SIMULATION OF SOIL MOISTURE VARIABILITY DUE TO CLIMATE CHANGE IN NORTHEAST POND RIVER WATERSHED, NEWFOUNDLAND, CANADA

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Abstract: The impacts of climate change on soil moisture in sub - Arctic watershed simulated by using the hydrologic model. A range of arbitrary changes in temperature and precipitation are applied to the runoff model to study the sensitivity of soil moisture due to potential changes in precipitation and temperature. The sensitivity analysis indicates that changes in precipitation are always amplified in soil moisture with the amplification factor for flow. The change in precipitation has effect on the soil moisture in the catchment. The percentage change in soil moisture levels can be greater than the percentage change in precipitation. Compared to precipitation, temperature increases or decreases alone have impacts on the soil moisture. These results show the potential for climate change to bring about soil moisture that may require a significant planning response. They are also indicative of the fact that hydrological impacts affecting water supply may be important in considering the cost and benefits of potential climate change.

Keywords: climate change, soil moisture, sub-Arctic watershed, Newfoundland, Canada.

1. INTRODUCTION

Soil water is an important state variable of the land surface. Soil water is depth integrated soil moisture over in the watershed. The depth of integration encompasses soil water that participates in surface runoff, and different flows. In this work we characterise soil water variability in the aforementioned range of scales using soil water estimates reconstructed from multidecadal historical records of land surface forcing response data (i.e. precipitation and temperature). Even though definitive statements must await the acquisition of extensive records of measured soil water data, these preliminary assessments are important in the context of planned experiments that involve multiscale focus. Transfer of information from the scales continental regions requires knowledge of the properties of soil water variability across a wide range of scales. Also, the design of multiscale experiments requires information as to whether one or more embedded catchments are representative of the embedding region as whole.

In the last few years there have been a multitude of studies on the potential impact of climate changes induced by global warming, on river flow characteristics and water resources (Nemec and Schaake, 1982; Cohen, 1986; Gleick, 1986; Bultot et al., 1988; Lettenmaier and Gan, 1990, Bobba et. al, 1994, 1997, 1999). Most of these studies have used a limited range of climate change scenarios. On the other hands a relatively there have been few attempts to explore the degree of sensitivity to eliminate change and to the factors which control such sensitivities, particularly at the monthly and seasonal scales. Most of the studies have been in catchments in which spring snowmelt is the dominant feature, and only Bultot et al. (1988) have concentrated on changes in humid temperate catchments. This work builds upon previous works by Bobba et al. (1997, 1999). Soil water estimates were obtained from water balance considerations in the sub-Arctic watershed. Indices of the temporal variability of soil water were then computed. The research described here represents part of an investigation into the implications of climatic variability and change for soil water regimes in a sub-arctic Northeast Pond River watershed Canada.

2. A HYDROLOGICAL MODEL FOR CLIMATIC IMPACT ASSESSMENT

A hydrological model (Bobba et al. 1997) was modified to evaluate the advantages and limitations of water balance methods for the hydrologic assessment of climatic changes. Details of model formulation, testing, and validation are provided in Bobba et al. (1992), and Bobba (1992, 1998), will not be repeated here.

It is assumed that the hydrological model calibrated on (or validated against) current climate and hydrological data remains valid under changed climatic circumstances: in other words, the parameters of the model must not simply reflect the current relationship between climate and hydrological response. This requirement eliminates the black-box empirical rainfall-runoff models that are occasionally used for runoff generation, such as those based on multiple regression analysis between climate and observed flows. Physically based models appear to offer the best prospects (because the parameters are based on measurements, not calibration), but their detailed realism poses a different set of complications. First, they require high resolution - in both space and time - climatic input data, and second, it is possible that model parameters may need to change as climate evolves: soil structure may change, for example, as summers become drier, and, more importantly, the distribution and composition of catchment vegetation will probably alter. There are at present too many unknowns for detailed physically based models to be used in climate impact studies. A typical approach is, therefore, to use a conceptual hydrological model with physically meaningful parameters calibrated using current climate and hydrological data, and hope that the parameters of this 'grey-box' model will not change too much as climate alters.

