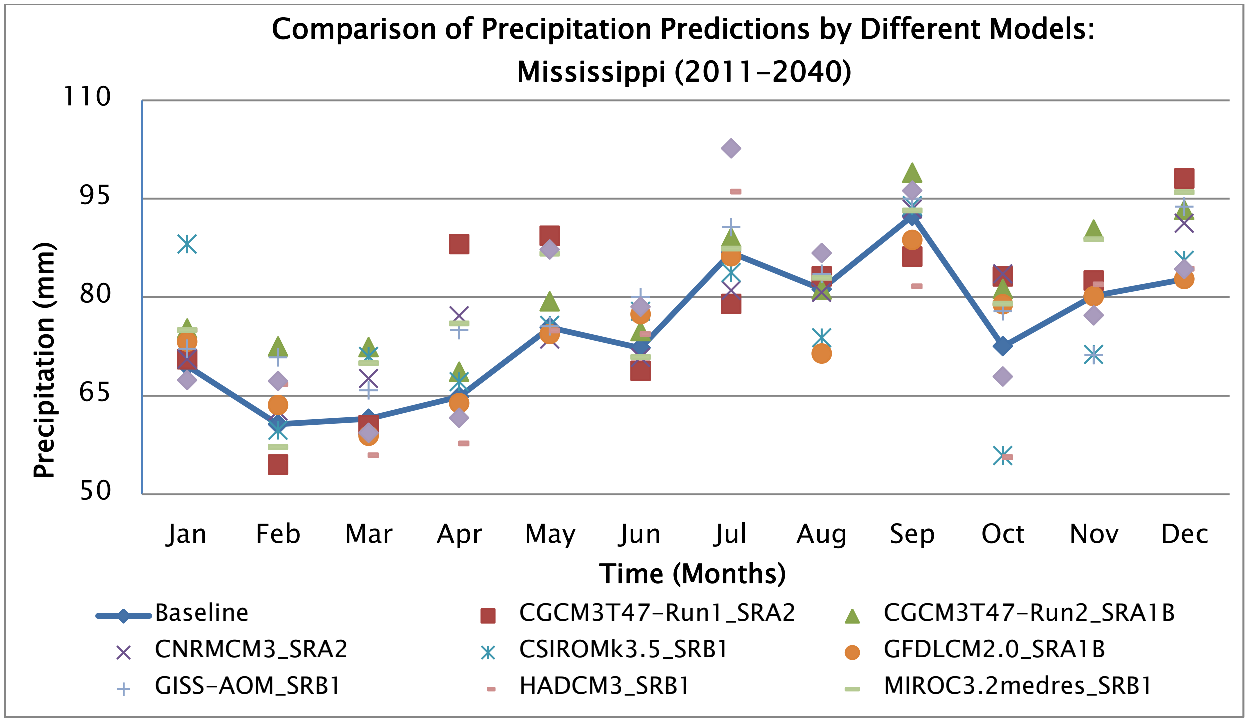

Figure 3-3. Monthly average precipitation (2011-2040, Mississippi watershed).

The statistical analysis shows all the selected scenarios have a good relative consistency in their temperature projections for the future. The results on average monthly temperature projections from the selected scenarios are shown in table 3-3. Among the scenarios, the variation in the monthly average temperature projections ranges from 1to 9^{0}C with the highest variability observed in the month of February.

But the precipitation projections highly varied among the selected scenarios. The variation in the average precipitation projections ranges from 11 to 54 mm (table 3-4). The projected temperature mostly varied in a particular month of February, but the variability in the precipitation projections varies throughout the year. However, the higher variation observes in the months of April, August, and September (45-54mm), and the minimum appears in January, March, and June. Even with the variability exists in the projections, the standard deviation, and standard error in both the temperature and the precipitation projections are in a lower range.

As shown in figure 3-4, seven out of nine scenarios in the 2020s projected increases from 0.5-1.5^{0}C in temperature from the baseline conditions. In 2050s, five out of ten projected 2.5-3.0^{0}C increase and two each projected 1.5-2.5^{0}C increase in 2050s. In 2080s, two each projected 2.5-3.0^{0}C, 3.5-4.0^{0}C, and 5.0-5.5^{0}C. Overall, most of the selected scenarios projected up to 1.5^{0}C, 3.0^{0}C, and 5.5^{0}C increases in the temperature in the 2020s, 2050s, and 2080s, respectively.

However, with the precipitation projection, seven out of nine scenarios in the 2020s, six out of ten in the 2050s, and five out of ten in the 2080s projected 0-10% increase, as seen in figure 3.5. Another three scenarios projected 10-20% increase in the precipitation in the 2080s.

For the Mississippi watershed, most of the selected scenarios projected an increase of 0-10% of precipitation in all the three periods.

Table 3-3. Statistical results of monthly temperature projections of GCM scenarios (Mississippi).

Mississippi	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline	-10.3	-8.7	-2.2	5.5	12.9	17.4	20.1	18.8	13.5	7.4	0.7	-6.6
Min_2020s	-9.8	-8.5	-2.1	5.3	13.2	17.9	20.7	19.5	14.0	7.8	0.8	-6.6
Max_2020s	-7.9	0.6	0.8	8.2	14.3	19.3	22.7	21.1	15.0	9.4	3.2	0.7
Min_2050s	-9.5	-8.3	-1.2	7.2	13.8	18.7	21.6	20.0	15.3	9.0	1.9	-5.1
Max_2050s	-5.2	1.0	2.6	9.2	15.8	20.9	24.3	23.0	16.6	10.5	3.8	1.0
Min_2080s	-7.9	-6.7	-0.4	7.9	13.8	18.8	21.9	20.4	15.2	9.1	2.8	-4.3
Max_2080s	-3.7	1.3	3.7	10.8	16.9	22.3	26.8	25.7	18.3	13.0	6.2	1.7
Av_2020s	-9.0	-7.5	-1.0	6.7	14.1	18.5	21.3	20.2	14.7	8.5	1.9	-5.3
Av_2050s	-7.1	-6.2	0.3	8.3	15.3	19.4	22.6	21.4	15.8	9.7	2.8	-3.7
Av_2080s	-6.0	-5.1	1.5	9.2	16.0	20.5	23.8	22.6	17.0	10.9	4.1	-2.1
Std. Dev_2020s	0.6	0.6	0.8	0.8	0.6	0.4	0.6	0.5	0.4	0.5	0.7	0.7
Std. Dev_2050s	1.3	1.0	1.1	0.5	0.7	0.7	0.8	1.0	0.4	0.6	0.6	1.0
Std. Dev_2080s	1.4	1.3	1.3	1.1	1.2	1.2	1.6	2.0	1.3	1.4	1.5	1.7
Std. Er_2020s	0.2	0.2	0.3	0.3	0.2	0.1	0.2	0.2	0.1	0.2	0.2	0.2
Std. Er_2050s	0.4	0.3	0.3	0.2	0.2	0.2	0.2	0.3	0.1	0.2	0.2	0.3
Std. Er_2080s	0.4	0.4	0.4	0.3	0.4	0.4	0.5	0.6	0.4	0.4	0.5	0.6

Table 3-4. Statistical results of monthly precipitation for 2010-2100 period (Mississippi).

Mississippi	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline	70	61	61	65	75	72	87	81	92	73	80	83
Min_2020s	67	54	56	58	74	69	79	71	82	56	71	83
Max_2020s	88	72	72	88	89	80	103	87	99	84	90	98
Min_2050s	69	56	62	64	61	64	75	74	74	58	78	79
Max_2050s	97	74	83	85	94	75	94	107	119	92	101	121
Min_2080s	68	62	58	65	67	58	71	59	77	53	67	84
Max_2080s	97	87	81	117	102	91	100	113	111	88	106	110
Av_2020s	74	64	65	71	80	75	88	81	92	74	80	90
Av_2050s	82	65	71	76	83	70	84	82	91	79	89	96
Av_2080s	83	70	71	82	84	71	83	78	94	75	90	99
Std Dev_2020s	5.8	6.1	6.1	9.4	6.3	4.0	7.4	4.9	5.4	11.2	6.7	5.8
Std Dev_2050s	9.5	5.1	6.5	7.2	10.5	3.6	6.3	10.1	13.0	9.7	7.1	12.4
Std Dev_2080s	8.3	7.4	7.6	16.7	11.1	8.4	9.0	14.1	9.8	10.0	12.5	8.7
Std. Er_2020s	1.9	2.0	2.0	3.1	2.1	1.3	2.5	1.6	1.8	3.7	2.2	1.9
Std. Er_2050s	3.0	1.6	2.0	2.3	3.3	1.1	2.0	3.2	4.1	3.1	2.2	3.9
Std. Er_2080s	2.6	2.3	2.4	5.3	3.5	2.7	2.8	4.5	3.1	3.2	3.9	2.7

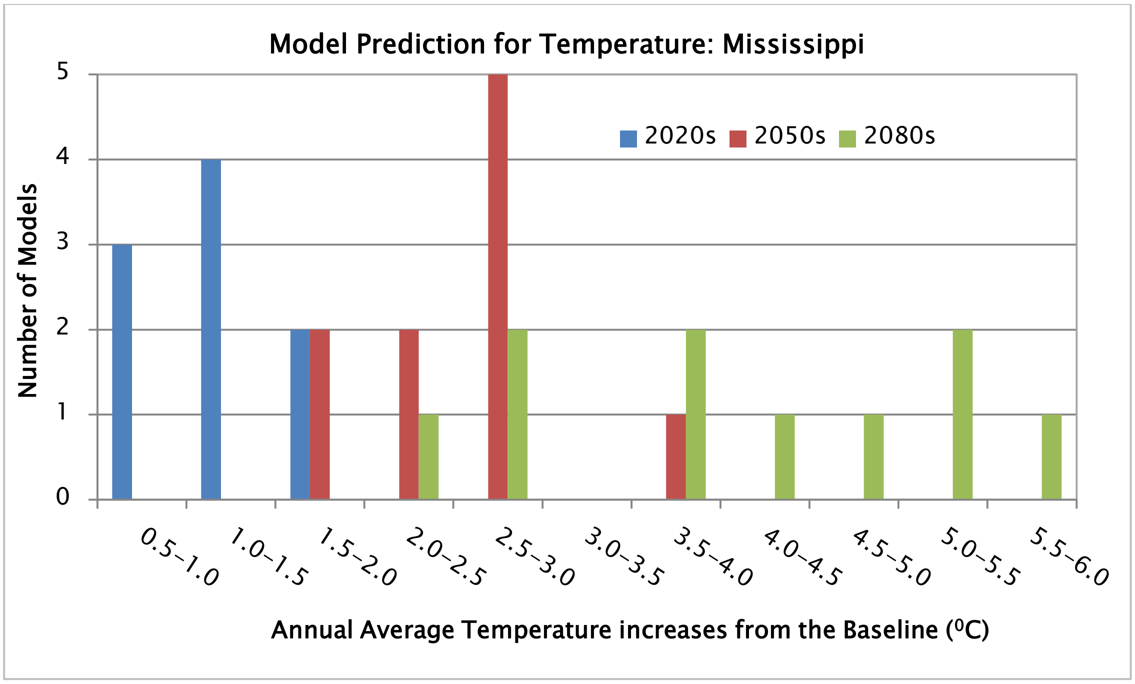

Figure 3-4. Percent change in temperature among the selected scenarios (Mississippi).

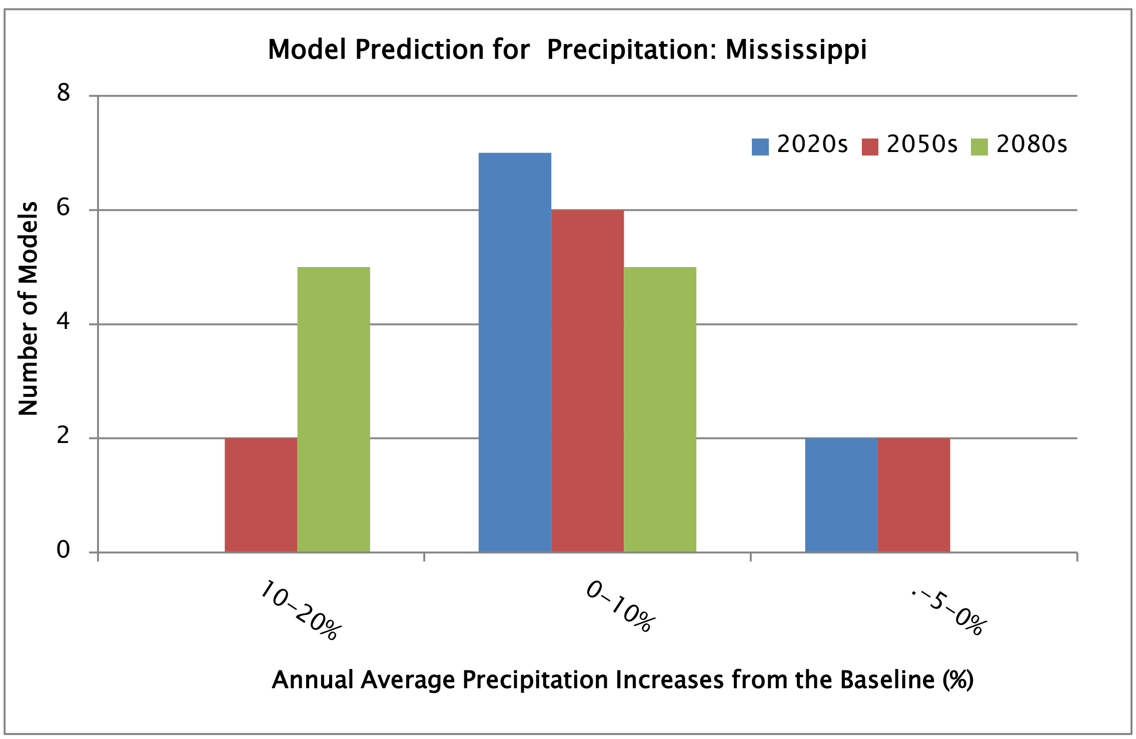

Figure 3-5. Percent change in precipitation among the selected scenarios (Mississippi).

3.2.2 Rideau (Ottawa Airport Climate Station)

In the Rideau Valley watershed, the monthly average temperature from the selected ten GCM scenarios in the 2020s and the baseline condition of the Ottawa Airport station are shown in figure 3-6. In contrast to the Drummond Centre climate station in the Mississippi watershed, only eight out of ten scenario projections were consistent across the months. The GFDLCM2.0 SRA1B (50^{th} percentile) and CGCM3T47-Run1 SRA2 (75^{th} percentile) scenarios, both selected based on the temperature ranking, were above the projected temperatures from the other scenarios. However, both projected a relatively similar increase across the months. Therefore, treating these scenarios as outliers is questionable.

The average of all ten selected GCMs and the eight without the two over-projected GCMs are also included in figure 3-6. Both averages fall within the range of other eight GCM projections. As expected, the average of the eight GCMs falls close to the upper range while the average of the ten GCMs fall in the middle range.

Similar to Drummond Centre climate station in Mississippi, the precipitation projections from all ten selected scenarios for Ottawa Airport station in Rideau showed a high degree of variability throughout the year, as shown in figure 3-7. The two scenarios that projected higher temperature in the 2020s also had different precipitation projections. The precipitation outputs from the GFDLCM2.0 SRA1B were the lowest while that from the CGCM3T47-Run1 SRA2 were the highest among the ten scenarios (figure 3-7).

However, as seen in figures 3-2 and 3-7, the trend of increases in the monthly average temperatures and high variability in the precipitation across the months was similar in both watersheds. All selected scenarios in the 2020s, 2050s, and 2080s were consistent with the temperature and the precipitation projections, except two, which projected higher temperature in the 2020s as compared to other selected scenarios (Appendix: C). The variation in the monthly precipitation for all ten scenarios also increased from 2020s to 2080s. The INMCM3.0 SRAB1 scenario in the 2020s and FGOALS-g10 SRA1B scenario in 2050s projected relatively low precipitation as compared to the other nine scenarios (Appendix: C).

The statistical results of the average monthly temperature projections from all ten selected scenarios are detailed in table 3.5. Results were compared with 8 scenarios when the two scenarios consistently projected higher temperature were omitted.

The average monthly temperature varied from 2 to 7^0C among the scenarios, however, when the two scenarios which over-projected temperature in 2020s were omitted, the variation extended to between 1 and 10^0C. Among the remaining eight scenarios, higher and consistent variations in the temperature were observed in five months across December through April. However, when the two over predicted scenarios were included, the higher variations were observed only in the first three months ending in February.

While considering all selected scenarios the variations are consistent in all three periods (3 to 7^0C) therefore caution should be taken when treating those two scenarios as outliers based on the objective of any study (e.g. in river modeling, flood forecasting, extreme analysis, etc.) using the projected data.

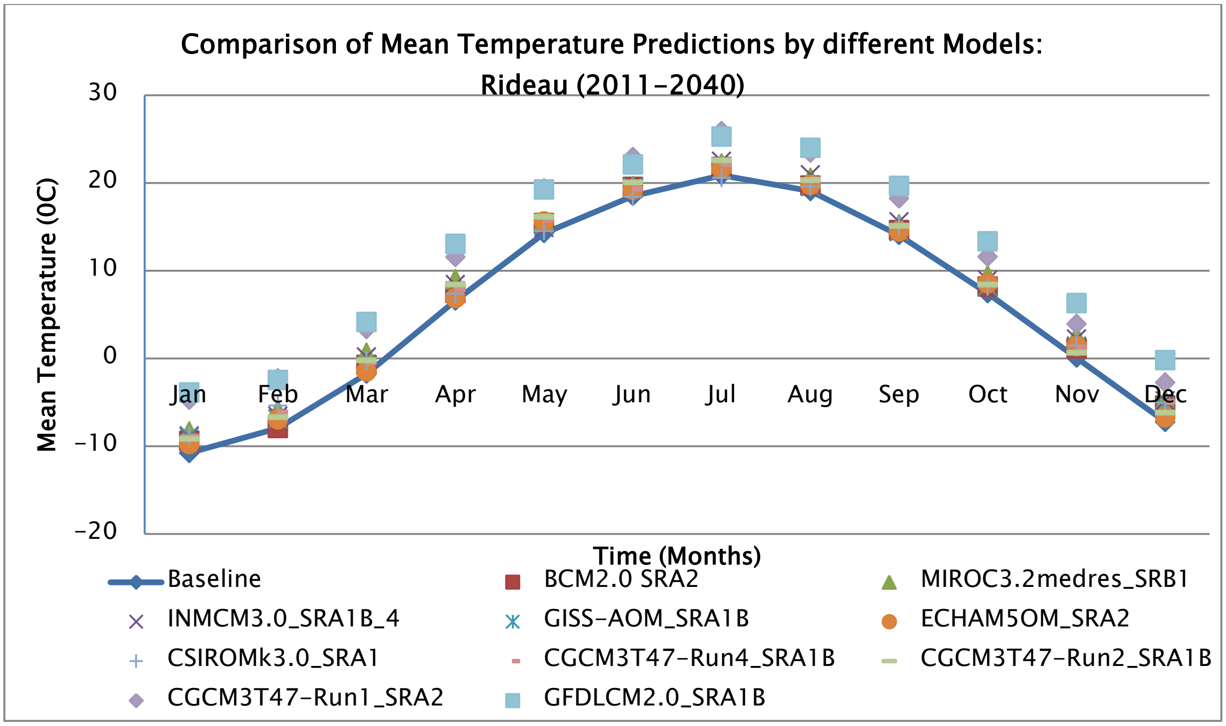

Figure 3-6. Monthly average temperature projections of GCM scenarios (2011-2040, Rideau).

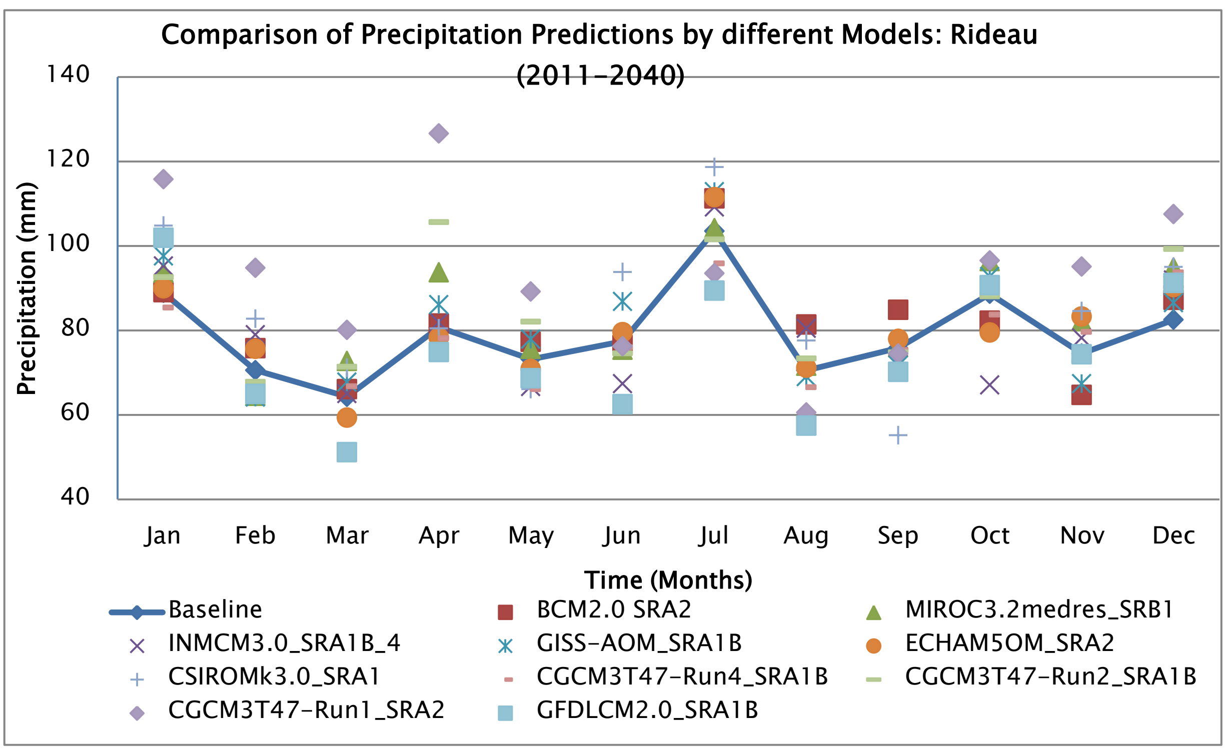

Figure 3-7. Monthly average precipitation projections of GCM scenarios (2011-2040, Rideau).

Table 3-5 .Statistical results of average monthly temperature predictions by the selected GCM scenarios for the 2010-2100 period (Rideau).

Rideau	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline	-10.8	-8.0	-1.7	6.6	14.3	18.5	20.9	19.1	14.1	7.4	0.1	-7.2
Min_2020s	-9.8	-7.9	-1.5	6.9	14.5	18.4	20.6	19.6	14.4	8.2	0.6	-6.7
Max_2020s	-3.9	-2.3	4.1	13.1	19.4	22.9	25.9	24.0	19.7	13.4	6.3	-0.2
Min_2050s	-10.0	-7.5	-0.7	8.4	15.3	20.0	22.4	20.4	15.8	9.1	1.3	-5.8
Max_2050s	-6.9	-4.4	2.7	11.1	17.9	21.8	24.6	23.3	17.8	11.3	4.5	-2.3
Min_2080s	-7.6	-5.9	0.7	8.7	16.2	19.7	23.0	21.0	16.0	10.2	2.1	-4.7
Max_2080s	-3.9	-1.2	6.0	13.4	19.8	23.0	26.1	25.3	20.3	13.7	6.5	-0.7
Av_2020s	-8.1	-5.7	0.4	8.8	16.2	20.0	22.6	20.8	15.8	9.3	2.2	-4.6
Av_2050s	-8.3	-5.8	0.9	9.3	16.5	20.8	23.4	21.8	16.6	9.9	2.6	-4.2
Av_2080s	-6.0	-3.6	2.7	11.0	17.8	21.6	24.7	23.0	18.0	11.4	3.9	-2.8
Std Dev_2020s	2.0	1.9	1.8	2.0	1.7	1.4	1.7	1.6	1.8	1.7	1.7	1.9
Std Dev_2050s	1.0	1.0	1.0	0.8	0.8	0.6	0.8	1.0	0.7	0.8	1.1	1.1
Std Dev_2080s	1.4	1.5	1.6	1.5	1.2	1.1	1.1	1.5	1.2	1.1	1.4	1.1
Std. Er_2020s	0.6	0.6	0.6	0.6	0.5	0.4	0.5	0.5	0.6	0.6	0.5	0.6
Std. Er_2050s	0.3	0.3	0.3	0.2	0.3	0.2	0.2	0.3	0.2	0.3	0.3	0.4
Std. Er_2080s	0.4	0.5	0.5	0.5	0.4	0.3	0.4	0.5	0.4	0.3	0.5	0.4

Table 3-6 shows the statistical results of the average monthly precipitation projected by the selected scenarios. As expected, the variability is high among the model projections and varies from 21 to 87 mm among the scenarios for the future periods. As seen in tables 3-4 and 3-6, the variation is higher with the Ottawa Airport station as compared to Drummond Centre data (17-87 mm vs. 1-54 mm). The variability was higher in the months of December through February, with a maximum variation of 68-87 mm. The minimum precipitation is projected in January, February, and March and the maximum in January, April, and July.

Similar statistical results were obtained in the Rideau Ottawa Airport station as well. The temperature projections showed relative consistency among the selected scenarios and even with high variability, the standard error and standard deviation among the precipitation projections were low.

As shown in figure 3-8 for the Rideau, in the 2020s six out of ten scenarios projected 1.0 to 2.0^{0}C increase in the temperature from their baseline conditions, while in 2050s four out of ten projected 2.5 to 3.0^{0}C increase, and two each projected 1.5 to 2.0^{0}C and 2.5 to 3.0^{0}C increase. In 2080s, the temperature projections are 3.5 to 4.0^{0}C by three models, 4.0 to 4.5^{0}C and 5.5 to 6.0^{0}C by two models each.

