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WATER SUPPLY NEEDS AND SOURCES ASSESSMENT ALTERNATIVE WATER SUPPLY STRATEGIES INVESTIGATION EFFECTS OF WATER USE RESTRICTIONS ON ACTUAL WATER USE

by

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EXECUTIVE SUMMARY

This report documents findings of Phase II, Task IV, of St. Johns River Water Management District (SJRWMD) Investigation of Alternative Water Supply Strategies - Water Conservation and Reuse of Reclaimed Water within the water resource caution areas identified in the *Water Supply Needs and Sources Assessment* (Vergara 1994). This task deals specifically with assessing the effects of water use restrictions on actual water use within the Wekiva River Basin.

Phase I of this study developed a detailed methodology and assessed the data requirements for the Phase II investigation. These data were then utilized to determine the effects of the water shortage during the summer of 1989 and from the summer of 1993 to the summer of 1994.

Data gathered during Phase II included:

- Documentation of water use restrictions and enforcement activities from SJRWMD.
- National Oceanic and Atmospheric Administration meteorological data from 1985 to date for Clermont, Orlando and Lisbon stations.
- Monthly operating reports from the Florida Department of Environmental Protection for the selected utilities in the Wekiva Basin from 1988 to date.
- Site visits to selected utilities and water treatment plants to obtain data on:
    - monthly operating reports and/or operating logs from 1988 to date,
    - meteorological records from 1985 to date, or for the period of record available,
    - records for water restriction compliance and enforcement activities.

- Diurnal demand data (delivery rates) in the form of strip chart and disk recorder records for a period before, during and after the water use restrictions.

Data were reduced, analyzed and organized into two categories:

- The period with no water use restrictions, and
- The period with some level of water use restrictions in effect.

The completed spreadsheets provided the necessary input for the regional model development.

Using the Statistical Package for the Social Sciences (SPSS), the meteorological and water use records were used to develop preliminary multiple linear regression models for each utility. With the exception of Sanlando, less than 50 percent of the variability in water demand was accounted for by the available predictor variables. A stepwise multiple linear regression technique was applied for regional model estimation. Only the Sanlando Regional Model was determined to be suitable for application and even at Sanlando as much as 37 percent of the variability in water use cannot be explained by the available predictor variables.

Using the preliminary regional models as a starting point, several model refinements were completed in an attempt to improve the usefulness of the regional models. The refinements investigated were as follows:

- Aggregating and analyzing the combined water use data for the Sanlando and Apopka utilities.
- More detailed analysis based on monthly rainfall.
- More detailed analysis based on expected weekly water use.

- More detailed analysis of higher order forms of the independent variables and various combinations of products of independent variables.

These refinements did not significantly improve modeling results. However, with the last refinement we have represented the optimum ordinary least squares regression model that is achievable with the available information.

Based on the results of the Regional Model development there were no significant differences between predicted and observed water use during periods of water use restrictions. Therefore, it can be concluded that the water use restrictions did not result in a significant decrease in water use.

Based on the Local Event analysis it was concluded that the water use restrictions did not cause any significant changes in the total daily water use. However, a discernible trend can be seen in the daily flow pattern. In every case, there is a net reduction in average water use during the day and a net increase in water use at night. It appears that the water use restrictions did not cause a net reduction in water comsumption, but that they did alter water use patterns. Unfortunately, the principal effect of the altered water use pattern is to increase the magnitude of the early morning peak flow demand.

It may be more useful to develop a stochastic modeling approach to determine impact of the water use restrictions. Accordingly, we recommend that a preliminary assessment of the stochastic approach be evaluated and considered. We further recommend that SJRWMD consider possible modifications to the water use restrictions policy, which might reduce total water demand rather than just shifting water demand from one part of the day to another.

An analysis of cost implications was not conducted. Costs were to be developed on the basis of cost per 1,000 gallons saved during the period of water use restrictions. Because the analysis indicates that there were no significant savings in water, there was no basis for developing costs. The effort allocated for cost estimating was redirected to develop additional model refinement as described in the discussion of the Development of a Regional Model.

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INTRODUCTION

BACKGROUND

St. Johns River Water Management District (SJRWMD) is responsible for managing ground water resources in a nineteen-county area of northeastern Florida. Ground water aquifers are currently the primary sources of potable water supply in SJRWMD. The most dependable ground water source is the Floridan aquifer. However, the *Water Supply Needs and Sources Assessment* (Vergara 1994) projected shortfalls in available water supply in certain critical areas throughout SJRWMD boundaries by the year 2010. Areas with existing or 2010 projected water supply problems were designated as priority water resource caution areas (WRCAs).

As a result of the *Water Supply Needs and Sources Assessment*, SJRWMD embarked on an Investigation of Alternative Water Supply Strategies. Strategies being investigated include using lower quality ground water supplies, surface water, reclaimed water, aquifer recharge, aquifer storage and recovery, mitigation and avoidance, and various water conservation techniques.

SJRWMD contracted with Post, Buckley, Schuh & Jernigan, Inc. (PBS&J) to perform various tasks for the purpose of assessing water conservation and reuse of reclaimed water as effective alternative water supply strategies. PB Water was contracted by PBS&J to assist in performing Tasks II and IV of Phases I and II of the Investigation of Alternative Water Supply Strategies project.

PURPOSE

The purpose of Task IV is to determine the effects of extended hours on irrigation water use restrictions on actual water use. Specific objectives of the study include:

- Establish the extent of volumetric water use changes resulting from water use restrictions, if any.

- Establish any shifts in peak hour demand as a result of water use restrictions, if any.

- If significant changes in water use were determined to result from water use restrictions, estimate costs associated with water savings.

SCOPE OF SERVICES

Specific tasks performed in the Phase II investigation included:

- Task 1. Data assembly:

  - Basic data for all aspects of Phase II study were collected based on a preliminary screening of the utilities whose service areas are primarily within the Wekiva River Basin.

- Task 2. Data reduction:

  - Data collected (hard copy) were input in digital format as required to accomplish tasks 3 and 4.

- Task 3. Development of a regional predictive flow model:

  - Develop a regional predictive flow model based on meteorological data.

  - Test the model's effectiveness at estimating actual water use.

  - Determine and quantify volumetric changes as a result of water use restrictions, if any.

- Task 4. Development of a local event interpretation:

  - Analyze water patterns to establish any shifts in peak hour demand as a result of water use restrictions.

- Task 5. Analysis of Cost Implications:
  - Assess the cost of water use restrictions on the basis of cost per 1,000 gallons of water saved (Task contingent upon whether water savings were realized).
- Task 6. Report:
  - Prepare a report summarizing the work accomplished under Tasks 1 to 5.

METHODOLOGY

The following data assessed in Phase I and in Phase II were used to compile the Phase II Report:

- Documentation of water use restrictions and enforcement activities from SJRWMD.

- Daily rainfall and daily maximum and minimum temperature records for the period 1985 to 1996 for Clermont, Orlando and Lisbon stations provided by NOAA.

- Monthly operating reports for the selected utilities in the Wekiva Basin for the period 1988 to 1996 collected from the Florida Department of Environmental Protection (FDEP).

- Site visits to the selected utilities or to water treatment plant facilities were conducted to obtain data on:

  - monthly operating reports and/or operating logs for the period 1988 to 1996,

  - meteorological records (precipitation, temperature and other data as available), for the period 1985 to 1996, if possible; otherwise for the period of record available,

  - formal records for water restriction compliance and enforcement activities.

- Diurnal demand data (delivery rates) in the form of strip chart and disk recorder records for a period before, during and after the water use restrictions.

During data reduction, the specific steps were as follows:

- Import long term rain gauge records from the stations Clermont, Orlando and Lisbon. These are available in digital format and import/check functions were done.

- Tabular numeric data regarding daily total water treated at the plant and any meteorological data from the gauges at the plant were typed into comprehensive spreadsheets formatted in a manner similar to the original material. This is a record copy of transcription.

- Strip charts were read and approximated hourly averages were typed into a spreadsheet.

The available water use and meteorological data were organized into two categories:

- The period of record with no water use restrictions,

- The period of record with some level of water use restrictions in effect.

All information was arranged chronologically and included: weekly water use for each utility, weekly rainfall, average weekly temperature, weekly temperature compared to indices of 45, 60, 70 and 85 degrees Fahrenheit, weekly rainfall, and daily time between sunrise and sunset.

The completed spreadsheets prepared in the data reduction task provided the necessary input for the regional model development.

Using the Statistical Package for the Social Sciences (SPSS) program, the meteorological information and water use records were used to develop preliminary multiple linear regression models for each utility.

In all cases a stepwise multiple linear regression technique was applied for regional model estimation. A variety of model estimation techniques were applied, including backward and stepwise elimination, and similar model results were obtained.

In some cases the log transform of water use, q, was used as the dependent variable. Several transforms of the available predictor variables were assessed.

Using the preliminary regional models as a starting point, several model refinements were completed in an attempt to improve the usefulness of the regional models. The refinements investigated are as follows:

- Using the water use data for the Sanlando and Apopka utilities, an aggregate data set was prepared and analyzed.
- On the basis of monthly rainfall, the aggregate data set was split into two subsets and each subset was analyzed.
- On the basis of expected weekly water use, the aggregate data set was split into two subsets and each subset was analyzed.
- Higher order forms of the independent variables and various combinations of products of independent variables were introduced into the list of candidate independent variables and the modified aggregate data set was analyzed.

The regional model was applied to the period of record for which water use restrictions were in effect. A comparison of predicted and actual flows for the periods with and without water use restrictions shows no significant reduction in water use due to the restrictions.

A local event analysis was conducted to establish the impact, if any, of water use restrictions on the diurnal pattern of water use.

The monthly flow data for the period of 1987 to 1995 for several water utilities in the study area were reviewed. In order to identify the high and low flow months, summary Box-Whisker plots were generated.

The approach to Local Event analysis was as follows:

- For the period of no restrictions, establish normalized flow patterns for each day of the week for the months of May and February (high and low water demand periods, respectively).
- Repeat Step 1 for the period of water use restrictions.

- Compare the normalized flow patterns with and without water use restrictions and establish if the difference is significant.

Because the analysis indicates that there were no significant savings in water, there was no basis for developing costs. In lieu of evaluating cost implications, the final refinement of the regional model was performed.

DISCUSSION

DATA ASSEMBLY

Prior to data collection, a preliminary screening was conducted using existing data to select three utilities for more detailed analyses. The *List of Utilities and Water Treatment Facilities in the Wekiva River Basin Area Designated as Water Shortage Phase I June 1993-1994* (SJRWMD), includes ten (10) utilities and twenty-three (23) water treatment facilities (see Table 1). For the screening, factors such as availability of detailed data, level of enforcement activities, and location within the basin were taken into consideration.

Table 1. List of Utilities and Water Treatment Facilities in the Wekiva River Basin Area Designated as Water Shortage Phase I June 1993-1994

UTILITY	WATER TREATMENT FACILITIES
Apoka	
Maitland	
Ocoee	
Orange County Utilities (OCU)	Bent Oaks Mt. Plymouth Lakes Orange Village Plymouth Regional Riverside
Sanlando	Des Pinar Knollwood Wekiva Hunt Club
Seminole County Utilities	Hanover/Heathrow Lynnwood/BellAire
Southern States Utilities (SSU)	Apple Valley Holiday Heights Lake Brantley Lake Harriet Meredith Manor
Utilities Inc. of Florida	Bear Lake Jansen Little Wekiva Weathersfield
Winter Park	
Orlando Utilities Commission (OUC)	Pine HIlls

The various utilities were reviewed and assessed for suitability for regional analysis. As shown in Rowney et al (1996), Winter Park had no response during Phase I activities and was eliminated from further consideration. A comparison was made of the individual utility service areas and the total area potentially impacted by water use restrictions. Orange County Utilities (OCU) includes five plants. OCU's Riverside and Bent Oaks plants were dropped from the analysis because they are interconnected with several other facilities whose service area is mostly outside of the study area. OCU's Plymouth Regional service area also is mostly outside of the basin. Finally, the service area for Maitland Utilities is largely outside of the area of interest, and therefore it was dropped from further analysis.

