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A WATER RESOURCE MONITORING SYSTEM FOR THE NORTHEAST UNITED STATES AN HISTORICAL OVERVIEW 1895 - 1994

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1. INTRODUCTION

An operational system for monitoring the condition of water resources across the northeast United States has been developed in conjunction with the Northeast Regional Climate Center (NRCC). This system employs the Thornthwaite/Mather climatic water budget methodology to monitor values of soil moisture surplus, soil moisture deficit and runoff on a monthly temporal scale and a climatic division spatial scale. Currently, information on water budget variables is updated monthly for each of the 54 climate divisions within the region and the information is sent to the NRCC on an operational basis. The operational products are complimented by an historical data base of water budget variables for the period 1895 through 1994. Thus, the operational products may be placed in an historical perspective, allowing the user to interpret the magnitude of the present situation correctly.

2. DATA AND METHODOLOGY

The Thornthwaite-Mather climatic water budget methodology (Thornthwaite and Mather 1955; hereafter referred to as the climatic water budget) is used to derive the water budget variables for the Northeast. In its simplest form, the climatic water budget is a mass conservation problem, comparing water input (precipitation) to water output; both evaporation and plant transpiration (collectively evapotranspiration).

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Whenever precipitation exceeds the output of water, soil moisture storage will increase, a water surplus may develop and runoff may occur. When outputs are greater than precipitation, soil moisture storage will decrease and there is a potential for the development of a soil moisture deficit. By comparing the precipitation to the potential evapotranspiration using this approach, it is possible to obtain the water budget variables including soil moisture surplus, runoff and soil moisture deficit.

The calculation of the climatic water budget requires four major data inputs: average temperature for the period under consideration, total precipitation, soil water holding capacity for a location and latitude and time of year (for the calculation of day length and solar angle). In this research, monthly temperature and precipitation data for the 54 climatic divisions (NOAA 1983a, 1983b) that make up the northeast region are used to calculate the climatic water budget for the period from 1895 through 1994. The soil water holding capacity of all climatic divisions in the Northeast is estimated to be 150 mm (Main, 1979). Locations of the climatic divisions are estimated as the center point of each division, and the time of year is taken as the mid-point of each month.

The most important variables in the estimation of the climatic water budget are precipitation and potential evapotranspiration. While precipitation is a routinely measured variable at all first order and cooperative meteorological sites, the measurement of potential evapotranspiration is not. Several different techniques have been used to estimate evapotranspiration, including mass transport, aerodynamic, eddy correlation and energy budget methodologies (Mather 1978). The climatic water

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budget utilizes an empirically derived equation (Thornthwaite 1948) that relates evaporation data from watersheds and irrigation plots to meteorological parameters. The estimate of the evapotranspiration that occurs over a given time period is a function of temperature, solar angle and day length. Although other methods of estimating evapotranspiration are more accurate on daily time-scales (Eagleman 1976), no estimation method has been universally accepted as being superior to the water budget technique on monthly time-scales (Mather 1978). Thus, the climatic water budget approach is arguably the best approach to use for an historical examination of water resources. Moreover, on an operational basis, this methodology allows for rapid calculation of water budget parameters using readily available data inputs.

3. RESULTS

The methodology described above was used to generate a climatology of water budget parameters for the period 1895 through 1994. The northeast portion of the United States lies within an area that receives consistent precipitation throughout the annual cycle. Thus, changes in the water budget parameters are mainly a result of changes in potential evapotranspiration associated with the annual cycle of temperature and solar angle. The temperature and precipitation climatology of the region results in a water budget regime that is characterized by large soil moisture surpluses from November through April (Figure 1). The months from May through October typically have soil moisture at or near capacity. However, during summer and early autumn, soil moisture deficits are common across the region. The annual cycle of runoff is generally similar to soil moisture surplus, lagging it by approximately one month (Figure 2).

