AN OVERVIEW OF RECENT CLIMATE CHANGE AND STREAMFLOW IN THE MASSAWIPPI RIVER BASIN

Norman K. Jones
Department of Environmental Studies and Geography, Bishop's University

ABSTRACT

A study of the trends of climatic and hydrologic variables between 1960 and 2004 was completed for the Massawippi River basin in southern Quebec. Analysis of these trends was used to evaluate possible changes in streamflow in the basin. This basin is flood-prone, especially during the spring months, with portions of the basin having been inundated 95 times during the 20th century. Trends were analyzed initially using cumulative percentage departure from the mean plots, taken from the raw data. The graphical results indicate trends toward increasing winter and spring temperatures and a change in precipitation type from snow to rain. Decreases in winter snow accumulations are particularly evident. Graphical analyses show some trend toward decreasing maximum and total river discharges, but the trends are not statistically significant. There is no clear evidence that changes in the climatic variables are causing significant changes in river behaviour. Thus there is no evidence that changing climatic conditions are creating greater streamflows.

RÉSUMÉ

Une étude sur les tendances des variables climatiques et hydrologiques entre 1960 et 2004 a été effectuée pour le bassin de la rivière Massawippi, dans le sud du Québec. L'analyse de ces tendances a été utilisée pour évaluer les changements possibles dans ce bassin. Vulnérable aux inondations, en particulier pendant la période printanière, le bassin a été en partie inondé à 95 reprises au cours du 20e siècle. Les tendances ont été analysées dans un premier temps au moyen du pourcentage cumulatif d'écart par rapport aux courbes moyennes, établi d'après les données brutes. Les résultats graphiques indiquent une tendance à la hausse des températures printanières et hivernales et une modification du type des précipitations, qui passent de la neige à la pluie. La diminution des accumulations de neige en hiver est particulièrement évidente. D'après les analyses graphiques, on note que les débits (maximal et total) de la rivière ont tendance à diminuer, mais ces tendances ne sont pas statistiquement *significatives. Rien ne démontre nettement que les changements des variables climatiques causent des changements significatifs dans le comportement de la rivière ou des crues. Rien ne prouve donc que le changement des conditions climatiques fasse augmenter les débits de la rivière.*

Introduction

Climate change, especially the concept of 'global warming', has become of increased public and scientific interest. Rapid climate change has been documented for past millennia (Harvey, 2000) and is anticipated for the future. One area of interest to geographers has been the effect climate change may have on river regimes. Numerous studies relating climatic and hydrologic changes have been completed in various regions of Canada.

Roy et al. (2001) anticipate serious increases in the volume of future streamflow in the Chateauguay River Basin of Quebec, based on their analyses of global warming predicted by general circulation models (GCMs). Dibike and Coulibaly (2005) use data output by GCMs to study changes in precipitation and streamflow in the Saguenay River Basin. They predict an increasing trend in temperature and precipitation values, leading to increasing trends in streamflow and earlier peak spring flows.

Burn et al. (2004), working in the Mackenzie River Basin, have also found a trend toward increasing streamflow, although they found most of the increase to be in winter and spring flows with a reduction in summer flow. Burn and Cunderlik (2004) found similar results for the Liard River Basin in northern Canada: increasing winter and spring flows, decreasing summer flow, and earlier spring and summer peak flows. Ashmore and Church (2001), in their pan-Canadian study, suggest these changes in streamflow regimes may be caused by increasing temperatures and precipitation, but decreasing snowfall amounts. However, they emphasize that the link between climate and hydrology is indirect and unknown.

Climate change is having, and will have, dramatically different effects in different regions of the country. For example, as glacier sizes diminish in western Canada, streamflows should drop significantly. In eastern Canada, increased precipitation amounts are expected to offset increased temperatures, resulting in total precipitation exceeding potential evapotranspiration and overall increased streamflows. Most previous research on this topic has been completed on large river basins (eg, Burn et al., 2004) or large geographic areas (eg, Ashmore and Church, 2001). The present study is a general overview of how some climate variables have affected streamflow in a relatively small drainage basin, the Massawippi River Basin, over the 45 year period from 1960 to 2004. This period has been chosen because hydrologic records for the basin begin in 1960.

The focus of the study is the relationship between regional climatic variables, such as temperature and precipitation amounts, and hydrological variables, such as average and peak flows, and how this relationship affects the quantity of water moving through a small river basin. The overall objectives of the research are, first, to determine whether there have been discernable changes in the climatic and hydrologic variables and, second, what effect any changes might have on surface water flow. Are the results of previous research in larger basins and areas, showing increases in temperature and precipitation leading to increases in streamflow, applicable in a smaller basin?

