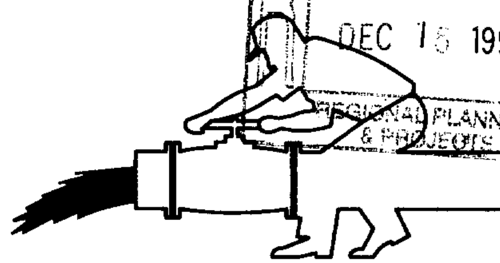

Valuing and Managing Water Supply Reliability

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Executive Summary

As a consequence of the simultaneous growth in water demand and water development costs, continued reliance on development as the primary water management strategy is increasingly irrational. Clearly, as the physical limits of the Texas water supply are approached, dollars become less effective in their ability to expand the usable water supply. In response, water resource professionals and Texas leaders are recognizing the need for more innovative responses to water scarcity.

One available approach is to work with, rather than against, the aridity of drought periods. Instead of emphasizing the creation of infrastructure and supply systems that fully insulate mankind from climate-imposed water deficiencies, it is possible to designate some measure of water supply *shortfall* as "efficient" for municipal water systems. That is, in an era of high water development costs it may not be sensible to expend large sums to maintain idealistic water supply levels during dry periods. Perfect water supply reliability, meaning no chance of future shortfall, cannot be generally regarded as optimal. To rationally design such a strategy requires an assessment of consumer preferences pertaining to the *reliability* of their water supplies. Furthermore, we must examine the tradeoffs between consumer evaluations of imperfect water supply reliability and the avoided development costs made possible by imperfect reliability.

To make progress on these issues, the research reported here has two primary objectives: to review the economic theory pertaining to optimal reliability and to obtain an indication of the value Texas households attach to the reliability of their water supply. Both objectives involve the extension of common models so that they explicitly incorporate *risk* and a probabilistically dimensioned water supply and demand.

A theory of optimal water supply reliability must acknowledge the various policy options available to water management officials. Four categories of policy control options are noteworthy. Water supply managers can work to: (1) adjust the long-run supply of water, (2) enhance the short-run supply of water during a shortfall event, (3) influence the long-run demand for water by consumers, and (4) lessen water demand during a shortfall. Rather than being viewed as substitute approaches, these options represent companions. The appropriate planning goal is to develop an efficient package of these options. This is a dynamic matter in that demand and supply parameters faced by planners are constantly changing. Water managers and policy makers must occasionally reevaluate their policy packages.

On the supply side, there are both physical and paper components of a water supply to be adjusted. While the physical components are generally well acknowledged, the various paper components (such as water rights, storage permits, contracts with other water suppliers, dry-year options) represent an increasingly important dimension of planning tools. Either physical or paper components can be modified to obtain optimal long-run water supply reliability. But supply-side tools are highly limited for short-run water supply adjustments. Only rapidly executable leases with water right holders or contracts with other water suppliers are generally practical.

Demand management tools have substantial relevance as both long- and short-term measures. Long-run policy options include plumbing codes requiring the installation of water-conserving fixtures and other water use regulations, education programs, and all dimensions of water pricing. Short-run demand tools involve contingency policies such as water use regulations, prohibitions, and pricing. Because of the relative impracticality of most supply policies during shortfall events, demand-based options have enhanced relevance.

In response to both long-run and short-run demand-oriented policies, consumers make important selections. These selections are broader than merely how much water to consume, for households choose additions/replacements of their water-using durables. The major durables of consequence are plumbing fixtures, appliances, pools, sprinklers, and lawn/landscaping. These durables are available in different sizes, models, and properties which influence water use and the ability of consumers to continue using durables during water supply shortfalls. Water use associated with a given durable is largely a fixed multiple of its operating time, so important determinants of household water use become less flexible when the household commits to the purchase/installation of each water-using durable. Long-run demand management policies influence these commitments.

Lawns and landscape plants are unique with respect to their interrelationship with water supply reliability. Lawns and landscaping are durables established for visual and aesthetic satisfaction. This satisfaction flows to residents on a continual basis that rises or falls according to the condition of the lawn/landscape. Long water supply shortfalls can depreciate or extinguish lawns and landscaping during hot weather, thereby also lowering the future net benefits to be derived from these durables. This implies that there may be instances in which consumers may attach high value to avoiding a severe, yet transitory shortfall, because they wish to avoid the loss of lawns or landscaping.

Such considerations disclose important interrelationships between water supply reliability, the value of reliability, water-using durables, and the value of these durables. When making commitments to specific durables, the rational consumer is mindful of water price and supply reliability. The average consumer likely forms expectations of future price and reliability based on recent experience and, perhaps, trends. Once a set of durables has been acquired by the household, prospective increases in reliability offer little short-run value because the durable base is fixed. On the other hand, decreased reliability constrains the satisfaction available from the accumulated durable base. Thus, consumers will have asymmetric attitudes towards increases and decreases in reliability. The change in value for an increase in reliability can be expected to be less, in absolute value, than the change in value for an equivalently measured reliability fall. This asymmetry is likely to be more pronounced in the short-run.

The theory of optimized water supply reliability remains relatively undeveloped, and what does exist owes a substantial debt to energy-focused literature. Two general versions are available. Both address the optimal tradeoff between avoided investment and avoided shortfalls. One emphasizes the optimal investment (for infrastructure) in a water supply system where shortfalls are allowed but are accompanied by consumer losses. The second treats both investment and water price as controllable in a more complex setting where, again, shortfalls cause losses. Both approaches maximize expected net benefits of community water use over a finite planning horizon. The availability of a price instrument in the second approach can allow a greater level of community net benefits to be achieved.

The empirical contributions of this research emerge from a survey of reliability value among Texas households. Over 4800 households in seven communities are surveyed by mail. The response rate was 43%. Primary features of the survey instrument are its design, the incorporation of household-specific water use and billing information, and two separate contingent valuation questions eliciting assessments for prospective changes in water supply reliability. To generate information on a range of potential changes in supply reliability, 72 distinct versions of this survey were prepared and mailed. The various versions differ in terms of reliability parameters presented to households. These parameters pertain to the strength of a shortfall (expressed as a percentage of demand that cannot be satisfied), the duration of a shortfall (measured in days – summer only), and the frequency of future shortfalls (such as one out of ten summers). Extensive examination is conducted for individual elements of survey responses as well as for the water use/bill information provided by the seven communities.

Detailed inquiries are pursued for the two contingent valuation questions. The first establishes a current, certain water supply shortfall of specified strength and duration and then queries the respondent concerning how much the respondent would be *willing to pay* to be excused from water-use restrictions enforced during the shortfall. The second, more complex question proposes a possible change in the frequency or strength of future shortfalls of a fixed duration, and then seeks to obtain a consumer valuation of this change. For the latter question, one-half of the mailed surveys involved improvements in some aspect of reliability, and willingness-to-pay assessments were sought. For the other half, some aspect of reliability was weakened, and respondents were asked to express a compensatory value (*willingness-to-accept*).

After selecting a set of consumer/community variables capable of conditioning current shortfall values, the collected current shortfall data is fitted to exogenous variables using a Logit model. Overall fit and predictive properties of the obtained model are quite satisfactory. In general, signs on the statistically estimated coefficients conform to prior expectations. Consumer willingness-to-pay to be excused from a current shortfall is most strongly related to household income and the average price of water. A second tier of factors related to willingness-to-pay is shortfall duration, shortfall strength, and whether the respondent lives at the surveyed residence.

Use of the Logit model to calculate expected willingness-to-pay produces one-time payment values ranging from $12.99 to $48.88 depending on household income and shortfall characteristics. These values represent one-time payments to avoid an immediate water supply shortfall. Some examination of these values as they vary across the seven surveyed communities is also performed in the analysis. This current shortfall valuation information is potentially useful to Texas planners contemplating costly measures to allay current shortfalls.

Separate models are estimated for the willingness-to-pay and willingness-to-accept editions of the survey future shortfall question. Each model is similarly formatted and estimated using a Tobit specification for censored data. From a statistical perspective, neither of these models performs comparably to the current shortfall model. It appears that the additional detail necessary to convey probabilistic future events to respondents introduces added "noise" for statistical models. Moreover, a much smaller amount of usable data emerges from the willingness-to-accept question, providing some testimony of the perplexing context of this query. Across both future value models, value is expressed as permanent modifications to monthly household water bills – increases for reliability enhancements and decreases for reliability declines. Both willingness-to-pay and willingness-to-accept are related to household income level and the community's average rainfall. Water supply shortfall parameters, such as duration and severity, are not found to be contributing explanatory variables for values expressed by households. Most of the remaining examined variables are also found to relate insignificantly to value, although certain variables achieve statistical significance in one of the two models.

Due to weaker performance of the future value models, the analysis cannot pursue as much resolution for the value of avoiding future shortfalls as is possible for current shortfalls. Estimated mean willingness-to-pay over all examined scenarios is $9.76/month. Depending on household income and the proportion of precipitation occurring in the summer, mean willingness-to-pay ranges from $8 to $13 per month. As expected, willingness-to-accept is larger than willingness-to-pay. Estimated mean willingness-to-accept over all examined scenarios is $13.20/month. Again, depending on income level and summer rainfall proportion, mean willingness-to-accept ranges from $8 to $16 per month. Using overall means, willingness-to-pay is approximately 25% of the respondents' mean monthly water bill, whereas willingness-to-accept is approximately 33%. While these results are suggestive of future shortfall values, there are important statistical deficiencies advising care in the extension of this information to decision making.

After completing the analyses just summarized, the report provides an example application in which a hypothetical water management issue pertaining to shortfall is economically considered. This example provides some indication of the decision-making capabilities enabled by this research and other similar research.

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The authors express their appreciation to the Texas Water Development Board and Steve Densmore for sponsoring this research. Thanks are also due to Michele Zinn for survey construction and management as well as preparing several drafts of this report. Dr. Mike Bowker provided insightful suggestions for improving the survey instrument. We especially thank the communities of Flower Mound, Huntsville, Nacogdoches, New Braunfels, San Marcos, Tyler, and Victoria – for both the able assistance of their utility personnel and for the households who took the time to participate in the survey.

I. Introduction

Opportunities for water supply expansion have become economically and environmentally exhausted in most areas of Texas. Realistically available sites for surface water development are fewer and can only be pursued at high cost. Federal water development subsidies have effectively vanished. Protection for plant and animal species potentially harmed by surface water development has never been higher, effectively raising water development costs. In addition, the exhaustibility and increased lift of ground water in much of Texas has similarly raised costs and constrained water development opportunities. While the demand for water is increasing as well, the benefits of water development must grow at a fast rate to overtake cost growth.

As a consequence of these pressures, continued reliance on water development as the primary water management strategy is increasingly irrational. This fact is growingly acknowledged by water resource managers, public leaders, and citizenry who are joining environmentalists and economists in calling for nontraditional and more innovative responses to water scarcity.

Water Supply Reliability: Focusing on Risk

An important dimension of the water scarcity problem is the management of water supply risk. The risk dimension calls to question potential policy reactions concerning drought. Water managers possess tools for both mitigating social losses under drought conditions and for affecting, through *a priori* means, the impact of drought on their water supply systems. That is, two facets of the water supply risk issue are: (1) choosing management responses for given levels of risk that are uncontrollable, at least in the short-run, and (2) the establishment of appropriate levels of risk where risk is controllable. The first facet is generally dominated by short-run policies that might compose drought management plans designed to help communities cope with limited water availability when it occurs. The second of these facets, which is the focus of this proposed study, possesses a crucial interface with water development problems. The traditional management practice for controlling water supply risk is one of avoidance, that is, to develop a sufficiently large water supply that the probability of any sizable or long-lived shortfall is small. This practice is now questionable due to the high cost of water development.

Given the cost of water development, it becomes sensible to revise the water planning paradigm, so that periodic shortfalls are professionally regarded as acceptable, even planned, events. However, in the municipal water use sector, there may to be a strong tendency to size the water supply system for severe droughts of low probability (Howe and Smith 1993). This tendency seems to occur for at least three reasons. First, municipal water has a relatively high value to its users in comparison to other sectors, and this relation may be intensified during drought. Second, water is usually supplied by a single entity that faces no competition and is legally endowed with the ability to pass all reasonable costs to consumers. Third, water supply systems are operated by people whose performance is gauged by their ability to deliver a dependable, steady, and problem-free water supply. They are not judged by their ability to deliver water which has value in excess of its costs (as typifies the private sector).

The last two of these three forces suggest municipal water managers may be overcapitalizing their water supply systems. That is, water supplies dedicated to municipal use may be too great, infrastructure expansion costs may be too large, and water rates may be too high. These consequences are magnified by the fact that water development costs have been growing rapidly in Texas.

These concerns are also relevant outside of the municipal sector. Given that the physical availability of water is limited, when municipal water users decrease the risk of water supply shortfalls, they are shifting risk to nonmunicipal sectors. Obviously, some water use(s) must incur the shortfall during drought situations. The traditional situation is that risk has been successively shifted to riparian and estuary habitat systems depended upon by many species. These systems have become the residual claimants, possessing only what is left over after man has diverted water to satisfy his wants. Recently, public policy emphasis on streamflow protection has begun to reverse this tradition. One result may be the redistribution of water supply risk back towards communities, thereby increasing the importance of appropriate urban water supply planning.

Of course, whether or not overcapitalization is present cannot be ascertained without comparing the costs and benefits of alternative levels of municipal water supply. From the municipality's perspective the costs of a more reliable water supply are equal to the costs of water development. Benefits are more difficult to assess, because they emerge from the risk preferences of actual water consumers. If water consumers are "risk neutral," water managers can appropriately approach water supply planning by targeting water demands in average climate periods. Typical consumers are not risk neutral; they are risk averse. This implies that losses to consumers in water-deficient periods are not offset by gains in water-surplus times. As a consequence of risk aversion, it is economically efficient to establish water supply infrastructure in excess of that desired for average climate periods. But what exactly are the risk preference of municipal water users? Secondary data concerning these preferences are not available. Research concerning the value of water supply reliability has only recently been performed in other areas of the U.S. Further research on these matters has been needed, especially as they relate to Texas. The provision of this information is the focus of the work reported here.

Research Overview

This research is designed to develop usable information on the value of water supply reliability to urban water consumers in Texas. This is achieved by using contingent valuation methods applied to water supply reliability valuation. Working with the Texas Water Development Board, several Texas communities were selected for in-depth examination of the value of water supply reliability. Selection criteria for these communities included community cooperation and the degree of previous experience with water supply shortfalls. Several hundred households in each of these communities were surveyed to obtain fundamental data on the demand for water and reliability. Statistical examination of this data produces the much needed information on the benefits of water supply reliability.

To place this research in perspective and to obtain insights on its proper application, the report contains a literature review and synthesis of risk-attentive models applicable to optimal public policy when water supply shortfalls are possible. Due to the relative absence of such literature for the water arena, this review relies heavily on the energy literature where such issues have received 30 years of attention.

Report Organization

The remainder of this report is separated into five primary sections. First, a synthesized theory addressing the establishment of optimal water supply reliability is presented. The second section reviews currently available empiricism where consumer evaluations of reliability have been studied. A description and rationalization of the survey research methods employed in this study are contained in the third section. The fourth section discusses summary statistics emerging from the collected survey data. Finally, the fifth section is devoted to more advanced statistical analysis of the survey data and the computation of reliability value using the obtained statistical models.

II. Theories of Optimal Reliability and Reliability Policy

Our interest in valuing reliability stems from the possibility of guiding management responses available for utility managers and public policy. The public sector possesses four general avenues for enhancing social welfare concerning the reliability of water supply. These four, which will be referred to as "control options" are:

1. establishing the long-run supply of water;
2. enhancing water supply in the short-run (during shortfalls);
3. influencing the long-run demand for water; and
4. lessening water demand in the short-run (during shortfalls).

These alternatives are interdependent in that an optimal reliability strategy would be a package incorporating elements of all four options.

Option 1 references the crucial matter of deciding upon the level of a community's water supply. This option incorporates all aspects of water production infrastructure such as reservoirs, wells, pumping plants, and ground-level and elevated storage tanks. It also pertains to the paper (permits and contracts) components of the long-run water supply, such as surface water rights, ground water rights, dry-year option contracts, reservoir storage permits, and long-term delivery contracts with other water supply authorities and districts. Though fixed at any point in time, both the physical and paper components of water supply are best viewed as dynamic items, subject to revision by the community. The community can usually drill a new well or negotiate an expanded contract, but these options are commonly viewed as long-run alternatives which are infeasible remedies for immediate shortages. Still, establishing efficient levels of water supply is a crucial aspect of planning when reliability matters.

Control option 2, the deployment of short-run measures to increase water supply during periods of shortfall is generally a weak option for the reasons just indicated. Some alternatives may exist, however, and they might be useful in certain settings. For example, it has been reported that some Corpus Christi residents paid substantial amounts for trucked wastewater to preserve their lawns when a community water supply shortfall during the 1980's motivated city leaders to restrict lawn irrigation. More recently, in 1996 water-short towns had potable water trucked in for distribution to residents, and they laid emergency pipelines to transport water over nontrivial distances. Another short-run option is to expediently execute water leases with water right holders or contract with a water purveyor for immediate supply, but these "paper" options generally require (1) a preexisting physical conduit for the water and (2) that such supplies are available at an acceptable price.

Option 3, which emphasizes policy influence over long-term water demand, potentially incorporates the full array of water conservation regulations and incentives available to the public sector. This option includes plumbing codes regarding maximum water use by newly installed fixtures (such as those recently enacted for Texas), education programs concerning conservation alternatives (e.g. xeriscape), and water pricing (i.e., rate structure). The modification of water pricing is an especially important component of this control option for several reasons and is a focus for the theory to be presented later. Here, concern for water pricing extends not merely to gallonage fees, but to other aspects of the rate structure as well. Other, especially pertinent dimensions of the rate structure concern the type of block-rate structure being used, whether any form of peak-load pricing is used, and the level of any connection charges (sometimes called tap fees). When a community relies on the proper pricing of its water supply to its customers, there is less worry about heavy water users foisting harm on other consumers because there is no social subsidy embedded in water prices. Pricing also has a permanent influence on long-run water demand (more on this later). Also, reliance on pricing as a means of allocating scarce water allows for differences among the preferences of consumers, and it frees individuals to make choices consistent with the personal benefits they receive from water use.

The fourth public control option for maximizing social welfare in the presence of water supply risk concerns the short-run management of water demand. Here, the public sector can exercise contingency policies which may or may not be part of a preconceived drought management plan. Such policies are customarily staged so that voluntary action is requested from water users during weak shortfalls, but these actions become requirements as the shortfall intensifies. It is also noteworthy that the loss of water pressure that accompanies water supply shortfalls has some ability to self-mediate the shortfall.

Economists, by virtue of their value-focused discipline, are prone to highlight price tools and economic incentives for addressing short-run shortfalls. However, commonly used short-run demand management policies rely on "quantity-guided" rather than "price-guided" instruments. For example, alternate day water restrictions, prohibitions of car washing, and meter removals are quantity guides. Economics favors price guides because such policies tend to preserve high valued uses while discouraging low value uses. For example, there are certainly people who attach high value to their lawns and gardens. Price guides allow these people to evaluate their water use practices against the prevailing economic incentive. Quantity guides eliminate this flexibility, therefore sacrificing some social net benefits in exchange for uniformity.

Fundamental Aspects of the Role of Water Price on Reliability

The water utility's selection of rate structure is important to reliability value in two key respects. Water price affects water consumption in both the short and long runs, and price also influences consumer choice among water-using durables (plumbing fixtures, appliances, pools, sprinklers, and lawn/landscaping). These durables are available in different sizes, different models, and different properties which influence water use and, very importantly, the ability of consumers to continue using durables during water supply shortfalls. Water use associated with a given durable is largely a fixed multiple of its operating time, so important determinants of household water use become less flexible when the household commits to the purchase/installation of each water-using durable. Household durables can be changed prior to obsolescence, but the expense of doing so is often nontrivial. Even with a fixed set of water-using durables, households have some discretion regarding water use, usually by modifying the operating time of their durable base. Increases in water rates do lower water consumption in the short run, but lower it still more in the long run, as consumers are able to economically rationalize and implement changes in their water-using durables (Dubin 1985; Wirl 1997).

The high cost of household water storage limits consumer options during shortfalls. The affected household must modify its water use behavior during a shortfall. Depending on shortfall severity, some household uses of water may continue unabated, but others will be curtailed on the basis of household priorities or, perhaps, community edict. Some subset of the durable base may be unusable during shortfalls, thereby lowering their net benefits to consumers. Other durables may be partially employed which lowers their net benefits as well. If households behave rationally, investment in water-using durables will be affected by the anticipated reliability of water supply during the expected lifetime of the durable as well as by anticipated water price (Wirl 1997). Increases in water price and decreases in reliability act to lower the value of water-using durables, and these changes may motivate the consumer to exclude specific durables from the household. Perhaps more importantly, these two forces motivate the consumer to select less water-intensive "models" from a given class of equipment rather than exclude the equipment entirely.

Lawns and landscape plants have some unique features with respect to their interrelationship with water supply reliability. Lawns and landscaping are durables established for the visual and aesthetic satisfaction they provide. This satisfaction "flows" to residents on a continual basis that rises or falls according to the condition of the lawn/landscape. The use of irrigation (1) steadies these flows during periods when precipitation is exceeded by evapotranspiration and (2) enables the establishment of lawns and landscape plants which could not survive the trials of local climate. The satisfaction enjoyed from lawns/landscaping can be sustained through shortfalls of short duration depending on stored soil moisture, climate, and the resiliency of the established grasses and plants. Shortfalls of intermediate length can degrade the condition of the vegetation, thereby lowering satisfaction. Longer shortfalls can depreciate or extinguish lawns and landscaping during hot and dry weather, thereby also lowering the future net benefits to be derived from these durables. This implies that there may be instances in which consumers may attach a high value to avoiding a severe, yet transitory shortfall, because they wish to avoid the loss of lawns or landscaping.

The above considerations disclose important interrelationships between water supply reliability, the value of reliability, water-using durables, and the value of these durables. These interrelationships include both dynamics and feedbacks. When making commitments to specific durables, the rational consumer is mindful of water price and reliability in the sense that the consumer has been paying utility bills. The average consumer likely forms expectations of future price and reliability based on this recent experience. At best, the informed consumer may consider trends in these variables, possibly recognizing increases in real water prices that may be occurring locally. Once a set of durables has been acquired by the household, prospective increases in reliability offer limited short-run value because the durable base is fixed. On the other hand, decreased reliability constrains the satisfaction available from the accumulated durable base. Furthermore, decreased reliability may threaten the long-term viability of established lawns and landscaping, even if the decreased reliability is transitory. For these reasons, consumers likely have asymmetric attitudes towards increases and decreases in reliability. The change in value for an increase in reliability can be expected to be less, in absolute value, than the change in value for an equivalently measured reliability fall. This asymmetry is likely to be more pronounced in the short-run where, by definition, the durable base is fixed.

Capacity Level Selection by Utilities: A Simple Approach

To date, Howe and Smith's recent research (1993; 1994) in Colorado appears to be the most significant work on water reliability economics. The central feature of the Howe and Smith research is a contingent valuation study of changes in the probability of a standard annual shortage event (SASE). They define a SASE to be a supply shortfall sufficient to cause the temporary use of a specific lawn watering restriction. A clear advantage of this approach is that the SASE offers a very tangible and known situation for residents of the study region. This survey research and its findings will be reviewed in a later section of this report.

