Agricultural & Applied Economics Association

Valuing Water Supply Reliability
Author(s): Ronald C. Griffin and James W. Mjelde
Source: *American Journal of Agricultural Economics*, Vol. 82, No. 2 (May, 2000), pp. 414-426
Published by: Blackwell Publishing on behalf of the Agricultural & Applied Economics Association
Stable URL: http://www.jstor.org/stable/1244661
Accessed: 22/07/2009 15:03

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VALUING WATER SUPPLY RELIABILITY

RONALD C. GRIFFIN AND JAMES W. MJELDE

Instead of creating water supply systems that fully insulate mankind from climate-imposed water deficiencies, it is possible that for municipal water systems a nonzero probability of water supply shortfall is efficient. Perfect water supply reliability, meaning no chance of future shortfall, is not optimal when water development costs are high. Designing an efficient strategy requires an assessment of consumer preferences pertaining to the reliability of water supply. Contingent valuations of both current and future shortfalls are reported. The consistency of these measures is gauged using an expected utility model.

Key words: reliability, water demand, water policy.

An important dimension of the water scarcity problem is the management of water supply risk, especially as it relates to drought. The traditional management practice for controlling urban water supply risk has been one of avoidance, that is, to develop a sufficiently large water supply that the probability of any tangible shortfall is very small. In light of the high and growing costs of water development, it may be sensible to revise the water planning paradigm, so that periodic shortfalls are regarded as acceptable, even planned, events.

In the municipal water use sector, there is an innate tendency to size the water supply system for severe droughts of low probability (Howe and Smith). Water is usually supplied by an entity that faces no competition and has the legal ability to pass all reasonable costs to consumers. Moreover, 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 that has value in excess of its costs. Consequently, the reliability[1] of water systems may be too high, water supplies dedicated to municipal use may be too great, and infrastructure costs may be too large.

Given that available water is physically limited in many regions, when municipalities increase water system reliability, they are shifting risk to nonmunicipal sectors. Obviously, some water users must incur the shortfall during drought situations. Traditionally, risk has been progressively shifted to the riparian and estuary habitat systems. These natural resource systems have become the residual claimants, possessing only what is left after man has diverted water to satisfy his wants. Recently, public policy emphasis on streamflow protection has begun to reverse this tradition (MacDonnell and Rice). One result may be the redistribution of water supply risk back toward municipalities, thereby increasing the importance of risk-attentive water supply planning.

Three dimensions of reliability analysis are addressed here. First, policy options and consumer behavior relevant to water system reliability are discussed. Second, the theory of optimizing water system reliability is briefly restated and refined. This basic theory outlines a method for optimizing reliability and identifies informational needs. Finally and primarily, contingent valuation analyses of modified reliability are presented.

Reliability Policy and Consumer Behavior

To affect water system reliability, managers can (*a*) adjust the long-run supply of water, (*b*) enhance the short-run supply of water during a shortfall event, (*c*) influence the long-run demand for water by consumers, and (*d*) lessen water demand during a shortfall. Rather than being viewed as substitute approaches, the appropriate planning goal is to develop an efficient package of all options.

The authors are professors in the Department of Agricultural Economics at Texas A&M University.

Appreciation is expressed to Mike Bowker for his advice and critiques of our survey instrument and to the Texas Water Development Board for funding support.

[1] The reliability of a water supply system is commonly regarded as inversely related to the probability of a system shortfall (demand > supply).

Amer. J. Agr. Econ. 82 (May 2000): 414–426
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On the supply side, both physical and paper components of a water supply can be adjusted. While the physical components are generally well acknowledged, various paper components (such as water rights, storage permits, contracts with other water suppliers, and dry-year options) represent an increasingly important dimension of planning tools. Either physical or paper components can be modified to adjust long-run water supply reliability, but these supply-side tools are limited for short-run water supply adjustments. Only rapidly executable leases with water right holders or contracts with other water suppliers are practical short-run tools.

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

In response to both long-run and short-run policies, consumers make decisions that are broader than merely how much water to consume. Households choose additions to and 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 that 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 (Dubin, Wirl).

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 continually, rising or falling according to the condition of the lawn/landscape. Long water supply shortfalls can depreciate or extinguish lawns and landscaping, thereby lowering their future net benefits. This implies that there may be instances in which consumers attach high value to avoiding a severe, yet transitory shortfall, because they wish to avoid diminished present and future net benefits.

These simple observations disclose important interrelationships among water supply reliability, the value of reliability, water-using durables, and the value of these durables. When making commitments to specific durables, the consumer is implicitly mindful of water price and supply policy. Consumers likely form expectations of future price and reliability based on recent experience and, perhaps, trends. Once a set of durables is 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 have asymmetric attitudes toward 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. For this reason, as well as the wealth effect, it should be expected that equivalent surplus exceeds compensating surplus for reliability improvements.

Optimizing Reliability

Although interest in water supply reliability is increasing (Lund), there are few empirical studies of the value households associate with the reliability of their water supply. Using a mailed survey in three Colorado cities, Howe et al. asked open-ended willingness-to-pay (WTP) and willingness-to-accept (WTA) questions about modifications to the frequency 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. An advantage of this approach is that the SASE offers a very tangible and known situation for the surveyed population.

Barakat & Chamberlin, Inc. report a WTP analysis of increased reliability performed for ten California water utilities. This contingent

valuation study uses a combination mail–telephone survey to obtain double-bounded dichotomous choice data. Households are asked if they would pay a specified amount per month to eliminate future shortfalls of a specified strength and frequency. Because the elimination of shortfalls is not a realistic planning scenario, the Barakat & Chamberlin, Inc. findings should be interpreted as upper bounds for consumer valuations pertaining to modified shortfall scenarios.

