Fish, Fisheries, and Water Resources: Adapting to Ontario's Changing Climate

Subproject 4: Water Management Response to Climate Change

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7/14/2008

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4.1 INTRODUCTION

The Mississippi River watershed is located in eastern Ontario and is comprised of a complex network of rivers, streams and lakes. The Mississippi River has a drainage area of 3,750 km from its headwaters in Kilpecker Creek, in the Township of Addington Highlands, to its outlet at the Ottawa River in the City of Ottawa. The river is 212 km in length and drops 252 m towards the east to an elevation of 73 m at its confluence with the Ottawa River.

The Mississippi River watershed is divided into three sub-watersheds (Fig. 4.1): the western and central sub-watersheds lie on the Canadian Shield, and the eastern sub-watershed lies off the Shield to the west of the Ottawa River. The western sub-watershed is speckled with deep, glacial lakes, whereas the eastern sub-watershed is dominated by riverine systems, which is a reflection of its topography and surficial geology. The central sub-watershed is a combination of both the western and eastern sub-watersheds, and may be considered a transitional zone between ecological land types and communities.

The Mississippi River system contains both cold and warmwater fish species. Historically, lake trout lakes dominated the watershed, but now only a few lakes in the western sub-watershed continue to be managed as coldwater fisheries. The central and eastern sub-watershed lakes are managed as warm water, walleye and bass dominated fisheries. Water levels and flows along the main branch of the Mississippi River are regulated to support a variety of interests. The watershed has many natural heritage features including several locally and provincially significant wetlands, rare species and species at risk, other significant natural features such as wild rice, a migratory bird sanctuary and Areas of Scientific and Natural Interest (ANSIs), Provincial Parks, Conservation Reserves and Crown land.

Development of the Mississippi River began in the 1800's to transport large timbers from Mazinaw Lake downstream to sawmills along the river and in Quebec. A series of dams were built at strategic points along the river to store water and slides were built to carry logs past falls and rapids (Mississippi Valley Conservation Report, 1970). Other dams such as Mazinaw, Crotch, Big Gull and Kashwakamak Lake were originally built solely for timber transport.

The lower river system through towns such as Carleton Place, Almonte, Pakenham and Appleton thrived with textile and grist mills as the river provided a useful source of water power. In the early 1900's a group of business interests representing mill owners and the Ontario Hydro-electric Commission acquired and reconstructed six of the upstream water control structures to augment stream flows in the lower river system for water power. The management regime utilized the large storage capacity behind these dams to store excess runoff during the spring freshet, providing a source of water to augment stream flows during the dry summer months. By the mid-1900's, recreational and tourism development along the shores of these storage reservoirs resulted in pressure to stabilize water levels during the summer months, restricting their use for downstream water supply during this period.

The largest and most downstream reservoir located at Crotch Lake was not subjected to these water level restrictions and was subsequently utilized to provide low flow augmentation during the summer months and then used to store water in the fall when the upper reservoirs

Page left intentionally for Figure 1: Map of Mississippi Watershed could be drawn down. This water could then be used to augment stream flows over the winter period. All six storage reservoirs would therefore be at their lowest level prior to the next spring freshet providing a measure of flood protection to downstream communities as water was again stored in the reservoirs. This semi-annual management cycle of reservoir storage and release has been successfully implemented since that time.

Today, the six upstream storage reservoirs are managed by the Mississippi Valley Conservation Authority (MVC) and Ontario Power Generation in consultation with MVC. Including these six reservoir dams, and five hydro generation facilities, there are a total 23 dams and water control structures maintained within the Mississippi River watershed.

Water use within the watershed is not significant at present. There are four current water-taking permits issued for the Mississippi River with a total maximum allowed taking or extraction of approximately 14,000 cubic metres of water per day (m^3/d), which is equivalent to 0.16 cubic metres per second (cms). The most notable of these is for the municipal water supply at Carleton Place, which has a maximum taking of water at 12,000 cubic metres of water per day (m^3/d).

There are two municipal sewage treatment facilities, which discharge effluent to the Mississippi River; Mississippi Mills (Almonte), with a population of 4600; and Carleton Place, with a population of 9300.

The mean seven-day drought estimate, with a 20 year return period, at Appleton is approximately 4 cms. At present, there have been no reports of significant surface water shortages that have affected either municipal supply or effluent requirements although water quality monitoring along the lower reaches of the Mississippi River suggest that Total Phosphorous levels may begin to exceed provincial water quality objectives. Other water takings within the watershed are either from off-line surface or groundwater sources, which are not directly influenced by stream flow conditions in the Mississippi River (Renfrew County-Mississippi-Rideau Groundwater Study – 2003).

In 2006, the Mississippi River Water Management Plan (MRWMP) was finalized which confirmed the current management regime for the Mississippi River and established flow and water level objectives for the major water control structures along the river. In the course of completing the hydro-technical analyses for the MRWMP, MVC noted trends in the stream flow conditions which could present difficulties for water managers to satisfy the established MRWMP objectives, particularly related to fish and aquatic habitat, if these trends were to persist. Further investigation of these findings suggested that they were consistent with recent research on water resources impacts from climate change.

In the event that the apparent changes in stream flow are attributable to climate change, it will become important for water managers to understand the extent to which these changes may progress and to determine the capacity of the existing infrastructure to respond to these changes and manage the associated risks in an integrated manner.

4.1.1 Objectives

The specific objectives of this research study include:

- downscale future climate predictions (precipitation and temperature) of the Coupled Global Climate Model [CGCM2] to the Mississippi Valley watershed;
- generate future climatic data based on historic trends and CGCM2 projections;
- quantify the potential effect of climate change on the watershed water budget components;
- calibrate and validate a rainfall-runoff [RR] model for the Clyde River @ Gordon Rapids stream gauge (WSC 02KF013);
- simulate future runoff and stream flow for periods [2010-2099] with the validated RR model;
- conduct reservoir and hydraulic modeling to simulate stream flows and water levels at reservoir sites and the downstream gauge site on the Mississippi River @ Appleton (WSC 02KF006)

4.2 METHODOLOGY

4.2.1 Global Climate Change Models

General Circulation Models (GCMs), (sometimes referred to as Global Circulation Models) are physically-based, complex, three dimensional climate models that integrate as many factors as possible that could influence climate to simulate the global climate system. As GCMs are essentially the only viable tools for simulating regional patterns of climate change, their outputs have been widely used to assess climate change impacts. Several GCM's have been recognized for their ability to represent, reasonably well, the main features of the global distribution of basic climate parameters (Lambert and Boer, 2001) including, CGCM2 (The Second Generation Coupled Global Climate Model Developed by the Canadian Centre for Climate Modelling and Analysis), The Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia's national science agency, The US National Oceanic and Atmospheric Administration (NOAA) Geophysical Fluid Dynamics Laboratory (GFDL), and Met Office, Hadley Centre for Climate Change, United Kingdom (Hadley).

In 1996, the Intergovernmental Panel on Climate Change (IPCC) distributed a set of greenhouse gas emission scenarios called the Special Report on Emissions Scenarios (SRES), based on developments in different social, economic, technological, environmental and policy dimensions, and named A1, A2, B1 and B2 scenarios. The A1 scenario describes a future world of very rapid economic growth, low population growth, and the rapid introduction of new and more efficient technologies. The A2 scenario describes a very heterogeneous world with themes of self-reliance and preservation of local identities. The B1 scenario describes a convergent world with the same low population growth as in the A1 storyline, but with rapid changes in economic structures toward a service and information economy, with reductions in material intensity, and the introduction of clean and resource-efficient technologies. The B2 scenario describes a world in which the emphasis is on local solutions to economic, social, and environmental sustainability.

Prior to this study, four different GCM models (namely: CGCM2, CSIRO, GFDL, and Hadley) were tested with Mississippi River watershed data using these four scenarios (A1, A2, B1, and B2). For this study, the Second Generation Coupled Global Climate Model CGCM2 model of the Canadian Centre for Climate Modeling and Analysis (CCCma) and the A2 scenario where self-reliance and preservation of local identities are of more importance is being used. The daily climate data is downloaded from the Environment Canada website http://www.cccma.bc.ec.gc.ca/data/cgcm2/cgcm2_a2.shtml for the Mississippi River watershed grid (Lat. 46.36˚ N, Long. 75.00˚W). Each grid is about 300 km x 300 km. The increase in mean monthly precipitation and air temperature obtained using CGCM2 for the Mississippi River watershed were similar to the results obtained by Booty et al. (2005) for the Duffins Creek watershed near Toronto using the same model.

4.2.2 Downscaling CGCM2 Data to Mississippi River Watershed

The main advantage of using a GCM is that it is the only tool that estimates changes in climate due to increased greenhouse gases for a large number of climate variables in a physically consistent manner. However, GCM simulations of current regional climate can often be inaccurate and the output from GCMs is usually produced at a coarse temporal and spatial resolution; therefore a downscaling technique is needed to calibrate and refine the resolution of the GCM model data required for impact studies (Xu, 1999; Prudhomme et al., 2002). Also downscaling is necessary to link GCM predictions to actual measured data at climate stations. Downscaling can be dynamic or statistical. Dynamic downscaling is a computer inten3ive task, while statistical downscaling is based on relationships among regional and local scale variables. There are three categories of statistical downscaling methods; estimating relationships using parametric, nonparametric, linear and nonlinear methods, using weather generators, and weather typing by linking GCM, regional outputs and local variables. Weather generators are numerical algorithms able to generate weather data with given statistical characteristics. Weather generator parameters of the local climate station for the future periods are updated with a relative change function between the GCM base and future grid data.

In order to assess climate change impacts regionally, daily time series of historic data for the Mississippi River watershed was statistically analyzed. To produce future climate change scenarios, a set of baseline climatology and GCM patterns are used. To conform with the World Meteorological Organization (WMO) standard values are derived from a 30-year period of record.

Climate data for the base period [1970-2000] and future period [2010-2099] were downloaded from the Environment Canada website for the grid which includes the Mississippi River watershed area and processed with the ClimGen model to create a climate parameter file (.LOC) for each period. The future period [2010-2099] is split into three 30 year windows, denoted as I for 2010-2039, II for 2040-2069, and III for 2070-2099, respectively. The relative change in climate parameters between the baseline period and future periods (I, II and III) from the grid data is subsequently applied to the Mississippi River watershed baseline period to obtain the future periods (I, II, and III) climate parameters. Observed data from the Drummond Centre Climate station, located in the watershed, is processed with the ClimGen model to create a local climate parameter file. The relative change in climate parameters derived from the grid data were applied to the local climate parameter file to create local climate parameter files for the future periods. These updated parameter files are then processed with the ClimGen to generate future climate data for the I, II and III periods. The statistical summary [mean and standard deviation] of the generated climate data was also calculated using the ClimGen software (http://www.bsyse.wsu.edu/climgen/).

4.2.2.1.1 ClimGen Model

A weather generator is a computer algorithm that uses an existing meteorological record to produce a long series of synthetic daily weather data. The statistical properties of the generated data are expected to be similar to those of the actual data for a specified station. ClimGen (Stöckle et al., 1999) was selected for this study from numerous weather generators developed since 1984. Castellvi et al. (2002), Stöckle et al. (2004), and McKague et al. (2006) have shown that ClimGen has produced promising results regarding the generation of weather data for various climatic data. In most cases, an excellent agreement between actual and generated weather data was found.

ClimGen provides utilities for computing all required generation parameters and statistical summaries from existing daily weather records. ClimGen generates precipitation, daily maximum and minimum temperature, solar radiation, air humidity, and wind speed. The program requires the input of a daily series of these variables to calculate parameters used in the generation process. Because all generation parameters are calculated for each site of interest, ClimGen can be applied to any world location with enough information to parameterize.

The weather data generated by ClimGen is stored in a universal environment database (UED) format. All the parameters are stored in a location file with an extension of LOC. Stored in this location file are the parameters used for weather data ge.eration, such as the monthly mean maximum and minimum temperature and their standard deviation; monthly mean solar radiation and its standard deviation; monthly mean precipitation, the monthly fraction of wet days, the mean and deviation of solar radiation, maximum temperature, and minimum temperature for wet days and dry days; the values of A, B matrix; as well as the values of alpha and beta for precipitation and wind speed generation. The GCM patterns are then used in this LOC file to downscale the global climate change scenario to the local spatial resolution, with projected time series from the baseline to the future based on the Intergovernmental Panel on Climate Change emissions scenarios.

Water Budget Model

The Modified Thornthwaite Water Budget Model from Environment Canada was used to estimate the water budget components. The model was run with the actual climate data from the Drummond Centre climate station to verify the program; and then subsequently ran with the future climate data to estimate future water budget components.

4.2.3 Rainfall-Runoff Model

MIKE 11, a Danish Hydrologic Institute software for river and channel modeling has different modules including hydrodynamic, rainfall-runoff, sediment transport, advection-dispersion, ECOLab, flood forecast, data assimilation, etc. Rainfall and runoff are often key issues when modeling river systems. The Rainfall-Runoff (RR) module can either be applied independently or used to represent one or more contributing catchments that generate lateral inflows to the hydrodynamic module for river routing. This module contains a number of different approaches to estimate catchment runoff, such as:

1. NAM: A lumped, conceptual rainfall-runoff model simulating overland flow, interflow and baseflow as a function of the water storage in each of four mutually interrelated storages representing the storage capacity of the catchment. The NAM method can take man-made interventions in the hydrological cycle such as irrigation and groundwater pumping into account.

2. UHM: The UHM module simulates the runoff from single storm events based on the unit hydrograph technique. This method is useful in areas where no stream flow records are available or where the unit hydrograph technique is well-proven.

3. SMAP: A monthly soil moisture accounting model is particularly useful when only monthly input data are available.

4. URBAN: Run-off methods specifically tailored to urban environments.

5. FEH: Catchment runoff estimation based on the UK Flood Estimation Handbook developed by CEH, Wallingford.

6. DRiFt: Semi-distributed rainfall-runoff - geomorphological approach.

Among these, NAM, a more suitable approach to the Mississippi River watershed was selected for this study. The NAM model is a well-proven engineering tool that has been applied to a number of catchments around the world, representing many different hydrological regimes and climate conditions (MIKE11 Reference Manual, 2004). NAM is the abbreviation of the Danish “Nedbør-Afstrømmings-Model” meaning precipitation-runoff model, which was developed by the Department of Water Resources at the Technical University of Denmark (Nelsen and Hansen, 1973). The NAM hydrological model simulates the rainfall-runoff processes occurring at the catchment scale. The NAM model has different applications such as general hydrologic analysis, flood forecasting, extension of streamflow records, and prediction of low flows. In this study, NAM was applied to general hydrologic analysis to estimate runoff distribution in the catchment area. The NAM model represents various components of the rainfall-runoff process by continuously accounting for the water content in four different, mutually interrelated storages that represent different physical elements of the catchment, including snow storage, surface storage, lower or root zone storage, and groundwater storage. Based on the meteorological data input, NAM produces catchment runoff as well as other information, such as the temporal variation of the evapotranspiration, soil moisture content, 'roundwater recharge, and groundwater levels. The generated runoff is conceptually split into overland flow, interflow, and baseflow components.

4.2.4.1 Rainfall-Runoff [NAM] Model Set Up

The NAM model was set-up for the Clyde River @ Gordon Rapids catchment area. The Gordon Rapids discharge data is not affected by upstream controls and was therefore chosen for this study. The NAM model for rainfall-runoff estimation requires model parameters, initial conditions, meteorological data (rainfall and potential evapotranspiration), and temperature for snow modeling as input files. Snow accumulation and melt are important hydrological processes in river basins where the snow pack acts as storage in which precipitation is retained during the cold season and subsequently released as melt water during the warmer periods of the year.

Daily precipitation data is sufficient in many cases, though rapidly responding catchments require precipitation data at a finer resolution to accurately represent peak flows. The NAM model will interpolate the precipitation data for the simulation time step. The precipitation data is treated as an accumulated total, and so the precipitation at any particular time is the precipitation accumulated since the previous time step. Temperature data is required as ~~the~~ snow accumulation and melt are included in the simulation. During the snow season, the time increments in the temperature data reflect the length of time step in the simulation. The temperature data at a given time represents the average temperature since the previously entered data. Daily precipitation and temperature data from the Drummond Centre climate station in the Mississippi River watershed area were used as input to the model.

Monthly potential evapotranspiration values are sufficient when daily time steps are used. The potential evapotranspiration data estimated by the Modified Thornthwaite Water Budget Model was used as an input to the NAM model. Similar to the precipitation data, the potential evaporation data was also treated as accumulated totals, and so the potential evapotranspiration at any particular time is the potential evapotranspiration since the previously entered data.

Observed discharge data at the catchment outlet is required to compare the simulated runoff for model calibration and validation. The observed discharge at Gordon Rapids at Clyde River (WSC 02KF012) was used as input to the model. Similar to the temperature data, the discharge at a given time represents the average discharge since the previously entered data. The major surface and root zone parameters to the NAM model are maximum water content in surface storage (U_{max}), maximum water content in root zone storage (L_{max}), overland flow runoff coefficient (CQOF), time constant for interflow (CKIF), time constant for routing interflow and overland flow (CK_{12}), root zone threshold value for overland flow (TOF), and root zone threshold value for interflow (TIF). Groundwater model parameters are baseflow time constant

(CK_{BF}), root zone threshold value for groundwater recharge (TG), recharge to lower groundwater storage (CQ_{LOW}), time constant to routing lower baseflow (CK_{low}), ratio of groundwater catchment to topographical catchment area (C_{area}), maximum groundwater depth causing baseflow (GWL_{BF0}), specific yield (S_y), and groundwater depth for unit flux (GWL_{FL1}). The snow module model parameters are degree-day coefficient, base temperature, radiation coefficient, and rainfall degree-day coefficient. Initial water content in the surface and root zone storages and initial values for overland flow, interflow, and baseflow are required by the NAM model as initial conditions. Values of the model parameters and initial conditions will be described in the model calibration section.

4.2.4.2 Calibration, Validation, and Simulation of NAM Model

The main objectives of the model calibration process are to obtain;

i. good agreement between the average simulated and observed runoff;

ii. good overall a'reement of the shape of the hydrograph;

iii. good agreement of the peak flows with respect to timing, rate, and volume;

iv. good agreement for low flows.

Compromises exist between these objectives, and so the parameter values that provide a very good simulation of peak flow might result in poor low flow simulations, and vice versa. Although equal importance was given initially to all four objectives, higher priority was given to low flow simulation at a finer level of calibration. Both graphical and numerical performance measures were applied to the calibration process. The graphical evaluation includes comparison of observed and simulated hydrographs, and comparison of observed and simulated accumulated runoff. The numerical evaluations include the overall water balance error (difference between the average simulated and observed runoff), and a measure of the overall shape of the hydrograph based on the coefficient of determination. The goodness-of-fit of the calibrated model are affected by errors in meteorological input data, recorded observations, errors and simplification inherent in the model structure, and due to the use of non-optimal parameter values. Only the last error can be minimized in the calibration process.

There are both automatic and manual calibration options available. The auto-calibration tool in the NAM model can be used to speed up the calibration of the model. Based on up to four objectives (water balance, overall hydrograph shape, peak flows and low flows), the auto-calibration tool will find the best fit between simulated and observed hydrographs. A global optimization routine called the Shuffled Complex Evolution (SCE) algorithm takes care of the actual parameter optimization. It will optimize nine different model parameters including maximum water content in surface storage (U_{max}), maximum water content in root zone storage (L_{max}), overland flow runoff coefficient (CQOF), time constant for interflow (CKIF), time constant for routing interflow and overland flow (CK_{12}), root zone t(reshold value for overland flow (TOF), root zone threshold value for interflow (TIF), baseflow time constant (CK_{BF}), and root zone threshold value for groundwater recharge (TG). Manual calibration can also be applied to the above nine different parameters within the permissible minimum and maximum values [Table 4.1]. The stopping criterion for the model optimization is the maximum number of evaluations that depend on the number of parameters and model complexity. The maximum number of evaluations in the range of 1000-2000 normally ensures an efficient calibration, and 2000 were taken for this study.

The model was initially run with auto-calibration; and finer level calibration was done with an objective to match low flows. After the auto-calibration, the model was manually calibrated first to adjust overall water balance in the system. The total evapotranspiration over the period is then compared to the difference in accumulated precipitation and runoff. The peak runoff events are caused by large quantities of overland flow, and can be adjusted by changing the CQOF, where the shape of the peak depends on CK_{12}. The amount of baseflow is affected by overland flow or interflow. A decrease in the overland flows or interflows results in higher base flows, and vice versa. The shape of the baseflow recession is a function of the baseflow time constant (CK_{BF}); if the baseflow recession changes to a slower recession after a certain time, a lower groundwater reservoir should be added, including calibration of CQ_{low} and CK_{low}. As the objective of the finer level manual calibration was an overall water balance and baseflow match, the above mentioned parameters were adjusted by trial-and-error until satisfactory results were obtained.

Table 4.1: NAM Model - Auto or Manual Calibration Model Parameter Ranges

Parameter	**Unit**	**Range**	**Parameter**	**Unit**	**Range**
U_{max}	Mm	5 - 35	TOF	-	0 – 0.9
L_{max}	Mm	50 – 400	TIF	-	0 – 0.9
CQOF	-	0	TG	-	0 – 0.9
CKIF	Hours	200 - 2000	CK_{BF}	hours	500 - 5000
CK_{12}	Hours	3 – 72			

The NAM m/del was calibrated with observed runoff at the Clyde River @ Gordon Rapids stream gauge (WSC 02KF013) for 21 years from January 1, 1973 to December 31, 1993 period. The parameters for the well calibrated model are given in table 4.2. The satisfactory calibrated NAM model was validated with 10 years of data [1994-2003 periods] by keeping the same calibration parameters in the model. The well calibrated and validated NAM model was then used to simulate runoff for future periods from 2010-2099. Generated future climate data along with potential evapotranspiration was used as input files to simulate the future runoff data for the Clyde River @ Gordon Rapids sub-watershed area.

Table 4.2: NAM Model - Calibration and Initial Conditions Parameters

Parameter	**Value**	**Parameter**	**Value**	**Parameter**	**Value**	**Parameter**	**Value**
Surface-Rootzone		Groundwater		Snow Melt		Initial Conditions	
U_{max}	19.8	CK_{BF}	1605	C_{snow}	2	U/U_{max}	0
L_{max}	298	C_{area}	1	T_0	0	L/L_{max}	0
CQOF	0.513	S_y	0.1			QOF	0

CKIF	751.8	GWL_{BF0}	10	QIF	0
CK_{12}	47.7	GWL_{BF1}	0	BF	0.5
TOF	0.874	CQ_{low}	0		
TIF	0.874	CK_{low}	10000		
TG	0.58				

4.2.5 Transposing and Validation of Reservoir Inflows

Daily water level and water control structure operation records are available for each reservoir site since 1993, providing estimates of reservoir inflow, outflow and change in reservoir storage. Due to errors associated with estimating reservoir inflow based on water level records which are typically recorded to an accuracy of +/- 1.0 cm, calibration of the NAM model for each reservoir site was not considered feasible for the present study.