Howe and Smith's work (1994) is accompanied by some basic theory outlining the optimal selection of water supply level. A noteworthy observation about this theory, which distinguishes it from leading theory regarding optimal energy supply reliability, is that it sets aside the potential role of price in managing excess demand.

The energy research on this subject has been understandably occupied with the collaborative role of pricing and investment for achieving an optimal response to this problem.

Two theoretical constructs can be discerned in Howe and Smith (1994). One is narrowly focused on the concept of SASE in order to identify proper use of valuation information for changes in the probability of the SASE. The second theory is broader and considers the general selection of investment for optimizing system reliability. Each of these theoretical models is developed below with some liberties taken in the interest of cohesiveness.

The narrow model posits that the probability of occurrence for the SASE in period t is a decreasing function of investment, I:

$$\text{Prob}\{\text{SASE}_t\} = P_t(I).$$

The chosen objective is to determine a level of investment that minimizes investment costs plus the expected losses due to the occurrence of the SASE. Let A(I) denote the annualized cost of investment, and let $E[L(P_t)]$ be the expected loss induced by the expected value of excess demand in period t. The expected value of L is an increasing function of P. The optimization problem is then

$$\underset{I}{\text{Min}}\left[A(I) + E[L(P_t(I))]\right].$$

This problem yields the simple first order condition

$$\frac{dA}{dI} = -\frac{dE[L]}{dI},$$

indicating that the marginal cost of investment should equal the negative of the marginal expected losses. In application, Howe and Smith do not optimize I, but they do compare changes in A and in E[L] where the changes are accomplished by sales or purchases of surface water rights.

A weak link for this theory is its myopic emphasis of a single type of shortage, the SASE. Nothing is said about the selection of investment for addressing more moderate or extreme shortage events. To obtain a more broadly applicable theory, suppose that aggregate water demand, D, is an increasing function of some short-term climate index which is called aridity, "a". Water supply, S, is a decreasing function of aridity and an increasing function of investment, I. As noted earlier, water price is omitted from the model because it is not envisioned as a control instrument. Water price is both fixed and exogenous.

When demand exceeds supply for a given aridity level in period t, the loss suffered is given by $\ell_t(D_t - S_t)$. Otherwise, the loss is zero, so

$$L_t(I, a_t) = \begin{cases} 0 & \text{if } D \le S \\ \ell_t\left(D_t(a_t) - S_t(I, a_t)\right) & \text{if } D > S. \end{cases}$$

If f_t is the probability distribution function (pdf) for the random variable a_t, then expected losses are as follows:

$$E\left[L_t(I, a_t)\right] = \int_{a_t^0}^{\infty} L_t(I, a_t) f_t(a_t) da_t$$

where a_t^o is the level of aridity for which $D_t(a_t) = S_t(I, a_t)$. In simplifying the derivation that follows, the fact that a_t^o is an implicit function of I is neglected.

Assuming that the social problem is to minimize the sum of investment costs and the expected welfare loss due to water supply shortfall, we obtain the following criterion for investment choice:

$$\underset{I}{\text{Min}}\left[I + \sum_t \int_{a_t^0}^{\infty} L_t(I, a_t) f_t(a_t) da_t \right].$$

Discounting may be added explicitly to this model or it may be viewed as implicit in the definition of L_t. After differentiating the objective function with respect to I and some minor subsequent processing, the first order equation for this problem becomes

$$1 = \sum_t \int_{a_t^0}^{\infty} \ell_t'(\ldots) \frac{\partial S_t}{\partial I} f_t(a_t) da_t.$$

The left hand side of this condition is the marginal cost of investment. The right hand side is investment's marginal benefit.

This basic theory has four informational requirements that must be met prior to application. First, an aridity variable must be constructed for which a pdf can be determined and which can be used as an argument of demand and supply functions. Second and third, D(a) and S(I, a) are needed. Finally, the loss due to shortfall function, $\ell_t(D_t - S_t)$, must be created. The later requirement has been a source of consternation for energy research in which both price and investment are perceived as control instruments.

Capacity and Price Selection for Optimizing Reliability

The introduction of price as a possible control instrument means that higher prices can be employed to moderate demand and mitigate losses during outages. [The term "outage" is prevalent in the energy literature where the focus is commonly on the complete, rather than partial, disruption of supply.] The availability of price tools can only improve social net benefits when contrasted to a situation in which only investment or capacity can be controlled. Optimal selection of both price and capacity is the major theme of a rich literature in public utility theory. In this theory, capacity is customarily viewed as a single-valued variable to be selected and locked into place for an entire planning period. Price, however, is allowed to vary. Because of the energy roots of this theory, future demand is regarded as uncertain, but supply is fully controlled. The general conclusions of this theory are, however, of considerable relevance for water management. In the model that follows, we reformulate a mainstream model of this literature. It is most indebted to Meyer (1975) and Crew and Kleindorfer (1979, chapter 5; 1978).

Model parameters are as follows:

- w_i is the amount of the commodity in question supplied in period i;
- Q is installed capacity for all periods (control variable);
- p_i is the price charged in period i (control variables);
- $\underline{p}$ is the vector of prices for all periods;
- b is the constant marginal cost of supply;
- β is the constant per unit cost of capacity;
- $D_i(p_i) + u_i$ is demand in period i with the additively separable random variable u_i;
- $S_i(p_i, Q, u_i)$ is the amount of w_i supplied in period i; it is the minimum of demand and capacity: $S_i(p_i, Q, u_i) = \min [D_i(p_i) + u_i, Q]$;
- $g_i(u_i)$ is u_i's pdf; and
- $G_i(u_i)$ is u_i's cumulative distribution function.

The adopted criterion is to maximize the expected value of the sum, across all periods, of willingness-to-pay net of supply costs. This is equivalent to maximizing the expected value of the sum of producers and consumers surplus. The problem is then

$$\underset{\underline{p},Q}{\text{Max}}\ E\left[\sum_i\left\{\int_0^{S_i(p_i,Q,u_i)} D_i^{-1}(w_i-u_i)dw_i - bS_i(p_i,Q,u_i)\right\} - bQ\right].$$

We'll obtain first order conditions after obtaining and partitioning the expected value problem:

$$E[\bullet]=\sum_i\Big\{\int g_i(u_i)\int_0^{S_i} g_i^{-1}(w_i-u_i)dw_i du_i$$

$$-b\int g_i(u_i)S_i(p_i,Q,u_i)du_i\Big\}-\beta Q.$$

The two expected value integrals in the latter expression do not yet indicate the range of u_i. The most definitive information regarding u_i is that it cannot be so negative that effective demand becomes negative:

$$D_i(p_i)+u_i \geq 0.$$

Hence, $u_i \geq -D_i(p_i)$. There are two especially relevant ranges for u_i: when u_i is small enough that effective demand is not capacity constrained, $S_i(\bullet)=D_i(p_i)+u_i$, and when u_i is sufficiently large to induce a capacity constraint, $S_i(\bullet)=Q$. Rewriting the previous $E[\bullet]$ so as to partition both expected value integrals into these two ranges of u_i:

$$E[\bullet]=\sum_i\Big\{\int_{-D_i}^{Q-D_i} g_i(u_i)\int_0^{D_i+u_i} D_i^{-1}(w_i-u_i)dw_i du_i$$

$$+\int_{Q-D_i}^{\infty} g_i(u_i)\int_0^{Q} D_i^{-1}(w_i-u_i)dw_i du_i$$

$$-b\Big\{\int_{-D_i}^{Q-D_i} g_i(u_i)\big(D_i(p_i)+u_i\big)du_i+\int_{Q-D_i}^{\infty} g_i(u_i)Q\,du_i\Big\}\Big\}$$

$$-\beta Q.$$

Setting the first partial derivative with respect to Q equal to zero for optimization, one obtains

$$\frac{\partial E[\bullet]}{\partial Q} = \sum_i\{\ 0$$

$$+\int_{Q-D_i}^{\infty} g_i(u_i)\left(D_i^{-1}(Q-u_i)\right)du_i$$

$$-b\left\{0+\int_{Q-D_i}^{\infty} g_i(u_i)du_i\right\}\Big\}$$

$$-\beta \;=\; 0.$$

Rearranging this results produces

$$\sum_i \int_{Q-D_i}^{\infty} g_i(u_i)\left(D_i^{-1}(Q-u_i)-b\right)du_i = \beta.$$

This condition says to set capacity so its expected marginal value (the left hand side) is equal to marginal costs (right hand side). The left hand side is probabilistically weighted net benefits when capacity is constraining.

Moving to first partial derivative with respect to price,

$$\frac{\partial E[\ldots]}{\partial p_i} = \int_{-D_i}^{Q-D_i} g_i(u_i)D_i' D_i^{-1}\left(D_i(p_i)\right)du_i$$

$$+\,0$$

$$-b\left\{\int_{-D_i}^{Q-D_i} g_i(u_i)D_i' du_i + 0\right\}$$

$$+\,0 = 0.$$

This implies

$$(p_i - b)(D_i')\int_{-D_i}^{Q-D_i} g_i(u_i)du_i = 0,$$

or equivalently,

$$(p_i - b)(D_i')\left(G_i(Q-D_i) - G_i(-D_i)\right) = 0.$$

Working with the last condition, the price in each period i must equal b unless demand is not price responsive $(D_i' = 0)$ or there is no chance that capacity will be adequate $\left(G_i(Q-D_i) - G(-D_i) = 0\right)$. Due to the improbability of these two events, price will normally be set at b, the marginal operating cost. This is a surprising pricing rule because it makes no contribution towards capacity costs. This seeming anomaly has garnered a lot of attention since it was first introduced by Brown and Johnson (1969).

The preceding model becomes applicable with knowledge of the D_i, the g_i, b, and β. With such information, both capacity and a price schedule can be optimally established. But the assumptive base of this model is disquieting in four noteworthy areas. First, the presumed constant marginal cost of supply, both in operating and capacity costs, constitutes a simplified case not customarily encountered. Second, certainty in supply is inappropriate for water provision, especially in the case of surface water. Third, like Howe and Smith's price-less models, the assumed criterion exhibits risk neutrality. Fourth, implicit to this model is the presumption that the supply shortfall occurring during outages is efficiently allocated even though optimal price remains at b. What policy instrument is there to guarantee that only the most valuable water users are served during shortfalls? This latter concern is similar to the unsettled specification of the loss function, $\ell_t(D_t - S_t)$, attributed to Howe and Smith's theory.

Further examination of these issues is required to render this theory a firmer foundation for empiricism. In the following sections we consider two of these topics – seeking redress for deficiencies or, minimally, some indication of their implications.

Nonconstant Costs

Two approaches have been forwarded to address the more general and realistic circumstances of nonconstant operating and capital costs. The first approach, also led by Crew and Kleindorfer (1976), extends their previous work by envisioning the availability of a "diverse technology" consisting of many different "plants." For each plant type, operating and capital costs are constant. Across plant types, cost changes are nondifferentiable. The second approach, well epitomized by Marino (1978), presumes the more general, neoclassical perspective on production costs where operating and capital costs need not be constant. In this case technology is not lumpy, and it is consistent with a differentiable cost function.

For the first approach, m plant types are indexed in order of increasing operating costs,

$$0 < b_1 < b_2 < \dots < b_m$$

which implies

$$\beta_1 < \beta_2 < \dots < \beta_m < 0.$$

If the latter set of inequalities were not met, then particular plant types would be economically dominated by others and would never be used.

The diverse technology scenario, in combination with the model presented previously, generates the following key results. As before, these results are obtained by maximizing expected welfare with respect to prices and installed capacity.

1. The optimal price in any given period should be equal to expected operating costs which, again, makes no contribution to capital costs.
2. Optimal price will be higher for periods of higher mean demand.
3. The optimal set of plants to employ in any period are "contiguous plant types arranged in order of increasing operating costs" and beginning with plant 1.

More precise results are omitted in the interest of expediency. For more specific information on optimal capacity, see Crew and Kleindorfer's equation 26 (1976, p. 216). Clearly, the noteworthy conclusion of the diverse technology model is the preservation of the optimal pricing rule in which price does not yield revenue sufficient to contribute to capital costs.

Expected Surplus vs. Option Price

Central to the construction of the above models is a social objective function maximizing the expected value of surpluses. Is it reasonable to believe that such an objective adequately captures risk aversion by water consumers? There is an important literature underscoring the need to sometimes use *option price* rather than expected surpluses when gauging projects in the presence of uncertainty (Bishop 1982; Freeman 1984). Clearly, the experienced net benefits of a given project will vary from period to period depending on exogenous state conditions such as weather. Given any specific addition to water supply, the addition's net benefits will be higher during future dry periods than in future wet periods. Thus, *expected surpluses* are computed as a probability-weighted average of net surpluses across the range of potential state conditions. This is a possibly different measure than that of option price – which is a constant (state independent) dollar amount that, if paid by consumers in every period of the project's operation, would leave consumers indifferent in their regard for pursuing or not pursuing a project. Hence, option price is a possible measure for the net benefits offered by a particular project. A theoretical rationale has been forwarded for preferring the option price measure over expected surplus sums when the situation involves a "collective" risk for similar individuals

(Graham 1981, p. 716). This is arguably the scenario for utility supply outages, because an outage or shortfall is a shared community event disliked by all.

The bias that may be introduced by using expected surplus sums rather than option price is difficult to assess, because option value, which is defined as the difference between the expected surplus and option price, cannot be theoretically signed (Graham-Tomasi and Myers 1990). That is, option value may be positive or negative depending on circumstances, making the matter an empirical question. There are, however, circumstances in which option value can be expected to be small (Freeman 1984). Because uncertainty about supply shortfall is rooted in the variability of climate rather than an uncertainty concerning economic conditions (e.g. income, price), option price may be well approximated by expected surplus (Freeman 1984). This is the presumption adopted here, because we suspect the distinction between option price and expected surplus may be slight for the matter under consideration. Indeed, whereas the theory outlined in this report is driven by expected surplus sums, the values obtained by forthcoming portions of our empirical work more closely resemble option prices.

III. Reliability Empiricism: A Literature Review

Undoubtedly, the universal tool for assessments of the reliability of some service or situation is contingent valuation. The contingent valuation technique relies on surveys (personal, telephone, or mail) inquiring about the respondents' monetary valuations of hypothetically altered circumstances. Due to its wide applicability, contingent valuation is the most important of the available nonmarket valuation techniques. As a method, it has acquired great importance in environmental and natural resource settings due to the heightened social significance of such issues and the relative absence of markets for providing valuation information.

The general difficulties associated with the contingent valuation method stem from the fact that survey respondents are being confronted by hypothetical and possibly unfamiliar circumstances by the survey instrument (Hanemann 1994). As a consequence, there is genuine concern regarding (1) strategic behavior on the part of respondents and (2) the context presented in the survey. Strategic behavior emerges because survey respondents may be aware that they can influence policy decisions via their responses without actually having to bear the costs indicated in the survey (Milon 1989). Contextual concerns arise because the information presented within the survey can influence respondents' responses in strong ways (Ajzen, Brown, and Rosenthal 1996). Thus, both of these considerations may introduce noteworthy biases, and much of the effort of contingent valuation efforts is aimed at the elimination of these biases.

In addition to the reliability theory outlined previously, there are three general literature subjects which have relevance to *empirical* research valuing the reliability of water supply: valuing health risks, valuing electricity supply reliability, and valuing water supply reliability. In this section we review some of the noteworthy published work in these areas – attempting to summarize key points and insights.

Health Risk

While they are not closely related to water supply valuation, studies in health risk valuation have been pioneering in terms of the methods used for valuing modifications to probabilistic events. By emphasizing novel applications of contingent valuation methods, which are central to all three subject areas, health risk valuations have offered important advice for the conduct of water-related research. For example, it has been observed that probabilistic risk information is difficult to communicate to respondents and that many people may have difficulty processing this information (Loomis and duVair 1993; Smith and Desvousges 1987). This literature has explored alternative graphical formats for presenting this information to respondents. While health risks generally involve very low exposure probabilities which likely compound the difficulty of communication and mental processing, research in water supply reliability should be mindful of these pitfalls. That is, the survey instrument should be designed so that it very clearly communicates the risky aspects of the contingent valuation scenarios, and these scenarios should be no more cumbersome than necessary to capture critical components of the issue.

Electricity Supply

In contrast to the many theoretical examinations of optimal energy supply reliability, empirical work addressing household valuations is rare. In fact, we were able to identify only one significant study, but this single study offers many useful insights. Hartman, Doane, and Woo (1991) have conducted an extensive contingent valuation study of electricity outages in California. Both willingness-to-pay (WTP) and willingness-to-accept (WTA) data were collected and analyzed. Electricity customers were asked for their WTP to avoid specified decreases in their service reliability. Several service reliability scenarios were examined which differed in terms of electricity rates and the consequentially expected outage frequency, duration, time of day, and time of year. Similarly, customers were asked for their WTA to be compensated for the same decreases in service reliability. It is generally expected that WTA-based assessments should exceed WTP-based assessments, because the WTA format assigns an implicit property right to the respondent – the right to the initial reliability situation. For the WTP format, this right is vested with the utility.

The Hartman, Doane, and Woo study combined the WTP/WTA data with data on household characteristics to provide the basis for an econometric regression analysis. A highlighted feature of the study stems from the fact that the survey (mailed) was applied to two service areas experiencing different levels of electricity reliability, and the survey tested WTP/WTA for the reliability properties of the other service area. While one might expect that people would tend to prefer a certain rate-reliability scenario regardless of status quo, the study found that each group preferred their current situation over that of the other group. The authors suggested the following possible explanation: "This predisposition for the status quo may result from familiarity and satisfaction with the current level of service; a belief that the utility will not be able to provide the actual level of service offered by the new rate options, habit, or inertia" (p. 154).

Water Supply

Although interest in water supply reliability appears to be increasing (Lund 1995), the work of Howe and Smith (1994) is the only significant inquiry into the value that households associate with the reliability of their water supply. Using a mailed survey in three Colorado cities, Howe and Smith ask open-ended WTP and WTA questions emphasizing modifications to the frequency of a SASE (standard annual shortage event). The open-ended format asks respondents to provide a dollar amount, whereas a close-ended format would ask for a yes/no response to a prespecified dollar amount. The SASE was defined as "a drought of sufficient severity and duration that residential outdoor water use would be restricted to three hours every third day for the months of July, August, and September" (p. 22). Howe and Smith argue that focus upon the SASE is justified because (1) it offers a practical simplification; (2) it is "meaningful to the water customer"; and (3) "outdoor residential uses are typically required to absorb initial shortages" (p. 22).

The various WTP and WTA scenarios used by Howe and Smith varied by community, because the three communities begin from different water supply situations. The baseline chances of a SASE in the three cities were determined to be 1/300, 1/10, and 1/7 (expressed in years, e.g., one year out of 300). The survey scenarios proposed two alternative decreases in reliability and two alternative increases in reliability. All scenarios examined changes relative to the baseline. Therefore, only WTP results were obtained for the proposed reliability increases, and WTA results were obtained for the proposed reliability decreases. The scenarios used in the survey did not employ the cross-area symmetry employed in the Hartman, Doane, and Woo study, so a firm testing of status quo effects was not produced.

An interesting aspect of the survey is that it described the current probability of a SASE and the respondent's "average monthly water bills for the preceding twelve months" (p. 24). The latter information was intended to provide an improved context for responding to the WTP/WTA questions. The survey was mailed to 1250 households, and a reminder postcard was mailed two weeks later. The overall response rate was 47%.

Howe and Smith's contingent evaluation analysis primarily consists of calculating mean bids, reported by city and by scenario. Depending on the city and the scenario, mean estimated WTP ranged from $4 to $8 per month and mean estimated WTA ranged from $4 to $16 per month. Howe and Smith then employ the mean WTP bids to calculate the gross benefits of a community-wide increase in water supply reliability. These benefits are then contrasted to the costs – calculated on the basis of a water right purchase. A similar procedure is employed to investigate the net benefits of decreases in reliability for each city. Only for the city experiencing very high system reliability (1/300) was any change shown to have positive net benefits. For this community, a decreased water supply reliability seemed economically warranted, because the city could sell some of its surface water rights at a value exceeding consumer-assessed reliability losses.

IV. Survey Methods

City Cooperators

One of the hypotheses to be examined in this study is: "other things being equal, households having experience with water supply shortfalls place a lower value on water supply reliability than do households without such experience." Because Texans have not had much experience with shortfalls, there may be some bias in reliability valuation if assessments are conducted using inexperienced households. It is hypothesized that experienced households may attach lower values to reliability for three general reasons. First, unfamiliarity with water supply shortfalls may support an artificially high, physiological objection to an event that is unknown. Once this unknown is removed, the consumer may have a "that wasn't so bad" reaction. Second, the learning of new water-use behaviors is likely pronounced during shortfalls. As the consumer becomes more proficient with coping strategies, the value of shortfall-created inconveniences may decline. Third, as discussed previously, if households are accustomed to a highly dependable water supply, they are more likely to have assembled a water-intensive set of water-using durables (plumbing fixtures, appliances, pools, sprinklers, and lawn/landscaping). Increasing experience with water shortfalls likely encourages consumers to hedge against the possibility of shortfall by acquiring durables having benefit flows which can be more easily sustained during periods of water supply deficit.

Based on interest in this hypothesis, we initially set about the task of identifying several cities that had some recent record of water supply shortfalls. After finding several such candidates, it was believed that each of these cities could be "paired" with a similar community – at least similar in many respects except for the water supply shortfall experience. By surveying households in each pair of cities, it was thought that the hypothesis indicated above could be better investigated.

Through consultations with various Texas Water Development Board (TWDB) personnel, a short list of eight possible "experienced" communities was identified. On their annual water use reports to the Board, these communities had reported having experienced at least one water supply shortfall in recent years. Three of the eight are in the Dallas area, so it was decided to use only one of these three even if all three wished to participate in the study. Thus, essentially six possible cooperators had been identified, and for each we identified at least four possible paired cities based on population levels and location proximity. In total, this process produced a list of 37 potential cooperators.

In February 1996, the managers/supervisors of these 37 were mailed a personalized letter soliciting their support (Appendix A). This mailing included a return postcard on which the recipient could indicate Yes, No, or that they needed more information. The letter informed utility managers of our goal to survey several hundred of their customers and why this research was needed. They were also told their cooperation would require that they provide three things: comments on a draft version of our survey; a mailing list or labels for a few hundred randomly selected households; and water consumption or meter readings for a very recent 12-month period for all selected households.

Some of the 37 communities responded rapidly. Others did not reply until March or April or did not reply in any manner. Follow-up phone conversations were necessary in some instances to firm up the participation of communities. By May, we only had commitments from 12 cities. Only four of these were from the original set of eight "experienced" communities, and three of these four were redundant in the sense that they all lay in the Dallas area. It was then decided to include all 12 cities in the study, and effort was devoted to refining a survey instrument and obtaining the required information from all participating communities.

In spite of some good intentions, some of these 12 never complied with our requirements for undisclosed reasons, and we abandoned their inclusion after numerous contacts throughout the summer. Eventually, seven cities provided the information needed to be included in the study. The primary element of this information was 1995 monthly water usage, water billings, and sewer billings for several hundred households in their customer base. Understandably, the provision of such information is not a trivial matter. Some degree of commitment and computer competence was generally necessary to satisfy our requirements. In the case of two communities, city policy or law regarding nondisclosure of utility records also made it necessary to for us to seek city council or mayor approval who then requested advice from their city attorneys. For the five communities from which this data was never received, it appeared that either the utility manager had reevaluated his level of interest or had delegated the duty to a staff member who could not or would not complete the task.

