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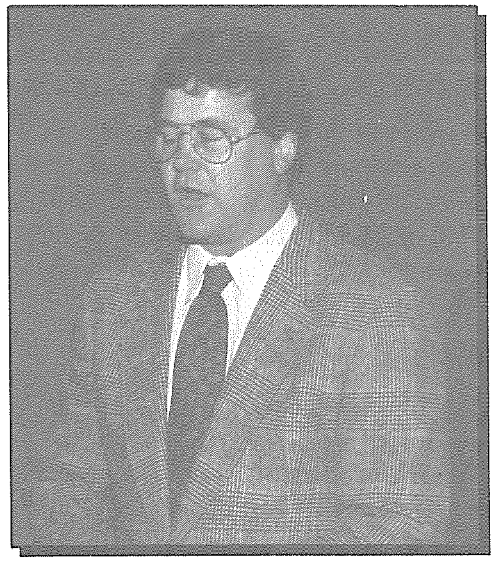

ESTIMATING RESIDENTIAL WATER DEMAND IN URBAN AREAS OF NEW MEXICO

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BACKGROUND

A major concern for the water-short western U.S. is appropriate conservation policies for urban water use. An obstacle in analysis of such policies has been the statistical and theoretical problems of estimating demand when water users face a variable price structure, such as increasing block rates. A further problem is limited data. More specifically, to properly estimate demand, it is necessary to have the percentage (number) of water users in each rate block, the distribution of users by rate classes (DURC). Our research has focused on estimating DURC to fill this data void. Our contention is that DURC can be estimated from aggregate revenue, consumption and price data that are generally available from the utilities. The model developed here asks the question, "What distribution of water users in rate classes best explains observed revenues collected by the utility?" Using optimization techniques, the model estimates the DURC that best predicts historical revenues.

The model has been used to predict revenues and water consumption in the cities of Las Cruces, Farmington, Albuquerque, and Santa Fe, New Mexico. Results have been extremely positive in that the model has predicted revenues and quantity of consumption with 97% correlation or accuracy. Ultimately, the results of this research will indicate the potential effectiveness of water conservation policies in reducing residential demand on regional water supplies.

MODEL

The model currently under construction is based on theory proposed by Robert Moffitt in an article titled *The Econometrics of Kinked Budget Constraints* (1990). Consider a demand function of the form

$$Q_i = f(P_i, M_i)$$

where i refers to the *ith* individual and Q_i is quantity demanded by the *ith* individual; P_i is marginal price faced by the *ith* individual; and M_i is income of the *ith* individual. The difficulty is that estimation of such a function requires an assumption about the direction of causality in water usage. In economic theory, it is assumed that individuals respond to the price of a commodity as a given and choose the appropriate quantity to consume. Faced with multiple rate classes, a consumer must choose both quantity and the corresponding price. The result is that causality runs from Q (the dependent variable) to price and income, the opposite of Equation 1. Traditional estimation techniques such as regression applied to this situation result in biased estimates of the demand coefficients. On the other hand, by estimating users' expenditure levels the direction of causality is left intact. Prices and income determine the amount the consumer wishes to expend on water usage as indicated in Equation 2,

$$Exp = r(P, M)$$

The difficulty here is that expenditures is a nonlinear function of consumption times the price rates. In addition, there is still the issue of how consumers are distributed among rate classes. To address these issues, a nonlinear simulation model of consumer water expenditures was developed. The theoretical basis for this model is briefly described below.

Moffitt suggests that water users are distributed among rate classes based on the concept of multiple consumer equilibrium and a random distribution of preferences. For simplicity, assume that there are two rate classes with an increasing price structure. The time frame is a billing cycle, usually one month. A consumer's demand is within the first rate class if at the first price, his/her consumption is within the first block,

$$Q_1 = \beta_1 + \beta_2 P_1 + \beta_3 M + \beta_4 T + \beta_5 R + v \text{ and } 0 \leq Q_1 \leq B_1$$

where the β_1 (betas) are estimated coefficients associated with consumer demand; Q_1 is quantity demanded if in first block; P_1 is marginal price on the 1st segment; M_i is adjusted income on the 1st block; T is monthly temperature; and R is monthly rainfall. The limit of the first block is designated by B_1. The key factor on whether a water user consumes within the first block is the level of preference represented by the stochastic variable, v. Moffitt assumes that consumer preferences are normally distributed with a zero mean and some positive variance, σ, (sigma). With this distribution, a percentage of the total population will fall in the first rate block, label this number of users, λ_1. Expenditures for the first block of water users would be

$$Rev_1 = P_1 Q'_1 \lambda_1$$

where Q'_1 is the average consumption of those users within the first block.