Estimating reservoir inflows on the basis of transposed streamflow records from an adjacent, hydrologically similar basin is recognized as a useful approach where stream flow records are not available. MVC has transposed streamflow records from the Clyde River @ Gordons Rapids stream gauge (WSC 02KF013) as an estimate of reservoir inflow, based on relative drainage area, for the subject reservoir sites in previous studies and has found 4hese to provide a reasonable estimate.

The resulting stream flow projections were subsequently transposed to the local drainage basin for each reservoir and intermediate sub-watershed along the Mississippi River to the Mississippi River @ Appleton stream gauge site [subwatershed details are given in Table 4.3 and Fig. 4.1]. Reservoir simulation was conducted with the Mississippi River Watershed Model (MRWM) which is an in-house reservoir operation model developed by MVC. This model was used to route reservoir inflow hydrographs through each reservoir using the storage-indication method, based on calibrated structure rating curves and reservoir stage-storage relationships. The model allows the user to adjust dam settings at each time step of the simulation. The resulting discharge hydrograph is subsequently routed to the next downstream reservoir using the Muskingum Method and then added to local basin inflows. The Muskingum routing parameters were calibrated through trial and error based on historical water level and available stream flow records [Table 4.4]. This process was continued through the river system, incorporating each storage reservoir and intermediate sub-watershed inflow to simulate the stream flow at the Appleton stream flow gauge (Mississippi River @ Appleton – WSC 02KF006)

Table 4.3: Mississippi River Sub-watershed Delineation

ID	Sub-watershed/Reservoir	Drainage Area (km^2)
SB1	Shabomeka Lake Reservoir	40.32
SB2	Mazinaw Lake Reservoir	298.60
SB3	Kashwakamak Lake Reservoir	42.60
SB4	Buckshot Creek	172.70
SB5	Mississagagon Lake Reservoir	22.00
SB6	Big Gull Lake Reservoir	141.40
SB7	Crotch Lake Reservoir	298.10
SB8	High Falls G.S	202.67

SB9	Dalhousie Lake	78.86
SB10	Clyde River @ Gordons Rapids	287.80
SB11	Clyde River @ Lanark	326.20
SB12	Fall River	427.30
SB13	Mississippi River @ Ferguson Falls	215.90
SB14	Mississippi Lake	209.40
SB15	Mississippi River @ Appleton	63.10

Table 4.4: Muskingum Routing Parameters

Routing Reach	**K**	**X**
SemiCircle Creek	6	0.2
Marble Lake	15	0.2
Farm Lake	42	0.2
Swamp Creek	9	0.2
Ardoch	42	0.2
Gull Creek	9	0.2
Snow Road	18	0.2
High Falls	6	0.2
Sheridans Rapids	17	0.2
Clyde	12	0.2
Ferguson Falls	12	0.2
Mississippi Lake	12	0.1
Appleton	6	0.2

4.3 RESULTS AND DISCUSSION

4.3.1 Present Climate at Mississippi Watershed

Generally the climate of eastern Ontario can be described as humid continental (MNR, 2005). The Great Lakes exert the major influence on the climate in the Great Lakes St. Lawrence region, promoting cold winters and warm summers due to humidity changes. Precipitation in the region is caused also by cold polar air from the north and warm moist air from the United States.

Annual precipitation for the region ranges from 840 to 1000 mm. According to another study by MNR, the mean annual precipitation in the region ranges from 800 mm to 1000 mm (MNR, 2005). The minimum, maximum, and mean temperatures in the region are in the ranges of -1.5 to -2^{0}C, 9.5 to 12^{0}C, and 4 to 7^{0}C, respectively (Dan McKenney et. al, 2002).

An inventory of all climate stations in the region found four active stations in the Mississippi Valley. In addition to these stations, there are eight rain gauge stations operated by Mississippi valley conservation authority All the active stations have rainfall, snowfall, precipitation, and temperature records. There are only twelve years (1994-2005) of data available in common for the active stations in the region, and are summarized in table 4.5. Generally, there is no pattern in the precipitation in the region from west to east or south to north. However, the highest precipitation (945 mm) was observed in the southwest and the lowest in the middle of the region (870 mm). There is an increase in the mean temperature from southwest to northeast of the region. The southwest region is 1 ^{0}C cooler than the northeast region (Table 4.5).

For the climate pattern discussion, 56-year mean values of precipitation (including rainfall and snowfall) and temperature at a centrally located climate station, Drummond centre (Drummond centre and Chatsfalls stations' data combined provide 56-years of data) data was used and summarized in table 4.6. Snowfall and rainfall account for 20% and 79% of the annual

Table 4.5 Annual average precipitation and mean temperature at active climate stations at Mississippi watershed (1994-2005)

Station name	An. Av. Ppn. (mm)	An. Mean Temp. (^{0}C)
Ompah	944.8	5.3
Ompah-seiz	924.7	6.1
Drummond Centre	870.0	6.4
Appleton	869.1	6.3

Table 4.6 Summary of climate data for Drummond centre [1950-2005]

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	An. Total/av.
Prec (mm)	69	57	59	62	75	72	81	88	85	71	82	80	881
Rain (mm)	27	16	33	54	75	72	81	88	85	69	66	32	698
Snow (mm)	42	41	26	8	0	0	0	0	0	2	16	47	183
Max Temp	6	7	15	23	29	31	33	32	29	24	16	9	21
Min Temp	-29	-28	-20	-10	-3	2	6	4	-2	-6	-13	-24	-10
Mean Temp	-11	-10	-2	7	13	17	19	18	14	9	2	-8	5
Potential ET	0	1	6	33	82	116	135	112	71	34	10	1	602

total precipitation in the region. The highest snowfalls occur in December through February (48, 42, and 41mm. The wettest months are May to November, with only 27 mm variability in monthly precipitation. The lowest precipitation is observed in February (57 mm). The highest precipitation without snowfall was observed in August (88 mm). Observed average annual precipitation of 880 mm is in accordance with the values obtained from the Hydrological Atlas of Canada and studies done by MNR, Moin & Shaw, and Canadian Forestry Service. The temperature in the region ranges from a minimum of -29^{0}C (January) to maximum of 33^{0}C. Although the precipitation is evenly distributed throughout the year, there is a deficit in the precipitation amounts in the summer months (May through August), when potential evapotranspiration rates are high.

4.3.1.1 Precipitation Pattern at Mississippi

Precipitation varies with changes in the climatic cycles, geographic location, and elevation. Figure 4.2 shows the annual total precipitation, rainfall, and snowfall occurring at the Drummond Centre for a period of 56-years (1950-2005). For the last 56-year period, there was no observed pattern in rainfall, snowfall, and precipitation occurrences; however, there does appear to be a decrease in the amount over the last 10-years. The driest period took place between 1957 and 1970, and the wettest between 1971 and 1987. The maximum and minimum precipitation occurrences in Mississippi are shown in table 4.7. Monthly distributions of precipitation occurring at Drummond Centre for the period of 1950-2005 is given in figure 4.3. The histogram shows the contribution of rainfall and snowfall to total monthly precipitation~~s~~. Maximum precipitation occurs in the summer months, when all of it appears as rainfall, and in the winter, 20 to 72 % of the total precipitation is in the form of snow.

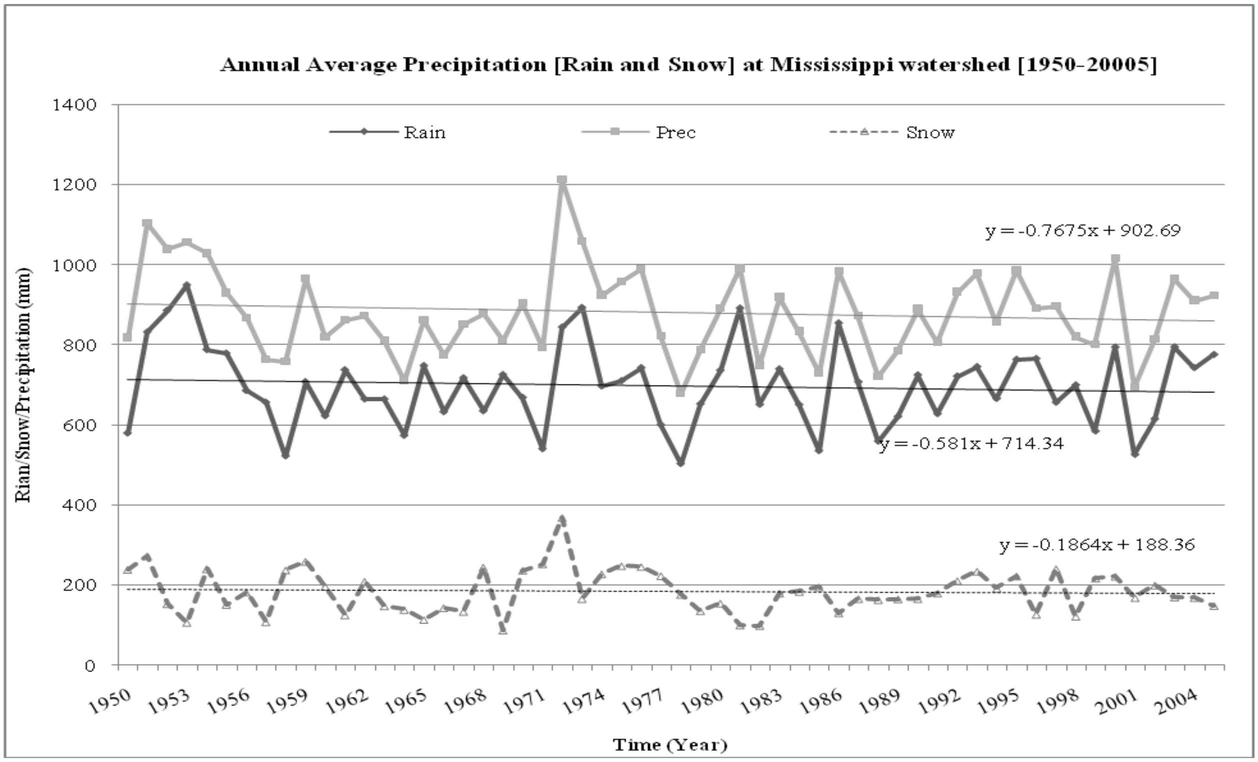


Figure 4.2 Annual Average Precipitation at Mississippi (1950-2005)

Table 4.7 Maximum and Minimum Precipitation Occurrences in Mississippi

Parameters	Amount and year
Maximum Annual	1211 mm (1972)
Maximum Snowfall	368 mm (1972)
Maximum Rainfall	949 mm (1953)
Minimum Annual	678 mm (1978)
Minimum Snowfall	86 mm (1969)
Minimum Rainfall	502 mm (1978)

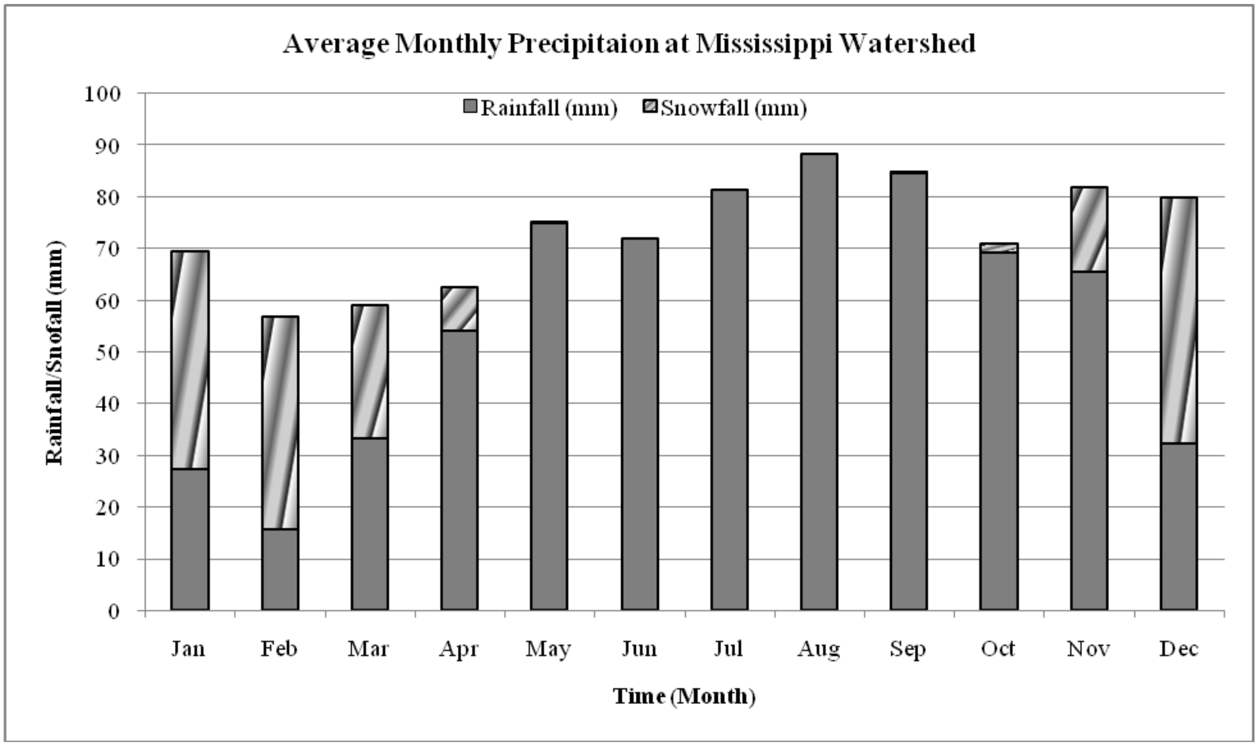


Figure 4.3 Average monthly precipitations at Mississippi watershed

4.3.1.2 Temperature Pattern at Mississippi

Similar to the precipitation, temperature also varies with change in climate cycles and geographic locations. Figure 4.4 shows the annual minimum, maximum, and mean temperatures occurring at Drummond Centre for a period of 56-years (1950-2005). It is observed that there has been a warming pattern over the last 10 years (1995-2005). Over the 56-years period, the maximum mean daily temperature of 38^0C occurred at Drummond centre in 1955; whereas, the minimum daily temperatures of -37^0C occurred in 1981.

Monthly distributions of average daily minimum, maximum, and mean temperatures at the Drummond Centre are shown in figure 4.5. Maximum temperatures ($>10^0$C) occur between mid-March and mid-November, and begin to significantly decrease in late August. Minimum temperatures ($<-10^0$C) occur between December and mid-April. Generally, monthly maximum temperatures in winter and summer are 6 to 16^0C, and 21 to 33^0C and the minimum temperatures are -29 to -27^0C and 2 to 6^0C, respectively.

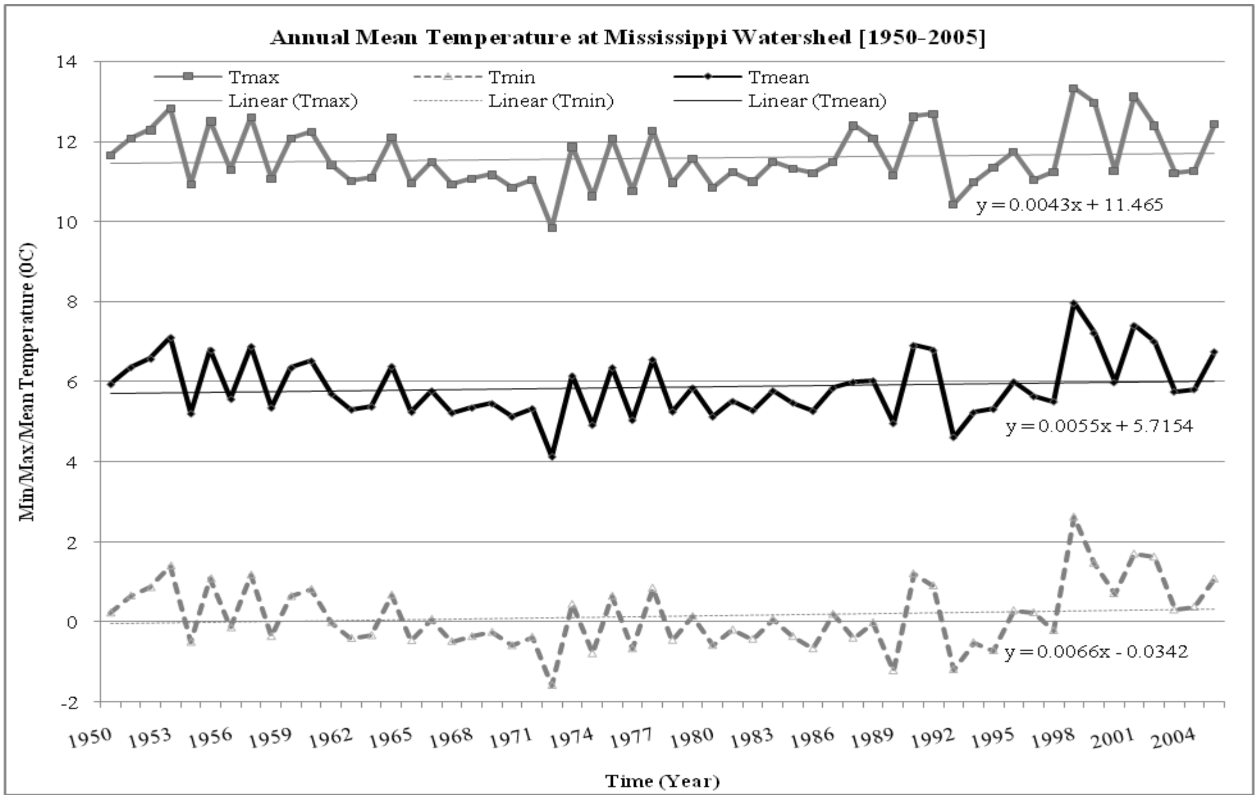


Figure 4.4 Annual temperature pattern at Drummond centre-Mississippi (1950-2005)

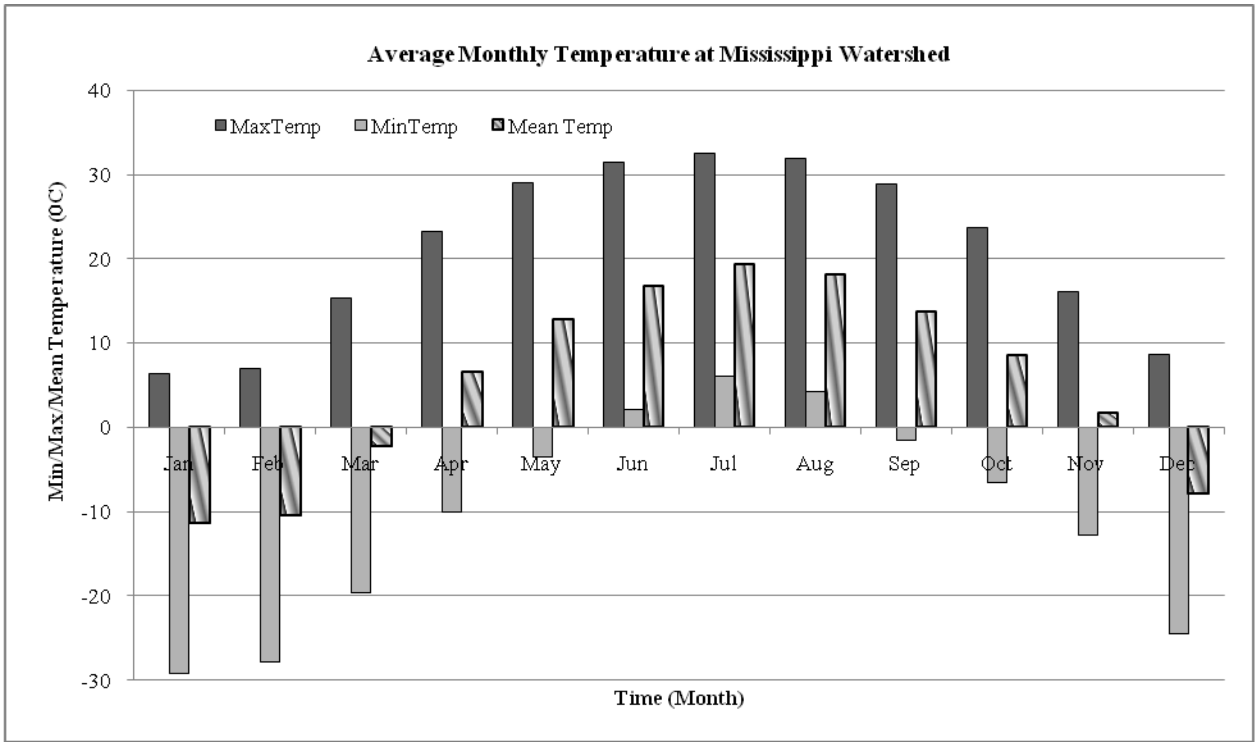


Figure 4.5 Monthly temperature at Drummond centre-Mississippi

4.3.2 Projected Future Climate Data with Downscaled CGCM2 Data to Mississippi River Watershed

Projections of mean monthly minimum and maximum temperature and precipitation for the future periods (I, II and III) in the Mississippi River watershed were derived by applying the relative changes in climate parameters to data from the Drummond Centre Climate station for 1985-2003 [baseline period]. These projections were compared with the actual baseline data, and shown in figures 4.6, 4.7, and 4.8, respectively. Table 4.8 shows the rate of change in the CGCM2 projected mean monthly maximum and minimum temperature (^{0}C/yr), and precipitation (mm/yr) in the Mississippi River watershed for the period 1984-2000.

The mean maximum temperature has been increasing in almost all months except in December and March; however the mean minimum temperature has been increasing significantly for all months of the year [Figs. 4.6 and 4.7]. The winter minimum temperatures are significantly increasing [especially in January through March] for the 2010 to 2099 periods. The winter and summer maximum temperatures are significantly increasing for the 2010 to 2099 periods. The highest rate of change was observed in the minimum temperature, which rose in the months of January and February [0.06 to 0.17^{0}C/yr] for the 2010 to 2099 periods [Table 4.8]. It is evident that in the winter months of December and January through March, precipitation has been decreasing while in the summer months and particularly in the months of September, October and November, precipitation has been increasing [Fig. 4.8]. Wetter fall conditions are predicted, however, winter conditions are more or less the same as the baseline period.

