INFLUENCE OF CLIMATE ON PUBLIC-SUPPLY SYSTEM WATER USE IN GEORGIA

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INTRODUCTION

As available water resources decrease and concerns rise over the influence of climate change, reliable estimates of current and future water use are becoming increasingly important to water managers. Analysis of current water-use patterns can be helpful in identifying key variables that will likely influence future water use. There are an estimated 533 public water-supply systems in Georgia for which records have been kept since 1980. About 85 percent of the water distributed by those public water-supply systems was provided by 100 suppliers in Georgia.

The Georgia Water-Use Program (GWUP), a cooperative project between the Georgia Geologic Survey and the U.S. Geological Survey, collects, compiles, and disseminates water-use data for the principal water users in the State. These data are entered and stored in the Georgia Water-Use Data System (GWUDS), a computerized data base developed by the GWUP.

A multiple-regression model was developed to describe the relation between climate and water use. Climate may have an important influence on the amount of water used. The climate in Georgia varies areally, seasonally, and annually (Golden and Hess, 1991). The study, conducted by the GWUP, focuses on a statistical analyses of public-supply system water use and climatological data in Georgia for the period from 1980 to 1990. Climatological data are available for about 80 percent of these 100 largest water suppliers; data for the remaining suppliers were estimated.

The results may be useful in understanding how short-term climatic variations affect water use, and provide a better mechanism for estimating future water use under a variety of climatic conditions. The process may provide a general tool for assessing the significance of climate on public-supply system water use in Georgia and other areas of the United States. Several reports have been published concerning water use in Georgia; however, this study is the first presenting monthly water-use forecasting techniques.

SELECTION OF VARIABLES

To estimate the significance of climatological factors, a multiple-regression model was developed. The multiple-regression analysis consists of one dependent variable and two or more independent variables. The dependent variable chosen for the regression model is monthly per capita water use in gallons per day, defined as the average amount of water used per person during a standard time period, (Solley and others, 1988). Per capita water use includes indoor or domestic use and outdoor water use.

Monthly water use is affected by many factors, including climate (precipitation, temperature, evaporation), peak demand (monthly, seasonally, annually), price of water, water availability, location, and emergency conditions (droughts, plant outages, water restrictions). Water use is influenced by these factors on different time scales. The independent variables considered for the regression model included pan evaporation, temperature, precipitation, lagged precipitation, and lagged temperature. However, after all the variables were examined, total monthly precipitation (which accounts for days of little or no rain) and average monthly temperature (which allows for the variations in temperature during a month) were chosen as the independent variables.

The data for each of the variables (water use, precipitation, and temperature) were compiled for the 100 largest public-supply systems in Georgia for each month for the period 1980-90. Monthly withdrawals for these public-supply systems were obtained from the GWUDS data base and represent 85 percent of the total water withdrawn for public supply in the State. All public-supply systems used in the multiple-regression model are permitted systems that withdraw at least 100,000 gallons of water per day. The permitted public-supply systems also represent the most reliable water-use data available. Withdrawal for each public-supply system then was used with the population served by the system to determine the per capita water use.

Data for the independent climatological variables (precipitation and temperature) were obtained from the National Oceanic and Atmospheric Administration (NOAA) (U.S. Department of Commerce, 1981-91).

These data were compiled from monthly reports at observation stations for municipal sites that yield the most accurate available climatological data. If climatological data for a public supplier were not available, climatic conditions were estimated.

THE REGRESSION MODEL

A strong correlation was assumed to exist between water use and climate. However, other factors needed to be considered to explain variations in the data. Statewide, Georgia receives an average 50 inches of rainfall each year that varies both areally and by physiographic province (Carter and Fanning, 1982). Two significant droughts occurred during the 1980's (1980-82 and 1985-89) (Golden and Hess, 1991). The differences in the precipitation and temperature at the public-supply systems may be explained by location. The northern half of the State is highly urbanized and surface water is used in larger quantities than ground water for public supply. The southern half of the State is mostly rural and ground water primarily is used for public supply (Fanning, 1991). Location of the public-supply systems and water-use practices may explain per capita water-use differ.

A plot of monthly per capita water use for the 11-year period 1980-90 (fig. 1) reveals higher values and greater variation occurring during the summer months, requiring adjustment of the model for seasonal effects.