For some users, their strength of preferences will take them to the limit of the first block, but not into the second block because of the higher marginal price. These water users will be concentrated at the limit of the first block, known as a kink. Revenue collected from users at the kink would be

$$Rev_2 = P_1 B_1 \lambda_2$$

Finally, a certain group of users will have strong enough preferences that results in consumption in the second block. This block is open ended, thus consumption is limited by traditional pricing and income. Revenue from this group of users is

$$Rev_3 = P_2 Q'_2 \lambda_3$$

For simplicity, successive blocks and kinks are referred to as segments. Predicted revenue (*rev_prd*) is the sum of revenues from all segments. For example, a two-block price structure would have three segments, a four-block price structure would have seven segments. The optimization procedure selects values of betas and sigma (in this model, 6 variables) in order to minimize the following objective function:

$$Min_{\beta_1 \ldots \beta_n} \sum_{i=1}^{n} (Rev\_prd_i - Rev\_act_i)^2$$

where *rev_act* is actual revenues collected by the utility and *n* is time frame of available data. The objective function is an accuracy function and is similar in purpose to the objective function implicit in ordinary regression.

PRELIMINARY ANALYSIS

Model Results for Santa Fe, New Mexico

The optimization model was used to analyze the period from April 1985 through March 1993 for the Santa Fe Water Utility. The utility charged users based on an inclining rate structure, with two blocks; Block 1, 0-5000 gallons; Block 2, over 5,000 gallons. The model generated estimates the percentage of users, mean consumption and revenue for the three segments of the rate structure.

TABLE 1. WATER CONSUMPTION RESULTS FOR SANTA FE, NEW MEXICO

	0-5,000 gal. (Block 1)	5,000 gal. (Kink)	>5,000 gal. (Block 2)
Percent of users	5.1	79.4	15.5
Mean consumption	2,400	5,000	16,700
Revenue	$6,376	$205,560	$161,890

The column labeled 5,000 gallons shows estimates for those users consuming at or near the kink. Presently, revenue and quantity estimates are predicting with 83 percent accuracy. Figure 1 illustrates the accuracy of the model prediction for revenue. Figure 2 illustrates the accuracy of the optimization model for predicting water consumption. As is apparent from both figures the model is excellent in obtaining seasonal trends, but has some difficulty with low levels of consumption during winter months.

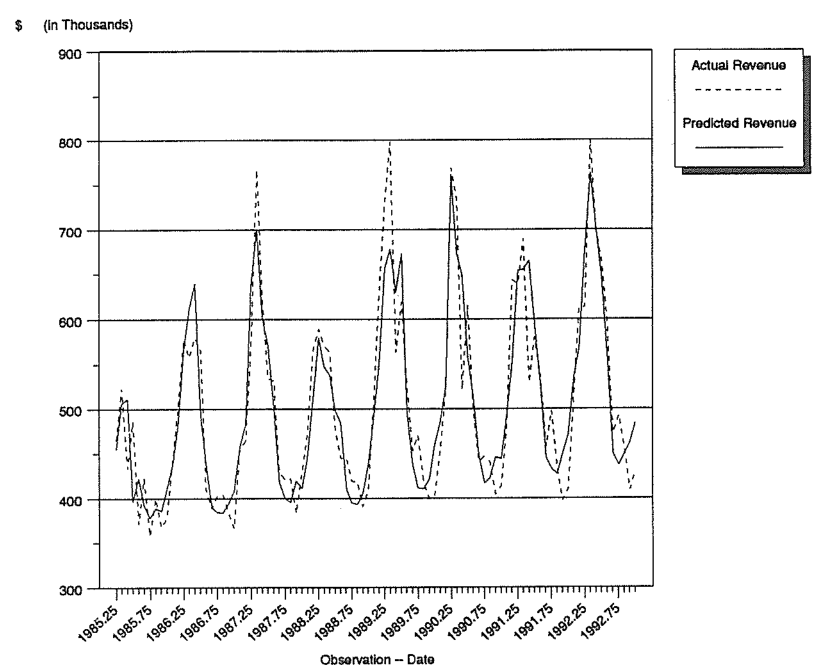

Figure 1. Predicted revenues versus actual revenues for the City of Santa Fe.

