SOUTH FLORIDA WATER MANAGEMENT DISTRICT

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An Analysis of Water Requirements and Water Demands for the South Florida Water Management District

by

John W. Toomey, Jr.

and

L. Carl Woehlcke

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Resource Planning Department
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ABSTRACT

A Water Requirements and Water Demand study was undertaken by the South Florida Water Management District pursuant to its responsibilities outlined in the Florida Water Resources Act of 1972 (Chapter 373). The purpose of this research effort was to investigate relevant variables which would (1) explain a utility's total annual pumpage of water and (2) identify factors which might explain the variation in the per capita consumption of water across utilities. Secondary data sources were used in the study and the data sample used included utilities located throughout the Water Management District.

The results of the water requirements aspect of the investigation, using time-series cross sectional data (1970-75), revealed that the service area's total population was by far the best explanatory variable of total water pumpages. Population dominated the model to such a degree that no other variables proved to be significant.

The research effort then concentrated on identifying factors causing variations in the per capita consumption of water across utilities. Rainfall was expected to be one of the explanatory variables; however, it failed to be significant. A hypothesis that lawn watering was a function of plant stress was then tested. A measure of water deficiency was developed and regressed against per capita consumption. The results indicated that the measures of water deficiency were significant in explaining variations in the per capita consumption of individual utilities.

A socio-economic model was then developed using data from the 1970 U.S. Census of Population. Unfortunately, time series data were not available for the 1970 to 1975 period. Numerous descriptors on age distribution of the population, housing characteristics, income variables and price were tested

for influence upon the per capita consumption of water. The results indicated that the additional price of water above the minimum charge was the most significant explanatory variable followed by the percent of total population sixty-five years of age and older, and average per capita income. The negative relationship between the per capita consumption and the water price indicates that in the long run higher water prices do promote measurable reductions in water consumption. The relationship between the percentage of the population 65 and over and per capita consumption was also negative indicating that utilities with higher average ages have lower per capita consumptions. On the other hand, the positive coefficient relating per capita water consumption to average per capita income indicates the extent to which higher incomes are associated with higher per capita consumptions. Climatological variables were not included in the socio-economic model because there was not enough variation in rainfall and water deficiency in 1970 to measure the impacts of these variables.

The research effort concluded that a utility's total pumpage of water can best be explained by its level of population. It also found that the price of water, income, age and rainfall deficiencies can explain a large portion of the variation in per capita consumption of water.

I. INTRODUCTION

In 1972 the Florida Legislature passed the Water Resources Act (Chapter 373). This piece of legislation outlines four areas of responsibility for the Department of Environmental Regulation and the five water management districts[1]: (1) water management planning, (2) construction and operation of water management structures; (3) regulation and permitting of consumptive use of water; and (4) regulation and permitting of surface water management systems. The regulation and permitting is of primary importance to the water management districts because the language of Chapter 373 mandates that in order for a permit to be issued the use of the water must adhere to the following requirements: (1) the use of the water is reasonable and beneficial; (2) it will not interfere with any presently existing legal use of water; and (3) the use is consistent with the public interest.[2] These requirements coincide with the equally important mandate concerning water management planning. The Water Management Districts are required to prepare a Water Use Plan which identifies sources and uses of existing water supply and to project future requirements (i.e., human and environmental) which leads back to the regulatory and permitting process since the plan must determine the quantity of water that will be necessary to support future needs.

The purpose of this report is to contribute to the present knowledge of the South Florida Water Management District's (SFWMD) water use plan by developing relationships useful for understanding and projecting urban water

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[1] Maloney, F.E. and Hamann, R. G. "Interrelating Land and Water Management in Florida", Proceedings of ASCE Irrigation and Drainage Division and ASCE Water Resources Planning and Management Division Specialty Conference. 1978. pp. 150-169, American Society of Civil Engineers, 345 E. 47th Street, New York, New York, 10017.

[2] Op. Cit., p. 156.

demands. This study addresses two types of water "demand" research designs. The first type deals with the variations in utility water requirements while the second type analyzes variations in utility per capita consumption.

The study is divided into eight sections. Section I is the introduction. Section II discusses general economic demand theory. Section III is a literature review of typical water requirement and water demand studies and other studies dealing with the same topics using Florida or Southeastern United States data. Section IV explains the development of the water requirements data. Section V gives the results of the water requirements modelling effort and Section VI deals with the climatological model. Section VII presents the findings for the socio-economic portion of the study. Section VIII provides a summary and presents the conclusions of the study.

II. ECONOMIC DEMAND THEORY

Economic demand theory states that the quantity demanded of a product is inversely associated with the price of the good or service under consideration. That is, if price were to increase (decrease) then the quantity demanded would decrease (increase). Other factors which affect demand by shifting the whole curve include: (1) the price of complementary and substitute goods, (2) income, and (3) tastes and preferences of the consumer for the goods or services in question.

There are no close, reasonably priced substitutes for water; therefore variables which might represent this category are normally omitted from water demand studies. There are however, numerous complementary goods which use water in the consumption process such as dishwashers, washing machines, and scotch whiskey. Income can be measured in actual dollars and cents or it can be measured in terms of other units such as value of housing, number of bathrooms, or other similar factors which reflect a family's income. People's tastes and preferences in consuming water can be measured in terms of water quality variables such as color content and/or the mineral content of the water.