Howe and Smith et al. present some basic theory outlining the optimal selection of water supply level. A noteworthy observation about their 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 during shortfall events (Crew and Kleindorfer 1976, 1978, Marino, Meyer). The energy research on optimal reliability addresses the collaborative role of pricing and investment for achieving an optimal policy. The absence of price control in the Howe and Smith et al. theory can be criticized, but water managers remain far more concerned about appropriate concrete and pipe solutions than they are about establishing proper prices. Moreover, for stochastic settings, resource allocation by price may be economically inferior to quantity-based policy such as rationing rules (Weitzman).

A theoretical model offered by Howe and Smith et al. focuses on the concept of SASE. This model posits that the probability of occurrence for the SASE in period t is a decreasing function of supply-side investment I:

$$(1)\quad \text{Prob}\{\text{SASE}_t\} = P_t(I).$$

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

$$(2)\quad \min_I [A(I) + E[L(P_t(I))]].$$

This problem yields the first order condition

$$(3)\quad \frac{dA}{dI} = -\frac{dE[L]}{dI}$$

indicating that the marginal cost of investment should equal the negative of the marginal expected losses. Howe and Smith et al. 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 deficiency of this theory is its emphasis of a single type of shortage, the SASE (Lund). Nothing is conveyed about the selection of water supply capacity for addressing more moderate or extreme shortage events. Because supply investments alter the frequencies of all degrees of shortage, not just the SASE, this omission is important. To obtain a more broadly applicable theory (also initiated by Howe and Smith et al.), suppose that aggregate water demand D is an increasing function of some short-term climate index which we will call aridity "a." Water supply S is a decreasing function of aridity and an increasing function of investment I. Water price is assumed to be fixed.

When demand exceeds supply for a given aridity level in period t, the loss suffered is $\ell_t(D_t - S_t)$. Otherwise, the loss is zero. The overall loss function can be stated as

$$(4)\quad L_t(I, a_t) = \begin{cases} 0 & \text{if } D_t(a_t) \le S_t(I, a_t) \\ \ell_t\big(D_t(a_t) - S_t(I, a_t)\big) & \\ & \text{if } D_t(a_t) > S_t(I, a_t). \end{cases}$$

If f_t is the probability distribution function for the random variable a_t, then expected losses are

$$(5)\quad E[L_t(I, a_t)] = \int_{a_t^0}^{\infty} L_t(I, a_t) f_t(a_t)\, da_t$$

where a_t^0 is the level of aridity for which $D_t(a_t) = S_t(I, a_t)$.

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

$$(6)\quad \min_I \left[I + \sum_t \int_{a_t^0}^{\infty} L_t(I, a_t) f_t(a_t)\, da_t \right].$$

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 simplifying, the first order condition becomes

$$(7)\quad 1 = \sum_t \int_{a_t^0}^{\infty} \ell_t'(\cdots) \frac{\partial S_t}{\partial I} f_t(a_t)\, da_t.$$

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 index must be constructed for which a probability distribution function 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 function giving the value of loss due to shortfall, $\ell_t(D_t - S_t)$, must be obtained. The latter requirement is the focus of the research reported here.

Survey Design and Procedures

Two lines of inquiry are pursued here using contingent valuation methods. First, the value of current water supply shortfalls—existing shortages of known strength and duration—is addressed. Second, an inquiry into the value of future shortfalls is presented. The latter are probabilistic shortages of differing frequency, strength, and duration.

A questionnaire was mailed to 4,856 households in seven Texas cities.[2] For two of the seven surveyed cities, there were a priori indications of experience with water supply shortfalls. There may be some bias in reliability valuation if assessments are sought solely from shortfall-inexperienced households. Experienced households may attach lower values to reliability for three general reasons. First, inexperience with water supply shortfalls may support an artificially high, physiological objection to an unfamiliar event. 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 to be 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.

Each questionnaire includes two contingent valuation questions. Paired with each of these questions is a question designed to ferret out protest responses. The first contingent valuation question is a closed-ended WTP question concerning a hypothetical current shortfall. This question establishes 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 is 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 during this shortfall. Thirty-six different X-Y-Z combinations are used, and a logit model is fitted with the resulting data.

The second contingent valuation question is an open-ended WTP or WTA question concerning a hypothetical increase or decrease in future water supply reliability. This question poses an initial situation in which approximately once every U years a shortfall of V% would occur with a duration of W days. The question then poses a potential improvement or decline in one of the U or V parameters with the other being unchanged. Shortfall duration W varies among questionnaires, but it is constant in a given questionnaire. In the case of reliability improvements, the respondent is asked for a maximum WTP where this amount is expressed as a permanent increase in monthly water bills. In the case of reliability declines, the respondent is asked for a similarly expressed minimum WTA. Thirty-six distinct before and after regimes (U-V-W combinations) are used. Thus, there are thirty-six WTP questions and, by reversing the before and after components, thirty-six WTA questions. Each survey contains only one of these seventy-two variants. Respondents therefore answer either a WTP or WTA question concerning future shortfalls, but not both. Resulting data are used to estimate two tobit models, one for WTP and one for WTA.

Because there are thirty-six different constructions for the current shortfall question and seventy-two different constructions for the future shortfall questions, each of the current shortfall question variants are employed with two of the future shortfall question's scenarios. These assignments were made randomly.

The future shortfall question is more definitive in that it incorporates frequency information regarding prospective supply shortfalls, and it involves both WTP and WTA formats. However, it also presents a more perplexing proposition to respondents,

[2] Each mailing included a preaddressed and postage-paid return envelope. After two weeks, nonrespondents were mailed a reminder postcard. 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.

and there is justifiable concern that this question might overwhelm people. In the health risk valuation literature, 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, Smith and Desvousges). The survey's current shortfall question poses a simpler, more comprehensible, and less challenging query for surveyed households. Inclusion of two general question styles offers the possibility of checking the consistency of survey results with expected utility theory.

A WTA version of the current shortfall question is not investigated because of the reduced information provided by close-ended questions (thereby necessitating larger datasets to achieve a given level of explanatory power). Moreover, the normative, status quo foundation of the reliability issue is closer to one where consumers do not possess entitlements to particular reliability positions.