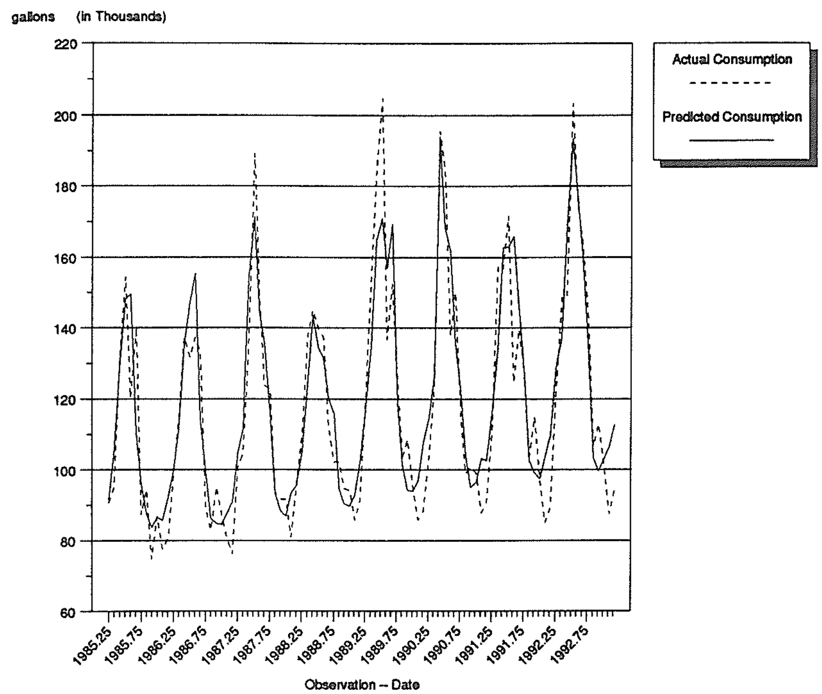

Figure 2. Predicted consumption versus actual consumption for the City of Santa Fe.

MODEL RESULTS FOR LAS CRUCES, NEW MEXICO

The optimization model also was used to analyze the period from July 1987 through May 1993 for the Las Cruces Municipal Water Utility. The utility charged users based on an inclining rate structure, with four blocks. Similar results were generated and given in Table 2, divided into seven segments. Rate block limits are measured in thousand gallons. Figures 3 and 4 indicate accuracy of the model in predicting pattern historical revenues and consumption.

COMBINED DATA BASE

The model also was parameterized using the combined data base of Las Cruces, Farmington and Santa Fe. Results of this parameterization were extremely good. The model has a 95 percent correlation coefficient predicting revenues and a 91 percent correlation coefficient predicting quantity of consumptions. Figure 5 indicates predicted versus actual revenue for the three cities. Figure 6 indicates predicted versus actual quantities.

TABLE 2. MODEL RESULTS FOR LAS CRUCES, NEW MEXICO

	Water Segments (000 gallons)						
	0-5	5	5-10	10	10-50	50	>50
Percent of users	0.4	0.9	1.4	46.9	48.9	1.5	0
Mean consumption	2,970	5,000	7,890	10,000	22,180	50,000	0
Revenue	$77	$312	$759	$34,124	$128,860	$8,799	0