Price Elasticity of Demand

Price elasticity of demand (η_p) measures the responsiveness of changes in quantity demanded resulting from changes in price by comparing the percentage change in quantity demanded with the percentage change in price. Price elasticity expressed in mathematical terms is

$$\eta_p = \frac{\%\Delta Q}{\%\Delta P}$$

where:

η_p = price elasticity

$\%\Delta Q$ = percentage change in quantity

$\%\Delta P$ = percentage change in price

There are three types of price elasticity of demand: (1) unitary, (2) elastic and (3) inelastic. Unitary elasticity exists where $\eta_p = -1.0$ which means that the $\%\Delta Q$ exactly equals $\%\Delta P$ (for example if $\%\Delta P$ = a 10% increase then $\%\Delta Q$ would reflect a 10% decrease so that $\eta_p = -1.0$). Demand is considered to be price elastic when $|\eta_p| > 1.0$ which implies that $\%\Delta Q$ is greater than the $\%\Delta P$ so that a small increase (decrease) in price causes a large decrease (increase) in the quantity demanded. For example: if the price increases by 10% and Q drops by 15%, then $\eta_p = -1.5$ and demand will be elastic. When demand is inelastic $|\eta_p|$ will be less than 1.0 which implies that the quantity demanded is not relatively responsive to a change in price because the $\%\Delta Q$ is less than the $\%\Delta P$. Therefore, when demand is inelastic, there would have to be a large change in price in order to effect a smaller change in quantity demanded. For example: if $\%\Delta Q = 10\%$ and $\%\Delta P = -15\%$, then $\eta_p = -.67$.

Price elasticity yields information concerning the effect that price changes will have on revenues. When price elasticity is unitary, total revenues remain the same regardless of the change in price. However, when demand is price elastic total revenues move in the opposite direction of price. That is, if price increases, then total revenues decrease because the price increase is not great enough to compensate for the decrease in quantity demanded. Assume that the price of water is $1.00 per thousand gallons and a utility sells 100,000 gallons of water - then the utility's total revenue will be Price times Quantity or $1.00 X 100 = $100 (remember price is for thousands of gallons and not gallons). Now assume that price increases by ten percent and quantity demanded decreases by fifteen percent so that P = $1.10 per thousand gallons and the quantity demanded equals 85,000 gallons; therefore, total revenue equals $1.10 X 85 = $93.50 whereas before total revenue was $100.00 however, since demand is elastic total revenue decreases when price increases. The opposite is also true - if price decreased by 10% and quantity demanded increased by 15% then total revenue would increase ($0.90 X 115 = $103.50).

Income Elasticity of Demand

Income elasticity of demand is very similar to price elasticity in that it measures the responsiveness of changes in demand resulting from changes in income.

Mathematically:

$$\eta_y = \frac{\%\Delta Q}{\%\Delta Y}$$

where,

η_y = Income Elasticity

$\%\Delta Q$ = Percentage change in quantity demanded

$\%\Delta Y$ = Percentage change in income

Since there is a direct relationship between income and demand one can expect a positive income elasticity, and in most cases this is true. However, once in a while there can be a negative income elasticity which would imply that demand would decrease with an increase in income (i.e., your consumption of hamburger might decrease as your income increases because you can afford to substitute the cheaper meat with more steak). Demand is considered to be income elastic when $\eta_y > 1.0$ because the $\%\Delta Q$ is greater than the $\%\Delta Y$ which means that consumption, percentagewise, increases more rapidly than income; while if $\eta_y < 1.0$ then demand is income inelastic. Therefore, the $\%\Delta Y$ is greater than the $\%\Delta Q$ which means that demand is less responsive to changes in income than when demand is income elastic. Thirdly, elasticity is unitary when $\eta_y = 1.0$ which means the $\%\Delta Q$ is equal to the $\%\Delta Y$.

III. LITERATURE REVIEW

The literature abounds with studies which attempt to isolate those factors which explain the variation in a utility's total pumpage. These types of models are not considered water demand studies by economists primarily because they do not include price as an explanatory variable. A better term for them would be "water requirement models". Burke (1) is a good representative of this type of research effort. The study sampled 488 cities throughout the United States and a national model was developed; then the data were subdivided into regions and sets of regressions were run on the subsamples. A model for Florida was obtained with a sample of eighteen utilities. The explanatory variables included total population, total number of families, rainfall and median family income. The model has a possible problem with multi-collinearity since theoretically there should be a strong relationship between total population and total number of families. The model may be useful for forecasting future water requirements since the population factor is a dominant variable and projections may be accurate when they are based solely upon changes in population; however, the model is suspect if it is used to explain why utilities pump different quantities of water.

Khanal (16) conducted a study for the SFWMD in 1975 using the basic Burke model. He tested the same variables for a south Florida model which Burke used; however, for numerous reasons all of these variables failed to be significant except for total population. Since population was the only independent variable in the final formulation, Khanal avoided the multi-collinearity problem although his predictive powers were less than Burke's.

Another type of requirement model attempts to explain variations in per capita consumption instead of total pumpage. A study was conducted in Israel by Darr, et. al., (2) during 1975 in which they sampled 1892 individual consumers. Variables used included monthly income, number of persons per household, number of rooms per dwelling unit, age of head of household, nationality, city of residence and educational level. This model may also have specification problems which contribute to multi-collinearity in that education level of the wage earner, and number of rooms per dwelling unit may be highly correlated with income.

Although Darr, et. al., were able to isolate some socio-economic variables which seemed to have an effect upon the per capita consumption of water, the model was not complete because it did not include factors which the utility could use to influence the magnitude of the dependent variable. A utility's price structure would be one such variable.

In an effort to isolate these influential variables, Foster and Beattie (3 & 4) conducted an economic water demand study. They used 218 cities throughout the United States in order to develop an aggregate model. After developing the national model they subdivided the U. S. into six regions and used a functional form in which average price was entered as a natural number and all the other variables were transformed into natural logarithms. The other independent variables were rainfall, average number of household residents and a dummy locational variable. All of these variables were regressed against household consumption of water and the results were rather typical in that price was the most significant variable.

A Canadian study by Grima (5 &12) defined price differently. He used the minimum block rate and the additional per unit price instead of average price. This study more closely corresponded with economic theory because the model included the marginal (or additional) cost of consuming water which economic theory postulates to be one of the most significant variables in demand estimations. Other independent variables included persons per household and value of housing to account for tastes and preferences and income, respectively.

Andrews (11) conducted a water demand study in Dade County (Miami) Florida in 1973. 355 households from eleven utilities throughout the county were used in the sample. Andrews used a marginal price and an average price model along with income, home value and family size. He concluded that the marginal price model was superior to the average price model since its coefficient of determination was stronger.