Because water supply reliability is an unusual item for individuals to value, it is important to provide households with a solid informational context. Therefore, the individual questionnaire relayed summary information about the household's own water use patterns and bills. Because water supply shortfalls generally occur during summer months, the survey also includes information regarding the cyclical nature of the household's water use. To accomplish this, monthly 1995 information from city utilities was obtained for every household in the survey sample, and these data were used to calculate personalized information provided on each survey. The calculated information could have been electronically merged into the survey instrument prior to printing, but hand writing of this information into surveys was selected to emphasize the customized nature of the entries.[3] On the questionnaire the customized personal information is preceded and followed by additional contextual information regarding the importance and meaning of water supply reliability. The contextual information is replicated in the Appendix of this paper.

[3] The personalized information includes: total 1995 water use (gallons), peak water use month, water use in peak month (gallons), water and wastewater bill for peak month ($), low water use month, water use in low month (gallons), water and wastewater bill for low month ($), total bill for 1995 water use ($), total bill for 1995 wastewater service ($), and average monthly water and wastewater bill ($).

Overall, 30% of the survey recipients had responded prior to remailing of the survey. The overall survey response is 43%. Across the seven cities, the response rate varies from a low of 32% to a high of 45.8%. These percentages include all surveys returned with at least one question answered. Respondent and nonrespondent water use characteristics are similar, and none of the differences in the water use characteristics are statistically significant.

WTP to Avoid a Current Shortfall

A representative sample of the thirty-six editions of the current shortfall WTP question is as follows:

> 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.

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

☐ Yes ☐ No ☐ Don't Know

Over all thirty-six scenarios, 437 respondents indicated they would be willing to pay the fee, whereas 1,595 indicated they would not be willing to pay the additional fee or did not know. Of these 1,595 respondents, 171 constituted nonprotest bids. Nonprotest bids are defined to be those meeting one of the following criteria: (*a*) any respondent answering yes to this question, or (*b*) any respondent answering no or don't know to the question *and* indicating the fee was too high to justify the payment in the subsequent protest filtering question. More than one-fourth of the 1,595 selected "Don't Know." The large number of protest bids appears to be partly a consequence of the good being valued. Some respondents indicated in hand-written notes something to the effect that "water

is a god-given right and should not be valued economically." Such public perspectives often confound water policy research because "access to water is regarded as a moral right, and discriminating among claimants to water on the basis of wealth or position is in many places regarded as immoral" (Martin et al., p. 28).

Current Shortfall Model

Because of the structure of the current shortfall question, the following logistic model is estimated using maximum likelihood techniques:

$$(8)\quad F[\beta'\mathbf{x}] = \frac{e^{\beta'\mathbf{x}}}{1+e^{\beta'\mathbf{x}}}$$

where $F[\beta'\mathbf{x}]$ is the cumulative density function associated with the logistic function, $\mathbf{x}$ is a matrix of explanatory variables, and β is a vector of associated coefficients to be estimated (Judge et al., p. 591). Explanatory variables are:

- rain — mean annual rainfall by city (National Climatic Data Center),
- summer — mean July plus August rainfall divided by the mean annual rainfall for each city,
- price — respondent's total annual water bill divided by total water use,
- fee — fee the respondent must pay to avoid the water use restrictions,
- shortfall — percent shortfall the respondent's community is facing,
- duration — number of days the shortfall will last,
- income — income level of the respondent (five categorical levels correspond to the categories on the survey; the first level is dropped to avoid a singular matrix),
- activities — respondent's preferences toward water use activities[4] (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 — 0/1 dummy variable with a 1 indicating the respondent rents the survey residence from another person or business,
- live — 0/1 dummy variable with a 1 indicating the respondent lives at the survey residence, and
- experience — 0/1 dummy variable with a 1 indicating the respondent has experienced water use restrictions in the past five years.

Surveys from all cities are combined into a single dataset for estimation purposes. City-by-city examinations of the data are available in an expanded report (Griffin and Mjelde). 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 indicate multicollinearity is not a problem in the dataset.

Estimated coefficients for the logit model are presented in table 1. A chi-squared value of 161 is obtained for the statistical test that

Table 1. Current Shortfall Value Logit Model Coefficients, 508 Observations

Variable	Estimated Coefficient	Standard Error	*p*-value
Intercept	−2.12	2.36	0.37
Summer	5.99	7.34	0.41
Rain	0.0325	0.0382	0.39
Price	−0.132	0.0594	0.03
Fee	−0.104	0.0135	< 0.01
Shortfall	0.0221	0.0168	0.19
Duration	0.0358	0.0237	0.13
Inc2	0.997	0.325	< 0.01
Inc3	1.81	0.347	< 0.01
Inc4	1.80	0.443	< 0.01
Inc5	2.80	0.567	< 0.01
Activities	0.0126	0.0494	0.80
People	−0.0626	0.0679	0.36
Rent	0.201	0.408	0.62
Live	1.07	0.729	0.14
Experience	0.255	0.323	0.43

[4] Instead of asking respondents for an inventory of their water-using durables, they were asked to select one of five levels of "importance" for each of three water activity categories. This preference-based approach avoids the impracticality of obtaining water consumption features of individual durables (e.g., area, condition, species of grass lawns), but it does not enable a testing of the role of durables in determining reliability values.

all coefficients are equal to zero. For this level, the null hypothesis is rejected at a p-value < 0.01, indicating the variables help to explain the probability of choosing to pay the fee to avoid water use restrictions. As the fee increases, respondents are less likely to pay to avoid the restrictions. Respondents are more likely to pay to avoid the restrictions as the duration and/or strength increases. All three coefficients associated with these variables are significant at p-values of 0.20 or less with fee being significant at the 0.01 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 survey residences are more likely to pay the fee than respondent landlords who do not live at the residence. The remaining variables are insignificant at the 0.20 level of significance.

Current Shortfall Valuation

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). Here, this fee level is the value the average household is willing to pay to avoid a current shortfall. Using mean levels of exogenous variables, a low income household would be willing to pay a one-time fee of $17.19 to avoid a current shortfall, and a high income household would be willing to pay $44.04. If shortfall parameters are varied across the questionnaire scenarios and income is varied across the five groupings, the predicted WTPs range from $12.99 to $48.88.