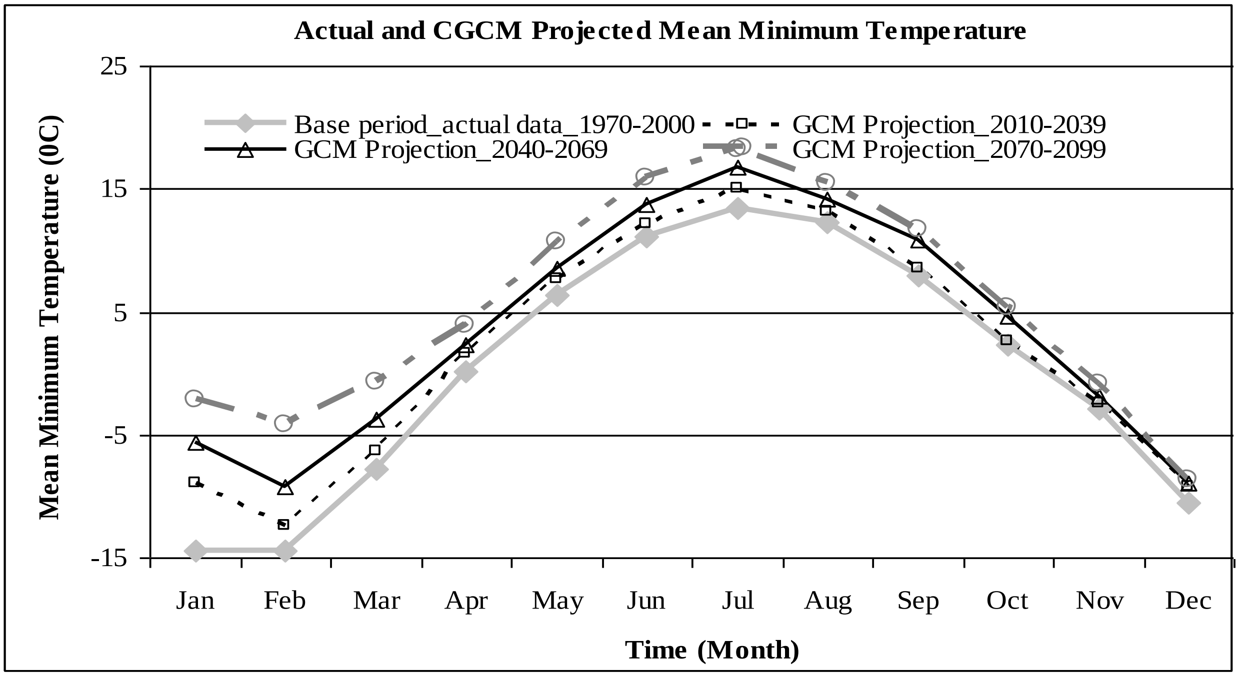


Figure: 4.6 Actual [1984-2000] and CGCM2 Projected Mean Minimum Temperature for 2010-2039, 2040-2069, 2070-2099 periods

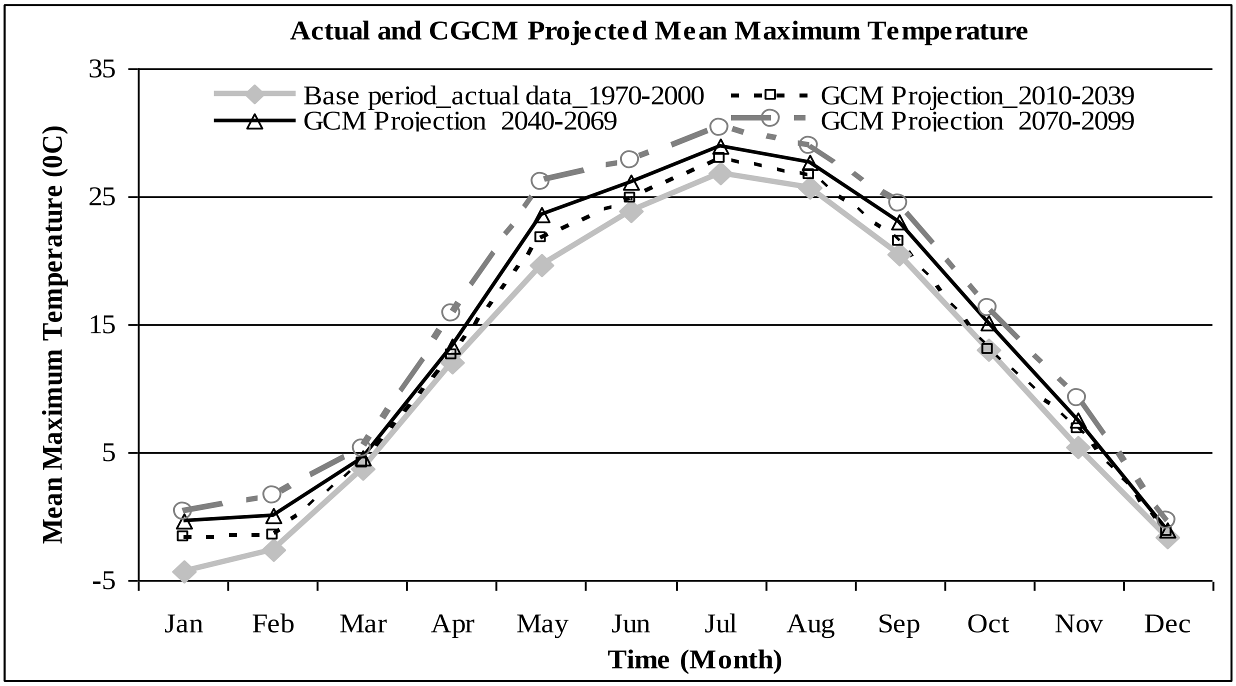


Figure: 4.7 Actual [1984-2000] and CGCM2 Projected Mean Maximum Temperature for 2010-2039, 2040-2069, 2070-2099 periods

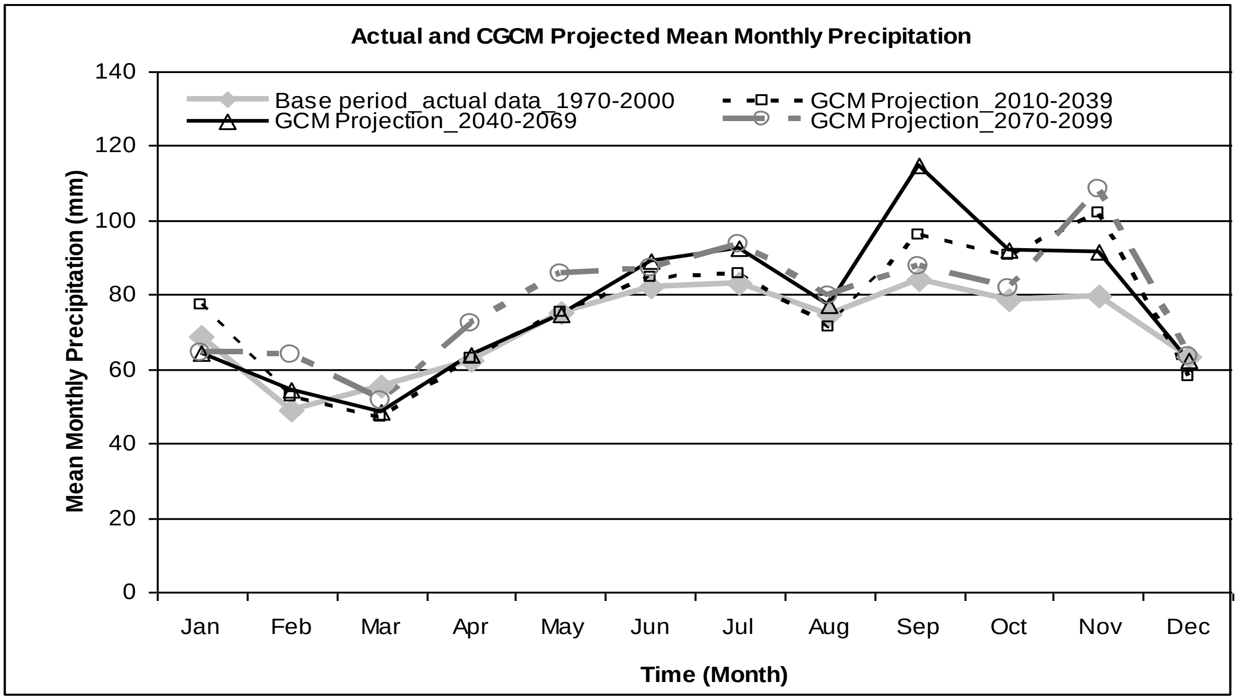


Figure: 4.8 Actual [1984-2000] and CGCM2 Projected Precipitation for 2010-2039, 2040-2069, 2070-2099 periods

Table 4.8: CGCM2 Projected Precipitation and Temperature Change Rates from Base Period [1984-2003]

	Max. Temp. Change Rate (^{0}C/yr)			**Min. Temp. Change Rate (^{0}C/yr)**			**Precip. Change Rate (mm/yr)**		
Month	I	II	III	I	II	III	I	II	III
Jan	0.08	0.06	0.05	0.17	0.14	0.13	0.26	-0.07	-0.04
Feb	0.03	0.04	0.05	0.06	0.08	0.11	0.10	0.09	0.16
Mar	0.01	0.01	0.02	0.05	0.06	0.08	-0.26	-0.11	-0.04
Apr	0.02	0.02	0.04	0.05	0.03	0.04	0.00	0.02	0.10
May	0.07	0.06	0.07	0.04	0.03	0.05	-0.01	0.00	0.11
Jun	0.03	0.03	0.04	0.03	0.04	0.05	0.08	0.11	0.05
Jul	0.04	0.04	0.04	0.05	0.05	0.05	0.08	0.15	0.11
Aug	0.03	0.03	0.03	0.03	0.03	0.04	-0.11	0.04	0.05
Sep	0.03	0.04	0.04	0.02	0.05	0.04	0.36	0.49	0.04
Oct	0.00	0.03	0.04	0.01	0.04	0.03	0.36	0.21	0.03
Nov	0.04	0.03	0.04	0.01	0.02	0.02	0.69	0.19	0.31
Dec	0.02	0.01	0.01	0.04	0.02	0.02	-0.16	-0.02	0.00

4.3.3 Climate Data Generation for Future Periods for Mississippi Watershed

The Drummond Centre Climate Station .LOC files updated with estimated percent changes for future I, II and III periods were run with ClimGen to generate future climate data for Mississippi watershed. The generated mean monthly minimum and maximum temperatures and precipitation data for I, II, III periods, were compared with the actual data [1984-2000], and shown in figures 4.9, 4.10, and 4.11, respectively. The table 4.9 shows the percent change rate in generated mean maximum, minimum, and precipitation rates of change in mean maximum and minimum temperatures (^{0}C/yr), and in Precipitation (mm/yr) for the Mississippi River watershed for the period 1984-2000.

Similar to CGCM2 model projection, ClimGen generated winter and summer maximum temperatures for the Mississippi River watershed are increasing significantly for the 2010 to 2100 periods [Fig. 4.10]. Similarly, CGCM2 projections and ClimGen predictions were showing significant increases in winter minimum temperatures (especially in January through March) for the 2010 to 2100 periods [Fig. 4.9]. Although the ClimGen generated precipitation is also similar to the CGCM2 projections where wetter fall conditions were predicted, there is more variability in precipitation generation than that of minimum or maximum temperatures [Fig. 4.11]. Therefore, not only the mean precipitation and the mean temperature data have to be considered, but also their standard deviation among the data. Table 4.10 shows the mean monthly precipitation and temperature and their standard deviation for the 2010-2039, 2040-2069, and 2070-2099 periods [see Appendices 4-A1 and 4-A2]. The statistical analysis results of future climate data from CimGen are given in Appendices 4-A3, 4-A4, and 4-A5, for the 2010-2039, 2040-2069, and 2070-2099 periods, respectively.

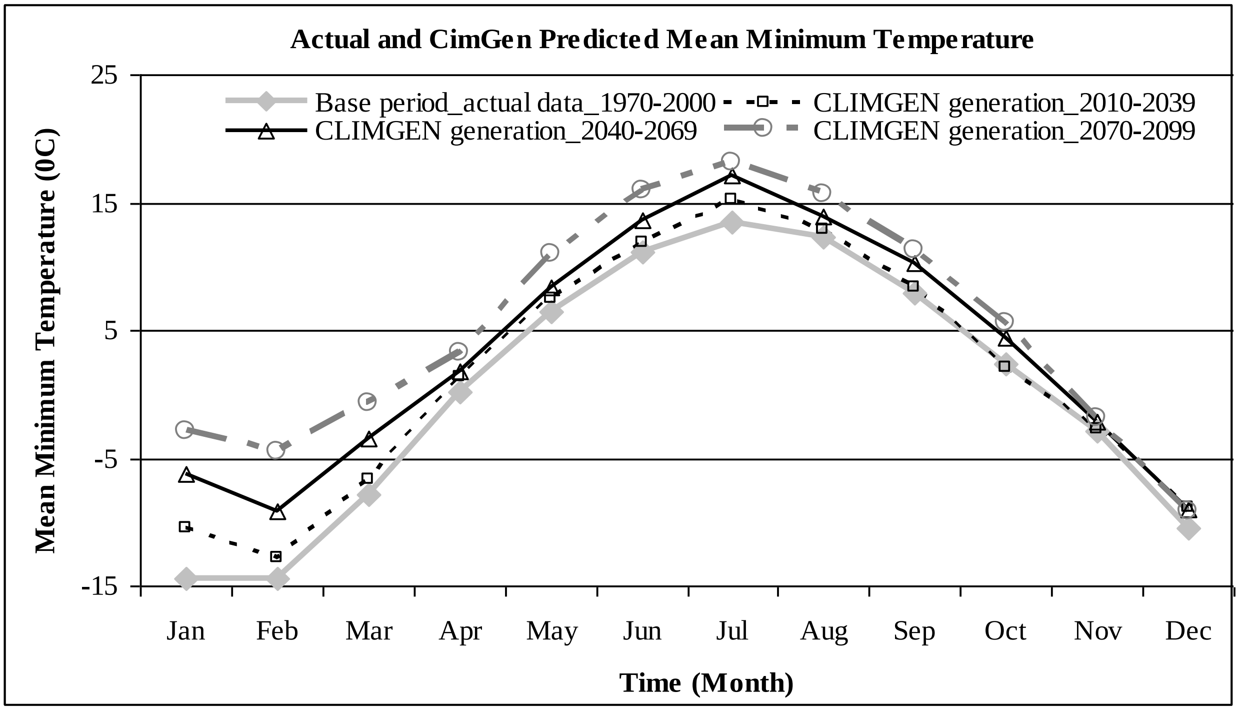


Figure: 4.9 Actual [1984-2000] and ClimGen Generated Mean Minimum Temperature for 2010-2039, 2040-2069, 2070-2099 periods

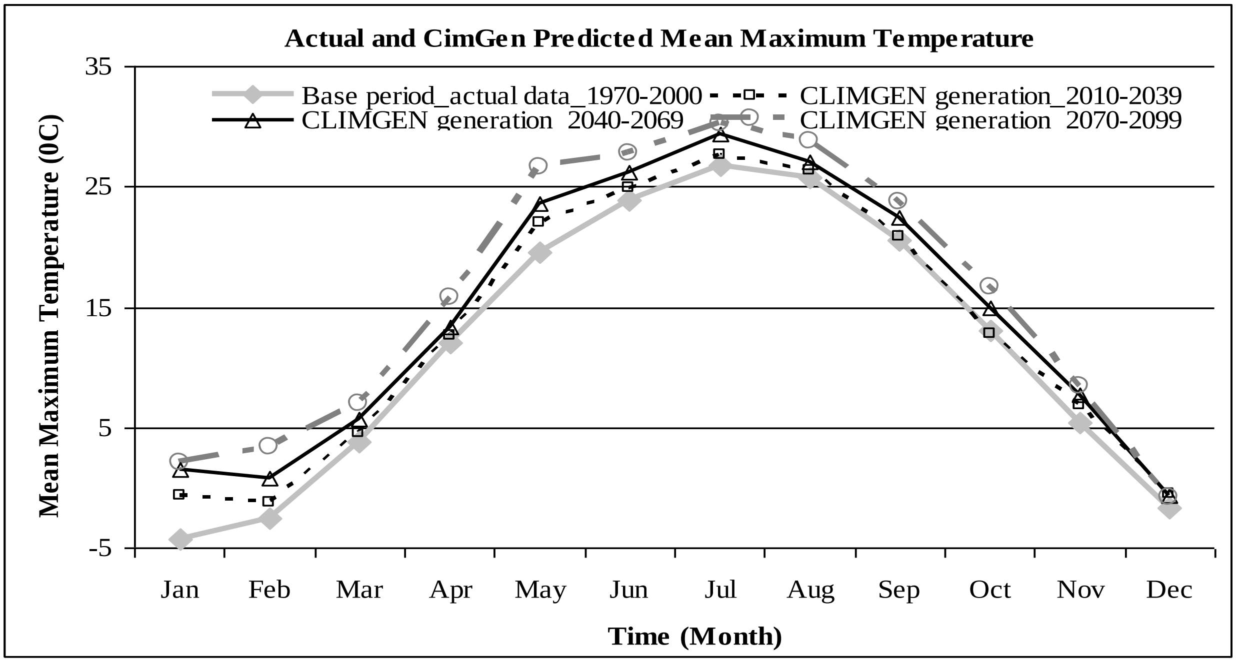


Figure: 4.10 Actual [1984-2000] and ClimGen Generated Mean Maximum Temperature for 2010-2039, 2040-2069, 2070-2099 periods

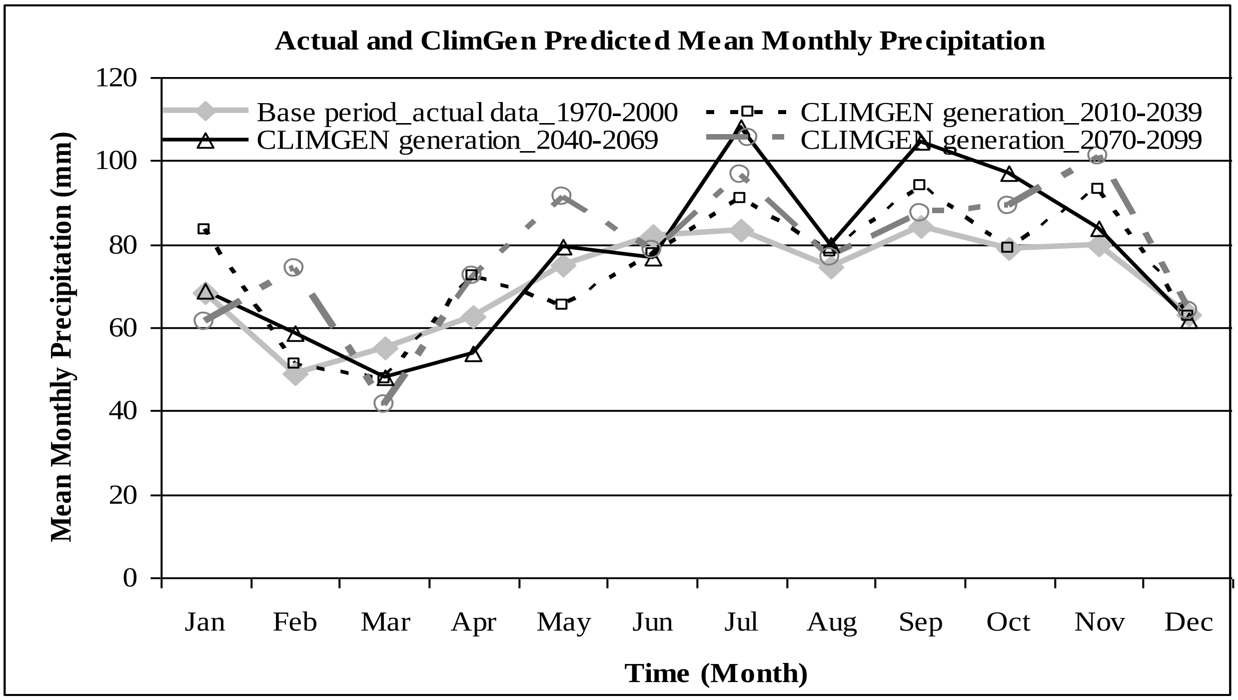


Figure: 4.11 Actual [1984-2000] and ClimGen Generated Mean Precipitation for 2010-2039, 2040-2069, 2070-2099 periods

Table 4.9: ClimGen Generated Precipitation and Temperature Change Rates from Base Period

	Max. Temp. Change Rate (^{0}C/yr)			Min. Temp. Change Rate (^{0}C/yr)			Precip. Change Rate (mm/yr)		
Month	I	II	III	I	II	III	I	II	III
Jan	0.11	0.09	0.07	0.12	0.13	0.13	0.47	0.00	-0.08
Feb	0.04	0.05	0.06	0.05	0.08	0.11	0.07	0.16	0.27
Mar	0.03	0.03	0.03	0.03	0.07	0.08	-0.24	-0.11	-0.15
Apr	0.02	0.02	0.04	0.04	0.02	0.03	0.30	-0.14	0.10
May	0.07	0.06	0.08	0.03	0.03	0.05	-0.30	0.07	0.18
Jun	0.03	0.04	0.04	0.02	0.04	0.05	-0.14	-0.09	-0.04
Jul	0.03	0.04	0.04	0.05	0.06	0.05	0.24	0.40	0.15
Aug	0.02	0.02	0.03	0.02	0.03	0.04	0.11	0.08	0.02
Sep	0.01	0.03	0.04	0.01	0.04	0.04	0.30	0.33	0.03
Oct	-0.01	0.03	0.04	-0.01	0.03	0.03	0.00	0.29	0.11
Nov	0.05	0.04	0.03	0.01	0.01	0.01	0.41	0.06	0.23
Dec	0.04	0.02	0.01	0.05	0.02	0.01	-0.01	-0.03	0.01

