ASSESSING THE EFFECTS OF CLIMATIC CHANGES ON SNOWPACK AND STREAMFLOW

by

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INTRODUCTION

Global atmospheric concentrations of CO_2 have increased dramatically over the past century, from 1840 values of about 260 ppm, to 340 ppm today. If trends continue, CO_2 concentrations are expected to reach 600 ppm by 2075. Although a minor constituent of the earth's atmosphere, changes in CO_2 concentrations of this magnitude could have a significant impact on the earth's climate, because CO_2 is relatively transparent to solar radiation, but largely opaque to thermal radiation, and thus creates a greenhouse effect.

Estimates of climatic changes that could be expected due to atmospheric CO_2 concentrations of 600 ppm have been made using theoretical models, empirical relationships, and actual climatic data. Estimated changes range from warming of surface temperature by 4 °C or more, to cooling the surface temperature somewhat. Precipitation was projected to increase or decrease by 10 percent or more in parts of the world (Rind and Lebedeff, 1984; Idso, 1983).

In this study, effects of such changes on snowpack development, snowmelt, and streamflow are analyzed, using the National Weather Service River Forecast System (NWSRFS) model. The model is driven by temperature and precipitation, and allows runoff ratios to change as the ratio of snowfall to rainfall changes (Anderson, 1973).

PROCEDURES

The 190^2 km Lower Willow Creek basin near Hall, Montana was chosen as the study site. The basin ranges in elevation from 1430 m above sea level at the dam, to over 2400 m at the highest point. Average annual precipitation varies from 350 mm to more than 760 mm. Streamflow records are available for most of the spring, summer, and fall months of each year from 1967 to 1984 (Farnes, 1972). The snow pillow data from two SCS SNOTEL sites located on the basin were used for calibration of the snow submodel. The Combination site (1700 m elevation) is in the southerly part of the basin and represents the lower end of a conifer forest. Daily snow water equivalent (SWE) data are available for 1973-1985. The Black Pine site (2164 m elevation) is located on the southerly upper end of the basin, and represents a continuous conifer forest. Records of SWE are available for the 1966-1985 period (SCS, 1984). Long-term temperature and precipitation records from the Drummond cooperative NWS weather station (1202 m elevation), located approximately 16 km northeast of the basin, were used as input to the model.

As a basis for comparison, the NWSRFS Model was first run for the 1973 to 1984 water years, and parameter values were adjusted until observed and simulated snowpack at the two SNOTEL sites and streamflow at the outlet were most nearly alike (Figure 1 shows best fit versus observed SWE, and Figure 2 shows the same for streamflow).

These runs, termed calibration or "Best Fit" runs, were based mainly on the spring runoff period since winter streamflow data were usually not available, and the majority of streamflow occurred in the spring. Then, using the same parameter values, the model was used to simulate snowpack and streamflow for changes in temperature of +2, +4, and -2 °C, and the same temperature changes plus an increase in precipitation of 10 percent, for the same time period.

RESULTS

The effects of changing temperature 4 °C at the Combination site are shown in Figure 3. A 4 degree increase in temperature reduces SWE as much as 80 percent, and causes the

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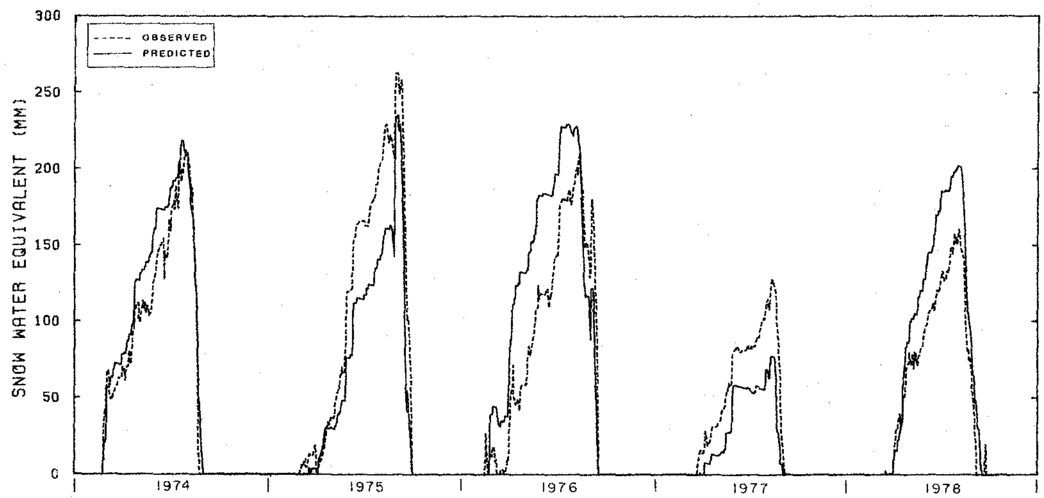

Figure 1. Simulated snow water equivalent at Combination snow pillow using Drummond weather station precipitation and temperature data, compared to observed snow water equivalent (-----) observed; ——— simulated).