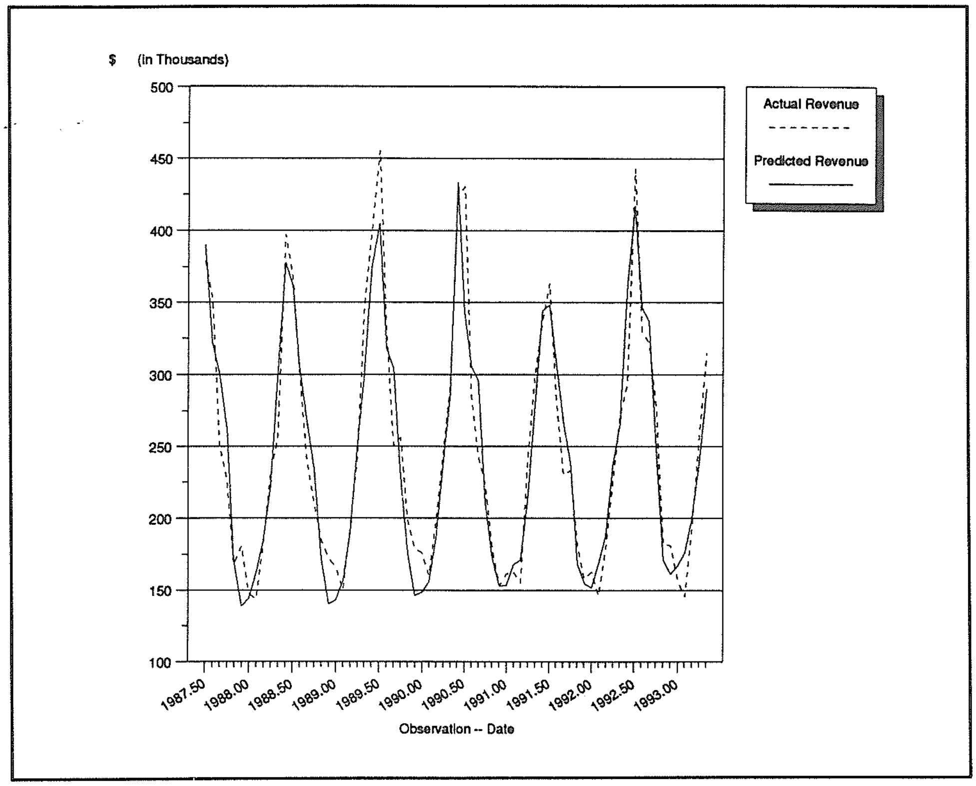

Figure 3. Predicted revenues versus actual revenues for the City of Las Cruces.

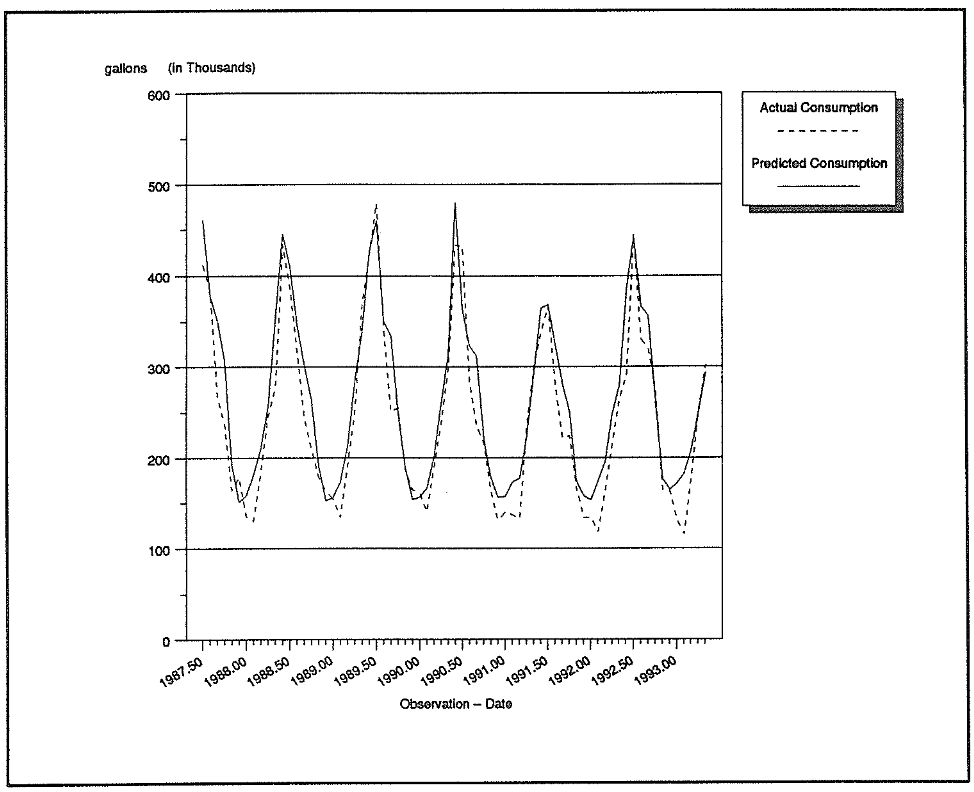

Figure 4. Predicted consumption versus actual consumption for the City of Las Cruces.