WTPs to avoid current shortfalls of various strengths and durations are presented in table 2. All other variables, including income class binary variables, are set at their means in the calculation of these values. As indicated earlier, WTP 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. A one-week increase (decrease) in shortfall duration increases (decreases) this value by $2.41. Every 10% increase (decrease) in shortfall strength increases (decreases) this value by $2.12.

Table 2. Current Shortfall Values (WTP)

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

WTP/WTA to Modify Future Reliability

An example of the thirty-six future shortfall WTP questions is as follows:

> *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 the years of shortfall to decrease demand 20% as needed to manage this shortfall.
> *Future*: 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.

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

The first blank was precompleted with the respondent's average monthly water bill, so the respondent only needed to state WTP. Bids of $0 for this question may be protests. A nonprotest $0 bid is defined here as one in which the respondent either (*a*) checked "the reliability improvement wouldn't help me much" in the accompanying protest filter question or (*b*) did not provide any responses to the protest filter.

Households receiving a future shortfall WTA survey encountered a boxed summary nearly identical to that above followed by this question:

> **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**

Nonprotest bids are defined to be those who selected the following response to the paired protest filtering question: "My answer is about right for the added inconvenience."

Future Shortfall 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., p. 609). In the WTP and WTA samples, the observable range of WTP and WTA range from zero to the highest bid. In such cases, ordinary least squares estimators are biased and inconsistent (Judge et al., p. 615). Consequently, tobit analysis is used here.

The underlying tobit model for this study is

$$(9) \quad y_i^* = \beta'\mathbf{x}_i + \varepsilon_i$$

where $\mathbf{x}_i$ 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. Also, $\varepsilon_i \sim N[0, \sigma^2]$; if $y_i^* \leq 0$, then $y_i = 0$; and if $y_i^* > 0$, then, $y_i = \beta'\mathbf{x}_i + \varepsilon_i$. This model is estimated using maximum likelihood techniques (Greene). Conditional means (prediction) from the tobit model are

$$(10) \quad E[y|\mathbf{x}_i] = \Phi(\hat{\beta}'\mathbf{x}_i/\hat{\sigma})\hat{\beta}'\mathbf{x}_i + \hat{\sigma}\phi(\hat{\beta}'\mathbf{x}_i/\hat{\sigma})$$

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 shortfall strength, and
- shortype — a binary variable which equals zero if the proposed change affects the probability of a shortfall occurring and equals one if the proposed change affects shortfall strength.

By design, the number of usable responses for the WTP and WTA questions will be less than the value of current shortfall question. Four hundred and sixty-six usable observations are available for estimation of the WTP model, whereas 240 observations are usable from the WTA surveys. The difference between WTP and WTA usable responses may pertain to two factors. First, water is better understood as a good for which one pays rather than as a good for which one might receive a payment. The unfamiliar WTA perspective may have caused some confusion. Second, the wording of the WTA question is more confusing than the WTP question. A large number of respondents checked "I don't understand the question" in the protest filter.

Of the 466 usable responses in the WTP data set, 21.4% (100/466) of the respondents indicated a monthly WTP equal to zero. Using dollar intervals of 0.01–1, 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. Also, 0%, 12.9%, 25.4%, 23.8%, and 32.5% of the respondents lie in the dollar intervals 0.01–1, 1–5, 5–10, 10–15, and 15+.

WTP for Reliability Enhancements

Presented in table 3 are the estimated coefficients and statistics for the WTP model.

Table 3. Future Shortfall Value Tobit Model Coefficients

	WTP Model 466 Observations		WTA Model 240 Observations	
Variable	Estimated Coefficient	p-value	Estimated Coefficient	p-value
Intercept	47.8	0.00	27.3	0.08
Summer	−42.5	0.32	5.97	0.90
Rain	−0.751	< 0.01	−0.643	0.01
Price	−0.113	0.78	−1.09	0.09
Severity	−0.527	0.23	−0.178	0.83
Shortype	0.618	0.67	2.18	0.13
Duration	−0.0711	0.57	0.0222	0.86
Inc2	5.03	0.01	−2.50	0.22
Inc3	3.70	0.10	−4.79	0.02
Inc4	4.17	0.11	−2.76	0.34
Inc5	8.45	< 0.01	0.207	0.94
People	1.22	0.05	0.716	0.19
Activities	−0.104	0.73	0.946	< 0.01
Rent	2.23	0.37	−0.684	0.78
Live	−8.28	0.03	3.08	0.49
Experience	−6.18	< 0.01	−0.882	0.65
σ	14.7		10.8	

The Wald chi-squared test that all coefficients are jointly significantly different from zero is rejected at a p-value below 0.01. The water reliability variables are all insignificant at p-values less than 0.23. Insignificance of the severity variable suggests that consumer valuations are unaffected by dimensions of the initially posed shortfall. The insignificance of the shortype variable indicates respondents did not value improvements in shortfall frequency or shortfall strength differently. These results corroborate the "threshold" nature of valuations suggested by Barakat & Chamberlin, Inc.:

> ...respondents regard even a mild shortage scenario as an inconvenience that they want to avoid. They may make a greater distinction between "shortage" and "no shortage" than between different sizes or frequencies of shortages (p. 15).

Individual income levels are significant at p-values of 0.11 or less. Respondents in income categories two through five (inc2–inc5) are willing to pay more for reliability increases than respondents in income category one (inc1—the base which is omitted from the model). Rain is significant at the 0.01 level with respondents in cities with higher rainfall willing to pay less than respondents in drier cities.

In contrast to the value of a current shortfall, individual characteristics appear to help explain WTP bid levels. 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 the live variable are different than prior expectations. It was expected that respondents who do not live at the survey residence would be willing to pay less than respondents who do. 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 dataset only sixteen observations fall into the "don't live at the residence" category; mean WTP for these sixteen is $14.56, whereas the mean WTP for the remaining observations is $8.25. Remaining variables are insignificant at p-values below 0.20.