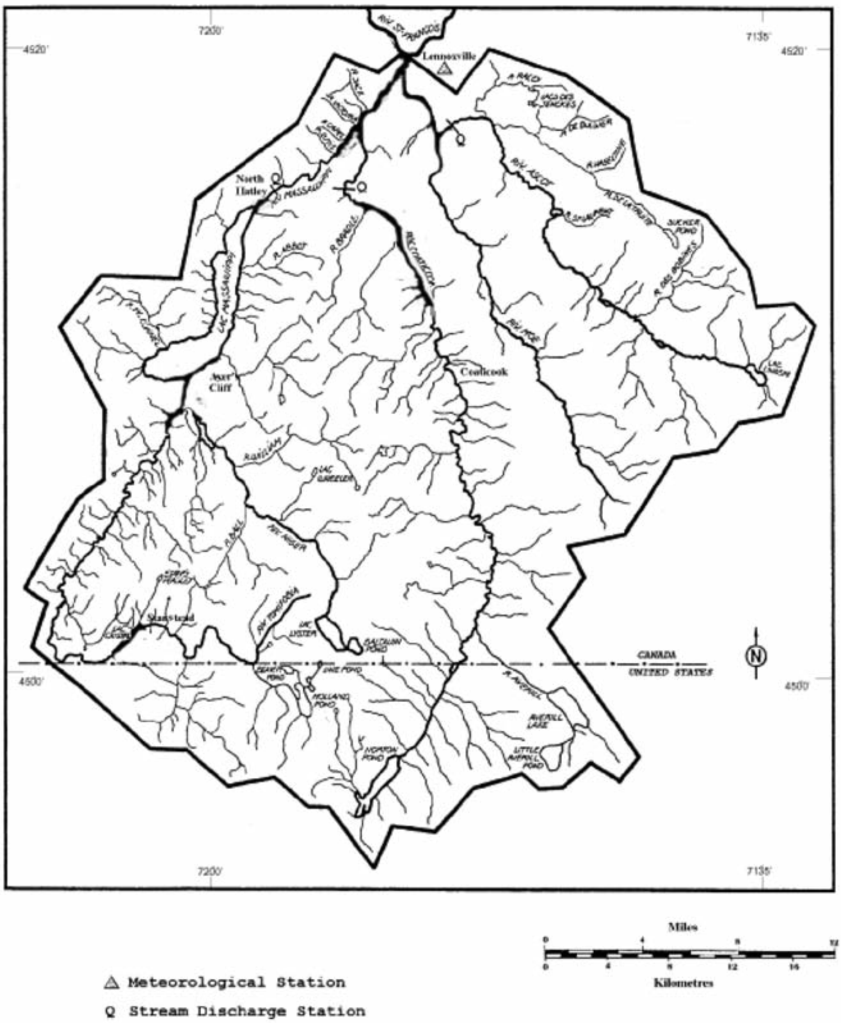
Methods

Trends in climatological and hydrological variables are assessed using a variety of statistical and graphical methods, both types of analyses being well suited for following recent trends in data. For this paper trends in data will be displayed using graphical plots of the data. Data plots present the data in its simplest form. Climate information is taken from the Environment Canada Lennoxville meteorological station which is situated at the north end of the study basin (Fig. 1). Temperature and precipitation data are available for the 1960 to 2004 period; hydrologic data from streamflow monitoring sites on the Massawippi, Coaticook and Ascot Rivers operated by *Le Centre d'expertise hydrique du Quebec* are available for the same period. Streamflow information for the Moes River has been calculated using a linear regression equation based on data from the adjacent Ascot River.

Data Presentation and Analysis

Previous studies (eg, Ashmore and Church, 2001) have shown that precipitation, rather than temperature, is the dominant climatic influence on streamflow. The graphical plots presented here are meant to show some of the possible relationships between precipitation, temperature and streamflow in the Massawippi Basin. The trends in the data, which can be highly variable, are identified by

Figure 1: Study Area Locations



plotting the raw data over time. Figures 2–4 contain raw data plots for all variables used in this study. The raw data plots are shown with a superimposed 5-year running mean trendline. This trendline allows a clear view of any overall trend in the raw data. Rising trend-lines indicate short-term increases in the graphed variable, while falling ones indicate decreases. The strength of the increase or decrease can be assessed by the steepness of the line. Thus, a sequence of above-average years appears as an upward trend, below-average years as a downward trend and average conditions as a flat trend.

The following climatic variables from the Lennoxville meteorological station were used in the study: mean annual, winter (previous December, January, February), spring (March, April, May), summer (June, July, August) and autumn (September, October, November) temperatures, and mean annual and individual seasonal total precipitation amounts. Five streamflow variables are used to illustrate hydrological conditions in the Massawippi River Basin over the 45-year study period: mean annual and individual seasonal flows, all measured as stream discharge in cubic metres per second (cms) of water.

Analysis of Climate variables:

Of the ten climate variables analyzed only three show strong, observable trends according to the data plots: mean annual and winter temperatures, and total annual precipitation. Mean annual and winter temperatures show increasing trends, indicating increasing mean temperatures over the 1960 to 2004 time period. This positive trend has been strongest since approximately 1980 (Fig. 2a and 2b). There is evidence from the other seasonal plots for increases in the mean spring and summer temperatures, but these trends are weak (Fig. 2c and 2d). Mean autumn temperatures, according to the plots, have remained approximately the same over the study period (Fig. 2e).

The other strong climate trend is related to precipitation: total annual precipitation. This trend is a strong negative one and, along with the trend for mean annual temperature, is the clearest of all the variable trends. The raw data plots for the total annual precipitation variable clearly display the decrease in precipitation amounts, especially since the late 1970s. In 1976 annual precipitation reached its highest amount for the period of record, 1520.5 mm, then, despite a brief peak in the mid-1990s, one of the lowest precipitation totals on record was recorded in 2004, 918.4 mm. This represents a decrease in annual precipitation of over 600 mm from the mid-1970s to the early 2000s, mainly because of a reduction in winter precipitation (Fig. 3a). Seasonal precipitation trends are more complex and, thus, not as easily observed. The total winter precipitation data show a weak negative trend, but a highly variable one. Winter precipitation is decreasing from the late 1970s to the early 1990s, then becoming relatively stable for the remainder of the study period (Fig. 3b). In addition, there is a change in the percentage of total winter precipitation falling as snow from approximately 85% in the early 1970s to approximately 70% in the past decade

(Environment Canada, 2006). All the other seasonal precipitation plots lack clear trends. The total summer, spring and autumn data show no trends. The raw data plots are essentially flat (Fig. 3c, 3d and 3e).