IV. DEVELOPMENT OF ESTIMATES OF PUMPAGE AND POPULATION

Data Requirements

In investigating the responsiveness of per capita water consumption in south Florida to socio-economic characteristics, climatological variations and land use patterns, the first step was to develop a firm data base on per capita consumption. To meet the requirements of the later analysis, the per capita consumption data had to cover utilities showing significant variation in the socio-economic, climatological and land use patterns, and had to cover utilities where both the per capita consumption and the other types of data were available from secondary sources. This pointed to the use of data for municipal utilities in the data base for the following reasons:

1. University of Florida and Census of Population estimates were generally available to use as cross checks on the utilities' estimates of population served, and

2. Socio-economic and land use data are most readily available for areas served by local units of government.

In order to obtain good variation on the climatological observations, it was felt that a time series of observations covering some wet and some dry years would be desirable as opposed to attempting to measure the variations using only a cross section of observations.

Selection of a Data Source

The data set which was available and most nearly met all these characteristics had been developed by the U. S. Geological Survey and was most recently published in July 1977[1]. It covers water use for 169 municipalities and 5 county water systems in Florida in 1975 and almost the same number of systems for the preceding 5 year period (1970-1974). Certain data were also presented for selected earlier years but the reliability of these estimates could not be verified. This source offered the three principal variables of interest, water pumpage, per capita consumption, and population served, as well as data on capacity, high and low pumpages and sewage treatment, which were not of primary interest in this analysis.

The chief alternative data source on per capita consumption is a series compiled by the South Florida Water Management District, covering approximately 45 utilities each year for the period 1972-1976. These data, like the USGS data, were compiled largely from estimates of the utilities themselves, gathered either by direct contact or through mail questionnaires. There are, however, a higher number of pumpage observations with significant discrepancies between the two sources than might be expected, given that both were estimated by the utilities. For example, in 1975, of 20 utilities in both sets of observations, four had differences over 10 percent, three had differences of

[1] Henry G. Healy, Public Water Supplies of Selected Municipalities in Florida, 1975, U. S. Geological Survey, Tallahassee, Florida, July 1977.

5-10 percent and 13 had differences of 0-5 percent. Comparable figures for 1974 for 13 observations were 2 of 5-10 percent and the remainder 0-5 percent.

The USGS series was used because it seemed to offer greater continuity in the procedures by which the data were assembled, it offered more continuity in having the same cities for many years, it offered comparable data for other Florida municipalities outside the District, and because more cities and a higher percentage of the larger cities responded to the USGS. It may be noted that the USGS series was the source of the population and pumpage estimates used by Khanal in his earlier estimation of a water demand model for southern Florida.[1]

Data Checking and Adjustment of the Estimates of Population Served

Before using the data they were reviewed to determine if any problems existed which would require further attention. The chief problem found was that many of the utilities had not put much effort into estimating the populations served and merely repeated a single estimate over several years. This weakness in the observational procedure would not only introduce some distortion in the overall estimates but would especially tend to mask changes due to variations in rainfall.

Since almost all of these were municipal utilities it was felt that the Florida Estimates of Population[2] and the 1970 U. S. Census of Population estimates of municipal populations could be used to cross check the utility estimates. After completing the review, a judgement was made as to the best procedure to follow in each case. In some, the utility estimates were used; in others, the University of Florida estimates were substituted; thirteen were decided only after special calls to the utilities; and, where the data problems could not be adequately resolved, the utility was dropped from the data set.

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[1]Nagendra Khanal, Predictive Water Demand Model for Central and Southern Florida, Technical Publication #76-2, South Florida Water Management District, April, 1976.

[2]Division of Population Studies, Bureau of Economic and Business Research, University of Florida, Florida Estimates of Population, annual.

The completed and checked data set contains 182 observations on population and pumpages from 41 utilities (refer to Table 1 for a list of the utilities used). The data set was now ready for testing the relationship of pumpage to population and then for use in testing the responsiveness of per capita water consumption to socio-economic, climatological and land use variables.

V. WATER REQUIREMENT MODEL

The initial phase of this study dealt with determining the relationship between the quantity of water pumped by a municipal utility and the size of the population of the utility's service area. The initial phase of this study did not include any socio-economic variables but rather, was used to test the sensitivity of Khanal's earlier work which was the basis for the original water requirement projections used in the SFWMD's Water Use Plan of 1977.

Khanal's data were purely cross-sectional and his results therefore ignored any explicit or implicit effect time or time related changes might have had on the measured relationship between the quantity of water pumped by utility and the size of the population served. No large sample of reliable data for an extended period of time was readily available for Khanal's study. Healy's 1977 publication was the first known reliable source of time series and cross-sectional data on municipal utility water withdrawals.

The Healy pumpage data and the revised population estimates for municipally owned utilities in south Florida were used to test the relationship between service area population and the utility's water withdrawals, where population (P) was the independent variable and pumpage (Q) was the dependent variable. Two sets of regressions were run. The first data set included the Miami-Dade Water Authority (M-DWA) and the second data set excluded this utility from the sample. Two regressions were run on each data set. The first regression was linear and the second regression was non-linear (using a double logarithmic transformation to linearize the relationship for estimation). (Refer to table 2 for actual regression results.)

Equations 1 and 3 proved to be statistically significant at the 1 percent level. These were simple regressions testing the variation in pumpages over time and space as a function of population. Population accounted for 99.44% of the variation in pumpage in equation 1 and 95.62% in equation 3. Clearly, population alone dominates the explanation of water pumpages.

Equations 2 and 4 were the double logarithmic form of equations 1 and 3, respectively. These regressions were also statistically significant at the one percent level. These R^2's were lower than the linear forms, however, their standard error of estimates (SEE) were lower which implies that the non-linear forms may be better for projecting future water requirements.

The population coefficient for equation 1 implies that 177 gallons per day (GPD) on average, would be needed by each additional person moving into the SFWMD area. Equation 3, which excludes data for M-DWA implies that, on average, 214 GPD will be needed for each new person moving into the District's region. This discrepancy arose because almost half of the sample's total pumpage and population was accounted for by the M-DWA.

The M-DWA data were excluded from the second data set because the growth boom in south Florida had shifted from Dade County to other counties like Palm Beach, Broward, Lee and Collier. In fact, over the last few years Lee and Collier counties have experienced some of the largest growth in population (percentagewise) in the country.