Requested information from the seven cooperators was received during June to September. In some cases it was necessary to obtain additional data or fully revised datasets from these cities before consistent information had been obtained across all communities. We are extremely grateful to those communities that managed to persevere through our many requests. Utility personnel in these cities stepped beyond their job descriptions by assisting us in this novel research. The seven communities instrumental in this research are Flower Mound, Huntsville, Nacogdoches, New Braunfels, San Marcos, Tyler, and Victoria. For both Flower Mound and San Marcos, we had earlier indications of experience with water supply shortfalls.

In some cases, city personnel in these communities went well beyond the call of duty in their participation – either through the placement of an encouraging letter in the local newspaper, shear persistence with an inflexible accounting program or city billing contractor, or bearing with residents who were disappointed about the city's decision to release this information to us.

Overall Survey Design and Procedures

Because water supply reliability is an unusual item for individuals to value, it is important to provide households with a solid basis for conducting their evaluation. Therefore, at an early stage of this research it was decided that households would be provided with individual, mailed surveys that relayed summary information about the household's own water use patterns and bills. Because water supply shortfalls generally occur during summer months, it was decided that the survey instrument should include information regarding the cyclical nature of the household's water use, if indeed such cycles exists. To accomplish these goals, monthly 1995 information was obtained for every household in the survey sample, and portions of this data were used to calculate information provided on each survey. This information could have been electronically merged into the survey instrument prior to printing, but we opted for hand writing this information into surveys to emphasize the customized nature of this information. The personalized information included:

1. address
2. total 1995 water use (gallons)
3. peak water use month
4. water use in peak month (gallons)
5. water and wastewater bill for peak month ($)
6. low water use month
7. water use in low month (gallons)
8. water and wastewater bill for low month ($)
9. total bill for 1995 water use ($)
10. total bill for 1995 wastewater service ($)
11. average monthly water and wastewater bill ($)

While this amount of information is conceivably confusing to the recipient, efforts were made to organize it sensibly.

In the survey the customized information was preceded and followed by additional contextual information regarding the importance and meaning of water supply reliability. Preceding information highlighted four "key points":

- A temporary water supply shortfall is when water supply is less than water demand. During a temporary water supply shortfall, households usually experience a drop in water pressure, NOT the loss of all water.

- A water pressure drop causes water to flow more slowly through pipes. Sinks and bathtubs take longer to fill. Water-using appliances such as washing machines take longer to operate. Outdoor sprinklers operate more slowly, and the sprinklers won't spray as far.

- Usually, water supply shortfalls occur during the summer months. Average Texas households use 40% less water in December/January than in July/August.

- During a shortfall, your community may employ voluntary or mandatory outdoor water use restrictions (such as restrictions on lawn watering or car washing) to reduce use.

After the customized household data, the survey included two short paragraphs containing basic details about why shortages tend to occur during the summer and about the important tradeoffs this creates.

> In Texas, water use and water supply change seasonally. Water demand is highest during the summer because of outdoor uses like lawn watering. This is also the season when water supply may be the lowest.
>
> Texas water utilities have traditionally designed their water supply systems to reliably provide peak summertime needs. The full capacity of these systems may be utilized only a few days a year. A portion of water supply systems costs and the rates you pay are therefore for capacity which is used only part of the year. On the other hand, this service capacity also offers Texas communities some insurance against short-term droughts and unexpected water system failures.

Accompanying the survey was a personalized letter that included very little contextual information. Instead, it emphasized the general importance of the research, and it guaranteed confidentiality. This letter is reprinted in Appendix A. Similarly, the survey booklet's cover did not include contextual information. This four-page survey, which was professionally printed on off-white paper and distributed as a booklet, is replicated in Appendix A. In its final form the survey had two alternative fourth pages because different versions of questions 8 and 9 went to different addresses. Both of these pages are included in Appendix A. The questionnaire's cover indicated sponsorship by the Texas Water Development Board, Texas A&M University, and the city or town. Also on the cover were (1) Spanish instructions for easily obtaining a Spanish language version of the survey, (2) a confidentiality reminder, and (3) a note indicating the presence of personalized information in the survey.

The survey contained ten questions designed to elicit data regarding the respondent's valuation of prospective, hypothetical changes in the community's water supply reliability as well as characteristics of the household which might be related to these valuations. These questions will be discussed in the next section. Many more questions were considered for inclusion in the survey but were rejected in the interest of constructing a brief instrument in hopes of improving the response rate.

Various drafts of the survey were circulated to the cooperating communities for comment. The Board's project officer, Steve Densmore, also reviewed multiple drafts. Although it is recommended practice for such surveys to be tested upon "focus groups" selected from target populations, time and funding considerations indicated that this would not be possible. Instead, the survey was administered to over 30 "locals", albeit without accurate water consumption/billing information for the recipient. This test population was not fairly composed because it was dominated by graduate students, but the exercise was successful in identifying some improvements.

Beginning in September 1996, a supervised team of student workers began the process of preparing surveys and mailing them. The surveys were prepared one city at a time and were mailed as soon as each city's surveys were completed. As a consequence of the individualistic nature of the surveys, this was time-consuming task and care had to be taken so that each survey was mailed to the correct household. Each mailing included a preaddressed and postage-paid return envelope. After two weeks, nonrespondents were mailed a reminder post card. After three to four additional weeks, individualized surveys were again prepared for nonrespondents and were mailed with a new cover letter and a return envelope. All of these written communications are replicated in Appendix A. Overall, 30% of the survey recipients had responded prior to remailing of the survey. The entire process was completed with the final mailing for the final city made in the middle of November, 1996.

The Survey Questions

The 10 questions of the survey included six background/explanatory questions, two contingent valuation questions, and two questions to identify protest respondents. The six explanatory questions pertained to:

1. whether the respondent or other family members occupy the residence,
2. whether the respondent rents the residence from its owner,
3. the number of people occupying the residence by age grouping,
4. whether the respondent had recent experience with water use restrictions,
5. the relative importance of three, outdoor, water-intensive activities, and
6. household income.

To generate information on a variety of potential changes in reliability parameters, 72 separate scenarios were constructed for the contingent valuation questions. That is, 72 different surveys were prepared, and these were randomly mailed for each community. In each of these 72 surveys question #5 was a closed-ended, willingness-to-pay question concerning a hypothetical increase in the community's water supply reliability. This question established an "immediate and known" water supply shortfall of X% of the community's water demand expected to have a duration of Y summer days. The respondent was then asked if he/she would pay a one-time fee of $Z to be exempt from the outdoor water use restrictions the city would impose to address this shortfall. The 36 X-Y-Z combinations employed for this question are identified in Table 1.

The remaining contingent valuation question, #8, was an open-ended, willingness-to-pay (WTP) or willingness-to-accept (WTA) question concerning a hypothetical increase or decrease in the community's water supply reliability. This question posed an initial situation in which approximately once every X years a shortfall of Y% would occur with a duration of Z days. The question then posed a potential improvement or decline in one of the X-Y-Z parameters with the others being unchanged. In the case of improvements, the respondent was asked for a maximum willingness-to-pay where this amount was to be expressed as a permanent increase in monthly water bills. In the case of reliability declines, the respondent was asked for a similarly expressed minimum willingness-to-accept. Thirty-six distinct before and after regimes were assembled for this question. They are presented in Table 2. Thus, there are 36 WTP questions and, by reversing the before and after components, 36 WTA questions. Each mailed survey contained only one of the 72 variants of question 8. Respondents therefore answered either a WTP or WTA version of question 8, but not both.

Because there are 36 different constructions for question 5 and 72 different constructions for question 8, each of the question 5 variants were employed with two of the question 8 scenarios. These assignments were made randomly.

The logic of this design is as follows. Question 8 is more definitive in that it incorporates frequency information regarding prospective supply shortfalls, and it

Table 1. The 36 Scenarios Employed in Question 5.

Shortfall Strength (%)	Shortfall Duration (days)	Proposal Fee ($)
10	14	3.00
10	14	6.00
10	14	10.00
10	14	20.00
10	21	3.00
10	21	6.00
10	21	10.00
10	21	20.00
10	28	5.00
10	28	10.00
10	28	20.00
10	28	30.00
20	14	3.00
20	14	6.00
20	14	10.00
20	14	20.00
20	21	5.00
20	21	10.00
20	21	20.00
20	21	30.00
20	28	10.00
20	28	20.00
20	28	30.00
20	28	40.00
30	14	5.00
30	14	10.00
30	14	20.00
30	14	30.00
30	21	10.00
30	21	20.00
30	21	30.00
30	21	40.00
30	28	10.00
30	28	20.00
30	28	30.00
30	28	40.00

Table 2. The 36 Scenarios Employed in Question 8 – WTP.

Initial Shortfall Frequency (Once every _ years)	Initial Shortfall Strength (%)	Shortfall Duration (days)	Subsequent Shortfall Frequency (Once every _ years)	Subsequent Shortfall Strength (%)
5	30	14	10	30
15	20	14	15	10
10	10	28	15	10
10	30	21	10	20
5	20	21	10	20
10	20	14	15	20
5	20	28	10	20
15	30	14	15	20
5	30	14	5	20
5	30	28	10	30
5	20	14	5	10
5	10	14	10	10
10	10	14	15	10
10	30	28	10	20
15	20	21	15	10
5	20	28	5	10
10	30	14	15	30
10	30	28	15	30
5	10	28	10	10
15	30	28	15	20
10	20	28	15	20
10	10	21	15	10
10	20	28	10	10
10	20	21	15	20
15	30	21	15	20
5	30	21	5	20
10	20	14	10	10
10	30	14	10	20
5	20	21	5	10
10	20	21	10	10
5	20	14	10	20
10	30	21	15	30
15	20	28	15	10
5	30	28	5	20
5	10	21	10	10
5	30	21	10	30

involves both WTP and WTA formats. It is also more definitive with its open-ended format where respondents are asked to provide a value rather than a yes or no to proposed value. But it also presents a more confusing proposition to respondents, and there is justifiable concern that this question might overwhelm people. Alternatively, question 5 poses a simpler, more comprehensible and less challenging query for surveyed households. In part, question 5 constitutes a hedge lest question 8 be too imposing for potential respondents. Moreover, the inclusion of two general question styles offers the possibility of checking the consistency of survey results. While it may be argued that a WTA version of question 5 should have also been included, we opted for using only the WTP format due to the reduced information provided by close-ended questions (thereby necessitating larger datasets to achieve a given level of explanatory power) and the fact that the normative, status quo foundation of the reliability issue is one where consumers do not possess entitlements to set reliability positions.

Paired with each of the contingent valuation questions was a question designed to ferret out protest responses. That is, responses to questions 5 and 8 are valid bases for examining reliability value unless these responses constitute psychological objections to the premises of these questions. For example, a person may reject the fee proposed in question 5 because fees are perceived as unfair, rather than because the fee is too high. These protest-identifying questions have the added benefit of gauging peoples' attitudes regarding basic principles surrounding water supply issues.

V. Descriptive Statistics

Water Use Characteristics - Community Data

Water use characteristics by respondents and nonrespondents are presented in Table 3. Details concerning definitions of this information is provided in Appendix B, Table B-1. The data used in calculating these values were obtained from city records and not the respondents. Obtaining city records rather than relying on the responses allows for a comparison between respondents and nonrespondents. Water use characteristics presented in Table 3 indicate nonrespondents on average used less water and had lower water and sewer bills than respondents. These differences are minor; for example, the respondents mean water bill is $38.08, whereas nonrespondents mean bill is $36.69. This difference of $1.39 is not statistically significant. Indeed, all differences in the water use characteristics are not statistically significant. This can readily be verified by examining the mean and standard deviation values. The mean values between respondent and nonrespondents are easily within a fraction of one standard deviation from each other. As such, the statistical test results are not presented.
Measures of dispersion, standard deviation, and range indicate a wide range of water use present in the data set. For example, mean water bill for respondents ranged from $6.00/month to $197.00/month. Nonrespondents' bills range from $3.00/month to $470.00/month. No clear pattern is evident from the summary statistics to indicate a noteworthy distinction between respondents and nonrespondents. In Tables B-2 through B-8, water use characteristics by city are presented. Generally, the comparisons concerning mean values between respondents and nonrespondents continue to hold true. One counterexample is the mean water bill for respondents and nonrespondents of Nacogdoches. In this city, nonrespondents had a somewhat higher mean water bill. The two major conclusions from these tables are: (1) there appears to be little nonrespondent bias in terms of water use characteristics, and (2) a wide range of water use is represented in the data set.

One interesting aspect presented in Table 3 and Tables B-2 through B-8 are the months associated with the highest and lowest water use. This example also

Table 3. Water Use Characteristics of Respondents and Nonrespondents for All Cities.

Variable[1]	Mean	Standard Deviation	Range		Obs
			Min	Max	
		Respondents			
Gallons	115.7255	93.0831	0.5	1549.0	2090
High Gallons	19.3800	18.4972	0.1	307.7	2090
High Month	7.5407	2.5752	1.0	12.0	2090
Low Gallons	4.3274	3.0737	0.0	24.9	2090
Low Month	5.3249	3.8110	1.0	12.0	2090
Water	271.1057	178.6803	59.0	2101.0	2090
Wastewater	190.7268	84.7852	0.0	779.0	2039
Low Bill	27.4048	12.8821	3.0	111.0	2090
High Bill	57.0163	39.6747	9.0	592.0	2090
Mean Bill	38.0842	19.2193	6.0	197.0	2090
		Nonrespondents			
Gallons	108.3870	78.8639	0.4	1122.0	2766
High Gallons	17.6321	16.1732	0.3	220.6	2766
High Month	7.3529	2.8651	1.0	12.0	2766
Low Gallons	4.3918	3.3270	0.0	45.0	2766
Low Month	5.6208	3.8784	1.0	12.0	2766
Water	255.6341	158.4259	40.0	2808.0	2766
Wastewater	188.6976	100.8854	0.0	2833.0	2708
Low Bill	27.1251	13.3854	3.0	207.0	2765
High Bill	53.6229	37.9753	5.0	901.0	2766
Mean Bill	36.6923	19.1551	3.0	470.0	2766

[1]See Table B-1 for variable definitions and units.

illustrates the caution needed when examining summary statistics. Mean highest and lowest month of water use is calculated using the month number (i.e. January=1, ... , December=12). In examining the mean lowest month one obtains May (mean month = 5). This is misleading as shown in Figures B-1 through B-4. In these figures histogram of the highest and lowest water use months for the number of residences (respondents plus nonrespondents) are plotted. These figures clearly illustrate the summer and winter use of water.

Background Summary - Survey Data

Summary statistics for survey questions are presented on a question-by-question basis. If a person responded to question 1, this response is included in the summary statistics for question 1 whether or not the person answered any other questions. Such a procedure allows all individuals who responded to be included in the summary, but also causes the number of observations to vary by question. The number of observations used in calculating the summary statistics are, therefore, included in the summary. Summary statistics as presented here do not attempt to analyze interactions among variables, and any discussion/inference from the statistics needs to be viewed in this light.

Presented in Table 4 are the survey response rates by city. The overall survey response is 43%. The response rate varies from a low of 32% for Tyler to a high of 45.8% for Nacogdoches. These percentages include all surveys returned with at least one question answered, and do not indicate usable response rates.

As shown in Table B-9, the majority of respondents either live or have family members living at the survey residence. For all cities, the percentage of respondents indicating they or family members live at the survey residence is over 90%. These percentages range from a low of 90.2% for New Braunfels to a high of 98.1% for Flower Mound. The majority of respondents indicated they do not rent the survey residence from another person or business (Table B-10). The highest percentage of respondents indicating they rent is 15.2% for Tyler, whereas, the lowest is 3.4% for Flower Mound. One might expect Flower Mound to have the higher percentage of ownership and living in the residence as it is a suburban neighborhood of the Dallas metroplex whereas the remaining cities are not suburbs of a larger city.

Table 4. Number of Surveys Mailed and Responses Received by City.

City	Number of Surveys Mailed	Responses	Percentage
San Marcos	817	343	42.0%
Victoria	735	348	47.3%
New Braunfels	847	374	44.2%
Tyler	576	184	32.0%
Flower Mound	839	380	45.3%
Huntsville	524	224	42.4%
Nacogdoches	518	237	45.8%
Total	4856	2090	43.0%

The number of people living at the survey residence ranges from none to 36 people, whereas the mean number of people living at the survey residence is 2.72 people (Table B-11). The mean number of people living at the survey residence ranges from a low of 2.33 at Huntsville to a high of 3.22 at Flower Mound. As with the other summary statistics, these differences are not statistically significant.

Nearly half (48.5%) of the respondents indicated they have experienced water use restrictions in the last five years (Table B-12). Respondents of the various cities have experienced water use restrictions differently. Ninety-three percent of the respondents from Flower Mound have experienced water use restrictions. Other cities with a high percentage of respondents experiencing water use restrictions are San Marcos (76.6%) and New Braunfels (76%). In the remaining cities experiences with water use restrictions are much lower – ranging from 4.1% for Victoria to 16.5% for Huntsville.

Presented in Tables B-13 through B-15 are responses to questions attempting to gauge respondents' opinions concerning the importance of outdoor uses of water. Respondents where asked to indicate the importance of fruit and vegetable gardening, lawn and landscaping, and car washing at home on a scale of 1 (very unimportant) to 5 (very important). Using this scale, the lawn and landscaping mean value indicates this is more important than the remaining two activities. Car washing is the least important. Again, the differences are not statistically significant across cities and/or activities. The percentage of respondents by category is, however, enlightening. Over 58% of the respondents indicated categories 1 or 2 for the importance of fruit and vegetable gardens and washing of vehicles, whereas for the lawn and landscaping over 47% indicated categories 4 or 5.

The last background question is income level of the respondents (Table B-16). Using the categories defined in this table, the mean income is 2.38, which falls between the categories $25,001 -50,000 and $50,000-75,000. Given the open-ended nature of the final highest income category, a mean income level cannot be determined. Differences between cities is more apparent with the income level question than any of the other questions. Flower Mound respondents have the highest mean income level, whereas respondents from Tyler have the lowest mean income level. Flower Mound and Tyler mean category income levels are not statistically different at the 0.05% level, but the difference is statistically significant at approximately the 0.15% level. Differences among the remaining cities are much less pronounced.

Water Valuation Summary - Survey Data

As noted earlier, on each survey, two sets of water reliability valuation questions are asked. Responses to these questions are summarized similarly to those of the previous questions, in that the summaries are based on individual questions independent of all other questions. A close-ended shortfall value is obtained from survey questions 5 and 6. Question 5 contained information concerning an immediate and certain water shortage scenario and a cost the respondent could choose to pay to avoid water use restrictions. A series of subquestions in question 6 attempts to ascertain if the response to question 5 is a protest response. Thirty-six different scenarios are presented in question 5, but only one scenario applies per respondent. Questions 8 and 9 are similar to questions 5 and 6 in construction. Question 8 is an open-ended WTP or WTA question that posed a prospective change in the probability and intensity of future shortfalls. Protest bids are determined through a set of subquestions contained in question 9. As noted earlier, seventy-two different scenarios (36 for WTP and 36 for WTA) are contained within question 8, but only one scenario is presented to each respondent.

Value of a Current Shortfall

For each of the thirty-six scenarios in the shortfall value question (question 5), the number of no, yes, and don't know responses are presented in Table B-17. For purposes of determining option value, nonprotest bids are defined to be those meeting one of the following criteria: (1) any respondent answering yes to question 5, the shortfall value question, or (2) the respondent answered no or don't know to the shortfall value question and indicated the fee was too high to justify the payment, question 6a. One hundred respondents indicated the fee was too high and also selected one of the other protest answers to question 6, 6b-6e. These respondents are considered to be nonprotest bids. In addition, twenty-seven respondents indicated they were willing to pay the fee, but also indicated a protest scenario; again these respondents are assumed to represent nonprotest respondents.

Over all 36 scenarios, 437 respondents indicated they would be willing to pay the fee, whereas 1,595 indicated they are not willing to pay the additional fee or didn't know. Of these 1,595 respondents, 171 indicated their no response or don't know was a nonprotest bid according to the criteria just described. This disproportionately large number of protest bids may be a consequence of the good being valued (water). Water is often popularly perceived as a unique good to which everyone has a right. Numerous respondents indicated in hand-written notes something to the effect that "water is a given right and should not be valued economically." This belief is somewhat evident in Tables B-18 and B-19 which give the number of respondents by scenario indicating why their bid was a protest bid. Included in these tables are the nonprotest respondents who indicated a protest feeling.

Returning to Table B-17, for all 36 scenarios, three or more respondents indicated they are willing to pay the fee. In addition, nonprotest no or don't know bids are given in all but two of the 36 scenarios. In an attempt to determine any patterns, the responses presented in Table B-17 were sorted in various fashions using shortfall, duration, and fee (not presented here). Only a weak pattern was observed in that the percentage of yes bids tends to decrease as the fee is increased.

A clear pattern is observed in the protest bids (Tables B-18 and B-19). In all but one scenario, the number of protest responses indicating "I don't think it is fair for some people to pay to avoid the restrictions" is equal to or greater than the other protest responses. The second most common protest is “I don’t think fees are appropriate for this issue”, whereas the “other” category is the third most common protest. This category inspired many hand-written comments, as noted earlier, referring to the public right to water. The issue of “mandatory water restrictions not being appropriate” is the least common protest. Although the respondents were asked to indicate the category which best described how they felt, 294 indicated more than one protest category. Listed in Table B-20 are the various combinations of possible protest bids and number of respondents indicating the combination. Combinations of “fees are inappropriate” and “it is not fair to pay to avoid the restrictions” dominate the number of multiple protest responses. Only two respondents indicated all four possible protest categories.

Willingness-to-Pay for Reliability Enhancements

Provided in Tables B-21 and B-22 are a summaries of the respondents' willingness-to-pay (WTP) to avoid a water shortfall. The summary statistics in Table B-21 are for all respondents, whereas Table B-22 is a summary of nonprotest WTP. A nonprotest bid is defined here as a respondent which indicated either (1) question 9a (the reliability improvement wouldn’t help me much) best described why a zero bid was provided or (2) did not provide an answer to question 9 (the series of protest questions). As expected, the mean WTP is higher for the nonprotest responses than for all responses. Considering only the nonprotest responses, the mean WTP over all scenarios is $8.33/month. WTP ranged from $0.00 to $100.00/month with a standard deviation of $12.79. Mean WTP is approximately 22% ($8.33/$38.08, values from Tables 3 and B-22) of respondents' mean monthly water bill which does not appear unreasonable. As with the shortfall value question, patterns associated with the different scenarios are difficult to ascertain. Ascertaining patterns is especially difficult because of the three factors (frequency, shortfall, and duration) composing the scenarios.

Summaries of reasons given for protest bids are provided in Tables B-23 and B-24. Protest responses are somewhat evenly divided between questions 9b, 9c, and 9e. Question 9b indicated the feeling that “mandatory water restrictions are not needed”, whereas question 9 c indicated “economic considerations are not appropriate" for water reliability issues. The last question (9e) is a catchall "Other" category. Hand-inserted responses associated with the other category where similar in nature to the previously discussed shortfall value reasons for protest, primarily that people have a right to water. The remaining reason (question 9c) for protest bids allowed respondents to indicate they didn't understand the question. A summary of multiple reasons for protest bids is provided in Table B-24. As shown in this table, very few respondents provided multiple reasons for protest bids.