Mean monthly maps of water budget parameters for the period of record were constructed and delivered to the NRCC. The completed climatology includes hard copy and digital maps of mean monthly precipitation, mean monthly temperature, mean monthly soil moisture surplus, mean monthly soil moisture deficit and mean monthly runoff.

The historical data base of water budget variables may be utilized to better understand the spatial and temporal variability of water resources across the Northeast. A 100-year time series of areally averaged summer soil moisture deficit is presented in Figure 3. Although there is great interannual variability in the time series, at least two periods of persistent anomalies are apparent. The mid 1960s are characterized by five years of large summer soil moisture deficits. This period is followed by more than a decade of deficit values below the 100-year mean. The period from 1990 through the summer of 1994 shows great variability in soil moisture deficits across the Northeast.

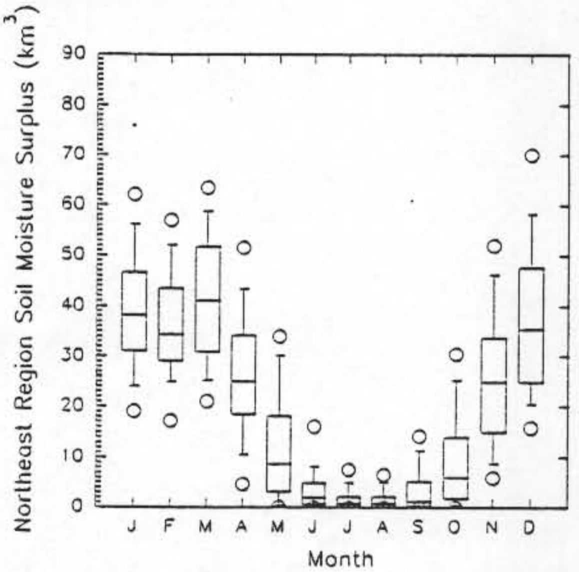

Figure 1. Box plot showing areally averaged mean monthly soil moisture surplus (km^3) across the northeast region for the period 1895 through 1993.

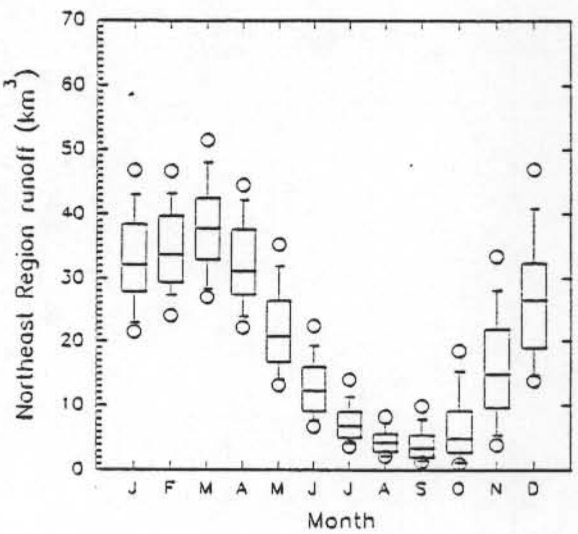

Figure 2. Same as Figure 1, except for areally averaged mean monthly runoff.

The historical data base also allows for spatial comparisons between individual periods. Figure 4 shows the accumulated soil moisture deficit for the summer (June, July, August) of 1993. This summer had the 6th largest areally averaged deficit within the 100-year record (approximately 38 km^3; Figure 3). Very large deficits are apparent along the southern New England and Mid-Atlantic coasts. The magnitude of the soil moisture deficits decreases to the north and west across the region. It is interesting to compare this spatial pattern with that of the year with the largest areally averaged deficit for the summer months, 1991 (Figure 5). During the summer of 1991, deficit values are relatively small from New England, south through the costal Mid-Atlantic region. However, large deficit values are apparent across the central portions of Virginia, Maryland and Pennsylvania. The large-scale atmospheric patterns associated with these two events are generally similar, but possess subtle differences that are responsible for the diverse spatial patterns. This discussion represents one example of the type of studies that may be pursued with the historical data base of water budget variables.