Table 3-6. Statistical results of average monthly precipitation predictions by the selected GCM scenarios for the 2010-2100 period (Rideau).

Rideau	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Baseline	89	71	64	81	73	77	104	71	76	89	75	83
Min_2020s	85	64	51	75	66	63	89	57	55	67	65	87
Max_2020s	116	95	80	127	89	94	119	81	85	97	95	108
Min_2050s	36	24	42	77	60	75	91	49	63	76	61	34
Max_2050s	119	92	80	108	83	98	116	84	96	111	95	121
Min_2080s	42	33	60	80	68	72	90	58	65	67	63	48
Max_2080s	117	95	86	127	89	89	121	86	95	107	95	108
Av_2020s	97	74	67	89	74	77	105	71	73	87	78	94
Av_2050s	95	71	71	91	72	80	102	68	77	92	82	93
Av_2080s	100	74	73	100	78	78	100	69	77	92	81	91
Std Dev_2020s	8.9	9.9	7.8	16.1	7.8	8.8	9.5	7.9	7.6	9.0	8.9	6.1
Std Dev_2050s	22.8	18.4	11.1	10.6	8.2	6.6	8.7	9.8	9.6	11.2	10.0	24.5
Std Dev_2080s	22.0	16.0	9.1	16.7	6.6	4.5	10.2	7.7	10.4	11.0	9.5	17.5
Std. Er_2020s	2.8	3.1	2.5	5.1	2.5	2.8	3.0	2.5	2.4	2.8	2.8	1.9
Std. Er_2050s	7.2	5.8	3.5	3.4	2.6	2.1	2.8	3.1	3.0	3.5	3.2	7.7
Std. Er_2080s	7.0	5.1	2.9	5.3	2.1	1.4	3.2	2.4	3.3	3.5	3.0	5.5

The majority of the selected scenarios for the Rideau in the 2020s, 2050s, and 2080s projected 1.0 to 1.5^{0}C, 2.5 to 3.0^{0}C, and 3.5 to 4.5^{0}C increases in temperature respectively, notably a continuous increase in the temperature in the future periods.

The majority of the selected scenarios for the Rideau projected 0-10% increases in the precipitations from their baseline conditions, except in 2080s where five scenarios projected 0-10% increases and another four projected 10-20% increases, (figure 3-9). Out of ten scenarios, seven, five, and five scenarios respectively in the 2020s, 2050s and 2080s projected a 0-10% increase in the precipitation, while four and three out of ten scenarios respectively in 2050s and 2080s projected 10-20% increases.

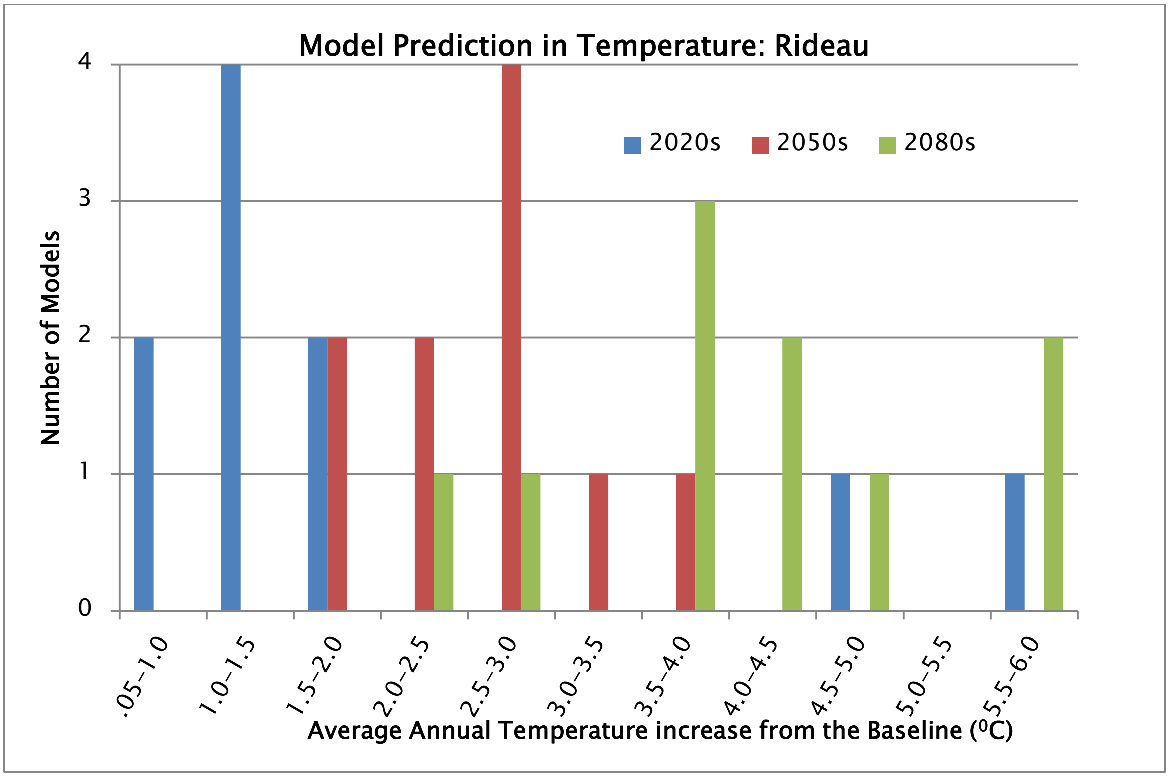

Figure 3-8. Percent change in temperature among the selected scenarios (Rideau).

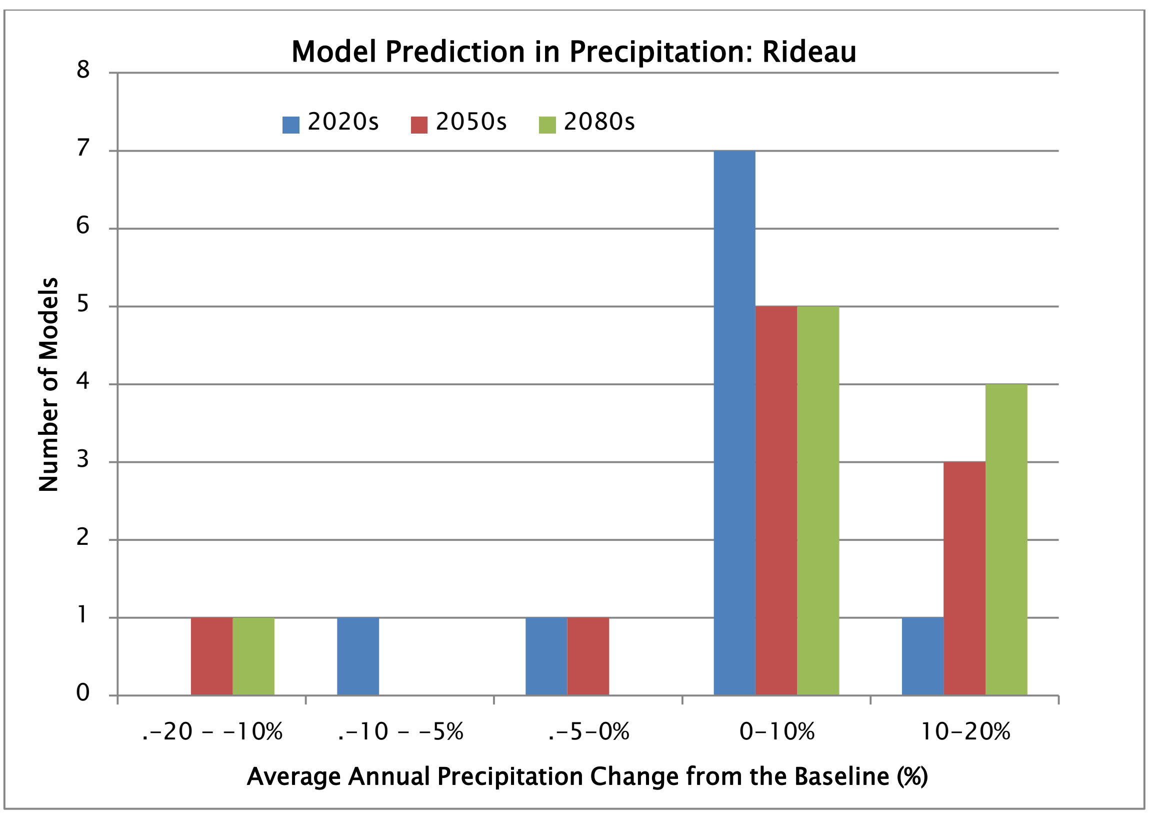

Figure 3-9. Percent change in precipitation among the selected scenarios (Rideau).

3.3 Temperature and Precipitation Projections

3.3.1 Mississippi Watershed

The monthly average temperatures and precipitation amounts for the baseline and the future periods are shown in figures 3-10 and 3-11, respectively. From 2020s to 2080s, there is a continuous increase in the average temperature as compared to the baseline condition. The rate of increase is higher in the winter (December to February) and the summer (June to August). The increase in temperature and percent increase in the precipitation in each period of the baseline conditions are given in tables 3-7 and 3-8.

The temperature increase is the highest in winter months in all three periods; 1.3^{0}C increase in 2020s, 2.8^{0}C in 2050s and 3.8-3.9^{0}C in 2080s. Similar to other climate change studies, there is a significant increase in temperature in all months from the baseline to the future periods of 2100 (table 3-7 and figure 3-10).

Although high variability exists in the future precipitation projections there is a general trend where precipitation amounts increased in the winter and the fall season as compared to the baseline conditions. As seen earlier, the average monthly precipitation amounts decreased during the summer low flow season, from June to September as seen in figure 3-11. During the summer months, the decrease was from 0 to 3%, as compared to the baseline conditions, which will be crucial in managing the water levels and flows in the system during the low flow conditions.

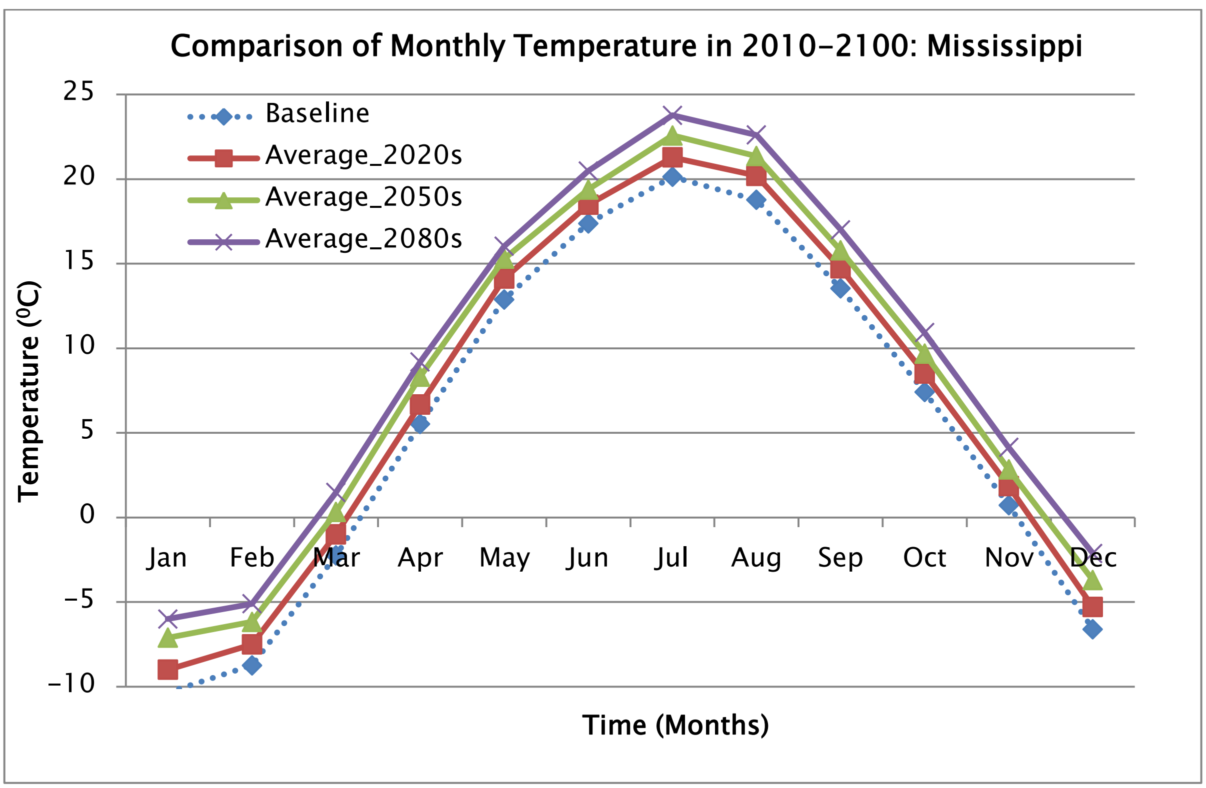

Figure 3-10. Monthly temperature in Baseline, 2020s, 2050S, and 2080s (Misissippi).

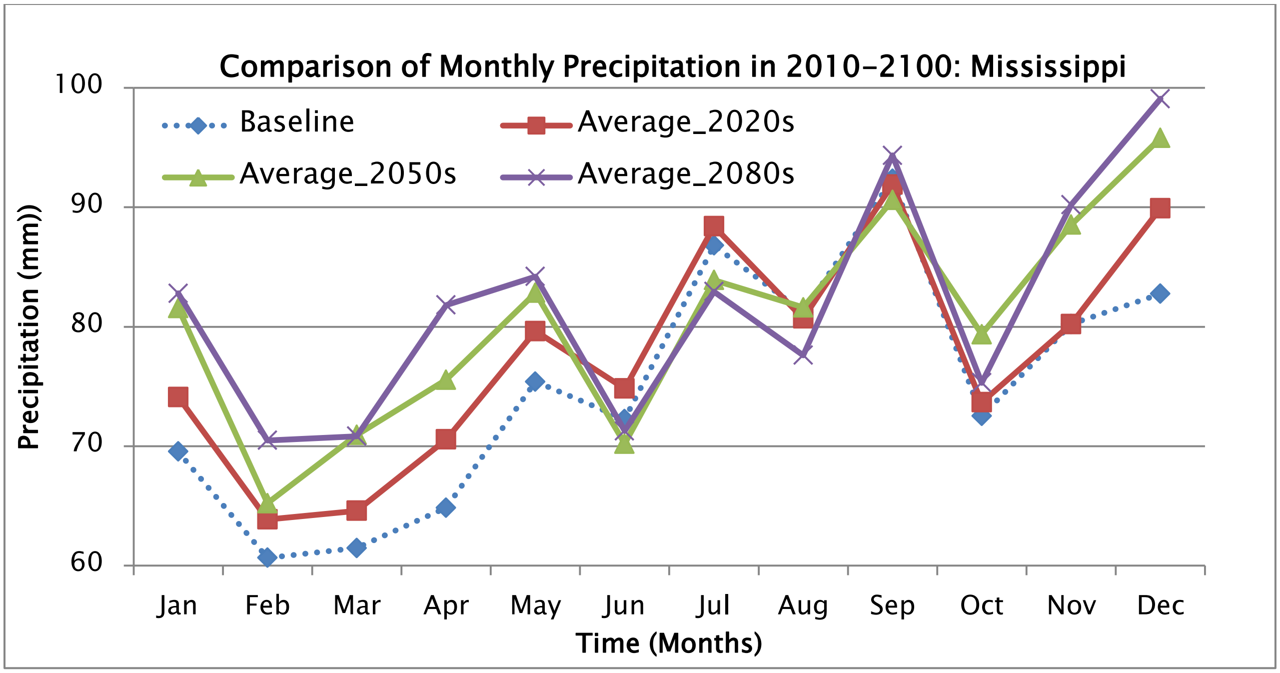

Figure 3-11. Monthly precipitation for Baseline, 2020s, 2050S, and 2080s (Mississippi).

Table 3-7. Changes in Average Monthly Temperature and Precipitation in 2010-2100 from the Baseline (Mississippi).

Mississippi	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (⁰C)												
Baseline	-10.3	-8.7	-2.2	5.5	12.9	17.4	20.1	18.8	13.5	7.4	0.7	-6.6
2020s	1.4	1.2	1.3	1.1	1.2	1.1	1.2	1.4	1.2	1.1	1.1	1.3
2050s	3.2	2.6	2.6	2.8	2.4	2.0	2.5	2.6	2.3	2.3	2.1	2.9
2080s	4.3	3.6	3.7	3.7	3.2	3.1	3.6	3.8	3.5	3.5	3.4	4.5
Precipitation (mm)												
Baseline (mm)	70	61	61	65	75	72	87	81	92	73	80	83
2020s (%)	7%	5%	5%	9%	6%	4%	2%	-1%	-1%	2%	0%	9%
2050s (%)	17%	8%	15%	17%	10%	-3%	-3%	0%	-2%	9%	10%	16%
2080s (%)	19%	16%	15%	26%	12%	-1%	-4%	-4%	2%	4%	12%	20%

Table 3-8. Changes in Average Seasonal Temperature and Precipitation in 2010-2100 from the Baseline (Mississippi).

Mississippi	Winter (Jan-March)	Spring (April-June)	Summer (July-Sept.)	Autumn (Oct.-Dec.)
Temperature (^{0}C)				
Baseline	-7.1	11.9	17.5	0.5
2020s	1.3	1.2	1.3	1.2
2050s	2.8	2.4	2.4	2.4
2080s	3.9	3.3	3.7	3.8
Precipitation (mm)				
Baseline (mm)	63.9	70.8	86.8	78.5
2020s (% change)	6%	6%	0%	3%
2050s (% change)	13%	8%	-2%	12%
2080s (% change)	17%	12%	-2%	12%

Table 3-9 shows the average percent change rate in the future maximum and minimum temperatures, the precipitation, the snow, and the rain from the baseline period with the selected scenario projections. The rates of changes in the maximum and the minimum temperatures per year were same in future three periods and range from 0.03 to 0.05^{0}C/yr. Both the minimum and the maximum temperatures increased consistently from the baseline to 2080s, throughout the year (Appendix D). The rate of change is higher in the temperature observed in 2080s as compared to 2020s and 2050s.

Table 3-9. Temperature, Precipitation, Snow, and Rain Change Rates from the Baseline Period (Mississippi).

Mississippi	Min. / Max. Temp. Change Rate (^{0}C/yr)			Precipitation Change Rate (mm/yr)			Snow Change Rate (mm/yr)			Rain Change Rate (mm/yr)		
Months	*2020s*	*2050s*	*2080s*	*2020s*	*2050s*	*2080s*	*2020s*	*2050s*	*2080s*	*2020s*	*2050s*	*2080s*
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

The precipitation rate of change is highly variable both among the months and future periods, and it ranges from -0.05 to 0.24 mm/yr. In the 2020s, there is a decrease in the rate change observed in the months of August and September, but it is observed as early as June and extends until August or September in 2050s and 2080s. In most of the months in the future periods, the rate of change in snow decreases and it ranges from -0.08 to 0.05 mm/yr. However, similar to the precipitation change rate, the rate of change in rainfall also varies highly throughout the year in the future periods. The rainfall rate of change is from -0.05 to 0.30 mm/yr.

The decrease in the rate of change of rainfall during the summer/fall, with the increasing rate of change in both the minimum and the maximum temperatures, is crucial in water management during the low flow season.

The percent changes in temperature and precipitation from the baseline period are shown in figures 3-12 and 3-13, respectively. In Mississippi, there is a consistent increase in temperature from the 2020s to 2080s. The highest increases are observed in the months of January and December, increasing up to between 4.3 to 4.5^{0}C in 2080s.

Just as the variability in precipitation was high, the percent change in the precipitation projections also varied across the months as seen in figure 3-11. The increase in the precipitation across the months was in the range of 2 to 26% with a consistent increase in the months of November through May. However, though the decrease in precipitation in 2020s is observed only in August and September, in 2050s and 2080s the decrease started early in June and lasted until September. This is crucial in managing water levels and flows during the low flow season, especially in the Mississippi River watershed.

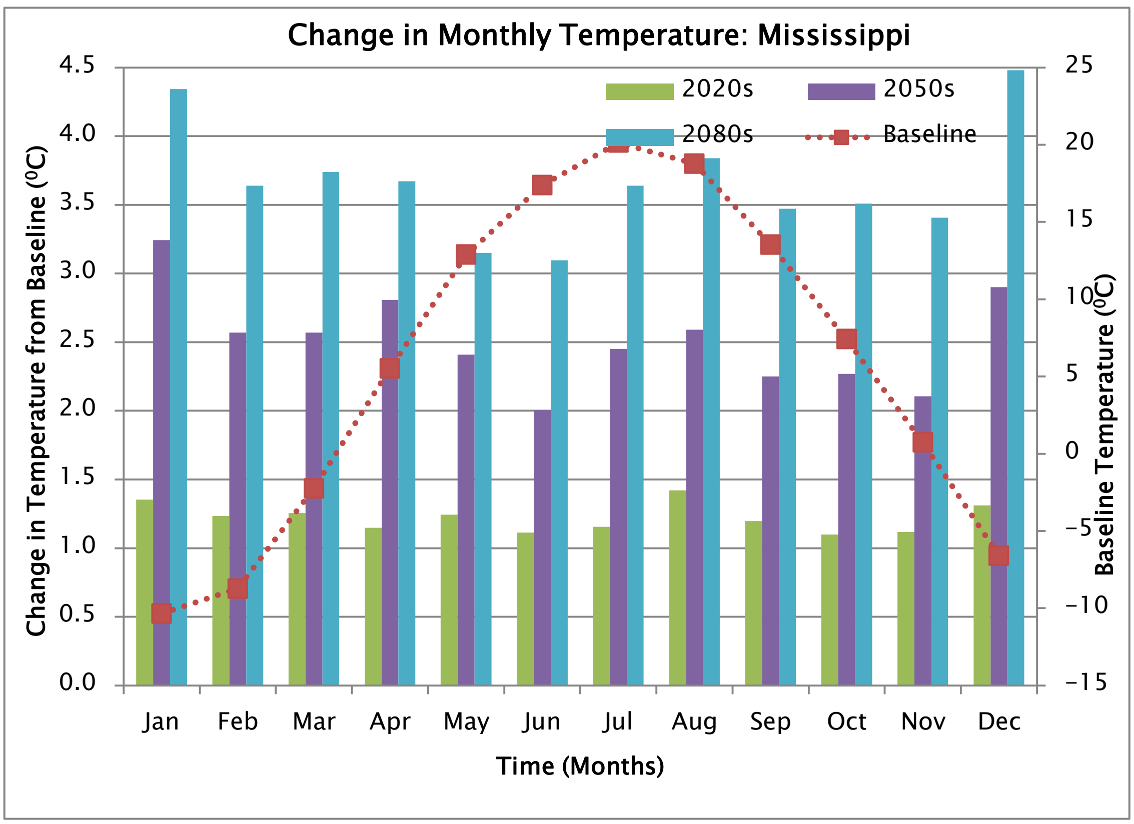

Figure 3-12. Changes in the Average monthly temperatures (Mississippi).

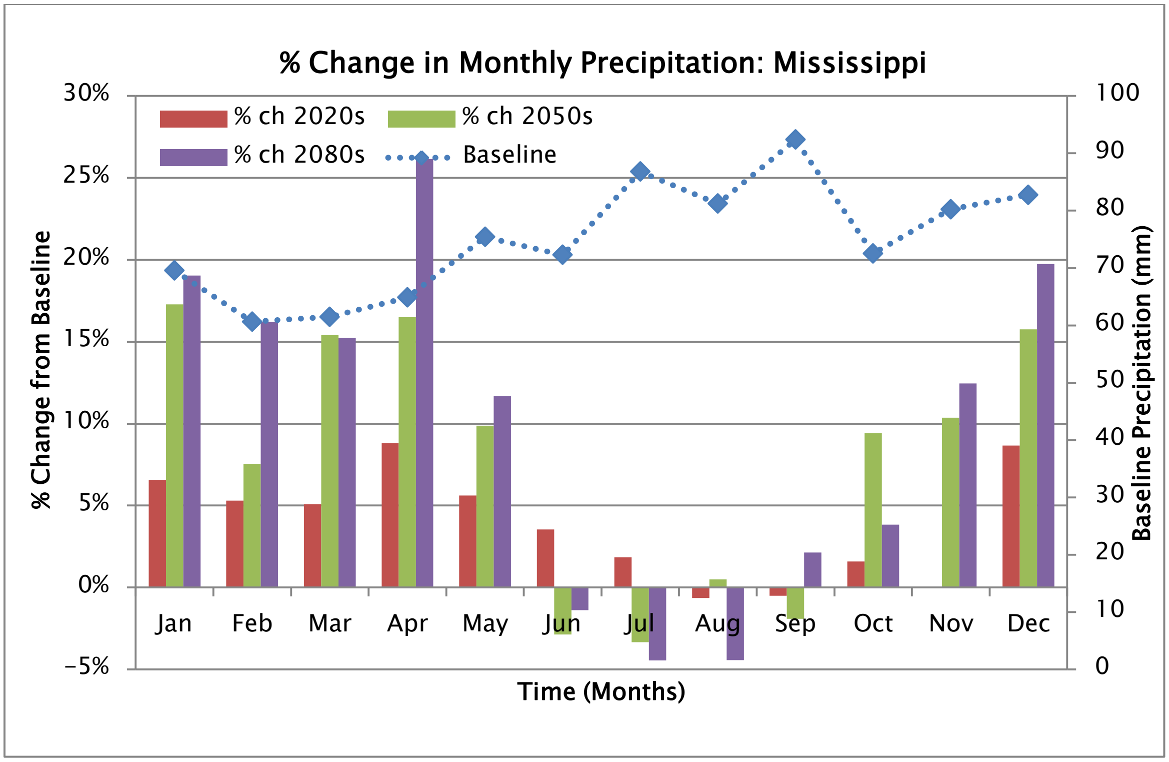

Figure 3-13. Percent change in the average monthly precipitation (Mississippi).