In order to determine the effects of changing climate on the soil moisture of the region, a series of climate-change scenarios (involving changes in temperature and precipitation) were used to drive the water balance model. They included both purely and hypothetical climate-change scenarios. The hypothetical scenarios of temperature and precipitation changes were chosen after reviewing state-of-the-art estimates of future changes in climatic conditions Bobba et al. (1997, 1999).

3. CLIMATIC SCENARIOS

To assess the potential impacts of climatic change on runoff in the basin, scenarios of changes in temperature and precipitation were used as inputs to a watershed runoff model. Currently, we lack the ability to estimate the regional scale details of climatic change in sub - Arctic watersheds. Thus, for this study we relied on purely hypothetical scenarios as well as scenarios derived from the outputs of general circulation models. Climate change scenarios used in the watershed runoff model were:

The values chosen for hypothetical scenarios typically reflect best estimates of changes in important climatic variables, although extreme values are occasionally chosen to explore where a system might fail to perform as expected or designed. Thus, the practice of using hypothetical temperature increases of 1,2,3,or 4°C reflects the consensus that greenhouse warming will produce temperature rises in this range, given an equivalent doubling of atmospheric CO_2 (Hengeveld, 1995). Because much greater uncertainty surrounds estimates of change in regional precipitation, both increases and decreases in average temperature and precipitation are modeled in this study.

Scenarios	**Change in temperature**	**Change in precipitation**
Scenario 1	T plus 2°C	Precip * 2.00 (Jan to Apr) Precip * 0.50 (May to Sept) Precip * 1.50 (Oct to Dec)
Scenario 2	No change	same as above
Scenario 3	T plus 2°C	No change

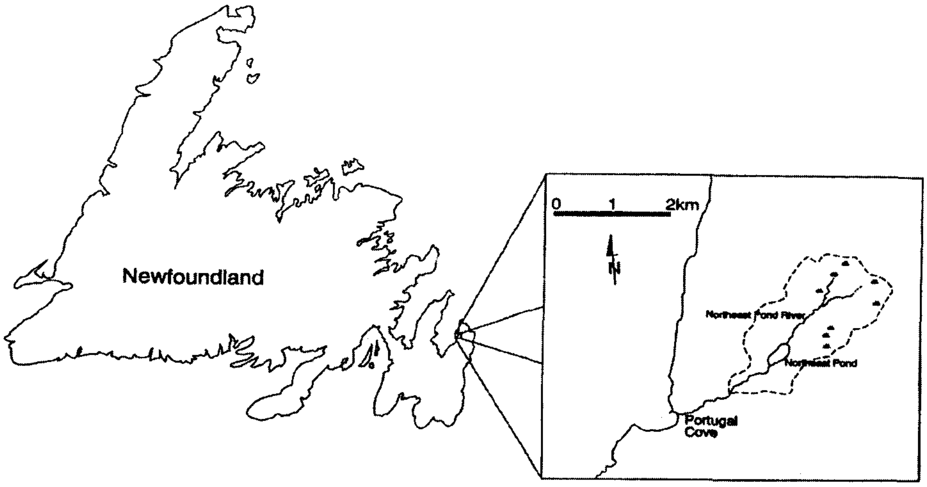

Fig. 1 Location of Northeast Pond River watershed, Canada

4. APPLICATION OF WATERSHED RUNOFF MODEL

The watershed runoff model has been applied to different Canadian watersheds (Bobba and Lam, 1990). This runoff model was applied to Northeast Pond River watershed which is located approximately 20 km west of St. Johns', Newfoundland, Canada (Figure 1). It has an area of 3.90 km^2 and its geomorphological description is given in Bobba et al. (1998, 1997, and 1994). Mean monthly temperature, precipitation, and runoff for the Northeast Pond River basin are illustrated in Figure 2 (average values for years 1954-1983). Daily temperature and precipitation data were obtained from St.John's

