Delaware River water resources and climate change

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Abstract

Water resources are important in every aspect of human life, and river systems are one of the dominant sources of water resources. The Delaware River is a major source of water for 20 million people living in and around the river basin. The purpose of this project is to examine how the availability of water in the Delaware River may change due to climate change induced by increasing levels of atmospheric greenhouse gases. A hydrologic model was developed based on precipitation, groundwater infiltration, evaporation, snow accumulation, and management infrastructure that is in place today. By using climate change scenarios for the Delaware River Basin based on a global climate model (GCM), potential changes in streamflow, New York City reservoir storage, and salt front position are examined.

Introduction

The Delaware River basin encompasses 33,061 km^2 (Figure 1), with 17,560 km^2 of the basin above Trenton (Ayers et al. 1993). The Delaware River flows for more than 300 km from southern New York State to Trenton, NJ. The river is a tidal estuary for 190 km before entering the Atlantic Ocean at the mouth of Delaware Bay. The basin has a humid, temperate climate with a mean annual precipitation of 1.2 m and mean annual temperature of 12^{o}C (Wolock et al., 1993).

There is considerable variation in the soils, vegetation, and topography of the basin. The northern region is characterized by a mountainous topography with steep hillslopes and well-drained soils and also contains reservoirs that supply water to New York City. This northern portion is the only region where snow accumulation is substantial (Ayers et al., 1993). The central region can be characterized by rolling hills, where the soil is a relatively thin, clayey-loam. This causes the streams in this region to respond quickly to rainfall. Flat topography and thick, sand-loam soils characterize the southern portion where nearly all stream-flow is derived from groundwater discharge. In the lower region the Delaware River is under tidal influence and the salt front position is defined as the monthly average distance upstream where the chloride concentration is 250 micromoles per liter.

An important question to address is how the availability of water for human consumption might change in the future in response to climate change caused by increasing levels of atmospheric greenhouse gases. Atmospheric levels of CO_2, the most important greenhouse gas after water vapor, has been rising and is expected to double during the next century. An increase in CO_2 concentrations is expected to cause global warming, sea level rise, and shifts in precipitation patterns (Houghton et al., 1996). In order to predict the impact this increase in CO_2 concentration will have on our environment, GCMs have been developed to model the global climate system. These models are used to estimate changes in temperature, precipitation, evaporation, soil moisture, snow cover, and sea level that a doubling of CO_2 would cause. GCMs simulate the climate of the entire earth with a coarse resolution, typically with grids ranging from 200 to 500 km in width (Robock et al., 1993). This lack of geographic detail makes it difficult to derive parameters on smaller scales, such as the Delaware River basin, which measures 300 km by 100 km.

Regional scenarios of future climate are needed in order to study the true impacts of climate change, but current GCMs are unable to properly simulate the seasonal cycle of climate on a regional basis (Robock et al., 1993). the methods which GCMs use to treat many important physical and biological aspects of the climate system, such as clouds, soil hydrology and ocean circulation, still need to be improved. Because the best scenarios are subject to many limitations, the results from GCMs cannot be considered forecasts, but can be used in sensitivity tests. Even if the GCM does a poor job of simulating the current climate, there is general information contained in the GCM output that can be used in scenario creation (Robock et al., 1993).

Methods

For the present study, a water balance model has been developed using the Stella Modeling system from HPS (Stella II, 1992). With this system, one is able to create box models relatively quickly and efficiently. The river is divided into three sections, above Montague, between Trenton and Montague, and below Trenton. Each section has individual functions controlling precipitation, groundwater infiltration, evaporation, snow accumulation, and management infrastructure that is in place today. The amount of precipitation is input as a monthly mean from climatological data, as is the temperature mean for that month. A diagram for the hydrologic model is shown in Figure 2. The rectangles are reservoirs for river water, snow and groundwater, the lines with arrows are flows in and out of the reservoirs, and the circles are used as converters with different equations used to simulate the natural processes that influence the flow between reservoirs. For additional details of the model, including equations, see Hassell (1999).