The M-DWA also represents around half of the total population of the sample. Exclusion of the M-DWA data made it possible to test for differences in the per capita marginal water requirement estimates.

The two linear models yield a fixed marginal per capita consumption estimate which makes the interpretation of the equations quite easy. However, the non-linear equations 2 and 4 do not yield a fixed marginal per capita consumption estimate. The marginal per capita consumption estimate will vary depending upon the level of population for the utility's service area. The per capita coefficient estimate shows that the marginal per capita consumption for a given utility will increase as the population increases.

Khanal's study included M-DWA in his sample and he estimated double logarithmic equations. The inclusion of time series data may have improved upon Khanal's original study as is evidenced by the improvement in the R^2. Khanal's R^2 was .8646 for utilities in the Lower East Coast area and .892 for utilities in the District. This study's R^2's varied from .8865 to .9944 depending on the functional form and the data selected. Although Khanal's estimates and this study's estimates are not fully comparable, a reasonable comparison can be made since this study's per capita consumption figures, for the most part, were within Khanal's range. (Refer to Table 3 for a comparison of per capita consumption estimates for each of the four equations produced by this study and Khanal's work.)

Population dominated the explanation of the quantity of water pumped to the extent that no other variables could be included in the equation to test for the impact that climatological and socio-economic variables might have on water withdrawals. Therefore, the remainder of the study deals with the impact that those types of variables might have on the per capita consumption of water.

VI. CLIMATOLOGICAL MODEL

South Florida has an unusual climatological cycle. Rain is not evenly distributed through time or space even though the area averages more than fifty inches of rainfall each year. Two distinct rainfall periods exist. The period of abundant rainfall occurs between May and October (wet season) while the period of scarce rainfall occurs between November and April (dry season). The amount of rainfall varied from year to year during the time frame of this study.

Two basic variables, a water deficiency factor and total rainfall, were used to test the hypothesis that the purchase of water from utilities varies significantly depending on climatological variables. A measure of rainfall deficiency (WDF) during a period of time was used to test the hypothesis that people water according to the needs of the lawn and not simply in response to rainfall since the WDF incorporates the impact of evapotranspiration as well as rainfall in estimating the irrigation requirements of grasses.

The water deficiency factor was an attempt to measure the amount of supplemental irrigation needed for grass per month for a given year. The equation used was

$$WDF = R - \alpha K$$ where

WDF = water deficiency factor

K = is the empirically estimated pan evaporation factor for a specific month

α = the crop requirement factor for grass (an empirical constant)

R = rainfall in a specific month

αK then was the estimated total monthly water requirement of grasses needed to obtain optimal growth.

Monthly pan evaporation factors were obtained from current unpublished research by Ronald Mierau of the Water Resources Division at the South Florida Water Management District. These data were estimated monthly for each of the years 1970 thru 1976. The α constant was also estimated by Mierau for pasture grasses. This constant is considered to be applicable to all grasses commonly found in south Florida.

No supplemental irrigation was anticipated for any month in which the WDF was positive since the rainfall in that month was greater than the water requirement for that month. All positive WDF's were then set to zero since no supplemental watering was thought to be needed for that month. Therefore, the WDF was a negative summation. A negative WDF was taken to indicate that rainfall was not great enough to meet all plant requirements and therefore supplemental watering would be applied to sustain the plant.

Three measurements were used to describe the water deficiency factor; (1) annual (AWDF), (2) wet season (WWDF), and (3) dry season (DWDF). The AWDF was the summation of the individual monthly WDF's for a given year. WWDF was the summation of the WDF's for the wet season and the DWDF was the summation of the WDF's for the dry season.

The weakness of the WDF measure is that the calculation assumes that rainfall for the month is evenly distributed; however, this assumption is often not true. The use of the monthly periods to determine the water deficiency factor is an attempt to build some carry-over in the availability of rainfall, but not too much, since this assumption would not be realistic.

Three factor measurements were used to describe the rainfall variable; (1) annual rainfall (AR), (2) wet season rainfall (WR), and (3) dry season rainfall (DR). Annual rainfall was the total rainfall for a given year. Wet season rainfall was the summation of rainfall for the months of May thru October for a particular year and dry season rainfall was the summation of rainfall for the months of January thru April and November thru December of the same year.

Monthly rainfall data were collected from rainfall stations operated by three different agencies, (1) U. S. Weather Bureau, (2) the South Florida Water Management District and (3) the U. S. Forest Service. The rainfall station used was that station closest to the utility service area with the same climatological characteristics as the utility service area. Rainfall contour maps were used to determine the similarity of climatological characteristics.

The original sample size was 182 observations. Rainfall and/or pan evaporation data were not available for all 182 of the original observations. The subsample was comprised of eleven coastal utilities and six utilities around Lake Okeechobee for which six years (1970-1976) of pumpage, population, rainfall, and pan evaporation data were available (see Table 4).

The regression results using the rainfall data and/or the water deficiency factors to explain per capita consumption proved to be statistically insignificant when used by themselves for one or two major reasons:

1) the equation and/or the coefficients were not significant, or
2) the coefficient's sign was positive which would indicate that the higher the rainfall the greater the water use.

None of the climatological variables by themselves were statistically significant; however, further research was necessary before these variables could be categorically dismissed as having no ability to explain any variation in the per capita consumption of water. Dummy variables were introduced to simulate other variables which might explain variations in per capita consumption. Ten dummy variables were used along with the climatological variables. A dummy value of "1" was used for utility "i", otherwise zero was used.

The data were subdivided into two planning areas. One for the East Coast of Florida where cities ranged from as far north as Ft. Pierce to Key West in the south. The second subdivision was for the Lake Okeechobee planning area which included cities located on and around the Lake whose primary source of water supply was Lake Okeechobee.