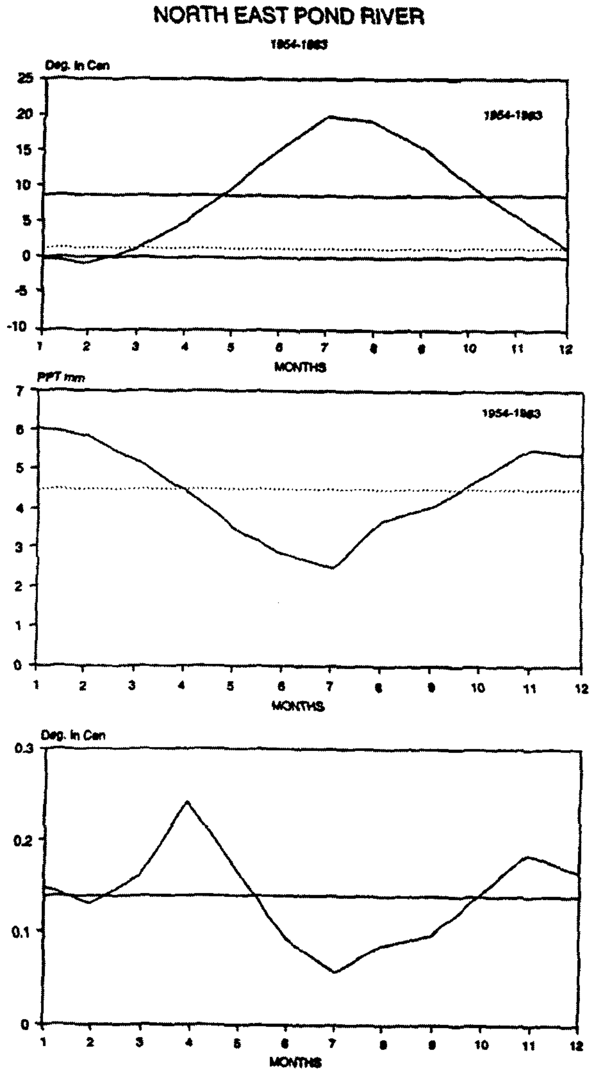

Fig. 2 Mean monthly temperature, precipitation and runoff of watershed.

