Effects of Climate Change on River flow Stochastic Approach

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***Abstract*—. One enduring objective in the scientific community has been to understand how climate change impacts the distribution of river flows. In this paper, we explore the impact of this phenomenon on the river flow levels of the Arkansas River in the state of Colorado. Changes in monthly flow regimes were projected and aggregated to decadal time scale using two future climate scenarios. To achieve this, a neural network was employed to map the region, and from this, the relationship between streamflow and accumulated snow and temperature was analyzed and used to derive the streamflow projections. Streamflow projections for the April-September period in the Arkansas River were analyzed and the results show that river flow increases following the increase in precipitation and temperature regimes throughout the river basin. The historical peak flow in June shifted to occur in April. Frequency analyses of flow show that the any flow in the months April-July would be exceeded more frequently in the future. The percentage change in exceedance for each month will vary – with a substantial difference for April-July, a minor change for the month of August, and almost no change at all in September.**

Keywords—climate change, river flow, impacts)

I. Introduction

In the western United States, snowmelt forms an integral component of the regional hydrologic cycle, accounting for 50-80% of the annual runoff in the area. The anticipated impact of climate change has heightened concerns about the changes in snowmelt and the overall hydrology of the region. The potential impact of climate variability ranges from changes in the level of winter snowfall and snow-melt and the extent of growing season rainfall amounts and intensities, to new minimum winter temperatures and rises in summer average temperatures ([2], [3]). Numerous studies have supported this hypothesis by demonstrating an upward trend in spring and early summer temperatures ([12], [11]) as well as a decline in the levels of snowpack during the spring season.([10]). Numerous other studies of snowmelt dominated systems have established similar seasonal changes in snowmelt runoff due to rising temperatures and the resultant shorter snow accumulation period (e.g.,[8], [14]).

Historical data analyses carried out in some of these recent studies (e.g.,[2], [3], [10]) have also discovered a change in the timing of snowmelt runoff, with many snowmelt-dominant river basins in the western United States showing an earlier occurrence of this phenomenon. The overwhelming majority of these studies employed site-by-site analysis, and none of them demonstrated any increases in streamflow.

Earlier papers, analyzing regionalized data sets rather than site data, have indicated a noticeable increase in heavy precipitation events throughout the region and this has resulted in subsequent increases in changes to streamflows. [7].

Data on precipitation and temperature fields, sourced historical records and General Circulation Models (GCM), have been routinely employed in hydrologic models in order to observe the impacts of climate variability and change on river runoff. This paper explores how the climatic changes will affect the distribution of the flow in Arkansas River. Our approach employs precipitation and temperature field data extracted from two GCMs. Namely, the Hadley Centre for Climate Prediction and Research (HAD) and the Canadian Climate Centre (CCC). This paper focuses specifically on changes to streamflow in the April-September period, the time of effective river runoff and also the regional growing season. For future climates the mean monthly flow is estimated from 90-years artificial neural network (ANN) model simulation [5]. The results are compared to historical records of streamflow to give insights in the direction of the change.

II. Data

Several data sets were used in this study. The Vegetation-Ecosystem Modeling and Analysis Project (VEMAP) was the main source of the data, [5]. The data consists of both historical climate data, covering the period 1895-1993 and two GCM-based future scenario projections ranging from 1994-2099.

In order to simulate the impact of small-scale influences such as local topography and ecosystems on regional climates, the VEMAP divided the conterminous US into 0.5°x0.5° grid cells, [5]. The National Center for Atmospheric Research (NCAR) also processed, spatially interpolated (downscaled), and topographically adjusted both the historical and projected climate data to the 0.5° lat/long VEMAP grid. Fig. 1 shows the historical and the future scenario projections of the temperature and precipitation in the study area. The mean +/- standard deviation for the data sets are shown in the figure.