The average annual temperature consistently increased from baseline to future periods as seen in figure 3-14. However, though the annual average precipitation increases over the years, high variability exists in both the baseline and the future periods. In the baseline period, the annual average precipitation varied from 680 to 1213 mm and it increased to a range of 704 to 1327 mm in the future periods (figure 3-14). In the future periods, across the fall and the winter seasons, precipitation increased 2-20%. Similar to the average annual temperature, all the selected scenarios projected an increase in the annual average total precipitation in all three periods, except GFDLCM2.0_SRA1B (-1mm) and HADCM3_SRB1 (-13mm) in 2020s and INMCM3.0_SRB1 (-12mm) in 2050s.

During the baseline period, the average annual temperature in the Mississippi was 5.7^{0}C; and the projections show an increase up to 7.0^{0}C in the 2020s, 8.3^{0}C in 2050s and 9.7^{0}C in 2080s, with percent increases of 21%, 43%, and 71 %, respectively (figure 3-15). The variations in the annual average temperature across the 30-year periods were in the range of 6.6-7.7^{0}C, 7.3-9.5^{0}C, and 8.0-11.4^{0}C in the periods 2020s, 2050s, and 2080s, respectively. Similarly, the annual average total precipitation in the baseline of 887mm increased to 918mm (4%), 952 mm (7%), and 968 mm (9%) in 2020s, 2050s, and 2080s, respectively (figure 3-15). The variations in the total precipitation were 875-963 mm, 876-1043 mm, and 907-1054 mm, in the 2020s, 2050s, and 2080s respectively.

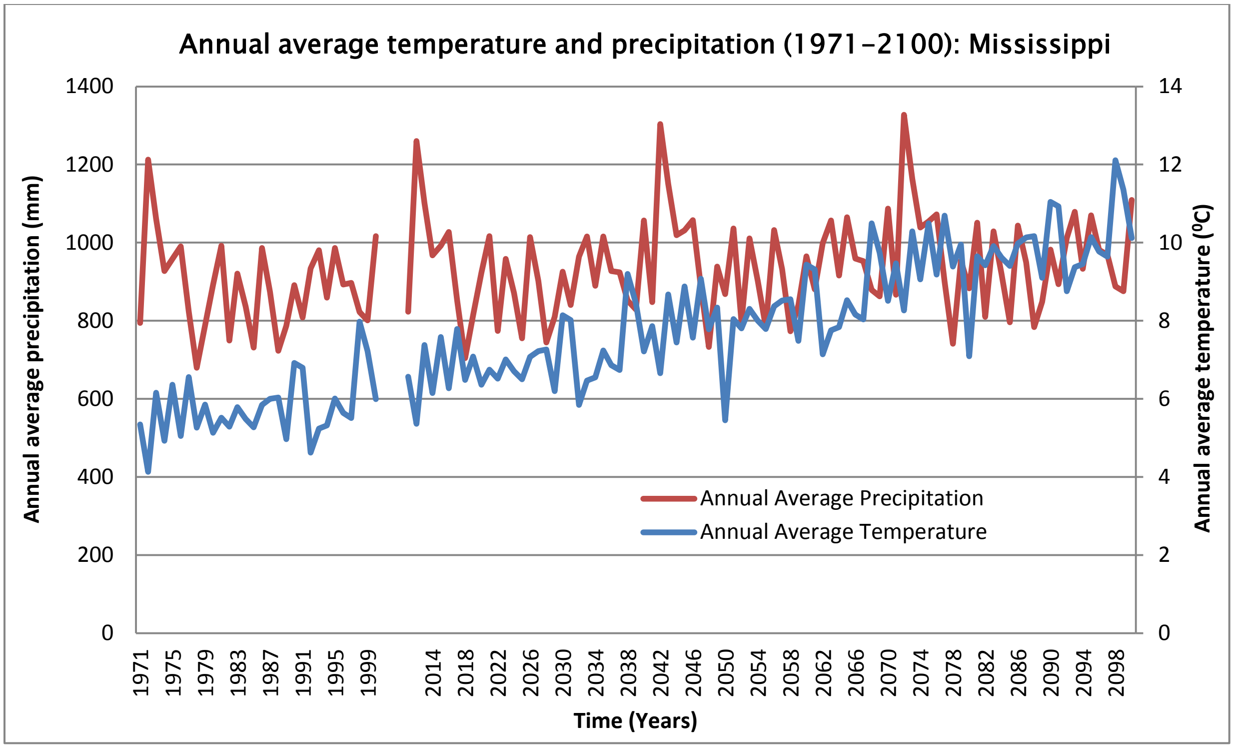

Figure 3-14. Trend in annual average temperature and precipitation in baseline (1971-2000) and future periods (2011-2100, Mississippi).

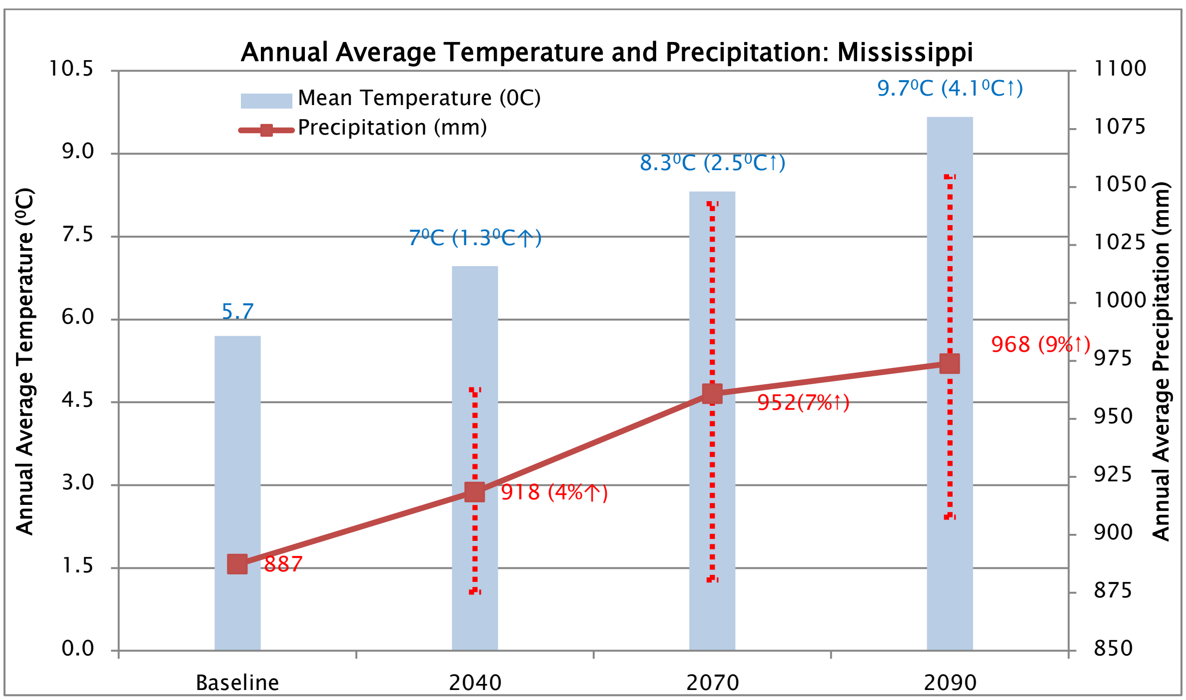

Figure 3-15. Annual average temperature and annual average total precipitation in baseline (1971-2000) and future periods (2011-2100, Mississippi).

3.3.2 Rideau Watershed

The monthly average temperature and precipitation in the three future periods, as well as the baseline conditions are shown in figures 3-16 and 3-17, respectively. From 2020s to 2080s, there is a continuous increase in the average temperature as compared to the baseline conditions. However, between 2020s and 2050S, the variation in the increase in the temperature was less as compared to that projected to occur in 2080s. This might be because the two over-projected scenarios increased the average for the 2020s projections and brought them closer to 2050s projections. Similar to Drummond Centre climate station, the increase in temperatures appeared higher in winter and summer months.

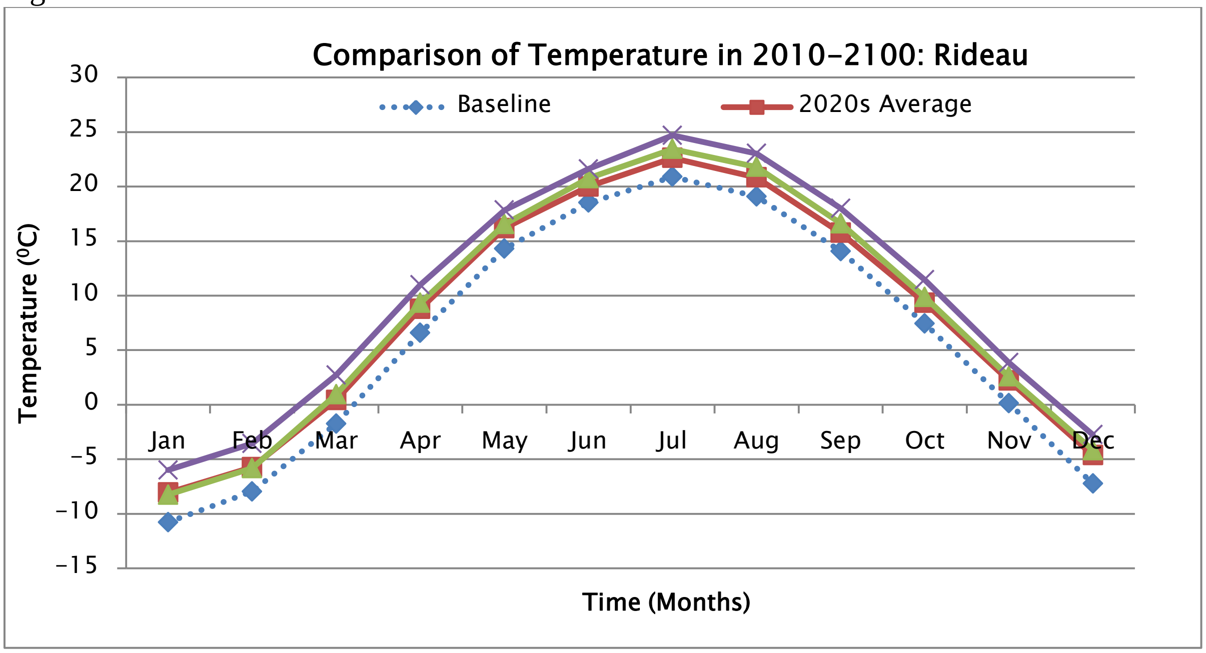

Figure 3-16. Monthly temperature in Baseline, 2020s, 2050s, and 2080s (Rideau).

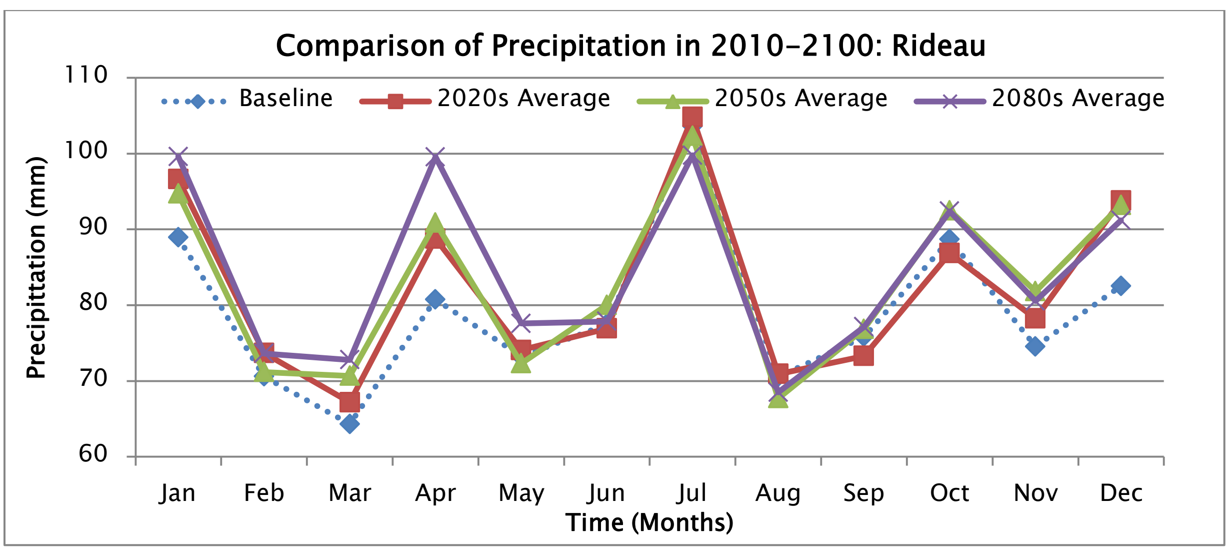

Figure 3-17. Monthly precipitation in Baseline, 2020s, 2050s, and 2080s (Rideau).

The percent changes in temperature and precipitation in each period from the baseline are given in tables 3-10 and 3-11. The temperature increase is high in the winter months in 2020s (2.4^{0}C) and 2080s (4.5^{0}C). Similar to MVCA, the precipitation amounts decrease in summer months (1-1.6%).

Table 3-10. Monthly changes in temperature and precipitation in 2010-2100 periods from the baseline (Rideau).

Rideau	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Temperature (^{0}C)												
Baseline	-10.8	-8.0	-1.7	6.6	14.3	18.5	20.9	19.1	14.1	7.4	0.1	-7.2
2020s	2.7	2.2	2.2	2.2	1.9	1.5	1.7	1.8	1.7	1.9	2.1	2.6
2050s	2.5	2.1	2.7	2.8	2.3	2.2	2.5	2.7	2.6	2.4	2.5	3.1
2080s	4.8	4.4	4.5	4.4	3.6	3.1	3.8	3.9	3.9	4.0	3.7	4.5
Precipitation (mm)												
Baseline	88.9	70.6	64.3	80.8	73.2	77.5	103.6	70.5	75.8	88.7	74.5	82.5
2020s (% change)	9%	4%	4%	10%	1%	-1%	1%	1%	-3%	-2%	5%	14%
2050s (% change)	7%	1%	10%	13%	-1%	3%	-1%	-4%	1%	4%	10%	13%
2080s (% change)	12%	4%	13%	23%	6%	0%	-4%	-3%	2%	4%	8%	10%

Table 3-11. Seasonal changes in temperature and precipitation in 2010-2100 from the baseline (Rideau).

Rideau	Winter (Jan.-March)	Spring (April-June)	Summer (July-Sept.)	Autumn (Oct.-Dec.)
Temperature (^{0}C)				
Baseline	-6.8	13.1	18.0	0.1
2020s	2.4	1.9	1.7	2.2
2050s	2.5	2.4	2.6	2.6
2080s	4.5	3.7	3.9	4.1
Precipitation (mm)				
Baseline	74.6	77.2	83.3	81.9
2020s (% change)	6%	3%	-1%	6%
2050s (% change)	6%	5%	-1%	9%
2080s (% change)	10%	10%	-2%	8%

Though higher variability exists in the precipitation projections, the amounts generally increased in the fall and the winter months as compared to the baseline conditions. As stated previously, the average monthly precipitation amounts decreased in the months of May to September and this decrease was in the range of -4 to 6%, and (table 3-10).

Table 3-12 shows the percent change rate in future maximum temperatures, minimum temperatures, precipitation, snow, and rain from the baseline conditions. The change rates for the maximum and the minimum temperatures per year were same in the future periods at 0.03 to 0.060C/yr. The increase in the rate change in both the maximum and the minimum temperature was consistent throughout the year among the three periods (Appendix D). Similar to the

Mississippi watershed, the rate change in the temperature was higher in the winter months and were little higher in the 2020s and 2080s as compared to the 2050s (Remember: Two scenarios in the 2020s projected slightly higher temperatures).

Table 3-12 Temperature, Precipitation, Snow, and Rain Change Rates from the Baseline Period (Rideau).

Rideau	Min. / Max. Temp. Change Rate (^{0}C/yr)			Precipitation Change Rate (mm/yr)			Snow Change Rate (mm/yr)			Rain Change Rate (mm/yr)		
Months	***2020s***	***2050s***	***2080s***	***2020s***	***2050s***	***2080s***	***2020s***	***2050s***	***2080s***	***2020s***	***2050s***	***2080s***
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

With the high variability in the precipitation projections, the rate of change also varied highly throughout the year in the future periods and ranges between -0.08 to 0.35 mm/yr. The rate of change for the precipitation was decreased in the months of September and October in the 2020s, but in 2050s and 2080s the decrease starts early in July and lasts until August/September. The majority of the months in the future periods shows a decrease in the rate of change in the snow amounts and range between -0.22 to 0.05 mm/yr. Similar to the precipitation, the rate of change in the rain also varies widely throughout the year among the future periods and ranges from -0.13 to 0.37 mm/yr. The decrease in the rate change of rain along with the consistent increase in the minimum and the maximum temperature rate changes in the summer months is critical for water managers during the low flow season.

The percent change in temperature and precipitation from the baseline period shown in figures 3-18 and 3-19. All three periods show a consistent increase in the temperature across the months. October through April shows a temperature increase of greater than 50% compared to the baseline period. The highest increases are projected in the months of March and November, increasing from 2.5 to more than 5 times compared to the baseline condition.

As seen earlier, with the observed high variability in precipitation projections the percent changes also greatly varied across the months (figure 3-19). On an annual basis most of the climate models project an increase in the future precipitation amounts. Similarly, in all three future periods, the selected scenarios projected an increase in the average annual precipitation amounts, but the increase observed was consistent only in March and April (figure 3-19). All scenarios showed a decrease in the precipitation amounts in the summer and fall months. In the 2020s, the precipitation projections decreased in the months of September and October, but it deceased early in July in 2050s and much earlier in June in 2080s. This early onset of decreasing precipitation will be crucial in watershed management during the low flow season. In addition, the magnitude of these decreases in precipitation amounts increases from the periods 2020s to 2080s.

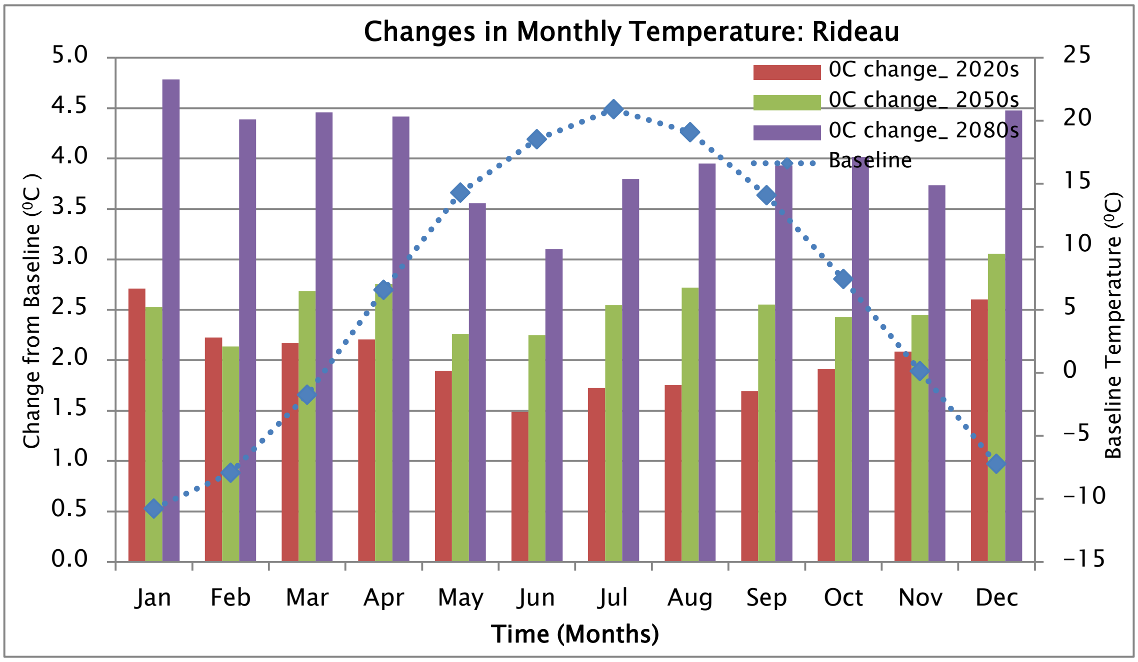

Figure 3-18. Average percent change in the monthly temperature (Rideau).

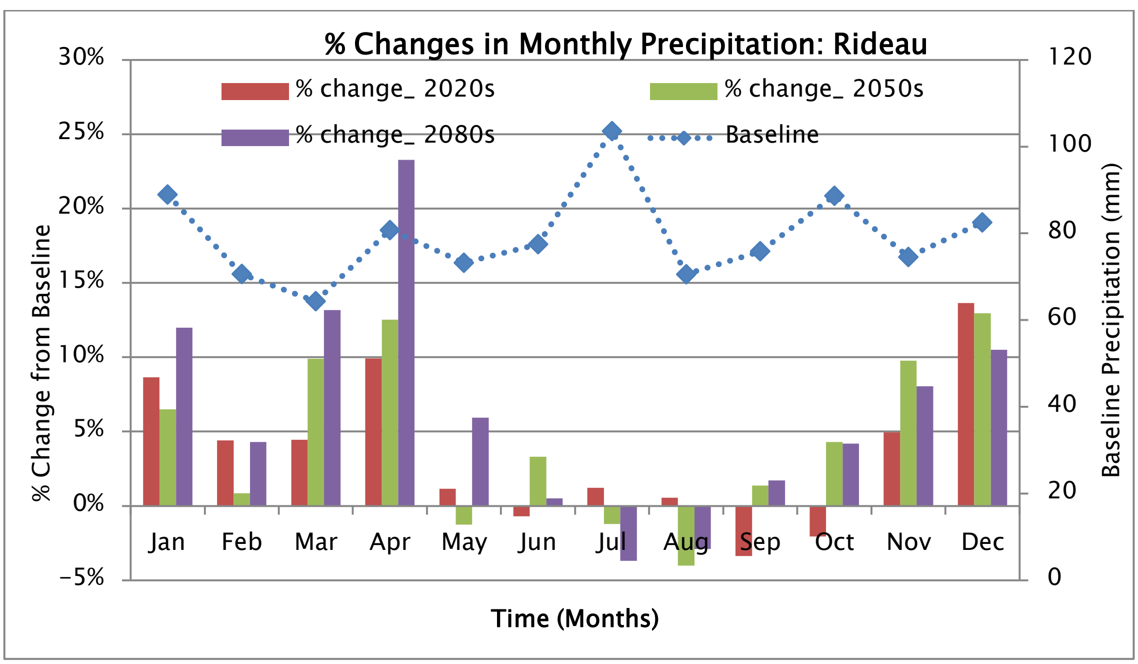

Figure 3-19. Average percent change in the monthly precipitation (Rideau).

The average annual temperature in the baseline period was 6.1^{0}C for the Ottawa Airport station, which increases to 8.1^{0}C in the 2020s, 8.6^{0}C in 2050s and 10.2^{0}C in 2080s (figure 3-20). Similar to the average annual temperature, the majority of the selected scenarios projected an increase in the annual average total precipitation in all three periods. However, the scenarios CGCM3T47-Run4 SRA1B (-16 mm), and GFDLCM2.0 SRA1B (-53 mm) in 2020s and the scenarios FGOALS-g1.0 SRB1 (-1 mm) and INMCM3.0 SRB1 (-191 mm) in 2050s, and scenario FGOALS-g1.0 SRA1B (-175 mm) in 2080s projected decreases in the average annual precipitation amounts.

Therefore, while considering all ten selected scenarios, the annual average total precipitation in the baseline (951mm) increased to 985mm (4%), 994mm (5%), and 1010mm (6%) in 2020s, 2050S, and 2080s, respectively. But when the two scenarios that projected comparatively low precipitation (INMCM3.0 SRB and FGOALS-g1.0 SRB) were omitted from the analysis, the annual average total precipitation was 985mm (4%), 1020mm (7%), and 1031mm (8%) in 2020s, 2050s, and 2080s, respectively, as shown in table 3-13. These increases in the average annual precipitation in each phase are similar to that observed with Drummond Centre station in the Mississippi watershed (table 3-13).