WTA for Reliability Declines

Also presented in table 3 are the estimated coefficients and standard errors from the WTA estimation. The Wald chi-squared test that all coefficients are jointly equal to zero

is rejected. The magnitudes, signs, and significance of the estimated coefficients differ between the WTA and WTP models. As in the WTP model, rain's impact is negative and significant at the 0.01 level. Summer and rent are insignificant in both the WTP and WTA models. In contrast to the WTP model, both water price and water activities are significant in the WTA model. The signs and significance of the income categories change, weakening results relative to the WTP model. Similarly, variables for experience and live are insignificant in the WTA model.

As with the WTP model, the coefficients associated with initial severity and duration are insignificant. The coefficient associated with shortype is, however, significant at a p-value of 0.13. The coefficient implies that mean WTA is approximately $2.00 higher for an increase in shortfall strength than an increase in shortfall frequency.

Future Shortfall Valuations

WTP and WTA measures can be obtained as means from survey responses, or they can be calculated as means of the in-sample predicted values from the tobit models using the conditional means equation presented earlier. Both methods are employed here. Presented in table 4 are summary statistics associated with the monthly WTP and WTA measures. Mean data WTP is $8.47, whereas the predicted WTP is $9.76. These WTP measures constitute 22.2% and 25.6% of the respondents' mean monthly water bills. These values compare with means of $11.63 to $16.92 (depending on initial shortfall frequency) reported by Barakat & Chamberlin, Inc. for the complete elimination of future Californian shortfalls. Consistent with earlier discussion regarding consumer behavior, both the predicted and data mean WTA are larger than the WTP mean values. Mean WTA is $12.66 and $13.20 for the raw data and predicted values, respectively. These mean WTAs are 32.4% and 33.8% of mean monthly water bills.

Consistency of Results

A useful inquiry pertains to whether obtained future shortfall valuations are consistent with the current shortfall valuations reported earlier. That is, are consumer valuations of modified shortfall probabilities compatible with the values they assign to avoiding current shortfalls?

The future shortfall WTP question asks respondents to state a payment p to accompany a lowered shortfall frequency such that the new state would be viewed indifferently to the initial state. Adopting the expected utility model, this means that initial expected utility must equal subsequent expected utility. Therefore,

$$(11) \quad b \cdot U(y - v) + (1 - b) \cdot U(y) = c \cdot U(y - v - p) + (1 - c) \cdot U(y - p)$$

where b is initial shortfall probability, c is subsequent shortfall probability, $U()$ is the utility function, y is income, and v is the value of a known (current) shortfall. This equality implicitly relates future shortfall value p to current shortfall value v.

The utility function is assumed to be locally given by the constant absolute risk aversion form $U(w) = n - me^{-rw}$, where n, m, and r are constant preference parameters. With this assumption, an explicit function can be obtained for p:

$$(12) \quad p = \frac{1}{r} \ln \left[\frac{be^{rv} + 1 - b}{ce^{rv} + 1 - c} \right]$$

where r is the Arrow–Pratt risk aversion coefficient. For demonstrative purposes, we employ two coefficients, $r = 0.01$ and $r = 0.05$. Both of these values lie at the high end

Table 4. Summary Statistics on Willingness-to-Pay and Willingness-to-Accept Using Individual Observations ($/Month).

	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

of empirically estimated ranges—indicative of a high degree of risk aversion (Raskin and Cochran). For before and after shortfall probabilities, we use the two scenarios posed in the WTP versions of the survey: $\langle b = 1/10, c = 1/5\rangle$ and $\langle b = 1/5, c = 1/10\rangle$.

Table 5 contains the results of calculating future shortfall values based on current shortfall values and the above methodology. For example, a household willing to pay \$30 to avoid a current shortfall and having a risk aversion coefficient of 0.05 should be willing to pay a one-time fee of \$1.80 to support a project that alters shortfall frequency from 1/10 to 1/15. The same household should be willing to pay \$4.59 for a project that alters shortfall frequency from 1/5 to 1/10. Our respondents provided average indications of being willing to pay larger amounts than these each and every month. Consequently, the future shortfall values reported here appear inconsistent with the reported current shortfall values.

One is inclined to look to the future shortfall valuation work for the source of the discrepancy because (*a*) the context of the current shortfall valuation offers a firm and well understood platform for respondents, (*b*) this platform is not confused by the added dimension of frequencies or probabilities, and (*c*) the resulting logit model performs well. Several potential reasons for the incompatible current and future shortfall valuations can be hypothesized. First, respondents may not have understood the future shortfall query well. Even though only one parameter was altered, we may have parameterized shortfalls beyond common comprehension. Second, using frequency to convey probabilistic information may be a bad idea because of scaling problems. When shortfall frequency is altered from one out of ten years to one out of fifteen, the change in probability is quite minor (0.033). In retrospect, we wonder whether respondents could grasp the smallness of this change. Third, perhaps respondents place some value on the convenience or social fairness of regular payments to achieve high system reliability as opposed to one-time payments to sidestep temporary shortfall policies. These hypotheses may be useful suggestions for the conduct of future research in this arena.

Conclusions

If economists are to contribute policy advice concerning water system reliability, we must establish and refine a guiding theory, understand the behavior and reactions of managers and consumers, and investigate the values associated with probabilistic shortfalls. The research reported here builds upon prior contributions in each of these areas.

The theoretical development offers modest improvements and questions the use of a "standardized shortage event" in theoretical or applied research. Given the range of potential water shortfalls, in terms of probability, strength, and duration, it is important to examine empirical options for obtaining shortfall values as a function of shortfall parameters. Such pursuits promise to be a challenging departure from the valuation of a standardized shortfall.

Whereas prior research has acknowledged the attitudes of water managers toward system shortfall, important features of consumer behavior have not been examined. When consumers are considered, it becomes evident that their accumulated bundles of water-using durables influence their actions as well as the values they assign to shortfalls. There is noteworthy feedback here too. The potential for shortfalls affects the selection of durables

Table 5. Consistent Future Shortfall Values (p).