The statistical analysis of the data indicated that the Dry Season Water Deficiency Factor and the Annual Water Deficiency Factor used along with the dummy variables was statistically significant at the 1% level of confidence in a one tail test. The coefficients for the Lower East Coast of Florida indicate that per capita water consumption would increase (decrease) by 1.85 gallons per capita per day for every one inch decrease (increase) in the annual water deficiency factor. The model's coefficients, however, were insignificant for the Lake Okeechobee area. These results showed that DWDF and AWDF when used with other properly defined variables, would prove to be statistically significant. However, more research was needed in order to determine which variables besides DWDF and AWDF could prove to be statistically significant in explaining the variation in per capita consumption of water over location and time. It was the absence of these variables which forced the use of the dummy variables to explain the large differences in average per capita consumption among the utilities.

VII. SOCIO-ECONOMIC MODEL

Preliminary Variables Tested for Relevancy

The research continued with the investigation of possible socio-economic variables which could explain the significance of the dummy variables used in the preceding climatological analysis. Unfortunately, time series data did not exist for the theoretically relevant socio-economic variables. Cross sectional socio-economic data used in the model were obtained from the 1970 U. S. Census of Population (10) and were collected at the municipal level. Per capita consumption data came from Healy (15).

Twenty-two utilities were used in the modeling effort. An attempt was made to expand the sample size by including cities outside the District which were located south of a line drawn across Florida from the Atlantic Ocean to the Gulf of Mexico. The boundary line, which approximately corresponds to the southernmost boundary of Seminole County, was chosen since it closely represents a climatological divide between south Florida and north

Florida weather patterns. Drastic differences in climatological variations were avoided by using this delineation (refer to Table 5 for sample city identification).

Three regressions were run using per capita consumption of water (Q) as a function of the percent of population sixty-five years of age and older and per capita income. The marginal price variable was not tested because it was not collected for those cities outside the District's boundaries. The first regression used all of the cities sampled (inside and outside the District) as observations, while the second regression tested these variables for all sample cities within the District's boundaries and the third regression used only those cities which were outside the District.

The purpose of running these three regressions was to test whether or not the two city samples were from the same statistical population. The conclusion drawn from the regression results indicated that the cities outside the District came from a different population than those cities inside the District. The simple correlation between Q and the dependent variables for the two subsamples were quite different as were the model F-ratios and their adjusted coefficients of determination (see Table 6). The mean Q for the inside of district subsample was 175 gallons per day per capita while the outside of district sample mean Q was 119 gallons per day per capita. The subsample for cities outside the District were excluded from the final model.

Standard economic theory states that the quantity demanded of a commodity is a function of its marginal price, the level of people's income, and their taste and preference for the commodity. In this study, hypothesized relationships between per capita consumption on the one hand, and price, population characteristics, income, housing characteristics and water quality data were tested. The socio-economic data included individual descriptors for population in order to isolate the impact of people's tastes and preferences. The water quality data were used for the same reason. Data used to simulate the impact of income on per capita consumption of water included individual descriptors on different measures of income. Housing data were used primarily because other studies have used them as surrogates for income (5) (11) (12).

The population variables which were obtained from the Census (1970) included median age, percent of population under eighteen years old, percent of population sixty-five years of age and older and the average number of persons per household. The percent of population over sixty-five was hypothesized to be significant since south Florida is a retirement area. An inverse relationship between this variable and per capita water consumption (Q) was expected since retirement incomes are relatively fixed. The percent of population eighteen and under was selected to identify communities with large percentages of children.

Income variables included per capita income, mean earned income by place of residence and mean social security income. Mean earned income could be considered a measure of a community's industrial and commercial activity since it reflects only wage and salary income, while social security income could be used to capture any direct effect retirement income might have on per capita consumption. Social security income may not be the best indicator for retirement income because it does not include other types of income received by retirees (i.e., stock and mutual funds dividends and income from pensions and IRA accounts); however, it is the only readily available statistic which could be used for this purpose. Per capita income was tested since it would include influences from all types of earned and unearned income.

Numerous housing variables were tested. Four different variables describing types of housing were used, including: percent of single family housing to total housing, percent of total housing having two to four units per building, percent of total housing with more than four units and percent of total housing that was at least twenty years old. Three other housing income surrogate type statistics were tested. They included value of housing, percent of total housing with more than one bathroom and percent of total housing with air conditioning.

Single family housing was believed to have a direct effect upon Q because of lawn watering. Single family homes normally have large areas for lawns in comparison to dwelling space area. Conversely, multiple family housing was expected to have a negative effect on Q. Older housing normally has more plumbing leaks than newer housing because of the natural deterioration of the plumbing system; therefore, the percent of housing over twenty years old was hypothesized to have a positive effect upon Q, although older housing might not use water consuming appliances such as dishwashers and garbage disposals.

Value of housing has been used as a surrogate for an income variable in past studies, such as Grima (1972 & 1973). This variable was expected to have a direct relationship with Q. The percent of total housing having more than one bathroom was expected to have a positive effect on Q as was the expected effect of the percent of total housing with air conditioning for the same reason.

The percent of total housing vacant was the last housing variable tested. No hypothesis was made concerning its impact upon Q; however, it was thought to be one measure for tourism and/or seasonal population which might indicate a positive relationship with the dependent variable since this segment of the population was not used in computing the level of population for an area even though their consumption of water was included in a utility's total water pumpage figure.

Two water quality variables were also used in the research. The natural color of water in south Florida is clear but with a brownish tint to it. The theory was that clear, untinted water was preferred over water containing color. Mineral content was also tested. It was expected to have a negative impact on Q since soft water seems to be preferred over hard water.

Statistical Analysis

All of the variables mentioned above were fitted into a forward stepwise regression. The selection of a basic model was based upon maximizing the adjusted coefficient of determination. The stepwise regression did not test for multi-collinearity; but rather selected variables according to the strength of their individual F-ratios.

The next step was to analyze the significance of each variable in the basic equation using its student t ratio. Variables were eliminated from the equation if their t's were not significant and/or the variable proved to be correlated with more theoretically relevant variables.

The model selected was

$$Q_i = B_o \, e^{B_p P_i} \, A_i^{B_a} \, Y_i^{B_y} \qquad (1)$$

and the estimation form was

$$\log Q_i = \log B_o + B_p P_i + B_a \log A_i + B_y \log Y_i \qquad (1a)$$

where,

Q_i = the per capita consumption of water for utility "i".