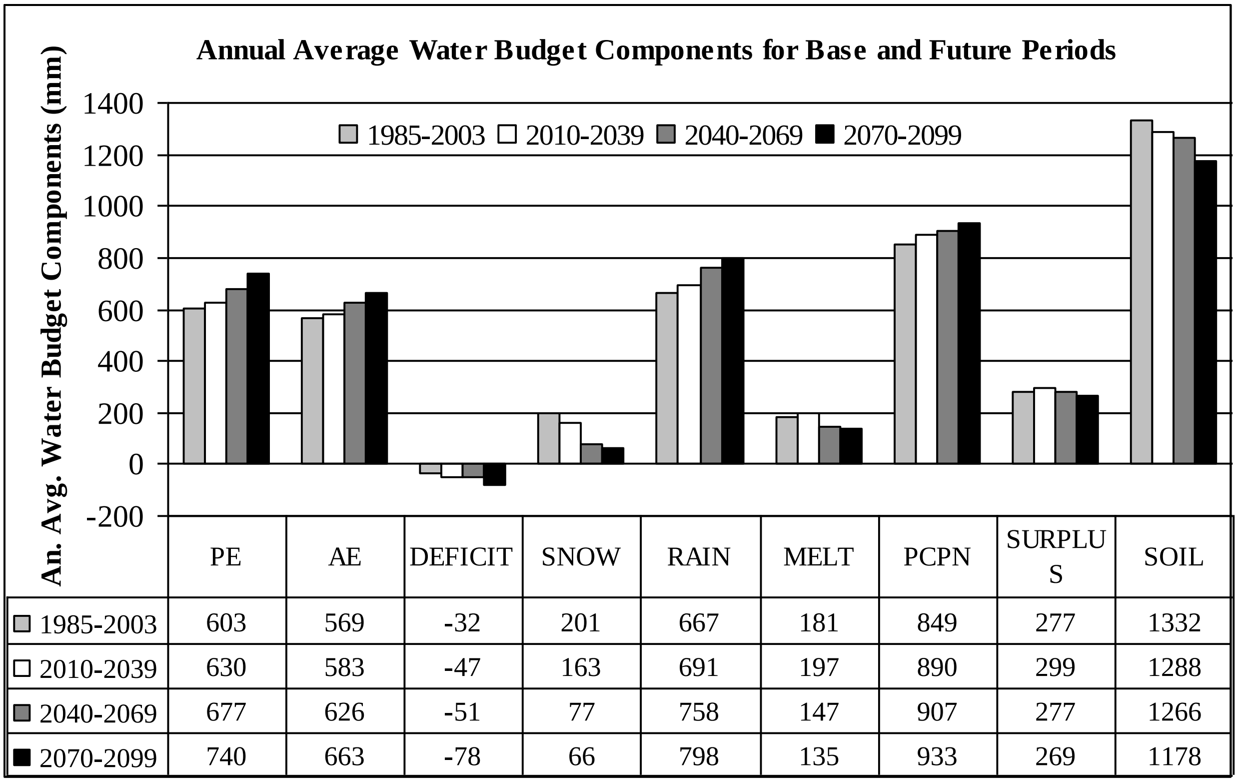
The mean temperature of 6^{0}C in the baseline period increased to 10.5^{0}C in 2099 with a standard deviation range of 1.3 to 1.7^{0}C over a year for future periods as compared to 1.9^{0}C for the baseline period [Table 4.10]. Large variations in mean temperature occurred from November to April. The average annual precipitation of 849mm increased to 907mm in 2099, with the standard deviation varied from 32 to 34mm over a year for the future periods, with a 31mm variation for the baseline period. The variation in precipitation was small from November through May. This variation might be due to drier winter conditions. There was no significant trend observed in the actual or predicted precipitation data [α = >0.1, Appendices: 4-A6 and 4-A8], whereas the minimum and maximum temperatures were significantly increasing in both periods Increases in the minimum, maximum, and mean temperatures are predicted to be highly significant for the future periods [α = >0.001, Appendices: 4-A7 and 4-A8].

Table 4.10: Mean and Standard Deviation of Actual and ClimGen Generated Future Temperature and Precipitation

	Mean Temperature (^{0}C)				Std. Dev. Mean Temperature (^{0}C)			
	Actual	2010-2039	2040-2069	2070-2099	Actual	2010-2039	2040-2069	2070-2099
Jan	-9.7	-5.5	-2.3	-0.4	3.2	2.3	1.4	1.5
Feb	-8.6	-7	-4.3	-0.5	2.6	2	1.2	1.9
Mar	-2.1	-1	1	3.1	2.1	2.3	1.5	2
Apr	5.9	7	7.6	9.6	1.6	1.6	1.7	2
May	12.8	14.7	15.9	18.7	1.5	1.4	1.3	1.5
Jun	17.6	18.3	19.8	21.8	1.3	1.4	0.8	1.7
Jul	20.1	21.4	23.2	24.2	1.2	1.1	0.6	1
Aug	19	19.6	20.4	22.3	1.2	1.4	1	1.4
Sep	14.4	14.6	16.3	17.5	1.3	1.4	1.4	1.7
Oct	7.6	7.4	9.7	11	1.3	1.4	1.3	1.8
Nov	1.2	2.1	2.7	3.3	1.7	1.9	1.7	2
Dec	-6.1	-4.6	-4.8	-4.9	3.4	1.8	1.5	1.4
Av.	*6.0*	*7.3*	*8.8*	*10.5*	*1.9*	*1.7*	*1.3*	*1.7*
	Mean Precipitation (mm)				Std. Dev. Precipitation (mm)			
	Actual	2010-2039	2040-2069	2070-2099	Actual	2010-2039	2040-2069	2070-2099
Jan	68	82	68	61	34	29	29	23
Feb	51	50	59	75	21	17	22	32
Mar	53	48	48	42	28	18	22	24
Apr	61	73	54	72	33	37	33	27
May	76	66	77	91	26	27	49	44
Jun	80	76	73	77	40	36	37	46
Jul	85	90	108	98	30	43	48	36
Aug	75	78	80	78	33	40	32	29
Sep	88	94	102	87	33	49	38	36
Oct	78	77	96	89	35	31	41	37
Nov	76	93	82	100	33	35	32	36
Dec	58	63	60	63	27	25	24	23
Total/Av.	*849*	*890*	*907*	*933*	*31*	*32*	*34*	*33*

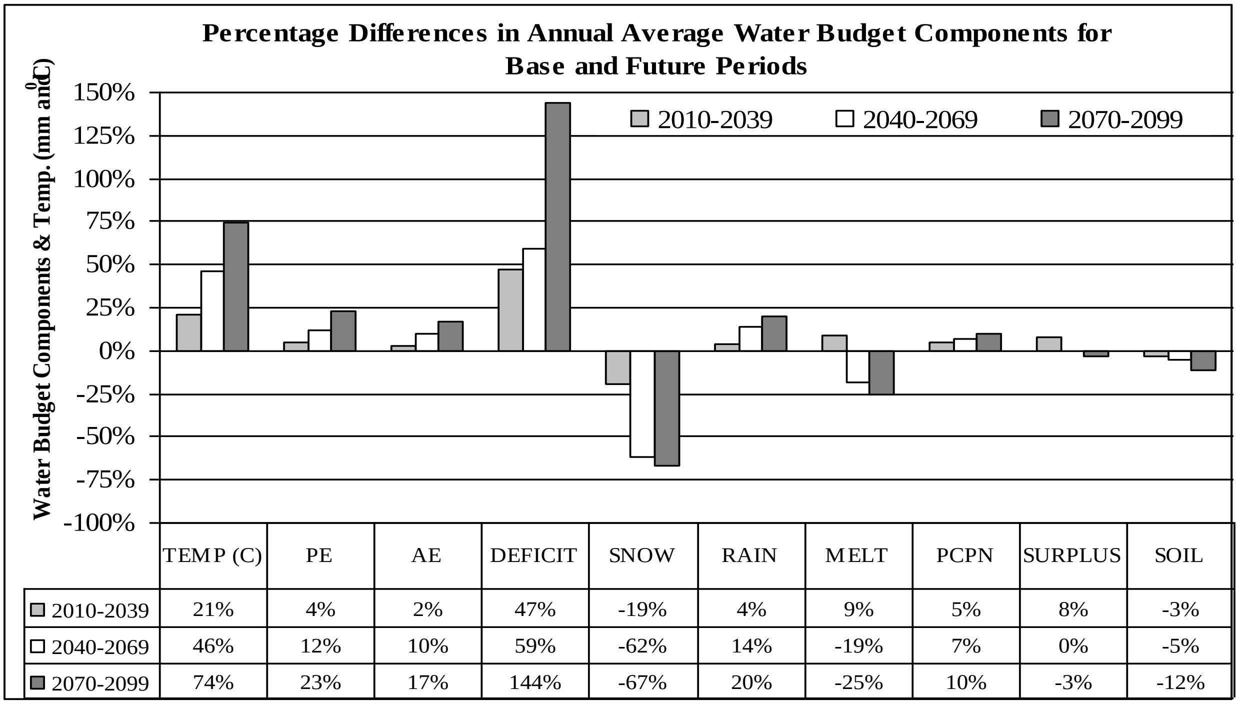
4.3.4 Water Budget Modeling

The comparison of water budget components between baseline and future periods showed a 17% increase in the annual actual evapotranspiration [663mm vs. 569mm] in the III period from the baseline period [Figs. 4.12 and 4.13]. Even with a 10% increase in precipitation in the III period, a 74% increase in the temperature with a 23% increase in the potential evapotranspiration will result in a 144% deficit [Fig. 4.13]. This is because the estimated runoff [P-ET] reduced by 53mm with 193mm increase in ET due to 4.5^0C increase in the temperature and 154mm reduction in soil moisture content. Though the rain will increase from 667mm to 798mm in the III period, the snow will decrease from 206mm to 66mm during that period [Fig. 4.12]. While the precipitation is continuously increasing from the baseline to III period, the snow is decreasing with the most significant decrease shown in the II period [Fig. 4.13]. There are significant increases in the temperature observed from the baseline to all three future periods.



	PE	AE	DEFICIT	SNOW	RAIN	MELT	PCPN	SURPLUS	SOIL
▒ 1985-2003	603	569	-32	201	667	181	849	277	1332
□ 2010-2039	630	583	-47	163	691	197	890	299	1288
▓ 2040-2069	677	626	-51	77	758	147	907	277	1266
■ 2070-2099	740	663	-78	66	798	135	933	269	1178

Figure: 4.12 Annual Average Water Budget Components for Base and Future periods.

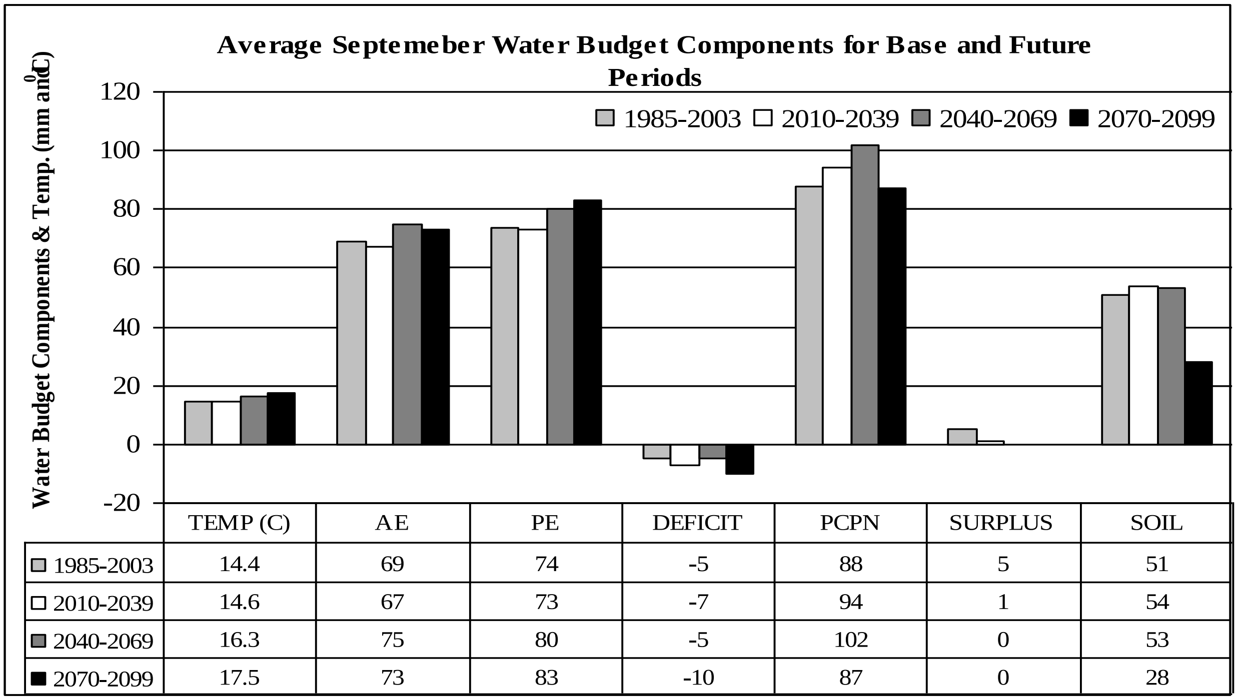


	TEMP (C)	PE	AE	DEFICIT	SNOW	RAIN	MELT	PCPN	SURPLUS	SOIL
▨ 2010-2039	21%	4%	2%	47%	-19%	4%	9%	5%	8%	-3%
☐ 2040-2069	46%	12%	10%	59%	-62%	14%	-19%	7%	0%	-5%
■ 2070-2099	74%	23%	17%	144%	-67%	20%	-25%	10%	-3%	-12%

Figure: 4.13 Percentage Differences in Annual Average Water Budget Components of Base and Future periods

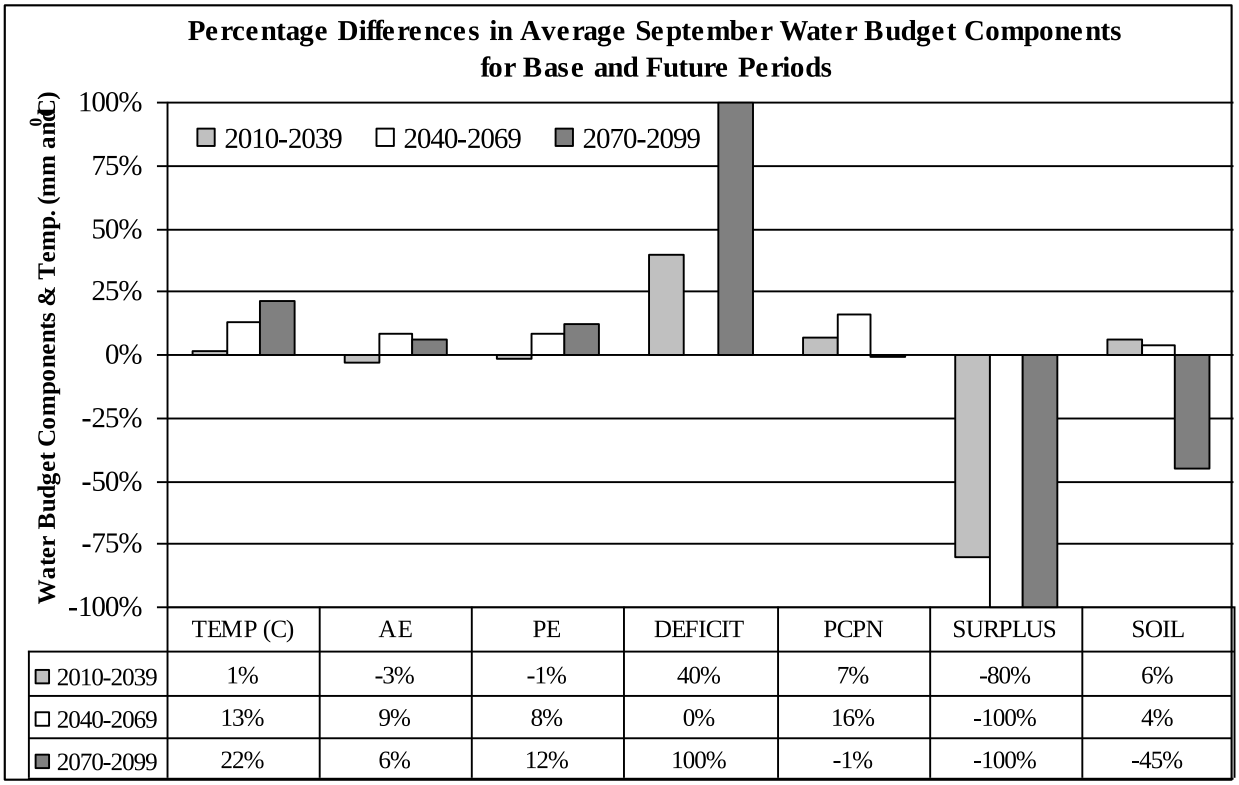
From the recent Source Water Protection-Tier I Water Budget study (Mississippi-Rideau Source Protection Region), the highest water demand in the watershed upstream of Appleton [for Carleton Place surface water taking] was observed in September, a low flow month [unpublished CA-MNR draft document]. Therefore, the water budget components in September were analyzed to determine the effect of future water takings. There might be an increase of 3.1^{0}C in the temperature [22% from the base period] by the III period [Fig. 4.14 and 4.15]. In the II period, the variation in the actual and potential evapotranspiration was less [9% vs. 8%] with 16% increase in the precipitation, and hence resulted in no deficits [Fig. 4.15]. However, there will not be any surplus water [100% decrease]. A 22% increase in the temperature increased 12% of the actual evapotranspiration in the III period. The precipitation may also decrease by 1% and so the deficit will increase and surplus will decrease by 100% [Fig. 4.15]. Though the soil moisture contents decrease continuously from I to III periods, a significant decrease [-45% vs. 4-6%] were observed in the III period. This is due to reduced runoff [10mm], soil moisture [23mm], increased ET [9mm] and no surplus in the III period.

In general, with respect to the baseline period conditions, the temperature is continuously increasing at 1 to 22%; the surplus is decreasing at -80 to <-100%; and soil moisture content also decreasing at 6 to -45%. Though there was decrease in potential or actual evapotranspiration in the I period, the values observed will increase in the II and III periods. Similarly, although the precipitation observed will increase in the I and II periods, it will decrease in the III period. The deficit will be in the range of 0-100% within the three periods. So, even with some increase in the precipitation, increase in the ET along with higher temperatures continuously increased the deficit and reduced the surplus. Therefore, more studies and/or better water management options should be implemented to meet the water demand especially in low flow periods.



	TEMP (C)	AE	PE	DEFICIT	PCPN	SURPLUS	SOIL
▨ 1985-2003	14.4	69	74	-5	88	5	51
□ 2010-2039	14.6	67	73	-7	94	1	54
▩ 2040-2069	16.3	75	80	-5	102	0	53
■ 2070-2099	17.5	73	83	-10	87	0	28

Figure: 4.14 Average September Water Budget Components for Base and Future Periods



	TEMP (C)	AE	PE	DEFICIT	PCPN	SURPLUS	SOIL
▨ 2010-2039	1%	-3%	-1%	40%	7%	-80%	6%
□ 2040-2069	13%	9%	8%	0%	16%	-100%	4%
▩ 2070-2099	22%	6%	12%	100%	-1%	-100%	-45%

Figure: 4.15 Percentage Differences in Average September Water Budget Components for Base and Future Periods

4.3.5 Calibration of NAM Model

The NAM model was calibrated with observed runoff at Gordon Rapids for 21 years from January 1, 1973 to December 31, 1993 period. The simulated and observed runoff [hydrograph] and simulated and observed accumulated runoff for the period 1973-1993 are shown in figure 4.16. Simulated and observed flows match well, and their accumulated flows also compared well with each other. A higher coefficient of determination of 0.72 was obtained for observed and simulated flow, and the difference between the average annual observed and simulated flow was 25 mm/yr [Fig. 4.16].