	Δ Frequency: $b \to c \equiv \frac{1}{10} \to \frac{1}{15}$		Δ Frequency: $b \to c \equiv \frac{1}{5} \to \frac{1}{10}$	
Current Value (v)	$r = 0.01$	$r = 0.05$	$r = 0.01$	$r = 0.05$
\$10	\$0.35	\$0.41	\$1.04	\$1.18
\$20	\$0.72	\$1.00	\$2.14	\$2.74
\$30	\$1.14	\$1.80	\$3.32	\$4.59
\$40	\$1.57	\$2.78	\$4.58	\$6.58
\$50	\$2.05	\$3.87	\$5.91	\$8.48

by consumers. Another crucial observation is that durable fixity in the short run gives rise to asymmetric values for reliability improvements and reliability declines.

When contingent valuation methods are employed to assess consumer losses due to shortfall, the contingent valuation analysis can address either the value of avoiding a current shortfall or the value of changing the character of probabilistically defined future shortfalls. The probabilistic information necessary for future shortfall surveys confounds respondents and reduces data quantity and quality. A demonstrated option is to employ expected utility theory in conjunction with assessments of current shortfalls to calculate implied future shortfall values. This alternative eliminates the need to convey probabilistic information to respondents but requires additional assumptions regarding consumer risk preferences. Moreover, current shortfall values can be directly used to specify the loss function, $l_t(D_t - S_t)$, needed to ascertain optimal water supply. Given these findings, future research should concentrate on refining the value of current shortfalls rather than pursuing contingent valuation of probabilistically specified future shortfalls.

Even in the absence of probabilistically defined contingent valuation scenarios, there are pitfalls for the nonmarket valuation of shortfall losses. Two such pitfalls can be encountered in other arenas, but they are certainly pronounced for water issues. These are the "birthright" perspective and consumers' lack of personal consumption information. With respect to birthright, water is popularly thought of as a public good to which people have some inalienable entitlement. Many see water bills as a tax rather than as an invoice for the on-demand delivery of treated, pressurized tap water. Consequently, there is a strong tendency for respondents to protest proposed WTP scenarios. Overcoming this pitfall appears extremely difficult at this time, but some redress may be achieved through very carefully worded survey prefaces. The analyst's burden is high here.

With respect to the second pitfall, most households are not aware of their actual water use or their water bills. Not only is water a low budget share item for most households, thus failing to motivate much attention, but water bills are lumped into utility bills that may include electricity, natural gas, and solid waste components. This lack of consumer information also raises the burden for survey instruments. Our instrument's inclusion of consumer-specific data is a novel approach worthy of use, and perhaps testing, by future research.

[Received November 1998; accepted June 1999.]

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Appendix: Background Information

The questionnaire's introduction included contextual information highlighting 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 will not 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 questionnaire includes 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.

QED Research, Inc.

125 California Ave. • Suite 200 • Palo Alto • California 94306 • (415) 321-9827

ECONOMIC VALUE OF RELIABLE WATER SUPPLIES FOR RESIDENTIAL WATER USERS IN THE STATE WATER PROJECT SERVICE AREA

For

THE METROPOLITAN WATER DISTRICT OF SOUTHERN CALIFORNIA

BAY/DELTA HEARING
DOCUMENT MANAGEMENT
SYSTEM

AGENCY CODE SWC

NUMBER 0056

DATE RECEIVED

Prepared by:

Richard T. Carson
(University of California, San Diego)

Robert C. Mitchell
(Resources For the Future)

(Subcontracting to QED)

June 9, 1987

SWC EXHIBIT NUMBER 54

ECONOMIC VALUE OF A RELIABLE WATER SUPPLIES FOR RESIDENTIAL WATER USERS IN THE STATE WATER PROJECT SERVICE AREA

Introduction and Summary

Actions taken by the State Water Resources Control Board as a result of the Bay-Delta Hearing Process may have an impact on the reliability of the water supply of households served by the State Water Project (SWP). This paper reports economic values for changes in the reliability of that water supply. From the perspective of the residential water user, these values reflect the cost of damages expected from a period of water shortage.

From the household's perspective, a reliable water supply can be defined as one without the threat of periodic shortages and mandatory rationing. Reductions in reliability can be defined in terms of the magnitude and frequency of expected shortages. Four scenarios of reductions in reliability are evaluated using an economic technique for valuing non-marketed goods known as contingent valuation. The annual aggregate value for water reliability based on the median household in the SWP service area **range from 450 million (1987) dollars per year** to avoid a projected 10-15% water supply shortage once every five years to **1.4 billion dollars per year** to avoid two projected water supply shortages every five years, one a 30-35% shortage and the other a 10-15% shortage. Values for water reliability over longer periods of time, 5 and 30 years, are also estimated and range from 4.2 to 13.2 billion dollars depending on the time period and the type of projected shortage. A comparison of results for households in Northern and Southern California suggests that the two areas of the state have similar attitudes toward water shortages and value avoiding the damages of a water supply shortage in a similar fashion.

Contingent Valuation

Contingent valuation is one of a number of economic techniques for valuing non-marketed goods. Non-marketed goods are those goods and services which are not ordinarily bought and sold in the private market place. Most often non-marketed goods are provided directly or indirectly by public agencies. Clean air and recreational fishing are classic examples of non-marketed goods. The contingent valuation technique is a survey based approach where a fairly detailed scenario is posed to a respondent. The scenario involves a change in the level of a non-marketed good of interest, in this case a change in the level of water reliability. The respondent is asked what the maximum dollar amount he or she would be willing to give up (or minimum he or she would be willing to accept) in exchange for having the level of the non-marketed good in the scenario as opposed to some specified baseline level of the good. Typically, this baseline describes a household's current level of consumption of the good. Contingent valuation can be viewed in some respects as a sophisticated marketing survey for a new product.