Willingness-to-Accept for Reliability Declines

Summaries similar to the previous summaries associated with the WTP for an increase in water supply reliability are provided in Tables B-25 through B-28 for the WTA a decrease in water supply reliability. Nonprotest bids are defined similarly to the WTP nonprotest bids, indicating no answer to question 9 or indicating 9a, "the change in water supply reliability will not impact me much." As with the WTP results, mean overall scenarios WTA is higher for the nonprotest bids than when all bids are considered. Concentrating on the nonprotest bids, the mean WTA a decrease in water reliability over all scenarios is $14.00/month. The range of WTA is $0.00 to $100.00/month with a standard deviation of $13.20. Mean WTA is approximately 37% of respondents' mean monthly water bill. Again, this mean value does not seem unreasonable. Although not completely comparable, a higher WTA than WTP is expected. As with the other valuation questions, patterns are difficult to ascertain in the summarized data.

Reasons for protest bids are summarized in Tables B-27 and B-28. When compared to the WTP question, the need for voluntary restrictions is less important in the WTA protest bids. The largest number of respondents indicated, "I don't understand the question" (question 9d) as the reason for a protest bid. This result is reasonable given the unfamiliar context of the question and its unavoidably difficult language. In comparison to the WTP question, more respondents indicated multiple reasons for protest (Table B-28). No explanation is apparent for this later difference in the WTP and WTA questions. The difference may lie in peoples' experiences with paying rather than receiving dollars in response to a change in a good, but this is just speculation.

VI. Analysis

The analytical portion of this report consists of two major sections. In the first, the econometric (statistical) procedures and results are presented. These results develop three main models – one each to link respondents' current shortfall answers (question 5), WTP answers (question 8), and WTA answers (question 8) to known reliability conditions and consumer circumstances. The second major section employs these models to estimate the value of water supply reliability modifications.

Econometrics

Current Shortfall

Because of the nature of the value of a current shortfall question, a dichotomous choice model is estimated. As discussed later, these models can be viewed as a special case of a general utility maximization model. Dichotomous choice models range from parametric models, such as the logistic or probit models, to nonparametric models such as kernel estimators. For purposes of this study, the logistic model is estimated using maximum likelihood techniques (Greene 1995). Logit models have been successfully used in previous contingent valuation techniques, see for example Bowker and Stoll (1988). The logit model is

$$F[\beta'x] = \frac{e^{\beta'x}}{1+e^{\beta'x}}$$

where $F[\beta'x]$ is the cumulative density function associated with the logistic function, x is a matrix of explanatory variables, and β is a vector of associated coefficients to be estimated (Judge et al. 1980, p. 591). To use this model, the following behavioral assumption is made. Let $I_i = \beta'x$. Each individual makes a choice between saying yes to paying the fee or not paying the fee, by comparing the value of I_i to some critical value of the random index I*, which reflects the tastes, preferences, and situation of the individual. If an individual chooses paying the fee only if I_i is greater than I^*, the conditional probability of paying the fee is

$$\text{Prob(paying the fee} \mid I_i) = \text{Prob}(I^* \leq I_i) = f(\beta' x).$$

To estimate the logit function, the matrix of explanatory variables must be determined along with the dependent variable. The dependent variable takes on a value of one for respondents indicating they would pay the fee and a value of zero for respondents not willing to pay the fee. Explanatory variables used, in addition to an intercept, are:

rain	mean annual rainfall (National Climatic Data Center 1992),
summer	mean July plus August rainfall divided by the mean annual rainfall for each city,
price	is the respondent's total annual water bill divided by total water use,
fee	is the fee the respondent must pay to avoid the water use restrictions,
shortfall	is the percent shortfall the respondent's community is facing,
duration	is the number of days the shortfall will last,
inc	is the income level of the respondent (five categorical levels which correspond to the categories on the survey are used, the first level is dropped to avoid a singular matrix.),
activities	is a variable to represent the respondent's preferences toward water use activities (This variable is the sum of a linear index of the importance attached by the respondent to lawn and landscaping, fruit and vegetable gardening, and car washing),
people	total number of people living at the residence,
rent	a binary (0 - 1) variable with a one indicating the respondent rents the survey residence from another person or business,
live	a binary variable with a one indicating the respondent lives at the survey residence, and
experience	a binary variable with a one indicating the respondent has experienced water use restrictions in the past five years.

Five hundred and eight usable responses are obtained from the surveys for estimation of the logit model. To be a usable response, the respondent had to provide all information necessary to calculate the above variables and had to indicate their response was not a protest bid. A statistical summary for the variables used in the estimation is provided in Table C-1. These summaries differ from the statistical summaries presented earlier because Table C-1 is based on usable observations and not the entire sample for each question. Surveys from all cities are combined into a single data set for estimation purposes. Estimation of the logit model with dummy variables for each city indicated no statistical differences in the probabilities of paying the fee between respondents in different cities. Further, simple correlation coefficients and auxiliary regression equations were estimated. These statistics indicated multicollinearity is not a problem in the data set.

Table 5 contains estimated coefficients for the Logit model. A Chi-squared value of 161.31 is obtained for the statistical test that all coefficients are equal to zero. For this level, the null hypothesis is rejected at a p-value of 0.00, indicating the variables help to explain the probability of choosing to pay the fee to avoid water use restrictions. In general, the signs on the estimated coefficients conform to prior expectations. Variables associated with the water shortfall are: fee, shortfall, and duration. As the fee increases, respondents are less likely to pay to avoid the restrictions, but as the duration and/or shortfall increases respondents are more likely to pay to avoid the restrictions. All three coefficients associated with these variables are significant at p-values of 0.19 or less with fee being significant at the 0.00 level. As the respondent's average water price increases, the respondent is less likely to pay to avoid the restrictions. The coefficient associated with water price is significant at the 0.03 level.

Of the variables associated with the respondent's individual characteristics, income is highly significant with respondents in higher income categories generally more likely to pay the fee than respondents with lower incomes. The one exception to this observation is that the fourth income category's estimated coefficient is slightly less than the third income category's coefficient. Respondents who live at the residences are more likely to pay the fee than respondents who do not live at the residence. The remaining variables are insignificant at any reasonable levels of significance.

Table 5. Estimated Coefficients and Standard Errors Associated with the Current Shortfall Value Logit Model, 508 Observations.

Variable	Estimated Coefficient	Standard Error	p-value
Intercept	-2.124200	2.356200	0.36730
Summer	5.992200	7.337000	0.41409
Rain	0.032494	0.038176	0.39467
Price	-0.131670	0.059441	0.02675
Fee	-0.104190	0.013464	0.00000
Shortfall	0.022071	0.016847	0.19018
Duration	0.035763	0.023685	0.13107
Inc2	0.996890	0.324610	0.00213
Inc3	1.806700	0.346580	0.00000
Inc4	1.798200	0.443410	0.00005
Inc5	2.797100	0.567270	0.00000
Activities	0.012553	0.049430	0.79953
People	-0.062641	0.067944	0.35655
Rent	0.200920	0.408000	0.62240
Live	1.073500	0.729250	0.14100
Experience	0.255730	0.323020	0.42854

Presented in Table 6 is the number of observations correctly classified by the estimated logit model using a critical value $I^* = 0.5$. Over 82% of the observations are correctly classified using this critical value. If all observations are classified as willing-to-pay the fee, only 74% of the observations would be correctly classified. Of the 132 no-pay observations, 73 or 55% are correctly classified. 92% of the observations indicating they would pay the fee are correctly classified. Wald Chi-squared tests are employed to examine the significance of four different groups of independent variables. The groups are: (1) water reliability group (consisting of shortfall, fee, and duration), (2) income level (inc2, inc3, inc4, and inc5), (3) individuals' characteristics (activities, people, rent, live, experience), and (4) city characteristics (rain, percent, and price). Price is a function of both the city and the individual's

Table 6. Frequencies of Actual and Predicted Outcomes for the Current Shortfall Value Logit Model.

Actual	Predicted		Total
	Will Not Pay Fee	Will Pay Fee	
Will Not Pay Fee	73	59	132
Will Pay Fee	30	346	376
Total	103	405	508

water use, but it is classified as a city characteristic for purposes of the Wald tests. The Wald test jointly tests if all coefficients in a group are equal to zero. For the reliability and income groups, the null hypothesis all coefficients are equal to zero jointly is rejected at a p-value of 0.00, whereas, for the individual's characteristics the null hypothesis is not rejected for any α values less than 0.50. The null hypothesis for city characteristics is rejected at p-value of 0.13

Willingness-to-Pay and Willingness-to-Accept Estimation Procedures

Both the WTP and WTA open-ended questions result in a censored sample, that is "... some observations on the dependent variable corresponding to known sets of independent variables are not observed" (Judge et al. 1980, p. 609). In the WTP and WTA samples, the observable range of WTP and WTA range from zero to the highest bid, [0, B]. By design, respondents' bids had to be greater than or equal to $0.00. Use of ordinary least squares to determine the influence of various independent variables leads to bias and inconsistent estimators (Judge et al. 1980, p. 615). To overcome the estimation process, Tobit analysis is used.

The underlying Tobit model for this study is:

$$y_i^* = \beta' x_i + \varepsilon_i \qquad \varepsilon_i \sim N\left[0, \sigma^2\right]$$

$$\text{if } y_i^* \le 0\text{, then } y_i = 0\text{, and}$$

$$\text{if } y_i^* > 0\text{, then, } y_i = \beta' x_i + \varepsilon_i$$

where x_i are the independent variables for observation i, y_i is the dependent variable, β's are coefficients to be estimated, and ε_i is an error term. The observed dependent variable is, however, as given in the last two lines of the above equations. As noted earlier, the observations on the dependent variable are censored at zero. The above model is estimated using maximum likelihood techniques (Greene 1995).

Predictions from a Tobit model are not $\hat{\beta}'x_i$ as given by ordinary least squares. Instead, predictions from the Tobit model must be adjusted because of the censored dependent variables and the estimation technique. Conditional means (prediction) from the Tobit model are:

$$E[y \mid x_i] = \Phi\left(\hat{\beta}'x_i / \hat{\sigma}\right)\hat{\beta}'x_i + \hat{\sigma}\phi\left(\hat{\beta}'x_i / \hat{\sigma}\right)$$

where Φ represents the cumulative standard normal distribution function, ϕ represents the standard normal density function, $\hat{\sigma}$ is the estimated standard error for the error term, and $\hat{\beta}$ is the vector of estimated coefficients.

Independent variables used in the estimation procedure for both the WTP and WTA models are the same. These variables are defined equivalently to those used in the current shortfall logit model previously presented with the exception of new variables defining water reliability. The two new variables are:

severity	the initial severity of the water shortfall, defined as probability of shortfall occurring in any given year times percent shortfall, and
dumshort	a binary variable which equals zero if the proposed change impacts the probability of a shortfall occurring and equals one if the proposed change impacts shortfall percentage.

In addition to the change in independent variables, the dependent variables are different. Question 8 from the survey provided an open-ended question in which the respondents indicated their monthly WTP or WTA for a given water reliability change. For both the WTP and WTA questions, as previously discussed, the respondents were given an initial water reliability scenario. This scenario consisted of shortfall frequency which gave the probability of the shortfall occurring stated in terms of the how often the shortfall will be experienced, (i.e. once in every x years). In addition to shortfall frequency, the shortfall duration in days and shortfall amount in percent was also provided. For the WTP questions, either shortfall frequency or shortfall amount was altered to increase the reliability of the water supply system. Respondents were asked to provide their maximum WTP each and every month for the increase in reliability. The WTA question is similar except frequency and shortfall were altered such the water system's reliability was decreased. Respondents were asked what is the minimum they would be WTA each and every month in exchange for the reliability reduction. Duration varied between surveys, but never varied on a given survey for either the WTP or WTA questions.

A priori expectations for the impact (positive or negative) of the independent variables are similar between the WTP and WTA models. Variables hypothesized as having a positive impact on maximum WTP or minimum WTA are income, severity, duration, people, activities, live, summer, and rain, whereas, rent and experience are hypothesized to have negative impact. In the WTP and WTA models, water price is hypothesized to have a negative impact. No prior expectations are place on dumshort for either WTP or WTA.

Each survey contained the value of a current shortfall question and either the WTP or WTA question. By design the number of usable responses for the WTP and WTA questions will be less than the value of current shortfall question. Criteria similar to that use in the value of a current shortfall are used to determine usable responses. The first criteria is the respondent had to provide all necessary information to calculate the necessary independent variables. Second, the respondent had to submit a nonprotest bid. Four hundred and sixty usable observations are available for estimation of the WTP model, whereas, only 240 observations are usable from the WTA surveys. The difference between WTP and WTA usable responses may pertain to two interrelated factors. First, water is viewed as a good in which one pays for and not a good in which one receives a payment. This change in viewing a product may have caused some confusion. Second, the wording of the WTA question was more confusing than the WTP question. As with the current value of a shortfall, surveys from all cities are combined into a single data set for estimation purposes.

Of the 466 usable responses in the WTP data set, 21.4% (100/466) of the respondents indicated a WTP equal to zero. Using dollar intervals of 0-1, 1-5, 5-10, 10-15, and 15+, the percent of responses in each interval are 1.7, 22.1, 21.7, 17.8, and

15.2%. The WTA sample is less censored, with only 5.4% (13/240) of the respondents indicating a WTA equal to zero. Using the same breakdown as WTP, 0, 12.9, 25.4, 23.8, and 32.5% of the respondents lie in the dollar intervals 0-1, 1-5, 5-10, 10-15, and 15+.

Willingness-to-Pay for Reliability Enhancements

A statistical summary of the variables used in the estimation is provided in Table C-2. Because these summaries are based on the usable WTP sample, they differ slightly from summaries previously presented. Presented in Table 7 are the estimated coefficients from the WTP Tobit estimation along with summary statistics. The Wald Chi-squared test that all coefficients are jointly significantly different from zero is rejected at a p-value of 0.00.

In general, the signs and significant levels associated with the WTP model are not as intuitively pleasing as with the current value of a shortfall model. The water reliability variables are all insignificant at p-values less than 0.22. Both the severity and duration variables have signs that are opposite of expectations. *A priori*, it was felt as initial severity of a shortfall or the duration of the shortfall increased, respondents would be willing to pay larger amounts for a increase in reliability. In both cases, the estimated coefficients are negative, but insignificant at p-values less than 0.22. No expected sign was placed on dumshort. This variable indicates if respondents value a decrease in frequency or a decrease in percent shortfall differently. The insignificance of the variable indicates respondents did not value improvements in these two components differently. Jointly testing if these three coefficients equal zero gives a Chi-squared value of 1.93 which is significant at the high p-value of 0.59.

Individual income levels are significant at p-values of 0.11 or less. Jointly using the Wald test, the coefficients associated with income are significant at a p-value of 0.03. Respondents in income categories two through five (inc2 - inc5) are willing to pay more for the reliability increase than respondents in income category one (inc1 – the base which is not included in the model to avoid a singular matrix). Respondents in income category two are on average willing to pay more than those in income categories three and four, whereas, respondents in income category five are

Table 7. Estimated Coefficients and Standard Errors Associated with Willingness-to-Pay for a Reliability Increase Tobit Model, 466 Observations.

Variable	Estimated Coefficient	Standard Error	p-value
Intercept	47.823000	14.98800	0.00142
Summer	-42.507000	42.84400	0.32114
Rain	-0.751070	0.23998	0.00175
Price	-0.112660	0. 39692	0.77653
Severity	-0.526740	0.43495	0.22588
Dumshort	0.618410	1.44210	0.66805
Duration	-0.071111	0.12566	0.57146
Inc2	5.027600	2.04740	0.01407
Inc3	3.698200	2.23650	0.09822
Inc4	4.174300	2.59260	0.10738
Inc5	8.451000	2.85480	0.00307
People	1.219300	0.62313	0.05037
Activities	-0.103590	0.29914	0.72912
Rent	2.228800	2.49590	0.37186
Live	-8.275900	3.85970	0.03202
Experience	-6.179600	2.09590	0.00319
$\hat{\sigma}$	14.732000	0.56221	0.00000

on average willing to pay the most. Estimated coefficients for inc2, inc3 and inc4 are only slightly different, indicating only small differences in these income categories. Reestimation of the model with income categories two through four combined had little impact on the estimated coefficients and significant levels. As such the more general model is presented here.

Average water price, rain, and summer levels are jointly significant using the Wald test (p-value of 0.02). Individually, rain is significant at the 0.00 level, whereas, summer and price are insignificant. The coefficient associated with water price had the expected negative sign. Both summer and rain had unexpected signs. In contrast to the value of a current shortfall, individual characteristics appear to help explain

WTP bid levels. As a group, activities, rent, live, experience, and people, are significant at a p-value of 0.00. Individually, live, experience, and people are highly significant. As the number of people living at a residence increases, the respondent is willing to pay more for the reliability enhancement.

Respondents who have experienced water shortfalls in the last five years are on average willing to pay less for the reliability increase than those who have not experienced a shortfall. The signs associated with rent and live are different than prior expectations. It was expected respondents who rent and/or those who do not live at the survey residence would be willing to pay less than respondents who don't rent and/or who live at the residence. One possible explanation for this discrepancy is that the variables are not picking up the desired impact. By far the majority of respondents live at and own the survey residence. In the usable data set only 16 observations fall into don't live at the residence; mean WTP for these 16 is $14.56, whereas the mean WTP for the remaining observations is $8.25. Twelve of these observations fall into they own the residence and no family members live at the residence, but by design for a usable observation, at least one person must live at the residence. What this category is representing is not known. Reestimation of the Tobit model eliminating these 12 observations, had no impact on the signs of the estimated coefficients, but did alter the magnitude and significance. The significance of the coefficient associated with live changed from a p-value of 0.02 to 0.82, whereas, the coefficient associated with rent p-value went from 0.411 to 0.26. The estimated coefficient for live went from -8.2 to -1.8, whereas, the estimated coefficient for rent went from 2.2 to 3.0.

To test for functional form, the above Tobit model was reestimated to include quadratic and interaction terms for severity, summer, duration, and rain. The Wald Chi-squared test indicated these nonlinear terms are not jointly significant at p-values less than 0.28. Of the 10 nonlinear terms, only the interaction between severity and dumshort is individually significant at p-values less than 0.25. Inference for the remaining variables changed little with the inclusion of the nonlinear terms. These results are not tabulated.

Willingness-to-Accept for Reliability Declines

A statistical summary of the variables used in the WTA sample is provided in Table C-3. As with the value of a current shortfall and WTP samples, the statistical summaries differ slightly than previously presented because of the redefinition of the sample. Presented in Table 8 are the estimated coefficients and standard errors from the WTA Tobit estimation. The Wald Chi-squared test that all coefficients are jointly equal to zero is rejected at a p-value of 0.00.

The magnitudes and signs of the estimated coefficients differed between the WTA and WTP models. As with the WTP model, the results for the WTA model are not as intuitively pleasing as those for the current shortfall value model. Between the WTA and WTP models signs change for some of the variables (duration, activities, rent, and live), making the results more intuitively agreeable. Unfortunately, the signs on some of the income categories change which makes the results less intuitively pleasing. As with the WTP model, the coefficients associated with initial severity and duration are insignificant. The coefficient associated with dumshort is, however, significant at a p-value of 0.13. Respondents minimum mean WTA increases by approximately $2.00 for a increase in percentage shortfall over a increase in change in frequency of occurrence. The coefficient associated with severity is negative, contrary to prior expectations. As expected, as the duration of the shortfall increases, minimum WTA increases, but duration is highly insignificant. The Chi-squared test for the water reliability variables as a group significant value is 0.50, which indicates as a group these variables are insignificant at reasonable levels.

As a group, the income variables are significant at a p-value of 0.16 (chi-squared test). Individually, inc2, inc4, and inc5 are insignificant. *A priori*, it was expected the minimum WTA for respondents with higher incomes would be higher. This is the demonstrable case for respondents in income category five. For income categories two, three, and four (inc2, inc3, and inc4) minimum WTA decreases relative to the base. The coefficients associated with inc2 and inc3 are negative with the coefficient associated with inc3 larger in absolute value than the coefficient associated with inc2. For respondents in income category 4, the coefficient is negative, but it is smaller in absolute value than the coefficient for inc3.

Table 8. Estimated Coefficients and Standard Errors Associated with the Willingness-to-Accept for Reliability Declines, Tobit Model, 240 Observations.

Variable	Estimated Coefficient	Standard Error	p-value
Intercept	27.294000	15.38600	0.07606
Summer	5.972000	45.98100	0.89666
Rain	-0.642870	0.25878	0.01298
Price	-1.094400	0.65367	0.09410
Severity	-0.178000	0.81507	0.82713
Dumshort	2.175900	1.42550	0.12690
Duration	0.022238	0.12405	0.85773
Inc2	-2.502300	2.05700	0.22381
Inc3	-4.789500	2.12730	0.02436
Inc4	-2.755100	2.91580	0.34471
Inc5	0.206550	2.56180	0.93574
People	0.716200	0.55112	0.19376
Activities	0.946100	0.29956	0.00159
Rent	-0.684280	2.47310	0.78202
Live	3.082000	4.44490	0.48807
Experience	-0.881690	1.95580	0.65212
$\hat{\sigma}$	10.807000	0.51249	0.00000

City characteristics (price, summer, and rain) as a group are significant at a p-value of 0.02. Summer has the correct hypothesized sign (positive), but highly insignificant. Rain's impact is opposite to that expected, negative, and is significant at the 0.01 level. As water price increases, minimum WTA decreases. This variable is significant at a p-value of 0.09. Individual's characteristics as a group are highly significant having a Chi-squared value of 13.42 which corresponds to a significance level of 0.02. All five of these characteristics have the hypothesized sign. As the number of people living at the residence, the importance of water-using outdoor activities, or the respondent or family members lived at the residence increases, minimum WTA increases. Respondents who rent the residence have a lower on average minimum WTA. The coefficients associated with number of people residing at the residence and importance of outdoor water using activities are significant at p-values of 0.19 and 0.00. Respondents who have experienced water shortfalls in the last five years on average had a lower minimum WTA. The coefficient associated with this variable is, however, insignificant.

The WTA model was reformulated including quadratic and interaction terms for duration, severity, rain, summer, and days. These nonlinear terms as a group are significant at a p-value of 0.09. Individually, the coefficients associated with summer squared and interaction between severity and summer are significant at p-values of 0.01. The remaining eight coefficients are insignificant at levels less than 0.27%. Further, inclusion of these variables had little impact on the inference from the remaining variables.

Valuation

Reliability valuation with the above models address different issues. Survey question number 5, from which the Logit model is developed, concerns the value of a current (immediate) water supply shortfall. While the shortfall parameters presented in question 5 indicated alternative shortfall strengths and duration, the shortfall is not uncertain – it is occurring now. Thus, analysis with this model indicates the value households associate with avoiding a current shortfall.

Whereas question 5 addresses the value of a known, existing shortfall, question 8 pertains to an uncertain future shortfall. The two models developed using question 8 data address the value of changes in the risk, strength, and duration of future shortfalls. Although duration of shortfalls is not varied within question 8 of any given respondent's survey, it is varied across surveys. There are two alternative models for question 8 because roughly half of all surveys proposed a hypothetical increase in water supply reliability and the other half proposed a decrease in reliability. In both situations, the perspective is that the respondent is endowed with an implicit "right" to the current reliability situation, and that the respondent must pay for reliability enhancements or be compensated for reliability declines.

Another major difference between questions 5 and 8 is the timing of the prospective payments. In question 5, the payment is a single one-time payment, whereas, for question 8 the amount is paid or received each and every month from this time forward.