Analysis of Hydrology variables:

Of the five hydrologic variables measured in this study only winter and spring show a strong, observable trend (Fig. 4b and 4c). Mean spring discharge has the strongest trend of these two variables. The raw data plot for this variable indicates that a decrease in spring discharge has been occurring since the early 1970s, when spring discharge levels were the highest on record. The mean annual discharge data trend is somewhat similar to the spring one, showing a very weak negative trend over the 45-year study period (Fig. 4a).

Mean winter discharge has the next strongest trend of the five hydrologic variables measured. A weak positive trend is indicated by the graphical analyses (Fig. 4b). Mean summer and autumn data show no graphically apparent trends (Fig. 4 d and 4e).

Discussion

The analysis of selected climate variables taken from the Lennoxville, Quebec climate station indicate that mean annual and mean winter temperatures have increased significantly over the 45-year study period. The mean annual temperature trend is especially strong. This strong positive trend in mean annual temperature is manifested most prominently in the strong positive trend in the mean winter temperature, and less prominently in the positive trends for spring and summer temperature. The positive mean autumn temperature trend is very weak. The presence of positive trends in all of the seasonal data, and their manifestation in the mean annual data, is an important indicator of a warming climate in the study area.

The precipitation trends, unlike the temperature trends, are not uniform. Only the total annual precipitation trend is easily observable, with a strong negative trend. In contrast, none of the graphical analyses of the seasonal precipitation trends support this strong annual trend. The winter, spring and autumn trends are negative, indicating decreasing precipitation totals, but all are weak trends and none of them are significant. The summer precipitation trend is the only positive one. However, despite being the relatively strongest seasonal trend, it is still quite weak.

In general, strong mean annual and mean winter temperature trends, an overall positive trend in all other seasonal temperatures, and a contrasting strong negative trend in total annual precipitation, result in no significant changes in streamflow trends in the Masswippi River basin between 1960 and 2004. The two relatively strongest hydrological trends are, in winter, a positive trend, and in spring, a negative trend. This may represent a balancing of flow between these two seasons. Increasing winter temperatures should cause a change from precipitation as snow to rain, adding to the streamflow during this season. Reduced winter snow accumulation would lead to reduced snowmelt water in the spring, thus the negative trend in spring streamflow seen in the data. The strong positive mean winter temperature trend also helps to explain the weak positive trend in winter streamflow.

The results obtained in this study do not agree completely with previous studies completed in Quebec river basins. Both Roy et al. (2001), and Dibike and Coulibaly (2005), using data generated from GCMs, predict increases in temperature, precipitation and streamflows. The historical analysis presented in this study shows definite increases in mean temperatures, both annual and seasonal, some evidence for a decrease in total annual precipitation, complex changes in seasonal precipitation amounts, and no observable graphical evidence for changes in streamflows between 1960 and 2004. The predicted increases in streamflow may still occur, but there is little evidence for these increases in this 45-year historical analysis.

Conclusion

Based on the data available from the Lennoxville meteorological station, the Massawippi River environs have seen increases in annual and winter mean temperatures. Temperatures in the other three seasons have increasing positive trends, but they are not significant. In contrast, there has been a strong negative, decreasing trend in total annual precipitation. No seasonal precipitation trends are found. Also, no trends in Massawippi River streamflow trends, either annual or seasonal, are apparent in the data. There is a graphical indication of lower spring and higher winter streamflows but the trends are not strong.

The strong increase in winter temperatures should lead to more winter rain, less winter snow and, thus, less snow available for the spring melt period. There is some indication, especially in the graphical plots presented here, of increased winter and decreased spring streamflows. A more balanced flow between these two seasons may be occurring.

In general, annual river volumes have not changed significantly over the 45-year study period and cannot be predicted to change significantly in the immediate future. None of the data presented in this paper support either a future decrease or an increase in the annual surface water flow in the Massawippi River basin. However, a seasonal shift in surface water flow from spring to winter is suggested.

REFERENCES

Ashmore, P. and M. Church, 2001. "The Impact of Climate Change on Rivers and River Processes in Canada." *Geological Survey of Canada Bulletin* 555, 58 pp.

Burn, D.H. and J.M. Cunderlik, 2004. "Hydrological Trends and Variability in the Liard River Basin." *Hydrological Sciences-Journal-des Sciences Hydrologiques*, 49(1), 53–67.

Burn, D.H., O.I. Abdul Aziz and A. Pietroniro, 2004. "A Comparison of Trends in Hydrological Variables for Two Watersheds in the Mackenzie River Basin." *Canadian Water Resources Journal*, 29(4), 283–298.

Dibike, Y.B. and P. Coulibaly, 2005. "Hydrologic Impact of Climate Change in the Saguenay Watershed: Comparison of Downscaling Methods and Hydrologic Models. *Journal of Hydrology*, 307, 145–163.

Environment Canada, 2007. *Canadian Climate Normals 1971 to 2000: Lennoxville, Quebec*. <http://www.climate.weatheroffice.ec.gc.ca/climate_normals/results_e.html>.

Harvey, L.D.D., 2000. *Global Warming: The Hard Science*. Prentice Hall, Toronto, 336 pp.