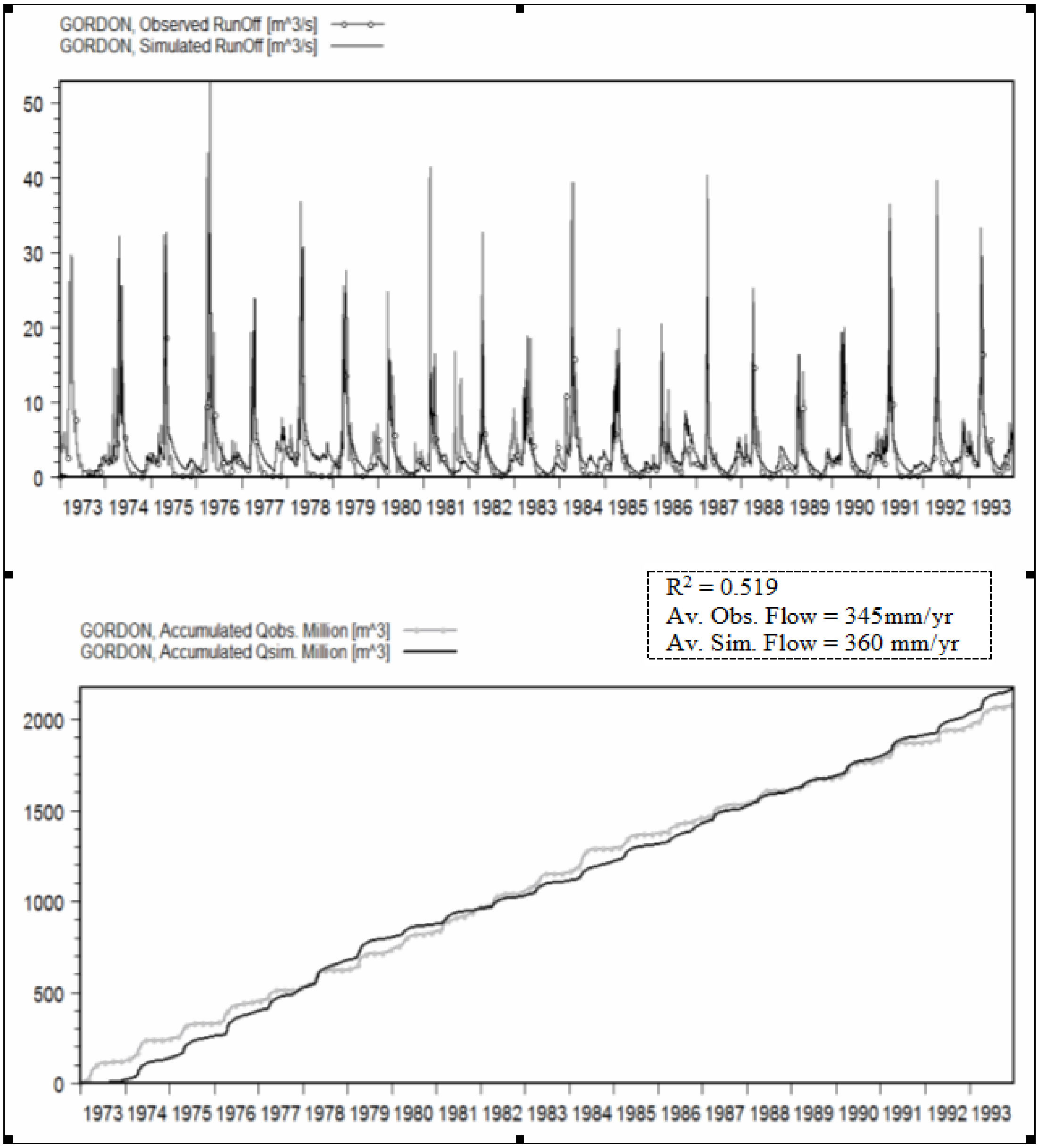
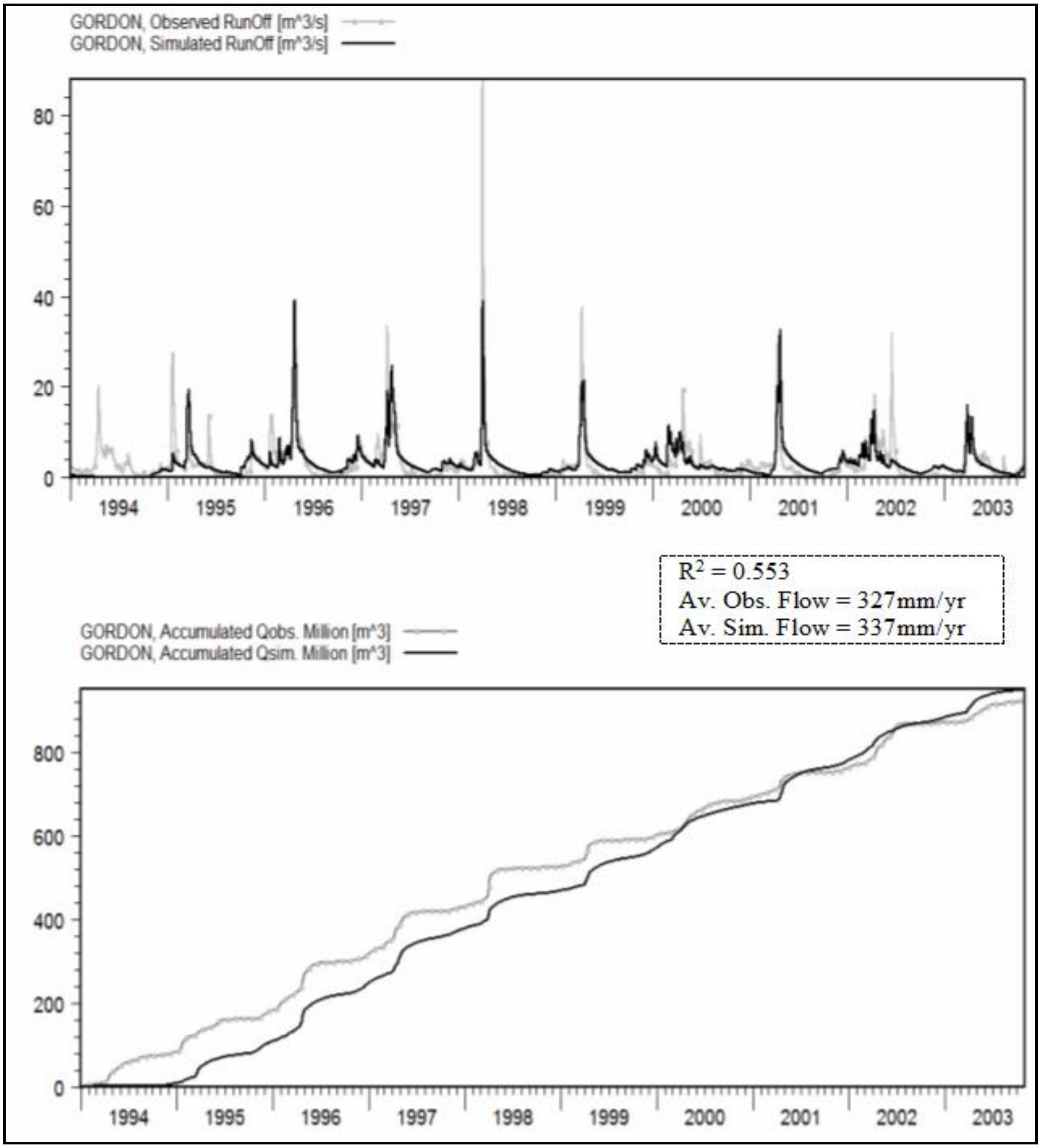


Figure 4.16: NAM Model Calibration – Runoff Hydrograph and Accumulated Runoff of Observed and Simulated Flows at Gordon for1973-1993 periods.

4.3.6 Validation of NAM Model

The calibrated NAM model was validated with 10 years [1994 - 2003] of observed runoff at Gordon Rapids. The figure 4.17 shows a good comparison between the simulated and observed runoff (hydrograph). Accumulated runoff of simulated flows is well matched from the year 2000 onwards; a coefficient of determination of 0.743 and less difference [10 mm/yr] in accumulated observed and simulated flows are good for the modem validation.



$R^2 = 0.553$
Av. Obs. Flow = 327mm/yr
Av. Sim. Flow = 337mm/yr

Figure 4.17: NAM Model Validation – Runoff Hydrograph and Accumulated Runoff of Observed and Simulated Flows at Gordon Rapids for 1994-2003 periods

4.3.7 Simulation of Runoff for Future Periods

The well calibrated and validated NAM model used to simulate runoff for future periods from 2010-2099. The simulated and accumulated runoff flows (hydrograph) are shown for 2010-2099 periods are shown in figure 4.18.

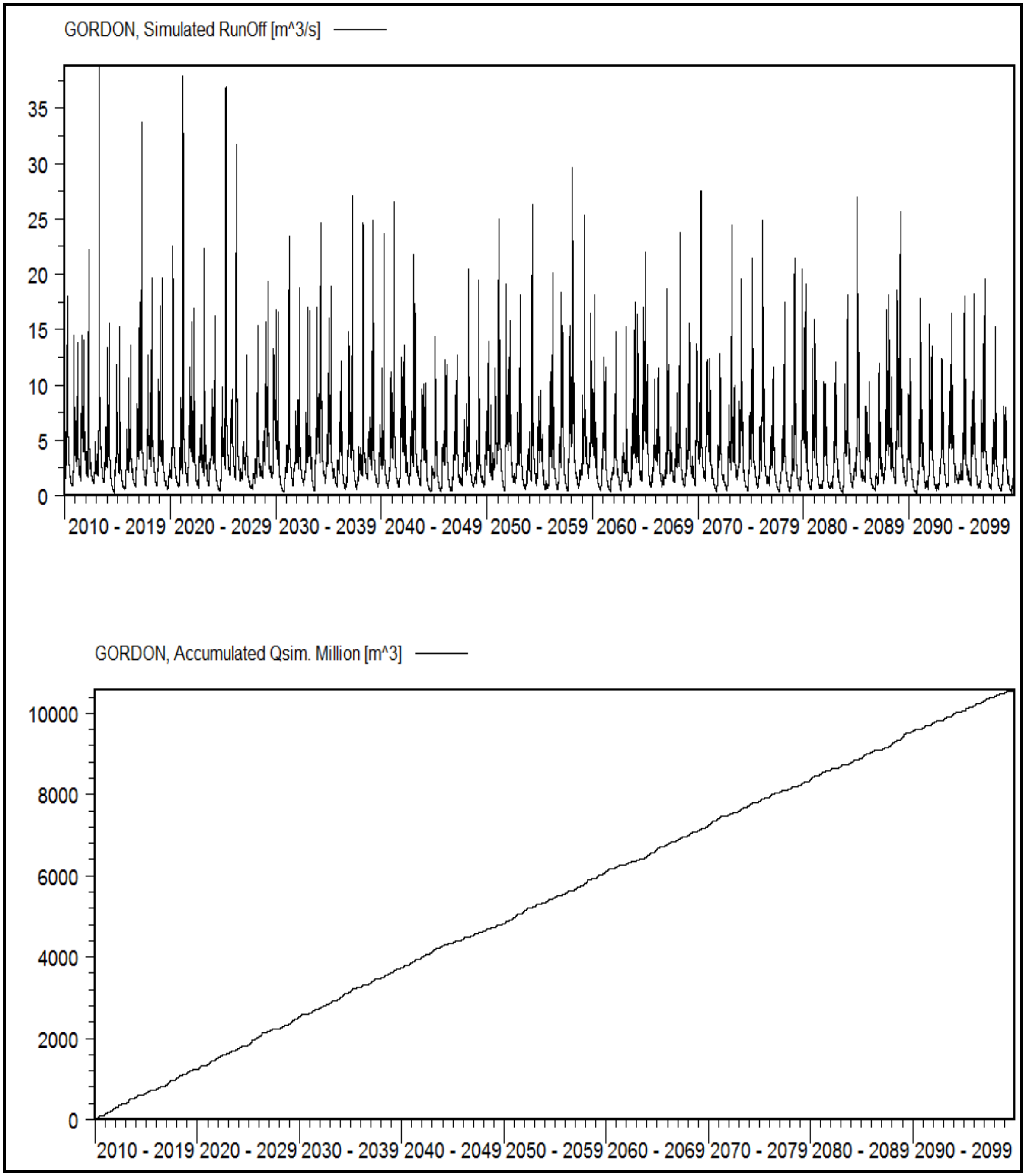


Figure 4.18: Runoff Hydrograph and Accumulated Simulated Runoff at Gordon Rapids for 2010-2099 periods

4.3.8 Adjusted Simulated Flows

Although much effort was taken to match low flows and overall water balance in model calibration, the model overestimated flows in June to October. As this difference was observed in summer months, this might be due to the evapotranspiration data used in the model calibration. The ET data was taken from the source protection study, where the ET was generated by a GIS based Thornthwaite Model which took soil, slope, land use, and water holding capacity into account. The model was primarily run with climate data from the Ottawa station; therefore it might have some difference while applied to Mississippi watershed area.

In order to correct the difference while keeping the simulation for other months the same, a ratio of observed and simulated flows for each month were estimated and applied to daily simulated data. The figure 4.19 shows the average daily flows of observed, adjusted simulated and original simulated flows. The adjusted simulated flows match well with the observed flows for all months [Fig. 4.19]. Therefore, the ratios were similarly applied to the simulated daily flows for the future periods [2010-2099].

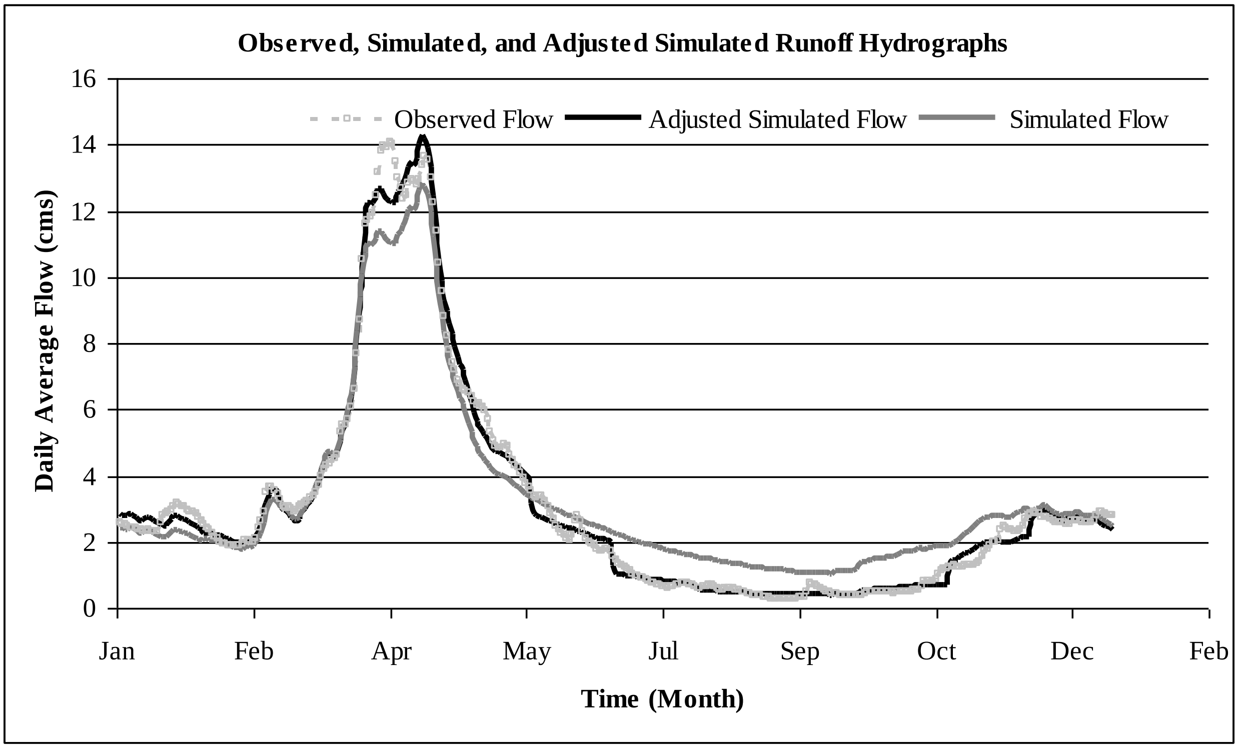


Figure 4.19: Average Daily Runoff Hydrograph of Observed, Adjusted Simulated, and Sim5lated Flows at Gordon Rapids

4.3.9 Validation of Mississippi River Watershed Model (MRWM)

Calibration of the Mississippi River Watershed Model (MRWM) was previously completed as part of the Mississippi River Water Management Plan and is not presented as part of this report. As the MRWM is principally a hydrologic routing algorithm, calibration essentially consists of the following components:

- Structure stage/discharge and stage/storage relationships
- Muskingum routing parameters
- Estimates of lake evaporation

Three years (1997, 1999 and 2001) were selected from the base periods (1974 – 2002) for which structure operating records are available to validate the MRWM for the present study. Figure 4.20 provide a comparison of simulated versus observed streamflows at the Appleton stream gauge site for 1999 and for 1997 and 2001 are shown in Appendix 4-A9 and 4-A10 respectively.

As can be seen the model provides a good representation of the observed hydrograph particularly as it relates to timing and further provides a good ability to model reservoir influences. The principal error introduced by the model is a result of the reservoir inflows and sub-watershed contributions being derived from transposed streamflows. This error however, is minimized by the significant storage and lag introduced by the reservoirs.

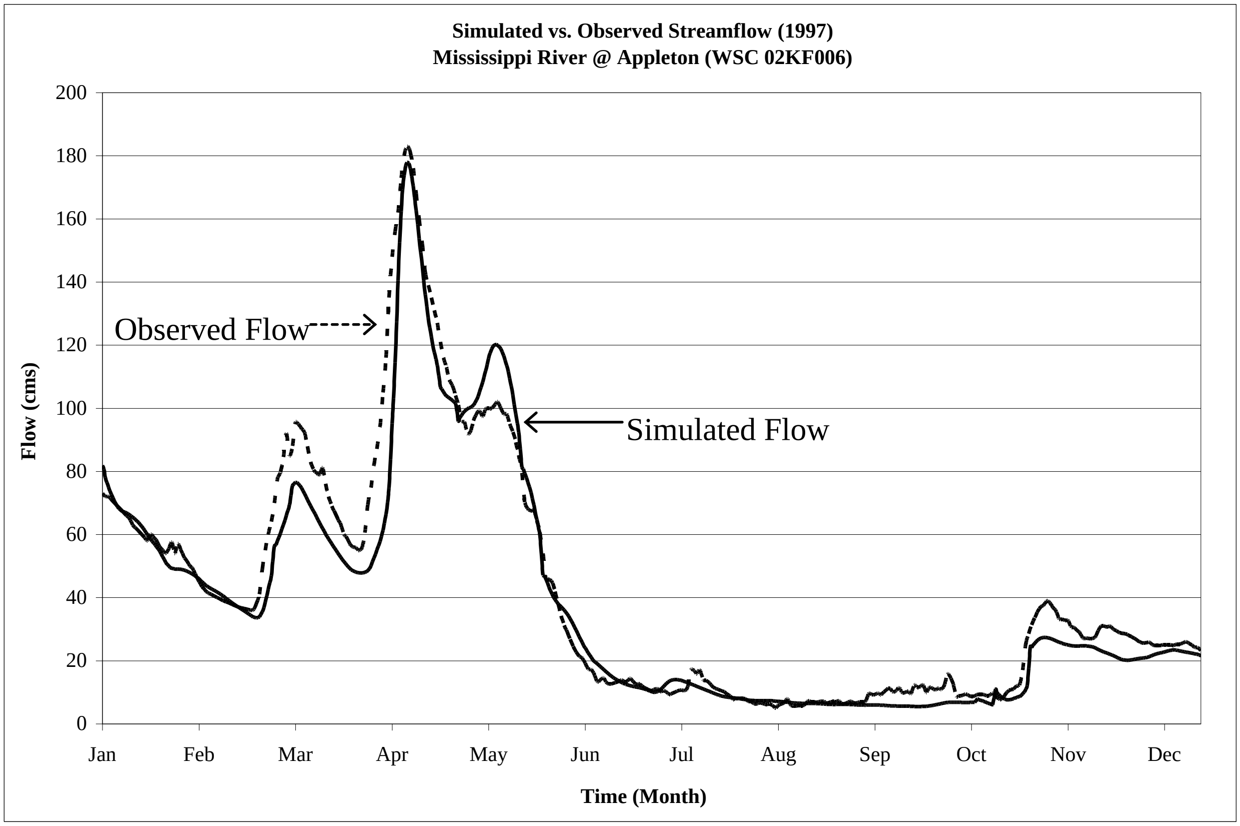


Figure: 4.20 Simulated vs. Observed Streamflow at Mississippi River @ Appleton Gauge

4.3.10 Water Resources Implications and Response

4.3.10.1 Overview of Current Management Strategy

Reservoir regulation involves the strategic storage and release of water over varying time periods to achieve a range of water management objectives. These objectives are established to address a variety of social, environmental and economic interests within the constraints imposed by the physical characteristics of the watershed and reservoir system under consideration.

Within the Mississippi River watershed, the water management objectives are defined by the Mississippi River Water Management Plan (2006) and reflect the management regime which has evolved over the past ninety years in response to development, resource use and climate conditions experienced in the watershed.

The mean annual streamflow hydrograph (Figure 4.21) from the Mississippi River @ Appleton stream gauge record (WSC 02KF006) demonstrates the typical response of this relatively large rural watershed to climate conditions in the region.

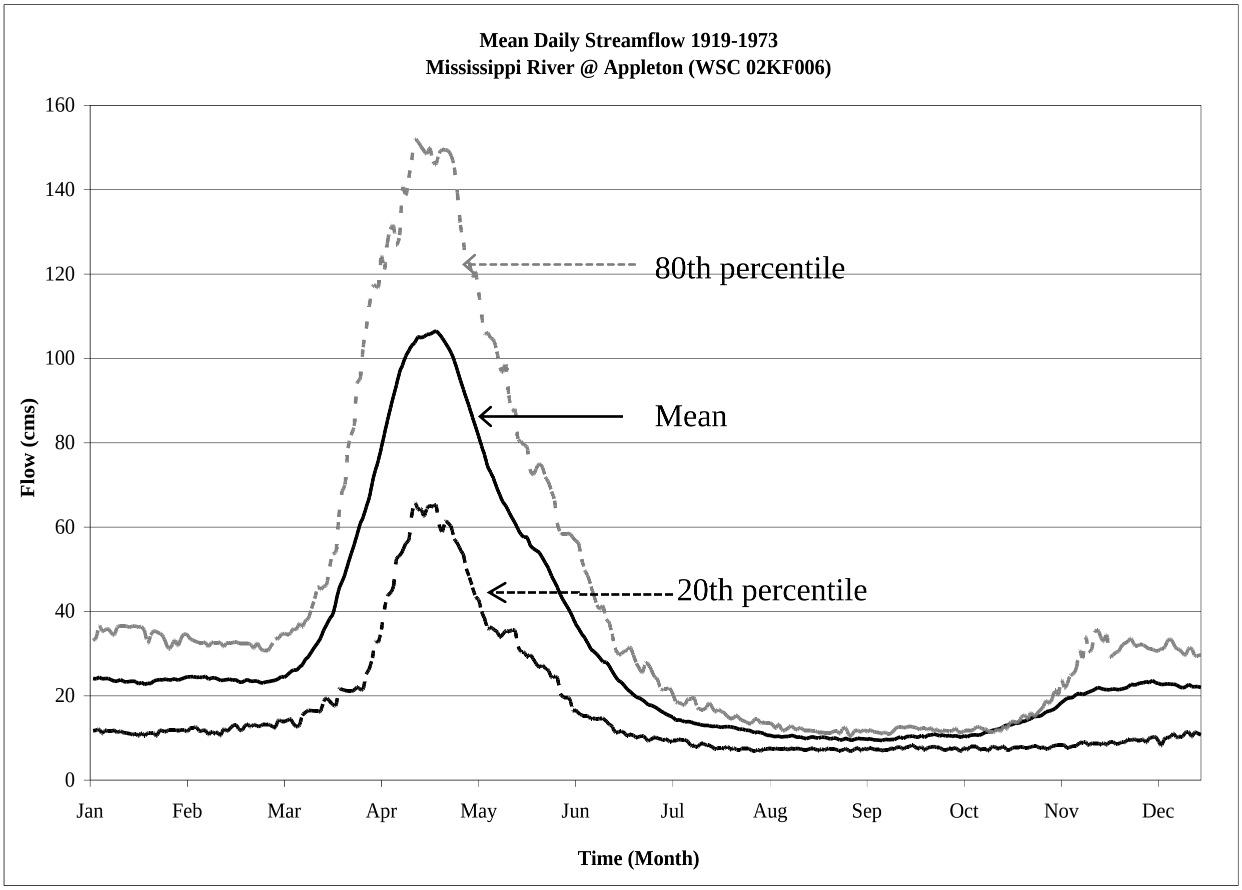


Figure 21: Mean Daily Streamflow at Mississippi River @ Appleton Gauge for 1919-1973 Period

This response generally reflects accumulation of the snow pack over the winter months with relatively stable streamflows. By mid-March, streamflows begin to increase as warmer temperatures begin melting of the snow pack followed by a spring freshet where streamflows are typically at their hi'hest level by mid to late April as a result of snowmelt and rainfall. Over the months of May and June, streamflows recede as runoff from the freshet drains from the upland areas reaching their lowest levels by early September. While the Mississippi River streamflows reflect the influence of reservoir storage, this annual cycle is characteristic of most rural streams in eastern Ontario.