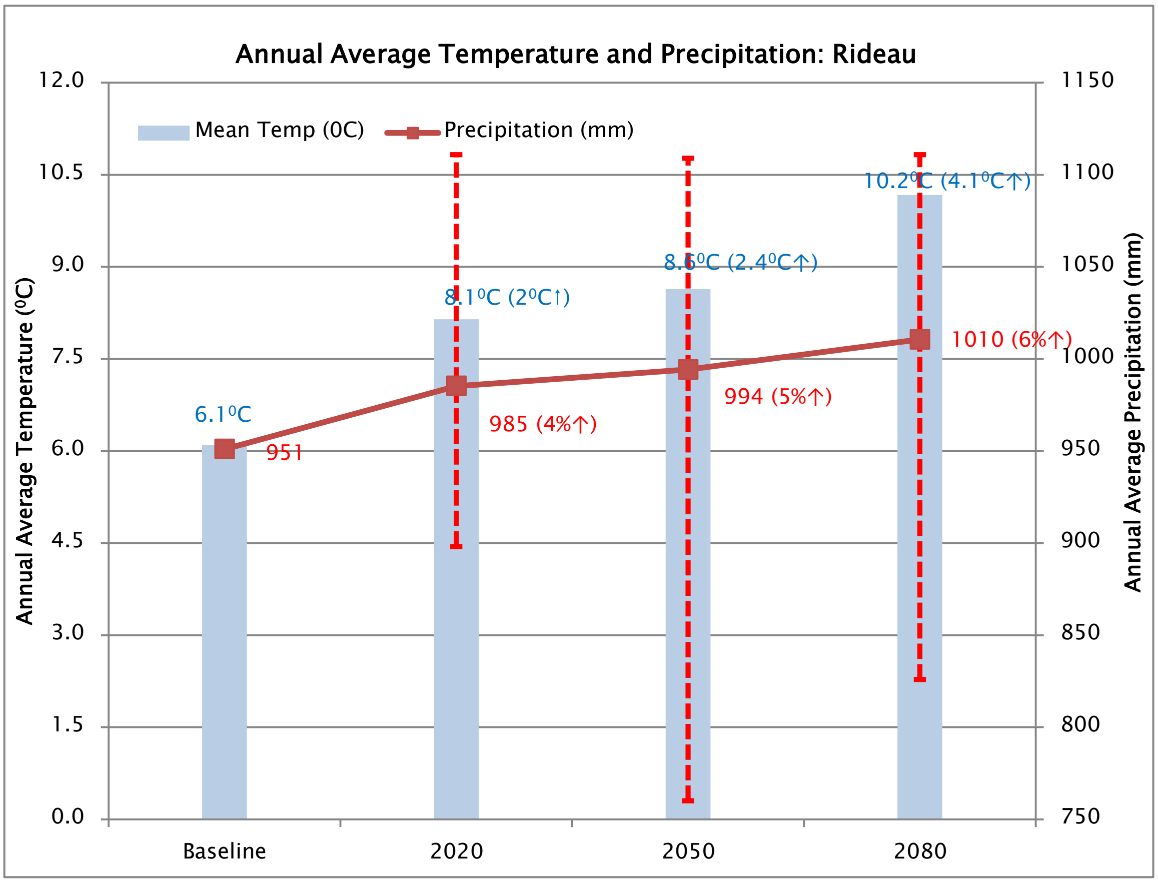

Figure 3-20. Annual average temperature and annual average total precipitation in the baseline (1971-2000) and future periods (2011-2100) Rideau.

Table 3-13. Comparison of percent change in temperature and precipitation in Mississippi and Rideau.

	Mean Temp (^{0}C) [^{0}C change from baseline]	Precipitation (mm) [% change from baseline] RVCA *without outliers	
Mississippi			
Baseline	5.7	887	
2020s	7.0 [1.3]	918 [4]	
2050s	8.3 [2.5]	952 [7]	
2080s	9.7 [4.1]	968 [9]	
Rideau			
Baseline	6.1	951	
2020s	8.1 [2.0]	985 [4]	985 [4%]*
2050s	8.6 [2.4]	994 [5]	1020 [7%]*
2080s	10.2 [4.1]	1010 [6]	1031 [8%]*

3.4 Water Budget Results

In addition to temperature and precipitation, water budget components such as rain, snow storage, potential evapotranspiration, actual evapotranspiration, moisture deficit, and moisture surplus were computed for the future periods using the Thornthwaite Water Budget program. The program calculated water budget components for the baseline and future periods for each climate station and a detailed discussion of the results follows. The water budget program runs individually with the daily climate data from each model to get the water budget components.

Following are some definitions for terms used in this section;

- **Surplus** is the amount of water remaining when precipitation exceeds potential evapotranspiration and the soil has reached its field capacity.
- **Recharge** is the amount of water added to soil moisture storage when precipitation exceeds PET but the soil has yet to reach its field capacity.
- **Soil moisture utilization** is the water withdrawn from soil moisture storage to meet the ET requirement when the soil has not yet reached dry conditions. A deficit occurs when potential evapotranspiration exceeds precipitation and soil storage has reached ‘zero’ or dry.

The average water holding capacity of the Mississippi watershed area is 150mm. In the water budget program the saturation level of the upper soil layer is set at 40% of the water holding capacity (60mm).

3.4.1 Mississippi Watershed

The monthly average of water budget components of the selected models for 2020s is given in figure 3-21. The water surplus (after reaching the field capacity of the soil) condition occurs for the 2020s occurs from mid-November to mid-April and then until mid-August, the soil moisture storage is available to partially meet the ET requirement. The deficit occurs from May to September and brings to a surplus condition again by mid-November when the recharge slowly starts to bring the soil moisture up to the field capacity (figure 3-21). Similar results were obtained for 2050s and 2080s as well (Appendix E).

As a rule of thumb, runoff should be equal to the precipitation minus AET (P-AET). The P-AET and the actual projected runoff amounts are not equal during the winter months, as seen in figure 3-22. That difference is acceptable as the expected runoff might be stored on the ground as snow and/or ice until the melt starts, often around March.

However, after August when the AET equals the PET, the actual runoff is expected to increase or match P-AET as it increases but results indicate that the runoff is not increasing until November. This may be because the excess precipitation, after meeting the ET requirement, may be retained in the soil to bring the soil moisture level up to the field capacity. Therefore, the increase in the runoff appears only in November as opposed to the expected period of early to mid-August.

Similar results were obtained in the 2050s and 2080s as seen in figure 3-22. In the baseline, the soil moisture content was below 60mm only in July to September, but in the future the soil moisture deficit starts early in mid-June and lasts longer, until October.

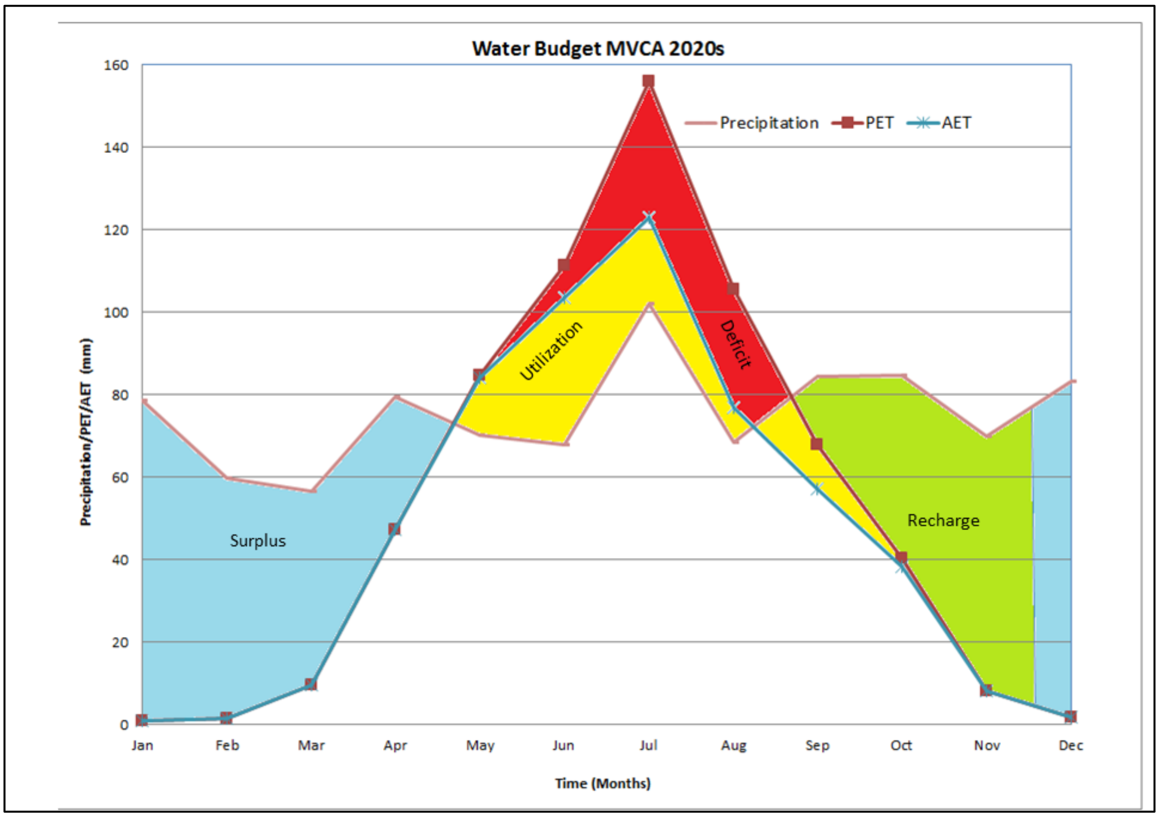

Figure 3-21. Water Budget in 2020s (Mississippi).

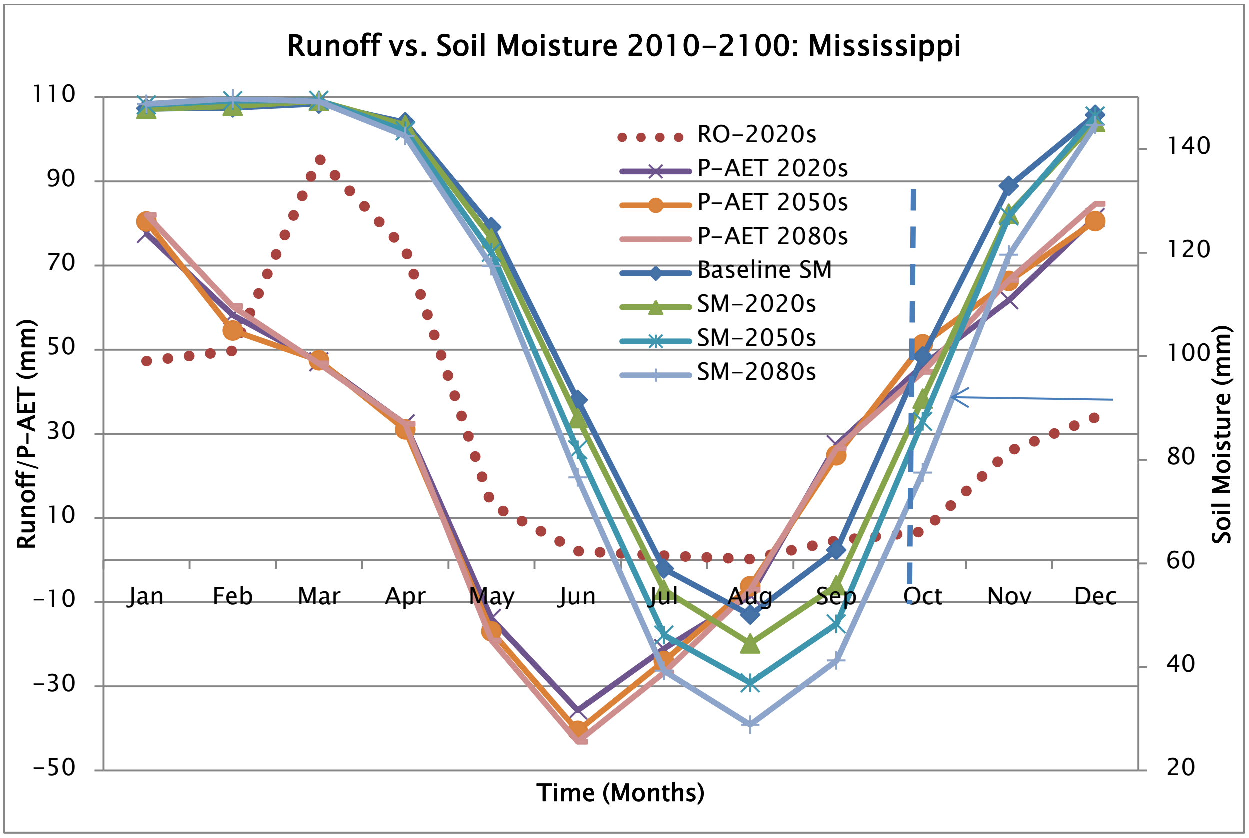

Figure 3-22. Water budget components in 2020s (Mississippi).

The low flow season with no or low runoff is observed in July and August in the 2020s, but occurs early in June and lasts up to mid-August in 2050s and 2080s. This suggests that the increase in the soil moisture deficit in the fall season is a key element to consider in the water management planning, especially during the low flow season.

3.4.2 Rideau Watershed

Similar to the Mississippi, the water surplus condition in the Rideau watershed also occurs from mid-November to mid-April in the 2020s, but in later periods in 2050s and 2080s it reaches the surplus condition couple of weeks later in November than seen in the Mississippi watershed (Figure 3-23). However, the soil moisture utilization (May to mid-August) and deficit (May to September) months are similar to the Mississippi watershed. Similar results were obtained in 2050s and 2080s as well, but the recharge takes a few more weeks to bring the soil moisture condition above the field capacity (Appendix E).

As seen with the Mississippi watershed, though P-AET increases after August the runoff does not show corresponding increases until mid-November (figure 3-24). In the baseline, soil moisture content below 60mm was observed only in August and September, but in the future it starts early in July and lasts longer, until October.

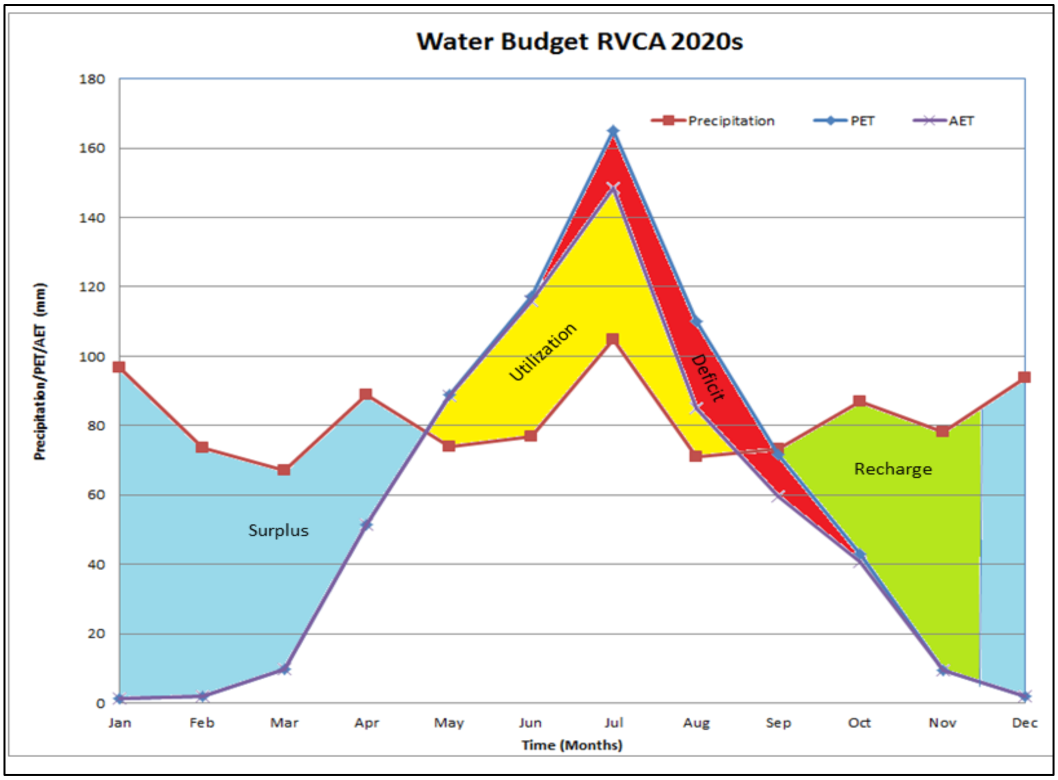

Figure 3-23. Water Budget in 2020s (Rideau).

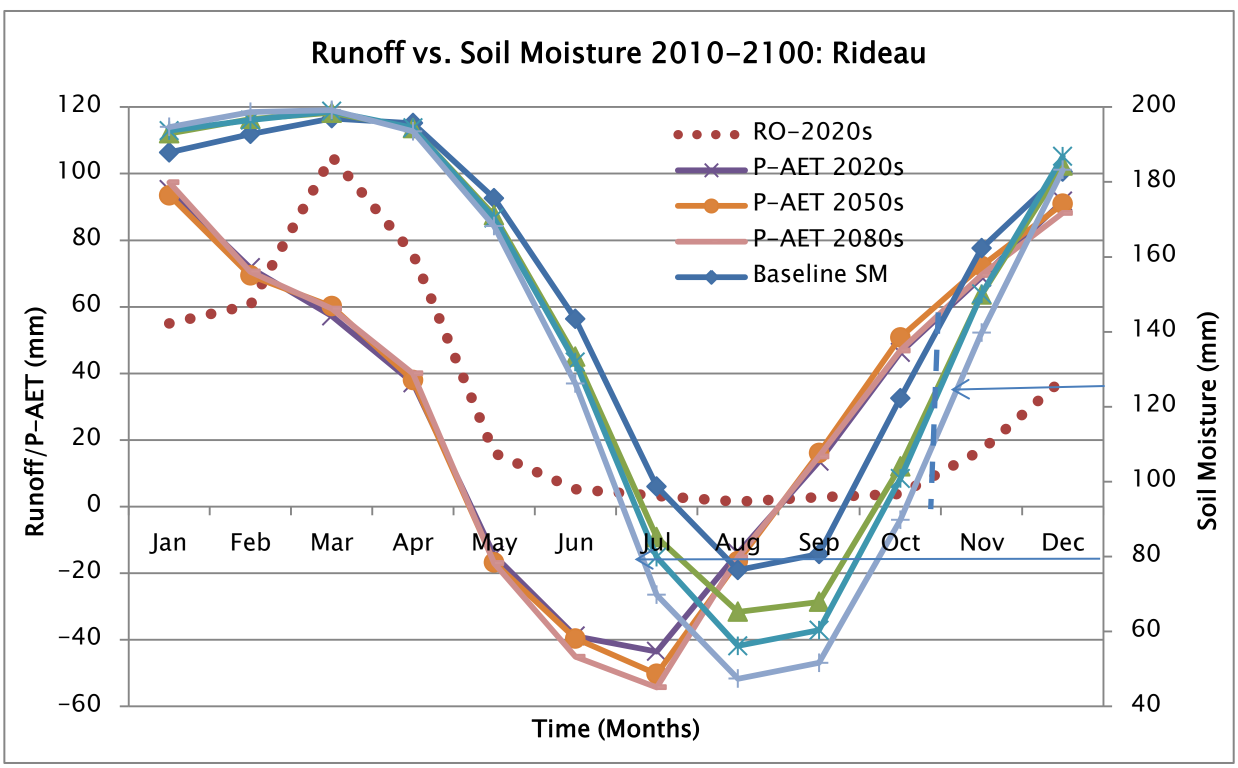

Figure 3-24. Water budget components in 2020s (Rideau).

Changes in water budget components in the Mississippi and Rideau watersheds over the future 90-year period is shown in table 3-14 and figure 3-25. In both watersheds, the projected annual average precipitation increased consistently from the baseline to the 2080s, with an increase of 3-7% in the Mississippi and 4-6% in the Rideau and the annual average temperature increased by 1.2-4.10C and 2-4.10C respectively. The snow amounts decreased consistently in future periods with a decrease of 26-73% in the Mississippi and 48-75% in the Rideau. This might directly result in a consistent increase in the water deficit and the soil moisture deficit. The increases in water deficit and soil moisture deficit were, respectively, 22-109% and 3-9% in the Mississippi and 82-177% and 4-9% in the Rideau.

Table 3-14. Average annual water budget components in 2010-2100 periods and the percent difference from the baseline conditions (Mississippi and Rideau).

	Temp						Water Budget Components *(mm) [% change]	
	(⁰C) [⁰C change]	**Precip(mm)** [%change]	**PET ***	**AET ***	**Deficit ***	**Runoff ***	**Snow ***	**Soil Moisture ***
Mississippi								
Baseline	5.7	887	598	530	-68	351	311	1357
2020s	7.0 [1.3]	918 [3%]	635 [6%]	552 [4%]	-83 [-22%]	354 [1%]	230 [-26%]	1320 [-3%]
2050s	8.3 [2.5]	952 [4%]	675 [13%]	568 [7%]	-107 [-58%]	371 [6%]	149 [-52%]	1285 [-5%]
2080s	9.7 [4.1]	968 [7%]	733 [22%]	591 [11%]	-141 [-109%]	366 [4%]	84 [-73%]	1235 [-9%]
Rideau								
Baseline	6.1	951	608	577	-32	384	398	1815
2020s	8.1 [2.0]	985 [4%]	672 [11%]	614 [7%]	-58 [-82%]	385 [0%]	207 [-48%]	1744 [-4%]
2050s	8.6 [2.4]	994 [5%]	691 [14%]	626 [9%]	-66 [-107%]	400 [4%]	190 [-52%]	1720 [-5%]
2080s	10.2 [4.1]	1010 [6%]	742 [22%]	655 [14%]	--88 [-177%]	386 [1%]	98 [-75%]	1662 [-8%]

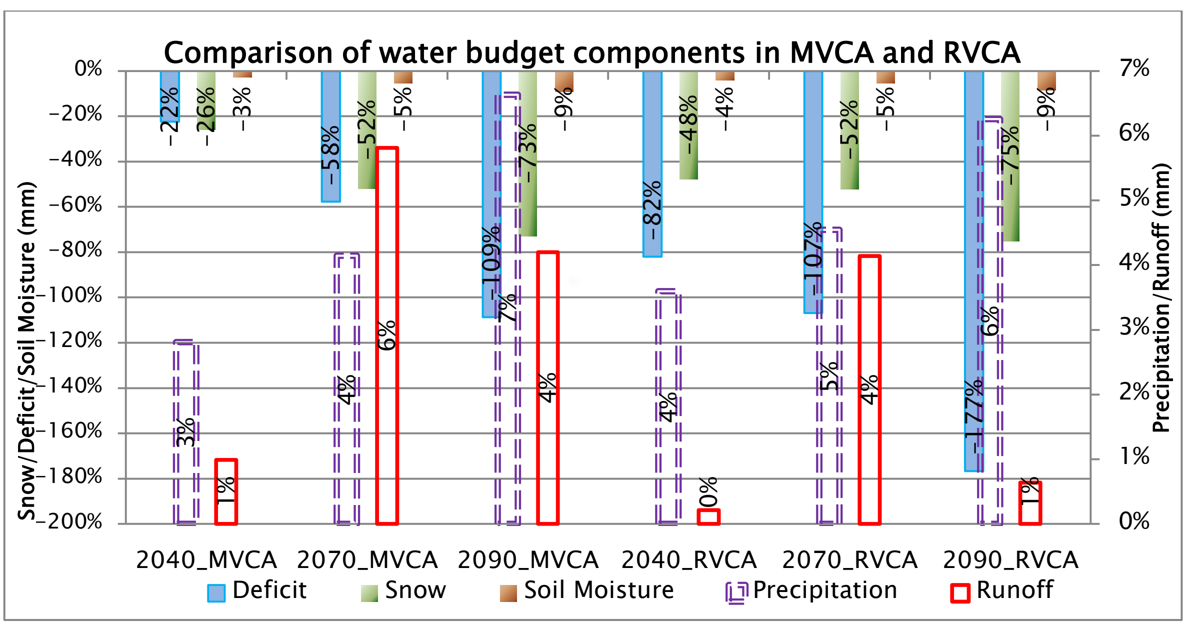

Figure 3-25. Comparison of water budget components in Mississippi and Rideau.

In both watersheds, the annual average runoff increases from the baseline and was high in the 2050s, 6% in Mississippi and 4% in Rideau. The reason may be due to the very low temperatures projected in the months of January and February of the 2050s as compared to the those months in the 2080s, which may keep the snow on the ground for a longer period and which then results in a rapid melt in March and April and produces higher runoff in those months (table 3-15).

Table 3-15. Comparison of Temperature and Precipitation in 2050s and 2080s (Mississippi and Rideau).

	Mississippi				Rideau			
	Baseline	2020s	2050s	2080s	Baseline	2020s	2050s	2080s
Temperature (^{0}C)								
Jan	-10.5	-9.2	-7.3	-5.8	-10.8	-8.1	-8.3	-6.0
Feb	-8.2	-7.0	-5.6	-4.1	-8.0	-5.7	-5.8	-3.6
Mar	-1.6	-0.3	1.0	2.6	-1.7	-0.3	1.0	2.6
Apr	6.2	7.4	9.0	10.4	6.6	8.8	9.3	11.0
Jan-April Totals (mm)								
Snow	268.0	196.6	123.2	68.8	349.0	180.0	165.8	81.6
PET	52.9	59.2	68.9	77.2	51.1	64.9	66.3	78.1
Melt	186.0	169.4	144.6	116.3	221.1	172.6	164.7	127.7
May-Aug Totals (mm)								
PET	435.3	457.8	480.0	512.9	446.1	481.3	494.8	521.4
Soil Moisture	325.4	310.2	285.0	262.0	494.2	454.8	438.2	411.5
Water Deficit	-57.9	-15.9	-20.5	-26.9	-23.5	-43.5	-49.7	-66.7

It has been observed that the total snowfall and melt amounts from January to April are higher and the PET is lower in 2050s as compared to 2080s, which might result in higher runoff. However, from May to August, though the total soil moisture content is higher and PET is lower in 2050s as compared to 2080s, the water deficit still occurs and is higher than 2020s. In addition, the soil moisture content decreasing and PET is increasing consistently from 2020s to 2080s (table 3-15).

Seasonal variation in the water budget components is given in table 3-16. In the analysis, the season winter, spring, summer, and autumn are respectively for the months January to March, April to June, July to September, and October to December. In both watersheds, the snow and water deficit amounts in all seasons of future periods are consistently decreased from the baseline amounts. But, although the runoff was increased annually, it consistently decreased in the spring and the summer months (table 3-16). As discussed earlier, this decrease in runoff is crucial during the low flow season. In all periods, the soil moisture content also decreased in all seasons except in winter months.

Table 3-16. Seasonal water budget components: Mississippi and Rideau.