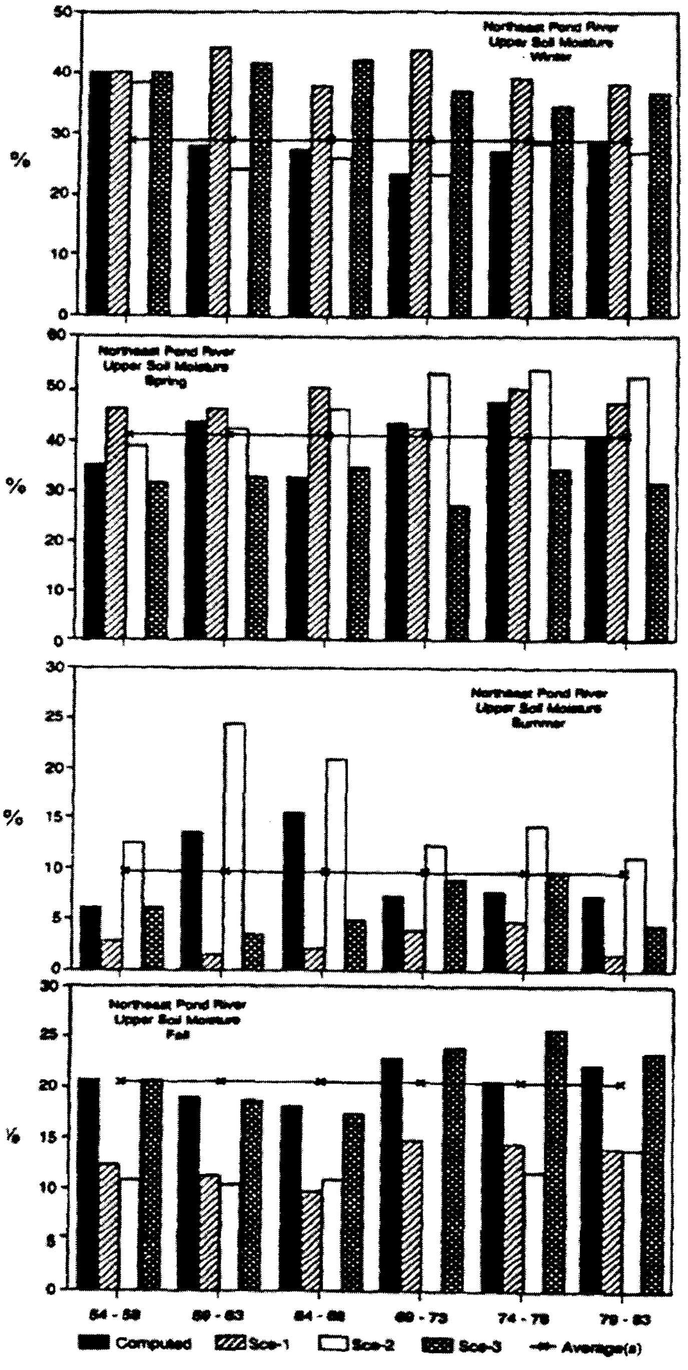

Fig. 3 Comparison of net supply in different seasons with thirty years average.

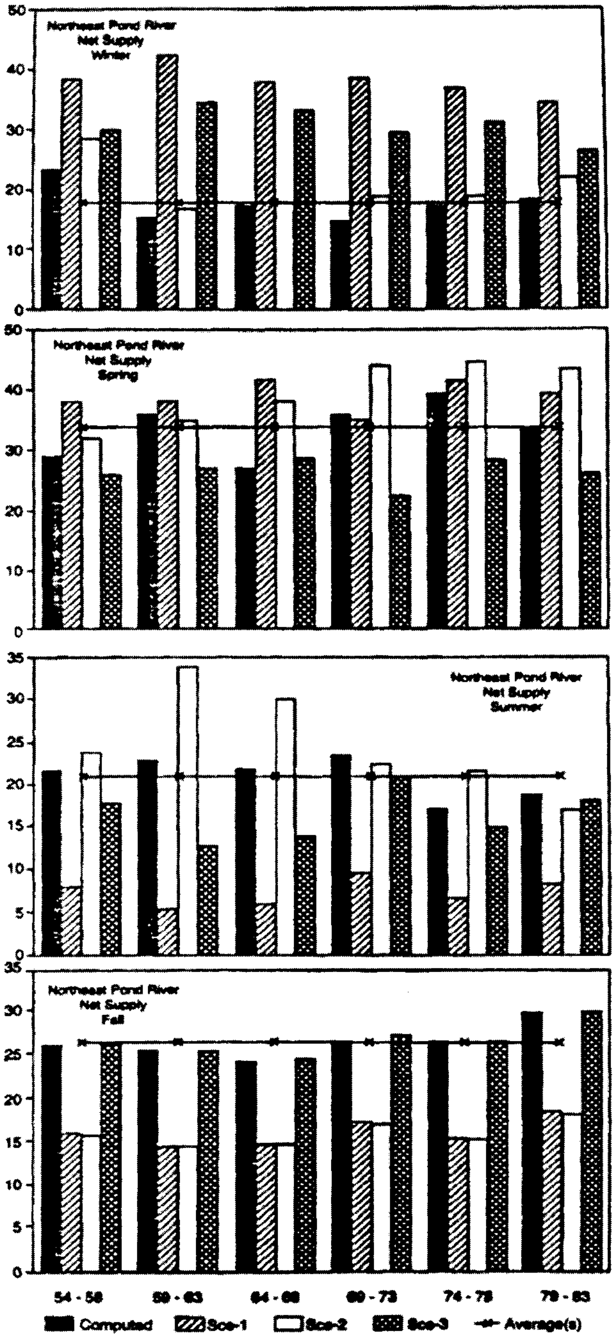

Fig. 4 Comparison of upper soil moisture in different seasons with thirty years average.

meteorological station and runoff data were obtained from the gauge at the watershed outlet. Mean monthly temperature and precipitation were calculated from daily data. The average temperature for the warmest month (July) varies from 13.5^{0}C to 16.5^{0}C over the study area, with the central part of the area being warmest and the coastal area coolest. February is the coldest month with an average temperature ranging from 4.5^{0}C to 2.0^{0}C.