The water management regime implemented on the Mississippi River utilizes the existence of several large natural lakes in the upper reaches of the watershed to store in water in times of excess runoff and then release it during drier periods when streamflow conditions are less reliable. The total storage available in these reservoirs, as described in Table 4.11, is approximately 13,300 ha-m or 47 mm of runoff when expressed as an average depth across the drainage area upstream of the Appleton stream gauge site.

Table 4.11: Reservoir Storage

Reservoir	**Storage (ha-m)**
Shabomeka Lake	428
Mazinaw Lake	1956
Kashwakamak Lake	2038
Mississagagon Lake	273
Big Gull Lake	1778
Crotch Lake	6836

To augment the available storage for streamflow regulation, the reservoir system utilizes a semi-annual drawdown regime of the main reservoir at Crotch Lake. Following the spring freshet, all six reservoirs are filled to their maximum operating levels. The upper five reservoirs are maintained within a tight operating band of +/- 0.1 m over the summer months to support tourism, recreation and navigational interests. In contrast, the Crotch Lake reservoir is gradually drawndown over this period to release storage and augment streamflows in the lower river system. The available storage in Crotch Lake is typically depleted by mid-October when the reservoir reaches its minimum level.

By this point, storage from the upper five reservoirs is released and retained in the Crotch Lake reservoir for subsequent release to the lower river system over the winter period. All six reservoirs reach their lowest levels by the end of March providing the maximum capacity to store excess runoff from the spring freshet thereby providing a degree of flood protection to downstream communities while again replenishing the reservoirs. Figures 4.22 and 4.23 describe this semi-annual management approach.

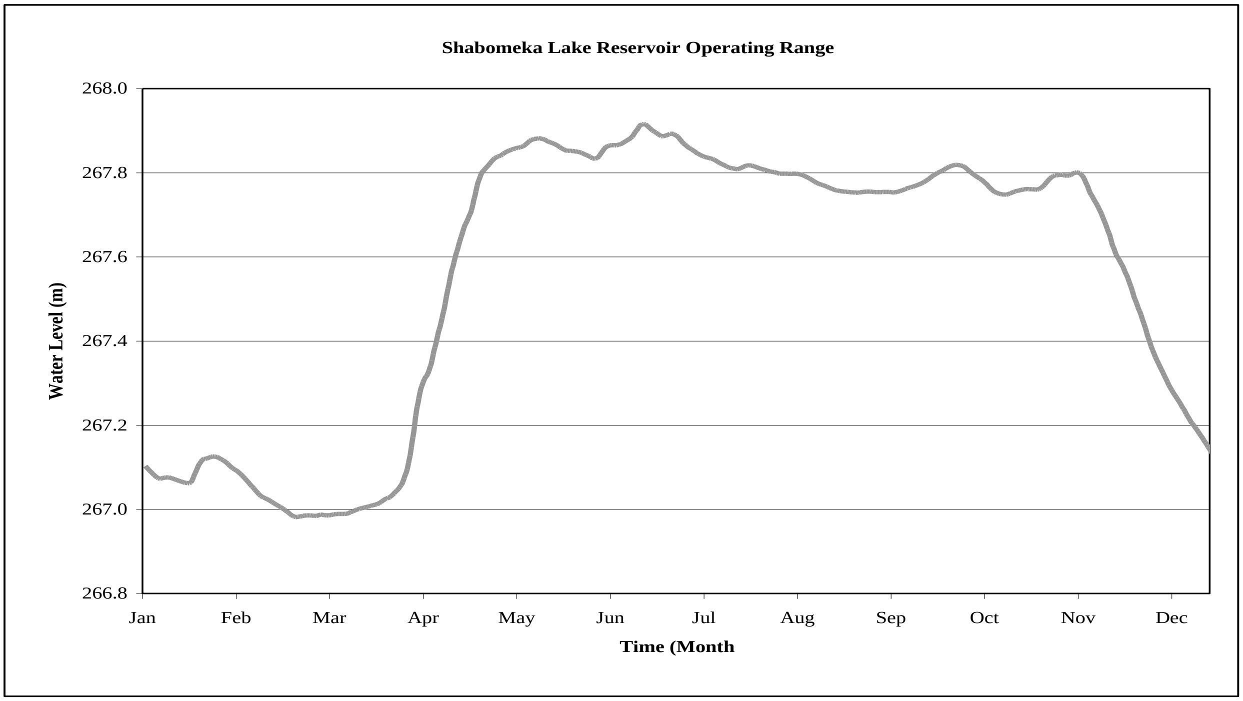


Figure 4.22: Shabomeka Lake Reservoir Operating Regime

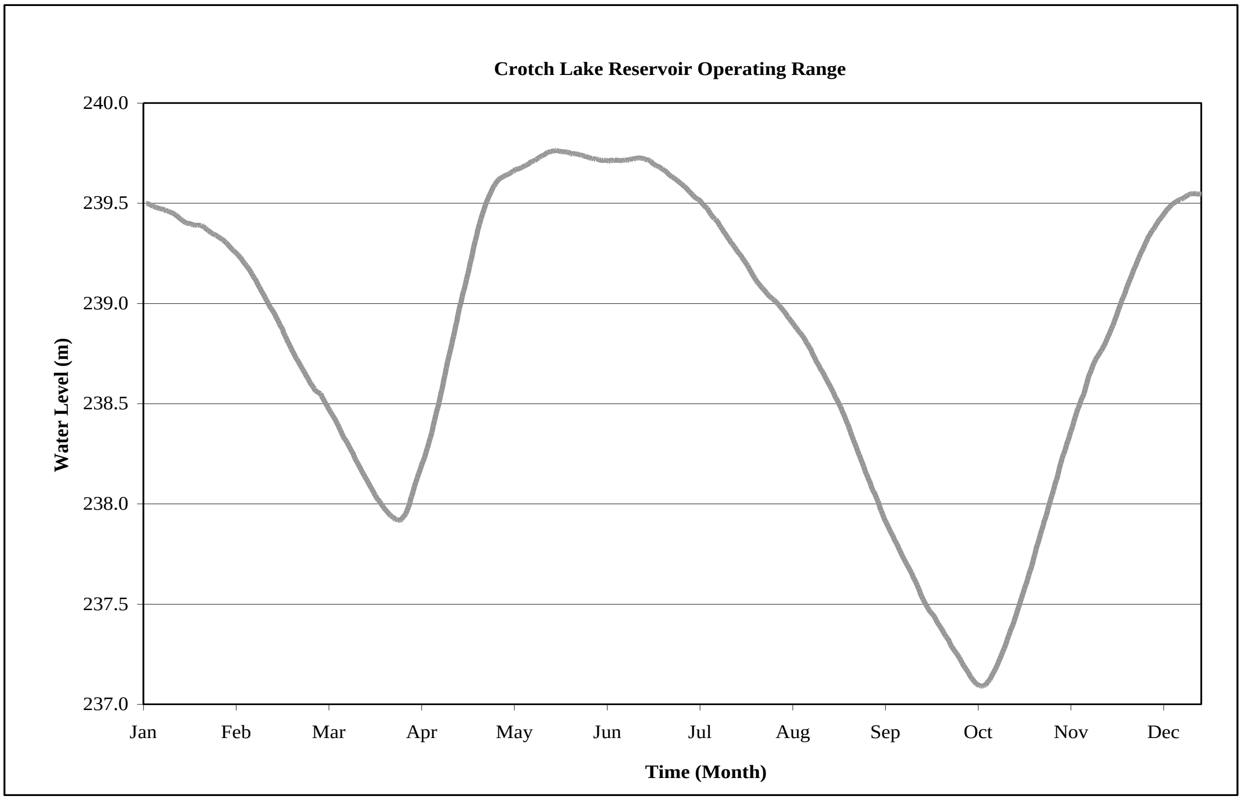


Figure 4.23: Crotch Lake Reservoir Operating Regime

The current strategy capitalizes on the historic runoff patterns to maximize available reservoir capacity and provide a variety of water management benefits including:

- Flood reduction during spring freshet
- Streamflow augmentation for water supply, hydropower, waste assimilation and aquatic ecosystems
- Stable water levels to support recreation, tourism and navigation
- Maintaining fish and aquatic habitat

4.3.10.2 Implications of Changes in Streamflow Characteristics

As mentioned previously, the existing infrastructure and present management regime is largely dependent on the continuation of historic runoff patterns within a degree of natural variability. In addition, development within the watershed and other resource management objectives for fisheries and water quality protection are premised on the present management regime being maintained.

A review of the streamflow record from the Appleton stream gauge (WSC 02KF006) which dates back to 1919, provides some insight into the potential implications of changing climate conditions. As shown in Figure 4.24, the streamflow record indicates a shift in average streamflow conditions between the periods 1919 – 1973 and 1974 – 2002. The spring freshet occurs approximately 10 days earlier in the later period with an increase in fall/winter streamflows of approximately 43%.

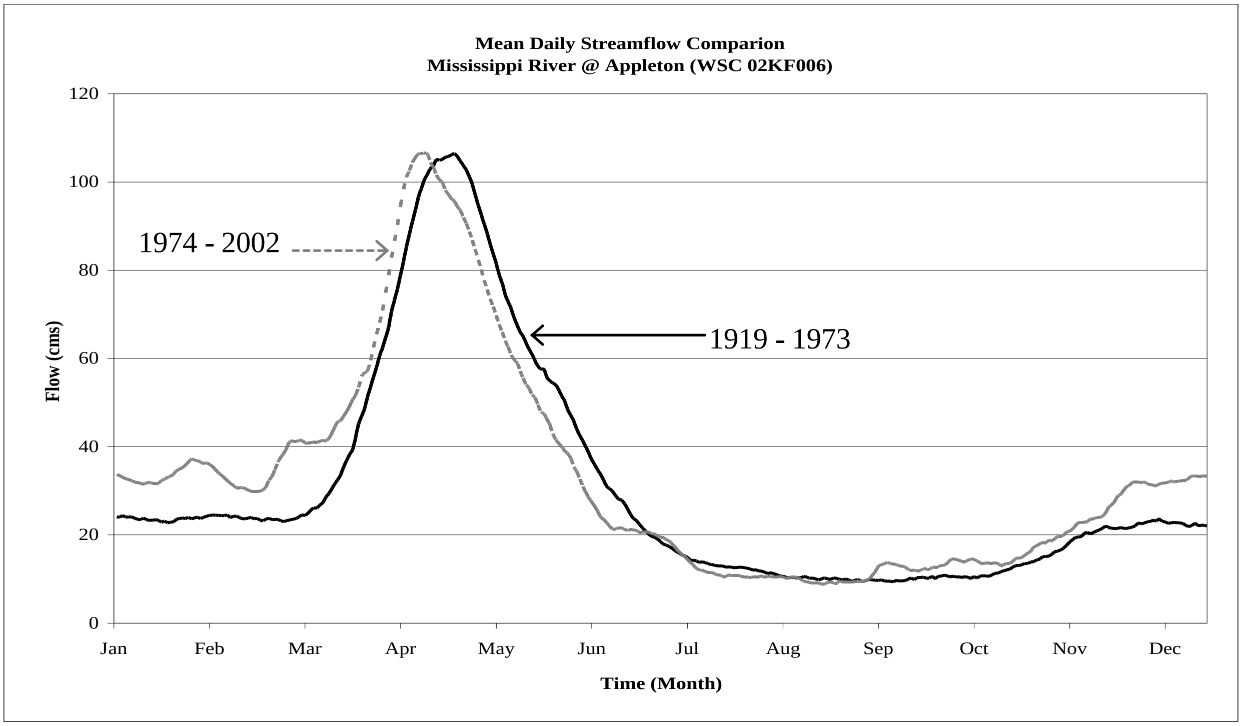


Figure 4.24: Comparison of Mean Daily Streamflow at Mississippi River @ Appleton Gauge for 1919-1973 and 1974-2002 Periods

Further insight can be gained by examining changes in seasonal streamflow characteristics. The Mann-Kendall test was applied to the seasonal streamflow series to test for statistically significant trends in the data set. Mean annual streamflow at Appleton over the period of record, shown in Figure 4.25 is approximately 30 cms and does not demonstrate any statistically significant trend [Table 4.12]. However, as shown in Figure 4.26, the mean streamflows for the months of January and February over the period of record demonstrates a statistically significant increase [α = 0.001] with a corresponding increase in variability [Table 4.12].

In contrast, Figure 4.27 shows a trend towards lower minimum streamflows expressed as a 7-day mean for the period of July 1 through October 15 [α = 0.001, Table 4.12]. In the period of record prior to 1960, streamflows consistently remain above 5 cms while after 1960 streamflows fall below 5 cms on 11 occasions and below 4 cms twice (1999 and 2001). The significance of this condition lies in the Mississippi River Water Management Plan (2006) which establishes a minimum outflow objective for the Crotch Lake reservoir of 5 cms which reflects the physical limitations of the Mississippi River reservoir system. This trend suggests that the existing water control infrastructure may not have the capacity to fully satisfy the current water management plan objectives.

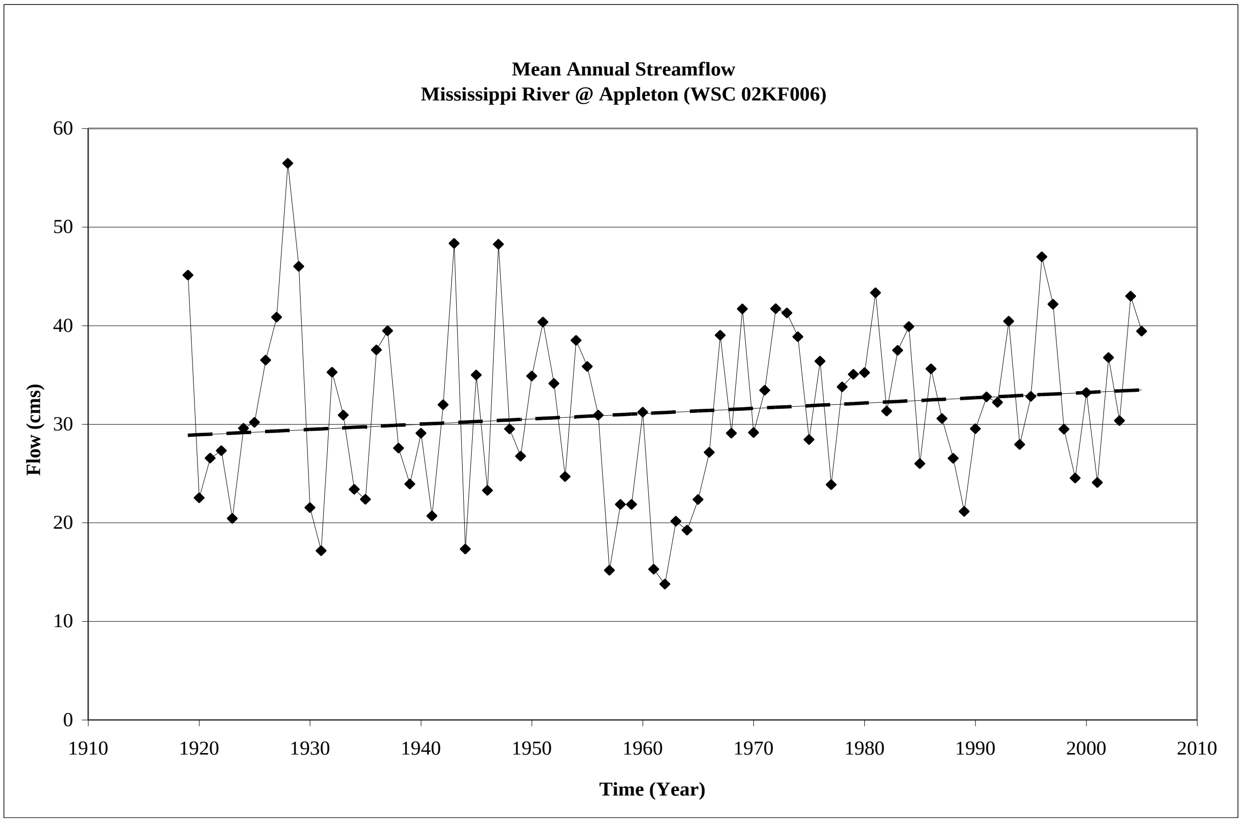


Figure 4.25: Mean Annual Streamflow at Mississippi River @ Appleton Ga5ge [1919-2005]

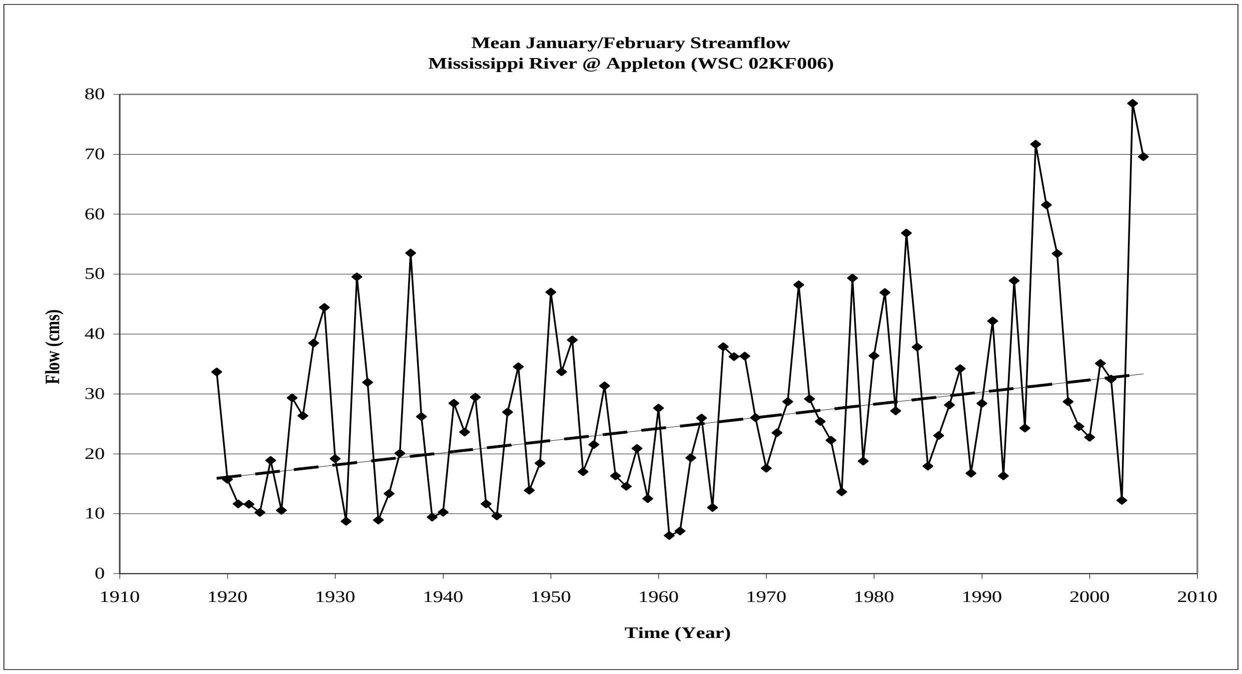


Figure 4.26: Mean Streamflow (January/February) at Mississippi River @ Appleton Gauge [1919-2005]

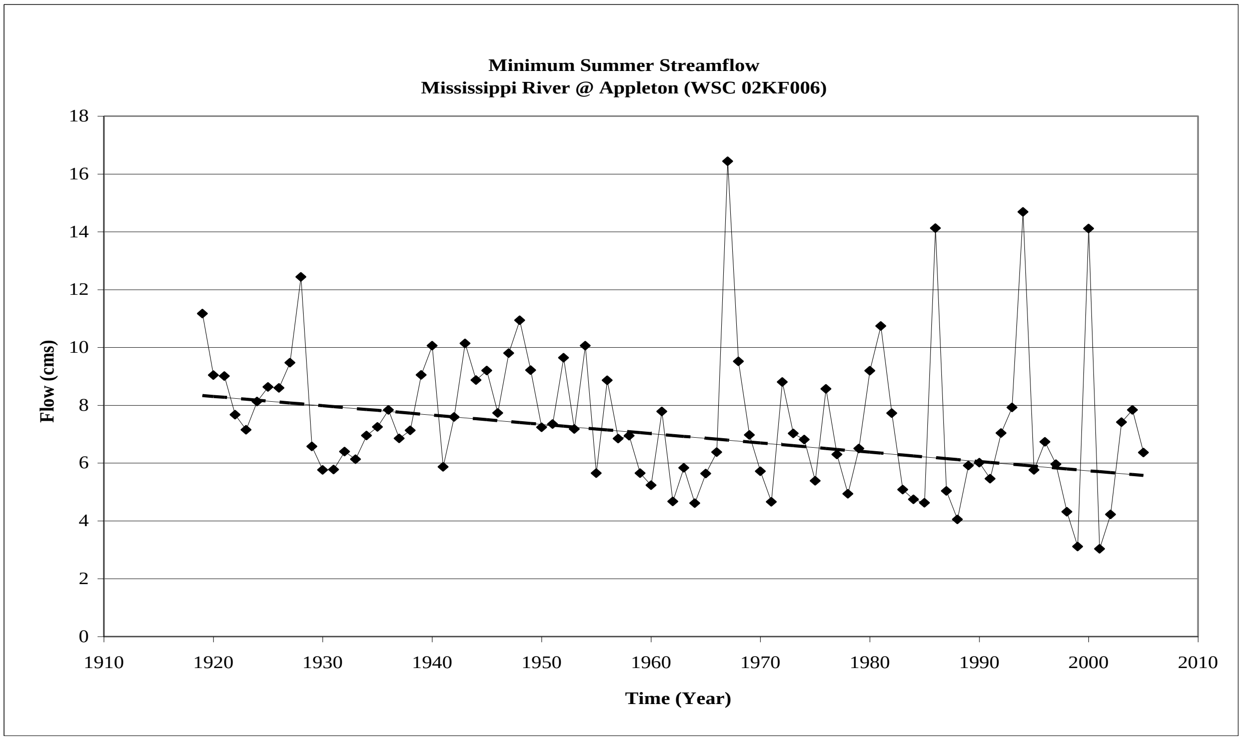


Figure 4.27: Mean Streamflow (July through October) at Mississippi River @ Appleton Gauge [1919-2005]

Table 4.12: Regression and Mann-Kendell Statistics

Data Period	**Regression Equation**	**Coeff. of Determination (r)**	**Mann-Kendell Statistics**	
			Z value	**Significant level (α)**
1919-2005 Flow @ Appleton				
Mean Annual Flow	Y = 0.053T - 73.81	1	1.4	>0.1
Mean Winter Flow	Y = 0.203T - 373.6	1	3.32	0.001
Min. Summer Flow	Y = -0.032T + 70.02	1	-3.45	0.001
1972-2003 Flow @ Gordon Rapids				
Mean Annual Flow	Y = 0.1437T + 28.685	0.16	-0.18	>0.1
Mean Winter Flow	Y = 0.0255T + 1.5494	0.00	0	>0.1
Min. Summer Flow	Y = -0.0022T + 0.6267	0.10	0	>0.1
Max. Summer Flow	Y = 0.0055T + 2.3047	0.04	0.57	>0.1
2010 - 2099 Simulated Flow @ Gordon Rapids				
Mean Annual Flow	Y = -0.0641T + 23.354	0.00	-1.24	>0.1
Mean Winter Flow	Y = 0.0009T + 4.489	0.00	-0.26	>0.1
Min. Summer Flow	Y = -.0072T + 1.0415	0.21	-2.16	0.05
Max. Summer Flow	Y = -0.0137T + 3.6061	0.22	-1.95	0.1
Model Calibration Validation 1975 - 2003 Flow @ Gordon apids				
Mean Annual Observed Flow	Y = -0.013T + 3.294	0.01	-0.66	>0.1
Mean Annual Simulated Flow	Y = 0.009T + 2.939	0.22	-0.43	>0.1

4.3.10.3 Other Factors Affecting Streamflow

Operating records for the reservoir system prior to 1950 are sparse, however, based on records that are available it appears that operation of the Crotch Lake reservoir has largely remained unchanged. However, based on available information and anecdotal evidence the upper reservoirs may have been subjected to some restrictions in their use for streamflow augmentation during the summer months. It is not expected that these restrictions can fully account for the trends being noted although they may be an aggravating factor.