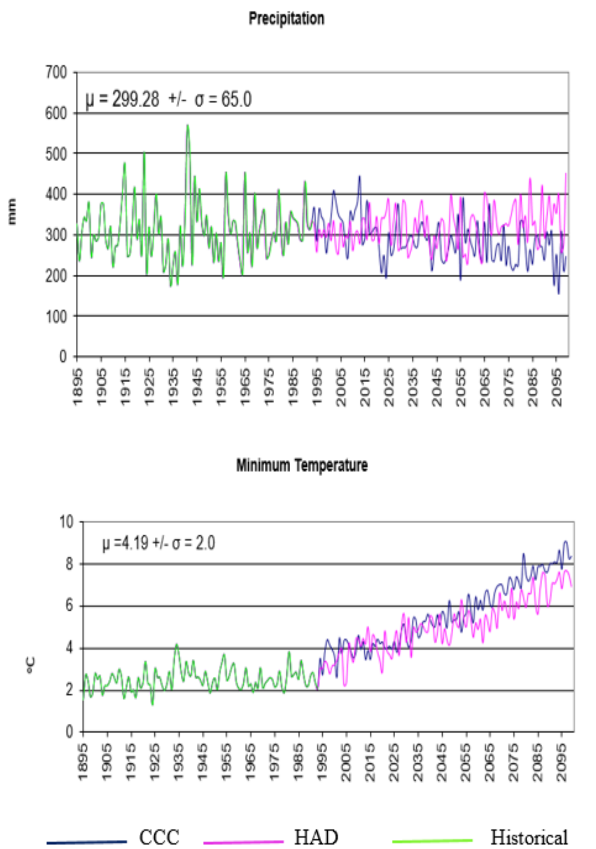

Fig. 1. Historical and the future scenario projections of Precipitation and Temperature

The locations of the climate data stations are shown in table 1. The snow courses selected reflect the natural runoff and demonstrate a high correlation with the amount of snowmelt over the entirety of the basin.

TABLE 1: Characteristics of Snow Courses

Station	Latitude (deg)	Longitude (deg)	Elevation (m)	Cell #
Apishapa	37.33	105.07	3,040	2683
Brumley	39.08	106.53	3,222	2220
Fremont Pass	39.38	106.20	3,465	2221
Prophyry	38.48	106.33	3,271	2451
South Colony	37.97	105.53	3,294	2567
Whiskey Creek	37.22	105.12	3,117	2683

III. METHODS

A model was developed in order to simulate the behavior of streamflow of the Arkansas River under the expected changing climate in the future. The model uses the climate data as input and streamflow as output. Several models were tested but the artificial neural network (ANN) model was found the most reasonable one to simulate the nonlinear relationship between the inputs (precipitation/temperature) and the output (streamflow), [9], [10], [16].

A. Modeling Streamflow

The model developed is well described, documented, and referenced, [5]. Here is a brief description of the model. The model is a neural network consists of three-layer. The model is best described as a feedforward network in which information from the inputs (PPT_a , T) is evaluated by a function through intermediate calculations. The function maps the relationship between the inputs and the output Q_r. The model takes the following form:

$$Q_r(t) = f(PPT_a, T) \qquad (1)$$

Where, Q_r , PPT_a , and T are the streamflow, precipitation, and temperature respectively. The data sets of streamflow and temperature were aggregated to monthly values while the precipitation was aggregated from October (beginning of the water year) to the end of each month in the following year. For example, the PPTa for April is the cumulative snow pack from October-April. The temperature (T) is taken as the average temperature from April to the end of each month being modeled. For example, the temperature for May is taken as the average temperature of April-May; while for April, we used the temperature in March.

B. Model Testing and Validation

The neural network was developed using data records spanning 90 years, ranging from 1911 to 2000. Fifty years (1911 – 1960) were used to train the network; fifteen years (1961-1975) were used to validate; twenty five years were used to test the network. All the data sets were normalized into the range (-1, 1).

