Effects of Weather on Weekly Municipal Water Use in the Tampa Bay Area

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Municipal water use fluctuates in response to many independent variables. Although long-term trends are related closely to economic and demographic factors, short-term variations are more frequently influenced by recent weather events. This study analyzes the relationships between recent weather events and weekly fluctuations in water use for the greater Tampa Bay urban area.

During the regional drought of 1989 and 1990, staff at the Southwest Florida Water Management District (SWFWMD) routinely evaluated the potential need for water use restrictions aimed at protecting this natural resource. Anticipated municipal water use was one of several variables considered in those deliberations. Although large quantities of data were available, it soon became apparent that there were no systematic evaluation procedures. The present work is intended to contribute to the development of such a procedure.

Hypotheses

It was hypothesized that weather contributes significantly to the fluctuations in weekly water use for the greater Tampa Bay area. It was further hypothesized that some weather variables are more relevant for modeling the area's water use than others and that such differences can be identified numerically.

Similar data had been used previously to model water use for other locations (Franklin and Maidment, 1986; Hansen and Narayanan, 1981; Maidment and Miaou, 1986; Maidment and Parzen, 1984a and 1984b; Miaou, 1990; Morgan and Smolen, 1976; Wilson, 1989; and Steiner, 1984). These studies have generally concentrated on somewhat closed supply and demand environments, where all the water supplied to the study area was provided by one or a few utilities and went to a well defined consumer population. The present model, however, faces the real-world necessity of forecasting water use for a large, diverse urban

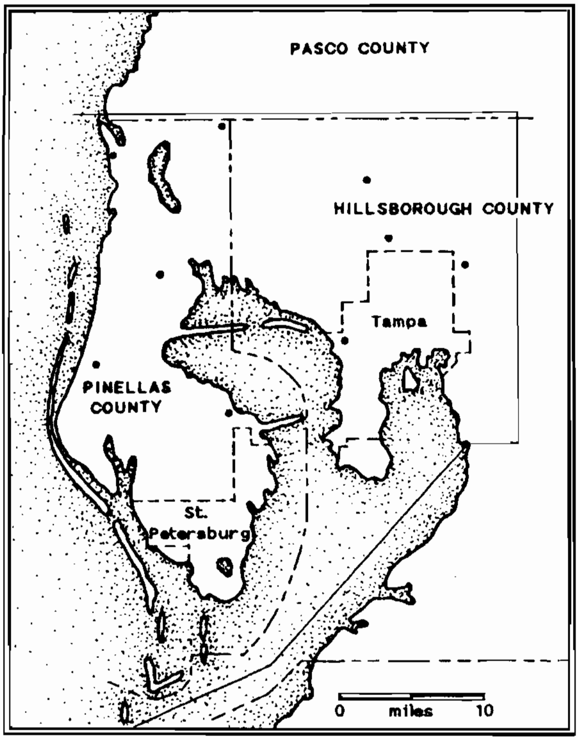

Figure 1. Study area
● *meteorological stations* —— *study area boundary*

area with many supply sources and markets. This work indicates whether the variables and methodology that have been used to model simpler systems can be successfully applied under complex circumstances.

Study area

The study area includes the cities of Tampa and St. Petersburg, all of Pinellas County, and a substantial part of Hillsborough County, Florida (Figure 1). The population is about 1.6 million. Average water use for the four major city and county utilities in the area was 228 million gallons per day (mgd) for the twelve-month study period (March, 1989 - February, 1990).

Public water supplies for the area come from many sources, including some in neighboring Pasco County. The supply and distribution system is large and complex, with many interconnections and exchanges of water.

Tampa and St. Petersburg and Hillsborough and Pinellas Counties, with nearby Pasco County, are members of the West Coast Regional Water Supply Authority (WCRWSA). This agency operates well fields and pipelines and coordinates bulk distribution. The WCRWSA directly manages some production and transmission facilities and coordinates with other facilities operated independently by the member local governments. The WCRWSA sells and buys water to and from its members. The members, in turn, carry on similar transactions with each other and with non-member smaller local governments and private utilities.

The study area is largely suburban and residents place high cultural value on the quality of lawns and landscaping. During the warm season, up to 53% of publicly-supplied water is used for this purpose (Hillsborough County, 1987). For hookups with separate irrigation meters, this figure rises to 74% (Camp, Dresser, and McKee, Inc., 1988). Thus, it can be expected that a substantial proportion of water use variability can be explained by meteorological conditions that affect the water needs of vegetation.

Data sources

Meteorological data were supplied by the Southwest Florida Water Management District. The SWFWMD collects data directly as well as compiling it from other agencies. Meteorological data from ten stations in or near the study area were used (Figure 1). Water use data were obtained from the Tampa, St. Petersburg, Hillsborough County, and Pinellas County public water systems via the SWFWMD.

Prior to the official declaration of a water shortage, in late February 1989, only daily and monthly data were compiled by the SWFWMD. Data compilation for weekly intervals began with the onset of the declared shortage. This study uses the first available full year of weekly data.