After completing the hydrologic model for the observed climate, the model was set up to run the climate change scenarios taken from Goddard Institute of Space Studies (GISS) GCM data for a grid containing part of the Delaware River basin (Russell et al., 1995). A linear regression, for both temperature and precipitation, was fit to the climate change scenario from the GISS GCM of Russell et al. (1995). During the first four decades (1950 to 1990) of the GCM simulation, the CO_2 increased at the observed rate, after which it increased at 0.5% per year. The annual mean change in temperature or precipitation is calculated 100 years into the future. These changes are then input into the hydrologic model. Based on the GCM scenario, temperature increased by 1° C over 100 years and precipitation increased by 0.005 mm/month over the 100 year period.

Results and discussion

The hydrologic model's mean monthly streamflows for the present climate simulate, reasonably well, the mean flows observed at Montague and Trenton (figure 3). Spring peaks in runoff due to snowmelt in the upper portion of the basin are clearly seen along with the substantial drop in streamflow during the summer due to increased evaporation.

Figures 4 a and b show the difference in streamflow between the streamflow predicted by the climate change scenarios on the one hand and the streamflow predicted for the present climate on the other. When only the temperature was increased, streamflow decreased in all months at both Montague and Trenton, except in the late winter and early spring because the snowmelt started earlier than usual. The reservoir storage showed the same variation as the streamflow.

When only precipitation was increased, water availability in all areas increased. The streamflows at Montague and Trenton increased above the current climate during all months of the year. Reservoir storage increased during all months except in mid spring when the reservoirs filled to capacity and spilled over. The salt front position moved downstream, further away from the Philadelphia water supply intakes (figure 5).

When the increases in temperature and precipitation were applied together, the precipitation increase specified by the GISS GCM for this region was enough to offset the increase in temperature and evaporation. Streamflow and reservoir storage increased during the first four months of the year and then leveled off back to the current climate. The mean monthly salt front position moved downstream further than the current climate during the first four months and then was approximately the same as for the current climate during most of the year.

Conclusions

One way to do regional hydrologic studies of climate change is the approach used in this paper where changes in temperature and precipitation from GCM climate change simulations are added to the mean observed values for the present climate. Such studies will become more realistic when GCM mean monthly variability more closely matches observed climate variability at the regional scale. The agreement between the GISS data used in this study of the Delaware River basin and the observed climate is reasonable, but far from perfect. As GCMs begin to use finer resolution, the accuracy of their applications to regional studies will improve. The information may be better than just for scenario creation and could have real world uses in planning. For now, regional scenarios are the best we can do.

The principal results based on these climate change scenarios can be summarized as follows:

- Temperature Change: When only the temperature increase is input to the hydrologic model, the mean annual streamflow decreased, the winter flows increased due to increased snowmelt, and the mean position of the salt front moved upstream.
- Precipitation Change: When only the precipitation increase was input to the hydrologic model, the mean annual streamflow increased, and the mean position of the salt front moved further downstream.
- Temperature and Precipitation Change: When both the temperature and precipitation increase were input to the hydrologic model the mean annual streamflow changed very little, with a small increase during the first four months of the year.

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Figure 1: Delaware River Basin
(Delaware River Basin Commission)