Contingent valuation is an officially approved method for valuing non-marketed goods by the U.S. Water Resources Council (1979; 1983) and under the Department of Interior's CERCLA regulations (1986) for valuing natural resources which are not traded in private markets, but which are enjoyed by the public. The method is also frequently used by the U.S. Environmental Protection Agency (e.g., Tolley and Randall, 1985), the U.S. Forest Service (e.g., Sorg and Nelson, 1986), and the U.S. Army Corp of Engineers (Moser and Dunning, 1986). Since its first proposal by Ciriacy-Wantrup (1952), the noted UC Berkeley resource economist, and first implementation by Davis (1964), contingent valuation has been used to value changes in a large number of non-marketed goods. Among others it has been used to value changes in: air visibility (Brookshire *et al.*, 1982), hazardous waste sites (Smith and Desvousges, 1987), fine arts

(Throsby, 1984), automobile safety regulation (Jones Lee, *et al.*, 1985), paramedical rescue programs (Acton, 1973), duck hunting (Hammond and Brown, 1974), park preservation (Thayer, 1981), river flow rates (Bishop *et al.*, 1986), regional water quality (Greenley, *et al.*, 1982), and national water quality (Carson and Mitchell, 1986). Mitchell and Carson (forthcoming) briefly describe over 100 contingent valuation studies which have been conducted. Recent reviews of the method have been undertaken in Schulze et al. (1981), Cummings *et. al.*, (1986), and Mitchell and Carson (forthcoming).

Four Levels of Reliability Reduction

The levels of reliability reduction valued by respondents in this study differed according to the magnitude and expected frequency of the shortage. Four scenarios are examined:

- **Scenario A** is based on an expected **30-35% reduction** from the baseline of the household's current water consumption **once every five years**.
- **Scenario B** is based on an expected **10-15% reduction** from a household's current water consumption **once every five years**.
- **Scenario C** is based on **two years** of expected water shortage out of every five years: one requiring **30-35% reduction** and one requiring a **10-15% reduction.**
- **Scenario D** is based on **two years** of expected water shortage every **five years, both requiring a 10-15% reduction.**

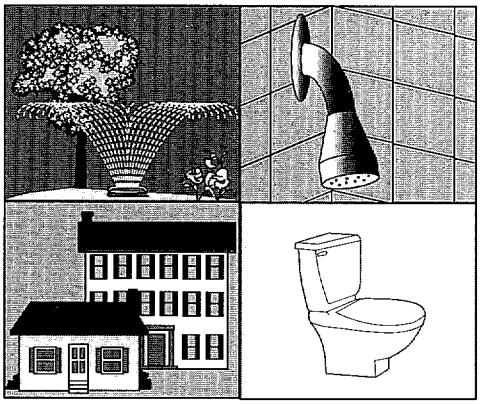
The 10-15% reductions are depicted as involving voluntary reductions in indoor water use and odd/even day cut backs in outdoor water use. The 30-35% reductions are depicted as involving mandatory water rationing for indoor water uses, the prohibition of many outdoor water uses with the possible loss of landscaping, and some adverse affects on businesses. In both cases, assurances of a sufficient water supply for drinking purposes is given.

California Department of Water Resources reports and discussions with officials from water utilities helped define the range of possible water shortages under different situations. The four scenarios were selected because they appear

Summary

The Value of Water Supply Reliability:

Results of a Contingent Valuation Survey of Residential Customers



California Urban Water Agencies

Prepared by:
Barakat & Chamberlin, Inc.

August 1994

Summary

THE VALUE OF WATER SUPPLY RELIABILITY:
Results of a Contingent Valuation Survey of Residential Customers

CALIFORNIA URBAN WATER AGENCIES

Participating Agencies:

Alameda County Water District
Contra Costa Water District
Los Angeles Department of Water and Power
Metropolitan Water District of Southern California
Municipal Water District of Orange County
Orange County Water District
San Diego County Water Authority
San Diego Water Utilities Department
San Francisco Public Utilities Commission
Santa Clara Valley Water District

Prepared by:

BARAKAT & CHAMBERLIN, INC.
Oakland, California

August 1994

ACKNOWLEDGEMENTS

The authors would like to thank California Urban Water Agencies for sponsoring this study. The study greatly benefitted from the expertise of Dr. Michael Hanemann of the University of California, Berkeley, who served as special consultant to the project. We also are grateful for the assistance and the sustained interest of the Project Advisory Committee. Committee members included:

Dr. Richard Berk, Department of Sociology, U.C.L.A.
Mr. Arthur Bruington, Municipal Water District of Orange County
Mr. Byron Buck, San Diego County Water Authority
Mr. Norman Buehring, Los Angeles Department of Water and Power
Mr. Shane Chapman, Metropolitan Water District of Southern California
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Ms. Christine Morioka, San Francisco Water Department
Mr. Dan Rodrigo, Metropolitan Water District of Southern California
Mr. Richard Rogers, Pacific Earth Resources
Mr. Jim Simunovich, California Water Service Company
Mr. Karl Stinson, Alameda County Water District
Mr. Leo Thompson, Contra Costa Water District
Mr. Peter Vorster, Consultant
Mr. Richard West, Los Angeles Department of Water and Power
Mr. Lyle Hoag, ex officio, California Urban Water Agencies

Consultant staff:
Gary Fiske
Ronnie Weiner
Sami Khawaja
Scott Dimetrosky
Helen Arrick

FOREWORD

California Urban Water Agencies (CUWA) is an organization of the largest urban water providers in California. Its member agencies serve water to metropolitan areas comprising about two-thirds of the state's 32 million population. CUWA was formed to work on water supply issues of common concern to its members. Paramount among these concerns is the reliability of our urban water supplies. Statewide surveys show that California citizens rank water shortages close to crime, taxes, and traffic in listing their concerns about current problems in our society.