A comparison of all the other utilities was prepared based on total water treated by utility (see Table 2). The utilities Sanlando, Apopka and OCU (the two plants being considered) account for over 47.6 percent of the total flow (29.0 percent, 17.6 percent and 1.0 percent, respectively). Also the three utilities provide a good mix of land use and facility sizes. Therefore, these utilities were selected and agreed upon with SJRWMD to consider for further analysis in tasks 3 and 4.

The following data were obtained in final form for completion of Phase II as follows:

- Documentation of water use restrictions and enforcement activities from SJRWMD.

- Daily rainfall and daily maximum and minimum temperature records for the period 1985 to date for Clermont, Orlando and Lisbon stations. There is no station in the vicinity of the study area that registers sunlight.

- Monthly operating reports for the selected utilities in the Wekiva Basin for the period 1988 to date collected from FDEP.

Table 2. Water Utility Treatment Flow in the Wekiva Basin

UTILITY	FACILITY	TOTAL WATER TREATED BY PLANT* (mgd)	TOTAL WATER TREATED BY UTILITY* (mgd)	(PERCENT)
Sanlando**	Wekiva Hunt Club	6,440,186		
	Des Pinar	3,539,667		
	Knollwood	88,525	10,068,378	29.0
OCU	Orange Village	14,084		
	Mt. Plymouth Lakes	326,896	340,980	1.0
Apopka			6,122,637	17.6
Seminole County	Hanover /Heathrow	1,188,441		
	Lynwood/BelAire	645,910	1,834,350	5.3
Ocoee**			3,767,776	10.9
SSU	Holiday Heights	20,135		
	Lake Brantley	21,234		
	Lake Harriet	69,047		
	Meredith Manor	272,982	383,398	1.1
Utilities Inc.	Bear Lake	75,890		
	Janser	93,103		
	Little Wekiva	19,019		
	Weathersfield	373,434	561,446	1.6
OUC	Pine Hills	11,642,437	11,642,437	33.5
TOTAL			34,721,403	100.00

* Monthly water use extracted from Monthly Operating Reports for March through May, 1994
** Sanlando Utilities: Wekiva Hunt Club, Des Pinar and Knollwood facilities are interconnected. Des Pinar and Knollwood are outside of the water shortage area.
Ocoee Utilities: Most of its service area is within the study area.

- Site visits to the selected utilities or to water treatment facilities were conducted to obtain data on:
  - monthly operating reports and/or operating logs for the period 1988 to date,
  - meteorological records (precipitation, temperature and other data as available), for the period 1985 to date, if possible; otherwise for the period of record available. None of the facilities included data that could be of any use in the present study.

- formal records for water restriction compliance and enforcement activities.

- Diurnal demand data (delivery rates) in the form of strip chart and disk recorder records for a period before, during and after the water use restrictions. Only Wekiva Hunt Club and Des Pinar (Sanlando Utilities) offered strip charts that could be read and input accurately in digital format.

DATA REDUCTION

Because the gathered information was not complex and was easy to manage using spreadsheets, it was seen that a data base was not necessary to manipulate the data as defined in the scope of services. The data were input in digital format to accomplish tasks 3 and 4, and to comply with the objective of subsequent use from SJRWMD.

The specific steps in this item were:

- Import long term rain gauge records from the stations Clermont, Orlando and Lisbon. These were available in digital format and import/check functions were done.

- Tabular numeric data regarding daily total water treated at the plant and any meteorological data from the gauges at the plant were typed into comprehensive spreadsheets formatted in a manner similar to the original material. This is a record copy of transcription.

- Strip charts were read and approximated hourly averages typed into a spreadsheet.

The available water use and meteorological information were organized into two categories:

- The period of record with no water use restrictions,

- The period of record with some level of water use restrictions in effect.

All information was arranged chronologically and included: weekly water use for each utility; average weekly temperature; weekly temperature compared to indices of 45, 60, 70 and 85 degrees Fahrenheit; weekly rainfall; and daily time between sunrise and sunset.

The sunlight time series was generated using the HEATEX subroutine of EPA's QUAL2E water quality model (*U.S. Environmental Protection Agency 1987*).

DEVELOPMENT OF A REGIONAL MODEL

The objective of the regional modeling development task was to determine, in a statistically defensible manner, if the imposition of water use restrictions resulted in a reduction in water use by more than 15 percent. The approach represents an extension of work described in *Selection of Climatic Variables for Modeling Weekly Municipal Water Use* (Brandes 1990). In general, standard multiple linear and non-linear regression analysis techniques were employed to identify the functional relationships between water use and various meteorological characteristics. A brief summary of relevant background studies is provided below:

- Brandes, Donald. 1990. *Selection of Climatic Variables for Modeling Weekly Municipal Water Use.* University of South Florida, Department of Geography, Tampa, FL. Brandes describes the development of several multiple linear regression models designed to predict weekly water consumption in the greater Tampa Bay, Florida area. As predictor or independent variables, Brandes utilized temperature, rainfall, and daylight. His work demonstrated that fluctuations in weekly water use in the Tampa Bay area could be adequately explained by climatic variables alone.

- Maimone and Labiak. *A Linear Regression Analysis of Nassau County's Water Conservation Program.* 1994. This work provides a comprehensive analysis of Nassau County's water conservation program. A multiple linear regression model is developed to predict average monthly pumping based upon the number of households and two weather related indexes: a temperature index and an antecedent rainfall index. Analysis of the data indicated that weather-related variability was large. Based on the model application, water use conservation measures yielded a maximum reduction in actual water use of about 11%.

- Weber, J.A.. Integrating Conservation Targets Into Water Demand Projections. *Journal of the American Water Works Association.* 1993. This work provides a general overview of various modeling approaches. Techniques discussed include single value regression models as well as time series approaches. This report illustrates the importance of an accurate database in generating accurate water demand projections. Furthermore, the paper demonstrates that an assessment of the current and future market penetration of key conservation measures is necessary in order to integrate current and potential conservation effects into demand forecasts.

- Cuthbert, R.W.. Effectiveness of Conservation-Oriented Water Rates in Tuscon: *Journal of the American Water Works Association.* 1989. This publication describes a recent analysis of water use patterns for single-family residential customers in Tuscon, Arizona. The analysis illustrates that significant rate responsiveness or price elasticity exists on the part of water users. Review of the available data demonstrated that significant correlation's exist between: 1. annual rainfall and actual year to year change in water use, and 2. monthly evaporation and the average water use per residential customer on an annualized basis. This publication presents a successful application of linear regression techniques to account for the role of precipitation, evaporation and cooling degree days in explaining monthly variations in water use.

- Billings, R.B. and Day, W.M.. Demand Management Factors in Residential Water Use. *Journal of the American Water Works Association.* 1989. Billings and Day present a recent analysis of water demand in a metropolitan area of Tuscon, Arizona. As presented by others, this publication illustrates that pricing is a powerful water conservation tool. A numerical model was developed to estimate lawn watering requirements. The independent variables in this model included temperature and rainfall. The model was applied to examine the correlation of water use to changes in price, income, publicity about the need for conservation, variations in the weather, and socioeconomic characteristics of groups of households. The model application demonstrated that price, income, and socioeconomic variables significantly influence residential water use decisions, while publicity about the need to conserve has a minimum impact.

- Shaw, D.T. and Maidment, D.R.. Effects of Conservation on Daily Water Use. *Journal of the American Water Works Association.* 1988. This work presents an analysis of water use and the impact of water use restrictions in Corpus Christi during the summer drought of 1984. The study area encompassed residential areas and a large industrial base. The applied water use restrictions ranged from initial voluntary measures to ultimate mandatory compliance as the effects of the drought became more severe. An innovative stochastic model was developed and applied to determine the impact of the escalating water use restrictions on actual water use. A stochastic process is a process, which is influenced by some random component. In most cases, the random component is assumed to be adequately described by a Normal (Gaussian) distribution. Similar models have been successfully applied to several cities throughout the US. The application demonstrated that the water use restrictions reduced actual water use by about 33%.

Based on the publications described above, a multiple linear regression approach to assessment of water use restrictions was determined to be the appropriate approach to develop a regional model. In most cases, using various meteorological characteristics and straight forward statistical approaches, such as multiple linear regression, result in reasonable predictive tools.

Multiple Linear Regression is a technique for estimating coefficients for a proposed linear model of the form

$$y= a_0+a_1(x_1)+a_2(x_2)+a_3(x_3)+\ldots a_n(x_n)+e,$$

where y represents the dependent variable, x_1 through x_n represents the set of independent variables, a_0 through a_n represents the set of fitted coefficients, and e represents the estimate error. The linear regression technique provides coefficient estimates that minimize the error term, e.

The completed spreadsheets prepared in the data reduction task provided the necessary input for the multiple linear regression analysis software, the SPSS (version 7.5 for Windows 95/Windows NT).

Preliminary Regression Analysis

Using SPSS, the meteorological information and water use records were used to develop preliminary multiple linear regression models for each utility. A definition of the variables used in this preliminary analysis is provided in Table 3.

In all cases a stepwise multiple linear regression technique was applied for regional model estimation. A threshold F statistic of 2.71 was used as a criterion for adding or removing a potential predictor variable from the model. For a given independent variable, say x, the F statistic is defined as the ratio of the drop in the sum of squared errors obtained for the complete model once the variable x is removed to the mean square error for the complete model. In general, a large F statistic indicates that the candidate predictor variable is responsible for explaining a significant fraction of the observed variability in the dependent variable. The dependent variable, commonly referred to as y, corresponds to the parameter to be predicted by a fitted model. The value of the dependent variable is assumed to be dependent on one or more independent variables. In the present study the dependent variable was weekly water use.

Table 3. Regional Model Variable Definitions

CLASS	VARIABLE	DEFINITION	UNITS
Flow	Q	weekly water use	mgd
	q	Log(weekly water use)	Log(mg)
Temperature	T_0	average weekly temperature	°F
	T_{45}	temperature below 45°F, sum of (45 °F-daily average temperature)	°F
	T_{60}	temperature above 60°F, sum of (daily average temperature-60°F)	°F
	T_{70}	temperature above 70°F, sum of (daily average temperature-70°F)	°F
	T_{85}	temperature above 85°F, sum of (daily average temperature-85°F)	°F
	T_1	temperature index (T_1=1 if temperature drops below 45°F during the week, otherwise, T_1=0)	-
	T_2	temperature index (T_2=1 if temperature rises above 60°F during the week, otherwise, T_2=0)	-
	T_3	temperature index (T_3=1 if temperature rises above 70°F during the week, otherwise, T_3=0)	-
	T_4	temperature index (T_4=1 if temperature rises above 85°F during the week, otherwise, T_4=0)	-
Rainfall	R_0	total rainfall during the current week	inches
	R_1	total weekly rainfall lagged one week	inches
	R_2	total weekly rainfall lagged two weeks	inches
	R_3	total weekly rainfall lagged three weeks	inches
	R_m	total rainfall during the past month, ($R_0 + R_1 + R_2 + R_3$)	inches
Date	D	Day of the year	
Sunlight	S	average hours of daylight (sunrise to sunset)	hours

Forward Stepwise Regression is a technique for determining which independent variables should be considered for a given multiple linear regression model. Candidate independent variables are added in sequence and model coefficients are estimated. Depending on the magnitude of the improvement in the fitted model, the independent variable is either removed or included in the final fitted model.

Through a trial-and-error approach using forward stepwise multiple linear regression, it was determined that a threshold F statistic of 2.71 resulted in a marginal change in the coefficient of determination, R^2, of less than 1 percent. An increase in R^2 of less than 1 percent, at the expense of one additional independent variable, is generally considered not significant. The coefficient of determination, R^2, represents the fraction of variability of a given dependent variable, which is explained by the proposed multiple linear regression model.

A variety of model estimation techniques were applied, including backward and stepwise elimination, and similar model results were obtained.

Backward stepwise regression is a technique for determining which independent variables should be considered for a given multiple linear regression model. An initial estimate of coefficients, using all of the available candidate independent variables, is completed. Independent variables are then removed in sequence and model coefficients are estimated. Depending on the magnitude of the improvements in the fitted model, the independent variable is left out of, or included in the final fitted model.

Expressing a variable, for example y, in an alternate form such as $Log_{10}(y)$ or y^2, is referred to as a variable transform. $Log_{10}(y)$ is referred to as a log transform. In some cases the log transform of water use, q, was used as the dependent variable. The transformation was necessary in order to normalize the residual error.