Methodology

Selected meteorological variables were used in a multiple linear regression model to analyze their relationships to fluctuations in weekly water use for the Tampa Bay area. Alternative combinations of variables were examined until statistical tests indicated that the best possible fit was achieved.

Selection of the linear regression methodology and of specific types of meteorological variables to be used were based opon the literature cited above. Multiple linear regression, or modified regression procedures, were used in all the previous works involved with modeling short-term municipal water use.

Although previous studies have generally used regression-based methodologies, their selection of independent variables has been inconsistent. No two models found in the literature have used the same variables set. Therefore, the relative performance of several independent variables was tested as part of the process of model development for the Tampa Bay area water use model. The selected variables have all been used in one or more of the cited references. They include the following items, taken individually and in combination:

Rainfall

- Current week rainfall;
- Lagged rainfall for up to four weeks, entered as separate variables;
- Cumulative rainfall for two, three, and four weeks; and
- Average number of rainy days per station for the current week.

Duration of daylight

- Minutes of daylight per day.

Temperature

- Mean high temperature;
- Temperature above 60°, 70°, and 80° F (15°, 21°, and 26° C);
- Combination of temperature above 70° F (21° C) with temperature above of 85° F (29° C) and 90° F (32° C); and
- Combination of temperature above 70° F (21° C) with the number of days during the week in which any station recorded a temperature below 45° degrees F (7° C).

Calibration of the model was based on standard error (se) fit (R^2), and probability that the variance of the resulting di not significantly different from that of the dependent variable being modeled (F-ratio). Models with lower standard error and higher R^2 were considered superior. An F-ratio indicating significance at the .05 probability level was considered the minimum for the model to be acceptable. The significance of individual variables, within combined variable models, was determined by t-scores. The relative importance of each variable in contributing to the overall outcome of the model was measured by standardized partial regression coefficients.

Results

Rainfall, with up to a three week lag, duration of daylight, and temperature proved to be the most effective variables for forecasting the Tampa Bay area's municipal water use. Rainfall and temperature were expected to be important factors in the model. The effects of daylight, however, are less obvious because they are indirect. Duration of daylight is a causal factor affecting both temperature and plant growth, and, therefore, the water needs of plants. Longer duration of daylight also provides greater opportunity for people who irrigate manually to apply water to their yards.

Several models produced significantly similar results at the .05 confidence level. R^2 values for these models varied from .79 to .86, with corresponding s.e. values of 10.23 to 8.91. The average difference between actual weekly water use and quantities generated by the models covered a range from a maximum of 3.6% down to 3.1%.

Improved results for R^2, s.e., and forecasting of actual water use quantities were obtained by including more variables in the model. The simplest model, which produced the R^2 of .79, s.e. of 10.23, and a 3.6% forecasting error, used only two independent variables. These were four weeks of cumulative rainfall and the current daily duration of daylight. The model that produced the .86 R^2 value, as well as the lowest s.e. and forecasting error, required six independent variables. These were four weeks of rainfall entered separately, current duration of daylight, and one week of average temperature above a 60° F (17° C) threshold. Models which compromised between these two approaches, using three or five variables produced intermediate R^2, s.e., and forecasting error values.

The author prefers the simplest model, containing only two variables. This approach dispenses with unnecessary complexity beyond that needed to achieve an adequate forecast. The more complex models, however, produce progressively better results as more variables are added, yielding

R^2 values up to 7% higher than that obtained by the two-variable version. This may indicate that differences between the model outputs are meaningful, though conventional statistical practices indicate they could be the result of random chance. Therefore, an alternative rationale exists for selecting the most complex model, based on the greater apparent precision obtained. Because a reasonable rationale exists for selecting either model, both are described below in greater detail.

The models take the general multiple linear regression form of:

$$y = a + b_1X_1 + b_2X_2 .. b_mX_m$$

where y is the estimated water use, a is the constant (y-axis intercept), b's are partial regression coefficients, and X's are the independent variables. Inserting the actual partial regression coefficients in place of the b's, the specific formulae used to estimate weekly water use for the greater Tampa Bay area are:

$$y = 69.66 - 6.40X_1 + 0.25X_2$$

for the two-variable model, where X_1 is four weeks of cumulative rainfall in inches, and X_2 is the current week's average duration of daylight in minutes; and

$$y = 88.492 - 4.77X_1 - 4.56X_2 - 11.06X_3 - 7.69X_4 + 0.19X_5 + 0.94X_6$$

for the six-variable model, where X_1 through X_4 are four consecutive weeks of rainfall in inches, from earliest to latest; X_5 is the current week's average duration of daylight in minutes; and X_6 is the average daily number of degrees above a 60° F (15° C) threshold.

Table 1 shows partial regression coefficients and t-scores for both models. The standardized partial regression coefficients indicate the relative contribution of each independent variable. The t-scores indicate that all variables contribute significantly to the regressions.