Roy, L., R. Leconte, F.P. Brissette and C. Marche, 2001. "The Impact of Climate Change on Seasonal Floods of a Southern Quebec River Basin." *Hydrological Processes*, 15, 3167-3179.

Figures 2a–e
Historical trends in Temperature variables for the Massawippi River Basin.
(The 5-year running mean trendline is in bold.)

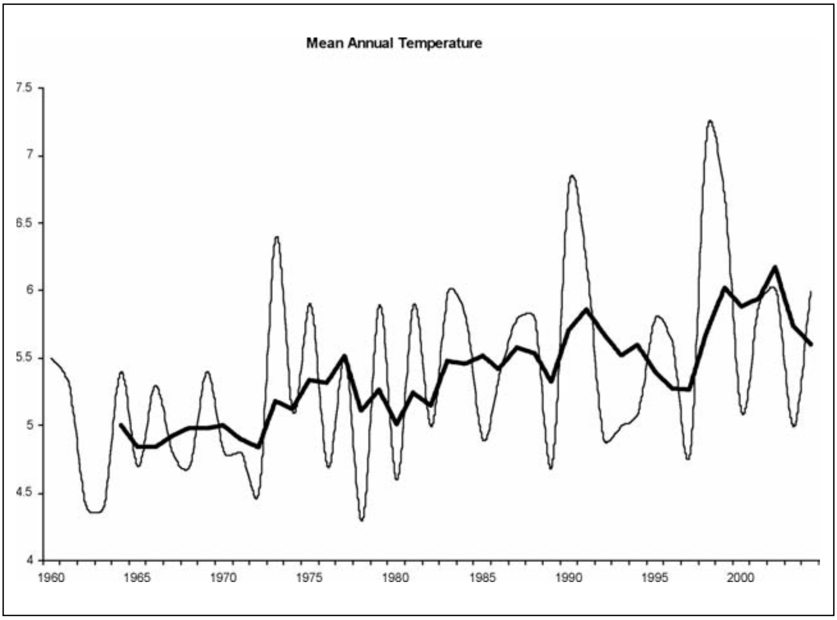


Fig. 2a

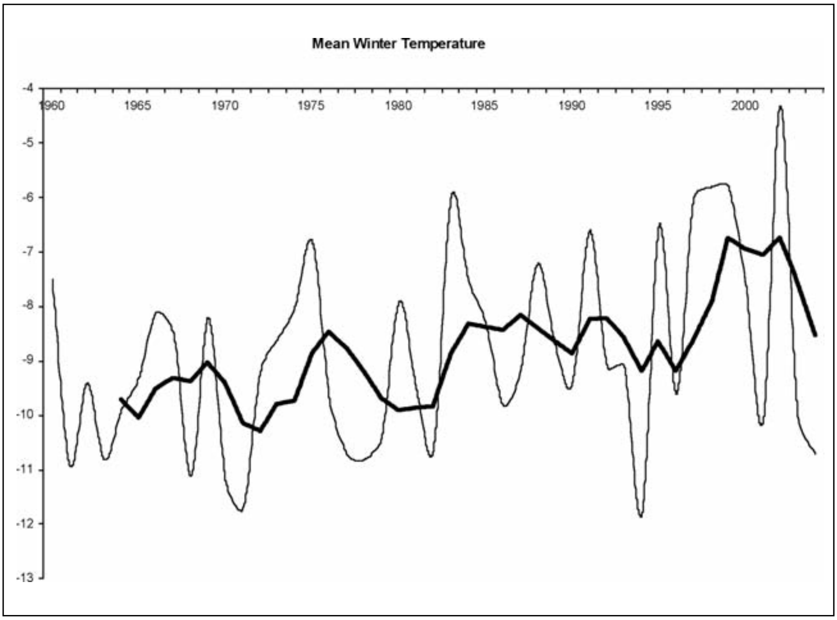


Fig. 2b

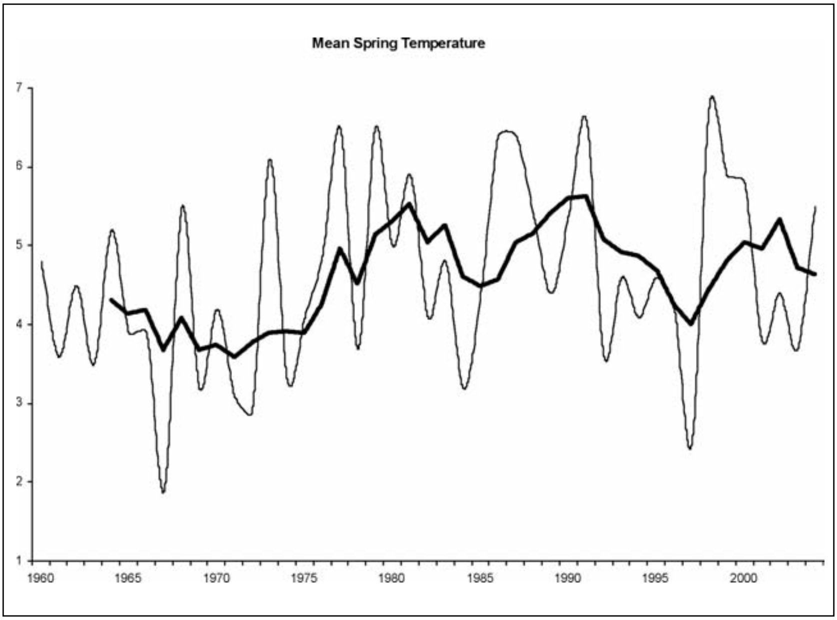

Mean Spring Temperature
7
6
5
4
3
2
1
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 2c