A normal, or Gauss distribution has a coefficient of skewness of 0 and a coefficient of kurtosis of 3.0. The coefficient of skewness defines a distribution's symmetry: a symmetrical distribution has a skewness of 0. The coefficient of kurtosis is one of many descriptors of a distribution's shape. In some cases, for analysis purposes the distribution of a particular series must be reasonably well approximated by a normal distribution. If this is not the case, some transformation of the series may be necessary to *normalize* the series. For example, expressing each value as a logarithm often can normalize a series with a relatively large positive coefficient of skewness.

A residual is the difference between the measured (or observed) and predicted value of a single realization of a dependent variable.

Several transforms of the available predictor variables were assessed, however, no significant improvement in model fit was achieved.

Almost all regional models were characterized by a coefficient of determination, R^2, of less than 0.5. R^2 is analogous to the correlation coefficient used in simple linear regression analysis. Simple linear regression is a technique for estimating coefficients for a linear model of the form

$$y = a_0 + a_1(x) + e,$$

where y represents the dependent variable, x represents the independent variable, a_0 and a_1 represent the fitted coefficients, and e represents the estimate error. Like multiple linear regression, simple linear regression is designed to minimize the error term, e.

Therefore, in most cases less than 50 percent of the variability in water demand was accounted for by the available predictor variables. Only the Sanlando Regional Model, with a coefficient of determination of 0.63, is suitable for application. The error associated with model predictions for the remaining models is too large. Even with R^2 equal to 0.63, as much as 37 percent of the variability in water use is not explained by the available predictor variables.

The results are summarized in Table 4 below.

Table 4. Preliminary Regional Models

Utility	Preliminary Model	Coefficient of Determination
Sanlando	$q = 5.935 + 3.855\text{x}10^{-2}(S) - 2.075\text{x}10^{-2}(R_m) + 9.161\text{x}10^{-3}(T_0) + 3.855\text{x}10^{-3}(T_{45})$ Equation [1]	0.63
Orange Village	$q = -1.840 + 2.174\text{x}10^{-2}(S) - 1.721\text{x}10^{-3}(T_{45})$ Equation [2]	0.13
Mount Plymouth	$Q = -0.399 + 5.028\text{x}10^{-2}(S) - 6.308\text{x}10^{-3}(T_0) + 3.307\text{x}10^{-3}(T_{60})$ Equation [3]	0.38
Apopka	$Q = -0.11 - 0.328(R_0) - 0.202(R_1) - 0.105(R_2) - 0.099(R_3) + 0.505(S)$ Equation [4]	0.43

Model Refinements

Using the preliminary regional models described in Table 4 as a starting point, several model refinements were completed in an attempt to improve the usefulness of the regional models. The refinements investigated are as follows:

- Refinement 1. Using the water use data for the Sanlando and Apopka utilities, an aggregate data set was prepared and analyzed.
- Refinement 2. On the basis of monthly rainfall, the aggregate data set was split into two subsets and each subset was analyzed.
- Refinement 3. On the basis of expected weekly water use, the aggregate data set was split into two subsets and each subset was analyzed.
- Refinement 4. Higher order forms of the independent variables and various combinations of products of independent variables were introduced into the list of candidate independent variables and the modified aggregate data set was analyzed. The order represents the exponent of a given independent variable. In multiple linear regression analysis the default order of a dependent variable is one. Using an exponent greater than one is normally referred to as using a higher order term.

The refinements 1 through 4 did not result in significant improvements in the coefficient of determination. Furthermore, an analysis of residuals indicated that the regional models generated by refinements 1 through 3 resulted in a systematic prediction bias: *each model tended to under-predict water use during periods of relatively high demand.* The final regional model refinement, listed above as refinement 4, was designed to reduce this systematic bias. This final revision was only partially successful.

A discussion of the regional model revisions and the application of the final regional model to the water use restriction period is provided below.

Refinement 1: Aggregate Data Set of Apopka and Sanlando:

Based on a recommendation of Dr. Brandes of the SJRWMD, an aggregate regional model was developed for the combined areas of Sanlando and Apopka. These two areas account for almost 50 percent of the total water supply within the study area. The Regional model for the combined areas of Sanlando and Apopka is provided below as equation [5].

$$Q = 12.96 + 1.1095(S) - 0.631(R_m) + 0.2138(T_0) + 0.0869(T_{45}) \qquad [5]$$

The standard error of the estimate for this modified regional model is 1.558 mgd, while the coefficient of determination is 0.632. The standard error of the estimate is an estimate of the standard deviation of an estimate.

Using equation [1], a plot of predicted versus measured water use is provided in Figure 1. Although this regional model provides a reasonable prediction of water use for most conditions, at large water demand the model consistently under-predicts the actual water demand.

A plot of residuals (the differences between the weekly observed and predicted water use) is illustrated in Figure 2. There is a noticeable trend in this residual plot, where the magnitude of the residual tends to increase with increasing observed water demand. Possible reasons for this trend and relatively poor model fit are:

- higher order, or non-linear, terms should be included in the model,
- a transformation of one or more of the independent variables or the dependent variable is necessary,
- one or more significant independent variables have been excluded from the model, and

Figure 1. Predicted vs Observed Water Use for Apopka/Sanlando Regional Model

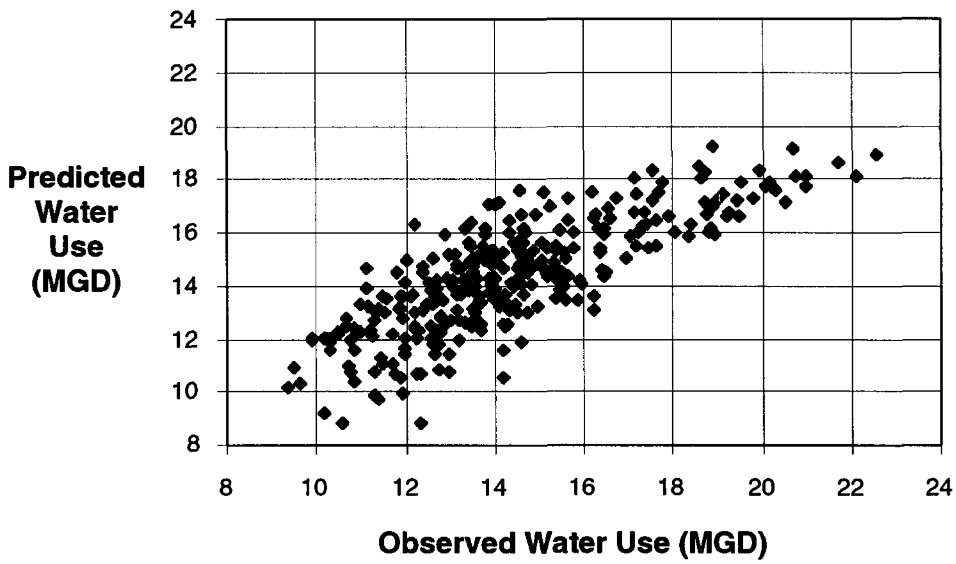
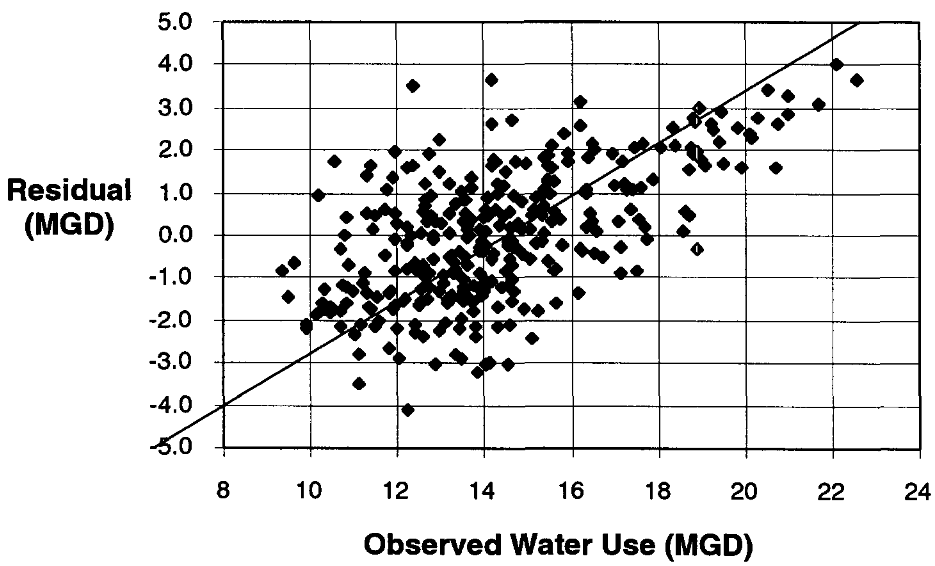


Figure 2. Residual Plot for Apopka/Sanlando Regional Model



- an alternative model, such as a time series approach, may give better results. Developing a true time series model, using Auto-Regressive-Integrated-Moving-Average (ARIMA) techniques or other approaches, might result in a more reliable predictive tool. ARIMA is a statistical approach to modeling a series of events or realizations and forecasting future values. However, a time series model was not developed for the following reasons:

    - Preliminary analysis of the available meteorological data and water use, completed during the previous phase of work, indicated that multiple linear regression models were appropriate.

    - Extensive model development work by Don Brandes and others indicated that the correlation between water demand and various meteorologic characteristics was significant. In particular, the work by Don Brandes demonstrated that correlation coefficients of 80 percent and greater could be achieved.

    - A review of the available utility information indicated that some minor data gaps existed. For formal time series analysis, In-filling of these data gaps would be necessary. However, for multiple linear regression analysis, no data in-filling was required.

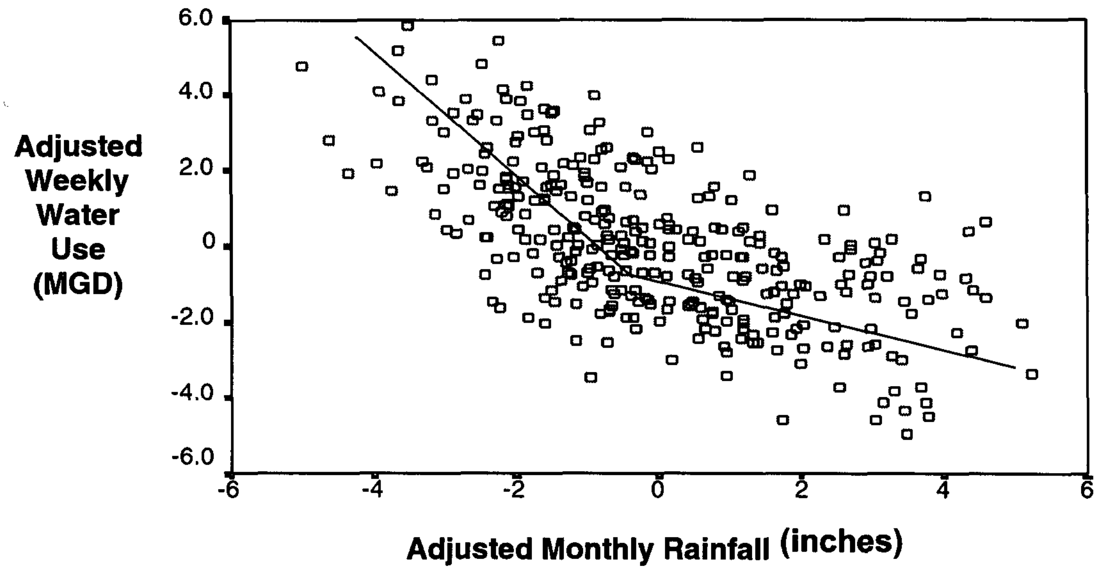
    - Project scope, budget, and time constraints prevented further exploratory modeling work.

It is possible that one or more important independent variables have been excluded from the model. For example, adding variables which address factors such as the duration of the antecedent drought period, socioeconomic conditions, or land use considerations may improve the regional model. Alternatively, an approach involving time series techniques may have yielded an improved regional model.