The optimization criterion in the calibration is the sum of the square of the differences between the observed and simulated water equivalents of snow, discharge, and water level. All available observations are used in the calibration. Further details are provided in Bobba and Lam (1990). The model, with parameters estimated in earlier studies, was applied to the Northeast Pond River watershed (Bobba, 1992, Bobba et al. 1999, 2000).

5. RESULTS

Previously the model results compared well with observed data (Bobba 1992,1998, Bobba et al. 1992, 1994). The thirty years computed data was analyzed as different set of years for climatic change effects (Bobba et al. 1997, 1999)

5.1 Net Supply

Figure 3 shows the percentage of net supply with the thirty years average in different seasons. For scenarios 1 and 3, the net supply was higher than the thirty years average in winter months. The computed and scenario 2 was equal to the thirty years average data in winter season. The increment in temperature influenced the higher net supply for scenarios 1 and 3 in winter. The spring thirty years average net supply was higher than all seasons. Scenarios 1 and 2 showed an equal value or higher than the thirty years average and computed data sets in spring season. The net supply in scenario 2 gradually increased from the 1954 - 1958 data set to the 1979 - 1983 data set in spring months. The higher precipitation in winter months might have influenced the net supply for scenario 2 in spring months. Scenario 3 showed less influence of net supply in spring months. For scenario 2, the net supply gradually increased until the 1964 - 1968 data set and gradually reduced until 1983 in summer season. The computed net supply for summer season data sets was equal, but for scenarios 1 and 3 it was less than the thirty years average. The computed and scenario 3 net supply was almost equal in percentage of the thirty years average in fall season. Scenarios 1 and 2 were less than the thirty years average for all data sets.

5.2 Upper Soil Moisture

Figure 4 shows the upper soil moisture in different years for different data set years. The computed data for scenario 2 showed less than the thirty years average except from 1954-1958 data set. The computed data and scenario 3 showed less than the thirty years average in spring season. Scenario 1 exhibited higher value than the thirty years average, but for scenario 2 it gradually increased from the 1954-58 data set to the 1979-83 data set. The thirty years average data was higher than was for other seasons. In summer, scenario 2 showed higher but scenarios 1 and 3 showed lesser than thirty years average. The percentage of the thirty years average was the lowest of all the seasons. The computed data and scenario 3 showed higher percentage than thirty years average except from the 1959-1968 data sets. Scenarios 1 and 2 showed lower than the thirty years average.