Figure 2: Hydrologic model of Delaware River and Northern Subsection

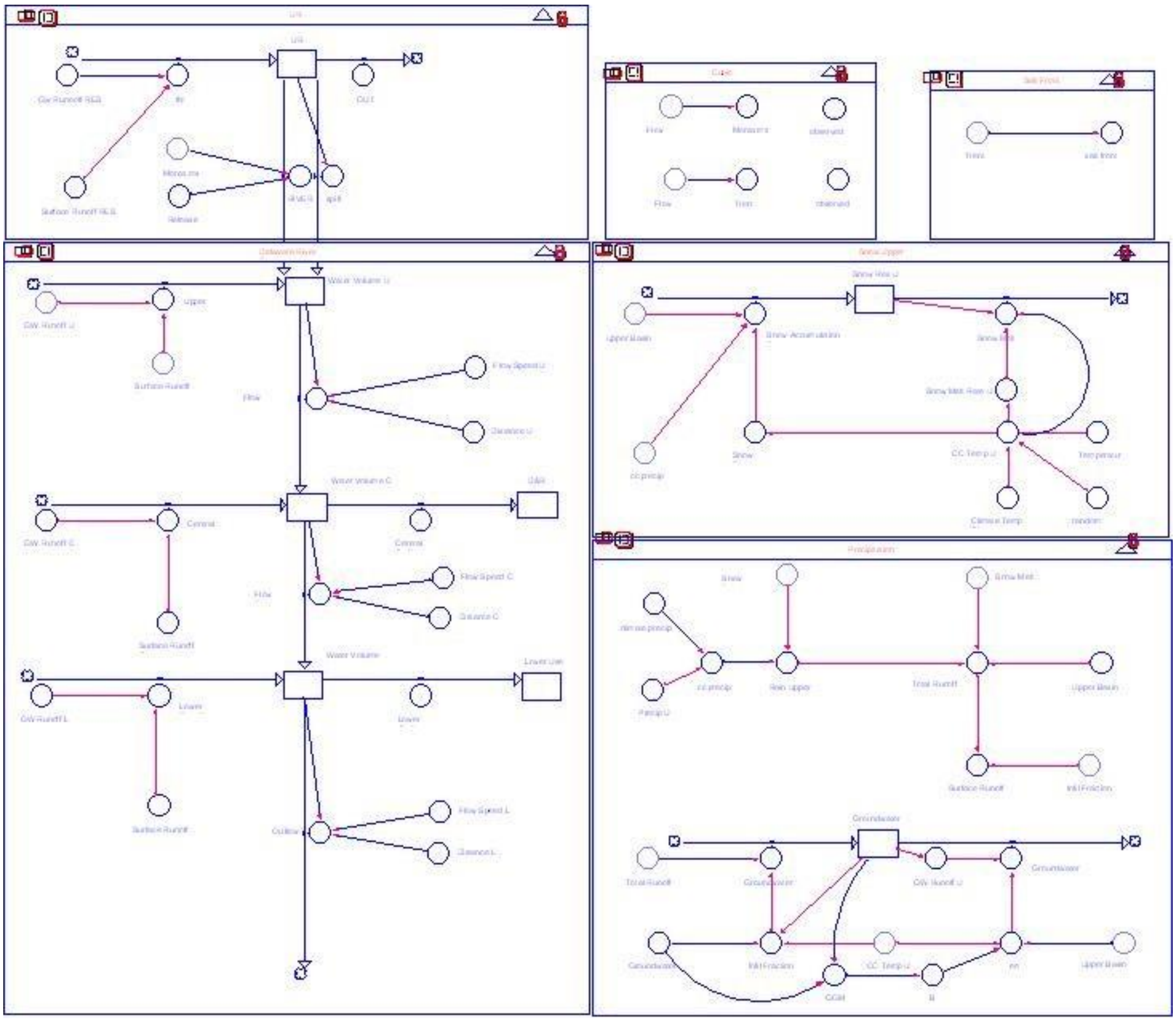


Figure 3: Comparison of observed mean streamflow and hydrologic model's streamflow