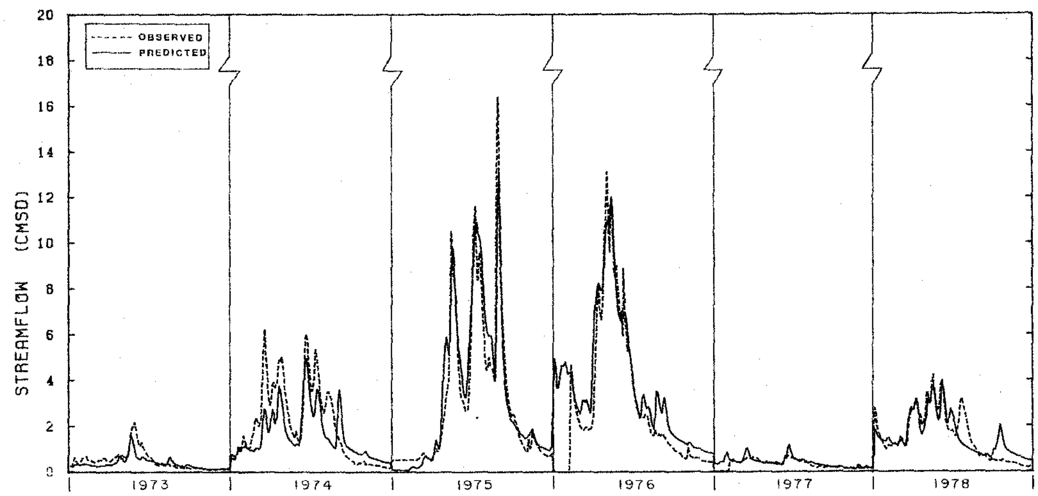

Figure 2. April through July observed and simulated streamflow at Lower Willow Creek, Montana for the 1973-1978 calibration period.

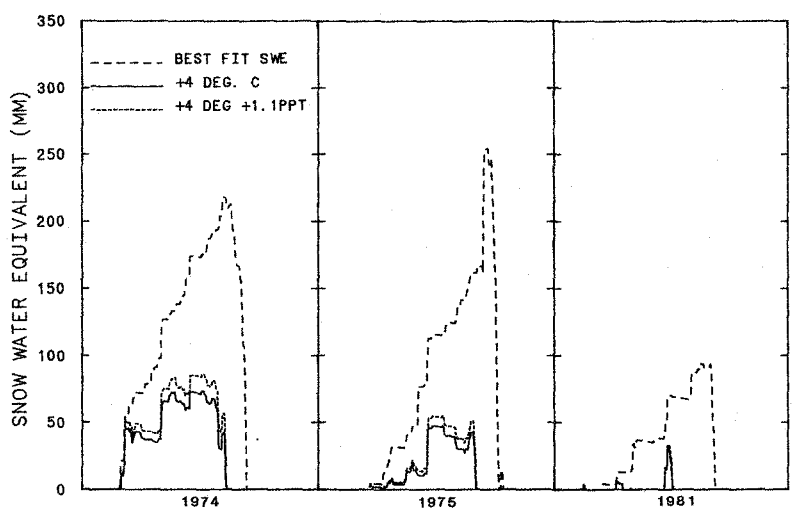

Figure 3. Simulated snow water equivalent (SWE) at the Combination SNOTEL site for the water years 1974, 1975, and 1981 under normal conditions (Best Fit), 4 °C warming, and 4 °C warming plus a 10 percent increase in precipitation.

snowpack to build later and melt out earlier in the spring, for the 1974, 1975, and 1981 water years, which represent average, high, and low snow years, respectively. Results were less dramatic at the higher elevation Black Pine site where SWE decreased by less than 50 percent for the same 4 degree warming. Results for the three water years under the various climatic conditions imposed, are shown in Tables 1 and 2 for the Combination and Black Pine sites, respectively. A 2 degree cooling is shown to increase snowpack by approximately the same ratio as a 2 degree warming decreases SWE. A 10 percent increase in precipitation tends to offset the effects of warming at the high elevation Black Pine site, but has less influence at the lower elevation Combination site where it must occur as rainfall in most instances.