Current Shortfall Valuation

The Logit model coefficients (Table 5) indicate that the probability of a respondent answering "Yes" to a given shortfall avoidance fee may be functionally related to several variables describing the shortfall and the respondent's individual situation. Changes in any of these variables may, potentially, alter the respondent's value of avoidance. Thus, it is conceivable that current shortfall values be calculated for a dizzying array of parameter sets. It is not sensible, however, to report current shortfall values for variations in exogenous variables which are statistically insignificant in the Logit model. Although some practitioners might argue that the Logit model summarized in Table 5 should be reestimated after dropping insignificant terms, the insignificant variables may predictively contribute as a group, and even if they do not, their inclusion is unlikely to influence subsequent value estimates because levels of these exogenous variables are held fixed.

The valuation procedure is illuminated by Figure 1 which contains 2 distinct graphs of the Logit function specified by Table 5. Each of these represent Prob[Yes] (on the vertical axis) as a function of alternative fee levels (on the horizontal axis). As maintained by the Logit functional form, these graphs resemble cumulative distribution functions in that the Prob[Yes] goes to 1.0 as the fee is decreased. The two graphed functions pertain to households in the first income grouping (less than $25,000 annually) and to persons in the last income grouping (more than $100,000 annually). As expected, Prob[Yes] is higher for a given fee level in the higher income group. All Logit model exogenous variables, except fee and income, have been set at their mean levels (reported in Table C-1) for both of these graphs. Shortfall strength and duration are also established at their dataset means.

The typical approach to obtaining valuations from such models is to determine the fee amount corresponding to a Prob[Yes] = 0.5, that is, the fee level that the average respondent would find agreeable (Hanemann 1984). Here, such a fee level can be regarded as the average value households would be willing to pay to avoid a current shortfall. Under the average conditions employed to construct Figure 1, a first income class household would be willing to pay $17.19 to avoid a current shortfall, and a fifth income class household would be willing to pay $44.04 to avoid a current shortfall. These values are also illustrated in Figure 1. It is important to note that these values correspond to dataset means. For example, these values pertain not to average shortfall strengths and durations actually occurring in Texas, but to average shortfalls occurring in the dataset as a consequence of scenarios posed by the survey instrument.

The information contained in Table 9 indicates how current shortfall values change in response to the strength and duration of water supply shortfalls. All other variables, including income classes, are established at dataset means in the calculation of these values. As indicated earlier, willingness-to-pay to avoid current water supply shortfalls increases with the anticipated strength and duration of the shortfall. For the average respondent, $29.86 is the avoidance value for a three-week current shortfall of 20%. Changes in shortfall parameters affect this value as follows. Increases/decreases in shortfall duration increase/decrease this value by $2.41 per week. Increases(decreases) in shortfall strength increase(decrease) this value by $2.12 per 10%. As always, extrapolating these findings outside of data ranges, 2-4 weeks and 10-30%, is inappropriate.

Table 10 contains similar information as that just discussed, only distinguished by income class. Income classes 3 and 4 are lumped together (setting Inc3=Inc4=0.5) because of the statistical insignificance of the difference between these two income groups.

City by city values for alternative shortfall strengths and durations are collected in Table C-4. Differences in cities can be examined by separating the predicted and raw data by rainfall levels, as no two cities have the same exact rainfall. While values attached to current shortfalls do not differ much across the seven communities, the order of valuation begins with Flower Mound, where the greatest value is associated with avoiding current shortfalls, followed by Victoria, Nacogdoches, Huntsville, New Braunfels, San Marcos, and Tyler.

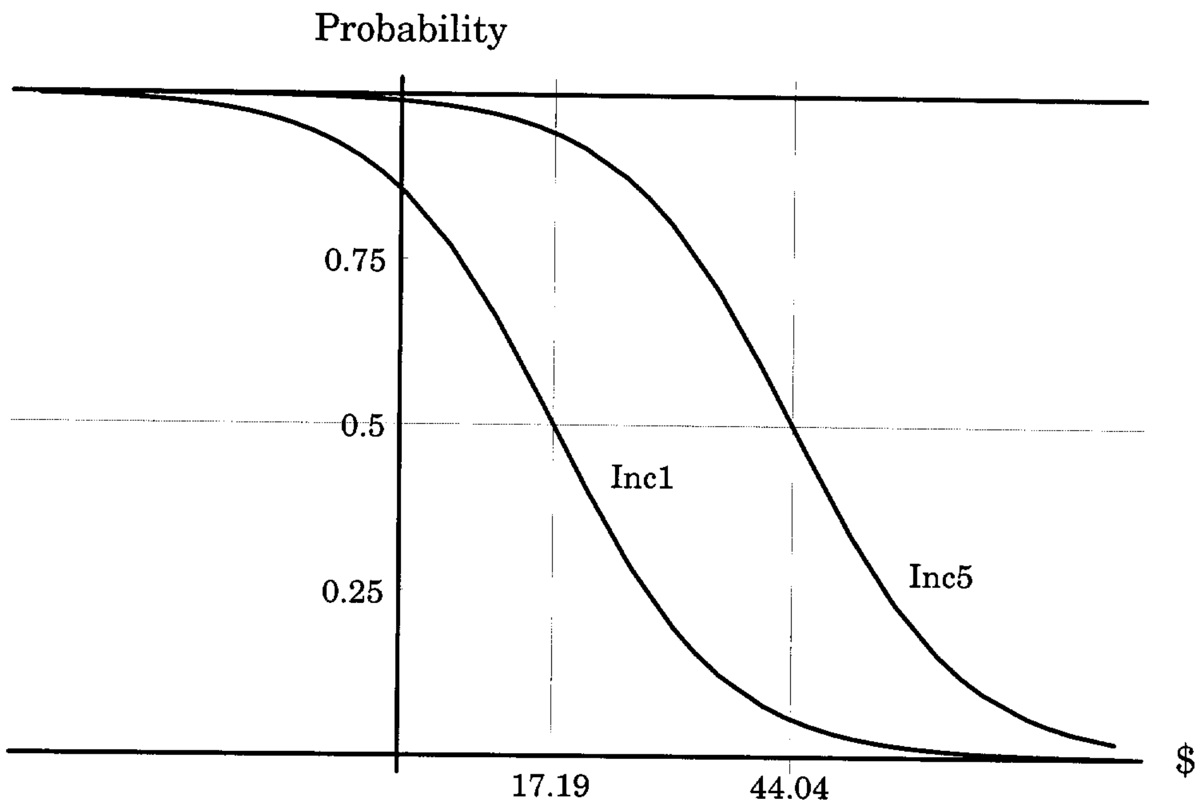

Figure 1. Logit Functions for Income Classes 1 and 5.

Table 9. Current Shortfall Values for the Average Respondent, Logit Model.

		Shortfall Duration		
		14 days	21 days	28 days
	10%	$25.34	$27.75	$30.15
Shortfall Strength	20%	$27.46	$29.86	$32.27
	30%	$29.58	$31.98	$34.39

Future Shortfall Valuations

Two measures of WTP and WTA are presented in this section. First, consistent with previous studies, WTP and WTA calculated as means from the usable samples (raw data WTP or WTA). By using Tobit analysis, the assumption is made that the sample is censored and as such is biased. The second calculated WTP and WTA measures presented are means of the in-sample predicted values from the Tobit models using the conditional means equation presented in the estimation procedures section (predicted WTP and WTA).

Presented in Table 11 are the WTP and WTA for the entire usable sample. Mean raw data monthly WTP is $8.47, whereas, the estimated WTP is $9.76. These WTP measures constitute 22.2% and 25.6% of the respondents' mean monthly water bills. WTP ranges from $0.00 to $100.00 for the raw data and $2.77 to $28.41 for the predicted values. As expected, both the predicted and raw data WTA are larger than the WTP mean values. Mean WTA are $12.66 and $13.20 for the raw data and predicted values. These mean WTA's are 32.4% and 33.8% of mean monthly water bills. It is interesting to note that both the raw data and predicted ranges for WTA are smaller than the ranges for WTP. WTP and WTA means and ranges by income category are presented in Tables 12 and 13. As expected, the largest WTP and WTA for both the predicted values and raw data are associated with the over $100,000 income bracket. WTP and WTA means and ranges by city are presented in Tables C-5 and C-6. In examining Table C-5, a distinct pattern of mean WTP and WTA is

Table 10. Current Shortfall Values by Income Class, Logit Model.

For Income Class 1: less than $25,000

		Shortfall Duration		
		14 days	21 days	28 days
	10%	$12.99	$15.40	$17.80
Shortfall Strength	20%	$15.11	$17.51	$19.92
	30%	$17.23	$19.63	$22.04

For Income Class 2: between $25,000 and $50,000

		Shortfall Duration		
		14 days	21 days	28 days
	10%	$22.56	$24.96	$27.37
Shortfall Strength	20%	$24.68	$27.08	$29.48
	30%	$26.80	$29.20	$31.60

For Income Classes 3 and 4: between $50,000 and $100,000*

		Shortfall Duration		
		14 days	21 days	28 days
	10%	$30.29	$32.70	$35.10
Shortfall Strength	20%	$32.41	$34.81	$37.22
	30%	$34.53	$36.93	$39.33

For Income Class 5: greater than $100,000

		Shortfall Duration		
		14 days	21 days	28 days
	10%	$39.84	$42.24	$44.64
Shortfall Strength	20%	$41.96	$44.36	$47.76
	30%	$44.08	$46.48	$48.88

*Obtained using Inc3 = Inc4 = 0.5

evident. The three cities with the highest rainfall levels, Tyler, Nacogdoches, and Huntsville, have the smallest WTP and WTA mean values. These cities are also located in eastern Texas. One discrepancy between the predicted values and raw data is illustrated in the Flower Mound WTP mean values. Mean WTP for Flower Mound using the raw data is $7.38/month which is lower than for the cities of New Braunfels, San Marcos, and Victoria. The predicted WTP is $10.86, which is higher than the predicted WTP for New Braunfels, San Marcos, and Victoria.

While not fully comparable, it was expected that the value obtained for a current shortfall would exceed that of future shortfalls. Reasons include the known nature of a current shortfall as opposed to a probabilistic future shortfall and the one-time payment for avoiding a current shortfall as opposed to a repeated monthly payment for future shortfalls. Overall, the mean maximum WTP and mean minimum WTA values are reasonable – constituting approximately 25-33% of respondents' water bills.

An Illustrative Application

Water managers have many means of addressing water supply reliability. As summarized early in this report, some of these tools are supply-oriented, others are designed to affect water demand. Results from this research can help to weigh management decisions that alter water supply for purposes of modifying reliability. Two management issues are potentially aided by this research. In the first, a community is currently involved in a water supply shortfall, but it can adopt a costly measure to alleviate the shortage. Possible measures may include trucked water, immediate infrastructure, water right leases, or a contractual agreement with another water purveyor. At issue is whether the benefits of such measures exceed the costs. In the second situation, water is not currently in shortage, but management is contemplating supply modifications intended solely to alter the probability/extent of future shortfalls. Examples include new wells, new or expanded reservoirs, dry-year options, and water right purchases. Such modifications can also be costly, and the issue is again whether any supply changes are economically warranted. In the paragraphs that follow, a demonstrative example of the first decision type is constructed to illustrate the manner in which such a decision can

Table 11. Summary Statistics on Willingness-to-Pay to and Willingness-to-Accept Using All Observations in Dollars/Month.

	Raw Data				Predicted			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
WTP	8.47	12.90	0.00	100.00	9.76	2.90	2.77	28.41
WTA	12.66	11.12	0.00	60.00	13.20	3.53	2.20	24.19

Table 12. Summary Statistics on Willingness-to-Pay by Income Category in Dollars/Month.

	Raw Data WTP				Predicted WTP			
Income	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Under $25,000	6.74	10.40	0.00	40.00	7.52	2.55	2.77	17.78
$25,000-50,000	9.69	17.26	0.00	100.00	10.40	2.94	4.59	28.41
$50,000-75,000	7.50	9.63	0.00	55.00	9.66	1.89	4.90	14.91
$75,000-100,000	7.83	9.46	0.00	50.00	10.06	2.43	3.35	16.90
Over $100,000	11.91	12.25	0.00	50.00	12.88	2.27	7.60	18.21

Table 13. Summary Statistics on Willingness-to-Accept by Income Category in Dollars/Month.

	Raw Data WTA				Predicted WTA			
Income	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Under $25,000	13.94	12.59	0.00	60.00	14.00	4.03	2.20	24.19
$25,000-50,000	11.94	10.58	0.00	40.00	12.64	2.93	5.25	17.37
$50,000-75,000	10.35	8.27	0.00	40.00	11.35	3.23	3.74	19.00
$75,000-100,000	13.32	11.22	0.00	40.00	13.71	2.42	9.90	18.85
Over $100,000	15.86	13.43	4.00	47.00	16.24	2.24	12.84	21.66

be assisted. Because of the statistical weakness of our research findings regarding future shortfall values, an example application of the second decision type is not offered, so as to avoid inviting overextended use of the research results.

In this example, it is midsummer and a city depends totally on a surface water supply that is dwindling. The fact that it is dwindling is well documented, because the city's only reservoir is progressively emptying at a relatively constant rate. In a few weeks, the reservoir will be too low for the pump plant to withdraw any more water, and the outlook for ameliorating rainfall is very poor at this time of year. The local utility provides potable water for the city's 5,000 households. Suppose that the utility is aware of two ready options. In the first (option 1), emergency rules can be enacted to place every household on a 70% "ration". More specifically, for the next month, every metered connection is limited to 70% of their water use in the preceding month. This regulation is to be accompanied by fines severe enough to guarantee 100% compliance. Advertising and administering this option will add $5,000 to the utility's operating costs. This policy is believed to be capable of extending the city's water supply into September.

Option 2 is to lease 80 acre-feet of water from an upstream irrigation district. The size of this lease is tailored so that, after incurring conveyance losses consequent to bring the leased water to the local reservoir, this approach will offer a roughly equivalent approach, in units of water, to option 1. Including legal and administrative costs, suppose that the cost of this lease is $15,000.

Should option 1 or 2 be pursued? The costs of option 2 exceeds those of option 1 by $10,000. But option 2 has the benefit of not forcing water use curtailments on residents. Do the benefits of option 2 exceed its $10,000 increment to costs? Results summarized in Tables 9 and 10 can help provide the answer. For demonstrative purposes, here we simply use the average respondent values reported in Table 9, but Table 10 can be employed to calculate benefits by income classification. The final entry in the table indicates that the average household would pay more than $34 to avoid the 30%, 28-day shortfall that would be established by option 1. Thus, the benefit of option 2 over option 1 can be estimated to be $\$34 \times 5000 = \$170{,}000$. Because these benefits are well in excess of costs, option 2 is the preferred strategy.

Many similar situations involving the economic analysis of current shortfalls can be envisioned. Added specificity and complexity can be employed. Some realistic situations may pertain to the value of purposeful reductions in water supply reliability to achieve substantial cost reductions or reallocations of shortage from one locale to another.

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Appendix A: Communiqués and Survey

1. Letter to 37 Utility Managers
2. Cover Letter for Survey
3. Survey with Alternate 4th Page
4. Text of Reminder Post Card
5. Cover Letter for Remailing of Survey

Letter to 37 Utility Managers: (mailed on TWDB letterhead)

February 7, 1996

«title» «first» «last»
«street»
«city», «state» «zip»

Dear «title» «last»:

Of the thousands of water suppliers reporting public water use in Texas, this letter soliciting research participation is going to only 37. Please think about our request and offers. After doing so, please write a phone number on the enclosed card and check the appropriate box prior to mailing it.

Texas A&M University researchers and the Texas Water Development Board are jointly investigating the value of water supply reliability to residential water users in Texas. Motivation for this research is derived from the rapidly growing cost of water supply development for our Texas communities. These high costs increase the need for improved information on the water consumer's evaluation of reliability. Such information enables better decision-making, for example, by indicating the worth of reliability enhancements relative to anticipated costs.

We are currently attempting to identify 4-8 water suppliers to cooperate with us. The direct benefit of cooperation will be the availability of specialized information on the value of reliability to your particular clientele. In addition, following completion of our primary data analysis, we will provide cost-free analysis on the desirability of reliability enhancements to your system if you wish to provide cost-side information. Of course, we encourage your participation so that important information can be obtained for promoting the welfare of all Texas water consumers, not just those living in your service area.

Your assistance, should you offer it, will first enable us to randomly select as many as several hundred households from your customer base. We will mail a brief survey to each of these households. We hope to prepare a customized survey in which actual water use during the past year is summarized for each household receiving a survey. We will then ask the respondent to provide a yes or no response to a pair of questions concerning the prospective value to the household of hypothetical changes in water supply reliability. A few questions concerning socioeconomic characteristics of the household will also be included. All obtained information will be regarded as confidential and will not be presented in any matter which would compromise confidentiality.

We will be asking three things of participating water suppliers:

- comments on a draft version of our survey;
- a mailing list or labels for randomly selected households (such as selecting every 15th customer in an alphabetized or enumerated database); and
- water consumption or meter readings for a very recent 12-month period for all selected households.

[Please do not commence any of these tasks yet.]

Some assistance with these tasks is available from Texas A&M students employed to work on this project.

Please consider this proposal as an opportunity to become involved in some interesting research with the potential to provide some useful information not to be found elsewhere. We will do our best to place minimal burdens on your office and customers.

Thank you for your valuable consideration.

Sincerely,

Dr. Ronald C. Griffin
Professor
Texas A&M University
409-845-7049
409-845-7122 (FAX)

Stephen Densmore
Chief, Water Supplies Section
Texas Water Development Board
512-936-0856

Cover Letter for Survey:

Dear ______________________:

A rising concern in Texas is the growing cost of supplying water to our homes. Costs are increasing because of rapid population growth, increased commerce and industry, and rising environmental and health standards for water and wastewater treatment. The City of San Marcos is cooperating with the Texas Water Development Board and Texas A&M University to examine the *value* that San Marcos households place on the *reliability* of their water supply system.

We need input of Texans like yourself. Please give us a few minutes to answer the 10 questions on the attached questionnaire. Your name, address, and all identifying information will be held confidential by Texas A&M University. None of your responses will be linked to you in the performance or reporting of our analysis, and all analysis is being conducted solely at Texas A&M University.

The survey contains information on actual water use in a residence for which you received water billings last year. You may find this information interesting and useful. Before answering any questions, please take the time to carefully read the residence and Texas situation summaries.

If you would like a copy of the survey results or have any questions, please feel free to contact me at 409-845-2333. Thank you for your time in helping us examine this very important issue facing Texas communities.

Sincerely,

Dr. Ronald C. Griffin
Texas A&M University

Assessing the Value of Water Supply Reliability to Texas Communities

A Collaborative Effort of

The Texas Water Development Board

and

Texas A&M University

in cooperation with

The City of Victoria

❒ Si usted desea recibir este cuestionario en español, favor indicarlo en la cajita que esté a la izquierda. Favor de NO contestar ninguna de las preguntas en el cuestionario y regresarnoslo en el sobre adjunto. Dentro de una semana, recibirá la encuesta en español.

Strict confidentiality will be maintained for all responses.

When you turn the page, you will find information about your water use and bills for the past year. This background information should help you in answering the questions that follow.

Water Supply Reliability and YOU

The two situation summaries on this page provide important background information. When reading these situations, please keep the following ***key points*** in mind.

- A temporary water supply shortfall is when water supply is less than water demand. During a temporary water supply shortfall, households usually experience a drop in water pressure, NOT the loss of all water.
- A water pressure drop causes water to flow more slowly through pipes. Sinks and bathtubs take longer to fill. Water-using appliances such as washing machines take longer to operate. Outdoor sprinklers operate more slowly, and the sprinklers won't spray as far.
- Usually, water supply shortfalls occur during the summer months. Average Texas households use 40% less water in December/January than in July/August.
- During a shortfall, your community may employ voluntary or mandatory outdoor water use restrictions (such as restrictions on lawn watering or car washing) to reduce use.

Your Situation at ______________________ (the Survey Residence)

During 1995, your total water use was __________ gallons. Your highest metered water use was __________ gallons in ____________. Your smallest metered water use was for __________ gallons in ____________ .

Also, during 1995, this residence was billed $ __________ for water use and $ __________ for wastewater (sewer) service. Both of these $ amounts are partially based on your metered water use. For your lowest water-use month in 1995, the water and wastewater bill was $ __________, and the highest combined bill was $ _________ . Your average bill is $ __________ per month.

Current Texas Situation

In Texas, water use and water supply change seasonally. Water demand is highest during the summer because of outdoor uses like lawn watering. This is also the season when water supply may be the lowest.

Texas water utilities have traditionally designed their water supply systems to reliably provide peak summertime needs. The full capacity of these systems may be utilized only a few days a year. A portion of water supply systems costs and the rates you pay are therefore for capacity which is used only part of the year. On the other hand, this service capacity also offers Texas communities some insurance against short-term droughts and unexpected water system failures.

Please answer the following 10 questions

1. Do you or other family members live at the Survey Residence?

❐ **Yes** ❐ **No**

2. Do you rent the Survey Residence from another person or business?

❐ **Yes** ❐ **No**

3. **How many people live at the Survey Residence most of the year?**

- ____ **persons under 18 (enter number of persons)**
- ____ **persons 18 to 64 (enter number of persons)**
- ____ **persons over 65 (enter number of persons)**
- ☐ **None (check the box)**
- ☐ **Don't know (check the box)**

4. **In the past 5 years, can you recall experiencing any water use restrictions anywhere you were residing?**

☐ **Yes** ☐ **No**

For questions 5 and 6 only, consider the following possible situation.

> Suppose that a community in which you live is facing an immediate and known shortfall of 10% that is expected to last for the next 14 *summer* days. This means that water supply is 10% less than demand. To correct this shortfall, the community is planning to restrict outdoor water use until the problem has passed. The Survey Residence can get a one-time exception from these water-use restrictions if you pay a one-time fee of $10.00 .

5. **Would you pay this one-time fee for this one-time exemption at the Survey Residence?**

☐ **Yes** ☐ **No** ☐ **Don't Know**

6. **If you answered the previous question with a <u>No or Don't Know</u>, please check the reason best describing why you felt this way:**

- ☐ **The proposed fee is too high for me to justify the payment.**
- ☐ **I don't think mandatory water restrictions are needed.**
- ☐ **I don't think fees are appropriate for this issue.**
- ☐ **I don't think it is fair for some people to pay to avoid the restrictions.**
- ☐ **Other, please specify** ____

____

---

7. **How important are the following activities to you at the Survey Residence during the summer months? Check one box to complete each statement.**

	very unimportant		just OK		very important
a. **Fruit or vegetable gardening is:**	☐	☐	☐	☐	☐
b. **Green lawn and landscaping is:**	☐	☐	☐	☐	☐
c. **Washing vehicles at home is:**	☐	☐	☐	☐	☐

(Turn to the next page)

For questions 8 and 9 only, consider the following possible current and future situations.

<u>Current</u>: For your community, suppose that water demand will exceed supply once every 10 years. This shortfall will have an average length of 14 days. Typically, water restrictions will be used in the years of shortfall to decrease demand 20% as needed to manage this shortfall.

<u>Future</u>: Suppose that your community is considering an expansion of its water supply system to improve reliability. Subsequently, water demand will exceed supply once every 15 years. This shortfall will have an average length of 14 days. Typically, water restrictions will be used in times of shortfall to decrease demand 20% as needed to manage this shortfall.

To Summarize:

	Current	Future	
Shortfall Frequency is once every	10	15	years.
Shortfall Length will average	14	14	days.
Shortfall Amount is	20	20	% of the city's demand.

Please consider the next questions carefully.

8. What is the largest increase in your average water bill of $______ per month that you would be willing to pay *each and every month* to obtain this reliability improvement *at the Survey Residence*?