Refinement 2: Split Data Set Based on Monthly Rainfall:

As a further refinement, partial residual plots were generated for the independent variables included in the regional model presented as equation [1]. A partial residual plot presents the residuals generated by removing one independent variable from the complete model as a function of the independent variable. Therefore, a partial residual plot provides a visual indication of the variability of the dependent variable that is explained by the independent variable. With the exception of the independent variable Rm (monthly rainfall in inches), the partial residual plots provided no indication of non-linearity. However, the partial residual plot for monthly rainfall, shown below as Figure 3, provided an indication of a change in slope at a monthly rainfall value approximately equivalent to the monthly average. Figure 3 presents the partial residuals and monthly rainfall as departures from the mean.

Figure 3. Partial Residual Plot for Monthly Rainfall for the Regional Model for Apopka and Sanlando



Based on the results presented in Figure 3, the stepwise multiple linear regression was repeated for two sub-sets of the original data. One sub-set included all observations for which monthly rainfall was less than the average for the period of record, while the second sub-set included all data for which monthly rainfall was greater than the average. For the period of record the average monthly rainfall was 3.80 inches.

The results of this revised regression analysis are summarized in Table 5 below.

Table 5. Summary of Refinement 2: Split Data Set Based on Monthly Rainfall

Sub-Set	Revised Regional Model	Coefficient of Determination R^2	Standard Error (mgd)
Monthly Rainfall Less Than Average (Rm<=3.80 in))	$Q = -13.975 + 1.283(S) - 0.768(R_m) + 0.202(T_0) + 0.0518(T_{45})$ Equation [6]	0.733	1.382
Monthly Rainfall Greater Than Average (Rm>3.80 in))	$Q = -13.171 + 0.766(S) - 0.638(R_m) + 0.282(T_0) + 0.152(T_{45})$ Equation [7]	0.541	1.595

A plot of the weekly predicted versus observed water use for the modified regional model defined in Table 5 is provided as Figure 4.

Although the underestimation of water use is still evident at high values of water use, a comparison of Figure 1 and Figure 4 indicates that this revision is an improvement over the original regional model.

Figure 5 provides a plot of the residuals for Refinement 2. Despite the improvement in the regional model, the poor fit at large water use results in residuals that generally increase with increasing water use.

Figure 4. Predicted vs Observed Water Use for Apopka/Sanlando Regional Model (2 sub-models based on monthly rainfall)

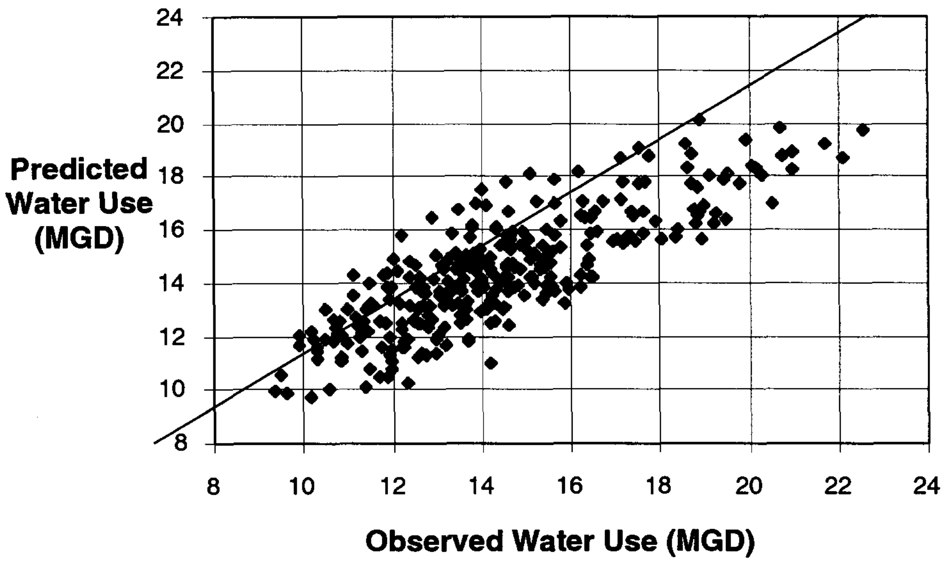
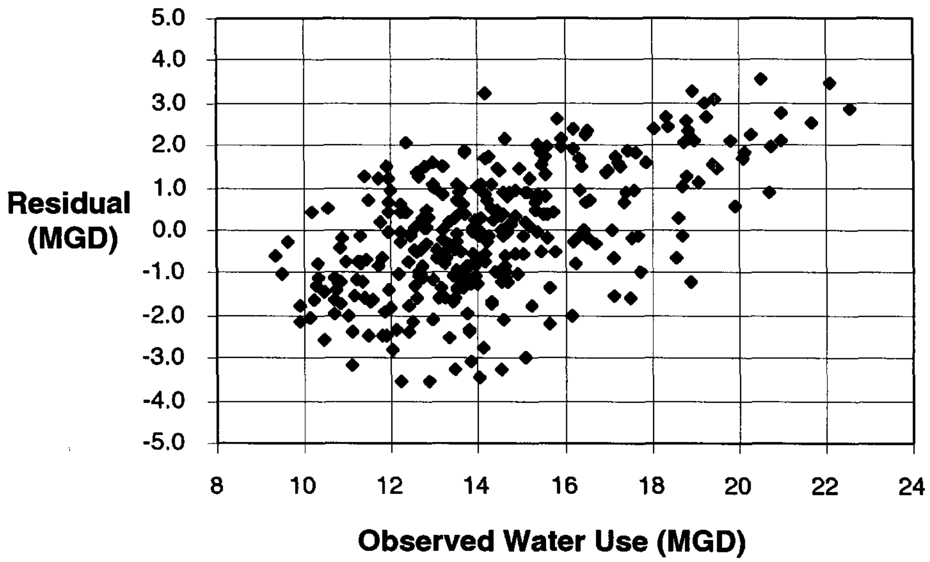


Figure 5. Residual Plot for Apopka/Sanlando Regional Model (2 sub-models based on monthly rainfall)



Refinement 3: Split Data Set Based on Expected Water Use:

In an attempt at removing the model bias, the stepwise multiple linear regression was repeated for two sub-sets of the original data. One sub-set included all observations for which observed water use, Q, was less than the average for the period of record. The second sub-set included all data for which observed water use was greater than the average. For the period of record the average aggregate water use was 14.3 mgd.

The results of this revised regression analysis are summarized in Table 6.

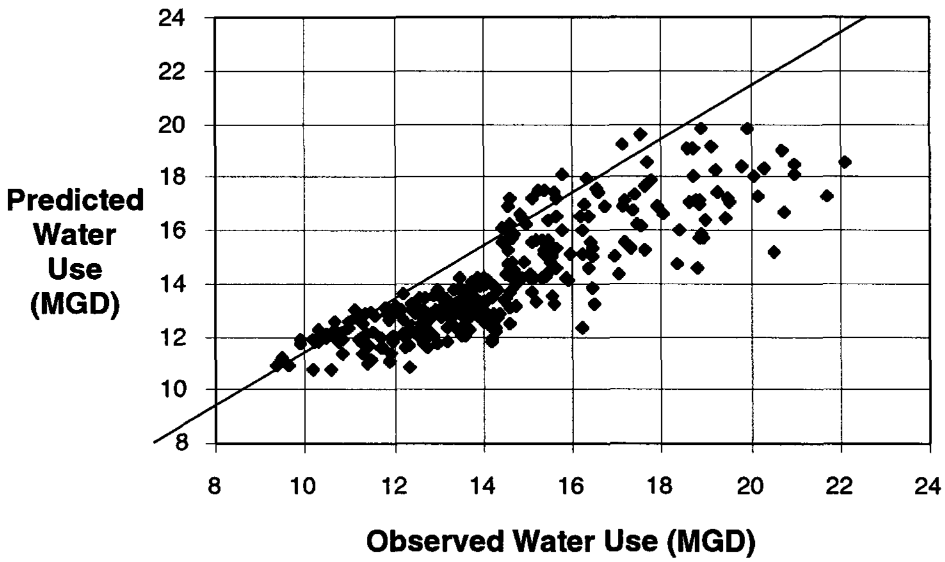
Table 6. Summary of Refinement 3: Split Data Set Based on Observed Water Use

SUB-SET	REVISED REGIONAL MODEL	COEFFICIENT OF DETERMINATION R^2	STANDARD ERROR (mgd)
Observed Water Use Less Than Average (Q<=14.3 mgd)	$Q = -1.938 + 0.370(S) - 0.257(R_m) + 0.153(T_0) + 0.0816(T_{45})$ Equation [8]	0.375	0.971
Observed Water Use Greater Than Average (Q>14.3 mgd)	$Q = -13.171 + 0.766(S) - 0.638(R_m) + 0.282(T_0) + 0.152(T_{45})$ Equation [9]	0.536	1.38

A plot of the weekly predicted versus observed water use for the modified regional model defined in Table 6 is provided as Figure 6.

Comparison of Figures 1 and 6 provides no indication that Refinement 3 results in an improved regional model. The prediction bias is still evident at above average water demand periods. In addition, the coefficient of determination, R^2, for each sub model of Refinement 3 is less than the coefficient of determination of the original model. Also there is a distinct difference in error variance between the two sub models. For these reasons, Refinement 3 was not investigated further.

Figure 6. Predicted vs Observed Water Use for Apopka/Sanlando Regional Model (2 sub-models based on observed water use)



Refinement 4: Assessment of Non-Linearity:

As a final attempt at improving the regional model, higher order forms of the independent variables and various combinations of products of independent variables were introduced into the list of candidate independent variables and the modified aggregate data set was analyzed using stepwise multiple linear regression techniques.

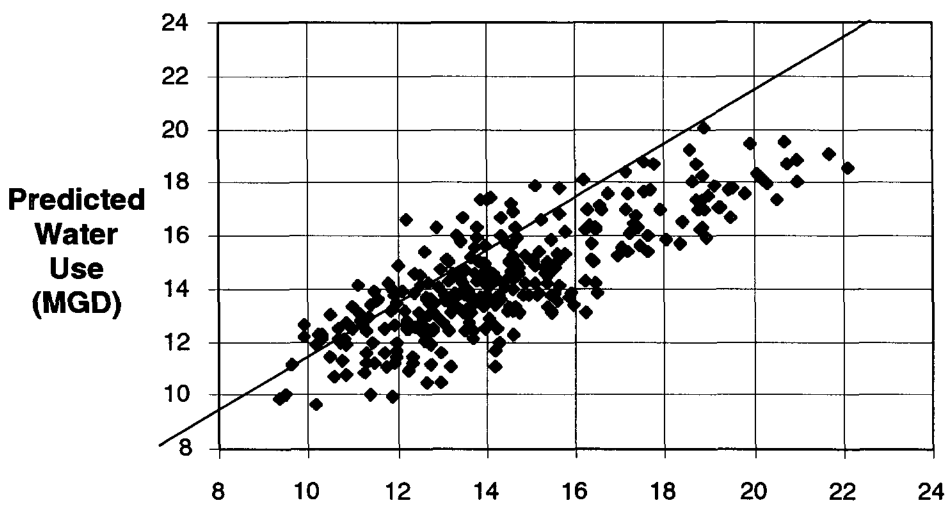
There is some evidence of a non-linear trend in Figure 1. Below average water use is under-predicted, average water use is over predicted, while above average water use is under-predicted. An analysis of the residuals generated by the original regional model revealed no evidence of non-linearity. To account for this apparent non-linearity, the list of candidate independent variables was expanded to include squared terms, cubed terms, and all possible cross-product terms. The resultant regional model for Refinement 4 is provided below as equation [10].

$$Q = 2.42 + 0.0148(T_0)(S) - 0.00536(T_0)(R_m) + 0.01466(T_{45})(R_m) \quad [10]$$

The standard error of the estimate for this modified regional model is 1.500 mgd, while the coefficient of determination is 0.66.

A plot of the predicted and observed water use for Refinement 4 is provided as Figure 7. Despite the changes to the list of predictor variables, the bias in the flow predictions is still evident in Figure 7. However, a comparison of Figures 1 and 7 indicates that the bias is reduced and the error variance is more uniform.