Table 1. Effects of various imposed climatic conditions on the maximum yearly snow water equivalent at the Combination, Montana SNOTEL site (mm).

Imposed condition	1974	1975	1981	Average (1974-81)	Percent change
Normal	218	254	94	178	---
+2 °C*	174	136	48	126	-29
+4 °C*	74	48	30	79	-56
-2 °C*	243	320	149	217	+22
+2 °C+1.1P**	195	150	54	140	-21
+4 °C+1.1P**	86	55	33	89	-50
-2 °C+1.1P**	266	355	164	240	+35

* Average daily temperature changed by the amount shown.

** Average daily temperature changed by the amount shown and precipitation increased by 10 percent.

Table 2. Effects of various imposed climatic conditions on the maximum yearly snow water equivalent at the Black Pine, Montana SNOTEL site (mm).

Imposed condition	1974	1975	1981	Average (1974-81)	Percent change
Normal	407	557	286	395	---
+2 °C*	392	510	221	336	-15
+4 °C*	331	356	154	262	-34
-2 °C*	463	582	311	455	+15
+2 °C+1.1P*	430	563	241	371	-6
+4 °C+1.1P*	366	396	173	291	-26
-2 °C+1.1P*	520	643	344	506	+28

* Average daily temperature changed by the amount shown.

** Average daily temperature changed by the amount shown and precipitation increased by 10 percent.

The changes in average monthly streamflow caused by the increase or decrease in snowpack noted above are shown in Figures 4 and 5. When only temperature changes are considered, the streamflow is seen to decrease by up to 22 percent due to warming, and to increase by 15 percent due to cooling (Fig. 4). When the precipitation is also increased by 10 percent, streamflow is increased, and the additional precipitation offsets the 4 degree Celsius warming. An increase in precipitation coupled with a 2 degree cooling increases streamflow by 45 percent.

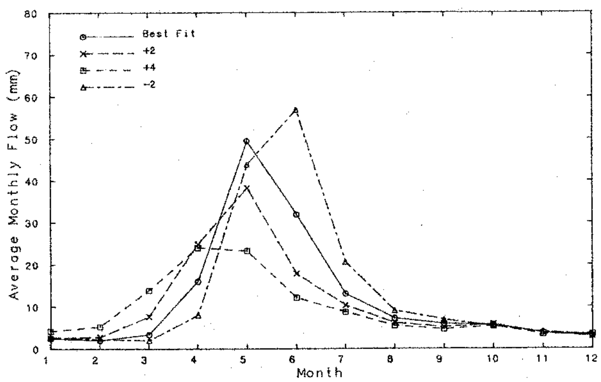

Figure 4. Simulated average long-term (1974-1984) monthly streamflow for Lower Willow Creek, Montana, under normal conditions (Best Fit), 2 °C warming, 4 °C warming, and 2 °C cooling.

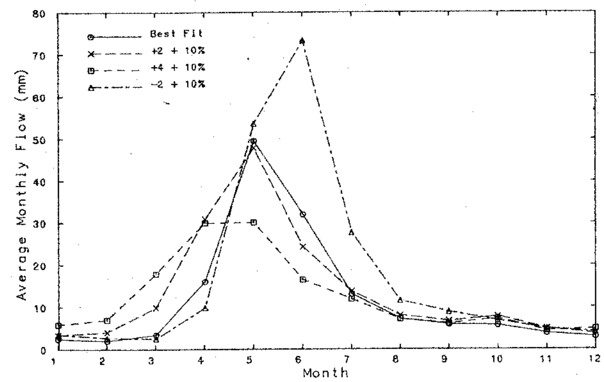

Figure 5. Simulated average long-term (1974-1984) monthly streamflow for Lower Willow Creek, Montana, under normal conditions (Best Fit), and with an increase in precipitation of 10 percent in addition to 2 °C warming, 4 °C warming, and 2 °C cooling.

CONCLUSIONS

Changing the air temperature by only 2 to 4 degrees Celsius can have a significant impact on the accumulation and melt of a snowpack depending on the original temperature regime of the site. For example, if the normal temperature range is near the threshold temperature delineating rain from snow, a small change in temperature could change the snowpack considerably. However, if the site is normally very cold or warm, a few degrees change may not alter the snowpack characteristics appreciably. Changes in streamflow are somewhat less than changes in snowpack since some of the snow that is changed to rain upon warming, still finds its way to the stream. If precipitation also increases with warming or cooling, streamflow will increase, and the increase in streamflow will be greater than the changes to the snowpack.

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