	Runoff (mm)				Snow (mm)				Soil Moisture (mm)				Water Deficit (mm)			
	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn	Winter	Spring	Summer	Autumn
Mississippi																
Baseline	179	103	7.5	61	253	15	0	43	445	362	172	379	0	-6	-60	-1
2020s	193	89	6	61	188	9	0	34	445	355	155	364	0	-8	-73	-2
2050s	213	70	4	67	121	2	0	26	447	345	131	361	0	-12	-92	-3
2080s	214	63	3.2	86	68	1	0	15	448	336	109	342	0	-16	-120	-5
Rideau																
Baseline	189	137	10	48	332	17	0	49	578	515	256	467	0	0	-31	-1
2020s	221	97	8	48	175	5	0	27	588	499	218	438	0	-2	-54	-2
2050s	240	88	5	59	163	2	0	24	589	497	196	438	0	-1	-62	-2
2080s	245	79	3	59	81	0	0	16	593	488	169	413	0	-2	-82	-4

3.4.3 Comparison of Water Budget Components at 15-year interval [Mississippi and Rideau]

Analysis using shorter periods of 15-years was carried out to better understand the trends in the monthly climate projections. The baseline period chosen was 1970-2000, so a current condition comprised of 13 years from 2001-2013 was also included in this analysis of the Mississippi watershed.

Temperature

The comparison of monthly average temperature in Mississippi and Rideau over the 15-year intervals of the baseline and the future periods shows how the future projections follow the trend in the baseline conditions (Appendix F). This is obvious in the winter months, where one can see that the 15-year period of each future period follows the trend in the corresponding 15-year of baseline conditions. The current conditions (2001-2013) have already shown a higher increase in the temperature than that projected in the first 15-years of the 2020s. Therefore, it has to be presumed that when the GCM models generate the future projections by delta approach it follows the chosen baseline conditions.

Precipitation

Similar to the temperature trend seen, in both watersheds over 30-year periods, the 15-year trends in the monthly average precipitation in the future periods follow the corresponding pattern of the baseline period (Appendix G). This is very clear in the Rideau where in July the precipitation amounts were very high in the last 15-year periods of the 2020s, 2050s and 2080s, as it corresponds to a similar pattern of increase seen in the last 15-year of the baseline period.

However, the current condition in the Mississippi shows the precipitation in January, February and in August was equal or less than what have seen in the immediate last 15-year period of the baseline condition, whereas it was higher in the spring/summer (April to July) and fall (September to December) months of previous 15-year period. The current conditions (2001-2013) in the Mississippi show much higher changes in the precipitation amounts than the models projected.

The decrease in precipitation, especially in the low flow season in August, must be given more importance when developing plans for managing flows and levels in the watershed. In addition, the highest average precipitation projected in May to July might not be enough to meet the water requirement as the corresponding PET increases (6-22%).

Snow

In the Mississippi, during the current period (2001-2013), the actual snowfall was less than the projected amount in the first 15-year of 2050s but the amounts were similar to what was observed in the last 15-year period of the baseline condition (Appendix H). This is because the model projections follow the 15-year pattern of the baseline, which in turn projected higher amounts of snow in the first 15-years of each period.

Actual and Potential Evapotranspiration

In both watersheds, the monthly PET and AET among the 15-year periods consistently increased from the baseline to the future periods (Appendices I and J). In the Mississippi, the current (2001-2013) conditions showed lesser AET and PET amounts across the months except in July. The reason might be the higher amounts of precipitation in 2001-2013 periods across the months. Therefore, one should be cautious while using the projected ET in water management planning as the summer peaks on ET might be much higher than model projections.

Runoff

The monthly average runoff trend over the 15-year period in the baseline and future periods is shown in figures 3-26 and 3-27, respectively, for Mississippi and Rideau. As seen with other water budget parameters, the runoff projections also follow the trend in the baseline conditions. In the first 15-year period of the baseline period, the peak runoff observed in the spring was 115 mm, which is much higher than the 97 mm that observed in the last 15-year periods. However, contrarily the current condition (2001-2013) in Mississippi showed 101 mm of peak runoff, and the monthly amounts were similar to that observed in the last 15-year period of the baseline as seen in figure 3-24.

Deficit

Figures 3-28 and 3-29 show the 15-year trend in the monthly average deficit in the Mississippi and the Rideau, respectively. In both watersheds, the water deficit significantly increases from the15-year period of the baseline to every 15-year in future periods. As seen in figure 3-28, the current conditions in MVCA also showed consistent increases in the water deficit in summer low-flow season.

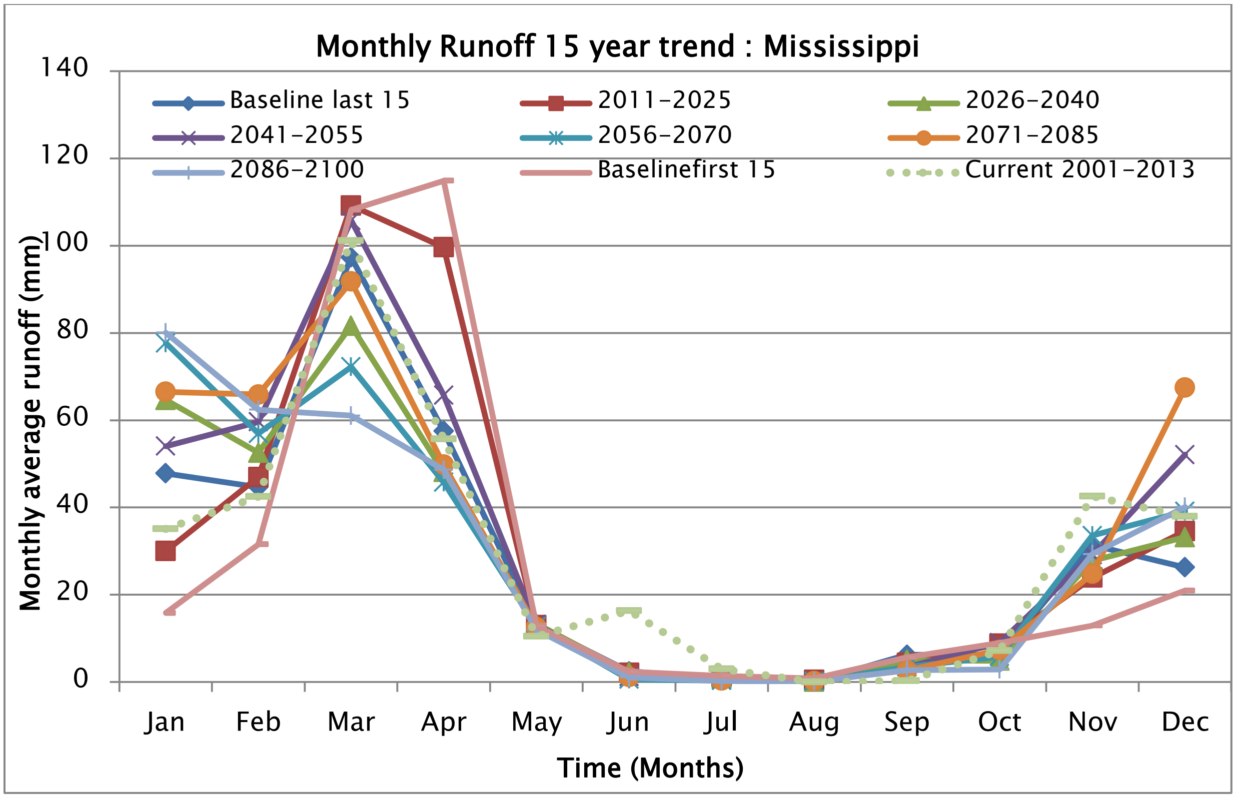

Figure 3-26. Monthly runoff trend in 15-year period (Mississippi).

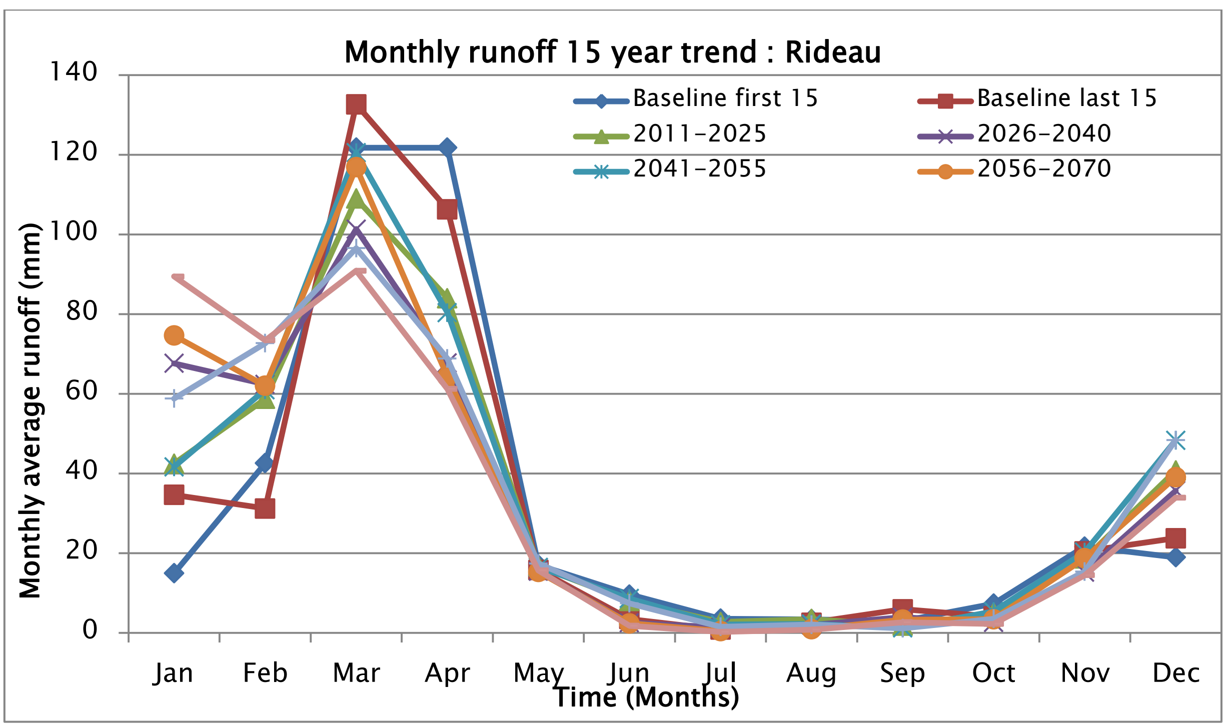

Figure 3-27. Monthly runoff trend in 15-year period (Rideau).

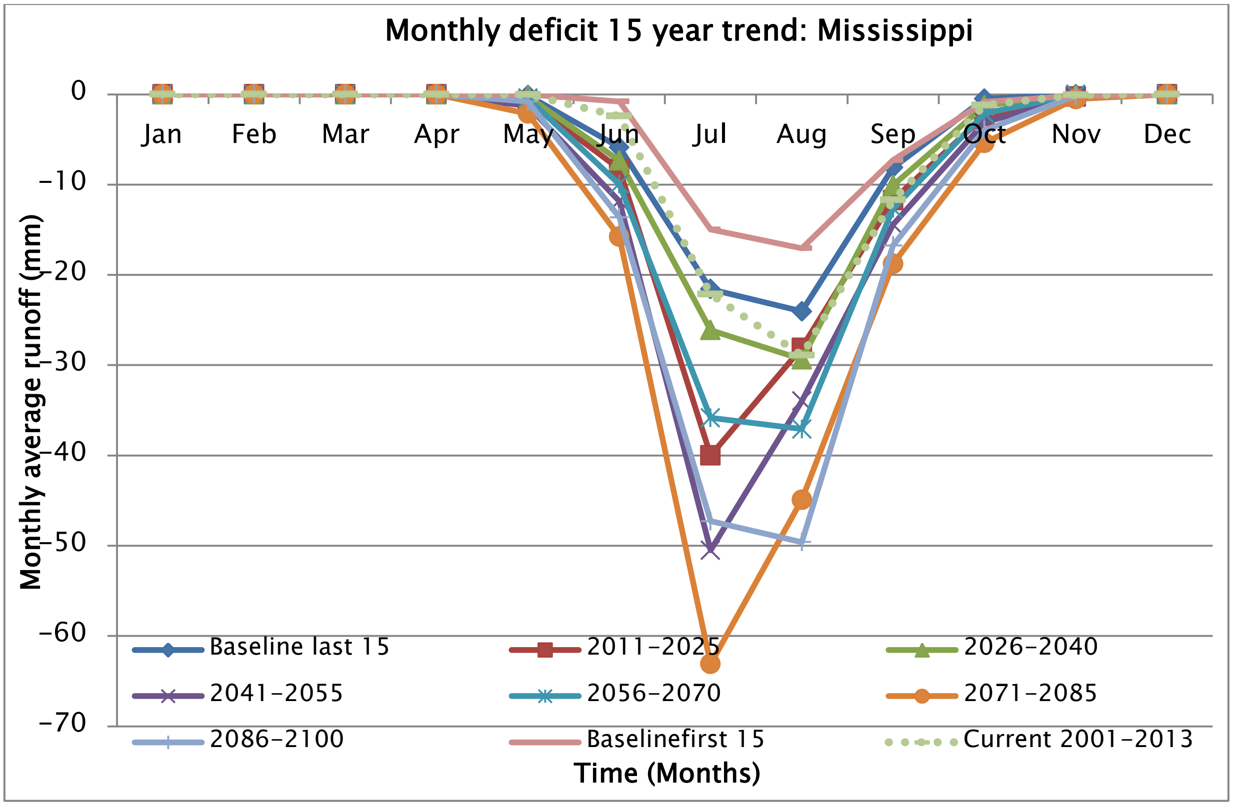

Figure 3-28. Monthly deficit trend in 15-year period (Mississippi).

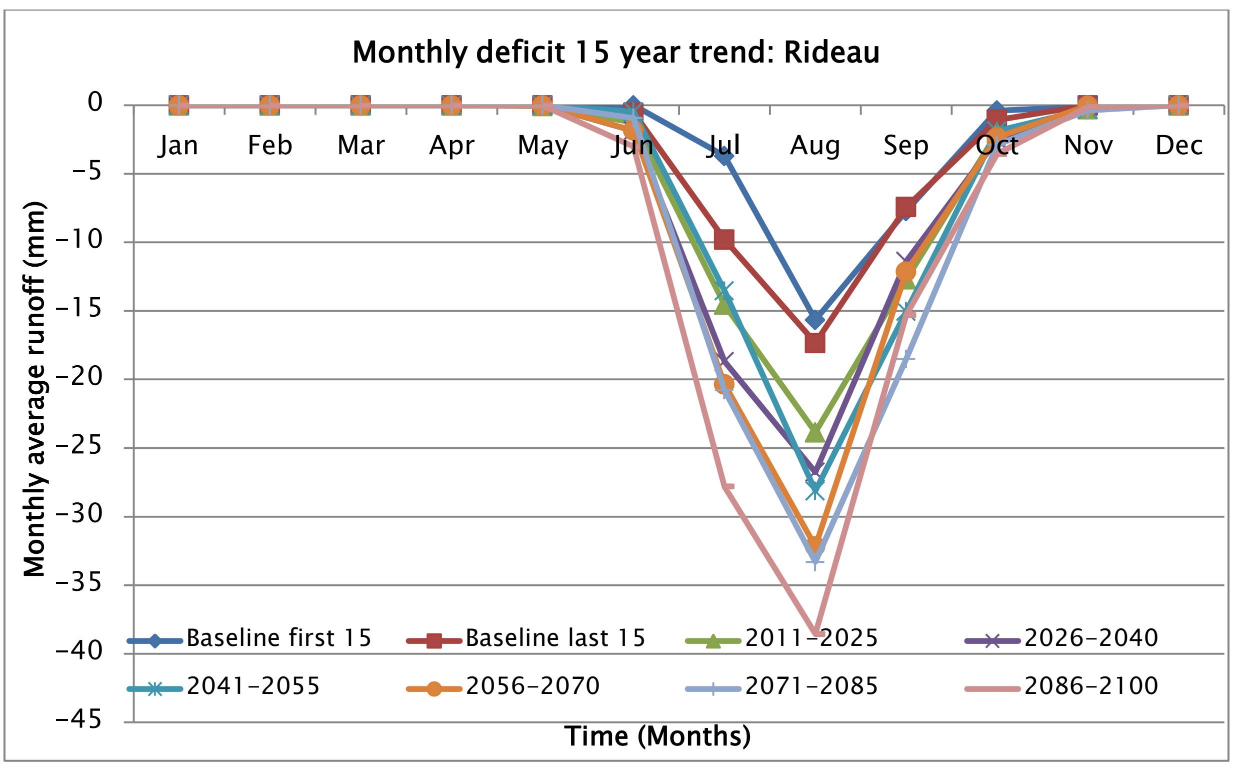

Figure 3-29. Monthly deficit trend in 15-year period (Rideau).

All the projected water budget components follow the trend in their baseline condition. The results confirm the limitation of GCM climate projections by delta method. The delta method uses multiplicative correction for precipitation and an additive correction for temperature, which makes it a robust and correcting the mean values makes all events change by the same amount monthly. This method could easily compare the historic and future projections (e.g. particular drought years in the historic record to future projections).

But a key limitation of this method is not capturing the potential changes in the variability or time series behaviour of temperature and precipitation. It captures a certain amount of intensity of climatic extremes from the GCM simulation, but fails to incorporate potentially changing inter-arrival time, duration, or spatial extent of climatic extremes (e.g. droughts and floods. Therefore, in any climate change and adaptation study, both the selection of GCM and the downscaling method crucially depend on the objective of the study.

4 Summary and Conclusion

This study is one of a numbr of subprojects consist in ‘The Mississippi Rideau Climate Change Vulnerability Assessment Project’ seeking adaptation measures for the region. Further studies have to build on the results of this paper to assess the impacts of climate change on reservoir operation, hydropower production and water management practice in the watershed region.

The objective of this study was to compare future climate projections from different GCM scenarios and to generate water budget components for the MR region to estimate the uncertainty pertaining to the impact of climate change on the hydrology. The study uses multi-modal, multi-scenario climate projections using the delta method in assessing the uncertainty in hydrologic components linked to the future climate.

The GCM scenarios selected by the percentile method project increased temperature and precipitation in the region for future 100-year periods.

The average annual temperature is projected at 7.0^{0}C, 8.3^{0}C, and 9.7^{0}C (in Mississippi) and is 8.1^{0}C, 8.6^{0}C and 10.2^{0}C (in Rideau), respectively for the 2020s, 2050s, and 2080s. It has projected an increase of 1.3^{0}C, 2.5^{0}C, and 4.1^{0}C from a baseline temperature of 5.7^{0}C in Mississippi and 2.0^{0}C, 2.4^{0}C, and 4.1^{0}C increase from 6.1^{0}C in Rideau. These projections varied between -2.0 to 1.7^{0}C and -2.0 to 3.6^{0}C, respectively in the Mississippi and the Rideau for the 100-year period.

For both watersheds, in all three periods, the highest increase in the temperature projections observed in the winter period and is crucial influencing most of the change that projected in runoff. The increase in winter temperature results in increased winter runoff, reduce the capacity of snow pack storage and volume of water that could infiltrate and to store in the soil.

Similar to other climate change studies, the precipitation projections for the region appeared to have more variation than the temperature. The average annual total precipitation projected 4% (918mm), 7% (952mm), and 9% (968mm) increases in the Mississippi and 4% (985mm), 5% (994mm), 6% (1010mm) increases in the Rideau, respectively for the 2020s, 2050s, and 2080s. However, these projections varied between -8.0 to 10.0% and -23.0 to 13.0%, respectively in the Mississippi and the Rideau for the 100-year period.

Though the total annual precipitation appeared to increase, all scenarios project up to a 2% decrease when considering the seasonal average for summer (up to 6% decrease on monthly average). This decrease in precipitation together with the increase in temperature is crucial to water managers during the low flow season.

In the MR Region, snowfall is projected to decrease consistently into the future between 26 and 75%, and PET is projected to increase between 6 to 22%. The increase in temperature and PET with a decrease in summer precipitation results in a consistent increase in water deficit (22 to 177%).

Most scenarios project 0-6% increase in annual average runoff in the region, but spring (April-June) and summer is estimated experience a decrease of 13 to 42% and 20 to 65%, respectively. The soil moisture deficit also increased consistently in all months except during winter months (January-March). The drop in runoff and precipitation/rain together with the increase in soil moisture deficit is challenging in meeting various water demands during the low flow season.

The study assesses the extent of uncertainty which exists in all the projected future hydrologic parameters and this would allow us to estimate the likelihood of future impacts in the MR region. As GCMs may carry large uncertainty in the climate projections, choosing a GCM is crucial and any climate impact and adaptation study based on a single GCM should be interpreted with great care. It is difficult to predict future flows correctly, but a water practitioner could and should include the uncertainty of future hydrologic parameters in water management plans in the watershed.

This study confirms the limitation of the delta approach, where the 15-year analysis presumes the climate projections will follow the patterns in the baseline data. Therefore the climate projections by delta method is not recommended for studies where a potential change in inter arrival time, duration, or spatial extent of climatic extremes are concerned (e.g. droughts and floods). Therefore, in any climate change and adaptation study, both the selection of GCM and the downscaling method crucially depend on the objective of the study.

5 *Recommendations for Future Study*

A monthly and seasonal streamflow analysis study with different stochastic models showing streamflow in the Mississippi River watershed is cyclic in nature with 3-years and 12-year period which may be affected by ENSO (El-Nino Southern Oscillation) phenomena. The knowledge of cyclic patterns and dominant wet or dry years are extremely important for water management, especially in Mississippi.

Traditional hydrological frequency analyses do not consider the increased impacts of climate variability to estimate the extreme rainfall frequency. However, a comprehensive water resources management strategy requires proper understanding of these extreme events in avoiding possible future vulnerabilities of an existing management strategy.

That being said it is recommended;

i. that a study is to be conducted to assess the ENSO effect on Mississippi watershed's historical and future climate, and

ii. that a study be conducted to analyze climate data for extreme events and estimate frequency and probability of extreme events such as floods and droughts. This will help in understanding and quantifying the uncertainties connected with the estimation of the design storms, which is very important for a sound watershed management at plan.

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Appendices

Appendix A *Climate Scenarios and rank of mean annual change in temperature and precipitation from the percentile method for the Drummond Centre station*

		Drummond Centre 2011-2040				**Drummond Centre 2041-2070**				**Drummond Centre 2071-2100**			
Model Name	**Emission Scenario**	**Precipitation Change [%]**	**Precipitation Rank [%]**	**Temperature Change [^{0}C]**	**Temperature Rank [%]**	**Precipitation Change [%]**	**Precipitation Rank [%]**	**Temperature Change [^{0}C]**	**Temperature Rank [%]**	**Precipitation Change [%]**	**Precipitation Rank [%]**	**Temperature Change [^{0}C]**	**Temperature Rank [%]**
BCM2.0													
	SRB1	11.5	100	0.9	11	7.3	59	1.5	3	8	40	2.2	3
	SRA1B	6.9	87	1	17	10.8	85	2	24	12	65	3.4	43
	SRA2	3.6	48	0.9	15	11.4	91	2.2	28	19	97	3.5	45
CGCM3 T47-Run1													
	SRB1	5.2	71	0.9	16	8.6	69	2.2	33	6.3	31	2.6	23
	SRA1B	5.3	72	1.3	57	9	73	2.8	67	14.7	80	3.7	53
	SRA2	3.5	47	1.3	51	12.8	95	2.8	68	17.4	95	4.8	83
CGCM3 T47-Run2													
	SRB1	4.2	55	1.4	61	9	76	1.9	20	13.2	72	2.8	25
	SRA1B	8.1	95	1.4	64	11.3	88	2.5	53	15.6	88	3.8	59
	SRA2	7.8	92	1.6	79	13.8	97	3	72	18.4	96	4.7	76
CGCM3 T47-Run3													
	SRB1	3.0	41	1	19	7.9	65	1.8	12	6.2	29	2.3	8
	SRA1B	4.3	57	1.3	52	6.6	51	2.6	64	12.7	67	3.5	44
	SRA2	2.0	31	1.3	53	11.7	93	3	79	12.7	68	4.8	80
CGCM3 T47-Run4													
	SRB1	4.7	65	1.4	69	1.4	17	2.2	32	5.9	27	2.4	12
	SRA1B	-1.9	4	1.3	59	3.5	25	2.6	63	10.4	59	3.9	60
	SRA2	0.6	17	1.1	36	6.1	43	2.7	65	9.5	47	4.7	79
CGCM3 T47-Run5													
	SRB1	0.8	21	0.9	12	9	75	2.2	35	8.8	44	2.6	21
	SRA1B	1.9	29	1.4	65	7.6	61	3	75	9.6	49	3.7	55
	SRA2	4.4	60	1.6	76	7.9	63	2.9	71	14.3	79	4.8	81