Figure 7. Predicted vs Observed Water Use for Apopka/Sanlando Regional Model (non-linear model)

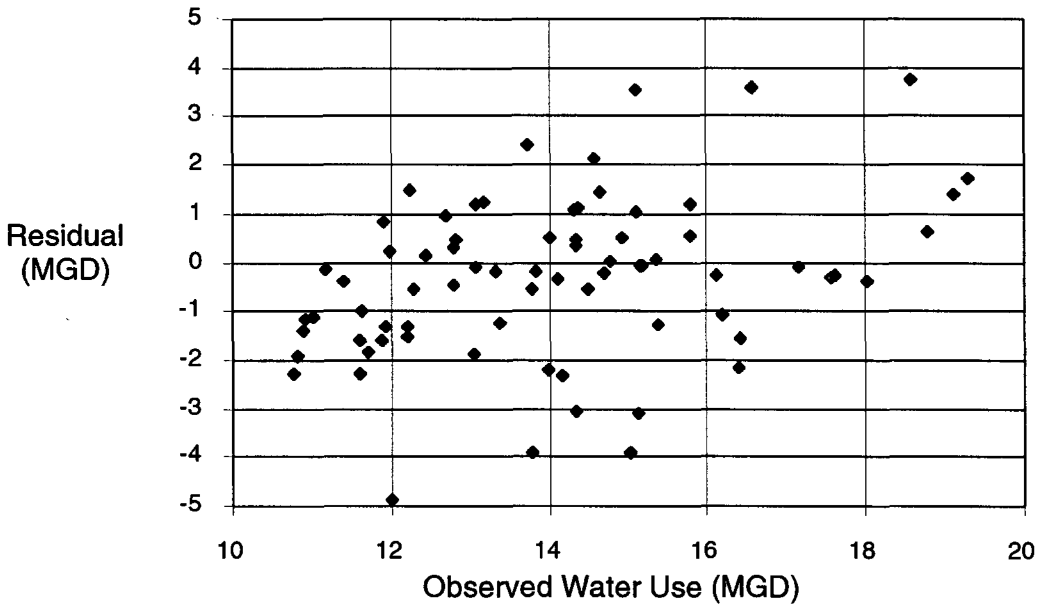


Because some bias remains in the model predictions the final regional model represented by equation [10] is not ideal. However, equation [10] represents the optimum non-linear regression model that is achievable with the available information.

Test Application of Final Regional Model

A plot of the residuals generated by applying the final regional model, Refinement 4, to the period of water use restrictions is provided as Figure 8.

Figure 8. Regional Model Residuals for Water Restriction Period (non-linear model)



The final regional model can be used to assess the effects of water use restrictions. The model was fitted to the period of data without water use restrictions, and a predictive relationship for water use was developed. This predictive relationship is then applied to the period with water use restrictions. If the water use restrictions resulted in water use savings, the observed water use would be less than the predicted water use during this period.

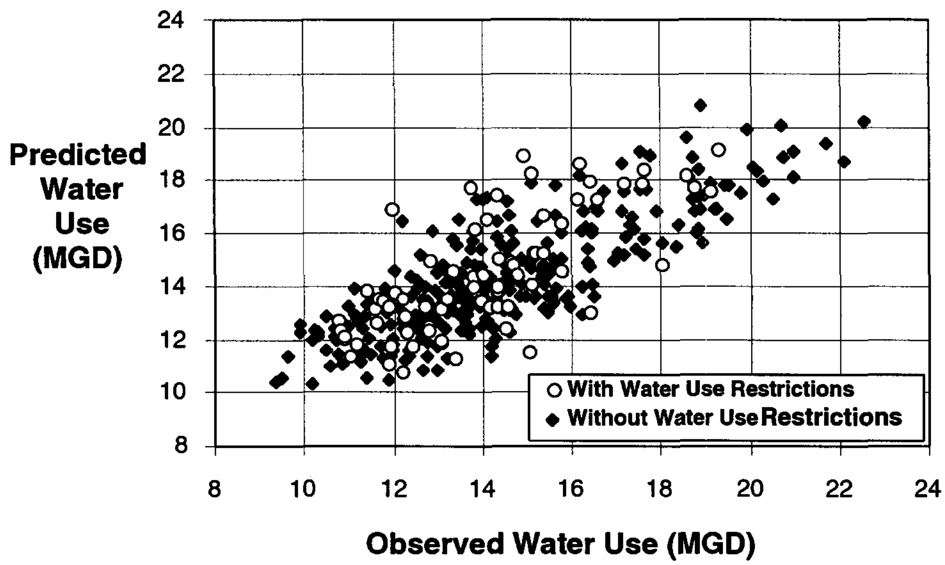
If the final regional model had resulted in a consistently well-fitted relationship between observed and predicted water use, it would have been possible to use simple statistical assessment of the regression residuals to assess the effects of water use restrictions. A calculation of the mean and standard deviation of the regression residuals with and without the water use restrictions would have provided a means of testing the statistical significance of any reduction in observed water use during the period of water use restrictions. However, the tests for statistical significance of residuals are not valid when there is a systematic bias in the regression such as the one observed in this case.

While the bias in the model fit prevents a purely numerical treatment of the effects of water use restrictions, it does not prevent us from drawing a conclusion. The observed and predicted water use values with and without water use restrictions are shown together in Figure 9. The effects of the water use restrictions can be assessed qualitatively by comparing the observed values of water use with and without restrictions at any specified level of predicted water use. If the water use restrictions had caused a reduction in water use, at any level of predicted water use the observed water use values during the period of restrictions would tend to be lower than the corresponding observed water use values during the period without restrictions. However, it can be seen from Figure 9 that this is not the case. The relationship between predicted and observed water use values is similar during the periods with water use restrictions and without water use restrictions.

Therefore, it can be concluded that the water use restrictions do not cause a significant decrease in water use.

Further refinements may lead to an improved regional model. However, based on the comparative analysis described above, it is unlikely that the predicted reduction in water use would be as a large as 15 percent, a goal of SJRMWD during water use restriction periods.

Figure 9. Predicted vs Observed Water Use for Apopka/Sanlando Regional Model With and Without Water Use Restrictions



LOCAL EVENT INTERPRETATION

Selection of Representative Wet and Dry Months

The monthly flow data for the period of 1987 to 1995 for several water utilities in the study area were reviewed. Summary Box-Whisker plots were generated, and typical example plots are provided as Figures 10 through 12. The upper and lower boundary of the box corresponds to the 75th percentile and 25th percentile, respectively. The monthly average flow is included as a diamond marker in the box. The *"Whiskers"* define the maximum and minimum values for each month. A brief review of Figures 10 through 12 indicates that May is consistently a high flow month, while February is consistently a low demand month.

Figure 10. Monthly Flow Box-Whisker Plot for Maitland Plant #4

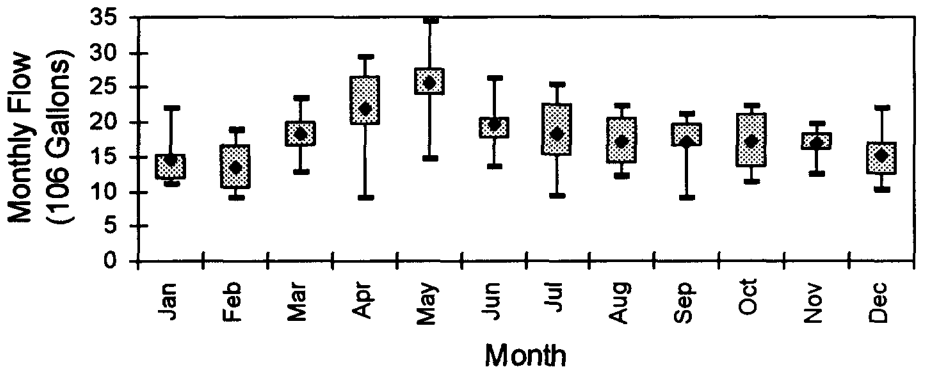


Figure 11. Monthly Flow Box-Whisker Plot for Wekiva Hunt Club

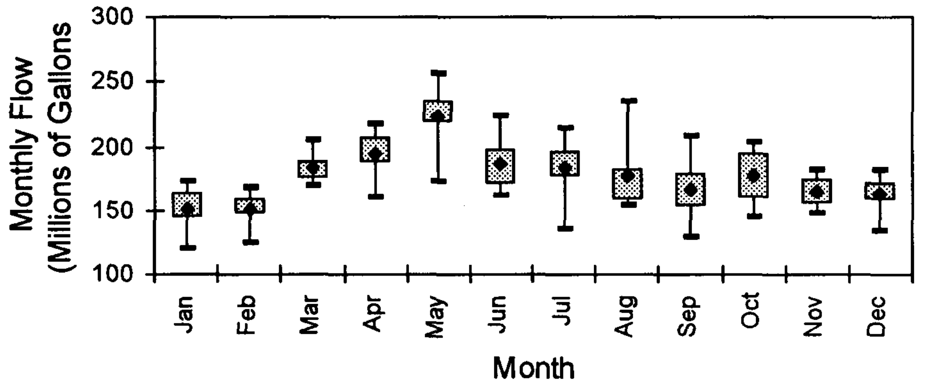
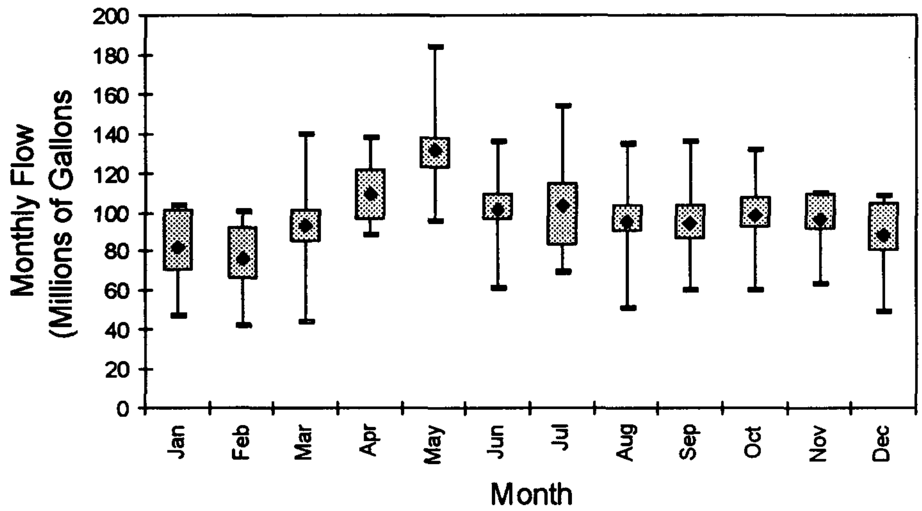


Figure 12. Monthly Flow Box-Whisker Plot for Des Pinar



Impact of Water Use Restrictions

As discussed previously, the Regional Analysis demonstrated that there was no significant difference in average daily water use between periods of water use restrictions and periods of no restrictions. However, diurnal variability in water use may have been impacted as a result of water use restrictions. Diurnal changes could have significant impact on a utility's ability to meet water demands if the change is an increase during a period of typical peak water demand. The purpose of the local event analysis was to establish the impact, if any, of water use restrictions on the diurnal pattern of water use.

The approach to Local Event analysis was as follows:

- Step 1. For the period of no restrictions, establish normalized flow patterns for each day of the week for the months of May and February (high and low water demand periods, respectively).
- Step 2. Repeat Step 1 for the period of water use restrictions.

- Step 3. Compare the normalized flow patterns with and without water use restrictions and establish if the difference is significant.

The hourly water demand data were normalized by dividing each hourly observation by the average daily flow for the week. The corresponding average normalized flows for each hour of the week are shown in Figures 13 through 16. These figures show the normalized variation in flows for each hour of the week for two test periods at two locations. The locations are the Wekiva Hunt Club Facility and the Des Pinar Facility. The two test periods are February and May for the years 1990 through 1996. The data from 1994 represent a period of flow restrictions, and the remaining data represent a period of no flow restrictions. These data provide up to 18 flow observations for each hour of the week for the period with no flow restrictions, and up to 3 flow observations for each hour of the week for the period with flow restrictions.

The data show a consistent pattern of altered daily flow distribution during the periods with flow restrictions. During the period of flow restrictions, normalized hourly flows were increased in the early morning hours and decreased in the late morning and afternoon hours. The net effect was a similar total daily demand distributed with increased demand during the hours of darkness and decreased demand during daylight hours.