The performance statistics presented in Table 2 summarize the relationship between the simulated (output of the network) and the measured (target) values being modeled. The correlation coefficient (R) determines the degree to which two variables' behaviors are connected. The values of R fall in the range of (0, 1) with one is the optimum. The Root Mean Square Error (RMSE) is used to measure the difference (residual) between the measured and simulated values, with zero is the optimum. However, the correlation coefficient (R) and the Root Mean Square Error (RMSE) values indicate the relatively high degree of association between the measured and simulated values.

Table 2. Summary of the Model Validation and Testing

Month	Training		Testing	
	R	RMSE	R	RMSE
APRIL	0.634	0.17	0.562	0.24
MAY	0.790	0.10	0.770	0.18
JUNE	0.863	0.11	0.847	0.15
JULY	0.899	0.06	0.740	0.13
AUG.	0.852	0.06	0.781	0.12
SEPT	0.904	0.07	0.769	0.17

IV. EFFECTS OF CLIMATE CHANGE

Fig. 2 shows distribution of historical and the two GCM (HAD/CCC) projected precipitation for the study area. Decadal-time scale changes in precipitation projections are shown. In general the changes in the precipitation levels mostly look like the changes in the observed historical data. Noticeably, the precipitation levels in winter and spring (Jan – April) relatively increased while the levels decreased in the summer (June – Sept.). The HAD scenario, tends to project large increase in the winter precipitation, small increase in the summer, and negligible increase in June. In general the CCC scenario tends to produce smaller projections than the HAD ones. The decrease under the CCC below the historical levels begins in May.

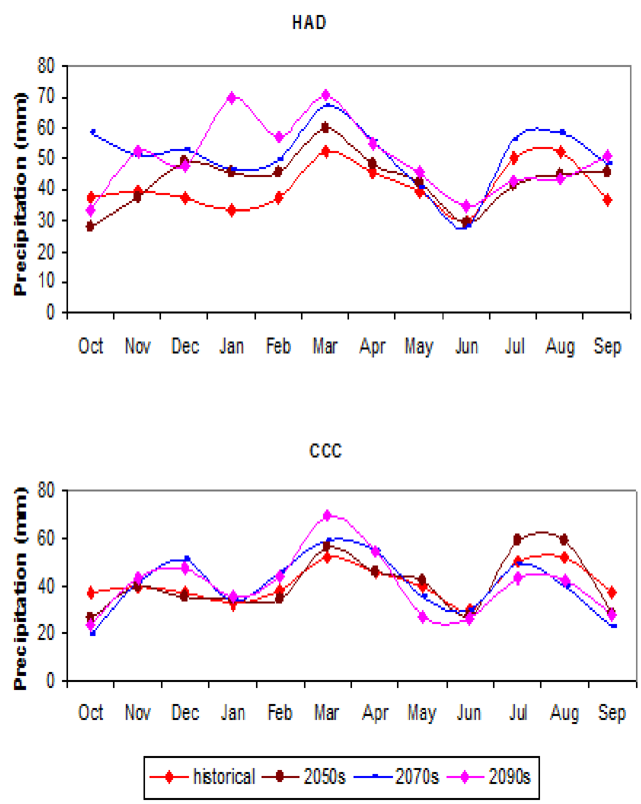

Fig. 2. Precipitation distribution- historical (1960-1990) and HAD/CCC

Fig. 3 shows the model's projected streamflow for the Arkansas River for historical and two expected climate scenarios. The figure shows that the greatest increases in river flow occur in the period from April to June, owing to the earlier than usual snowmelt occurring in the mountains. Both of the GCMs project significant increases (up to 70% of current levels) in winter snow. This increase, coupled with high projected temperatures is what results in early snowmelt. The historical flow peak occurs two months earlier in April. For climate change increased flow in April can be due to the combined effects of increase in precipitation in general and increase in the melting snow and rainfall due to the effect of increase in temperature. The major response to climate change in the Arkansas River basin is the increase in both precipitation and temperature, which in turn increases the river flow and causes the historical flow peak to occur earlier than usual. The monthly increases and decreases in river flow are moderately correlated with the increases and decreases in precipitation.