CGCM3 T63													
	SRB1	7.5	91	1.4	67	11.5	92	2.2	37	9.6	51	2.8	24
	SRA1B	10.6	99	1.4	68	10.3	81	3.1	80	20.2	99	4	64
	SRA2	9.2	97	1.6	73	10.3	83	3.1	81	17.3	93	5.2	88
CNRMCM3													
	SRB1	2.2	33	1.1	33	6.3	44	1.9	17	10	53	2.3	7
	SRA1B	6.1	79	1.2	45	6.6	49	2.6	61	9.6	48	3.5	47
	SRA2	2.6	40	1	25	8.7	71	2.4	48	15.2	83	4.1	71
CSIRO Mk3.0													
	SRB1	3.9	53	0.7	3	6.9	55	0.9	0	3.5	13	1.9	1
	SRA1B	7.3	88	1	23	3.9	29	1.7	9	7.2	36	2.8	28
	SRA2	4.2	56	1	21	7.2	57	2.2	31	13.1	71	3.7	56
CSIRO Mk3.5													
	SRB1	1.0	25	1.1	28	15.8	100	1.8	13	8.4	43	2.5	20
	SRA1B	4.9	67	1.2	40	11.4	89	2.6	57	15.7	89	3.4	40
	SRA2	6.6	85	1.2	39	10.6	84	2.6	56	15.8	91	4	63
ECHAM 5OM													
	SRB1	4.4	61	0.7	4	9	77	1.8	15	13.5	76	2.8	27
	SRA1B	2.5	39	1	20	9.5	79	2.9	69	14.3	77	4.1	69
	SRA2	2.4	35	0.8	7	12.9	96	2.2	29	15.5	87	4	65
ECHO-G													
	SRB1	-1.4	8	1.5	71	-1.1	4	2.6	55	3.6	15	3.7	52
	SRA1B	-3.7	3	1.7	81	0.1	11	3.2	85	7.9	39	5.3	89
	SRA2	-0.6	9	1.7	83	3.4	24	3.4	89	5.6	25	5.4	91
FGOALS-g1.0													
	SRB1	3.1	44	1.2	49	0	9	1.5	5	4.9	20	2.4	13
	SRA1B	6.2	80	1	27	3.8	28	2.4	47	3	12	3.6	51
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GFDLCM2.0													
	SRB1	0.6	19	1.4	63	1.4	16	2.2	39	2.8	9	3	33
	SRA1B	-0.1	12	1.6	75	0.5	13	3.2	84	5.9	28	4.3	73
	SRA2	0.3	15	1.3	56	1.8	19	3	76	-0.5	0	5.1	87
GFDLC													

M2.1													
	SRB1	8.5	96	1.2	48	6.4	45	2.1	27	11.8	63	2.4	15
	SRA1B	6.5	84	1.2	47	8.3	68	2.5	51	13.3	75	3.6	48
	SRA2	8.0	93	0.9	13	8	67	2.3	44	15.5	85	4	67
GISS-AOM													
	SRB1	5.8	75	1.2	44	7.1	56	1.8	16	10	52	2.3	5
	SRA1B	3.3	45	1.1	29	6.7	52	2.3	43	13.2	73	3	32
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GISS-EH													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	0.2	13	0.7	1	9	72	1.7	11	7.5	37	2.3	9
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GISS-ER													
	SRB1	5.8	76	1.4	60	4.7	33	1.5	1	10.2	55	1.5	0
	SRA1B	2.4	36	1.2	41	10.9	87	1.9	19	15.9	92	2.5	19
	SRA2	1.1	27	1.1	31	14.2	99	2.1	25	23.9	100	3.4	39
HADCM3													
	SRB1	-1.9	5	0.8	8	-1	7	2.2	40	5.4	23	3.3	37
	SRA1B	0.8	20	1.6	72	5.2	36	3.2	87	9.2	45	4.7	77
	SRA2	-3.9	1	1.3	55	5.5	39	2.6	60	3.8	16	5	84
HadGEM1													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	7.5	89	1.7	87	2.4	20	4.1	97	6.5	32	5.7	95
	SRA2	5.3	73	1.8	89	3.8	27	3.8	95	0.7	1	6.6	100
INGV-SXG													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	-1.5	7	1.1	32	-2.1	3	2.2	36	2.6	7	2.9	31
	SRA2	-8.4	0	0.9	9	-5.2	0	2.3	45	2.5	4	3.4	41
INMCM3.0													
	SRB1	-0.3	11	1.2	43	-1.1	5	2	23	2.8	8	2.4	16
	SRA1B	1.0	24	1.6	77	0.1	12	2.5	52	4.8	19	3.3	36
	SRA2	0.4	16	1.6	80	-2.3	1	2.6	59	2.9	11	4.4	75
IPSLCM4													
	SRB1	2.2	32	1.8	92	4.1	31	3	73	5.4	24	4.1	68
	SRA1B	1.5	28	2.2	97	3.2	23	4.2	99	6.7	33	5.4	92

	SRA2	3.8	49	1.8	91	-0.2	8	3.7	93	2.5	5	6	97
MIROC 3.2hire													
	SRB1	4.3	59	2.4	100	4.3	32	3.5	91	11.7	61	4.3	72
	SRA1B	5.1	69	2.3	99	7.5	60	4.3	100	10.4	57	5.9	96
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MIROC 3.2medr													
	SRB1	6.3	81	1.9	95	10	80	3	77	11.9	64	3.9	61
	SRA1B	3.8	52	2	96	5.7	41	4	96	5.3	21	5.6	93
	SRA2	6.1	77	1.8	93	7.9	64	3.6	92	2	3	6.2	99
MRICG CM2.3.2 a													
	SRB1	5.0	68	1.2	37	2.9	21	1.5	4	11.6	60	2.3	11
	SRA1B	4.5	64	1.1	35	5.3	37	2.2	41	13.1	69	3	35
	SRA2	3.0	43	1	24	5.6	40	2	21	14.9	81	3.6	49
NCARC CSM3													
	SRB1	2.5	37	1.7	84	6.6	48	2.5	49	8.3	41	2.3	4
	SRA1B	6.5	83	1.7	85	6.4	47	3.2	83	7	35	3.8	57
	SRA2	4.5	63	1.7	88	6.9	53	3.3	88	15.3	84	5.1	85
NCARP CM													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	3.8	51	0.7	5	1.3	15	1.6	7	10.2	56	2.4	17
	SRA2	1.0	23	0.3	0	4.8	35	1.6	8	4.1	17	2.9	29

Climate scenarios and rank of mean annual change in temperature and precipitation from the percentile method for the Ottawa Airport station

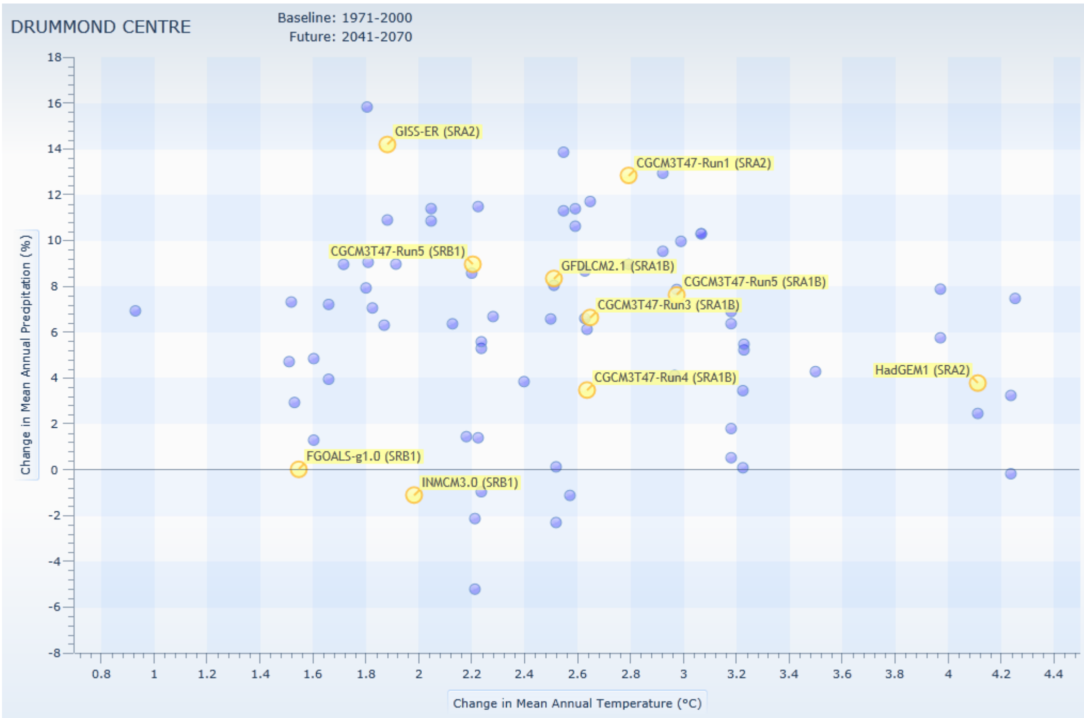
		Ottawa Airport 2011-2040				Ottawa Airport 2041-2070				Ottawa Airport 2071-2100			
Model Name	**Emission Scenario**	**Precipitation Change [%]**	**Precipitation Rank [%]**	**Temperature Change [^{0}C]**	**Temperature Rank [%]**	**Precipitation Change [%]**	**Precipitation Rank [%]**	**Temperature Change [^{0}C]**	**Temperature Rank [%]**	**Precipitation Change [%]**	**Precipitation Rank [%]**	**Temperature Change [^{0}C]**	**Temperature Rank [%]**
BCM2.0													
	SRB1	11.5	100	0.9	11	7.3	57	1.5	3	8	40	2.2	3
	SRA1B	6.9	88	1	17	10.8	85	2	24	12	65	3.4	41
	SRA2	3.6	51	0.9	15	11.4	91	2.2	28	19	97	3.5	44
CGCM3T47-Run1													
	SRB1	5.2	72	0.9	16	8.6	71	2.2	32	6.3	32	2.6	21
	SRA1B	5.3	75	1.3	57	9	76	2.8	67	14.7	80	3.7	53
	SRA2	3.5	49	1.3	51	12.8	95	2.8	68	17.4	95	4.8	83
CGCM3T47-Run2													
	SRB1	4.2	56	1.4	61	9	79	1.9	20	13.2	73	2.8	25
	SRA1B	8.1	93	1.4	64	11.3	89	2.5	53	15.6	91	3.8	57
	SRA2	7.8	91	1.6	79	13.8	97	3	71	18.4	96	4.7	76
CGCM3T47-Run3		0.0	0		0								
	SRB1	3.0	41	1	19	7.9	64	1.8	13	6.2	31	2.3	8
	SRA1B	4.3	57	1.3	52	6.6	53	2.6	61	12.7	68	3.5	43
	SRA2	2.0	32	1.3	53	11.7	93	3	79	12.7	69	4.8	80
CGCM3T47-Run4													
	SRB1	4.7	67	1.4	69	1.4	17	2.2	31	5.9	28	2.4	12
	SRA1B	-1.9	5	1.3	59	3.5	27	2.6	60	10.4	57	3.9	59
	SRA2	0.6	19	1.1	37	6.1	44	2.7	65	9.5	48	4.7	79
CGCM3T47-Run5													
	SRB1	0.8	23	0.9	12	9	77	2.2	33	8.8	44	2.6	20
	SRA1B	1.9	31	1.4	65	7.6	59	3	73	9.6	51	3.7	55
	SRA2	4.4	60	1.6	76	7.9	61	2.9	69	14.3	77	4.8	81

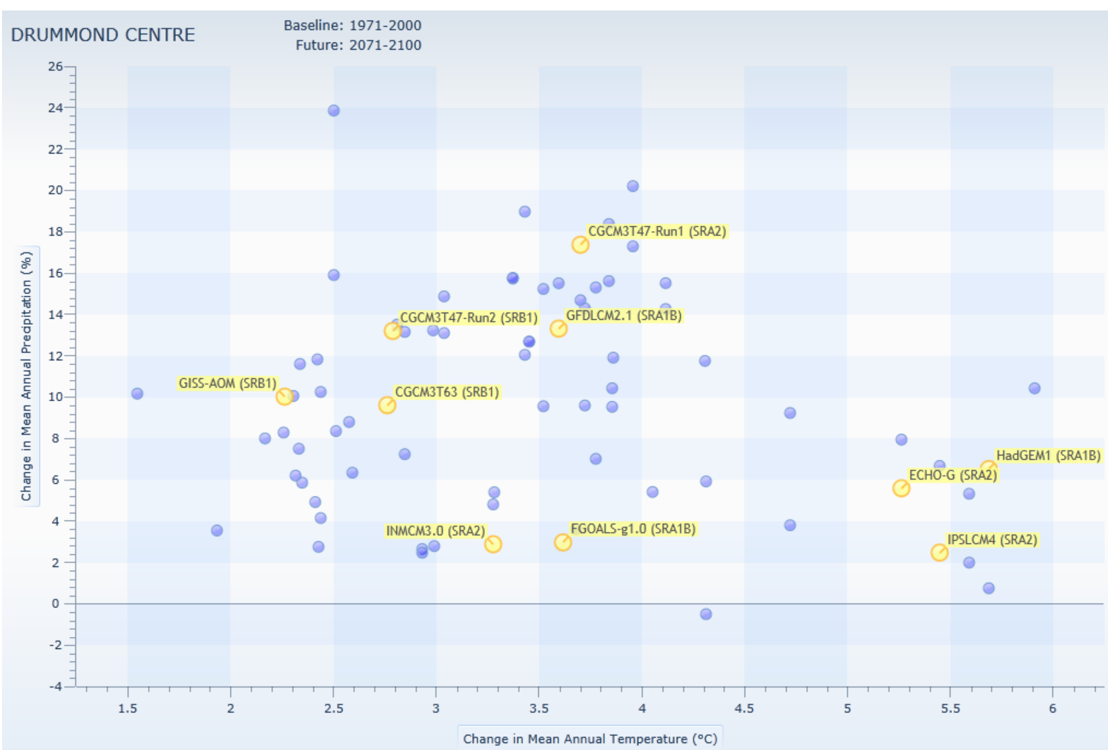
CGCM3T63													
	SRB1	7.5	89	1.4	67	11.5	92	2.2	36	9.6	52	2.8	24
	SRA1B	10.6	99	1.4	68	10.3	83	3.1	80	20.2	99	4	63
	SRA2	9.2	97	1.6	73	10.3	84	3.1	81	17.3	93	5.2	88
CNRMCM3													
	SRB1	2.2	35	1.1	33	6.3	47	1.9	15	10	53	2.3	7
	SRA1B	6.1	80	1.2	45	6.6	52	2.6	59	9.6	49	3.5	45
	SRA2	2.6	39	1	21	8.7	73	2.4	48	15.2	87	4.1	69
CSIROMk3.0													
	SRB1	3.3	47	0.8	4	6.1	45	1	0	3.8	16	2.1	1
	SRA1B	8.2	95	1.1	27	3.8	28	1.8	12	7.1	36	2.9	32
	SRA2	3.1	45	1.1	28	5.8	43	2.3	45	14.6	79	3.9	61
CSIROMk3.5													
	SRB1	0.0	13	1.1	31	14.2	100	1.9	16	8.2	41	2.6	23
	SRA1B	5.2	71	1.2	41	13.4	96	2.7	64	14.8	83	3.5	47
	SRA2	4.6	65	1.2	44	8.6	72	2.7	63	13.8	76	4	65
ECHAM5OM													
	SRB1	3.4	48	0.8	7	8.1	67	1.9	17	12.9	71	2.9	29
	SRA1B	2.8	40	1	23	9.1	80	3	77	11.8	60	4.3	71
	SRA2	1.9	29	0.8	5	11.1	88	2.3	41	15.2	85	4.1	68
ECHO-G													
	SRB1	-1.4	8	1.5	71	-1.1	4	2.6	55	3.6	13	3.7	52
	SRA1B	-3.7	3	1.7	83	0.1	11	3.2	85	7.9	39	5.3	89
	SRA2	-0.6	9	1.7	84	3.4	25	3.4	89	5.6	27	5.4	92
FGOALS-g1.0													
	SRB1	3.1	44	1.2	49	0	9	1.5	5	4.9	21	2.4	13
	SRA1B	6.2	83	1	24	3.8	29	2.4	47	3	12	3.6	51
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GFDLCM2.0													
	SRB1	0.6	20	1.4	63	1.4	16	2.2	37	2.8	9	3	33

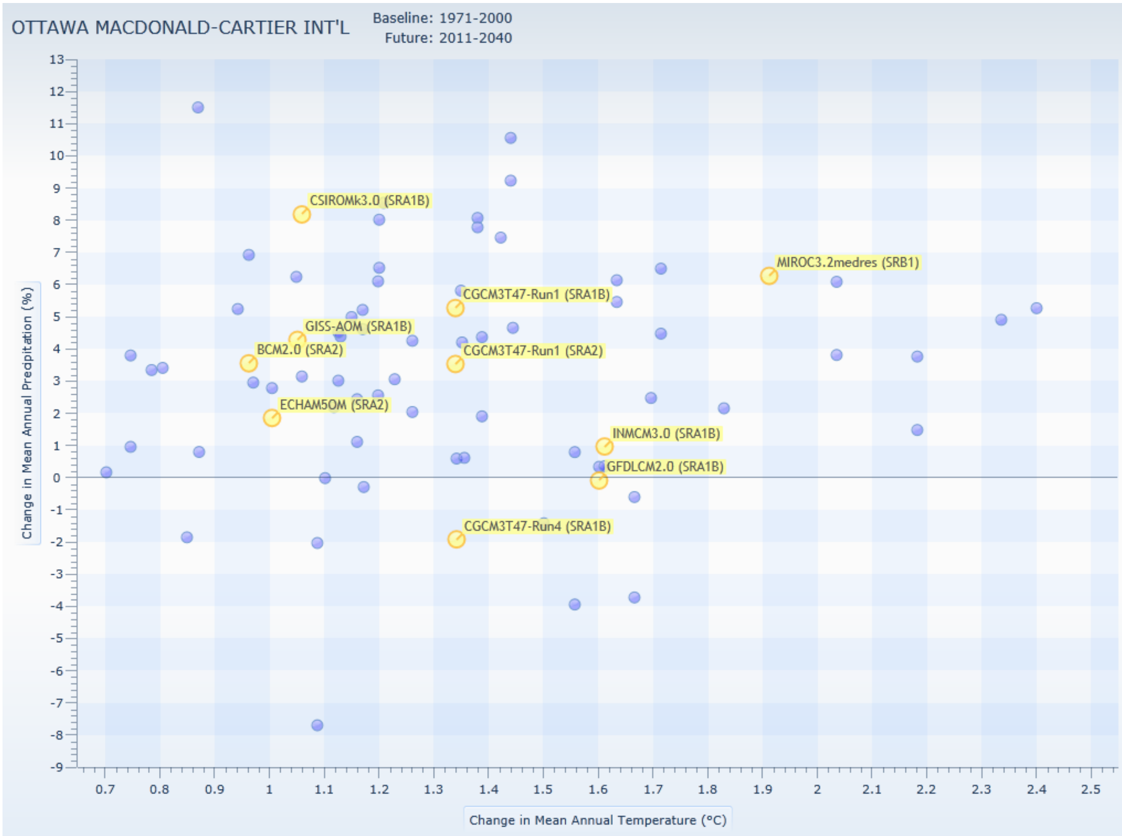
	SRA1B	-0.1	12	1.6	75	0.5	13	3.2	84	5.9	29	4.3	72
	SRA2	0.3	16	1.3	56	1.8	19	3	75	-0.5	0	5.1	87
GFDLCM2.1													
	SRB1	8.5	96	1.2	48	6.4	48	2.1	27	11.8	63	2.4	15
	SRA1B	6.5	87	1.2	47	8.3	68	2.5	51	13.3	75	3.6	48
	SRA2	8.0	92	0.9	13	8	65	2.3	43	15.5	89	4	64
GISS-AOM													
	SRB1	4.4	61	1.1	36	6.9	55	1.7	11	9.1	45	2.2	4
	SRA1B	4.3	59	1.1	25	7.7	60	2.2	35	14.7	81	2.9	31
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GISS-EH													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	0.2	15	0.7	1	9	75	1.7	9	7.5	37	2.3	9
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
GISS-ER													
	SRB1	5.8	77	1.4	60	4.7	32	1.5	1	10.2	55	1.5	0
	SRA1B	2.4	36	1.2	40	1.9	87	1.9	19	15.9	92	2.5	19
	SRA2	1.1	27	1.1	32	14.2	99	2.1	25	23.9	100	3.4	39
HADCM3													
	SRB1	-1.9	7	0.8	9	-1	7	2.2	39	5.4	24	3.3	37
	SRA1B	0.8	21	1.6	72	5.2	36	3.2	87	9.2	47	4.7	77
	SRA2	-3.9	1	1.3	55	5.5	39	2.6	57	3.8	15	5	84
HadGEM1													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	6.1	81	1.6	81	1.9	20	3.8	96	4.4	19	5.3	91
	SRA2	5.5	76	1.7	88	3	23	3.4	91	0	1	6.2	99
INGV-SXG													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	-2.0	4	1.1	29	-2.6	1	2.2	29	2.5	7	2.9	27
	SRA2	-7.7	0	0.8	8	-5.8	0	2.3	44	1.6	3	3.4	40
INMCM3.0													
	SRB1	-0.3	11	1.2	43	-1.1	5	2	23	2.8	8	2.4	16
	SRA1B	1.0	25	1.6	77	0.1	12	2.5	52	4.8	20	3.3	36
	SRA2	0.4	17	1.6	80	-2.3	3	2.6	56	2.9	11	4.4	75

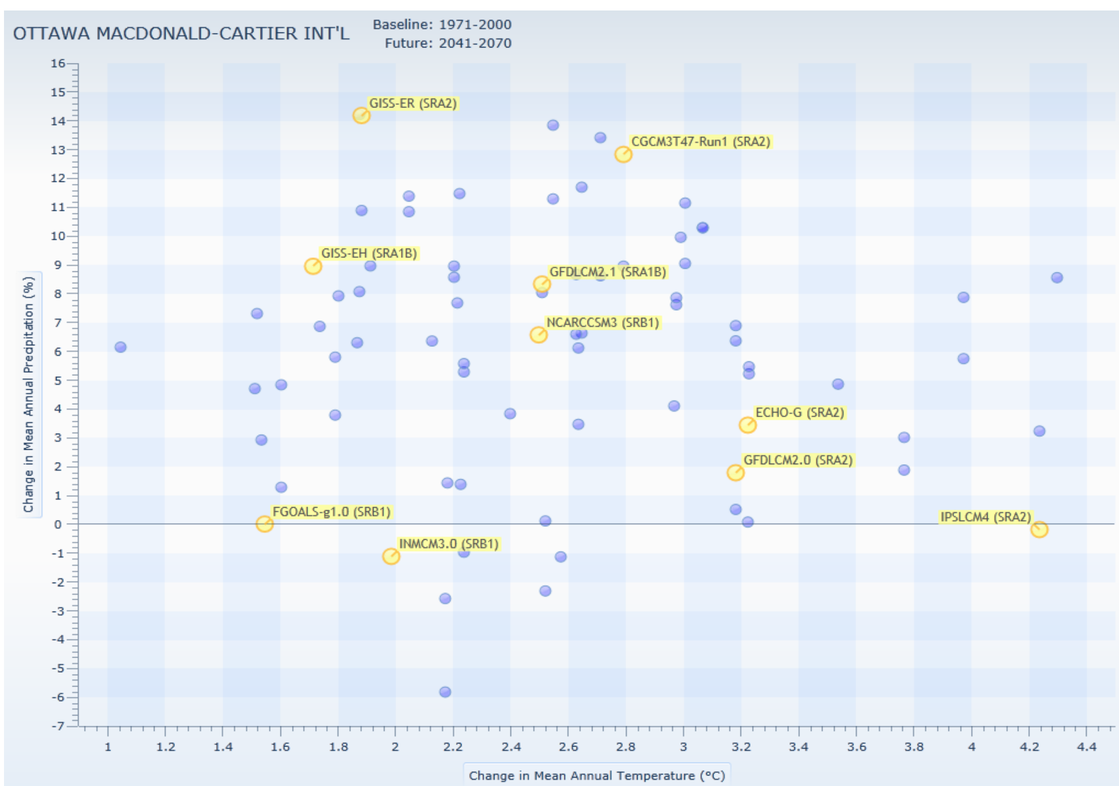
IPSLCM4													
	SRB1	2.2	33	1.8	92	4.1	31	3	72	5.4	25	4.1	67
	SRA1B	1.5	28	2.2	97	3.2	24	4.2	99	6.7	33	5.4	93
	SRA2	3.8	52	1.8	91	-0.2	8	3.7	95	2.5	5	6	96
MIROC3.2 hire													
	SRB1	5.3	73	2.4	100	4.9	35	3.5	92	11.8	61	4.4	73
	SRA1B	4.9	68	2.3	99	8.6	69	4.3	100	12.4	67	6	97
	SRA2	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
MIROC3.2 medr													
	SRB1	6.3	84	1.9	95	10	81	3	76	11.9	64	3.9	60
	SRA1B	3.8	55	2	96	5.7	41	4	97	5.3	23	5.6	95
	SRA2	6.1	79	1.8	93	7.9	63	3.6	93	2	4	6.2	100
MRICGCM 2.3.2a													
	SRB1	5.0	69	1.2	39	2.9	21	1.5	4	11.6	59	2.3	11
	SRA1B	4.5	64	1.1	35	5.3	37	2.2	40	13.1	72	3	35
	SRA2	3.0	43	1	20	5.6	40	2	21	14.9	84	3.6	49
NCARCCSM3													
	SRB1	2.5	37	1.7	85	6.6	51	2.5	49	8.3	43	2.3	5
	SRA1B	6.5	85	1.7	87	6.4	49	3.2	83	7	35	3.8	56
	SRA2	4.5	63	1.7	89	6.9	56	3.3	88	15.3	88	5.1	85
NCARPCM													
	SRB1	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
	SRA1B	3.8	53	0.7	3	1.3	15	1.6	7	10.2	56	2.4	17
	SRA2	1.0	24	0.3	0	4.8	33	1.6	8	4.1	17	2.9	28