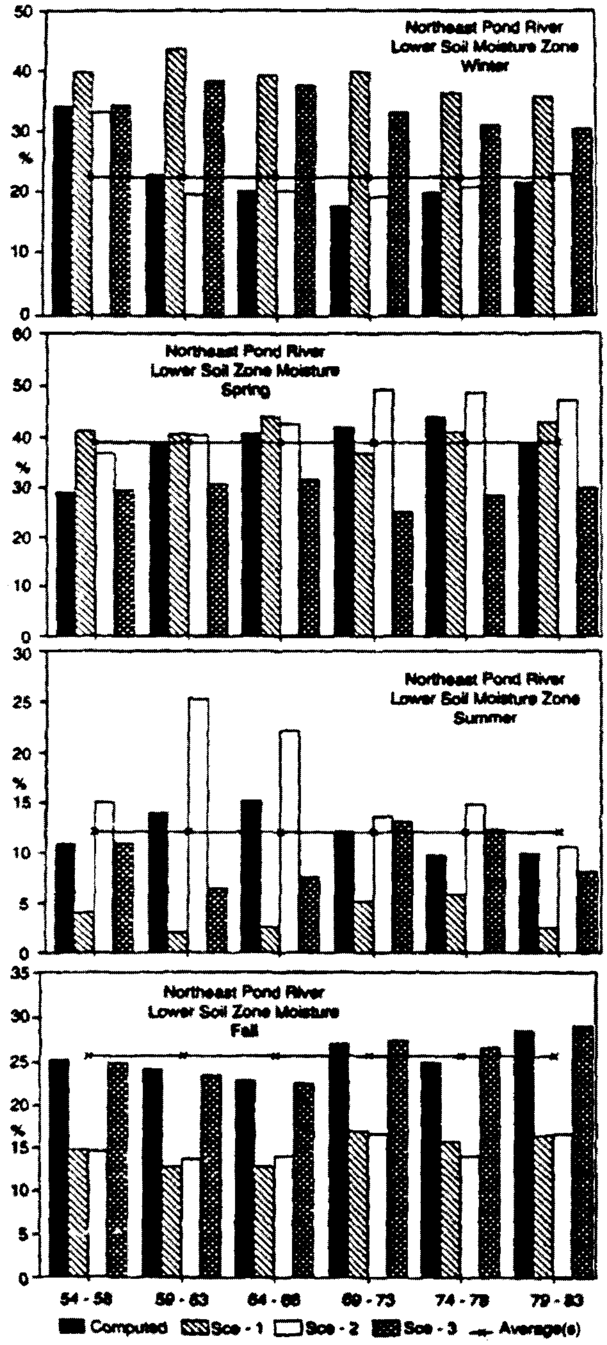

Fig. 5 Comparison of lower soils moisture in different seasons with thirty years average.

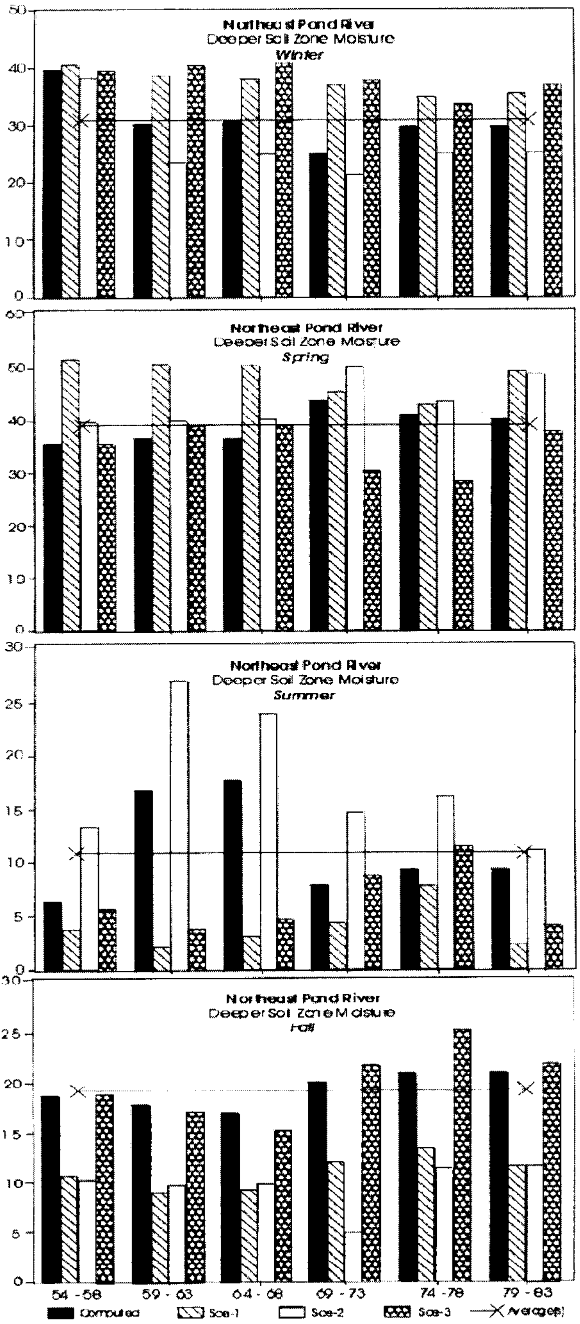

Fig. 6 Comparison of deeper soil zone moisture in different seasons with thirty years average.