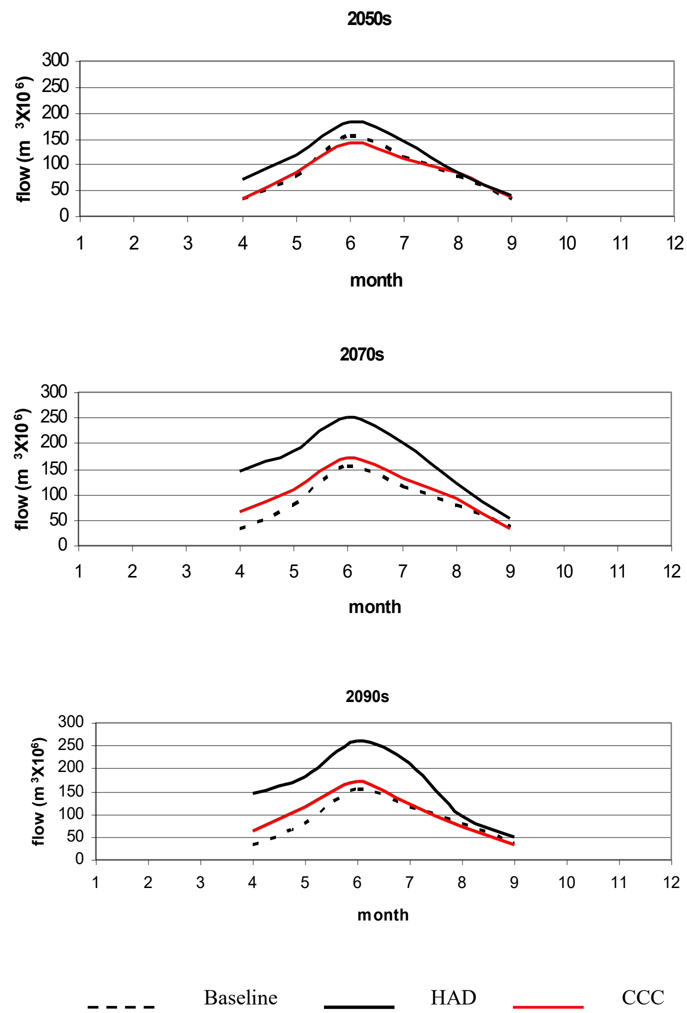

Fig. 3. Streamflow under baseline climate and the HAD and CCC scenarios

Fig. 4 shows flow duration curves developed for streamflow under baseline (historical) climate and the HAD scenario. The duration curves developed for streamflow from April to September. The flow duration curve shows the proportion of time that river flow exceeds a given flow value. It is very clear in the figure that under the HAD scenario the flow duration curve shifted above the baseline curve. This indicates that almost all the times the streamflow in the future will exceed the levels of the current or the historical streamflow.

The probability of exceedance varies between the months; being relatively high in April through to July and relatively low in August while in September the curves appear similar under both the baseline climate and the HAD scenario. The flow in the months of April-July is characterized by high variability indicated by the steep duration curves generated; while it is stable in the months of August and September indicated by the shallow duration curves shown.