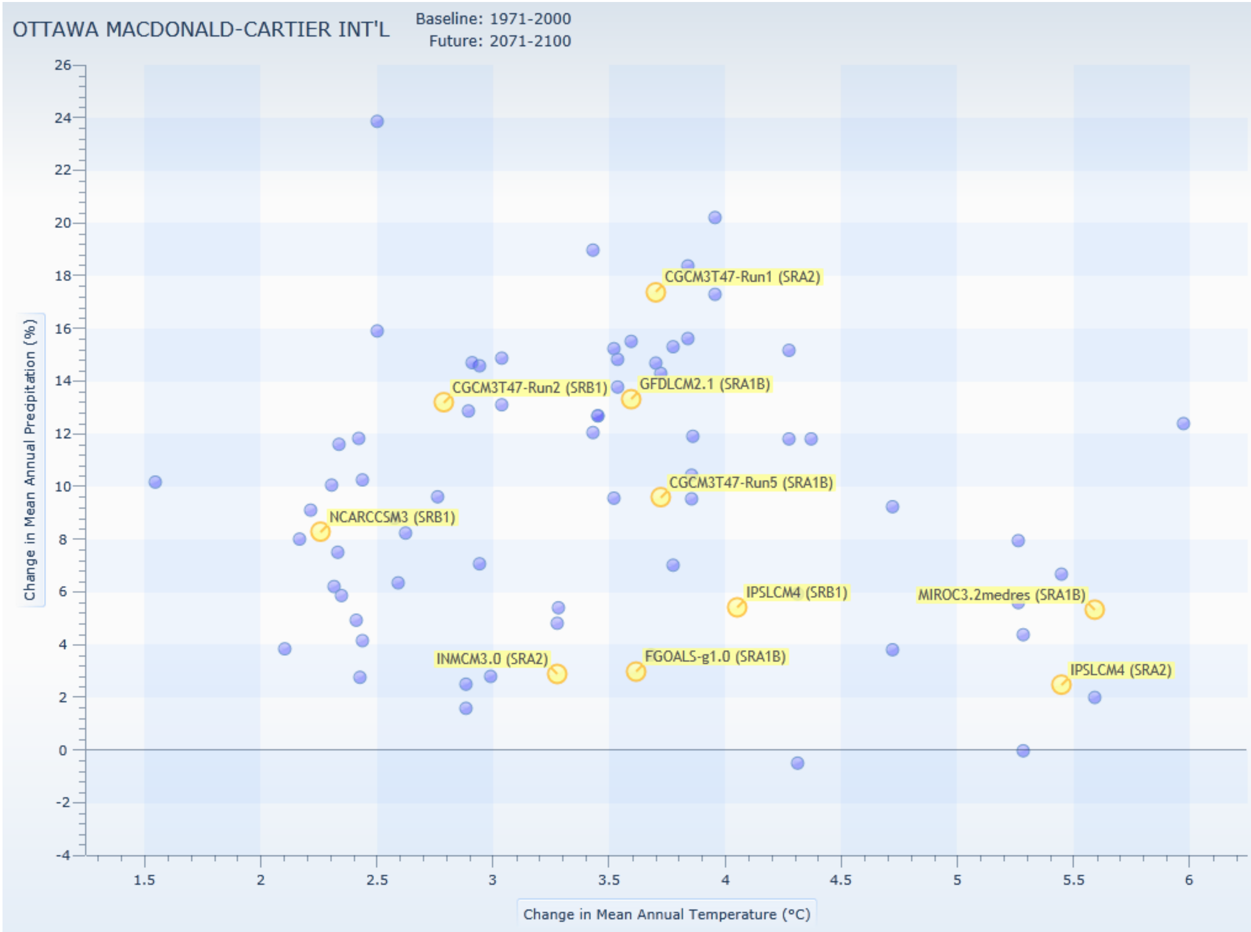
Appendix B *Graphical representation of the mean annual change in precipitation versus the mean annual change in temperature for the baseline [1971-2000] and the future periods for Drummond Centre [2041-2070 and 2071-2100] and Ottawa Airport [2011-2040, 2041-2070, 2071-2100]*





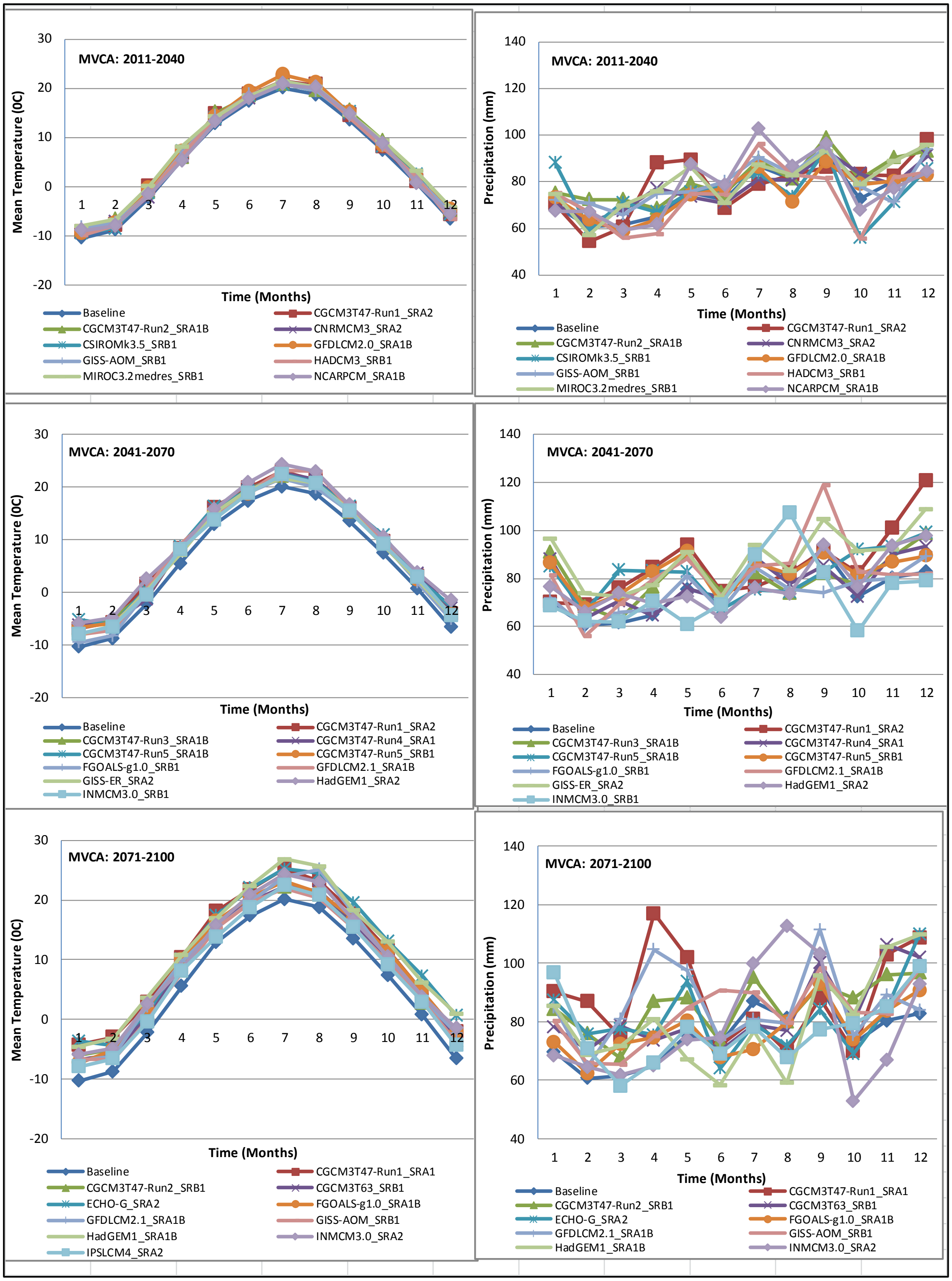

OTTAWA MACDONALD-CARTIER INT'L
Baseline: 1971-2000
Future: 2011-2040
CSIROMk3.0 (SRA1B)
MIROC3.2medres (SRB1)
CGCM3T47-Run1 (SRA1B)
GISS-AOM (SRA1B)
BCM2.0 (SRA2)
CGCM3T47-Run1 (SRA2)
ECHAM5OM (SRA2)
INMCM3.0 (SRA1B)
GFDLCM2.0 (SRA1B)
CGCM3T47-Run4 (SRA1B)
Change in Mean Annual Precipitation (%)
Change in Mean Annual Temperature (°C)


OTTAWA MACDONALD-CARTIER INT'L
Baseline: 1971-2000
Future: 2041-2070
GISS-ER (SRA2)
CGCM3T47-Run1 (SRA2)
GISS-EH (SRA1B)
GFDLCM2.1 (SRA1B)
NCARCCSM3 (SRB1)
ECHO-G (SRA2)
GFDLCM2.0 (SRA2)
FGOALS-g1.0 (SRB1)
IPSLCM4 (SRA2)
INMCM3.0 (SRB1)
Change in Mean Annual Precipitation (%)
Change in Mean Annual Temperature (°C)

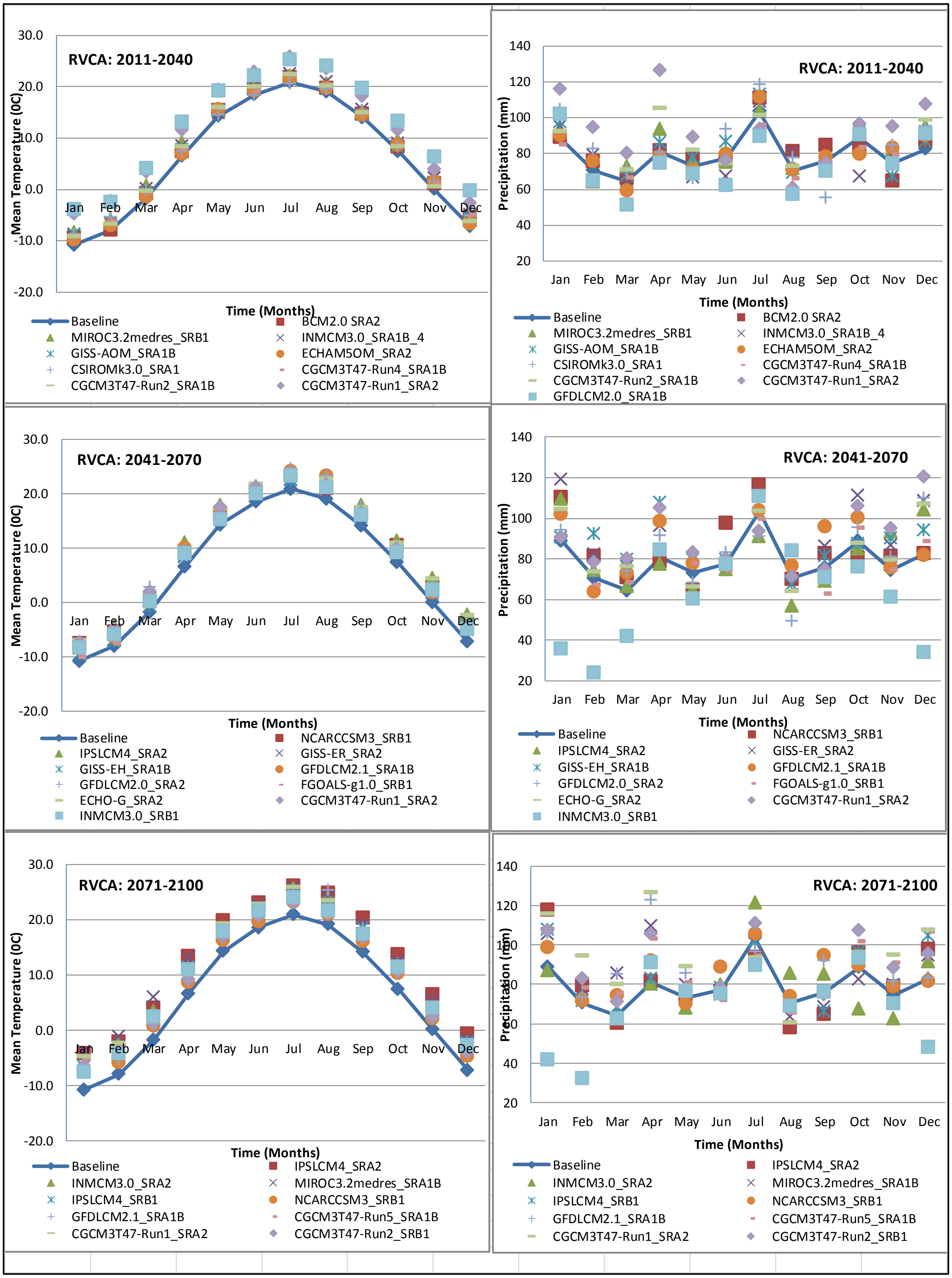

OTTAWA MACDONALD-CARTIER INT'L
Baseline: 1971-2000
Future: 2071-2100
Change in Mean Annual Precipitation (%)
Change in Mean Annual Temperature (°C)
CGCM3T47-Run1 (SRA2)
CGCM3T47-Run2 (SRB1)
GFDLCM2.1 (SRA1B)
CGCM3T47-Run5 (SRA1B)
NCARCCSM3 (SRB1)
IPSLCM4 (SRB1)
MIROC3.2medres (SRA1B)
INMCM3.0 (SRA2)
FGOALS-g1.0 (SRA1B)
IPSLCM4 (SRA2)

Appendix C *Monthly temperature and precipitation predictions for 2020s, 2050s, and 2080s*

Mississppi

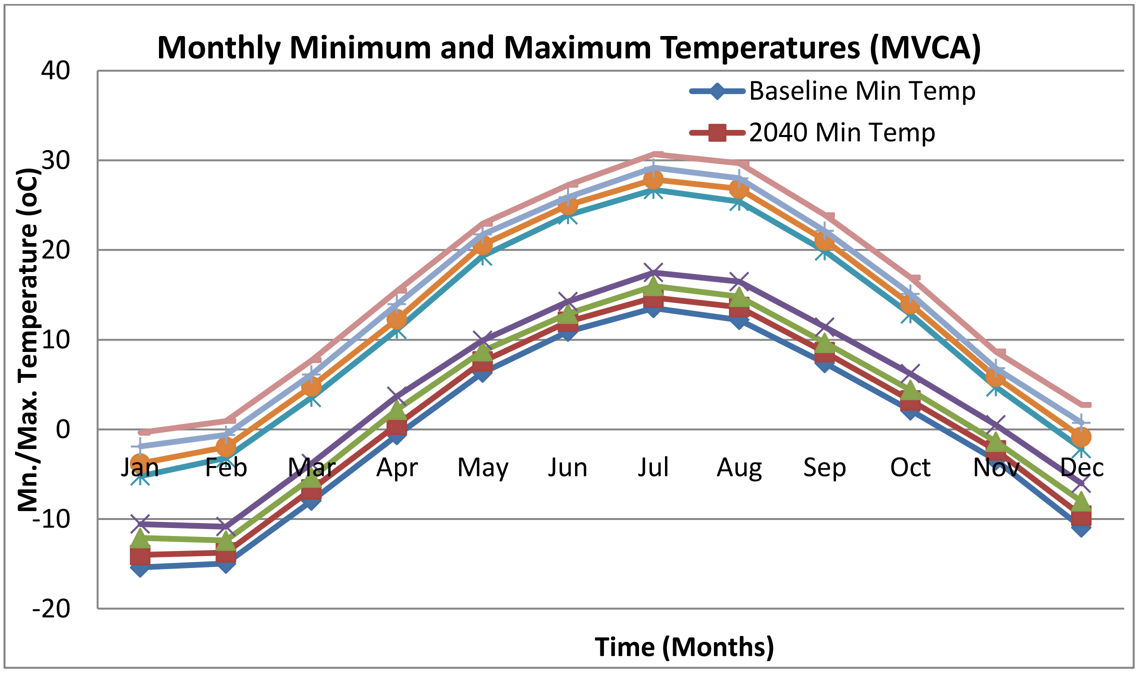


Rideau

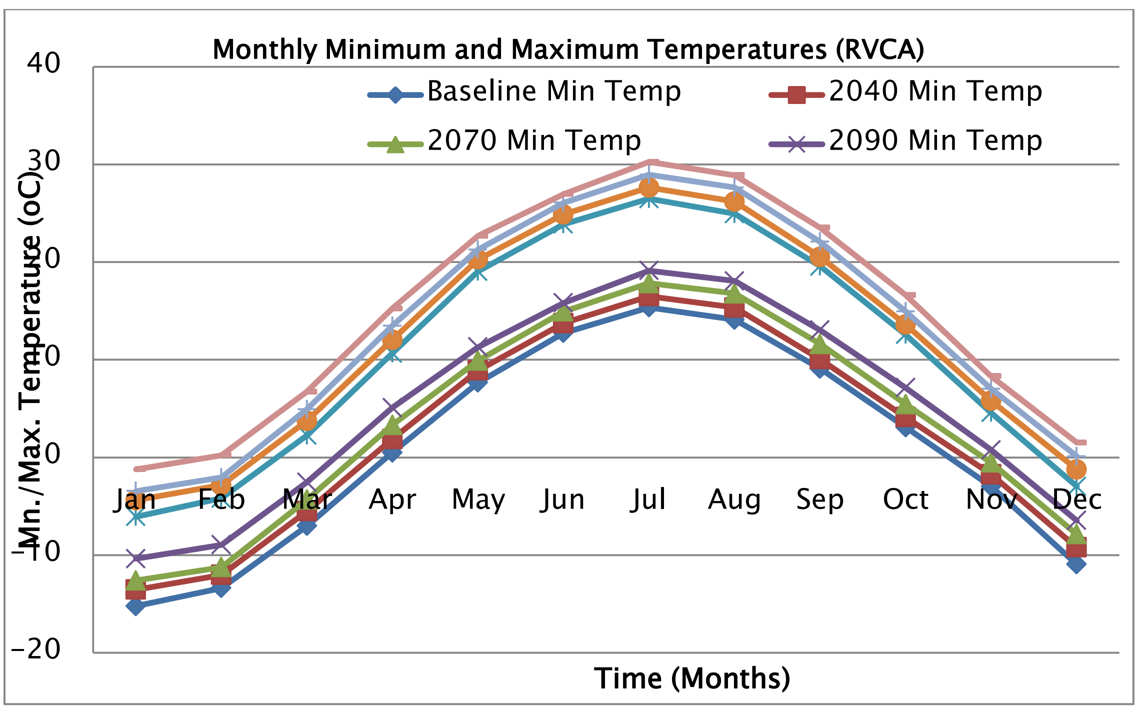

RVCA: 2011-2040
Mean Temperature (0C)
30.0
20.0
10.0
0.0
-10.0
-20.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Time (Months)
Baseline
MIROC3.2medres_SRB1
GISS-AOM_SRA1B
CSIROMk3.0_SRA1
CGCM3T47-Run2_SRA1B
BCM2.0 SRA2
INMCM3.0_SRA1B_4
ECHAM5OM_SRA2
CGCM3T47-Run4_SRA1B
CGCM3T47-Run1_SRA2
RVCA: 2011-2040
Precipitation (mm)
140
120
100
80
60
40
20
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Time (Months)
Baseline
MIROC3.2medres_SRB1
GISS-AOM_SRA1B
CSIROMk3.0_SRA1
CGCM3T47-Run2_SRA1B
GFDLCM2.0_SRA1B
BCM2.0 SRA2
INMCM3.0_SRA1B_4
ECHAM5OM_SRA2
CGCM3T47-Run4_SRA1B
CGCM3T47-Run1_SRA2
RVCA: 2041-2070
Mean Temperature (0C)
30.0
20.0
10.0
0.0
-10.0
-20.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Time (Months)
Baseline
IPSLCM4_SRA2
GISS-EH_SRA1B
GFDLCM2.0_SRA2
ECHO-G_SRA2
INMCM3.0_SRB1
NCARCCSM3_SRB1
GISS-ER_SRA2
GFDLCM2.1_SRA1B
FGOALS-g1.0_SRB1
CGCM3T47-Run1_SRA2
RVCA: 2041-2070
Precipitation (mm)
140
120
100
80
60
40
20
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Time (Months)
Baseline
IPSLCM4_SRA2
GISS-EH_SRA1B
GFDLCM2.0_SRA2
ECHO-G_SRA2
INMCM3.0_SRB1
NCARCCSM3_SRB1
GISS-ER_SRA2
GFDLCM2.1_SRA1B
FGOALS-g1.0_SRB1
CGCM3T47-Run1_SRA2
RVCA: 2071-2100
Mean Temperature (0C)
30.0
20.0
10.0
0.0
-10.0
-20.0
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Time (Months)
Baseline
INMCM3.0_SRA2
IPSLCM4_SRB1
GFDLCM2.1_SRA1B
CGCM3T47-Run1_SRA2
IPSLCM4_SRA2
MIROC3.2medres_SRA1B
NCARCCSM3_SRB1
CGCM3T47-Run5_SRA1B
CGCM3T47-Run2_SRB1
RVCA: 2071-2100
Precipitation (mm)
140
120
40
20
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec
Time (Months)
Baseline
INMCM3.0_SRA2
IPSLCM4_SRB1
GFDLCM2.1_SRA1B
CGCM3T47-Run1_SRA2
IPSLCM4_SRA2
MIROC3.2medres_SRA1B
NCARCCSM3_SRB1
CGCM3T47-Run5_SRA1B
CGCM3T47-Run2_SRB1

Appendix D *Monthly minimum and maximum temperature projections for 2020s, 2050s, and 2080s*

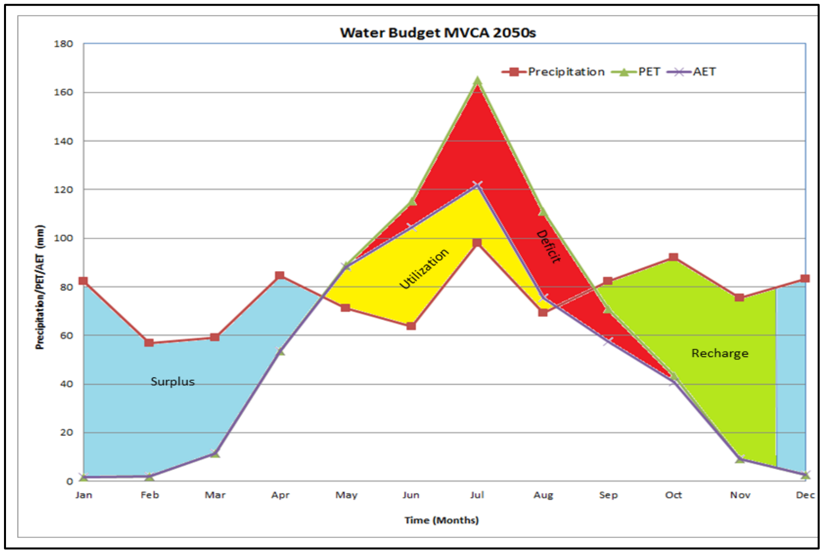
Mississippi

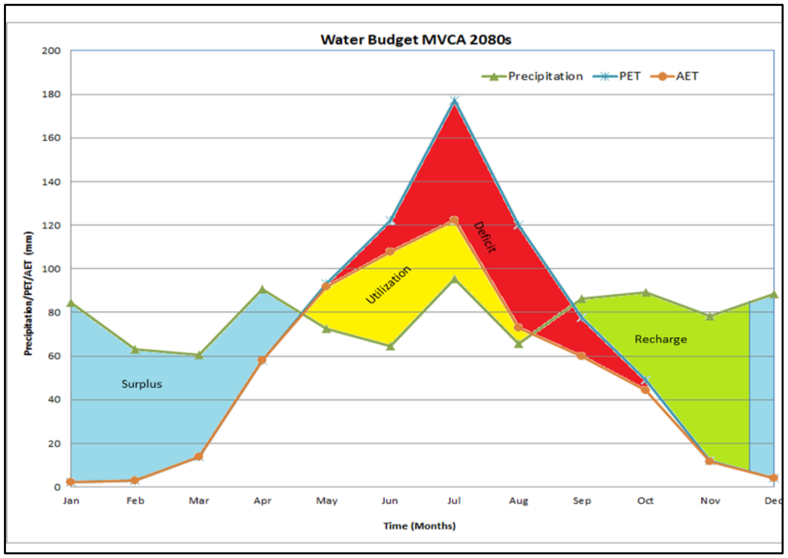


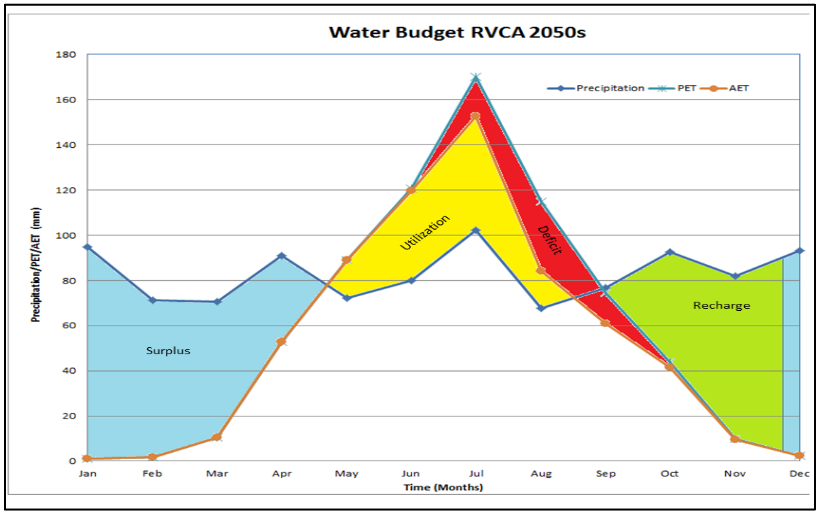
Rideau

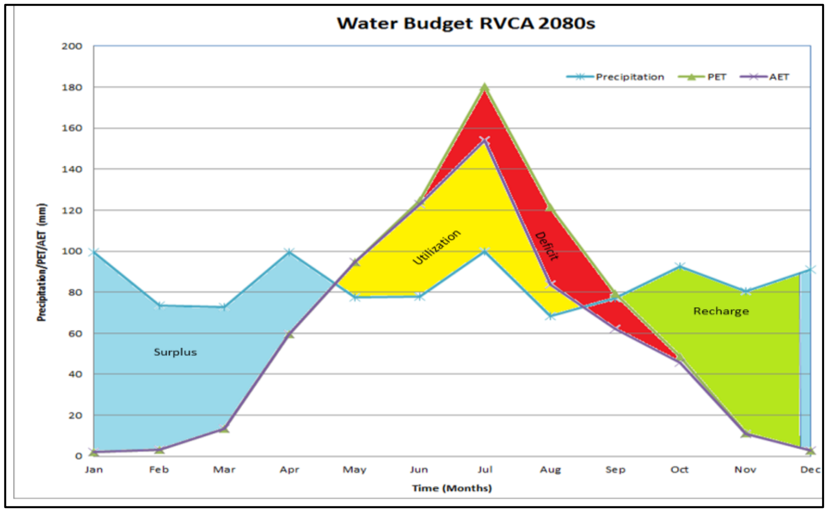


Appendix E *Water Budget in 2050s and 2080s in Mississippi and 2020s, 2050s, and 2080s in Rideau*