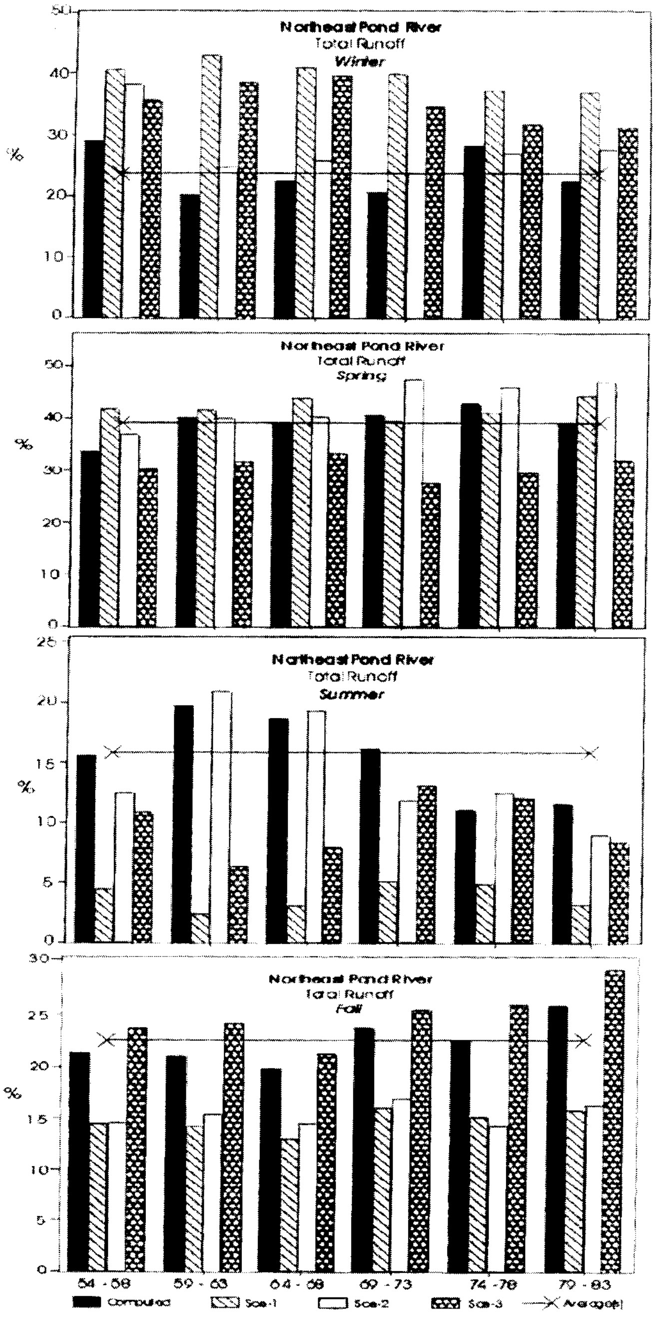

Fig. 7 Comparison of total runoff in different seasons with thirty years average

5.3 Lower Soil Moisture

Figure 5 shows the percentage of moisture in lower reservoir for different seasons and data set years. The scenarios 1 and 3 moisture percentage was higher than scenario 2 for different data sets in winter season. The scenario 2 moisture was less than the thirty years average and almost equal to the computed value in winter season. The scenarios 1 and 2 soil moisture gradually increased from 1954 to 1983 and higher or equal to the computed and thirty years average in spring season. Scenario 2 showed higher percentage moisture for some early year's data sets and equal to the thirty years average data in summer season. Scenarios 1 and 2 showed less percentage moisture than the thirty years average percentage and the scenario 3 data set in fall season.