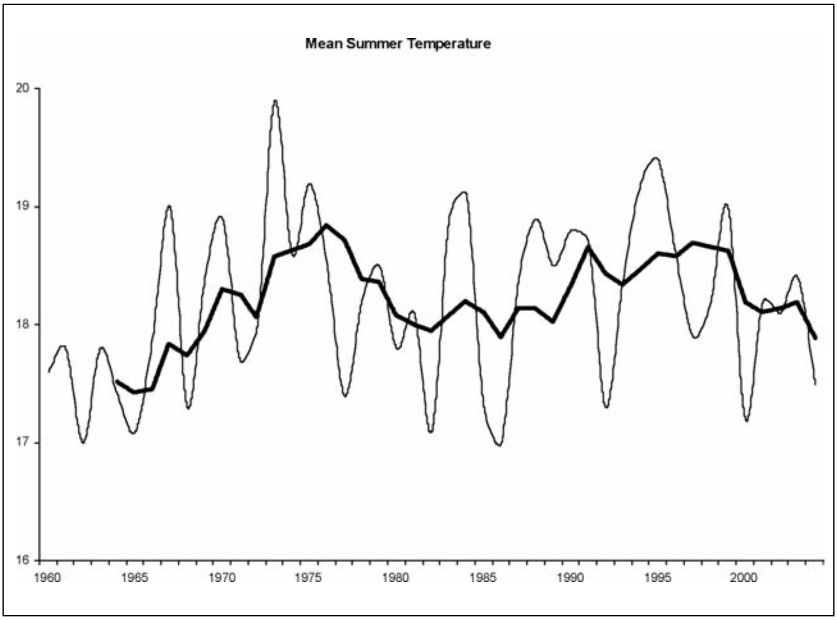

Mean Summer Temperature
20
19
18
17
16
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 2d

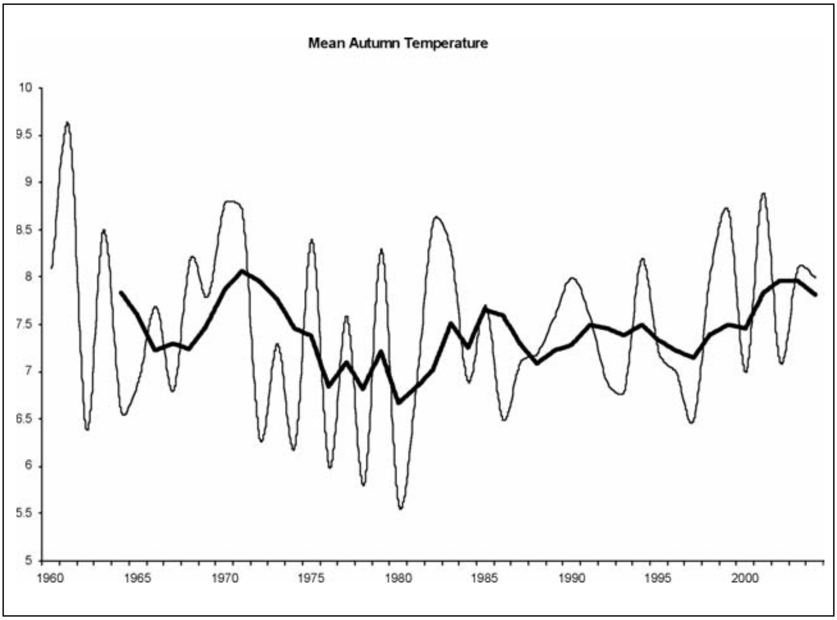


Fig. 2e

Figures 3a–e
Historical trends in Precipitation variables for the Massawippi River Basin.
(The 5-year running mean trendline is in bold.)