The difference between the average normalized hourly flows was calculated for each hour of the week by subtracting the average normalized hourly flow during the period with no restrictions from the average normalized hourly flow during the period with restrictions.

Figure 13. Normalized Flow Patterns - Wekiva Hunt Club Facility. February, 1990-1996

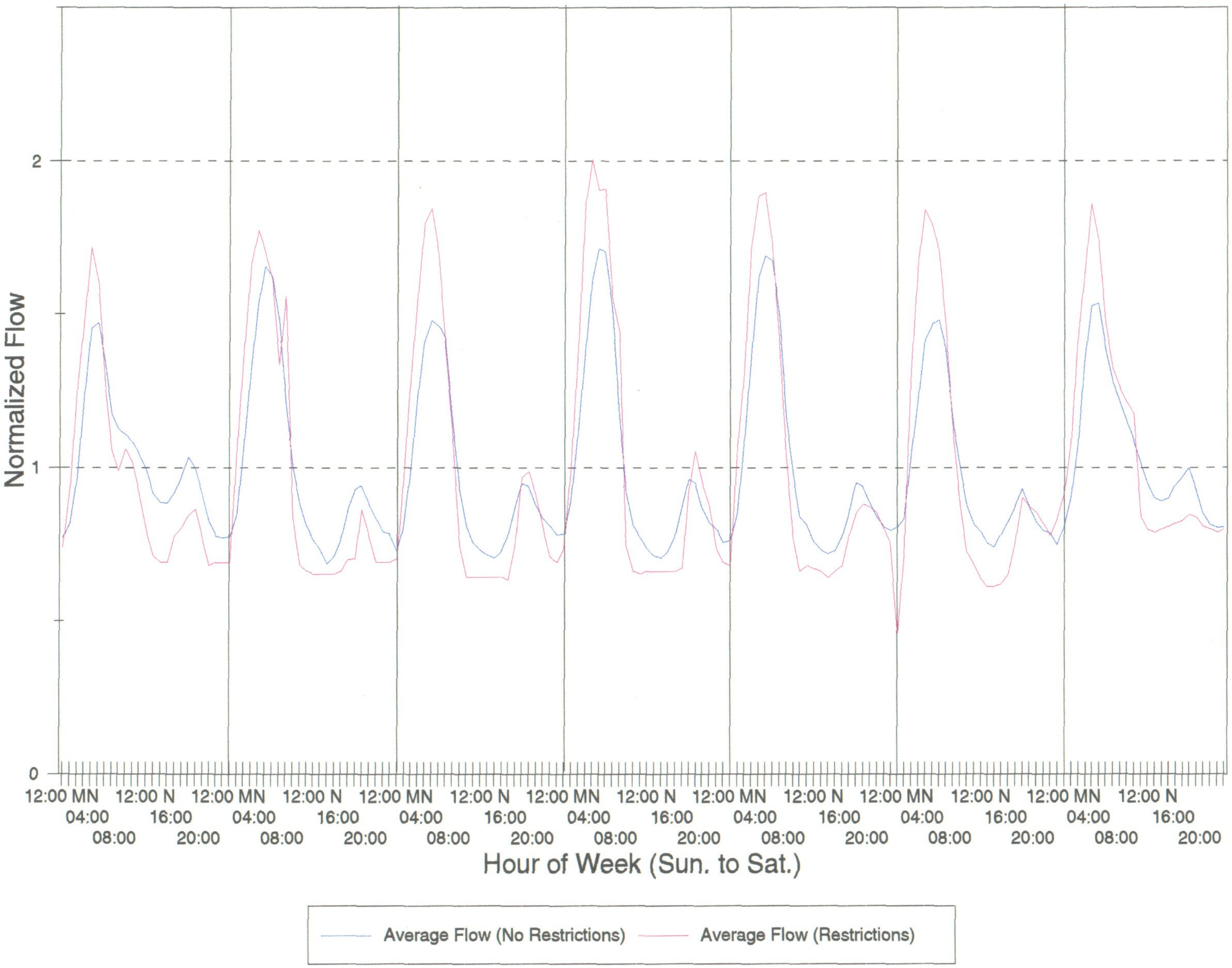


Figure 14. Normalized Flow Patterns - Wekiva Hunt Club Facility. May, 1990-1996

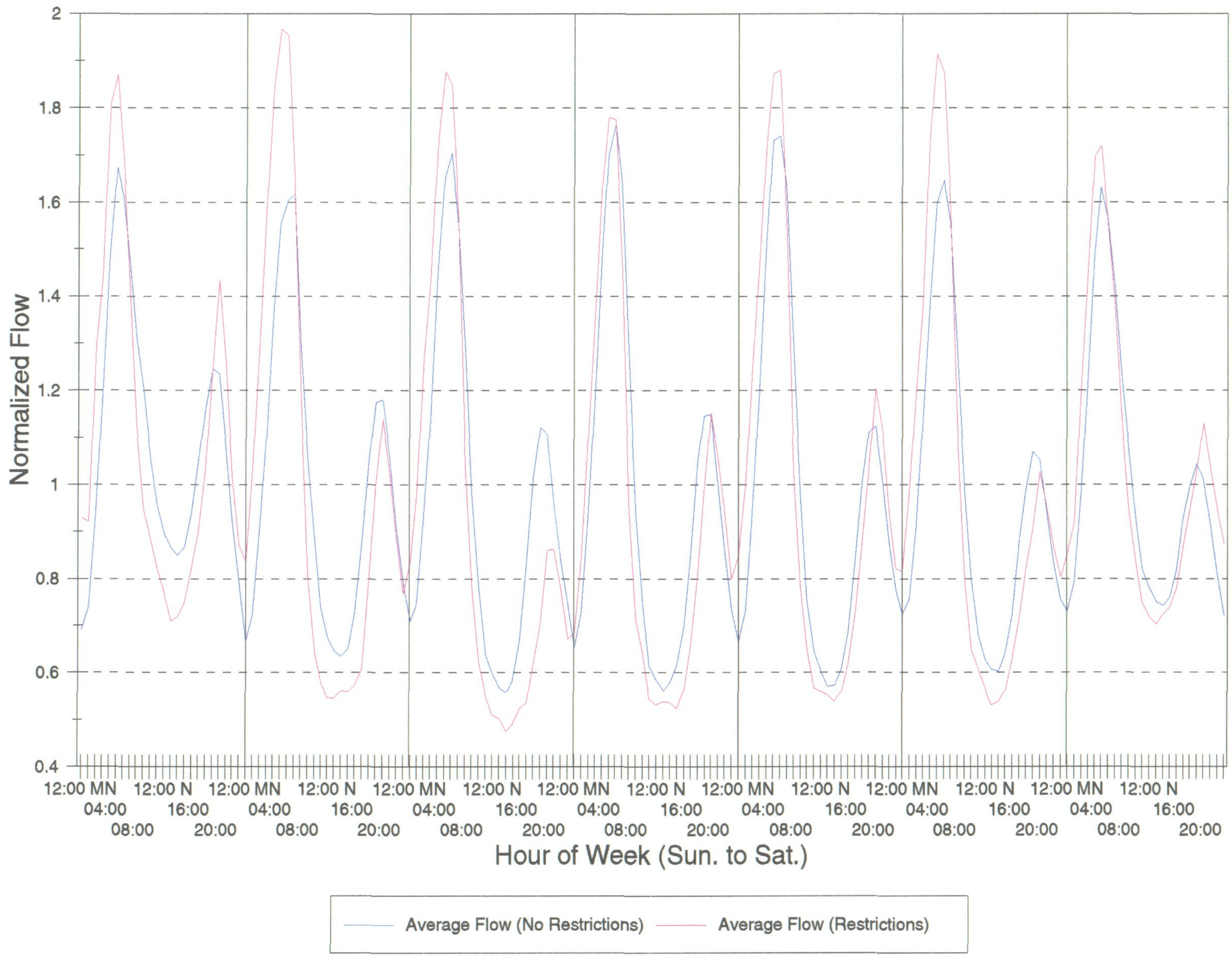
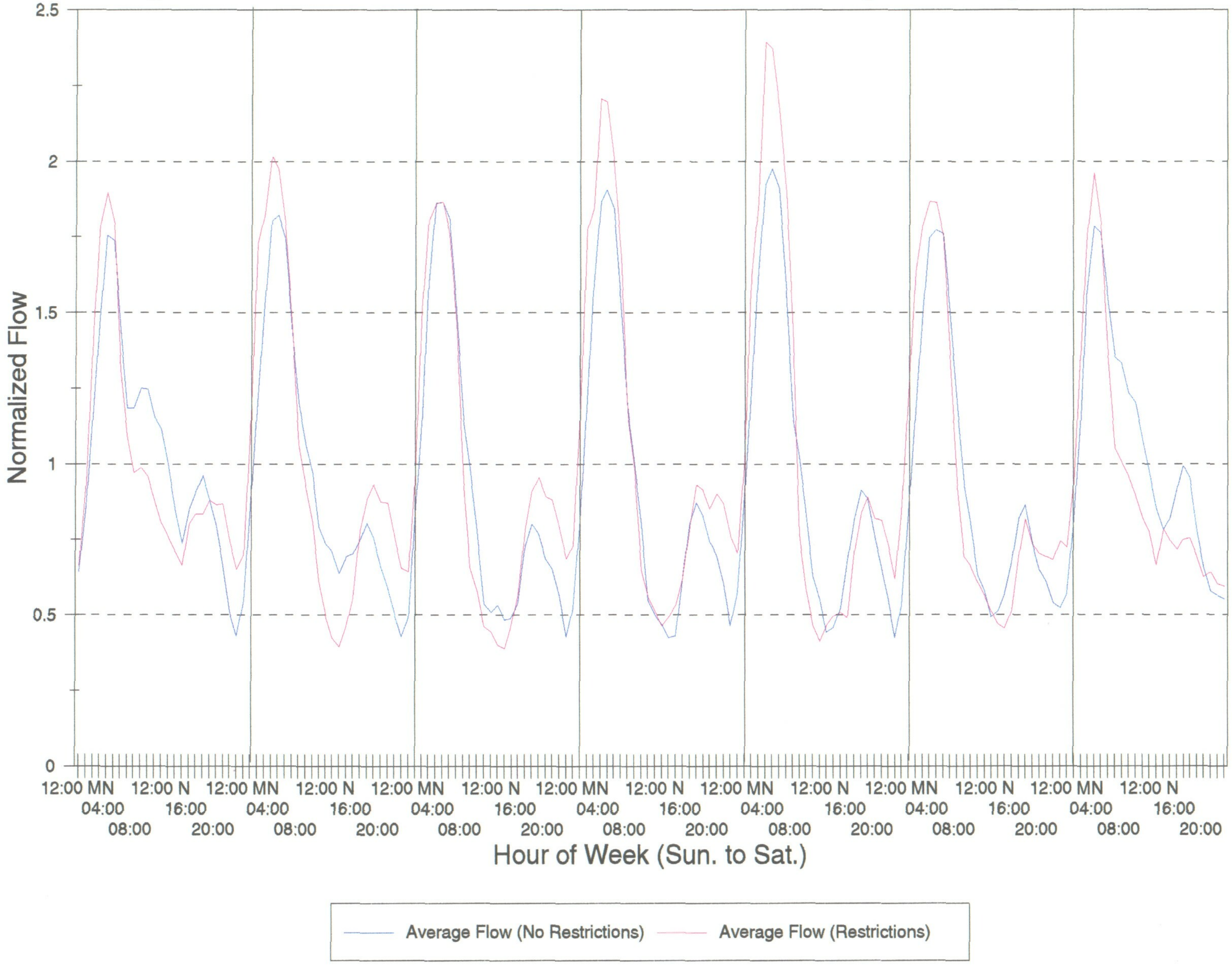