P_i = the marginal price of water for utility "i".

A_i = the percent of total population age sixty-five and over for utility "i".

Y_i = the per capita income for utility "i".

The semi-log form was selected primarily because it exhibits a varying price elasticity. The price-exponential demand curve (1) is considered the best because it shows that as price rises the quantity demanded of water will approach zero asymptotically which recognizes that people will require some minimum quantity of water regardless of its price. It also recognizes that there will be a maximum quantity consumed regardless of how low price might be (Foster & Beattie 3 & 4).

The final equation was

$$\log Q = 2.00 - 1.54P_i - .19 \log A_i + .54 \log Y_i \qquad (2)$$
$$\qquad (1.81)\ (.34) \qquad (.9) \qquad\qquad (.23)$$

in non linear form the equation would be

$$Q = 7.3929e^{-1.54P_i} A_i^{-.19} Y_i^{.54} \qquad (2a)$$

The equation (2 or 2a) is statistically significant at the one percent (1%) level with an F-ratio of 7.4984 and an adjusted R^2 of .5483. The intercept was not significant while the age and income variables were significant at the two and one half percent level (2.5%) (t's equal -2.1264 and 2.3377) and the marginal price was statistically significant at one percent (1%) (t = 4.5635). The "one-tail" test was used since there was a reason to hypothesize the sign of the coefficients. It is needless to say that the hypothesized signs were correct. The standard errors of estimate are in parentheses.

Price and Income Elasticity Estimates

The estimated price elasticity (η_p) for equation 2, evaluated at its mean price of forty-eight cents per thousand gallons, was - .7406. Elasticity measured at one standard deviation of fifteen cents per thousand gallons above and below the mean price was -.5082 at thirty-three cents and -.9702 at sixty-three cents per thousand gallons. Elasticity was unitary at sixty-five cents which means that demand is price inelastic below sixty-five cents and price elastic above sixty-five cents.

Wong (9) presented price and income elasticities for numerous water demand studies. Some of the studies calculated point (single) elasticities and others presented a range of values. The point measurements were comparable to the estimate from equation 2 when it was evaluated at the mean price of forty-eight cents.

The results from two point elasticity studies were directly comparable to this study's results. Metcalf calculated a price elasticity of -.65 in 1926 using a sample size of 29 public works systems, while in 1964 Gardner and Schick sampled forty-three Utah waterworks systems and derived a price elasticity of -.77. Four other studies estimated point price elasticities which were comparable to the estimates of equation 2 when it was evaluated at one standard deviation above or below the mean price. Fourt in 1958 used thirty-four American cities to estimate a η_p of -.39, while in the same year Renshaw estimated a η_p of -.45 using thirty-six American water service systems. In more recent studies Bain et. al., sampled forty-one California cities in 1966 to estimate a η_p of -1.099 and in 1970 Grima estimated a η_p of -.93 using ninety-one observations.

Variable price elasticity studies with which equation 2 may favorably compare include a 1963 Kansas study by Gottlieb in which the range for η_p was -.66 to -1.24. In the same year Wong et. al., did a study for Northeastern Illinois which yielded a range of η_p's from -.07 to -.72. Flack estimated a range from -.12 to -1.0 in 1965 for fifty-four western cities. Wong conducted another study in 1970 using cross-sectional data which yielded a range of results from -.26 to -.82. Other studies were conducted where the results were not favorable to the results derived from equation 2. They included a 1967 study by Howe and Linaweaver (η_p = -.21 to -.23), Conley (-1.02 to -1.09), Turnovsky (-.05 to -.40) and Wong (-.02 to -.28).

The income elasticity estimate for equation 2 was .54. Two point income elasticity (η_y) studies seem to verify this study's results. In 1956 Hanson and Hudson, Jr. sampled eight Illinois communities and estimated an income elasticity of .55 while in 1970 Grima estimated it to be .56. The Gottlieb study mentioned above estimated a range of .28 to .58 and Wong had an estimated range of .48 to 1.03.

Larson and Hudson, Jr. sampled fifteen Illinois communities in 1951 and obtained a result of .70 while Fourt derived an estimate of .28. Neither of these point studies were favorable comparisons nor were three of the range studies; Headly, 1963 (.00 to .40); Howe and Linaweaver, 1967 (.31 to .37) and Wong, 1970 (.20 to .26).

The results of more recent studies which used Florida utilities compared favorably with this study. Andrews (11) sampled customers from eleven Dade County utilities in 1973 and estimated η_p = -.51 to -.63 and η_y = .51. Dade County is completely contained within the District's boundaries. Foster and Beattie (3 & 4) estimated a water demand model for the Southeastern United States. Their results for the elasticities were η_p = -.38 to -.86 with η_y = .37.

Price and income elasticity estimates are two ways of comparing demand curve studies. Results are comparable with about half the studies presented in Wong (9) and they are also very favorable with the two recent studies conducted with Florida data which strengthens the understanding of this study.

Variables Excluded

Marginal price, per capita income, and percent of population 65 and older were the best variables describing the variation in per capita water consumption. Some other variables were also statistically significant, however they were judged not to be the best descriptors since they were highly correlated with more significant variables. Most of the housing variables were correlated with per capita income. This result was not surprising since housing is considered a status symbol in this society. Persons per household had the wrong sign and was correlated with median age. This multi-collinearity problem was the probable cause for the wrong sign.

The percent of total housing vacant was statistically significant and not highly correlated with any of the variables which were used in the basic model. It was excluded from the model because its contribution is difficult to interpret. Its sign is positive which indicates that the higher the vacancy rate the higher the community's per capita consumption will be. This may be true or it could be a chance occurrence. It probably indicates that variables describing the variation in Q resulted from tourism and seasonal residents, however more investigation is warranted before a conclusion can be reached.

VIII. SUMMARY AND CONCLUSIONS

The primary goal of this research effort was to expand the District's knowledge on water requirement and demand analysis and thus to improve upon the water use forecasts used in the District's Water Use Plan. A secondary objective was to isolate factors which affect the per capita consumption of water since there were large observed variations in per capita consumption among water utilities while, over time, any one utility's per capita consumption was relatively stable.