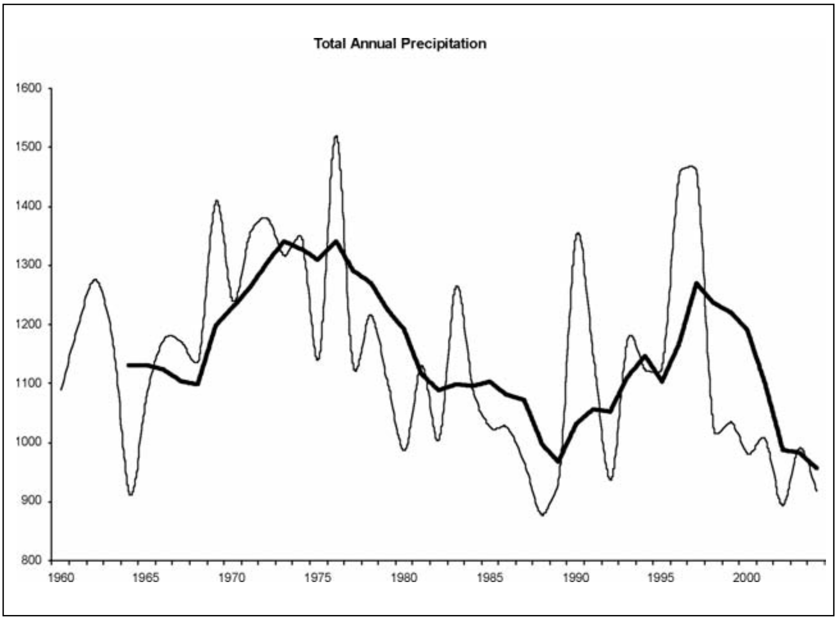


Fig. 3a

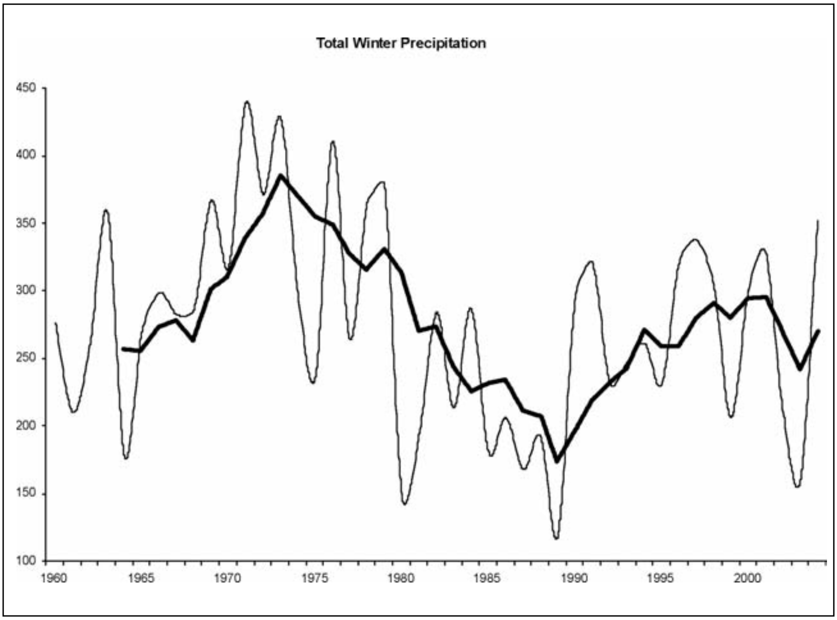

Total Winter Precipitation
450
400
350
300
250
200
150
100
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 3b

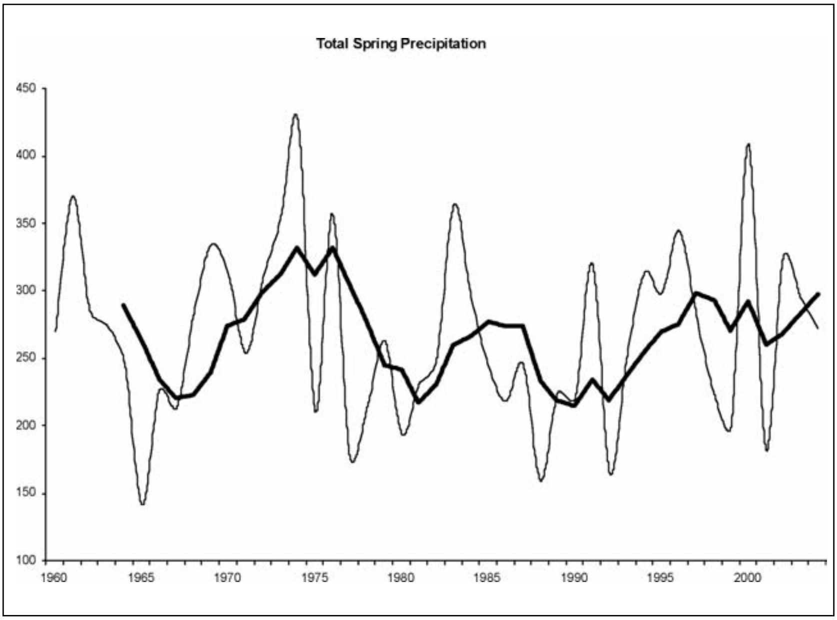

Total Spring Precipitation
450
400
350
300
250
200
150
100
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 3c

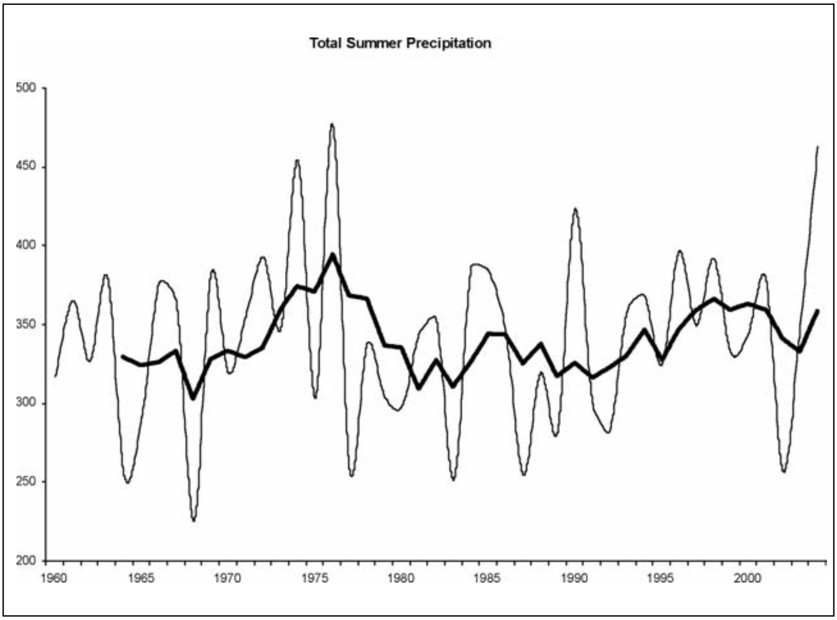

Total Summer Precipitation
500
450
400
350
300
250
200
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 3d