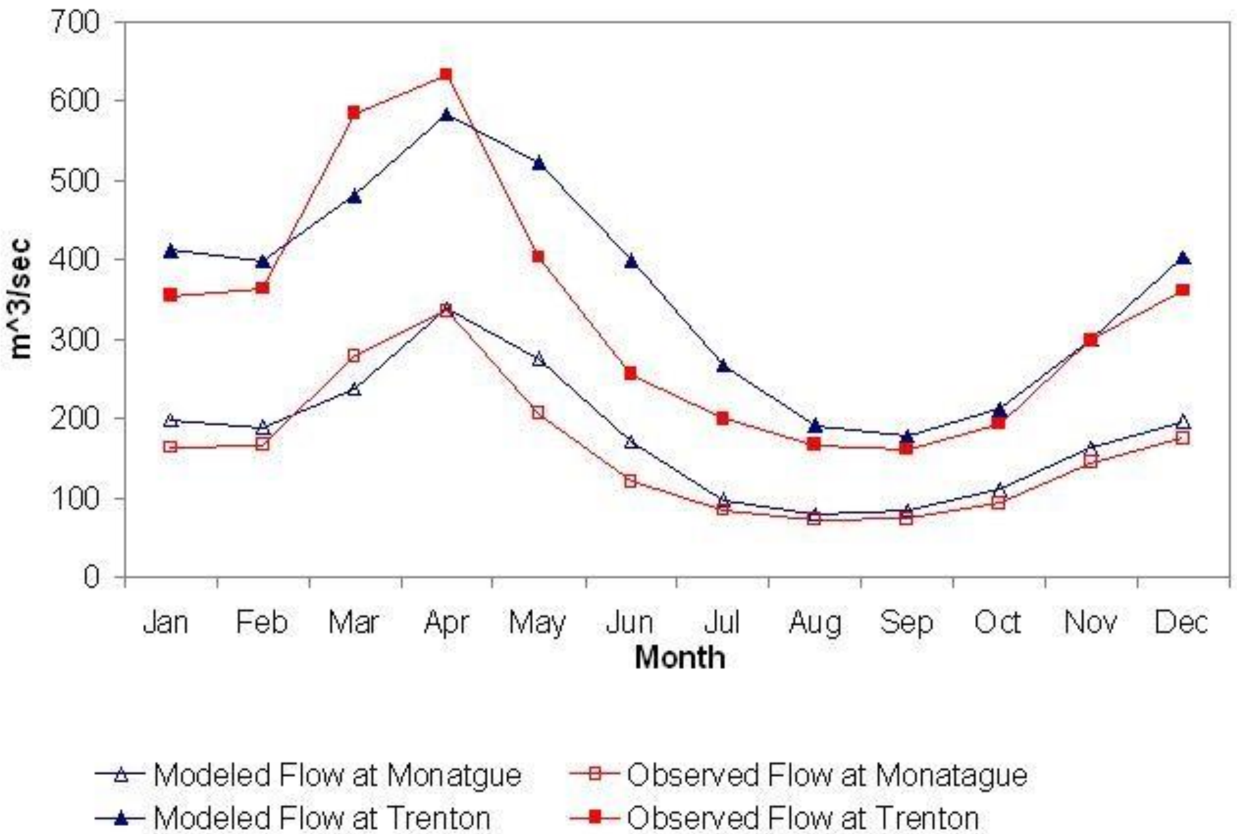
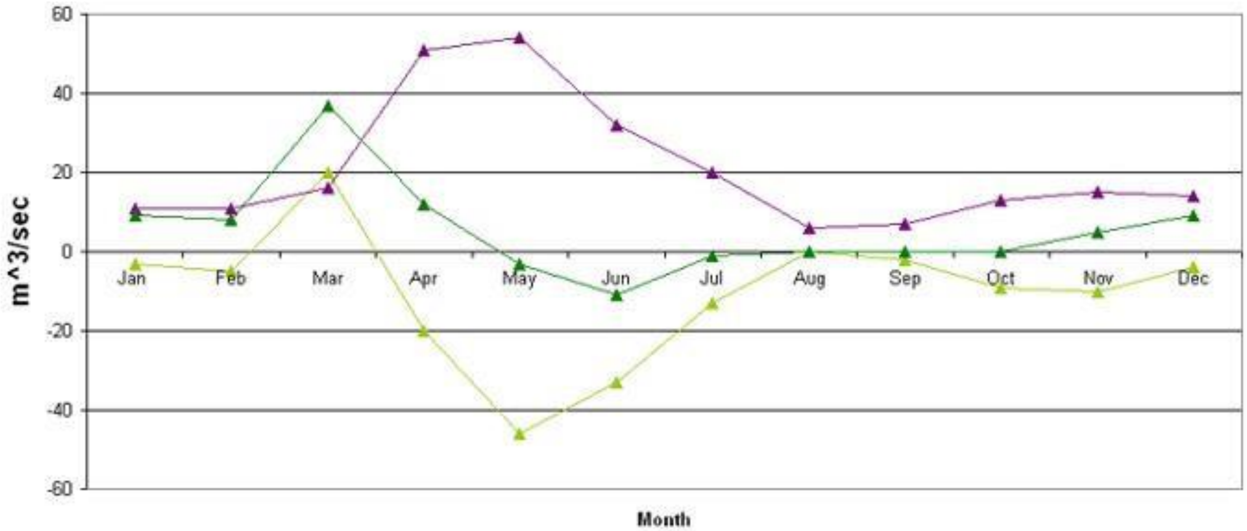