$ ___ per month

9. If you answered the previous question with a $ 0 (zero), please check the reason best describing why you felt this way:

- ❒ **The reliability improvement wouldn't help me much.**
- ❒ **I don't think voluntary or mandatory water restrictions are needed.**
- ❒ **I don't think economic considerations are appropriate for this issue.**
- ❒ **I don't understand the question.**
- ❒ **Other, please specify** ____

The following question is necessary to examine the influence of income on reliability value.

10. What is your approximate annual *household* income before income taxes?

- ❒ **Under $25,000**
- ❒ **$25,000 - $50,000**
- ❒ **$50,000 - $75,000**
- ❒ **$75,000 - $100,000**
- ❒ **over $100,000**

Thank you for your valuable time and assistance.
Please fold the completed survey and mail using the envelope provided.

For questions 8 and 9 only, consider the following possible current and future situations.

Current: For your community, suppose that water demand will exceed supply once every 10 years. This shortfall will have an average length of 14 days. Typically, water restrictions will be used in times of shortfall to decrease demand 10% as needed to manage this shortfall.

Future: Suppose that your community is considering some cost cutting that will result in some loss of water supply system reliability. Subsequently, water demand will exceed supply once every 5 years. This shortfall will have an average length of 14 days. Typically, water restrictions will be used in the years of shortfall to decrease demand 10% as needed to manage this shortfall.

To Summarize:

	Current	Future	
Shortfall Frequency is once every	10	5	years.
Shortfall Length will average	14	14	days.
Shortfall Amount is	10	10	% of the city's demand.

Please consider the next questions carefully.

8. **What reduction in your average water bill of $______ per month is the *minimum* you would be willing to accept *each and every month* in exchange for this reliability reduction *at the Survey Residence*?**

   $ ___ per month

9. **Please check the reason below which most influenced your answer to the previous question:**

   - ☐ **My answer is about right for the added inconvenience.**
   - ☐ **Reductions in water supply reliability are unacceptable.**
   - ☐ **I don't think voluntary or mandatory water restrictions are needed.**
   - ☐ **I don't think economic considerations are appropriate for this issue.**
   - ☐ **I don't understand the question.**
   - ☐ **Other, please specify** ____

The following question is necessary to examine the influence of income on reliability value.

10. **What is your approximate annual *household* income before income taxes?**

    - ☐ **Under $25,000**
    - ☐ **$25,000 - $50,000**
    - ☐ **$50,000 - $75,000**
    - ☐ **$75,000 - $100,000**
    - ☐ **over $100,000**

Thank you for your valuable time and assistance.
Please fold the completed survey and mail using the envelope provided.

Text of Reminder Post Card:

I hope that you recently received the Texas Water Reliability Study survey in the mail. If you have already completed and returned this survey, thank you for your help. If not, please take the time to complete and mail the survey. Your opinions concerning this issue are important.

If you did not receive the survey or have misplaced it, please contact my office at 409-845-2333 to receive another copy. If you have any questions or concerns, please call. Thanks in advance for your help with this important issue.

Sincerely,

Ronald C. Griffin
Texas A&M University
409-845-2333

Cover Letter for Remailing of Survey:

Dear ________________________ :

A short while ago you received a short inquiry concerning the value that you attach to the *reliability* of your water supply system. Because widespread input is important to this research, we are again asking for your response to the enclosed survey.

All information you provide will be held confidential by us at Texas A&M University.

The survey contains information on actual water use in a residence for which you received water billings last year. Before answering the 10 questions, please take the time to carefully read the residence and Texas situation summaries.

If you would like a copy of the survey results or have any questions, please feel free to contact me at 409-845-2333. Thank you for your time in helping us examine this very important issue facing Texas communities.

Sincerely,

Dr. Ronald C. Griffin
Texas A&M University

Appendix B: Descriptive Statistics – Supporting Tables and Figures

Table B-1. Variable Definitions for Water Use Characteristics.

Variable	Units	Definition
Gallons	1000 gallons	Total water used in 1995.
High month	-	Month with the highest water usage, in units of January = 1, February = 2,... December = 12.
Low gallons	gallons	Lowest monthly water used in 1995.
Low month	-	Month with the lowest water usage, January = 1, February = 2,... December = 12.
Water	dollars	Total water bill for 1995.
Sewer	dollars	Total wastewater for 1995.
Low bill	dollars	Lowest monthly water bill in 1995.
High bill	dollars	Highest monthly water bill in 1995.
Mean bill	dollars	Average monthly water bill for 1995.

Table B-2. Water Use Characteristics of Respondents and Nonrespondents for Flower Mound.

Variable	Mean	Standard Deviation	Range Min	Range Max	Obs
		Respondents			
Gallons	130.2447	69.5874	18.60	534.26	380
High Gallons	22.0148	14.6984	2.52	108.03	380
High Month	7.6658	2.0678	1.00	12.00	380
Low Gallons	4.6409	2.4532	0.12	14.75	380
Low Month	6.3316	4.4645	1.00	12.00	380
Water	412.4553	167.4825	177.00	1408.00	380
Wastewater	238.1246	81.4526	119.00	774.00	329
Low Bill	37.5974	12.4734	15.00	100.00	380
High Bill	79.6211	42.6779	16.00	351.00	380
Mean Bill	51.5500	18.7441	15.00	142.00	380
		Nonrespondents			
Gallons	125.9112	70.2712	11.24	710.96	459
High Gallons	20.9741	14.9189	2.30	126.89	459
High Month	7.7320	2.2487	1.00	12.00	459
Low Gallons	4.4780	2.4953	0.02	21.35	459
Low Month	6.6623	4.439	1.00	12.00	459
Water	401.1111	169.6483	177.00	1931.00	459
Wastewater	242.4938	93.7039	119.00	930.00	401
Low Bill	37.7298	13.2154	15.00	133.00	459
High Bill	77.0523	42.9416	15.00	395.00	459
Mean Bill	51.0915	19.3780	15.00	193.00	459

[1]See Table B-1 for variable definitions and units.

Table B-3. Water Use Characteristics of Respondents and Nonrespondents for Huntsville.

Variable	Mean	Standard Deviation	Range Min	Range Max	Obs
		Respondents			
Gallons	96.4192	59.2236	1.6	357.3	224
High Gallons	14.8277	10.1763	0.8	61.5	224
High Month	7.5446	2.4582	1.0	12.0	224
Low Gallons	3.7719	2.4198	0.0	14.2	224
Low Month	5.1071	3.3142	1.0	12.0	224
Water	245.1607	106.7250	128.0	763.0	224
Wastewater	171.7321	69.7158	0.0	269.0	224
Low Bill	24.0357	7.5334	11.0	62.0	224
High Bill	50.0268	22.3781	13.0	138.0	224
Mean Bill	34.7455	12.9657	11.0	86.0	224
		Nonrespondents			
Gallons	90.955	56.5182	1.6	335.4	300
High Gallons	15.111	13.7386	0.3	151.3	300
High Month	7.1767	2.8529	1.0	12.0	300
Low Gallons	3.7880	2.4800	0.0	11.6	300
Low Month	5.3267	3.6493	1.0	12.0	300
Water	234.0600	99.9513	128.0	667.0	300
Wastewater	161.0300	76.2226	0.0	269.0	300
Low Bill	23.7033	7.2777	11.0	51.0	300
High Bill	49.4467	26.8628	11.0	278.0	300
Mean Bill	32.9500	12.3158	11.0	77.0	300

[1]See Table B-1 for variable definitions and units.

Table B-4. Water Use Characteristics of Respondents and Nonrespondents for Nacogdoches.

Variable	Mean	Standard Deviation	Range Min	Range Max	Obs
		Respondents			
Gallons	83.5325	63.5854	11.8	435.7	237
High Gallons	15.7224	23.0901	1.8	307.7	237
High Month	7.5274	2.5136	1.0	12.0	237
Low Gallons	3.1958	2.8064	0.0	15.5	237
Low Month	5.6414	3.3965	1.0	12.0	237
Water	190.4008	116.3675	59.0	835.0	237
Wastewater	96.8228	55.7083	15.0	290.0	237
Low Bill	12.9958	8.7273	3.0	51.0	237
High Bill	46.6456	46.5622	9.0	592.0	237
Mean Bill	23.8819	14.0089	6.0	94.0	237
		Nonrespondents			
Gallons	87.7986	81.7235	1.1	801.0	281
High Gallons	16.4701	22.7347	0.7	216.7	281
High Month	7.0391	3.0229	1.0	12.0	281
Low Gallons	3.2352	3.5843	0.0	31.4	281
Low Month	6.0569	3.6180	1.0	12.0	281
Water	198.1601	149.5498	40.0	1503.0	281
Wastewater	98.6050	60.5040	1.0	305.0	281
Low Bill	13.0320	10.3979	3.0	86.0	281
High Bill	47.9644	46.5047	5.0	425.0	281
Mean Bill	24.7046	16.9828	3.0	151.0	281

[1]See Table B-1 for variable definitions and units.

Table B-5. Water Use Characteristics of Respondents and Nonrespondents for New Braunfels.

Variable	Mean	Standard Deviation	Range Min	Max	Obs
		Respondents			
Gallons	115.1420	83.4163	0.5	554.3	374
High Gallons	19.6075	15.8678	0.1	95.8	374
High Month	7.8021	2.1294	1.0	12.0	374
Low Gallons	4.3283	2.9618	0.0	17.4	374
Low Month	4.8262	3.9635	1.0	12.0	374
Water	219.8743	99.2492	90.0	1042.0	374
Wastewater	185.4893	82.7461	0.0	371.0	374
Low Bill	27.5615	8.7138	3.0	57.0	374
High Bill	45.1524	20.3890	15.0	172.0	374
Mean Bill	33.7620	11.9087	9.0	87.0	374
		Nonrespondents			
Gallons	114.0459	89.2815	0.4	912.2	473
High Gallons	18.5679	17.8616	0.4	220.6	473
High Month	7.6850	2.4304	1.0	12.0	473
Low Gallons	4.7351	3.5224	0.0	21.6	473
Low Month	4.9746	3.8581	1.0	12.0	473
Water	217.5793	101.1476	90.0	1061.0	473
Wastewater	194.0 063	85.1966	0.0	371.0	473
Low Bill	28.4640	9.4228	3.0	61.0	473
High Bill	44.5391	21.9742	12.0	258.0	473
Mean Bill	34.3044	12.5396	10.0	110.0	473

[1]See Table B-1 for variable definitions and units.

Table B-6. Water Use Characteristics of Respondents and Nonrespondents for San Marcos.

Variable[1]	Mean	Standard Deviation	Range Min	Range Max	Obs
		Respondents			
Gallons	122.8455	96.6835	7.3	752.7	343
High Gallons	20.6933	19.4625	1.1	148.3	343
High Month	7.6880	2.3481	1.0	12.0	343
Low Gallons	4.8971	3.6478	0.0	24.9	343
Low Month	5.0466	3.8454	1.0	12.0	343
Water	290.8571	222.3646	90.0	1935.0	343
Wastewater	233.6327	71.1372	102.0	625.0	343
Low Bill	28.1837	12.6564	14.0	82.0	343
High Bill	70.2857	51.6722	15.0	413.0	343
Mean Bill	43.6968	22.4007	16.0	197.0	343
		Nonrespondents			
Gallons	113.2945	82.0204	5.4	1122.0	474
High Gallons	17.3489	14.8741	0.7	187.2	474
High Month	7.4325	2.8188	1.0	12.0	474
Low Gallons	5.0930	3.7989	0.0	45.0	474
Low Month	5.7911	4.1193	1.0	12.0	474
Water	266.1181	185.2128	90.0	2808.0	474
Wastewater	240.2595	135.4040	102.0	2833.0	474
Low Bill	29.8819	14.3915	14.0	207.0	474
High Bill	62.5295	51.9422	15.0	901.0	474
Mean Bill	42.1962	25.3387	16.0	470.0	474

[1]See Table B-1 for variable definitions and units.

Table B-7. Water Use Characteristics of Respondents and Nonrespondents for Tyler.

Variable	Mean	Standard Deviation	Range Min	Range Max	Obs
		Respondents			
Gallons	136.7880	149.8151	6.0	1549.0	184
High Gallons	22.6359	26.2995	1.0	264.0	184
High Month	7.7065	3.8977	1.0	12.0	184
Low Gallons	4.5000	3.6380	0.0	21.0	184
Low Month	6.1902	3.0067	1.0	12.0	184
Water	267.3967	216.8206	72.0	2101.0	184
Wastewater	136.4402	35.9539	0.0	179.0	184
Low Bill	19.5489	9.1429	6.0	56.0	184
High Bill	52.9511	36.0054	12.0	357.0	184
Mean Bill	33.6630	19.9936	11.0	190.0	184
		Nonrespondents			
Gallons	107.1327	75.2398	4.0	596.0	392
High Gallons	16.8163	13.5794	1.0	102.0	392
High Month	7.1939	3.7680	1.0	12.0	392
Low Gallons	4.3750	3.1840	0.0	18.0	392
Low Month	5.9745	3.1855	1.0	12.0	392
Water	223.5842	126.4451	72.0	929.0	392
Wastewater	134.1531	34.5639	0.0	179.0	392
Low Bill	19.5383	8.2368	6.0	51.0	392
High Bill	45.0204	21.4904	8.0	151.0	392
Mean Bill	29.7832	12.8778	7.0	92.0	392

[1]See Table B-1 for variable definitions and units.

Table B-8. Water Use Characteristics of Respondents and Nonrespondents for Victoria.

Variable	Mean	Standard Deviation	Range Min	Range Max	Obs.
		Respondents			
Gallons	116.6954	108.9649	10.0	1062.0	348
High Gallons	18.6638	18.6521	1.0	160.0	348
High Month	6.8966	2.8650	1.0	12.0	348
Low Gallons	4.4598	3.1816	0.0	21.0	348
Low Month	4.5029	3.4503	1.0	12.0	348
Water	225.9741	169.9858	113.0	1630.0	348
Wastewater	214.1379	73.0606	140.0	779.0	348
Low Bill	31.4741	12.0162	21.0	111.0	348
High Bill	45.7155	28.3072	21.0	271.0	348
Mean Bill	36.6523	18.2603	21.0	188.0	348
		Nonrespondents			
Gallons	104.4083	81.561	13.0	680.0	387
High Gallons	16.4961	14.7687	2.0	138.0	387
High Month	6.9251	2.8123	1.0	12.0	387
Low Gallons	4.3359	3.5601	0.0	36.0	387
Low Month	4.5194	3.4493	1.0	12.0	387
Water	207.6822	133.2109	113.0	1125.0	387
Wastewater	205.4264	80.3638	140.0	1441.0	387
Low Bill	30.1085	12.6134	21.0	187.0	387
High Bill	42.0879	23.5264	21.0	270.0	387
Mean Bill	34.3953	15.7811	21.0	214.0	387

[1]See Table B-1 for variable definitions and units.

Table B-9. Number of Respondents by City Indicating Whether They or Other Family Members Live at the Survey Residence.

City	Number of Yes	Number of No	Percentage Yes	Obs
All Cities	1927	131	93.6	2058
Flower Mound	371	7	98.1	378
Huntsville	211	11	95.0	222
Nacogdoches	213	18	92.2	231
New Braunfels	331	36	90.2	367
San Marcos	318	21	93.8	339
Tyler	168	13	92.8	181
Victoria	315	25	92.6	340

Table B-10. Number of Respondents by City Indicating That They Rent the Survey Residence from Another Person or Business.

City	Number of Yes	Number of No	Percentage Yes	Obs
All Cities	213	1835	10.4	2048
Flower Mound	13	364	3.4	377
Huntsville	24	197	10.9	221
Nacogdoches	31	200	13.4	231
New Braunfels	46	319	12.6	365
San Marcos	46	294	13.5	340
Tyler	27	151	15.2	178
Victoria	26	310	7.7	336

Table B-11. Age Category of People Living in the Survey Residence by City.

Age	Mean	Standard Deviation	Range Min	Range Max	Obs
		All Cities			
all	2.72	1.56	1.0	36.0	2006
< 18	0.69	1.06	0.0	6.0	2006
18 - 64	1.59	1.28	0.0	30.0	2006
> 65	0.45	0.73	0.0	5.0	2006
		Flower Mound			
all	3.22	1.29	1.0	8.0	378
< 18	1.11	1.17	0.0	5.0	378
18 - 64	2.01	0.68	0.0	4.0	378
> 65	0.10	0.37	0.0	3.0	378
		Huntsville			
all	2.33	1.10	1.0	7.0	218
< 18	0.42	0.82	0.0	4.0	218
18 - 64	1.26	1.04	0.0	4.0	218
> 65	0.65	0.87	0.0	3.0	218
		Nacogdoches			
all	2.44	1.30	1.0	9.0	221
< 18	0.6	1.07	0.0	6.0	221
18 - 64	1.32	1.00	0.0	4.0	221
> 65	0.52	0.76	0.0	5.0	221
		New Braunfels			
all	2.70	1.45	1.0	11.0	351
< 18	0.67	1.08	0.0	5.0	351
18 - 64	1.41	1.18	0.0	5.0	351
> 65	0.61	0.80	0.0	2.0	351

Continued.

Table B-11. Continued.

Age	Mean	Standard Deviation	Range Min	Range Max	Obs
		San Marcos			
all	2.83	1.53	1.0	10.0	334
< 18	0.62	1.05	0.0	6.0	334
18 - 64	1.79	1.35	0.0	8.0	334
> 65	0.42	0.71	0.0	3.0	334
		Tyler			
all	2.58	2.87	1.0	36.0	175
< 18	0.55	1.11	0.0	6.0	175
18 - 64	1.48	2.44	0.0	30.0	175
> 65	0.55	0.71	0.0	2.0	175
		Victoria			
all	2.59	1.26	1.0	8.0	329
< 18	0.59	0.92	0.0	4.0	329
18 - 64	1.54	1.10	0.0	5.0	329
> 65	0.47	0.74	0.0	3.0	329

Table B-12. Number of Respondents by City Indicating Whether They Have Experienced Water Use Restrictions in the Past Five Years.

City	Number of Yes	Number of No	Percentage Yes	Obs
All Cities	989	1049	48.5	2038
Flower Mound	350	26	93.1	376
Huntsville	36	182	16.5	218
Nacogdoches	37	192	16.2	229
New Braunfels	272	86	76.0	358
San Marcos	259	79	76.6	338
Tyler	21	159	11.7	180
Victoria	14	325	4.1	339

Table B-13. Percentage of Respondents Indicating the Importance of Fruit and Vegetable Gardens.

City	Mean	St. Dev.	Percent by Category[1]					Obs
			1	2	3	4	5	
All Cities	2.21	3.73	49.6	9.4	22.4	7.3	11.4	1901
Flower Mound	2.04	1.35	55.1	11.9	15.2	9.9	8.0	363
Huntsville	2.19	1.36	46.5	14.2	24.2	3.8	11.4	211
Nacogdoches	2.25	1.45	49.3	8.8	22.9	5.9	13.2	205
New Braunfels	2.29	1.41	47.1	7.5	26.3	7.2	11.9	346
San Marcos	2.38	1.47	44.9	9.6	21.8	9.9	13.8	312
Tyler	1.95	1.31	58.8	8.5	20.3	3.9	8.5	153
Victoria	2.29	1.44	48.6	5.8	26.7	6.4	12.5	311

[1]Categories range from 1 (Very Unimportant) to 5 (Very Important).

Table B-14. Percentage of Respondents Indicating the Importance of Lawn and Landscaping.

City	Mean	St. Dev.	Percent by Category[1] 1	2	3	4	5	Obs
All Cities	3.45	1.22	10.3	6.1	36.4	22.1	25.1	2016
Flower Mound	3.89	1.03	3.2	5.6	22.8	35.7	32.8	378
Huntsville	3.50	1.26	11.8	4.6	32.3	25.0	26.4	220
Nacogdoches	3.44	1.18	9.8	4.9	40.0	22.7	22.7	225
New Braunfels	3.36	1.21	10.2	7.2	41.9	17.6	23.1	363
San Marcos	3.15	1.28	16.3	8.6	37.2	19.7	18.2	325
Tyler	3.36	1.32	13.2	7.5	37.4	13.8	28.2	174
Victoria	3.39	1.20	10.6	4.2	45.0	16.0	24.2	331

[1]Categories range from 1 (Very Unimportant) to 5 (Very Important).

Table B-15. Percentage of Respondents Indicating the Importance of Washing Vehicles at Home.

City	Mean	St. Dev.	Percent by Category[1]					Obs
			1	2	3	4	5	
All Cities	2.14	1.23	45.5	12.9	29.2	6.8	5.6	1960
Flower Mound	2.26	1.23	38.9	19.2	24.1	13.0	4.9	370
Huntsville	2.14	1.21	44.9	14.0	28.5	7.9	4.7	214
Nacogdoches	2.42	1.31	36.3	13.0	33.0	7.9	10.0	215
New Braunfels	2.08	1.21	48.5	11.6	28.7	6.2	5.1	355
San Marcos	1.98	1.19	52.6	11.5	26.9	3.7	5.3	323
Tyler	2.11	1.17	45.4	11.0	35.6	3.1	4.9	163
Victoria	2.07	1.20	49.4	8.8	32.8	3.8	5.3	320

[1]Categories range from 1 (Very Unimportant) to 5 (Very Important).

Table B-16. Income Level of Respondents by City.

City	Mean	St. Dev.	Percent by Category					Obs
			1	2	3	4	5	
All Cities	2.38	1.25	29.8	29.5	21.9	10.0	8.8	1916
Flower Mound	3.48	1.08	2.8	15.5	33.8	26.5	21.4	355
Huntsville	2.41	1.19	27.5	28.5	27.1	9.7	7.3	207
Nacogdoches	2.05	1.04	36.5	34.1	21.5	4.2	3.7	214
New Braunfels	2.13	1.12	35.4	32.9	19.7	7.1	4.9	350
San Marcos	2.05	1.08	36.4	37.3	16.9	4.1	5.3	319
Tyler	1.82	1.01	47.5	34.4	10.0	5.0	3.1	160
Victoria	2.27	1.28	35.4	28.9	19.0	7.1	9.7	311

Income level categories are defined as:

1 Under $25,000

2 $25,001-$50,000

3 $50,001-$75,000

4 $75,001-$100,000

5 Over $100,000

Table B-17. Summary of Responses for Question 5.

Shortfall (%)	Duration (Days)	Fee $	All			Non Protest Bids		Ratio	
			Yes	No	DK	No	DK	Y/(N+DK)	Obs
All			437	1167	428	118	53	02.6	2032
10	14	3	19	31	10	2	1	06.3	60
10	14	6	15	26	8	2	1	05.0	49
10	14	10	18	28	12	3	0	06.0	58
10	14	20	10	51	14	8	0	01.3	75
10	21	3	20	39	9	3	0	06.7	68
10	21	6	16	22	17	3	0	05.3	55
10	21	10	18	36	12	0	1	18.0	66
10	21	20	12	48	10	4	2	02.0	70
10	28	5	16	23	6	2	0	08.0	45
10	28	10	9	25	15	2	3	01.8	49
10	28	20	10	28	12	2	1	03.3	50
10	28	30	3	30	10	3	2	00.6	43
20	14	3	21	23	9	0	2	10.5	53
20	14	6	16	32	7	0	0	-	55
20	14	10	16	30	14	2	1	05.3	60
20	14	20	9	28	11	8	4	00.8	48
20	21	5	22	31	9	0	0	-	62
20	21	10	11	29	16	1	2	03.7	56
20	21	20	10	48	9	6	0	01.7	67
20	21	30	6	36	21	6	3	00.7	63
20	28	10	15	20	9	1	0	15.0	44
20	28	20	12	30	17	2	3	02.4	59
20	28	30	4	29	9	4	1	00.8	42
20	28	40	3	37	13	10	5	00.2	53
30	14	5	17	36	7	2	3	03.4	60
30	14	10	10	33	8	2	1	03.3	51

Continued.