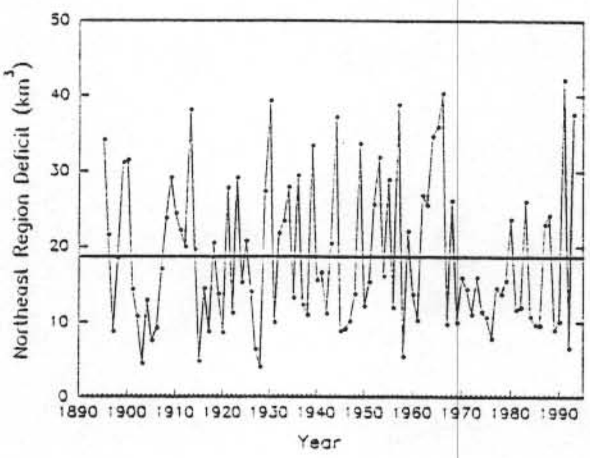

Figure 3. Time series of areally averaged accumulated summer soil moisture deficit values for the Northeast (km^3).

4. DISCUSSION

The operational products and historical data base produced in this research address the issue of soil moisture detention and runoff across the Northeast. The historical data base of water budget variables should prove quite useful in research exploring the relationship between water resources and atmospheric circulation variations. Moreover, this data base illuminates the spatial and temporal variability of water resources in this region, which is characterized by high population densities and large water usage. Diverse interests such as agriculture, hydrology, power generation, industrial concerns, recreation and transportation should benefit from this new data resource.

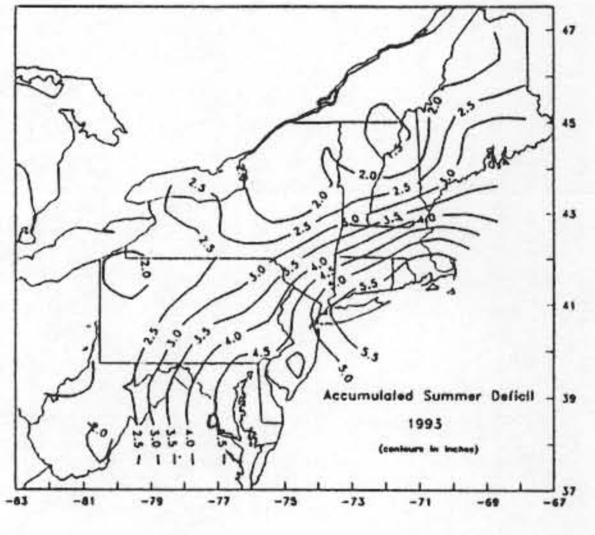

Figure 4. Accumulated summer soil moisture deficit for summer (JJA) 1993. Contours are given in inches.

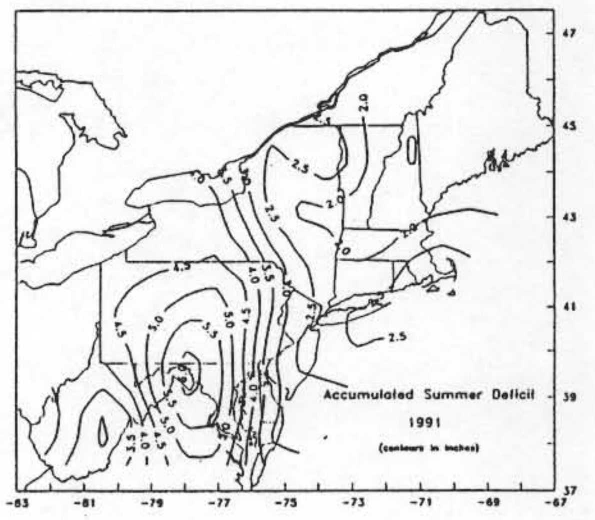

Figure 5. Same as Figure 4, except for summer 1991.

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