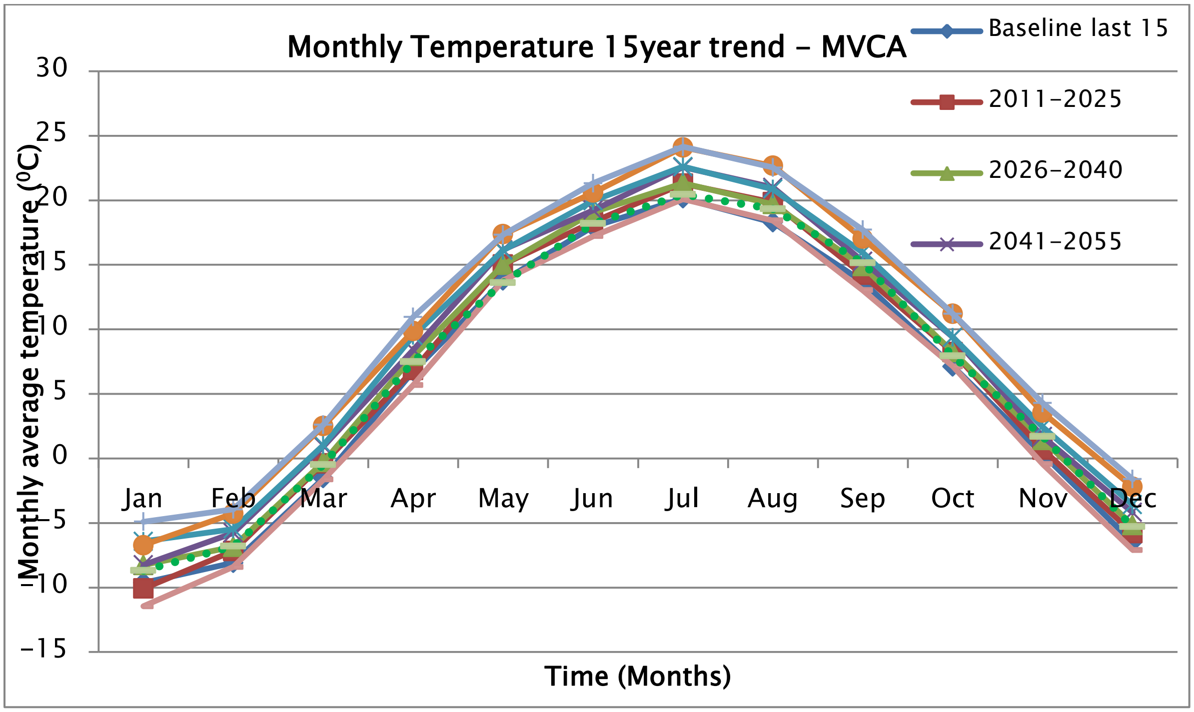




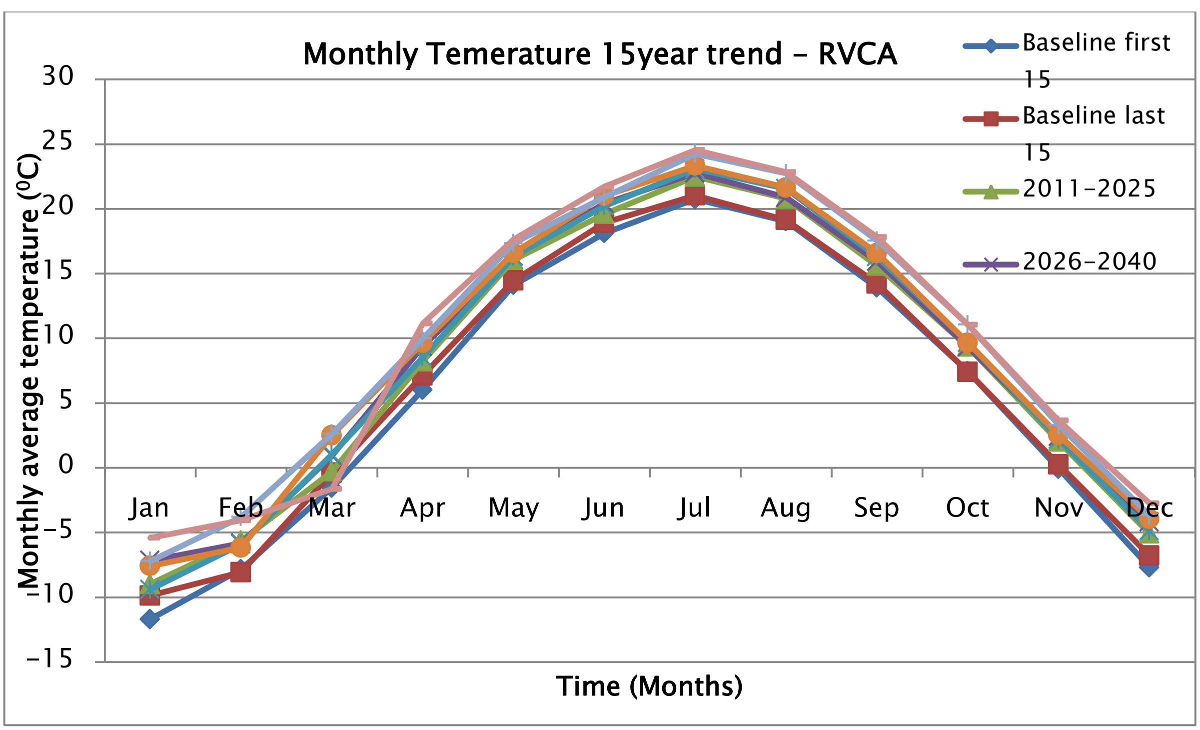


Appendix F *Monthly Average Temperature trend in 15-year period*

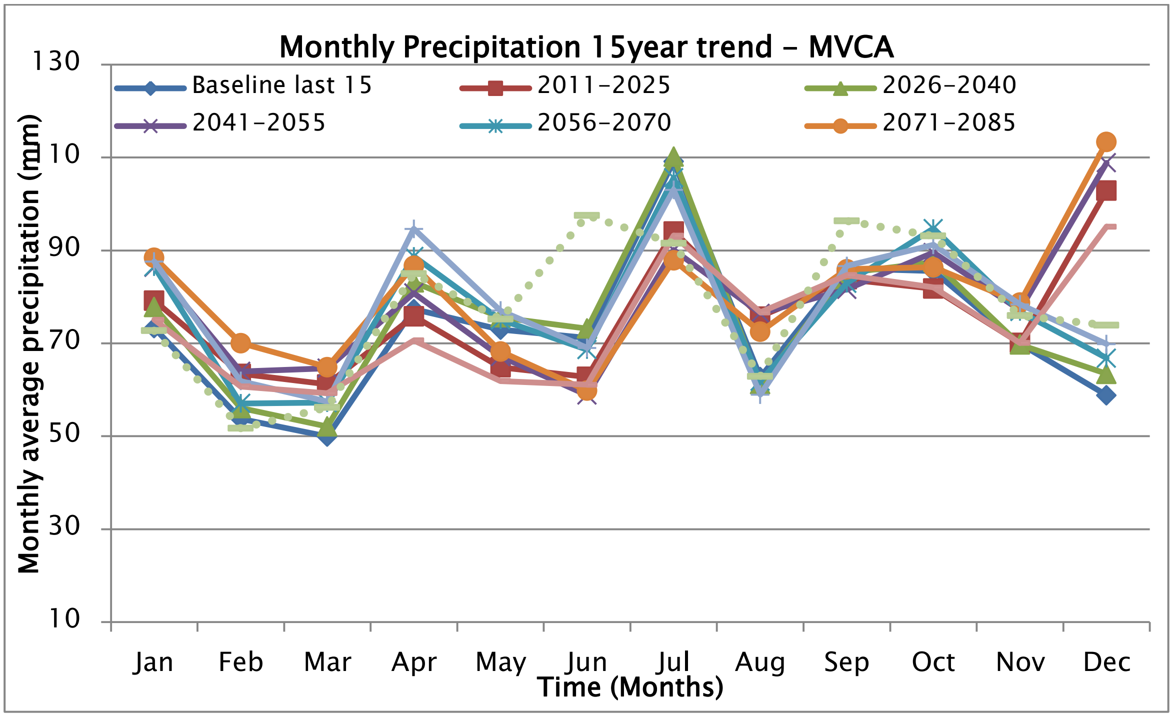
Mississippi



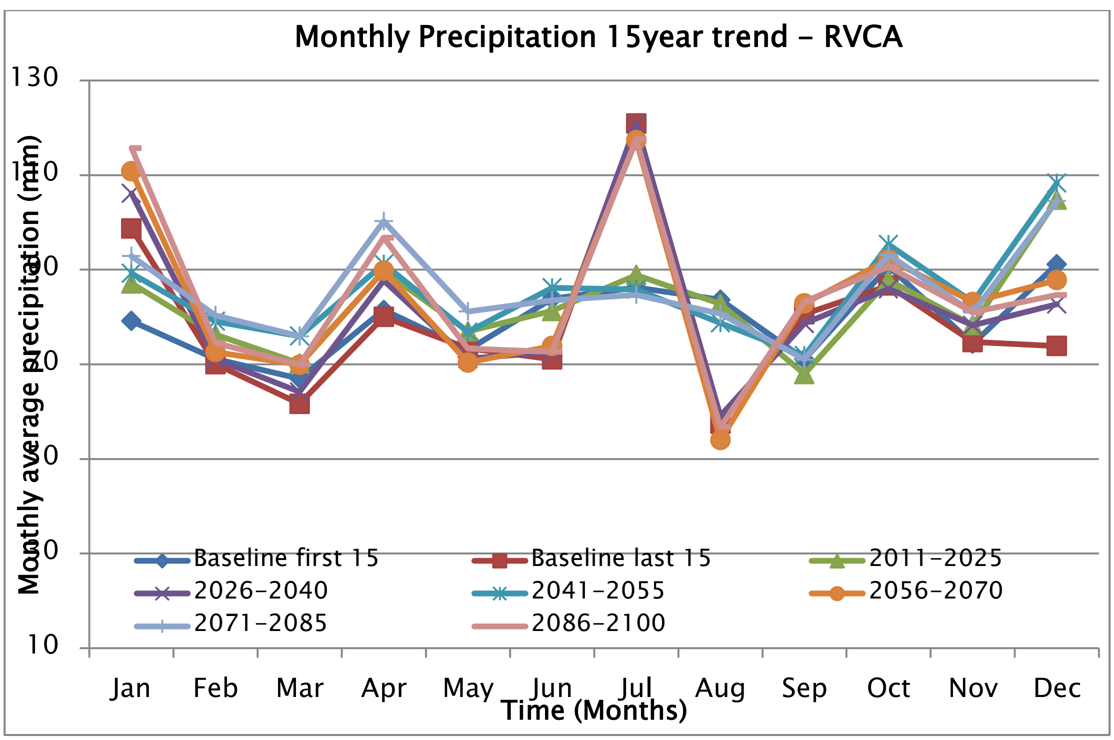
Rideau



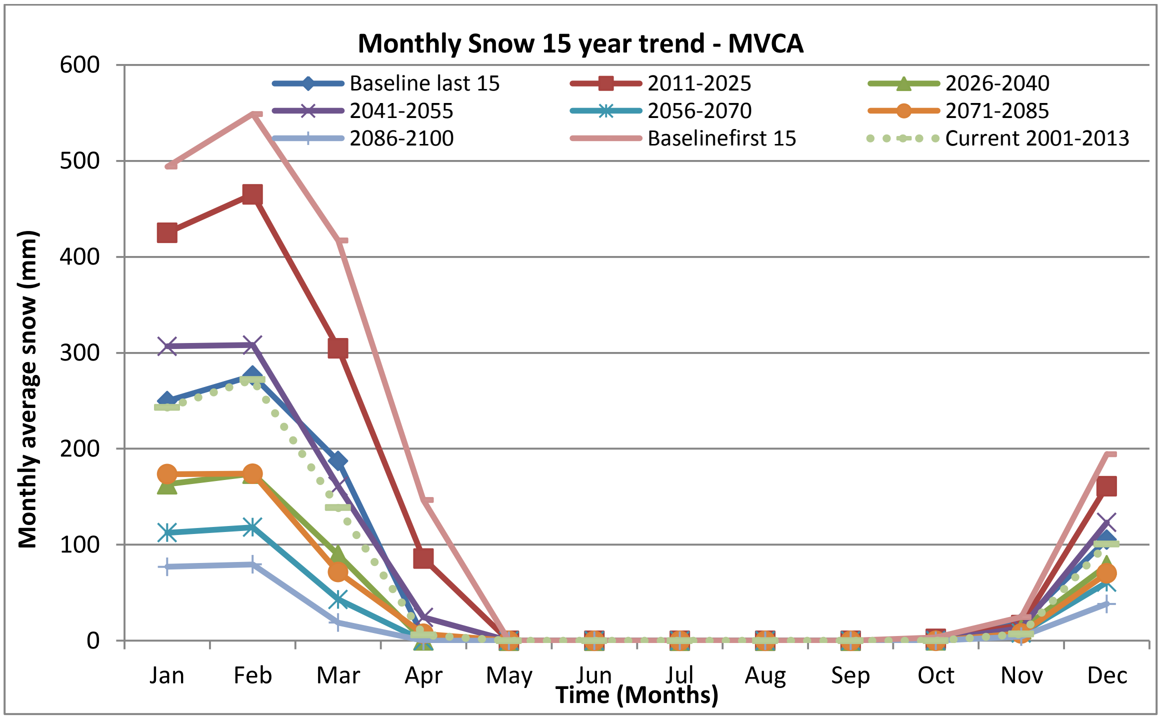
Mississippi



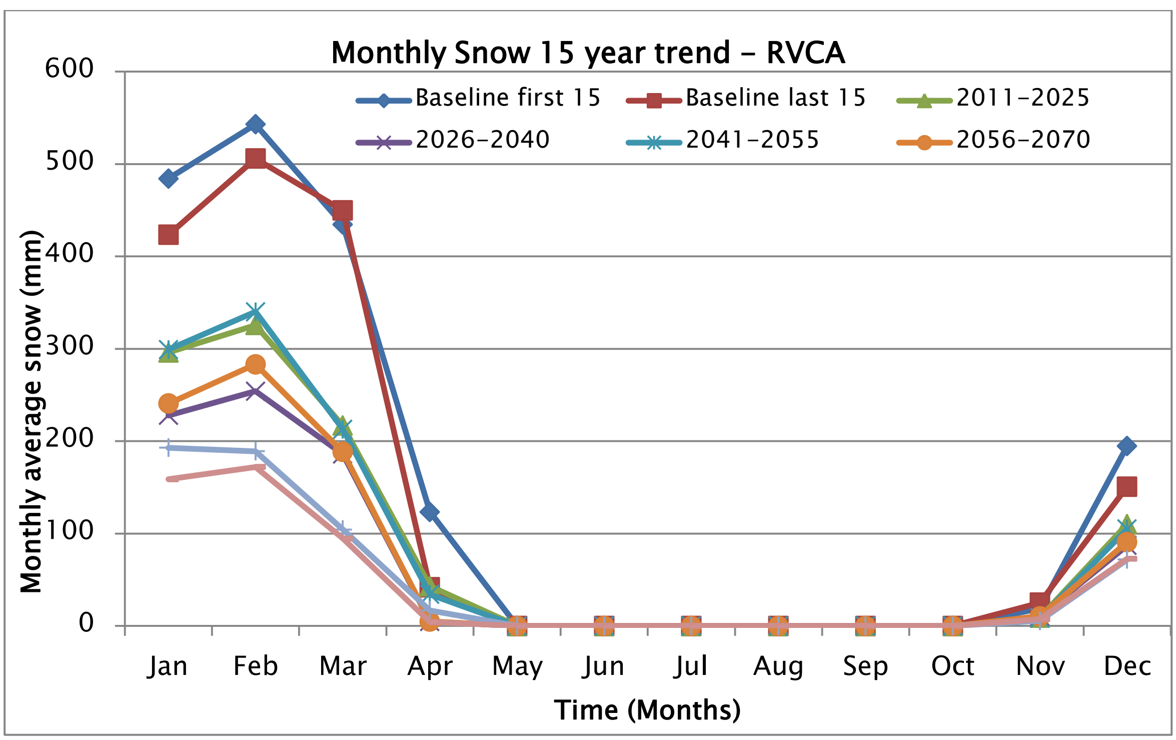
Rideau



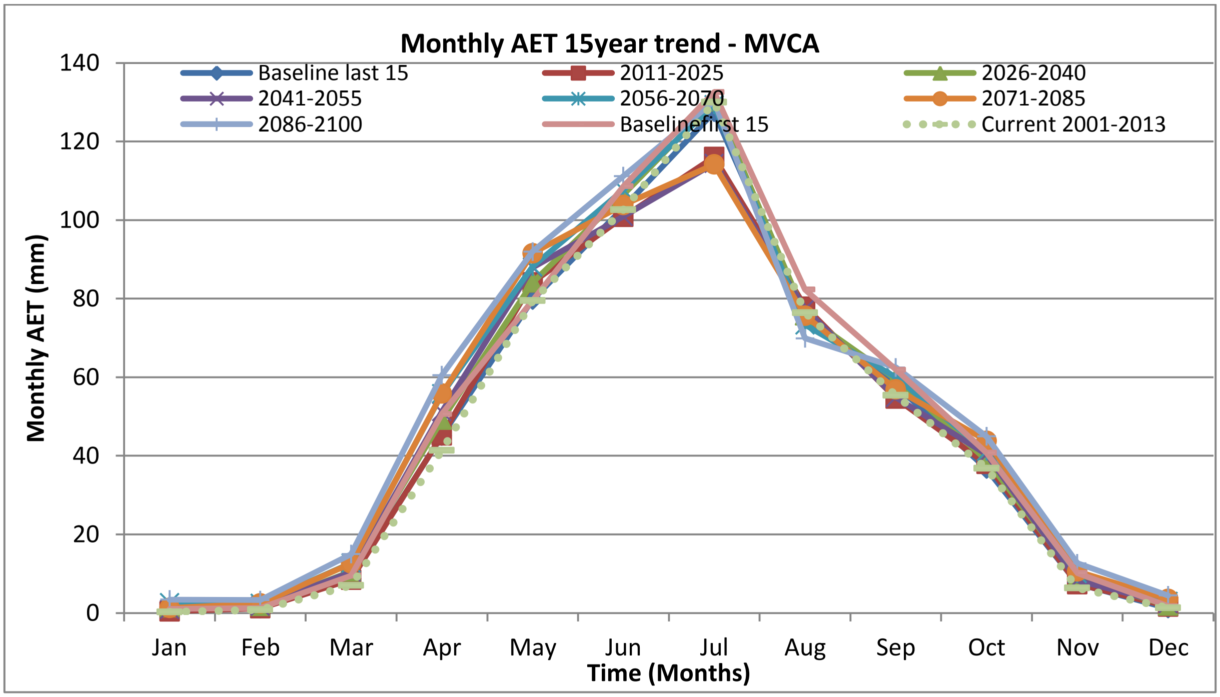
Mississippi



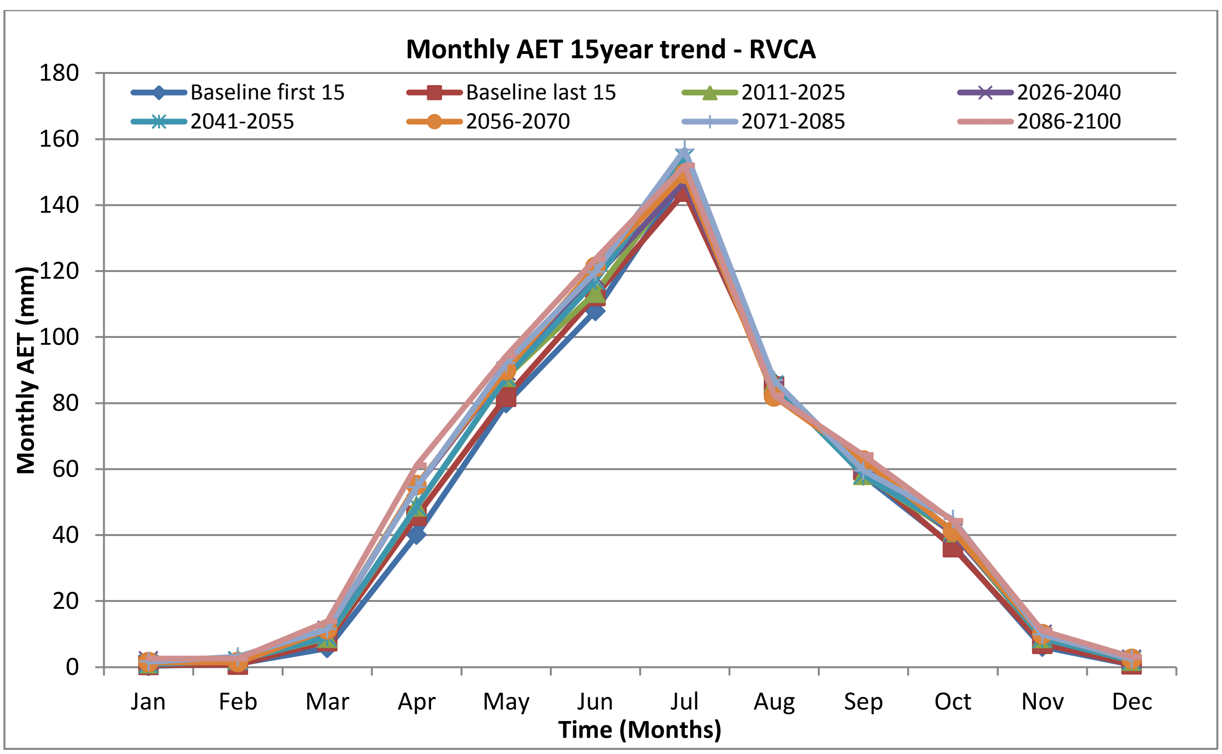
Rideau



Mississippi

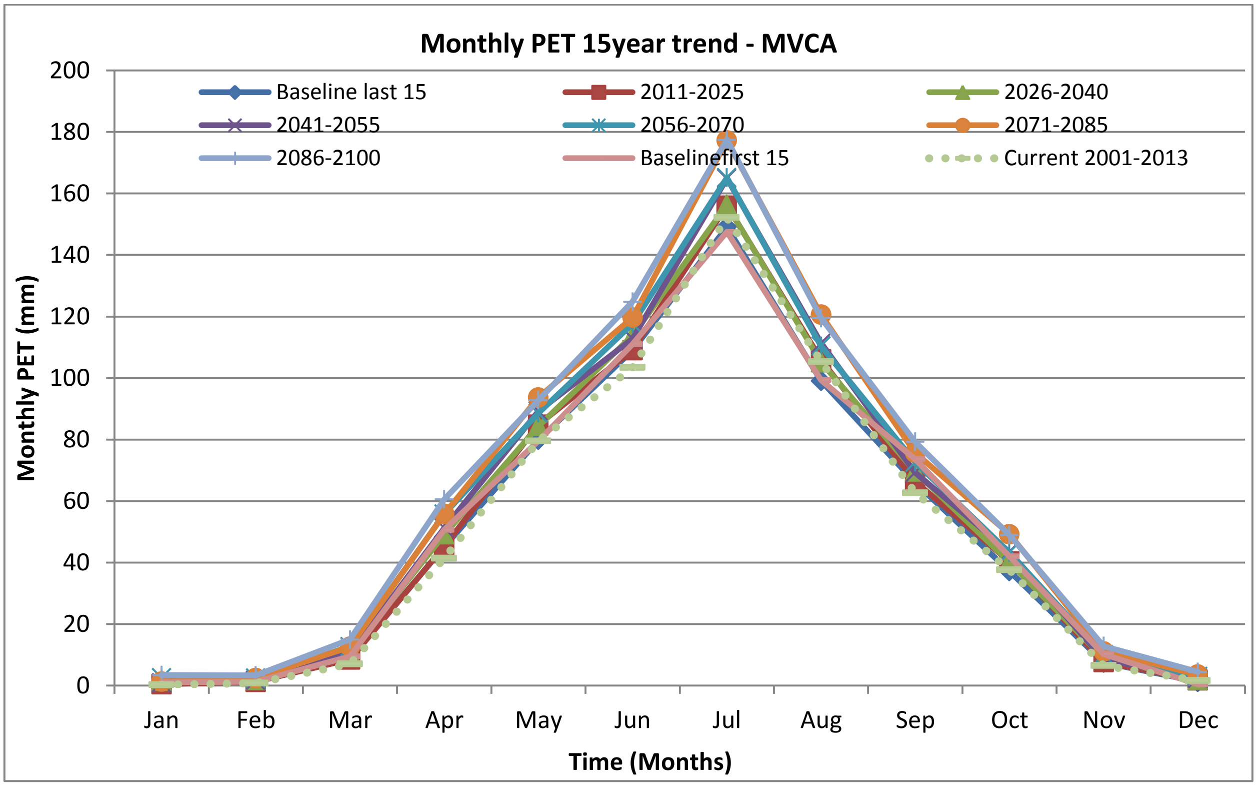


Rideau



Appendix J *Monthly Average PET trend in 15-year period*

Mississippi



Rideau