Large scale changes in land cover and drainage patterns can also have the ability to influence the streamflow characteristics of a watershed. Forest cover within the Mississippi River watershed upstream of Appleton is presently 70% with mixed deciduous and coniferous forest. Active forest harvesting has occurred particularly in Lanark and Frontenac counties, although this resource has been actively harvested over the past century and forest cover continues to be the dominant land use in the watershed.

No large scale drainage projects or wetland loss has been noted over the period of record which could account for changes in streamflow.

4.3.10.4 Water Resource Implications

In an effort to investigate the potential for climate change to influence the streamflow characteristics of the Mississippi River the present study was undertaken to assist in quantifying the impact which projected climate scenarios may have on streamflow conditions and the ability of existing water control infrastructure and management plans to respond to those conditions.

As discussed previously, the methodology used in the present study was to generate a synthetic streamflow series for the Mississippi River under projected climate scenarios to the year 2099. The streamflow series was subsequently applied as inflows to the reservoir system to assess the performance of the water control infrastructure in satisfying the water management objectives as established through the Mississippi River Water Management Plan.

The synthetic streamflow series generated from the climate modeling provided a continuous time series of streamflows for the Clyde River at Gordons Rapids for the period 1974 to 2099. This series was subdivided as discussed previously into four subsets representing 1974-2002, 2010-2039, 2040-2069 and 2070-2099. The 1974-2002 subset provided a base period on which to evaluate the impact of climate projections over successive periods relative to the base period.

Each period was initially described by the mean daily streamflow hydrograph for the period, then transposed to the adjacent sub-basins and subsequently routed through the watershed and reservoirs to the Mississippi River at Appleton based on current water management objectives. The resulting average streamflow conditions at Appleton are shown in Figure 4.28.

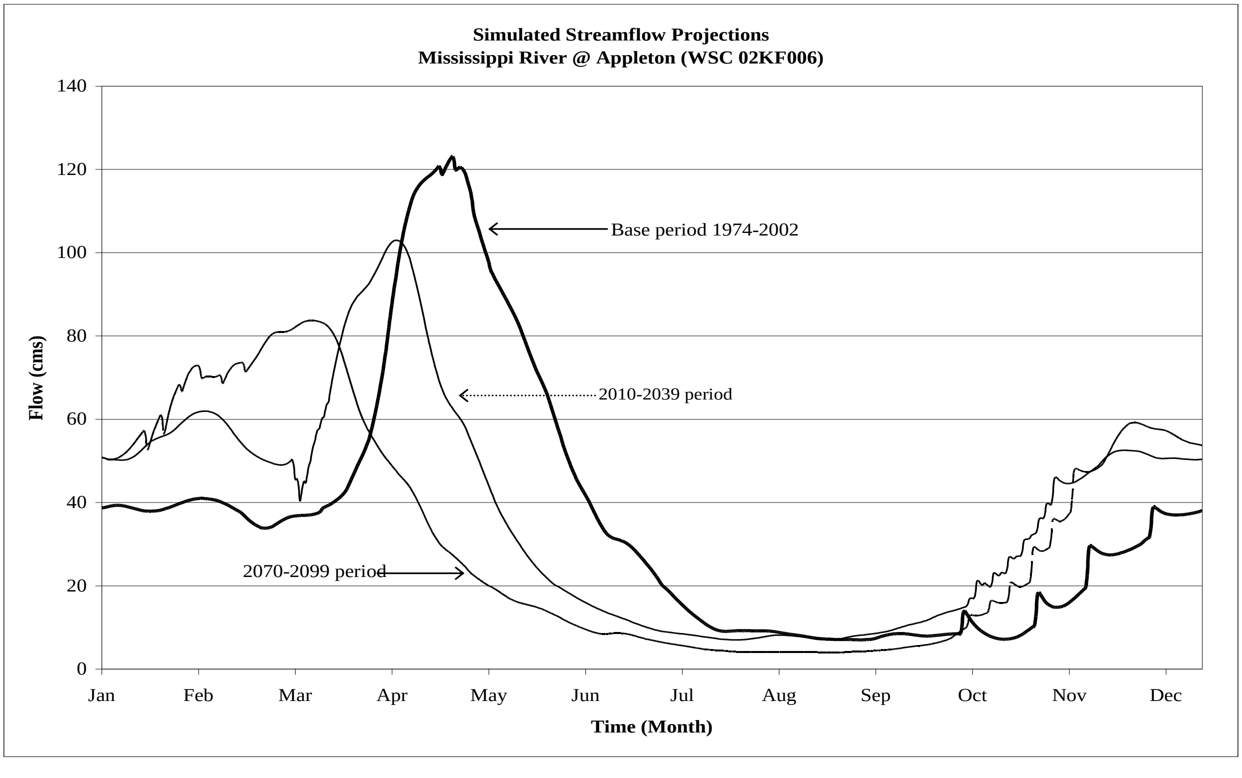


Figure 4.28: Simulated Streamflow projections at Mississippi River @ Appleton Gauge for 2010-2039, 2070-2099 Periods

As indicated in Figure 4.28, the changes in projected streamflow conditions are consistent with observed changes occurring in the actual streamflow record between 1919 and 2002. Results of the reservoir simulations indicate that average annual streamflow will decrease by 10% between the base period (1972 – 2002) and the future period (2070 – 2099). In general, streamflows will increase substantially in the fall (Oct – Dec) and winter (Jan – Feb) periods by 74% and 70% respectively while they will decrease in the spring (Mar – May) and summer (Jun – Sept) by 43% and 66% respectively. On average, spring freshets will occur 6 to 7 weeks earlier in the 2070 – 2099 period than in the 1972–2002 base period and will be approximately 33% lower in peak streamflow. Minimum summer flows will decrease by approximately 44% and will persist 28% longer.

4.3.10.5 Extreme Events

The Clyde River @ Gordons Rapids streamflow projections as shown in Figure 4.29 suggest that maximum annual streamflow will tend to decrease while the variability of summer maximum streamflows as shown in Figure 4.30 is expected to increase [α = 0.1, Table 4.12]. This will require further research to assess the potential implications of high intensity rainfall events on factors such as flood risk and nutrient loading from non-point sources.

Low flow conditions on the Mississippi River are expected to become more frequent and severe in the later periods. While these will be moderated through streamflow augmentation, the capacity of the reservoir system to satisfy current streamflow objectives will be insufficient. The reservoir capacity is insufficient to meet current objectives under extreme low flow conditions as experienced in 1999. Low flow events on the Mississippi River are expected to become more prolonged as seen in Figure 4.31. Minimum streamflows in 1999 were 2.5 cms as compared to 2.4 cms and 1.7 cms in 2030 and 2083 respectively.

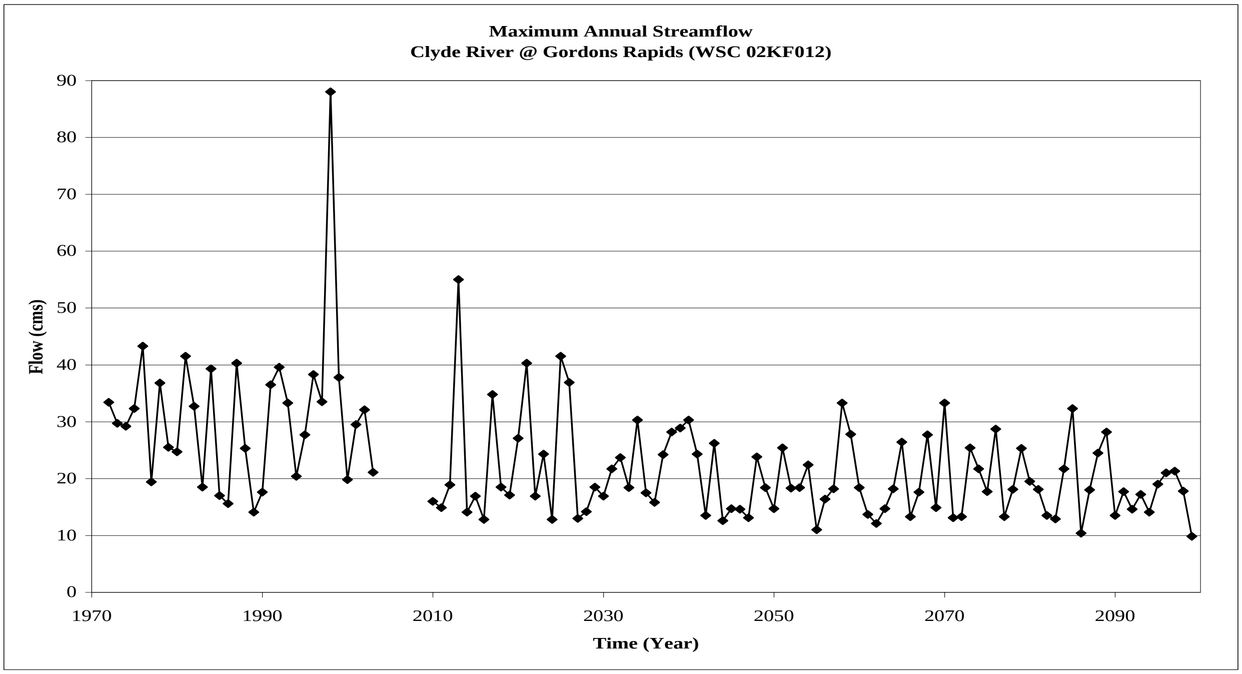


Figure 4.29: Maximum Annual Streamflow at Clyde River @ Gordon Rapids [1975-2100]

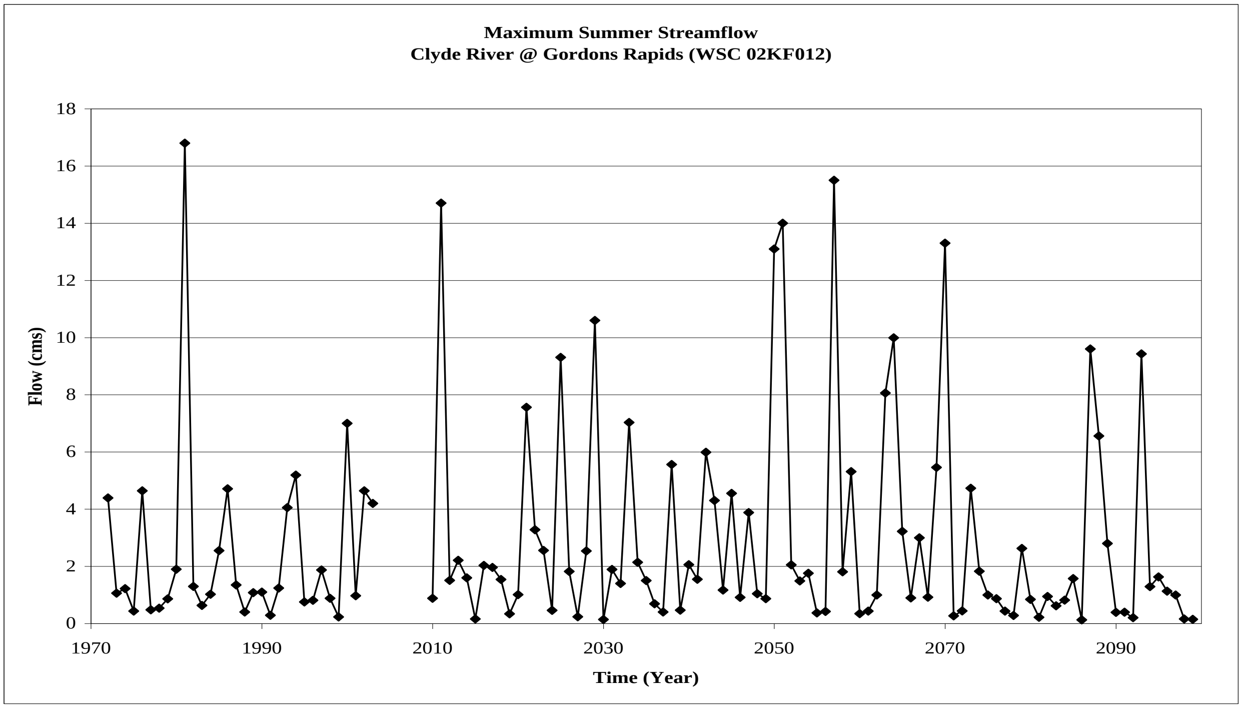


Figure 4.30: Maximum Summer Streamflow at Clyde River @ Gordon Rapids [1975-2100]

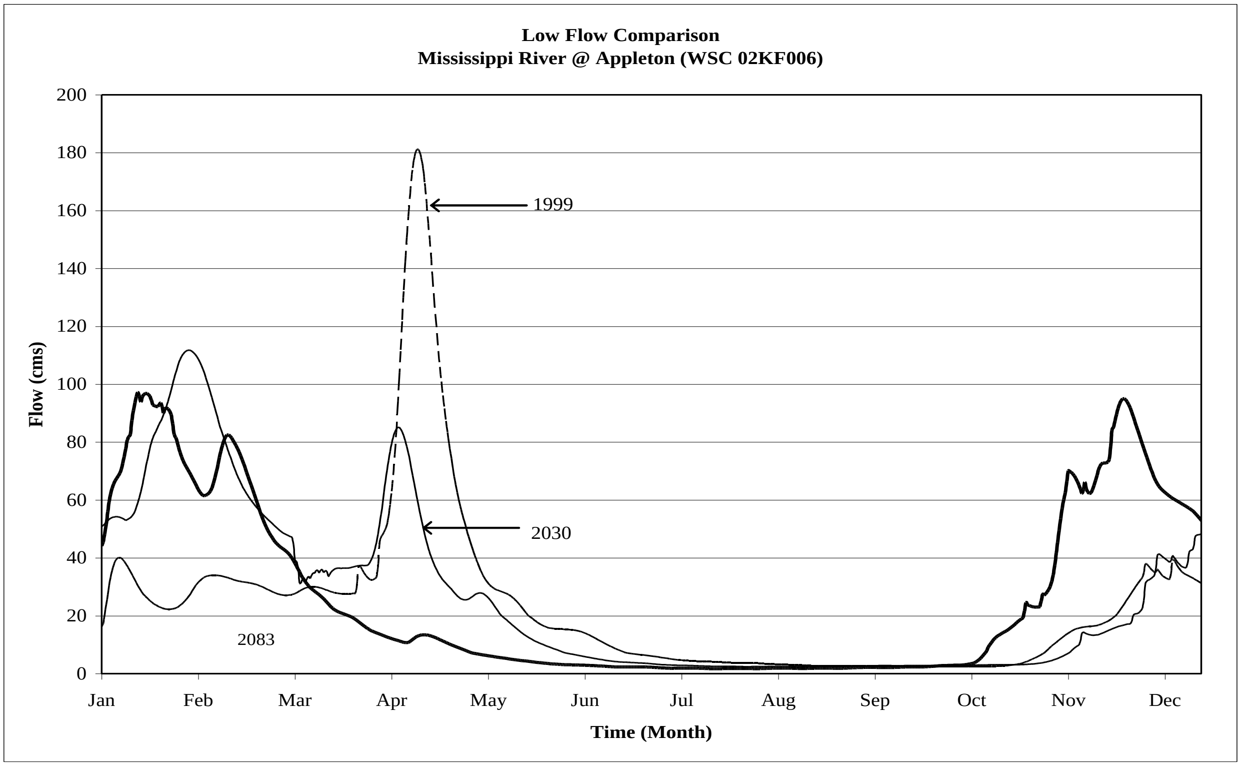


Figure 4.31: Low Flow Comparison at Mississippi River @ Appleton Gauge

4.3.10.6 Reservoir Operation and Capacity

As noted in Figure 4.28, the most significant affect of the projected change in climate conditions for the Mississippi River will be a shift in the temporal distribution of runoff which will be incompatible with current reservoir operation policies. The existing reservoir system addresses multiple water management objectives such as flood reduction, low flow augmentation, maintaining fish habitat and supporting recreation and tourism.

While in general recreational interests can be satisfied on the upper reservoirs, existing reservoir capacity is insufficient to meet downstream low flow augmentation objectives under extreme conditions. To satisfy these objectives additional reservoir volumes of 2000 to 3500 ha-m will be required.

The current strategy of reservoir drawdown in the fall will present risks for flood and erosion damage as streamflow conditions are expected to be on average 74% higher during the drawdown period. The mean projected streamflow rates (for all future periods) will be 3ufficient to place flood susceptible areas of the watershed near flood stage for much of the fall and winter periods. Restricting drawdown of the reservoirs to lessen the risk in the fall may subsequently place the same flood prone areas at risk from spring snowmelt should accumulation of a snow pack occur. Likewise, flood susceptibility and risk of erosion on reservoir lakes will increase with higher reservoir levels over the winter. There is a high degree of uncertainty associated with this risk as mean monthly temperatures approach 0°c during the winter months, and snow accumulation becomes more variable, particularly in the 2070-2099 period.

4.3.10.7 Water Resource Impacts and Response Summary

Table 4.13 provides a summary of water resource implications for the Mississippi River as a result of projected changes in climate conditions and potential response measures which may be considered to assist in adaptation. While the direct impacts of the projected changes in climate are significant to the basins water resources, the indirect or secondary affects on existing infrastructure and resource management policies are more difficult to assess.

The projected changes in climate and associated runoff patterns in the Mississippi River watershed are expected to create conflicts among competing interests for the basin’s water resources. More severe and prolonged low flow conditions when coupled with higher surface water temperatures and the potential for higher nutrient loading will also result in substantial stress on the aquatic ecosystem. Resource management policies and related infrastructure which have been developed based on our past experience and expectations of climate norms will require modification to address a range of social and environmental impacts. At the local level, addressing these will be more difficult given our current administrative structures which are not conducive to integrated planning and decision making.

Table 4.13: Water Resource Impacts and Response Summary

Objective	Water Resource Impact	Potential Response
Low flow augmentation Water supply Hydro Generation	More severe and prolonged low flow conditions Reservoirs will be insufficient to satisfy current low flow targets Municipal water supply requirements will be fully dependant on reservoir supplies Hydro generation potential will be reduced in summer low flow periods	Increased reservoir storage by 2000 to 3500 ha-m required to meet current objectives Continued maintenance and reconstruction of water control infrastructure Minimize water use and consumption
Fish habitat	Lower streamflows during typical walleye spawning periods Loss of traditional pike spawning habitat due to lower water levels during spawning period	Identify and protect significant spawning areas Develop opportunities for fish passage around str5ctural barriers
Flood protection	Generally lower risks from spring snowmelt/rainfall events Greater risk of fall/winter flood conditions coupled with reservoir drawdown	Discontinue/reduce fall drawdown regime Assess implementation of risk based reservoir management strategy Assess alternative flood damage reduction measures
Tourism/recreation	Generally capable of achieving recreational water level targets on reservoirs Lower streamflows will be insufficient to maintain recreational levels within current objectives	Assess efficacy of lower and broader operating targets on recreational lakes including the provision for flood reserves
Water quality protection	Lower streamflows in the summer will reduce flushing rates and waste assimilation capacity Higher intensity rainfall events will increase nutrient loading to the river system Total phosphorous levels currently approaching limit of provincial water quality objective for Policy 2 streams Greater risk for low dissolved oxygen levels	Quantify nutrient loading Reduce point and non-point loading Minimize disruption and alteration to natural stream corridors and shore lands

4.4 SUMMARY AND CONCLUSIONS

The CGCM2 climate projections and the CLIMGEN generated future climate data for the Mississippi River watershed projects an increase in the minimum and maximum temperatures throughout the year, except for the maximum temperatures in December. The winter [January through March] minimum temperatures, winter maximum temperatures and summer minimum temperatures increase considerably over the 2010 to 2099 periods. The highest percentage rate change was observed in the minimum temperature, which increased in the months of January and February by 0.05^0C/yr to 0.13^0C/yr for the 2010 to2099 periods. Wetter fall conditions are predicted, however, winter conditions are more or less the same as the base period [1984-2000]. There is more variability in both the actual and generated precipitation data than that of minimum or maximum temperatures. The base period average annual precipitation of 849 mm with a standard deviation of 31mm increases to 907 mm by 2099 with a standard deviation varying between 32 to 34 mm.

The water budget model projects increases of 74% in mean annual temperature, 10% in precipitation, 20% in rainfall, 23% in potential evapotranspiration and 144% in deficit. Snowmelt decreases by 25%, surplus decreases by 3%, snow accumulation decreases by 67% and soil moisture decreases by 12% between the 1985 and 2099 periods.