Figure 15. Normalized Flow Patterns - Des Pinar Facility. February, 1990-1996



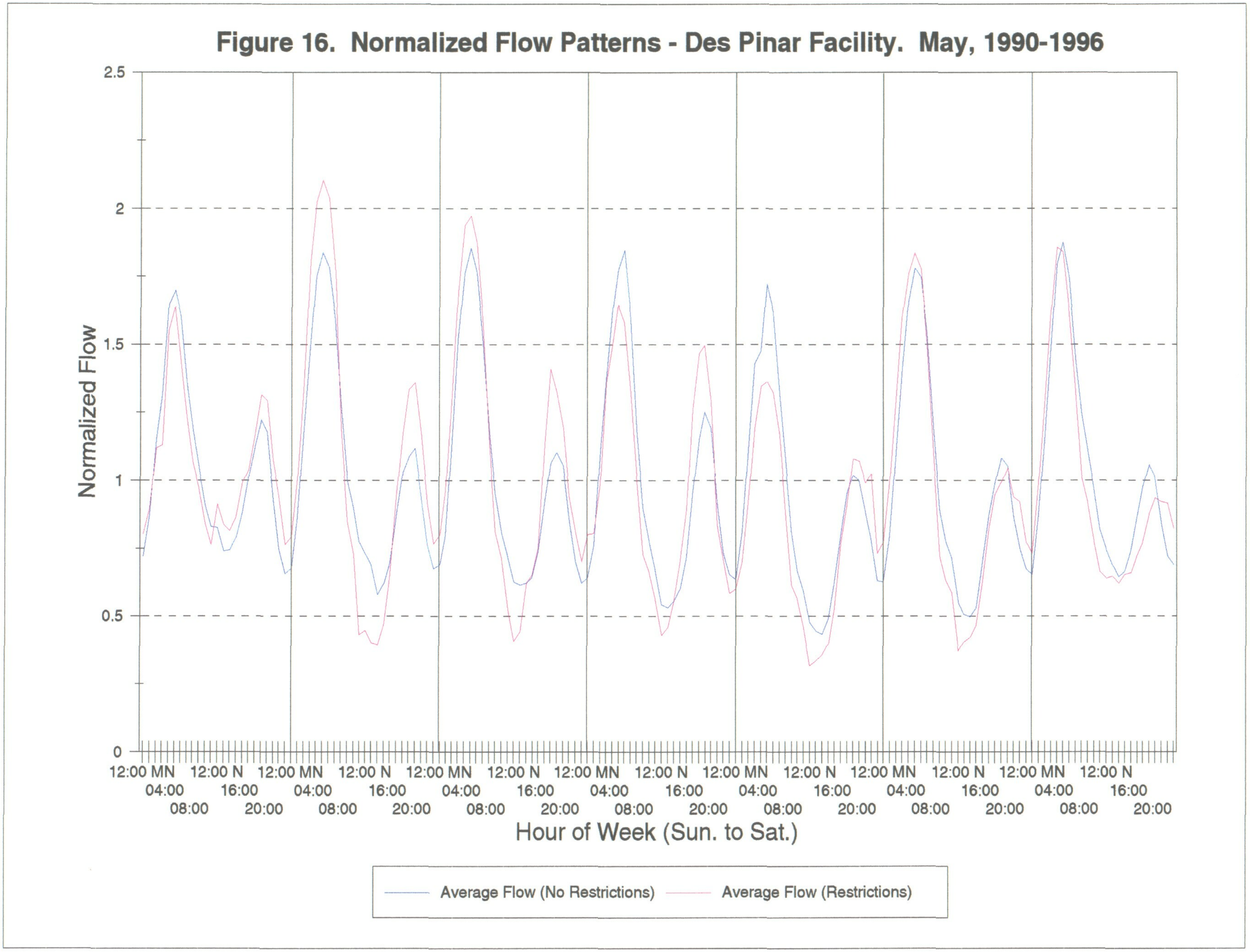


Figure 16. Normalized Flow Patterns - Des Pinar Facility. May, 1990-1996
2.5
2
1.5
1
0.5
0
Normalized Flow
12:00 MN
12:00 N
04:00
16:00
08:00
20:00
Hour of Week (Sun. to Sat.)
Average Flow (No Restrictions)
Average Flow (Restrictions)

The statistical significance of the change in flow patterns can be assessed by treating each hour's observations as normally distributed. For the two cases where missing data left only one hourly observation during the period with flow restrictions, the significance of the difference can be assessed by comparing the single observation of flow with restrictions to the 95 percent confidence limit on the individual observations of flow with no restrictions. In this case, the 95 percent significance limits are calculated as:

$$\left|X_R - \overline{X}_N\right| = 1.96\sigma_N$$

where:

X_R: Observed normalized flow during water use restrictions period
$\overline{X}_N$: Average normalized flow during no water use restrictions
σ_N: Standard deviation of the normalized flow with no water use restrictions

For the case where there are multiple observations of normalized hourly flows with restrictions and with no restrictions, the confidence limits are calculated using the test for significance of the difference between the means of two normal distributions. In this case, the 95 percent significance limits are calculated as:

$$\left|\overline{X}_R - \overline{X}_N\right| = 1.96\sqrt{\frac{\sigma_R^2}{n_R} + \frac{\sigma_N^2}{n_N}}$$

where:

$\overline{X}_R$: Average normalized flow during water use restrictions period
$\overline{X}_N$: Average normalized flow during no water use restrictions
σ_R: Standard deviation of the normalized flow with water use restrictions
σ_N: Standard deviation of the normalized flow with no water use restrictions
n_R: Number of flow observations with water use restrictions
n_N: Number of flow observations with no water use restrictions

The results of these calculations are shown in Figures 17 through 20. The figures show the difference between the average normalized hourly flows for each hour of the week and the corresponding 95 percent significance limits. The differences between the hourly flows with restrictions and without restrictions are significant at the 95 percent confidence level for those periods when the line representing the difference between the hourly flows with restrictions and without restrictions falls outside the region contained between the lines representing the upper and lower 95 percent significance limits.

In every case, the average difference during daylight hours (6:00 am to 6:00 pm) is negative, implying a net reduction in average water use during the day. The average difference during night hours (6:00 pm to 6:00 am) is positive, implying a net increase in water use over night.

The data from the Wekiva Hunt Club facility show a pattern of flows during the period of restrictions being significantly higher than flows without restrictions during the early morning hours, and significantly lower than flows without restrictions during some portion of the late morning and afternoon hours. During the rest of the day, the difference between the flows with restrictions and without restrictions is not significant at the 95 percent confidence level.

The data from the Des Pinar facility for February show a similar pattern of statistical significance to the data from the Wekiva Hunt Club. The data from the Des Pinar facility for May show a similar general pattern of flow distribution changes during the day, but most of the time the differences between flows with restrictions and without restrictions are not significant at the 95 percent confidence level.

Therefore, the water use restrictions appear to result in a systematic shift in the pattern of diurnal water demand. In general, during water use restrictions water use during the daylight hours decreases, while water use during the night hours increases. The difference between the normalized hourly flows with restrictions and with no restrictions tends to be statistically significant at a 95 percent confidence level during the early morning peak flow period, and again during the late morning/afternoon low flow period. The normalized daily peak flows for the period of water use restrictions averaged 9 percent greater than the normalized daily peak flows without restrictions, and ranged as high as 25 percent greater than normalized daily peak flows without restrictions.

The enforcement sweep activities were not formal or consistent throughout the time included in this study and the duration is short compared to the length of the total water use restriction activity. The impact of individual enforcement sweep operations could not be effectively assessed. The final regional model accounted for about 60 percent of the observed variability in water use and the error associated with model predictions was relatively large. Therefore, the only practical application of the regional model was for time periods of extended water use restrictions, where average differences would be evident. The error associated with a short-term regional model application would be relatively large and would be indistinguishable from any potential reduction in actual water use.

Analysis of Cost Implications

An analysis of cost implications was not conducted. Costs were to be developed on the basis of cost per 1,000 gallons saved during the period of water use restrictions. Because the analysis indicates that there were no significant savings in water, there was no basis for developing costs. The effort allocated for cost estimating was redirected to develop additional model refinement as described in the discussion of the Development of a Regional Model.

Figure 17. Normalized Flow Difference (Restrictions - No Restrictions)
Wekiva Hunt Club Facility. February, 1990-1996

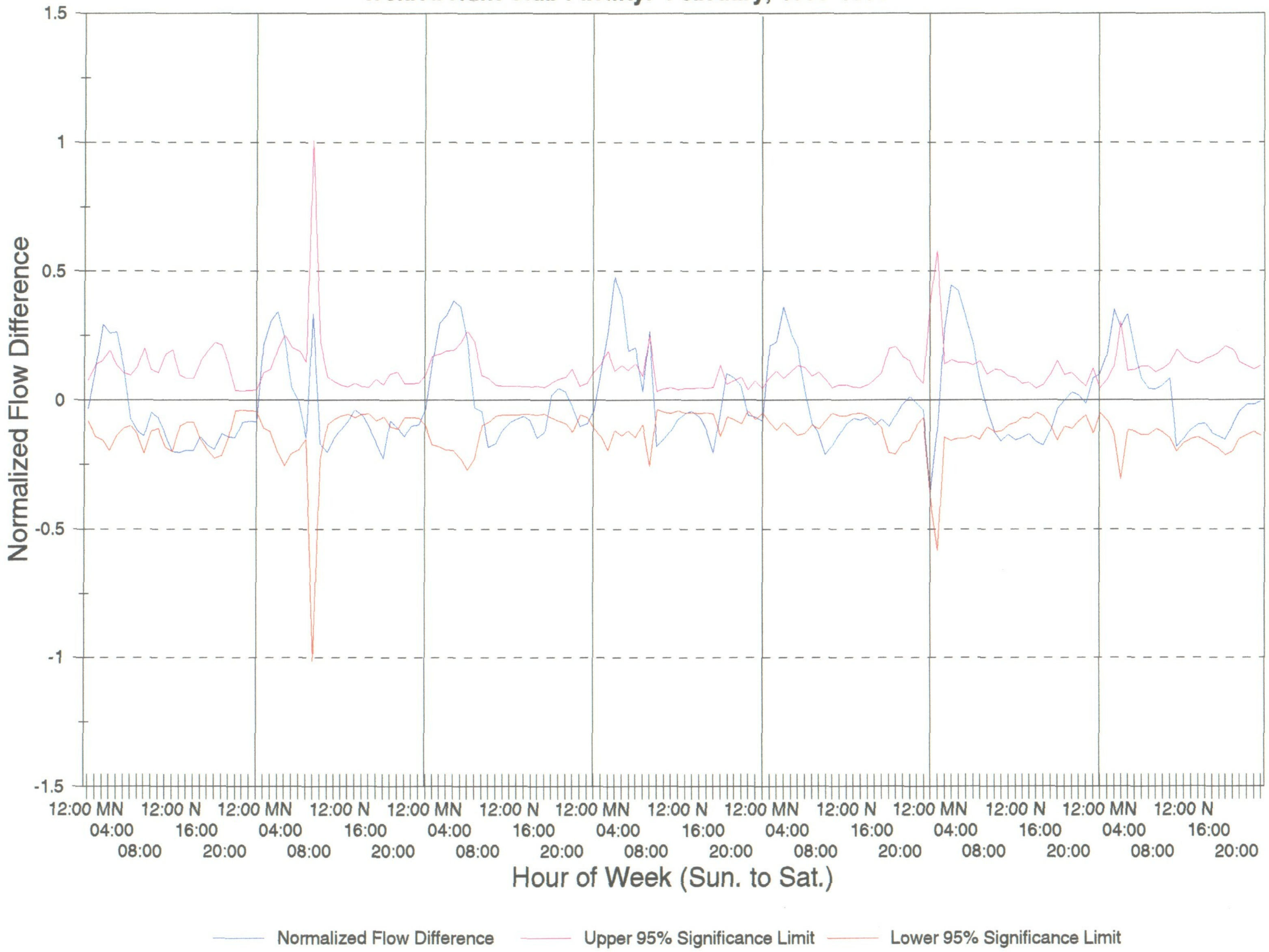


Figure 18. Normalized Flow Difference (Restrictions - No Restrictions)
Wekiva Hunt Club Facility. May, 1990-1996