The first objective was achieved by developing equations relating utility water pumpages to population served using time series and cross sectional data. The data used were improved over those of earlier efforts by expanding the observations to include time series as well as cross sectional data and through a thorough cross check of data sources and other information. The second objective was only partially met through the efforts of isolating relevant socio-economic and climatological variables.

The Water Requirements Model showed that variations in utility pumpages could be thoroughly explained by the total population of the utility's service area. The linear model, using Miami-Dade Water Authority data, explained 99% of the variation in pumpages while 95% of the variation was accounted for in the data set which excluded M-DWA. The large impact that the observations for the M-DWA have on the estimated relationship is evidenced by the difference in the marginal per capita consumption parameters (177 vs. 214) in the two relationships.

Further refinements of the requirements model were not expected to be useful since the variation was very well explained by total population. However, it was thought to be worthwhile to expand the investigation to include possible variables which affect per capita consumption. This not only offered the possibility of improving prediction capabilities but would allow the District to begin to focus on those variables which would indicate the distributive impact of its policies. For example, if utilities were forced to raise prices due to high costs of added capacity then relationships between per capita consumption and price could be used to measure the impacts of these changes.

The Climatological Model attempted to explain variations in per capita consumption based upon monthly rainfall data and estimates of plant water requirements. Two major formulations were tested, one based on variations in rainfall and one based on estimations of plant water requirements (plant stress) in order to test for variations in urban water demand between wet and dry years.

The results indicate that the stress hypothesis is more valid and, while the results were not overwhelming, a statistically significant relationship was developed relating per capita water consumption to climatological variables. It is felt that the results are significant enough to provide an interim relationship to use in estimating this impact. It is recognized that many questions can be raised about the data and procedures used in this analysis including the use of monthly data as the level of aggregation, the fact that many rainfall stations were located some distance from the utility service areas, the quality of available pan evaporation estimates and the accuracy of the crop adjustment factor. However, it is thought that as a minimum this study established that this relationship should be taken into account and deserves further investigation.

The final relationship investigated in this study was that between socio-economic factors and per capita consumption of water. Three variables (marginal price, per capita income and percent of total population sixty-five years of age and older) were related to the per capita water consumption. Many other factors were investigated; however, these three provided the most reliable relationship without creating multi-collinearity problems.

One weakness of the model is the use of cross sectional data. Time series cross sectional data could have been much better because the results would capture the effects which major changes in socio-economic characteristics of cities would have on their per capita consumptions and could have allowed tests for the stability of the relationships over time.

The reliability of the socio-economic model, while comparable with the levels achieved in other studies, still is in need of improvement. The present model explains 54.83% of the variation in per capita consumption of water which leaves 45.17% of the variation unexplained. Further research might indicate that certain variables such as geographic location of the city or place of birth of the head of household or other such cultural characteristics would enhance the reliability of the model without increasing multi-collinearity problems.

It should be noted that an attempt was made to expand the sample size by including utilities located outside the District's boundaries, but that these cities showed significantly different water use patterns and relationships between socio-economic variables and water consumption. This, therefore, does not appear to be a fruitful avenue for improving the estimates.

Overall, the study had one major success in that the total pumpage model was thoroughly successful in explaining water withdrawals. The climatological model was not as successful as it was hoped to be; however, this part of the research raised some interesting questions which lead to the socio-economic modeling effort. This effort proved to be partially successful in that a little over 50% of the variation in per capita water consumption was explained. The results however, indicate that more research will be needed in order to develop a thorough understanding of water demand for south Florida.

TABLE 1

UTILITIES USED IN THE PUMPAGE/POPULATION MODEL

A. Broward County

1. Coral Springs
2. Dania
3. Deerfield Beach
4. Ft. Lauderdale
5. Hallandale
6. Lauderdale Lakes
7. Lauderhill
8. Margate
9. Miramar
10. Oakland Park
11. Pompano Beach
12. Sunrise

B. Dade County

1. Homestead
2. Miami-Dade Water Authority
3. North Miami
4. Opa Locka

C. Hendry County

1. Clewiston
2. LaBelle

D. Collier County

1. Naples

E. Lee County

1. Bonita Springs
2. Cape Coral
3. Fort Myers
4. Sanibel

F. Monroe County

1. Key West

G. St. Lucie County

1. Fort Pierce

H. Glades County

1. Moore Haven

I. Palm Beach County

1. Belle Glade
2. Boca Raton
3. Boynton Beach
4. Century Village
5. Delray Beach
6. Jupiter
7. Lake Worth
8. Lantana
9. North Palm Beach
10. Pahokee
11. Palm Beach
12. Palm Beach Gardens
13. Riviera Beach
14. Tequesta
15. West Palm Beach

TABLE 2

ESTIMATED POPULATION - PUMPAGE RELATIONSHIPS

Equations - include data for Miami-Dade Water Authority

1	$Q = .569 + .177\ E\text{-}3(P)$		$R^2 = .9944$
	$\quad\ \ (.181)\quad (.993\ E\text{-}6)$		$F = 31692.9570$
			$SEE = 2.3131$
2	$Q = (.879E\text{-}4)P^{1.069}$		$R^2 = .9173$
	$\quad\ \ (.239)\quad (.024)$		$F = 1997.2285$
			$SEE = 1.470$

Equations - exclude data for Miami-Dade Water Authority

3	$Q = .409 + .214\ E\text{-}3(P)$		$R^2 = .9562$
	$\quad\ \ (.152)\quad (.342\ E\text{-}5)$		$F = 3905.9684$
			$SEE = 1.6222$
4	$Q = (.618\ E\text{-}4)P^{1.106}$		$R^2 = .8865$
	$\quad\ \ (295)\quad (.030)$		$F = 1359.0349$
			$SEE = 1.4730$

Where:

Q is the quantity of water pumped by a utility (millions of gallons per day)

P is the level of population of the utility's service area

TABLE 3

MARGINAL PER CAPITA PUMPAGE CALCULATIONS

Population	Equation One [a]	Equation Two [a]	Equation Three [a]	Equation Four [a]	Khanal's Equation
10,000	177	166	214	164	170
50,000	177	185	214	195	173
100,000	177	195	214	209	175
250,000	177	207	214	231	177
500,000	177	217	214	248	178
750,000	177	224	214	259	179
1,000,000	177	228	214	267	180

[a] Equations as designated in Table 2

SOURCE: Estimates are based upon regression results for this study and Khanal's study.