The NAM model calibrated with 21 years [01-01-1973 to 12-31-1993] of actual flow data for the Clyde River @ Gordon's Rapids stream gauge. Simulated and observed stream flows match well with a coefficient of determination of 0.72, and their accumulated flows also compared well with each other. Good agreement was observed between the simulated and observed runoff with a higher coefficient of determination of 0.74 for NAM model validation with 10 years [1994-2003] of actual flow data.

Results of the reservoir simulations indicate that average annual stream flow will decrease by 10% between the base period (1972 – 2003) and the future period (2070 – 2099). In general, stream flows will increase substantially in the fall (Oct – Dec) and winter (Jan – Feb) periods by 74% and 70% respectively while they will decrease in the spring (Mar – May) and summer (Jun – Sept) by 43% and 66% respectively. On average, spring freshets will occur 6 to 7 weeks earlier in the 2070 – 2099 period than in the 1972 – 2003 period and will be approximately 33 % lower in peak stream flow. Minimum summer flows will decrease by approximately 44% and will persist 28% longer.

4.5 REFERENCES

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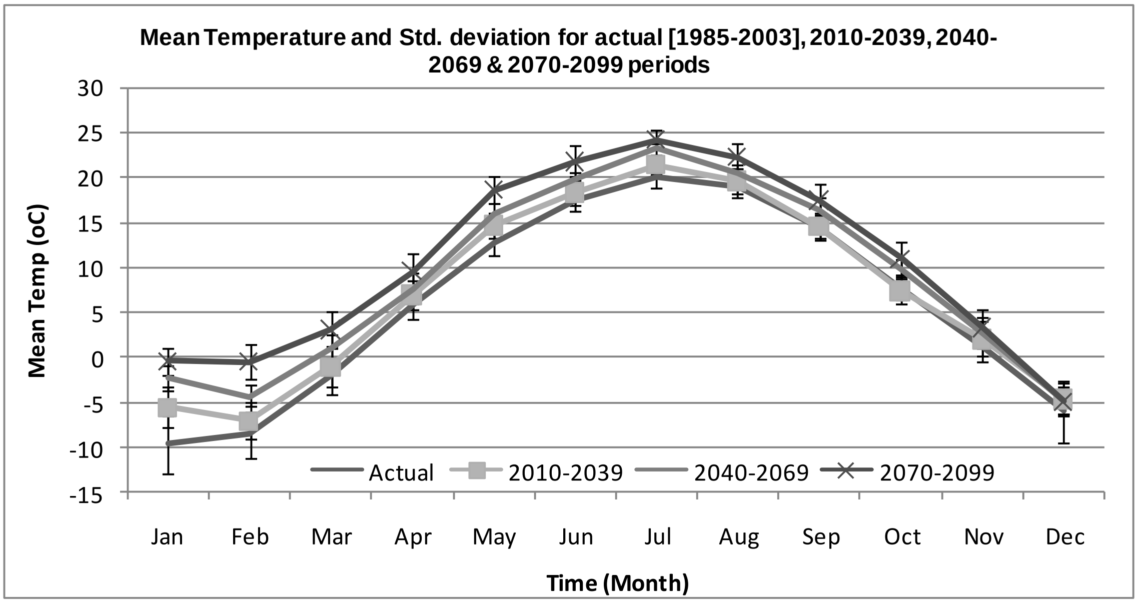
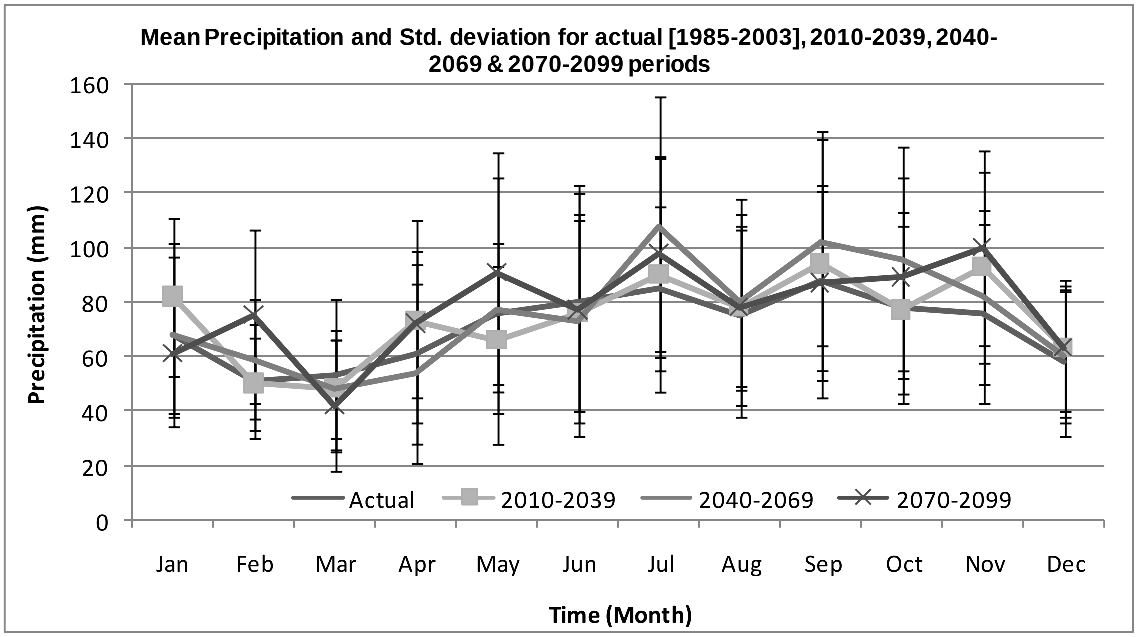
APPENDICES

Appendix 4-A1: Mean and Standard Deviation of Actual and Generated Temperature Data



Appendix 4-A2: Mean and Standard Deviation of Actual and Generated Precipitation Data



Appendix 4-A3: Statistical Analysis Results of ClimGen Generated Climate Data for 2010-2039 period

Variable		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wet day count		389	322	322	347	350	335	342	313	396	361	445	366
Dry day count		541	525	608	553	580	565	588	617	504	569	455	564
Wet days following dry days count		191	171	170	170	149	157	182	157	189	183	190	214
Wet days following wet days count		198	151	152	177	201	178	160	156	207	178	255	152
Days of valid data count		930	847	930	900	930	900	930	930	900	930	900	930
Precipitation	mean	83.52	51.31	47.5	72.31	65.46	77.58	90.73	78.08	93.9	78.93	93.09	62.86
Max. temperature for all days	mean	-0.63	-1.185	4.566	12.6	21.97	24.85	27.67	26.28	20.79	12.82	6.903	-0.54
	sum	-589	-1003	4246	11343	20436	22366	25729	24443	18712	11925	6213	-500
	std.dev.	6.033	5.792	6.771	7.463	5.305	4.656	3.917	4.405	4.955	5.797	6.397	6.194
	min	-20.6	-25.28	-14.9	-8.82	3.786	10.45	15.64	13.32	5.57	-4.36	-10.7	-20.7
	max	17.01	18.84	24.55	34.95	38.05	38.39	40.62	40.85	38.44	29.24	25.81	17.9
	count	930	847	930	900	930	900	930	930	900	930	900	930
Min. temperature for all days	mean	-10.5	-12.79	-6.74	1.392	7.452	11.8	15.16	12.92	8.392	2.047	-2.67	-8.84
	sum	-9757	-10829	-6265	1253	6930	10617	14095	12017	7553	1903	-2403	-8220
	std.dev.	9.039	8.435	8.44	3.857	5.099	4.506	3.877	4.817	5.084	5.253	5.805	5.06
	min	-44.1	-41	-37.2	-12.2	-8.8	-1.32	4.225	-2.35	-8.37	-13.6	-17.8	-26.6
	max	10.39	9.536	13.89	12.95	23.58	24.57	26.48	25.88	22.82	19.87	13.61	9.743
	count	930	847	930	900	930	900	930	930	900	930	900	930

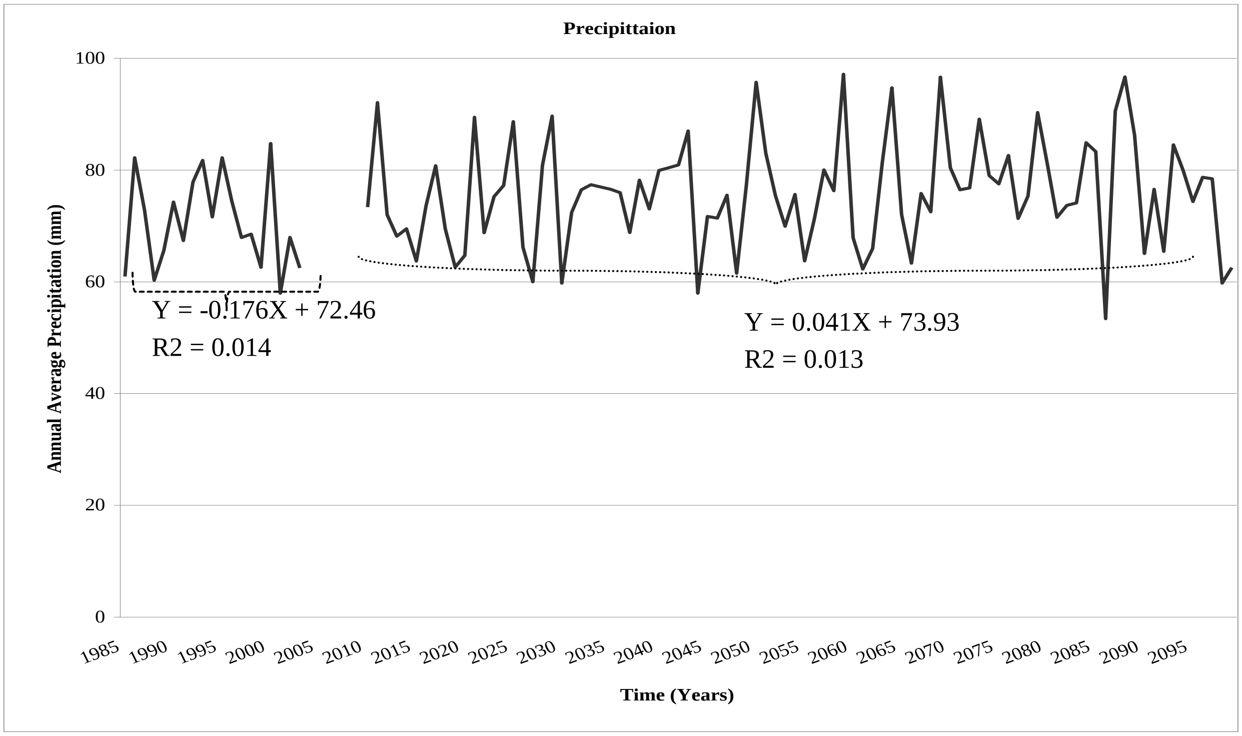
Appendix 4-A4: Statistical Analysis Results of ClimGen Generated Climate Data for 2040-2069 period

Variable		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Wet day count		348	346	283	283	354	356	377	300	407	399	422	386
Dry day count		582	502	647	617	576	544	553	630	493	531	478	544
Wet days following dry days count		194	194	158	147	155	172	207	160	174	181	170	199
Wet days following wet days count		154	152	125	136	199	184	170	140	233	218	252	187
Days of valid data count		930	848	930	900	930	900	930	930	900	930	900	930
Precipitation	mean	68.81	58.81	48.22	53.84	79.29	76.57	108	79.64	104.7	96.85	83.82	61.62
Max. temperature for all days	mean	1.557	0.779	5.69	13.41	23.55	26.15	29.32	27.06	22.44	14.99	7.68	-0.64
	sum	1448	660.9	5292	12066	21902	23533	27268	25162	20200	13941	6912	-598
	std.dev.	5.166	4.955	6.376	8.196	4.863	4.418	3.402	4.358	5.184	5.196	6.688	5.741
	min	-18.3	-15.24	-11.3	-9.5	2.972	14.04	17.03	12.76	4.111	-0.95	-10.5	-18
	max	22.1	13.92	30.33	40.97	41.76	44.5	38.9	39.98	40.08	31.78	26.56	16.87
	count	930	848	930	900	930	900	930	930	900	930	900	930
Min. temperature for all days	mean	-6.28	-9.172	-3.53	1.754	8.317	13.57	17.1	13.91	10.26	4.426	-2.16	-9.06
	sum	-5837	-7778	-3282	1578	7735	12214	15900	12940	9231	4116	-1941	-8425
	std.dev.	7.216	7.333	6.923	4.037	5.478	4.307	2.999	4.435	5.528	5.406	6.353	4.821
	min	-39.1	-30.51	-30.8	-20.8	-7.72	-1.75	7.641	-1.53	-9.99	-15.6	-19.5	-27.6
	max	12.58	10.85	15.39	17.28	24.38	25.6	26.89	26.73	27.61	18.9	15.83	5.638
	count	930	848	930	900	930	900	930	930	900	930	900	930

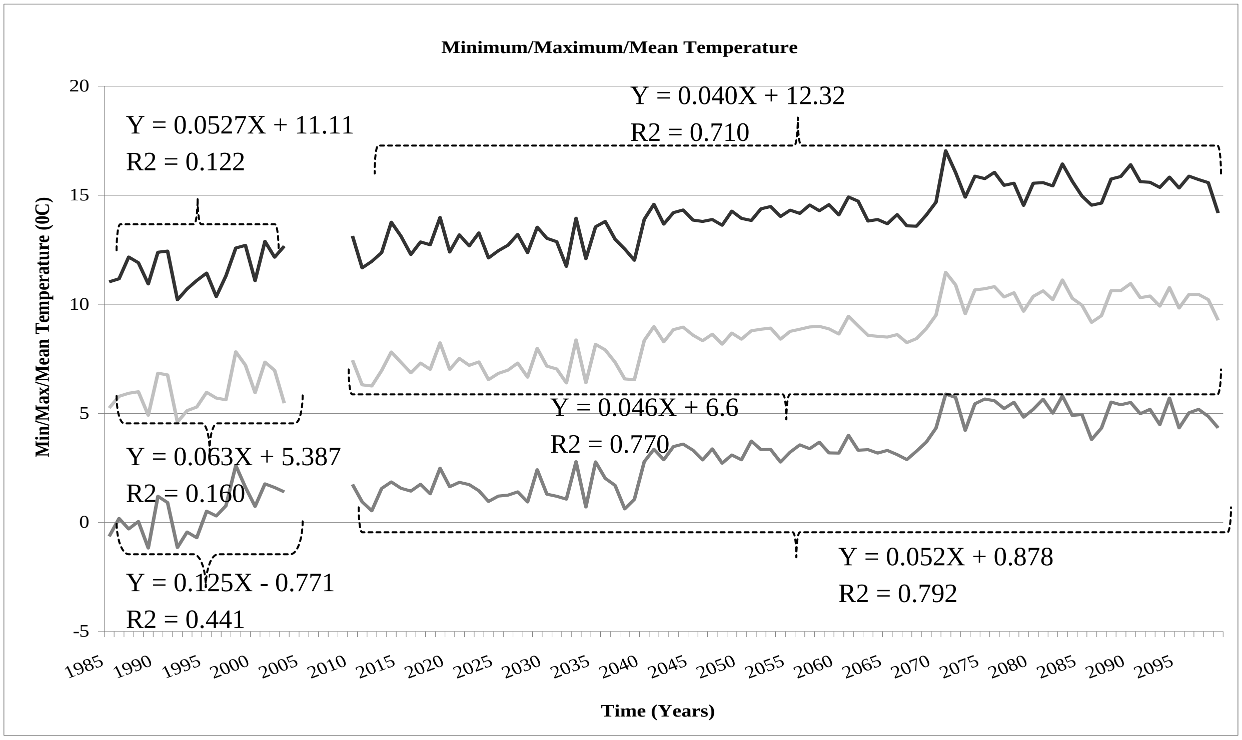
Appendix 4-A5: Statistical Analysis Results of ClimGen Generated Climate Data for 2070-2099 period

Variable		**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Wet day count		370	337	249	338	375	343	362	314	421	406	420	360
Dry day count		560	510	681	562	555	557	568	616	479	524	480	570
Wet days following dry days count		206	163	138	161	166	147	201	178	198	185	182	205
Wet days following wet days count		164	174	111	177	209	196	161	136	223	221	238	155
Days of valid data count		930	847	930	900	930	900	930	930	900	930	900	930
Precipitation	mean	61.32	74.17	41.42	72.15	91.43	78.72	96.72	76.66	87.44	89.29	101	64.03
Max. temperature for all days	mean	2.038	3.376	6.939	15.83	26.56	27.75	30.26	28.75	23.8	16.61	8.444	-0.88
	sum	1895	2859	6453	14247	24701	24975	28141	26739	21424	15446	7600	-820
	std.dev.	4.443	4.561	6.186	9.647	4.231	4.51	3.689	4.506	5.482	5.581	6.919	6.559
	min	-10.9	-7.98	-11	-6.66	9.329	12.74	17.7	8.207	9.02	-1.53	-13	-21.7
	max	24.12	23.37	33.28	46.08	39.55	40.3	41.15	40.36	38.79	34.74	29.61	20.06
	count	930	847	930	900	930	900	930	930	900	930	900	930
Min. temperature for all days	mean	-2.89	-4.422	-0.7	3.288	10.93	15.98	18.14	15.65	11.22	5.548	-1.83	-9.19
	sum	-2691	-3745	-649	2959	10161	14379	16870	14558	10100	5160	-1649	-8545
	std.dev.	4.784	6.786	6.27	3.896	6.213	4.661	3.617	4.295	5.718	5.825	6.915	4.777
	min	-22.9	-30.52	-29.4	-18.2	-9.73	1.838	6.108	0.729	-7.67	-14.2	-21	-25.8
	max	9.898	10.84	15.75	17.12	32.9	31.91	28.86	29.97	27.8	22.89	20.06	9.14
	count	930	847	930	900	930	900	930	930	900	930	900	930

Appendix 4-A6: Actual and Predicted Precipitation Trend at Mississippi Watershed [1985-2099 Periods]



Appendix 4-A7: Actual and Predicted Min., Max., and Mean Temperature Trend at Mississippi Watershed [1985-2099 Periods]



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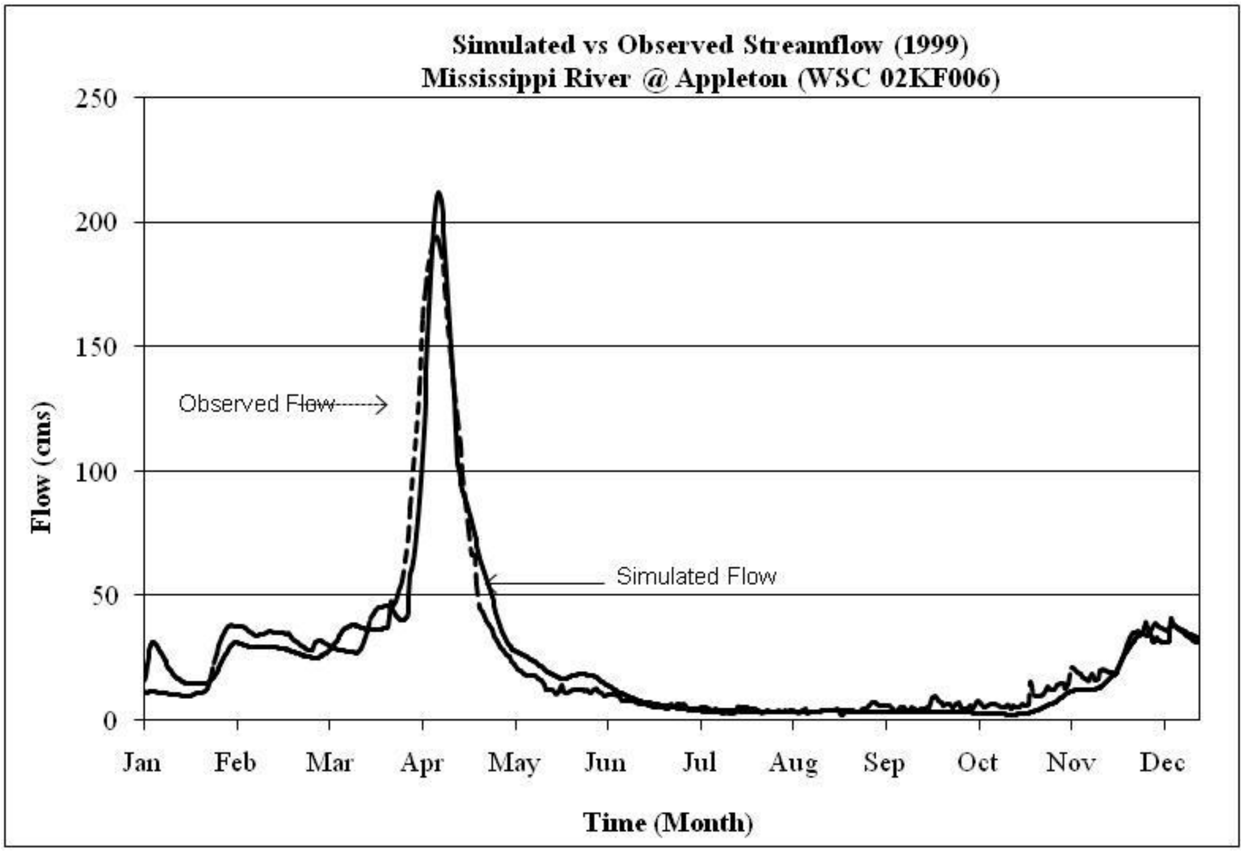
Appendix 4-A8: Regression and Mann-Kendell Statistics

Data Period	Regression Equation	Coeff. of Determination (r)	Mann-Kendell Statistics	
			Z value	Significant level (α)
1985-2003				
Precipittaion	Y = -0.176T + 72.46	0.118321596	-0.28	>0.1
Min. Temp.	Y = 0.125T - 0.771	0.664078309	2.73	0.001
Max. Temp.	Y = 0.052T + 11.11	0.349284984	1.68	0.1
Mean Temp.	Y = 0.063T + 5.387	0.4	1.54	>0.1
2010-2099				
Precipittaion	Y = 0.041T + 73.93	0.114017543	1.43	>0.1
Min. Temp.	Y = 0.052T + 0.878	0.889943818	8.93	0.001
Max. Temp.	Y = 0.040T + 12.32	0.842614977	8.97	0.001
Mean Temp.	Y = 0.046T + 6.6	0.877496439	9.2	0.001

Appendix 4-A9: Simulated vs. Observed Streamflow at Mississippi River @ Appleton for the year 1999



Appendix 4-A10: Simulated vs. Observed Streamflow at Mississippi River @ Appleton for the year 2001