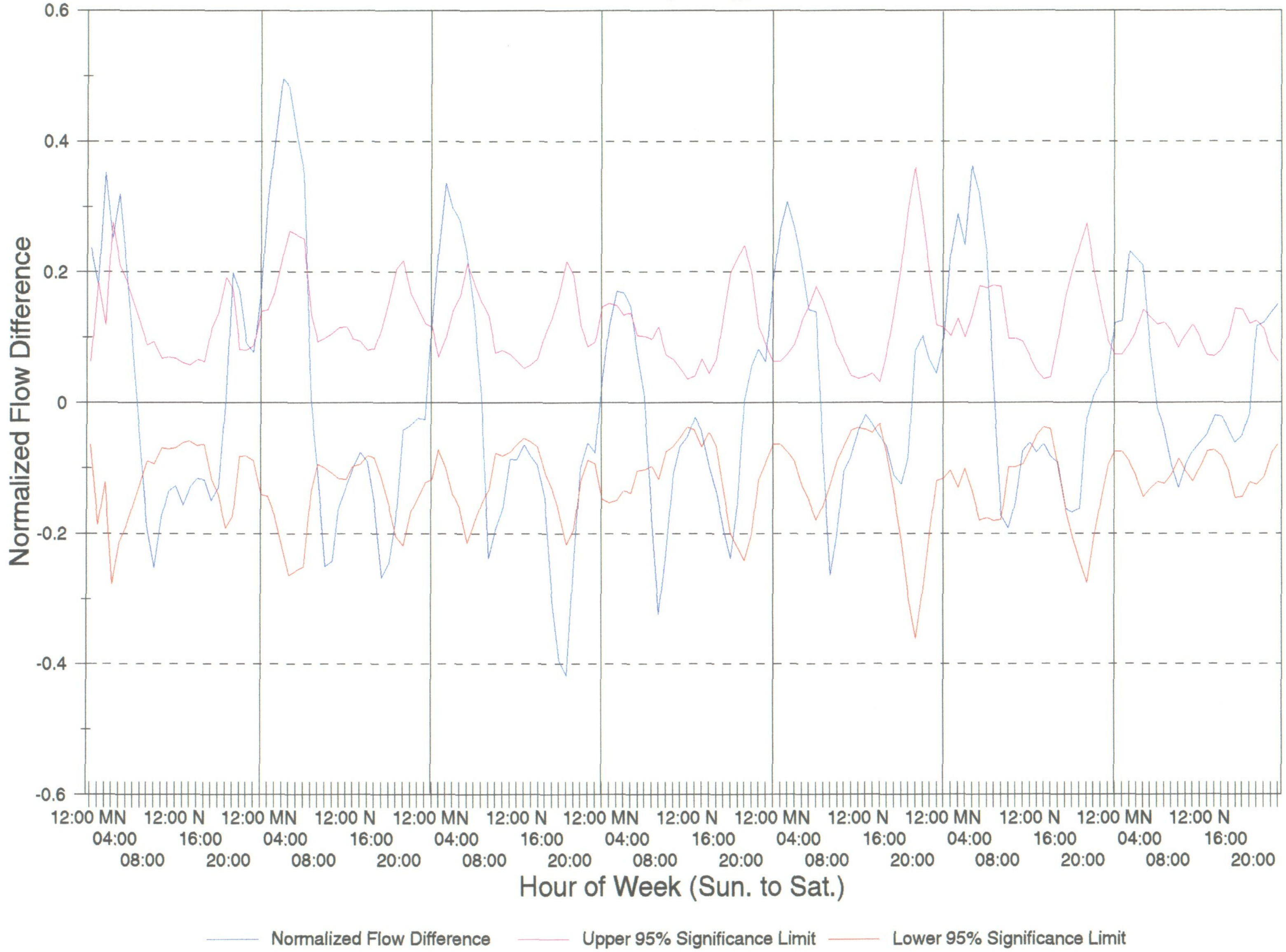


Figure 19. Normalized Flow Difference (Restrictions - No Restrictions)
Des Pinar Facility. February, 1990-1996

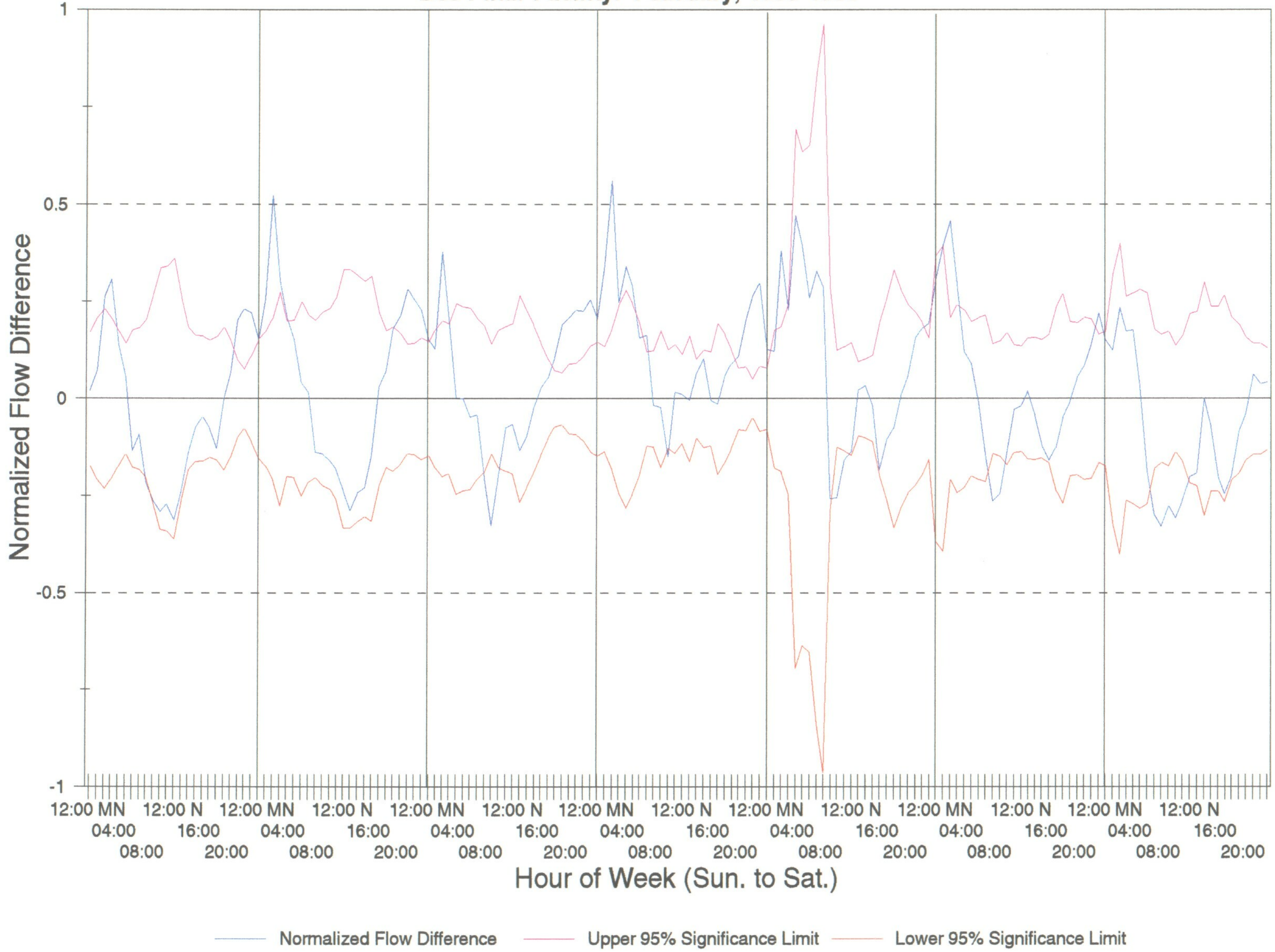


Figure 20. Normalized Flow Difference (Restrictions - No Restrictions)
Des Pinar Facility. May, 1990-1996

CONCLUSIONS

Using stepwise multiple linear regression analysis techniques, the available meteorological information and water use records were used to develop preliminary regional models for each utility. For each preliminary regional model, the independent variable was utility flow, while rainfall, sunlight, and temperature were used as dependent or predictor variables. No water use restrictions were in place for the period of record applied for regional model development.

With the exception of Sanlando, the coefficient of determination, R^2, for all preliminary regional models was less than 0.5. Therefore, in most cases, less than 50 percent of the variability in water demand was accounted for by the available predictor variables.

Using the preliminary regional models as a starting point, several model refinements were completed in an attempt to improve the usefulness of the regional models. By lumping the data for Sanlando and Apopka utilities into one aggregate data set and by adding several combinations of products of independent variables to the list of candidate independent variables, an improved regional model was developed. Other model refinements were explored without success.

The final regional model is provided below as equation [10].

$$Q = 2.42 + 0.0148(T_0)(S) - 0.00536(T_0)(R_m) + 0.01466(T_{45})(R_m) \quad [10]$$

The standard error of the estimate for this modified regional model is 1.50 mgd, and the coefficient of determination is 0.66. With an R^2 of 0.66, approximately 34 percent of the observed variability in water use is not explained by the model. By most accounts, 34 percent represents a significant fraction of the observed variability. Therefore, although an R^2 of 0.66 is the maximum R^2 achievable using the available predictor variables and conventional multiple linear regression techniques, the usefulness of the final regional model is limited.

Despite the relatively low R^2, equation [10] was applied to the period of record for which water use restrictions were in effect. Because of the non-ideal fit between observed and predicted water demands, it was not possible to use a simple t-test of regression fit to check if the relationship between the observed and predicted flows during the period with flow restrictions was different from the relationship without flow restrictions. However, a plot comparing the observed and predicted flows during both the period with no flow restrictions and the period with flow restrictions showed that both appeared to show the same non-ideal regression fit. This strongly suggests that the daily flows during the period of flow restrictions are similar to the daily flows that would have occurred without flow restrictions.

The low R^2 associated with the final regional model contributed to error in the t-test described above. It is conceivable that a more reliable regional model may have indicated that the impact of water use restrictions was significant. However, other investigations have demonstrated that the predictor variables selected for this analysis account for the majority of the observed variability in water use. In all likelihood, other factors, such as socioeconomic variables and random variability in household water use, account for the unexplained variability. Since these factors are largely independent of water use restrictions, their influence during a period of water use restrictions would be similar to that observed in the absence of any restrictions.

Therefore, it can be concluded that the water use restrictions do not result in a significant decrease in water use.

Because the diurnal pattern of water use may change without any significant change to the total daily water use, an analysis of diurnal patterns of water use was completed. This analysis demonstrated that there was a discernible difference between diurnal water use patterns with and without water use restrictions. A review of the difference between diurnal water use with restrictions and without restrictions indicated that the average difference during daylight hours (6:00 am to 6:00 pm) was consistently negative, implying a net reduction in average water use during the day. The average difference during night hours (6:00 pm to 6:00 am) was consistently positive, implying a net increase in average water use over night. Most of the data show that the difference between hourly average flows during the period of flow restrictions and the period of no flow restrictions is significant at the 95 percent confidence level for a portion of the early morning when peak flows are highest, and for a portion of the late morning and/or afternoon when flows are lowest. In general, the effect of the flow restrictions was to significantly increase the morning peak flows and to significantly decrease the late morning/afternoon low flows. The normalized daily peak flows for the period of water use restrictions averaged 9 percent greater than the normalized daily peak flows without restrictions, and ranged as high as 25 percent greater than normalized daily peak flows without restrictions.

RECOMMENDATIONS

- Develop and test a preliminary time series model using Auto-Regressive-Integrated-Moving-Average (ARIMA) techniques, or equivalent stochastic approaches.

  Based on our experience in this study, it is conceivable that a stochastic approach might yield a more reliable model. One important drawback to the stochastic approach is that the uncertainty associated with any model prediction increases with the length of the forecast period. However, as stochastic approaches were beyond the scope of this investigation, the magnitude of the prediction error and the potential benefits of such an approach, were not explored. As the present regional model explains only 66 percent of the variability in observed water use, a preliminary assessment of stochastic approaches is warranted.

- Modify Water Use Restriction Policy

  Since the regional model analysis demonstrated that the present Water Use Restriction Policy provides no significant savings in terms of reduced water demand, some Policy changes are recommended. The effect of the current policy appears to be a shift in the daily demand pattern towards more use at night and less use during the day. This tends to increase the early morning peak flow demand without reducing total water use. Other restriction programs, such as odd/even days, could be explored for their effectiveness.

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