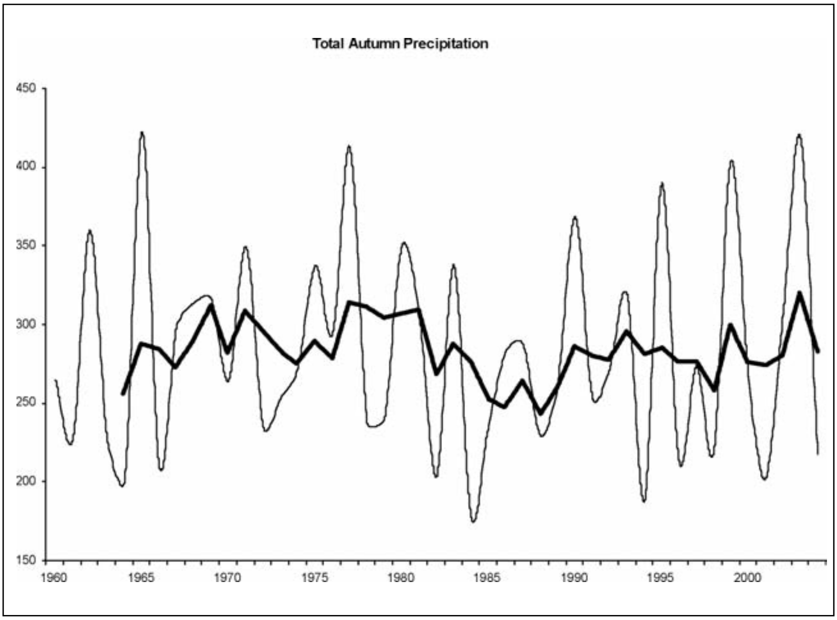

Total Autumn Precipitation
450
400
350
300
250
200
150
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 3e

Figures 4a–e
Historical trends in Stream Discharge variables for the Massawippi River Basin.
(The 5-year running mean trendline is in bold.)