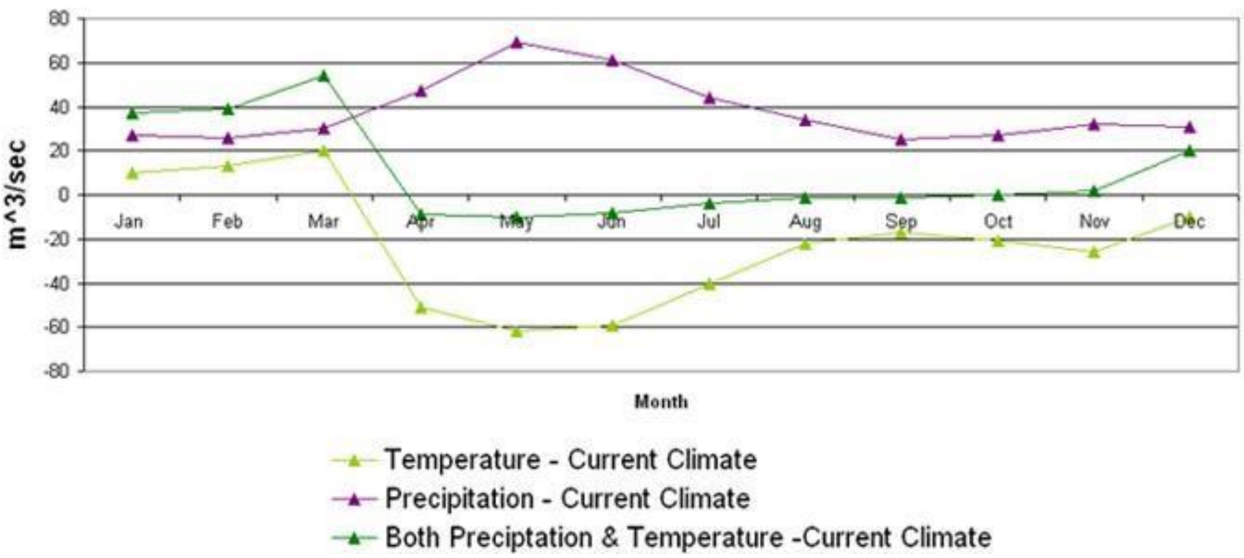
Figure 4 : Climate change scenarios for gauging station at (A) Montague, NJ and (B) Trenton, NJ.

Change in Streamflow for Climate Change Scenarios from Current Climate Runs at Montague



(A)

Changes in Streamflow for Climate Change Scenarios from Current Climate Runs at Trenton



(B)

Figure 5: Climate change scenarios for salt front position (km from mouth of Delaware Bay)

Change in Salt Front Position for Climate Change Scenarios from Current Climate