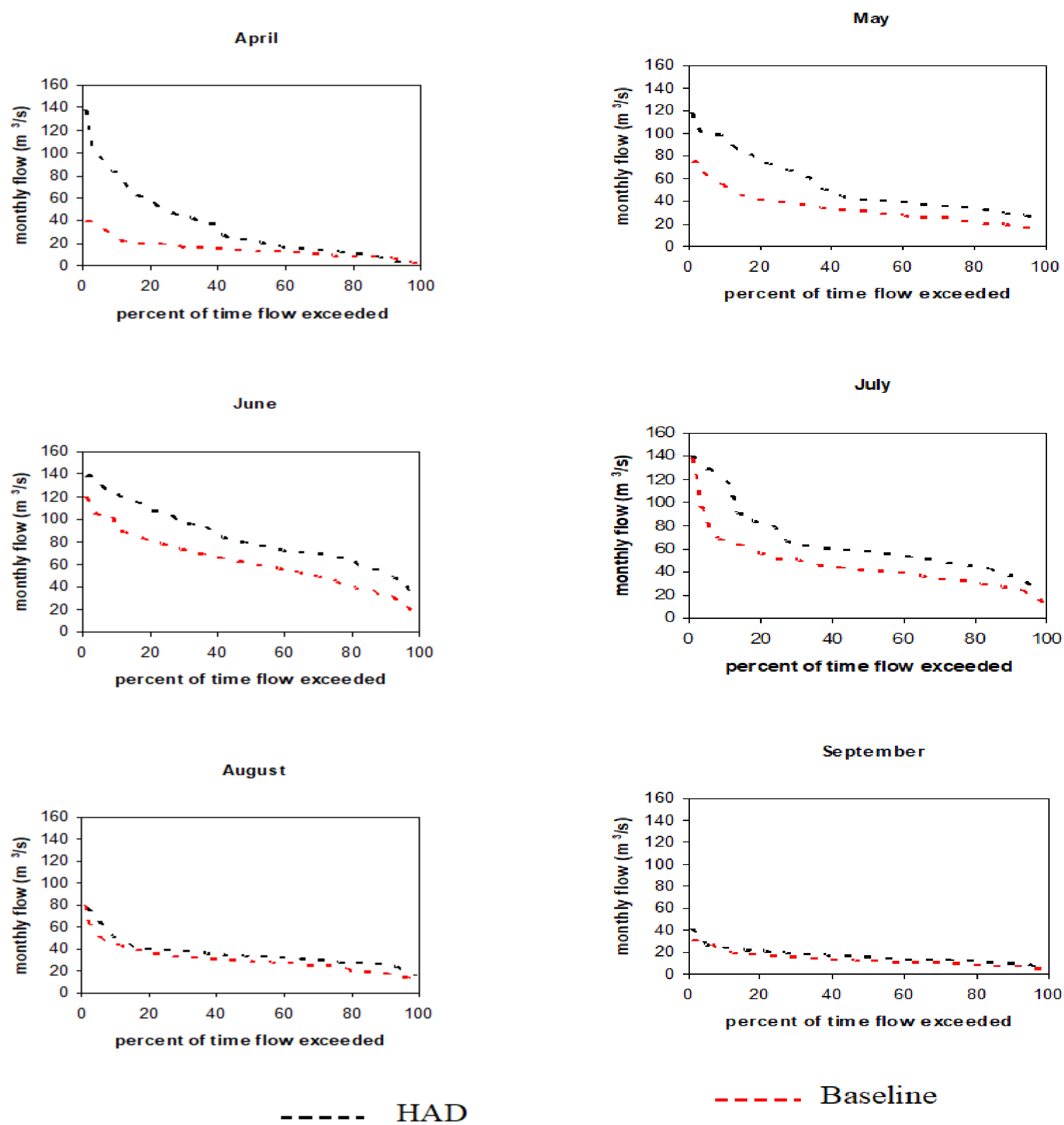

Fig. 4. Flow duration curves: baseline and the HAD scenario

V. Summary and Coclusions

The paper explored the impact of the climate change phenomenon on the river flow levels of the Arkansas River in the state of Colorado. Changes in monthly flow regimes were projected and aggregated to decadal time scale using two future climate scenarios (HAD and CCC). The results show that the changes in precipitation and temperature will be magnified and reflected on the streamflow. The results further indicate that the current magnitudes of the river flow, especially in April-July, will be exceeded with greater regularity in the future. The results also demonstrate an increase in spring time river flow; an increase large enough to offset any decreases in summer time flow. Noticeably, there is a shift in the peak flow from June to April. Overall, the results are consistent with what other studies (e.g., [4]) have predicted regarding the effects of increased temperatures in the western United States.

The study region is suggested to be one of the region's most vulnerable to climate change. If precipitation amounts and timing change as the projections would suggest, there will be a profound impact on water resource planning and management in the region.

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