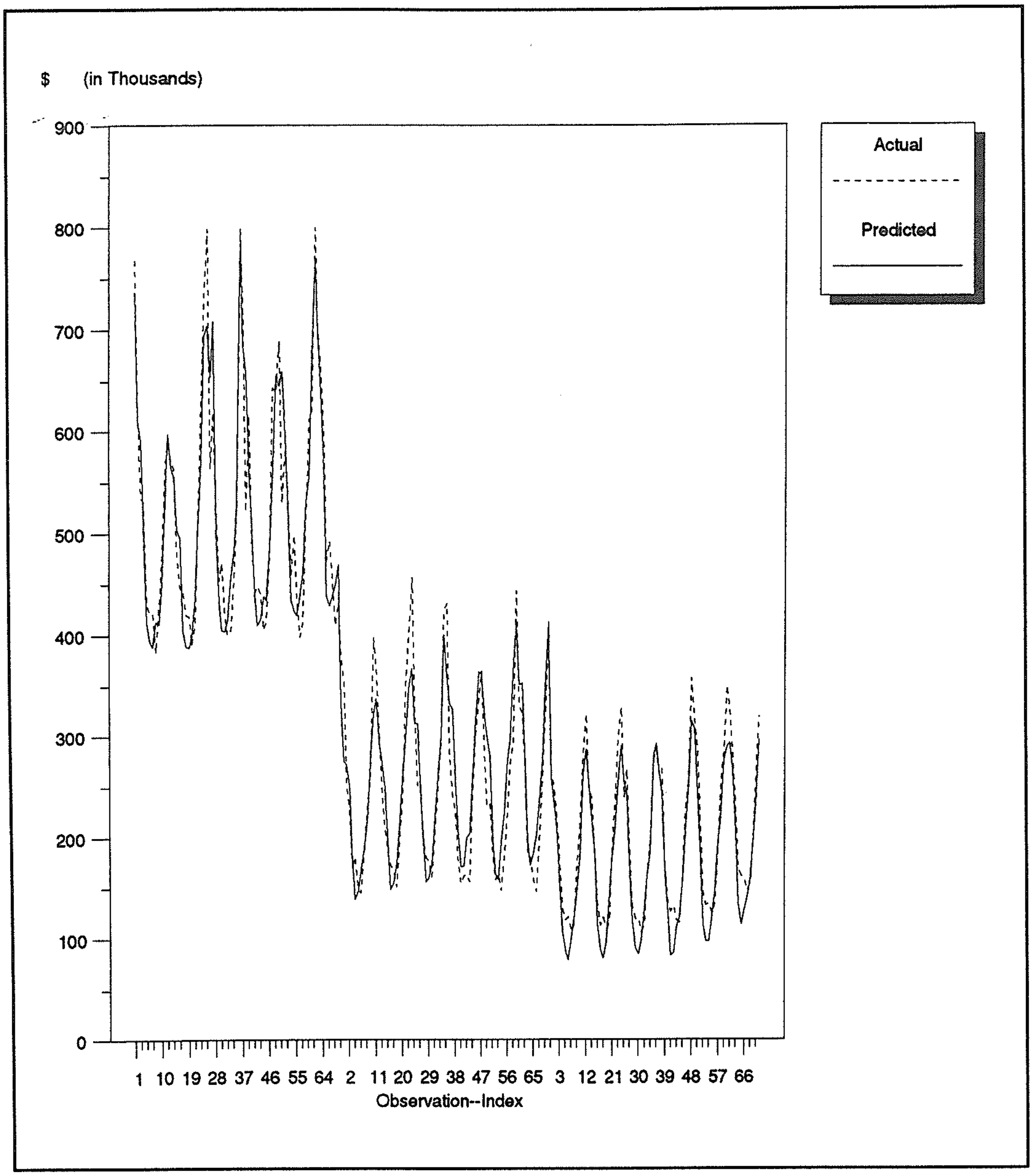

Figure 5. Actual revenues versus predicted revenues for the cities of Santa Fe, Las Cruces and Farmington.