Table B-17. Continued.

Shortfall (%)	Duration (Days)	Fee $	All			Non Protest Bids		Ratio	
			Yes	No	DK	No	DK	Y/(N+DK)	Obs
30	14	20	14	36	13	2	0	07.0	63
30	14	30	8	38	17	5	4	00.9	63
30	21	10	17	23	10	1	2	05.7	50
30	21	20	6	37	12	6	1	00.9	55
30	21	30	7	33	12	4	1	01.4	52
30	21	40	4	39	15	8	2	00.4	58
30	28	10	16	20	13	1	0	16.0	49
30	28	20	12	34	10	3	2	02.4	56
30	28	30	7	44	18	6	4	00.7	69
30	28	40	8	34	14	4	1	01.6	56

Table B-18. Summary of Reasons for Protest Bids for Respondents Answering "No".

Shortfall (%)	Duration (Days)	Fee ($)	Q6B	Q6C	Q6D	Q6E	Obs
---------- All ----------			65	271	658	243	1167
10	14	3	1	9	17	8	31
10	14	6	2	12	11	4	26
10	14	10	1	7	14	4	28
10	14	20	3	13	33	16	51
10	21	3	4	11	22	7	39
10	21	6	3	5	8	6	22
10	21	10	0	5	23	12	36
10	21	20	3	11	28	10	48
10	28	5	1	5	14	5	23
10	28	10	1	9	14	4	25
10	28	20	3	6	19	4	28
10	28	30	1	7	18	7	30
20	14	3	0	2	14	5	23
20	14	6	2	6	22	5	32
20	14	10	0	9	17	7	30
20	14	20	1	6	10	6	28
20	21	5	1	5	22	3	31
20	21	10	0	5	20	9	29
20	21	20	2	16	25	10	48
20	21	30	1	6	21	5	36
20	28	10	2	3	11	4	20
20	28	20	1	7	21	4	30
20	28	30	2	7	16	3	29
20	28	40	2	6	17	14	37
30	14	5	5	4	23	7	36
30	14	10	0	9	19	3	33

Continued.

Table B-18. Continued.

Shortfall (%)	Duration (Days)	Fee ($)	Q6B	Q6C	Q6D	Q6E	Obs
30	14	20	4	6	20	10	36
30	14	30	2	5	22	6	38
30	21	10	1	5	16	1	23
30	21	20	1	10	21	7	37
30	21	30	2	6	18	9	33
30	21	40	2	12	13	7	39
30	28	10	0	4	12	4	20
30	28	20	6	12	18	7	34
30	28	30	2	13	21	12	44
30	28	40	3	7	18	8	34

Table B-19. Summary of Reasons Stated for Protest Bids for Respondents Indicating "Don't Know".

Shortfall (%)	Duration (Days)	Fee ($)	Q6B	Q6C	Q6D	Q6E	Obs
---------- All ----------			65	271	658	243	1167
10	14	3	1	6	6	2	10
10	14	6	1	2	4	2	8
10	14	10	2	2	7	3	12
10	14	20	1	0	8	4	14
10	21	3	1	3	3	2	9
10	21	6	2	7	9	1	17
10	21	10	0	2	7	3	12
10	21	20	0	1	6	1	10
10	28	5	0	0	4	2	6
10	28	10	1	1	5	5	15
10	28	20	2	3	5	2	12
10	28	30	1	1	3	2	10
20	14	3	1	3	3	3	9
20	14	6	0	1	4	2	7
20	14	10	1	2	10	2	14
20	14	20	1	3	3	6	11
20	21	5	0	1	5	3	9
20	21	10	1	5	8	3	16
20	21	20	0	2	6	3	9
20	21	30	0	7	7	7	21
20	28	10	1	1	5	2	9
20	28	20	1	2	8	5	17
20	28	30	2	0	3	3	9
20	28	40	1	1	6	2	13
30	14	5	1	1	3	2	7
30	14	10	3	1	3	0	8

Continued.

Table B-19. Continued.

Shortfall (%)	Duration (Days)	Fee ($)	Q6B	Q6C	Q6D	Q6E	Obs
30	14	20	0	5	8	2	13
30	14	30	2	2	4	4	17
30	21	10	1	2	5	3	10
30	21	20	0	1	9	1	12
30	21	30	1	0	8	3	12
30	21	40	2	5	7	1	15
30	28	10	1	2	6	5	13
30	28	20	0	1	6	2	10
30	28	30	4	4	8	2	18
30	28	40	1	2	7	3	14

Table B-20. Summary of Multiple Reasons Given for Protest Bids for All Respondents Who Indicated More than One Reason.

Combinations of Q6	Number of Respondents
B+C	20
B+D	27
B+E	14
C+D	84
C+E	38
D+E	69
B+C+D	14
B+C+E	3
B+D+E	7
C+D+E	16
B+C+D+E	2

Table B-21. Summary of All Respondents' Willingness-to-Pay as a Function of Shortfall Frequency (once in every x years), Shortfall Strength (% of water shortfall), and Duration (length in days of the shortfall).

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
----------------- All -----------------					6.28	11.87	0.0	100.0	831
5	30	10	–	14	10.85	17.02	0.0	59.0	20
15	20	–	10	14	16.95	22.29	0.0	84.0	17
10	10	15	–	28	5.68	8.91	0.0	30.0	19
10	30	–	20	21	3.76	7.88	0.0	40.0	29
5	20	10	–	21	7.97	11.91	0.0	35.0	21
10	20	15	–	14	8.25	14.70	0.0	60.0	20
5	20	10	–	28	16.45	22.58	0.0	92.0	22
15	30	–	20	14	8.65	14.25	0.0	55.0	26
5	30	–	20	14	5.57	10.77	0.0	50.0	21
5	30	10	–	28	5.90	6.96	0.0	25.0	21
5	20	–	10	14	4.04	8.82	0.0	40.0	21
5	10	10	–	14	5.93	9.25	0.0	30.0	14
10	10	15	–	14	4.15	6.18	0.0	27.0	22
10	30	–	20	28	2.06	3.75	0.0	10.0	25
15	20	–	10	21	8.91	18.12	0.0	69.0	22
5	20	–	10	28	5.85	8.96	0.0	40.0	24
10	30	15	–	14	4.15	8.31	0.0	40.0	31
10	30	15	–	28	4.90	9.73	0.0	35.0	21
5	10	10	–	28	3.00	4.79	0.0	20.0	31
15	30	–	20	28	9.42	15.06	0.0	50.0	25
10	20	15	–	28	4.26	8.01	0.0	30.0	23
10	10	15	–	21	4.72	9.99	0.0	40.0	18
10	20	–	10	28	3.53	4.12	0.0	10.0	15
10	20	15	–	21	7.00	11.79	0.0	40.0	26
15	30	–	20	21	2.72	6.58	0.0	30.0	22
5	30	–	20	21	3.84	7.95	0.0	34.0	19
10	20	–	10	14	5.04	8.69	0.0	36.0	23
10	30	–	20	14	8.43	13.16	0.0	45.0	28

Continued.

Table B-21. Continued.

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
5	20	–	10	21	2.58	3.85	0.0	10.0	25
10	20	–	10	21	10.35	15.74	0.0	50.0	24
5	20	10	–	14	6.03	10.00	0.0	40.0	21
10	30	15	–	21	3.56	9.85	0.0	49.0	25
15	20	–	10	28	7.76	20.32	0.0	100.0	25
5	30	–	20	28	7.21	8.03	0.0	28.0	28
5	10	10	–	21	3.97	8.51	0.0	46.0	31
5	30	10	–	21	6.92	11.97	0.0	50.0	26

Table B-22. Summary of Nonprotest Respondents' Willingness-to-Pay as a Function of Shortfall Frequency (once in every x years), Shortfall Strength (% of water shortfall), and Duration (length in days of the shortfall).

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
- - - - - - - - All - - - - - - - -					8.33	12.79	0.0	100.0	537
5	30	10	–	14	9.81	14.77	0.0	59.0	16
5	20	–	10	14	24.02	23.18	0.2	84.0	12
10	10	15	–	28	7.09	9.17	0.0	30.0	11
10	30	–	20	21	3.84	4.09	0.0	10.0	18
5	20	10	–	21	11.10	13.04	0.0	35.0	13
10	20	15	–	14	13.20	18.55	1.0	60.0	10
5	20	10	–	28	21.00	23.91	1.0	92.0	17
15	30	–	20	14	12.50	15.73	0.0	55.0	18
5	30	–	20	14	6.16	11.18	0.0	50.0	19
5	30	10	–	28	6.19	5.55	0.0	20.0	16
5	20	–	10	14	6.29	10.71	0.0	40.0	13
5	10	10	–	14	9.11	10.35	0.0	30.0	9
10	10	15	–	14	5.07	6.50	0.0	27.0	18
10	30	–	20	28	4.29	4.49	0.0	10.0	12
15	20	–	10	21	11.86	21.07	0.0	69.0	14
5	20	–	10	28	3.97	4.08	0.0	10.0	16
10	30	15	–	14	5.80	9.42	0.0	40.0	22
10	30	15	–	28	8.58	11.73	0.0	35.0	12
5	10	10	–	28	4.68	5.45	0.0	20.0	19
15	30	–	20	28	11.82	14.69	0.0	40.0	14
10	20	15	–	28	5.18	8.94	0.0	30.0	17
10	10	15	–	21	8.40	12.44	0.0	40.0	10
10	20	–	10	28	5.30	4.00	0.0	10.0	10
10	20	15	–	21	8.06	11.24	0.0	38.0	17
15	30	–	20	21	4.99	8.38	0.0	30.0	12
5	30	–	20	21	6.08	9.41	0.0	34.0	12
10	20	–	10	14	8.62	10.28	0.0	36.0	13
10	30	–	20	14	10.67	13.87	0.0	45.0	12

Continued.

Table B-22. Continued.

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
5	20	–	10	21	4.61	4.15	0.0	10.0	14
10	20	–	10	21	11.83	16.33	0.0	50.0	21
5	20	10	–	14	7.91	10.84	0.0	40.0	16
10	30	15	–	21	2.50	2.47	0.0	5.0	12
15	20	–	10	28	13.86	25.90	0.0	100.0	14
5	30	–	20	28	9.00	7.60	0.0	28.0	20
5	10	10	–	21	3.80	3.65	0.0	10.0	20
5	30	10	–	21	7.22	11.35	0.0	50.0	18

Table B-23. Summary of Reasons for Protest Bids Associated with the Willingness-to-Pay for Water Reliability.

Before Change		After Change		Both					
Freq	Shortfall	Freq	Shortfall	Duration	Q9b	Q9c	Q9d	Q9e	Obs
All					110	142	82	169	1055
10	30	5	30	14	1	2	2	4	24
15	10	–	20	14	2	4	1	1	20
15	10	10	–	28	3	5	0	2	26
10	20	–	30	21	5	5	4	8	44
10	20	5	–	21	4	5	6	4	34
15	20	10	–	14	7	5	1	4	26
10	20	5	–	28	3	3	1	9	28
15	20	–	30	14	2	3	1	4	29
5	20	–	30	14	1	1	0	4	24
10	30	5	–	28	2	5	3	3	26
5	10	–	20	14	3	5	3	5	27
10	10	5	–	14	1	5	3	2	19
15	10	10	–	14	1	2	2	5	28
10	20	–	30	28	3	5	4	3	31
15	10	–	20	21	3	2	3	3	29
5	10	–	20	28	2	1	2	7	26
15	30	10	–	14	1	2	3	12	37
15	30	10	–	28	2	6	0	5	26
10	10	5	–	28	3	5	2	6	35
15	20	–	30	28	4	4	6	6	35
15	20	10	–	28	3	3	0	3	27
15	10	10	–	21	3	3	5	6	30
10	10	–	20	28	1	2	2	4	20
15	20	10	–	21	4	2	2	5	33
15	20	–	30	21	3	4	4	4	28
5	20	–	30	21	6	4	1	2	26
10	10	–	20	14	1	5	1	4	28
10	20	–	30	14	2	6	6	5	33
5	10	–	20	21	6	4	4	7	31

Continued.

Table B-23. Continued.

Before Change		After Change		Both					
Freq	Shortfall	Freq	Shortfall	Duration	Q9b	Q9c	Q9d	Q9e	Obs
10	10	–	20	21	4	3	2	4	31
10	20	5	–	14	4	2	1	6	32
15	30	10	–	21	8	4	1	3	29
15	10	–	20	28	1	6	1	5	28
5	20	–	30	28	3	6	1	2	29
10	10	5	–	21	4	8	3	7	41
10	30	5	–	21	4	5	1	5	35

Table B-24. Summary of Multiple Reasons Given for Protest Bids for All Respondents, Willingness-to-Pay.

Combinations of Question 9	Number of Respondents
b+c	0
b+d	0
b+e	0
c+d	3
c+e	14
d+e	4
b+c+d	0
b+c+e	0
b+d+e	0
c+d+e	1
b+c+d+e	1

Table B-25. Summary of All Respondents' Willingness-to-Accept a Decrease as a Function of Shortfall Frequency (once in every x years), Shortfall Strength (% of water shortfall), and Duration (length in days of the shortfall).

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
----------------- All -----------------					12.43	14.06	0. 0	100.0	663
10	30	5	30	14	13.27	17.73	0.0	85.0	26
15	10	–	20	14	19.86	17.78	0.0	50.0	14
15	10	10	–	28	10.32	12.23	0.0	42.0	22
10	20	–	30	21	9.90	10.11	0.0	40.0	22
10	20	5	–	21	12.32	13.45	0.0	39.0	22
15	20	10	–	14	18.18	18.19	0.0	60.0	17
10	20	5	–	28	9.93	9.26	0.0	40.0	28
15	20	–	30	14	13.92	14.05	0.0	47.0	26
5	20	–	30	14	10.50	13.11	0.0	33.0	14
10	30	5	–	28	10.45	14.19	0.0	43.0	11
5	10	–	20	14	16.76	13.76	0.0	47.0	17
10	10	5	–	14	12.67	20.06	0.0	85.0	18
15	10	10	–	14	13.50	15.30	0.0	54.0	12
10	20	–	30	28	13.76	14.80	0.0	48.0	17
15	10	–	20	21	14.39	20.83	0.0	91.0	18
5	10	–	20	28	16.50	10.86	0.0	40.0	16
15	30	10	–	14	12.50	14.40	0.0	50.0	15
15	30	10	–	28	11.94	12.23	0.0	35.0	17
10	10	5	–	28	10.50	11.81	0.0	40.0	22
15	20	–	30	28	20.56	25.88	0.0	100.0	18
15	20	10	–	28	10.04	10.42	0.0	30.0	15
15	10	10	–	21	13.71	14.92	0.0	50.0	21
10	10	–	20	28	7.93	8.95	0.0	25.0	15
15	20	10	–	21	15.14	12.83	0.0	40.0	14
15	20	–	30	21	8.68	10.12	0.0	35.0	22
5	20	–	30	21	13.30	14.45	0.0	50.0	20
10	10	–	20	14	11.07	13.81	0.0	50.0	27
10	20	–	30	14	12.68	12.02	0.0	43.0	20

Continued.

Table B-25. Continued.

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
5	10	–	20	21	12.39	18.54	0.0	70.0	16
10	10	–	20	21	9.12	9.31	0.0	30.0	17
10	20	5	–	14	6.00	5.03	0.0	15.0	12
15	30	10	–	21	11.26	10.43	0.0	35.0	19
15	10	–	20	28	11.88	16.23	0.0	56.0	17
5	20	–	30	28	13.79	12.86	0.0	40.0	19
10	10	5	–	21	14.11	10.68	0.0	45.0	22
10	30	5	–	21	5.20	6.00	0.0	20.0	15

Table B-26. Summary of nonprotest Respondents' Willingness-to-Accept a Decrease as a Function of Shortfall Frequency (once in every x years), Shortfall Strength (% of water shortfall), and Duration (length in days of the shortfall).

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
---------------- All ----------------					14.00	13.20	0.0	100.0	281
10	30	5	30	14	12.92	9.38	2.0	30.0	12
15	10	–	20	14	24.63	16.12	5.0	45.0	8
15	10	10	–	28	12.83	11.95	3.0	42.0	12
10	20	–	30	21	14.18	11.61	3.8	40.0	10
10	20	5	–	21	16.20	15.02	0.0	39.0	10
15	20	10	–	14	19.29	10.58	10.0	35.0	7
10	20	5	–	28	7.44	2.65	4.0	10.0	9
15	20	–	30	14	10.11	6.99	0.0	25.0	9
5	20	–	30	14	12.60	13.65	0.0	33.0	5
10	30	5	–	28	17.60	17.87	4.0	43.0	5
5	10	–	20	14	21.17	15.16	5.0	47.0	6
10	10	5	–	14	13.43	7.16	5.0	25.0	7
15	10	10	–	14	24.00	26.66	3.0	54.0	3
10	20	–	30	28	8.56	8.38	1.0	25.0	9
15	10	–	20	21	11.80	8.69	0.0	29.0	10
5	10	–	20	28	17.75	8.96	5.0	28.0	8
15	30	10	–	14	14.69	11.14	3.0	33.0	8
15	30	10	–	28	15.00	11.73	5.0	35.0	5
10	10	5	–	28	16.22	15.00	0.0	40.0	9
15	20	–	30	28	32.44	31.37	10.0	100.0	9
15	20	10	–	28	5.40	4.45	0.0	10.0	5
15	10	10	–	21	18.40	18.45	2.0	50.0	5
10	10	–	20	28	13.60	8.50	5.0	25.0	5
15	20	10	–	21	15.00	13.40	0.0	40.0	10
15	20	–	30	21	7.67	7.97	0.0	20.0	6
5	20	–	30	21	10.83	9.58	2.0	25.0	6
10	10	–	20	14	11.80	12.16	0.0	42.0	15
10	20	–	30	14	10.86	7.18	2.0	20.0	11

Continued.

Table B-26. Continued.

Before Change		After Change		Both			Range		
Freq	Shortfall	Freq	Shortfall	Duration	Mean	St. Dev.	Min	Max	Obs
5	10	–	20	21	21.33	23.93	5.0	70.0	7
10	10	–	20	21	7.17	5.04	2.0	16.0	6
10	20	5	–	14	7.43	5.38	0.0	15.0	7
15	30	10	–	21	12.64	9.15	5.0	34.0	11
15	10	–	20	28	7.71	10.14	0.0	30.0	7
5	20	–	30	28	16.71	15.40	2.0	40.0	7
10	10	5	–	21	12.15	5.77	3.5	20.0	10
10	30	5	–	21	0.00	0.00	0.0	0.0	2

Table B-27. Summary of Reasons for Protest Bids Associated with the Willingness-to-Accept for Water Reliability.

Before Change		After Change		Both						
Freq	Shortfall	Freq	Shortfall	Duration	Q9b	Q9bWTA	Q9c	Q9d	Q9e	Obs
----------------- All -----------------					79	177	160	229	162	1034
10	30	5	30	14	3	4	6	7	8	36
15	10	–	20	14	3	10	2	4	7	29
15	10	10	–	28	3	3	4	7	1	33
10	20	–	30	21	5	1	6	11	8	34
10	20	5	–	21	1	4	8	9	7	35
15	20	10	–	14	0	5	4	9	6	31
10	20	5	–	28	4	8	6	4	10	40
15	20	–	30	14	2	4	8	10	9	42
5	20	–	30	14	4	8	3	5	3	23
10	30	5	–	28	1	2	4	4	4	24
5	10	–	20	14	4	5	8	6	3	26
10	10	5	–	14	2	3	7	6	4	25
15	10	10	–	14	0	6	5	9	5	27
10	20	–	30	28	1	5	3	8	1	28
15	10	–	20	21	4	2	7	11	2	35
5	10	–	20	28	1	3	2	6	5	23
15	30	10	–	14	0	6	3	6	4	28
15	30	10	–	28	0	8	6	6	6	30
10	10	5	–	28	3	9	4	7	6	33
15	20	–	30	28	4	1	2	8	6	31
15	20	10	–	28	1	5	2	4	2	19
15	10	10	–	21	2	6	6	8	4	29
10	10	–	20	28	1	8	5	2	2	23
15	20	10	–	21	0	1	3	7	1	21
15	20	–	30	21	1	6	7	8	4	33
5	20	–	30	21	0	5	6	5	3	29
10	10	–	20	14	2	4	3	6	6	36
10	20	–	30	14	4	5	2	9	1	31
5	10	–	20	21	1	6	1	2	1	21

Continued.

Table B-27. Continued.

Before Change		After Change		Both						
Freq	Shortfall	Freq	Shortfall	Duration	Q9b	Q9bWTA	Q9c	Q9d	Q9e	Obs
10	10	–	20	21	2	3	9	6	3	25
10	20	5	–	14	1	1	2	7	5	21
15	30	10	–	21	5	5	4	5	3	31
15	10	–	20	28	1	3	4	4	6	22
5	20	–	30	28	5	7	2	1	7	27
10	10	5	–	21	5	9	4	7	3	30
10	30	5	–	21	3	6	2	5	6	23

Table B-28. Summary of Multiple Reasons Given for Protest Bids for All Respondents, Willingness-to-Accept.

Questions	Number of Respondents	Question Combination	Number of Respondents
b+c	10	bwta+b	7
b+d	11	bwta+c	10
b+e	4	bwta+d	8
c+d	15	bwta+e	15
c+e	8	b+bwta+c	6
d+e	21	b+bwta+d	4
b+c+d	6	b+bwta+e	2
b+c+e	1	bwta+c+d	4
b+d+e	1	bwta+c+e	1
b+c+d+e	1	bwta+d+e	1
b+bwta+c+d	3	bwta+c+d+e	1
b+bwta+d+e	1	b+bwta+c+e	1
b+bwta+c+d+e	1		

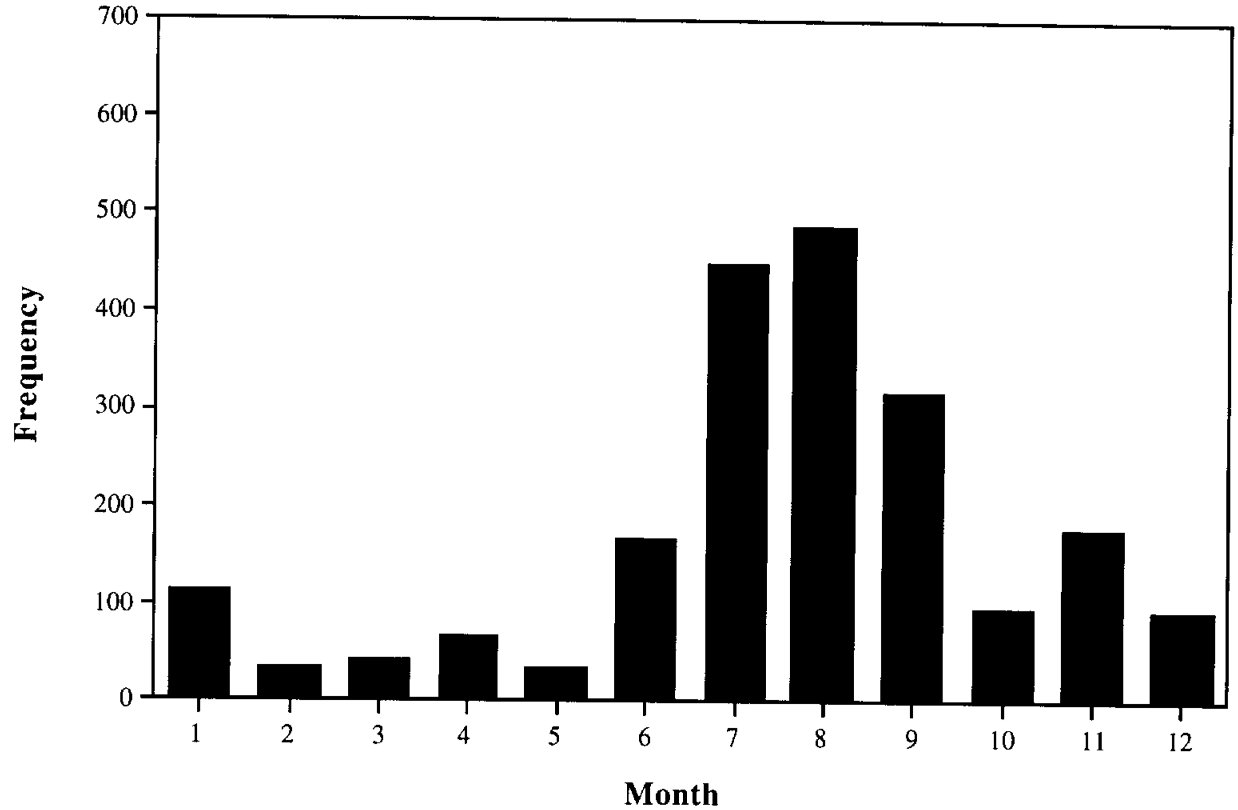

Figure B-1. Histogram of Respondents' Highest Month of Water Use in 1995.