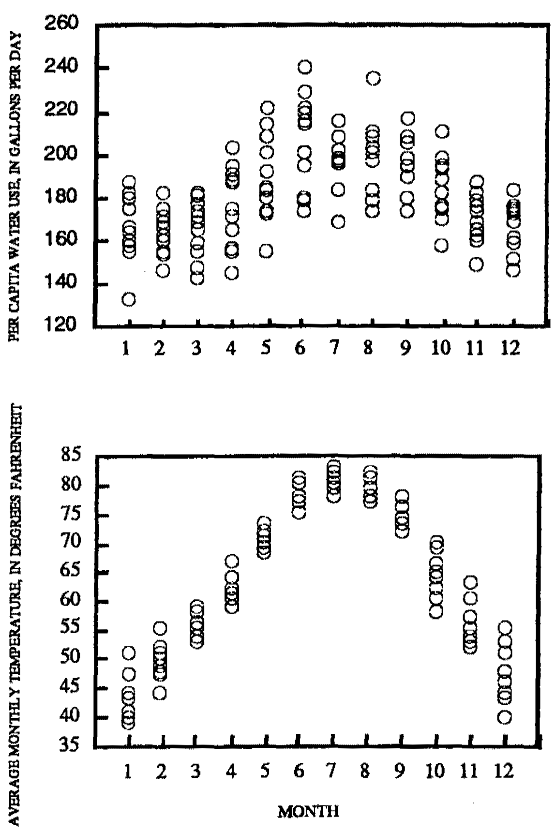

Figure 1.– Monthly per capita water use and average monthly temperature, 1980-90.

The plot of average monthly temperature over time (fig. 1) shows similar variation as per capita water use occurring during the summer and fall months. Statistics for the variables used in the regression model are listed in table 1.

Table 1.– Statistics of variables used in multiple-regression analysis

	Per capita water use, in gallons per day	Total precipitation, in inches	Average temperature, in degrees Fahrenheit
Count	132	132	132
Mean	181	259	64
Variance	439	17,110	162
Minimum	133	18	39
Maximum	240	952	83
Median	179	237	64
Standard deviation	21	131	12.7
Standard error	1.8	11	1.11
Coefficient of variance	0.1	0.5	0.2

A scatter plot of per capita water use and average monthly temperature has a positive correlation (correlation coefficient, r = 0.66, and coefficient of determination, $r^2 = 0.44$) (table 2); that is, as temperature increases, per capita water use increases (fig. 2). A strong relation exists at temperatures above approximately 55 degrees Fahrenheit.

Table 2.--Correlation results for average monthly per capita water use and selected independent variables

	Correlation coefficient, r	Coefficient of determination, r^2
Total monthly precipitation, in inches	0.66	0.44
Average monthly temperature, in degrees Fahrenheit	0.40	0.16

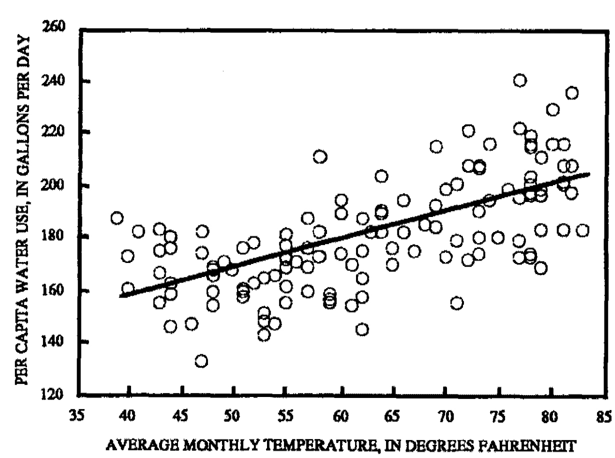

Figure 2.--Per capita water use and average monthly temperature, 1980-90 .

This relation indicates that temperature has the most direct influence on water use between April and September when temperatures are warmer. Total monthly precipitation, the other climatic variable considered in the study, has a negative correlation ($r = 0.40$ and $r^2 = 0.16$) with water use (fig. 3). The relation, however, indicates that, by itself, precipitation may not affect water use.