5.4 Deep Soil Moisture Zone

Figure 6 shows the percentage of deeper soil zone for all seasons. Scenarios 1 and 3 showed higher soil moisture than the thirty years average and computed (base) and scenario 3 for data set years in winter season. Scenarios 1 and 2 were equal to the thirty-year average data in spring season. Scenario 2 was higher than other scenarios 1 and 3 and the thirty year average data in summer season. Scenario 3 was higher than scenario 1 and 2 and less than the thirty year average for early year data sets (1954-1968 sets) and gradually increased in later part of the year data sets (1969-1983 sets) in fall season.

5.5 Total Flow

The total flow is combination of surface, inter and ground water (base) flows. Figure 7 shows the percentage of total flows in different seasons. All the scenarios showed a higher percentage than the thirty years average for all data sets in winter season. Scenarios 1 and 3 dominant scenario 2 and the computed value in winter season. The average flow in scenarios 1 and 2 was higher than the thirty years average flow in spring season. The spring season contributed 40% of the total flow of the year. Scenario 2 showed a higher percentage of flow than the thirty years average from the 1959 - 68 data set years in summer season. In scenario 3, the flow gradually increased and gradually decreased for some data set years in summer season.

6. SUMMARY AND CONCLUSIONS

This study evaluated soil moisture in the watershed impacts resulting from changes in global climate changes. Widely varying climate change scenarios were used to drive a water balance model designed to evaluate the impacts of global climatic changes on total runoff, and soil moisture in the watershed. The scenarios studied include three scenarios with hypothetical temperature and precipitation changes. The most important changes were persistent decreases in soil moisture, decreases in the magnitude of summer runoff, and increases in the magnitude of winter runoff.

Both seasonal and monthly impacts were studied because short-term hydrologic changes are often of greater interest and value to water-resource planners than annual-average `changes. Four ‘seasons' were evaluated - winter (January, February and March), spring (April May and June), summer (July, August, and September) and fall (October, November and December). These assumptions are consistent with most climatic analyses of seasonal climatic variables. They also correspond well to actual seasonal conditions in the basin, which receives much of its precipitation during winter months and is dry during summer months. Despite the uncertainties that surround the nature and timing of future climatic changes and their subsequent impacts, the results obtained here raise serious concerns about regional soil water availability. In particular, observed decreases in summer soil moisture and runoff and increases in winter runoff are robust and consistent across widely varying scenarios. This consistency strongly suggests that hydrologic vulnerabilities will make the impacts of climatic change on water resources an issue of major concern in many regions of the world. Four particularly important and consistent changes were observed: (1) Large decreases in summer soil-moisture levels for some climate-change scenarios, (2) decreases in summer runoff volumes for some climate-change scenarios, (3) major shifts in the timing of the average-monthly runoff throughout the year, and (4) large increases in winter runoff volumes for all of the climate change scenarios.

Several of the results support recent suggestions that summer soil moisture reductions may occur in many regions of the world (Manabe et al. 1981, Mitchell, 1983; Manabe and Wetherald, 1986). The principal physical mechanisms, involving the decrease in snow as a proportion of total winter precipitation, an earlier and faster disappearance of winter snowpack due to higher average temperatures, and a more severe evapotranspiration demand during the warmer summer months, are both physically plausible and consistent with hydrologic mechanisms that lead to summer soil moisture drying.

The relationships between runoff and soil water content were nearly linear for the range of scenarios studied. Model biases undoubtedly affect this relationship. Percentage changes in runoff are dominated by low soil water content years.

In general, watershed balance models suggest that soil moisture and stream flows are sensitive to climate change. The model results suggest that changes in runoff of up to 15 or 20% are plausible given state-of-art estimates of future climatic changes. Impacts of this magnitude on the Northeast Pond River could have enormous economic, social, and political repercussions. This study also points out the difficulty of observing climatic impacts. Most hydrologic records are quite short and have been subject to other complicating effects. The robustness of the results presented here is constrained by the reliability of the model. Although providing more detailed information than simple statistical relationships, current watershed runoff models have substantial limitations and their applicability under altered climatic conditions has not been established. Future research in this area would benefit from the collection of additional hydrologic data, the development and testing of regional hydrologic models specifically for climate-impact studies, and the standardisation of the statistical techniques for evaluating simulated data.

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