Tests against later data

An additional five and one-half months of data, covering March through mid-August, 1990, became available while the initial study was

Table 1
T-scores and Standardized Partial Regression Coefficients

	Lagged Rain 1 Wk	Lagged Rain 2 Wk	Lagged Rain 3 Wk	Current Week Rain	4 Wks Total Rain	Daylight in Minutes	Degrees Above 60 F
t-scores							
4 Weeks Total Rain, Daylight					-12.81	12.19	
4 Separate Week Rain, Daylight >60°F (15° C)	-3.95	-3.73	-9.13	-6.44		11.33	4.98
Standardized Partial Regression Coefficients							
4 Weeks Total Rain, Daylight					-1.026	0.914	
4 Separate Week Rain, Daylight >60°F (15° C)	-0.240	-0.227	-0.556	-0.393		0.691	0.303

Note: All shown t-scores are significant at the .01 level.

underway. These data, with adjustments described below, were combined with the partial regression coefficients generated by both selected models. The average difference between actual weekly water use and forecasted quantities for the follow-up interval was 3.6% for the two-variable model and 2.9% for the six-variable model. These results indicate that both models could forecast future water use as accurately as they accounted for the original water use data.

Conformity to actual use

Figures 2 and 3 illustrate the close conformance of the two-variable model's output to actual water use. The scattergram (Figure 2) however, reveals a tendency for the model to underestimate extremely high water use and overestimate extremely low use. The line graph (Figure 3) shows

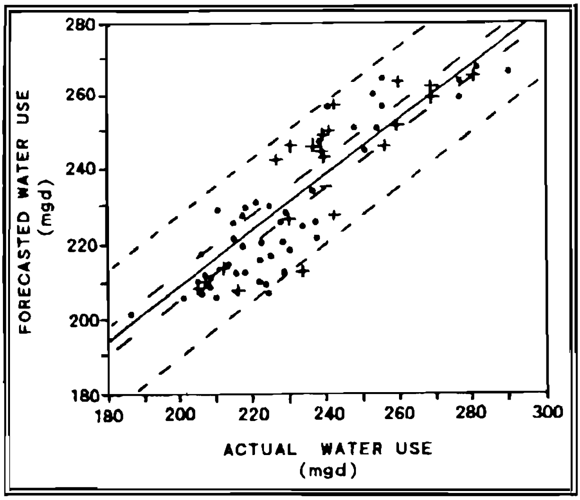

Figure 2
Actual and forecasted water use, scattergram
● *initial 12 months*
+ *5½ month test period*
— — *.05 predictive limits*
- - - *.05 confidence interval*

that this happens because the model output has a smoother distribution than actual water use. The standard deviation for the model output is 19.7 mgd. This may be compared with 21.8 mgd for actual use. Graphics for the six-variable model are sufficiently similar as to be redundant and, therefore, are not shown.

Data adjustments

Beginning in April 1990, the City of Tampa implemented a major water conservation campaign because of expected difficulties in meeting high seasonal demands. This program consisted of a massive public information effort and strict enforcement of mandatory outdoor water use restrictions. Consequently the City of Tampa's water use declined during the spring and summer of 1990, compared to the previous year, by about 15%, or 13 mgd. The throughput of the other three utilities used in the study also exhibited a consistent, though smaller, decline, probably resulting from the increased publicity given to water conservation at that time. The total decline in water use from April through mid-August amounted to about 21.6 mgd. To test the model, this amount was added to the actual 1990 water use for those months, to adjust for the successful conservation program.

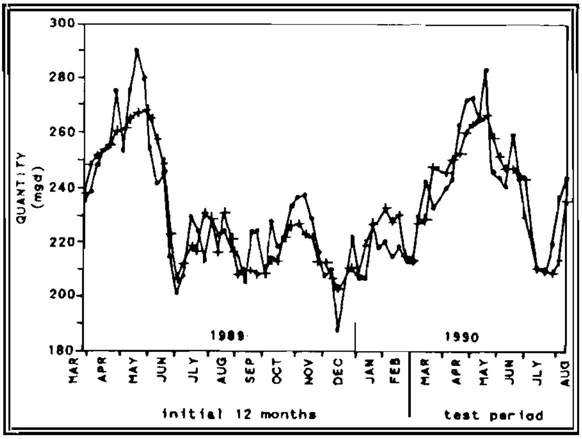

Figure 3. Actual and forecasted water use, lineplot
● *Actual water use* + *Forecasted water use*

No previous adjustments had been made for the effects of legal water use restrictions during the development of the model because the SWFWMD could not identify such impacts. Water use frequently continued to rise after the SWFWMD imposed or tightened restrictions. The decrease in use during the spring and summer of 1990 was the result of a local crackdown and increased public awareness, rather than a decree from the regional water management district.

Conclusions

The underlying hypotheses on which this project was based are supported by the model. The numerical procedures applied indicate that fluctuations in weekly water use for the Tampa Bay area can be adequately explained by climatic variables alone. Combinations of rainfall, duration of daylight, and temperature provided the most acceptable models.

The transfer of methodology from simpler supply and demand scenarios to the complex structure of the Tampa Bay area proved successful. This work has produced a valid model for forecasting public supply water use in the Tampa Bay area. In the present work, aggregate water use had to be determined for an area with a multiplicity of supply sources and markets. Meteorological data also had to be aggregated for the area from several stations. The modeling procedure was successful despite these complexities.

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