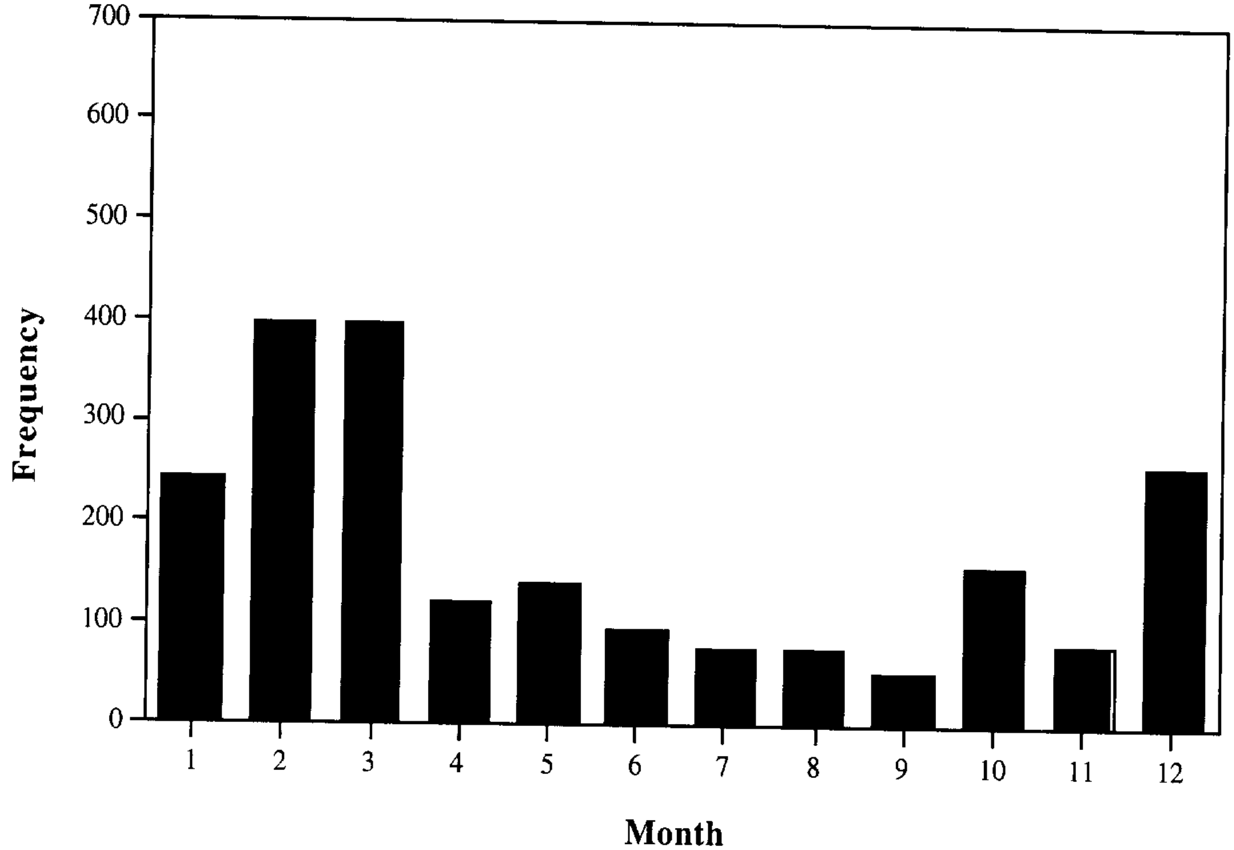

Figure B-2. Histogram of Respondents' Lowest Month of Water Use in 1995.

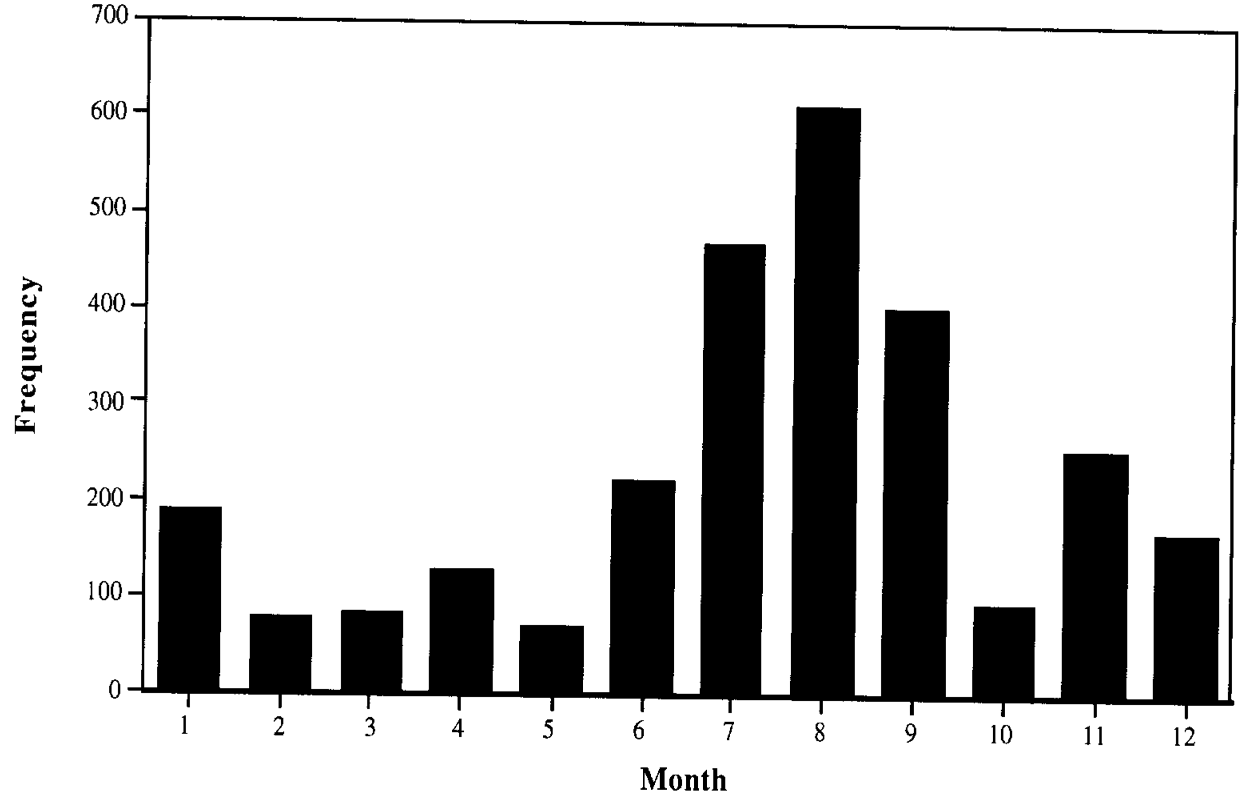

Figure B-3. Histogram of Nonrespondents' Highest Month of Water Use in 1995.

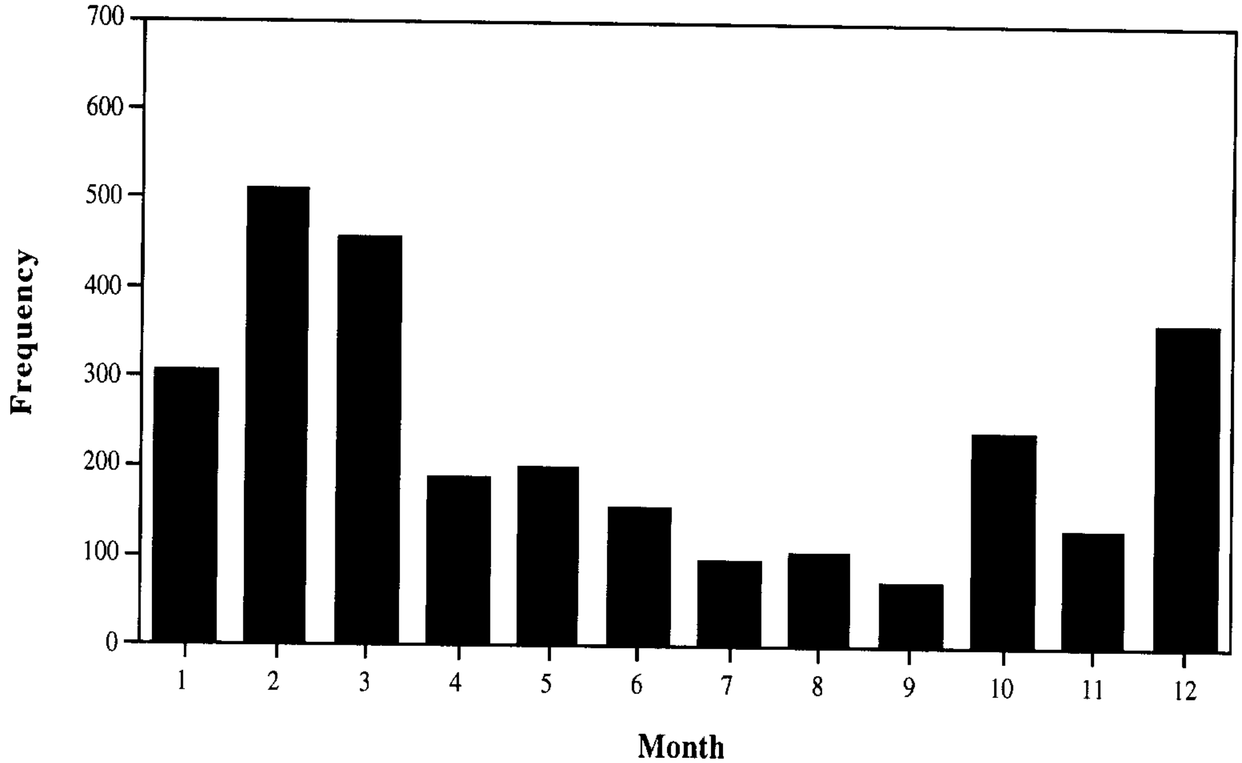

Figure B-4. Histogram of Nonrespondents' Lowest Month of Water Use in 1995.

Appendix C: Analysis – Supporting Tables

Table C-1. Summary Statistics of Variables Used in Estimation of the Value of a Current Shortfall Logit Model, 508 Observations.

Variable	Mean	Standard Deviation	Minimum	Maximum
Summer	0.1313	0.0193	0.1051	0.1697
Rain	37.5468	4.1314	33.6800	44.9600
Price	2.7561	1.7925	1.0779	33.6842
Fee	15.5827	11.0578	3.0000	40.0000
Shortfall	19.6063	8.1796	10.0000	30.0000
Duration	20.3110	5.6567	14.0000	28.0000
Inc1	0.2618	0.4401	0.0000	1.0000
Inc2	0.2205	0.4150	0.0000	1.0000
Inc3	0.2559	0.4368	0.0000	1.0000
Inc4	0.1280	0.3344	0.0000	1.0000
Inc5	0.1339	0.3408	0.0000	1.0000
Activities	8.1201	2.4742	3.0000	15.0000
Rent	0.0886	0.2844	0.0000	1.0000
Live	0.9744	0.1581	0.0000	1.0000
Experience	0.4803	0.5001	0.0000	1.0000
People	2.8110	1.9891	1.0000	36.0000
Yes/No	0.7402	0.4390	0.0000	1.0000

Table C-2. Summary Statistics of Variables Used in Estimation of the WTP, Tobit Model, 466 Observations.

Variable	Mean	Standard Deviation	Minimum	Maximum
Rain	37.9166	4.2896	33.6800	44.9600
Summer	0.1319	0.0196	0.1051	0.1697
Experience	0.4506	0.4981	0.0000	1.0000
Price	2.7983	1.8521	1.2949	33.6842
Severity	3.1202	1.6353	1.0000	6.0000
Dumshort	0.4979	0.5005	0.0000	1.0000
Duration	20.8948	5.7237	14.0000	28.0000
Inc2	0.3112	0.4635	0.0000	1.0000
Inc3	0.2339	0.4238	0.0000	1.0000
Inc4	0.1309	0.3377	0.0000	1.0000
Inc5	0.0944	0.2927	0.0000	1.0000
Activities	7.6996	2.4070	3.0000	15.0000
People	2.6695	1.2297	1.0000	7.0000
Rent	0.0923	0.2897	0.0000	1.0000
Live	0.9657	0.1823	0.0000	1.0000
WTP	8.4691	12.9019	0.000	100.0000

Table C-3. Summary Statistics of Variables Used in Estimation of the WTA for Reliability Declines, Tobit Model, 240 Observations.

Variable	Mean	Standard Deviation	Minimum	Maximum
Summer	0.1295	0.0176	0.1051	0.1697
Rain	36.9010	3.7594	33.6800	44.9600
Price	2.6640	1.1536	1.3729	12.0000
Severity	1.6898	0.8831	0.6700	4.0000
Dumshort	0.5250	0.5004	0.0000	1.0000
Duration	20.8542	5.8144	14.0000	28.0000
Inc2	0.2833	0.4516	0.0000	1.0000
Inc3	0.2500	0.4339	0.0000	1.0000
Inc4	0.0876	0.2832	0.0000	1.0000
Inc5	0.1208	0.3266	0.0000	1.0000
Activities	7.6000	2.3939	3.0000	14.0000
People	2.9208	1.3622	1.0000	7.0000
Rent	0.0958	0.2950	0.0000	1.0000
Live	0.9708	0.1686	0.0000	1.0000
Experience	0.5583	0.4976	0.0000	1.0000
WTA	12.6565	11.1155	0.0000	60.0000

Table C-4. Current Shortfall Values by City.

Flower Mound		Shortfall Duration		
		14 days	21 days	28 days
Shortfall Strength	10%	$30.54	$32.94	$35.34
	20%	$32.65	$35.06	$37.46
	30%	$34.77	$37.17	$39.58
Huntsville		Shortfall Duration		
		14 days	21 days	28 days
Shortfall Strength	10%	$24.73	$27.13	$29.53
	20%	$26.85	$29.25	$31.65
	30%	$28.97	$31.37	33.77
Nacogdoches		Shortfall Duration		
		14 days	21 days	28 days
Shortfall Strength	10%	$25.13	$27.53	$29.93
	20%	$27.25	$29.65	$32.05
	30%	$29.36	$31.77	$34.17
New Braunfels		Shortfall Duration		
		14 days	21 days	28 days
Shortfall Strength	10%	$24.10	$26.50	$28.91
	20%	$26.22	$28.62	$31.02
	30%	$28.34	$30.74	$33.14
San Marcos		Shortfall Duration		
		14 days	21 days	28 days
Shortfall Strength	10%	$22.09	$24.49	$26.90
	20%	$24.21	$26.61	$29.01
	30%	$26.33	$28.73	$31.13
Tyler		Shortfall Duration		
		14 days	21 days	28 days
Shortfall Strength	10%	$19.33	$21.73	$24.13
	20%	$21.44	$23.85	$26.25
	30%	$23.56	$25.96	$28.37
Victoria		Shortfall Duration		
		14 days	21 days	28 days
Shortfall Strength	10%	$26.45	$28.85	$31.25
	20%	$28.56	$30.97	$33.37
	30%	$30.68	$33.08	$35.49

Table C-5. Summary Statistics on Willingness-to-Pay by City in Dollars/Month.

City	Raw Data WTP				Predicted WTP			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Flower Mound	7.38	7.90	0.50	50.00	10.86	2.34	5.97	17.44
Huntsville	7.76	11.33	0.00	55.00	7.98	2.60	2.81	18.21
Nacogdoches	4.39	6.37	0.00	30.00	7.83	2.37	2.77	12.81
New Braunfels	9.68	16.50	0.00	92.00	10.15	3.16	5.07	20.80
San Marcos	11.59	18.19	0.00	100.00	10.15	3.35	5.60	28.41
Tyler	6.93	9.92	0.00	40.00	9.37	2.05	6.14	14.19
Victoria	9.38	13.55	0.00	60.00	10.61	2.58	5.70	15.72

Table C-6. Summary Statistics on Willingness-to-Accept by City in Dollars/Month.

City	Raw Data WTA				Predicted WTA			
	Mean	Std. Dev.	Min	Max	Mean	Std. Dev.	Min	Max
Flower Mound	14.51	11.94	1.00	43.000	14.27	3.32	3.74	21.66
Huntsville	10.25	13.84	0.00	40.00	8.25	2.94	5.25	14.50
Nacogdoches	6.41	5.28	0.00	25.00	10.45	2.48	6.58	16.80
New Braunfels	11.12	10.32	0.00	35.00	14.43	2.87	8.52	21.43
San Marcos	16.55	12.40	2.00	60.00	14.76	3.01	9.06	24.19
Tyler	12.24	7.66	0.00	29.00	10.95	3.54	2.20	16.93
Victoria	14.27	11.86	0.00	47.00	13.64	2.74	8.61	18.98

Appendix D: Report Comments and Responses

1. TWDB Comments
2. Researcher Responses

ATTACHMENT 1
TEXAS WATER DEVELOPMENT BOARD
REVIEW COMMENTS FOR TEXAS A&M UNIVERSITY
RESEARCH GRANT CONTRACT
CONTRACT NO. 95-483-140

(1) The authors repeatedly refer to alternate day watering as an example of mandatory water use restrictions. Alternate day watering may shave a bit of peak but in many cases it leads to increased lawn watering by encouraging consumers to water on their day whether the landscaping needs it or not. It would be better for the authors to refer instead to mandatory restrictions on discretionary water uses.

(2) The report explains in great detail the reliability theories and supporting calculations which are the basis for a model used in this study. These descriptions are highly specialized and difficult to understand, as is most of the report. The information meets the scope of work for Task 1 but is difficult to use.

(3) The survey design and accompanying information appear adequate.

(4) The report contains limited summary, analysis, conclusions or recommendations, these could be expanded. Task 3 requires a determination of management implications which could be expected in a conclusions and recommendations section of the report. Since this does not appear in the draft report it does not meet the requirements of Task 3. A section needs to be added in the summary to explain possible management implications using the data developed.

(5) It is recommended that the summary, conclusions and recommendations sections be presented in a format which is more understandable to a general audience.

(6) Generally, the questionnaire and supporting materials were well conceived. The draft extensively documents results of the questionnaire. However, much of the text is too academic in tone. The report needs to address the "management" implications of efficiently selecting the level of reliability.

(7) The authors have diligently researched past research regarding water supply reliability and associated risk. The information garnered from these research efforts underly the assumptions and work of the authors. It would be beneficial to the reader to have the executive summary expand on the conclusions of the study. It would be of a benefit to explain the implications of the difference in cost and what expected results various management options would have due to the cost difference.

(8) With respect to the use of the contingent valuation method for obtaining values for the risk and reliability assessments for the study, I, like many have some problems with this methodology, specifically with the high probability of bias entering into the responses. The authors have noted such problems with this methodology and it appears through the survey development they have tried to identify such bias responses to the questions. The contingent valuation descriptions was hard to understand and, if possible, the descriptions should be amplified.

(9) Pages 45 and 46 discuss "fees" for avoiding restriction during drought. One measure that many utilities use in the middle stages of drought is an "excess use fee." For example, Abilene and several other cities have as part of their stage 2 or 3 levels, rates of $20 to $50 per 1000 gallons for use above a certain amount, like above 15,000 gallons a month, for residential users. They then usually have use bans or quotas in the last (critical) stages. Comments about this type of situation could be addressed in the report comments.

(10) The tables which show the results are in the appendix. While including all of these tables in the text would be confusing, I recommend that the analysis and summary contain summaries of the "meaning" of these tables in layman's terms.

(11) This study contains significant information that can have impact on drought management plan development. The full impact of this study can only be realized once the analysis section and summary are expanded.

Reseacher Responses to the Board's Review Comments

(1) In the draft report alternate day watering was observed as a common example of a specific type of policy. This observation was not intended to promote alternate day watering as a desirable public policy. Two references to alternate day watering restrictions have been removed from the report; a third reference remains part of a list of "quantity-guided" policies intended to help define such policies by example.

(2) Thank you for recognizing the completeness of our Task 1 accomplishments. Because of the rigor associated with a theoretically oriented research task, a high degree of complexity is inevitable. We have tried to edit the text to make it more reader friendly.

(3) Thank you for drawing attention to the survey design that constituted an important part of the research effort.

(4) The focus of Task 3 highlights example evaluations of perspective management changes to water supply reliability. Given the statistical unreliability of research findings pertaining to future shortfall values, the objective of Task 3 is only tractable for management issues revolving around current supply shortfalls. Consequently, the example described at the close of section VI pertains to a current shortfall. Additional examples involving future shortfalls would overextend results. Further Task 3 work is therefore purposefully abbreviated, and more than 10% of the research budget is returned to the Board.

(5) Due to the advanced nature of portions of this research it was recognized that there would be communication issues. To surmount these difficulties, we resolved to omit the typical conclusions/recommendations sections in favor of a well rounded "Executive Summary". In the Final Report we have expanded this section where possible to improve upon communication.

(6) Thank you for acknowledging the "well conceived" aspects of this research. The "academic tone" is appropriate given the advanced nature of portions of the contracted tasks. Where practicable without compromising accuracy, we have strived to achieve a presentation level that provides accessible information for water management professionals.

(7) Section VI and the Executive Summary have been expanded.

(8) Reliance upon the contingent valuation methodology was specified within the research contract. The researchers have worked diligently to limit the known biases that occasionally complicate application of this valuation technique. Attention has been devoted to the explanation of this method.

(9) While "excess use fees" are feasible instruments within a package of drought management plans, there are many other feasible instruments as well (as noted in the report's first section). Consideration of excess use fees and other approaches are interesting but are beyond the study scope.

(10) To simplify presentation of considerable quantitative findings, key tables are fully incorporated in the report body. These key results are fully discussed. Secondary tables are relegated to appendicies for completeness but are not fully discussed.

(11) Section VI and the Executive Summary have been expanded.