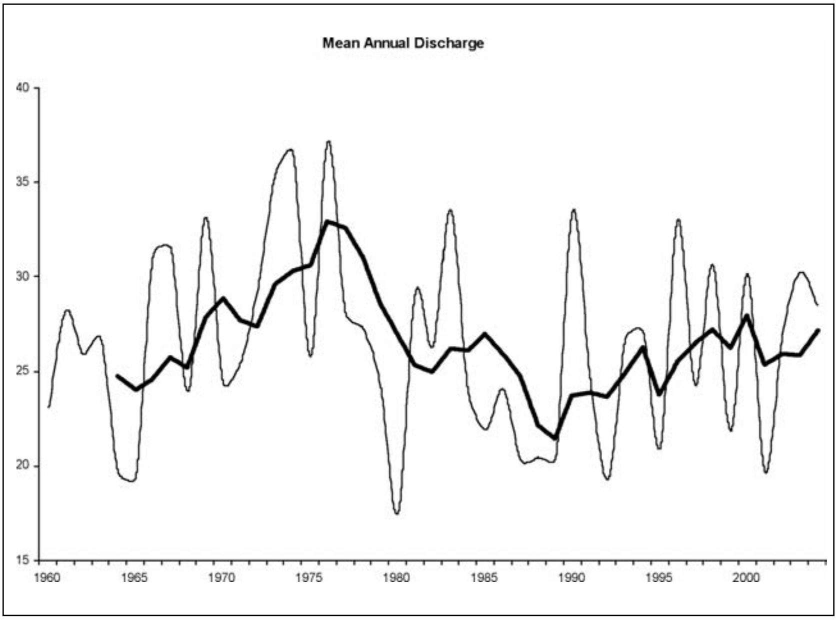


Fig. 4a

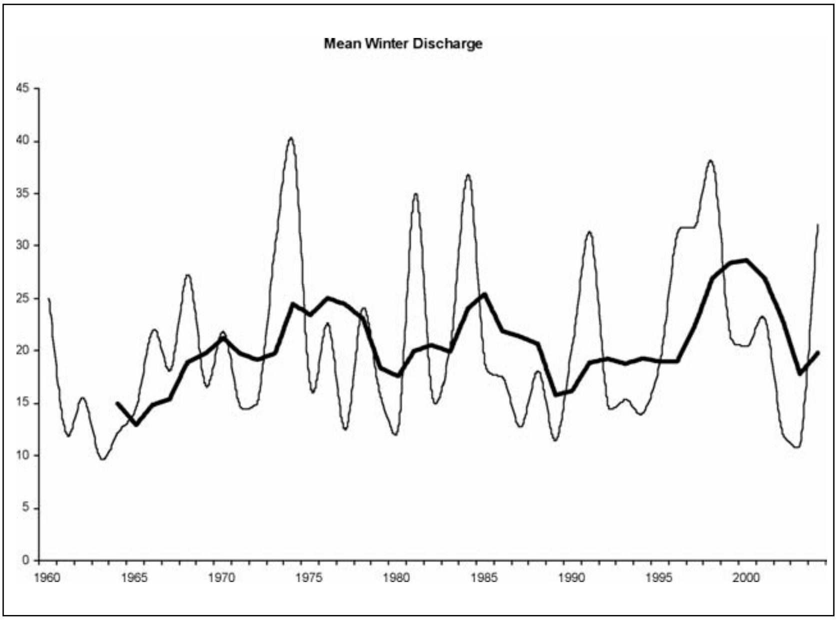


Fig. 4b

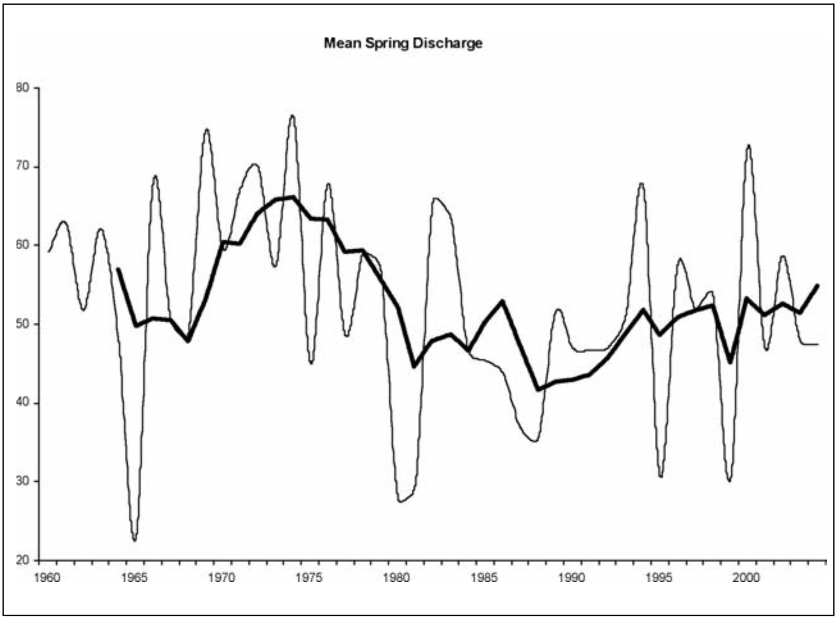

Mean Spring Discharge
80
70
60
50
40
30
20
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 4c

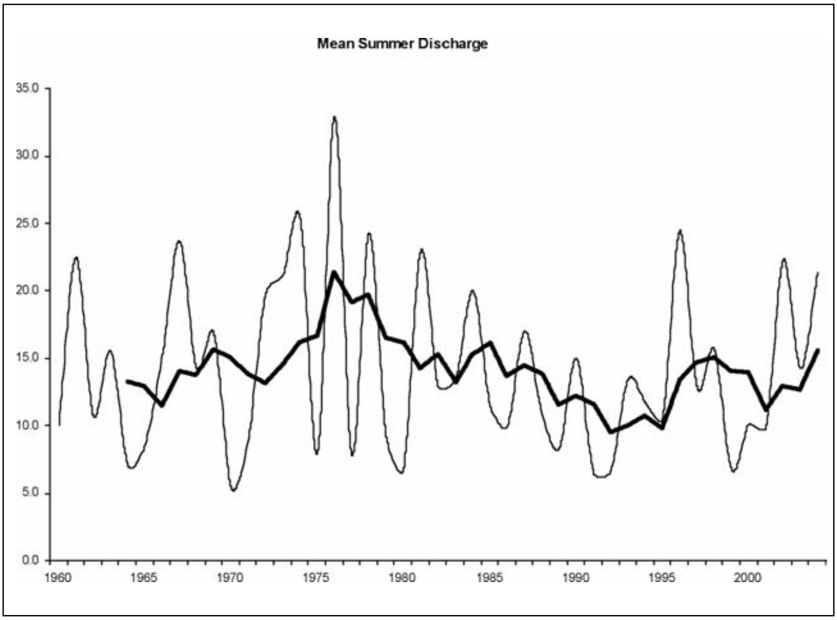

Mean Summer Discharge
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 4d

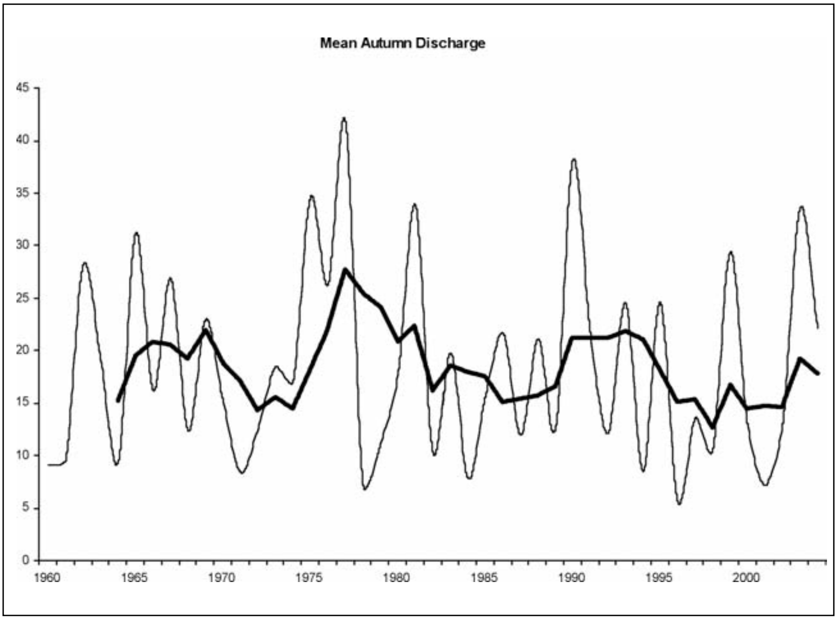

Mean Autumn Discharge
45
40
35
30
25
20
15
10
5
0
1960
1965
1970
1975
1980
1985
1990
1995
2000

Fig. 4e