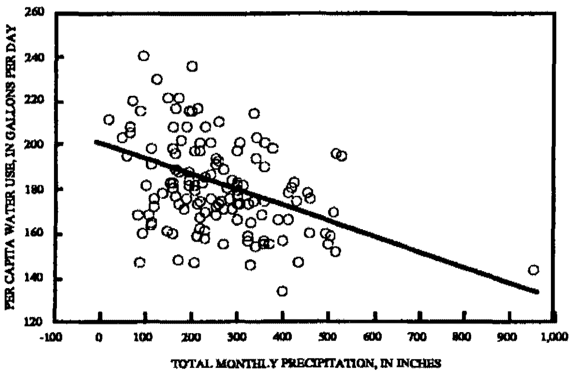

Figure 3.--Per capita water use and total monthly precipitation.

Six-month intervals (April through September) of water use, temperature, and precipitation were compared for the 11-year period (seasonal data base). Time and correlation plots were made using the seasonal data base and compared to water use plotted for the 12-month period. The time and correlation plots revealed similar patterns of water use as compared to the complete data set for both relations; however, plot comparisons also indicate that using data for the entire period produces greater correlations ($r = 0.47$ for average monthly temperature and $r = 0.47$ for total monthly precipitation).

MODEL IMPLEMENTATION

The run of the multiple-regression model yields the following regression equation:

$$Y = -0.06X' - 1.04X'' + 129$$

where:

Y = average monthly per capita water use, in gallons per day,
X' = total monthly precipitation, in inches,
X'' = average monthly temperature, in degrees Fahrenheit, and
X = intercept 129.

The value of the coefficient of determination ($r^2 = 0.56$), which is used to assess the quality of the regression model, indicates that nearly 56 percent of the per capita water-use variations are explained by total monthly precipitation and average monthly temperature. The coefficient, standard error, standard coefficient, and t-value of the independent variables are listed in table 3.

Table 3.--Regression results

	Coefficient	Standard error	Standard coefficient	t-value
Intercept	129	6.9	129	18.7
Total monthly precipitation, in inches	-0.06	0.01	-0.35	-5.88
Average monthly temperature, in degrees Fahrenheit	1.04	0.10	0.63	10.8

The t-value, or test hypothesis for the intercept, is significantly different from zero, which supports the relation between the climate and water use. Logarithmic transformations were used on the original data set; however, these transformations did not improve on the assumptions initially made for the model.

Monthly simulated and observed per capita water use for the period 1980-90 are shown in figure 4. Even with the strong correlation, it is evident that using the model for drought periods will not yield as accurate a prediction of per capita water use as it would for years of normal or near-normal precipitation. The model, however, can be a useful procedure for short-term estimation of per capita water use for a period of one to three months. The model also predicts variations in monthly use during the seasons of the year.

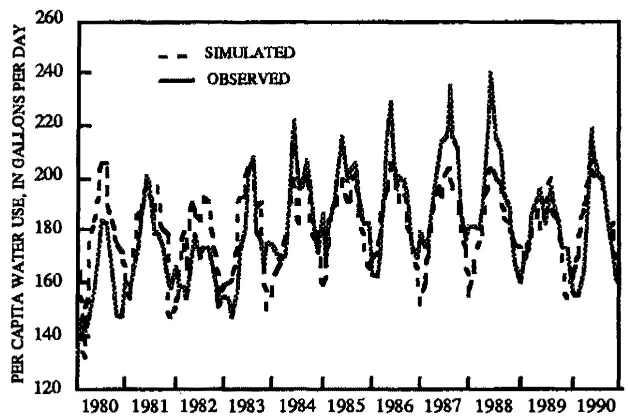

Figure 4.--Simulated and observed per capita water use.

SUMMARY

The multiple-regression analysis presented in this paper is one method of forecasting per capita water use in Georgia. The model consists of using one dependent variable (per capita water use in gallons per day) as it relates to two independent variables (total precipitation and average temperature). Total monthly precipitation and average monthly temperature proved to be appropriate for the multiple-regression analysis. The model should be useful in estimating short-term (monthly) per capita water use and probably could be improved by including other independent variables, such as daily or weekly precipitation and water use. The model produces a correlation coefficient $r = 0.75$, a coefficient of determination $r2 = 0.56$, and may provide a basis of comparison for conservation programs.

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