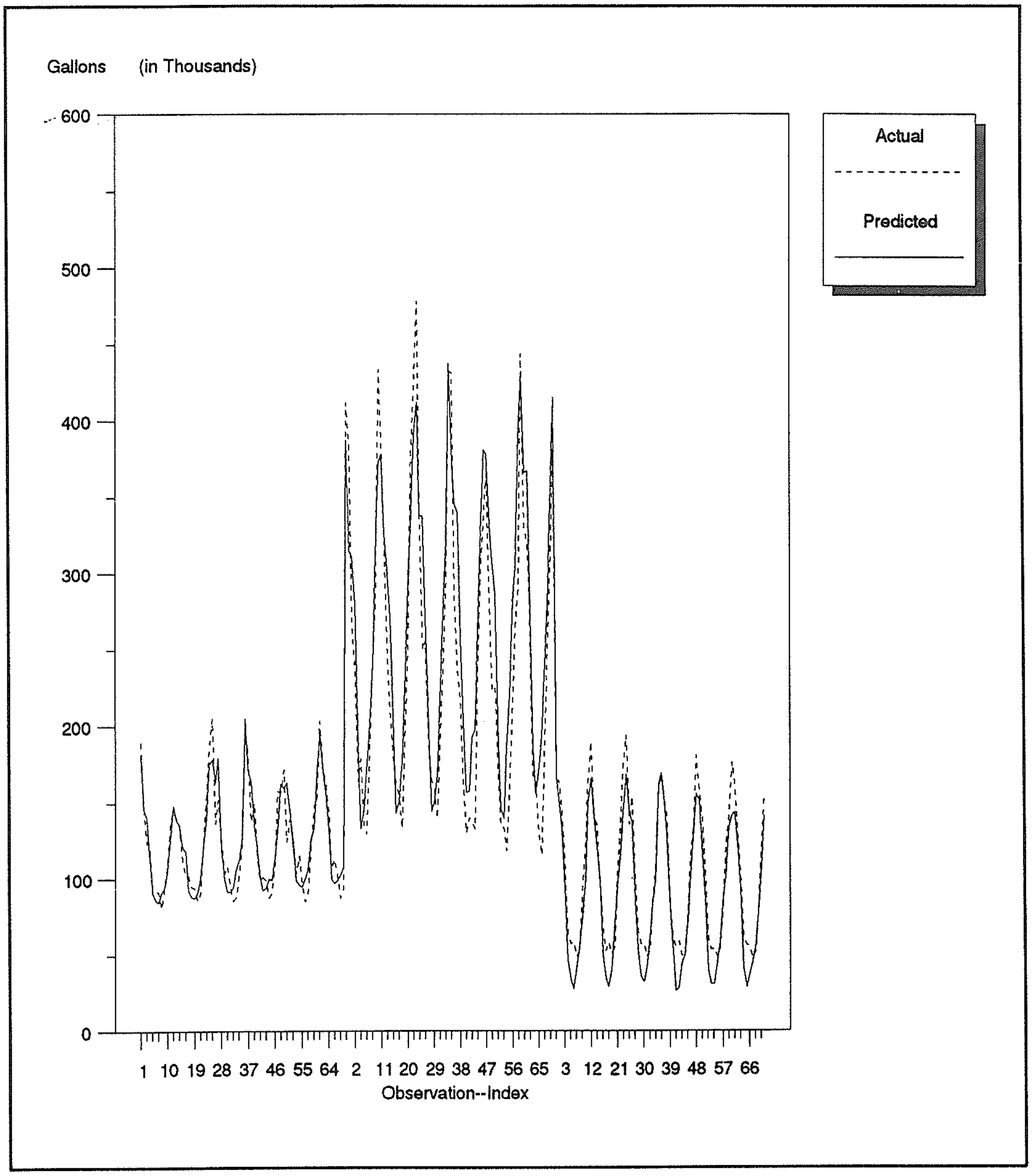

Figure 6. Actual versus predicted consumption for the cities of Santa Fe, Las Cruces and Farmington.

SUMMARY

The model developed here asks the question, "What distribution of water users in rate classes best explains observed revenues collected by the utility?" Using optimization techniques, the model estimates user characteristics that best predict historical revenues. The model has been used to predict revenues and water consumption in the cities of Las Cruces, Farmington, and Santa Fe, New Mexico. Results have been extremely positive in that the model has predicted revenues and quantity of consumption with 90 percent correlation or accuracy.

REFERENCES

Moffitt, R. 1990. The econometrics of the Kinked Budget Constraint. *Review of Economic Statistics and Business*. 27:11-32.