TABLE 4

UTILITIES USED IN THE CLIMATOLOGICAL MODEL

Coastal Area	Lake Okeechobee Area
1. Ft. Lauderdale	1. LaBelle
2. Oakland Park	2. Belle Glade
3. Ft. Pierce	3. Pahokee
4. Palm Beach	4. Clewiston
5. West Palm Beach	5. Moore Haven
6. North Palm Beach	
7. Palm Beach Gardens	
8. Riviera Beach	
9. Delray Beach	
10. Boca Raton	
11. Deerfield Beach	

TABLE 5

UTILITIES USED IN THE SOCIO-ECONOMIC MODEL

A. Within the District

1. Belle Glade
2. Boca Raton
3. Boynton Beach
4. Cape Coral
5. Clewiston
6. Dania
7. Deerfield Beach
8. Delray Beach
9. Fort Myers
10. Fort Pierce
11. Hallendale
12. Hollywood
13. Homestead
14. Lake Worth
15. Lantana
16. Miramar
17. Oakland Park
18. Okeechobee
19. Opa Locka
20. Palm Beach Gardens
21. Riviera Beach
22. West Palm Beach

B. Outside the District

1. Arcadia
2. Bartow
3. Bradenton
4. Brooksville
5. Cassilberry
6. Clearwater
7. Gulfport
8. Leesburg
9. Maitland
10. Palmetto
11. Pinellas Park
12. Plant City
13. Port Charlotte
14. St. Petersburg
15. St. Petersburg Beach
16. Sarasota
17. Tampa
18. Tarpon Springs
19. Tavares
20. Titusville
21. Winter Haven
22. Dunedin

TABLE 6

RESULTS OF THE COMPARISON REGRESSION

Statistics	Complete Sample	Inside of District Sample	Outside of District Sample
F-Ratio	2.0772	1.8763	.1090
Adjusted Std. Errors	.4417	.3333	.4818
t-ratio for Age	-1.3082	-1.2500	-.3840
t-ratio for Income	1.8561	1.9069	.2803
Simple R Age	- .125	- .071	- .085
Simple R Income	.233	.310	.060
$\overline{Q}$	146	179	119
Adj. R^2	.0477	.0770	.0000

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APPENDIX

SOCIO-ECONOMIC WATER DEMAND STUDIES (BASIC MODEL WITH QUALITY)   ECONOIC SFWMD (AUG 1978)

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**********************
*EQUATION NUMBER    1*     22 OBSERVATIONS      5 VARIABLES  1  7 10 11 12
**********************
ADJ. COEFFICIENT OF DETERMINATION          .5483
UNADJ. COEFFICIENT OF DETERMINATION        .6129

UNADJ. MULTIPLE CORR. COEFFICIENT          .7829

F-RATIO                                   9.4985

ADJ. STD. ERROR OF ESTIMATE                .2332
UNADJ. STD. ERROR OF ESTIMATE              .2109
```

ANALYSIS OF VARIANCE

SOURCE OF VARIATION	D.F.	SUM OF SQUARES	MEAN SQUARES
DUE TO REGRESSION...........	3.	1.5491	.5164
DEVIATION ABOUT REGRESSION	18.	.9785	.0544
TOTAL...	21.	2.5276	

VARIABLE NO.	MEAN	REGR. COEFF.	STD.ERROR OF REG.COE	COMPUTED T-RATIO	UNADJ.PARTIAL CORR.COEFF.	UNADJ.PARTIAL COEFF. OF DET.	ADJ.PARTIAL COEFF. OF DET.
1	1.0000	.200052D+01	.180700D+01	1.1071	.0000	.0000	.0000
7	.4809	-.153575D+01	336528D+00	-4.5635	7324	.5364	.4591
10	2.5484	-.185742D+00	.873511D-01	-2.1264	.4481	.2008	.0676
11	8.0875	.544071D+00	.232736D+00	2 3377	.4826	.2329	.1050

```
(Y)=     5.1888    VAR(Y)=       .1149

SPC=     4.064     SPCBAR=     4.493   DETERM=     .3787D-05

DW=   1.4456   DH=    .0000   RHO=   .7783   FER=   .0000   RHOFO=   .0000   THRHO=   .3209
```

N	ACTUAL	COMPUTED	RESIDUAL	FRACT RES.
1	5.1358	4.8772	.2586	.0504
2	5.9375	5.6129	.3246	.0547
3	5.2883	5.0569	.2314	.0438
4	4.6913	4.9892	-.2979	-.0635
5	5.2933	5.2341	.0592	.0112
6	5.2204	4.8710	.3494	.0669
7	5.4638	5.2793	.1846	.0338
8	5.6312	5.6802	-.0490	-.0087
9	4.8363	5.0521	-.2159	-.0446
10	4.8283	4.8522	-.0239	-.0049
11	4.9488	5.1287	-.1800	-.0364
12	4.8520	4.7797	.0724	.0149
13	5.1985	5.1172	.0813	.0156
14	5.2364	5.3751	-.1386	-.0265
15	4.4427	5.0062	-.5635	-.1268
16	5.0106	5.0609	-.0503	-.0100
17	5.0999	5.0063	.0936	.0183
18	5.2470	5.3888	-.1417	-.0270
19	5.5797	5.6579	-.0781	-.0140
20	5.1417	5.1862	-.0445	-.0087
21	5.5568	5.3788	.1780	.0320
22	5.5134	5.5631	-.0496	-.0090

VARIABLE IDENTIFICATION

1 = CONSTANT
7 = PRICE
10 = AGE (LOG)
11 = INCOME (LOG)
12 = PER CAPITA WATER CONSUMPTION (LOG)