CUWA has an ongoing program to improve understanding of all aspects of urban water supply reliability. One important component of planning for supply reliability is being able to estimate the economic impact of water shortages so that an appropriate balance between costs and benefits of water management improvements can be found. CUWA and its member agencies sponsored earlier work on the cost of water shortages in California's manufacturing industries and the urban horticulture industry. However, the largest shortage cost component in some communities is in the residential sector, and this factor has proven difficult to quantify. CUWA and its consultant, Barakat & Chamberlin, Inc., determined that contingent valuation (CV) is the best available method for studying residential water shortage losses, and so undertook this survey—the most comprehensive and informative survey of its type conducted in the urban water supply industry.

This report detailed results of the CV surveys which shows that, on average, California residents are willing to pay $12 to $17 more per month per household on their water bills to avoid the kinds of water shortages which they or their regional neighbors have incurred in recent memory. The statewide magnitude of such additional consumer payments would be well over $1 billion per year. This customer value can be considered in planning for various demand- and supply-related options to meet reliability goals. While environmental and social impacts were not assessed in the CV survey, this report points out that they must be considered in water resource planning. CUWA is planning an additional phase of its Water Supply Reliability Program which will help water managers integrate all aspects of reliability planning.

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THE VALUE OF WATER SUPPLY RELIABILITY:
Results of a Contingent Valuation Survey of Residential Customers

Summary

INTRODUCTION

California Urban Water Agencies (CUWA) is conducting ongoing research on issues of water supply reliability. The goal of the CUWA reliability project is to provide the framework and tools with which each water agency can better incorporate reliability issues into its overall resource planning. One of the key pieces of information needed to do this is the *value* that customers place on reliability.

To address this question, CUWA engaged the consulting firm of Barakat & Chamberlin, Inc., to design, conduct, and analyze the results of a *contingent valuation* survey to estimate the value to residential customers of water supply reliability. The survey was conducted within the service areas of ten CUWA member agencies. This summary discusses combined results for the ten participating agencies. The individual results for each agency are included as appendices to the full report.

As will be discussed below, estimates and patterns of willingness to pay (WTP) for increased water supply reliability are remarkably consistent across participating agencies. This consistency supports the integrity of the results and general findings of the study. However, contingent valuation is not an exact science, and dollar figures should be used with caution.

THE CUWA CONTINGENT VALUATION SURVEY

The primary purpose of the CUWA contingent valuation (CV) survey is to estimate the value residential customers place on water supply reliability, specifically how much they are willing to pay to avoid water shortages of varying magnitude and frequency.

The CUWA CV survey asked participants whether they would vote "yes" or "no" in a hypothetical referendum. Participants were told that if a majority votes "yes," water bills would be increased by a designated amount, and there would be no future water

shortages; if a majority votes "no," respondents were told that water bills would remain the same as they otherwise would have been, but water shortages of a specified magnitude and frequency would occur. Of course, individual customers differ in their willingness to pay to avoid different shortages.

The survey purposely did not tell customers where additional supply would come from, but rather indicated that it could come from any of a number of different sources. The intent was to avoid responses that were unduly influenced by preferences for or against particular resource types.

The CV questions are preceded by a series of questions that address a number of experiential and attitudinal issues, which help to place the CV questions in context and are also used in the analysis. The actual CV questions include a carefully worded description of the hypothetical "scenario" that will form the basis of a "yes" or "no" vote. The CV questions are followed by several "debriefing" questions that provide information on the reasons why respondents voted as they did. The survey concludes with a series of demographic questions.

Respondents are distributed randomly across a range of shortage scenarios. Shortage magnitudes range from 10% to 50%. Frequencies range from once every 3 years to once every 30 years. Bid amounts range from $1 to $50 increments to monthly water bills.[1]

Magnitudes and frequencies were combined to accomplish three objectives:

- To cover a wide range of shortage severity;
- To present shortage scenarios that would be perceived by respondents as realistic possibilities; and
- To avoid shortage scenarios that are too mild to elicit reliable WTP responses.

There are some critical concerns that are intentionally not addressed by the survey. The amount that some customers are willing to pay to avoid shortages will likely depend on one or more "external" impacts associated with the resource(s) added. These might include environmental or various social impacts. The CUWA Project

[1]Initial bid amounts ranged from $5 to $20. However, the follow-up portion of the double-bounded question accommodated values as low as $1 or as high as $50, if necessary.

Advisory Committee (PAC) and the consultants determined that, in the context of an agency's resource planning process, these issues would be best treated as costs associated with particular resource additions. Pretests and focus groups conducted during the survey design process indicated that, through proper wording of the survey questions, respondents could, in fact, give answers that were not influenced by such matters.

Because of the complexity of a survey of this type, it was decided to use a combination mail/telephone survey. A package of information was mailed to potential respondents. The mail package contained material that explained the purpose of the survey and helped customers understand the impacts of various shortage magnitudes. Interviewers called several days after the mail material was received.

The survey was conducted from August 1993 through February 1994. The total number of completions across all participating agencies was 3,769.

ANALYTICAL APPROACH

As described earlier, the contingent valuation (CV) survey uses the referendum approach. The referendum approach "bounds" the maximum willingness to pay (WTP) by asking the respondent whether he or she would be willing to pay a specified amount. A "yes" response indicates that the respondent would be willing to pay that amount or more, i.e, it gives a lower bound to the maximum WTP; a "no" response gives an upper bound. The mean WTP to avoid particular shortage scenario can be estimated statistically from responses of different residential customers to different shortage descriptions.

An extension of this approach, and one which is more statistically reliable, is the "double-bounded" technique. The CUWA contingent valuation survey asked respondents whether they would pay an additional monthly amount (or bid) to avoid a particular percentage shortage occurring with a specified frequency. A second choice question, whose bid depended on the answer to the first question, was then asked. If the response to the first question was "yes," then the second bid was an amount greater than the first bid, and if it was "no," the second bid was an amount smaller.

The superior statistical efficiency of the "double-bounded" approach makes intuitive sense given that the "double-bounded" approach yields more information than the "single-bounded" approach about each respondent's preferences. The solution to the

double-bounded model used maximum likelihood techniques, applying a program that was written in GAUSS, a statistical software package widely used by economists and statisticians.

Specification of the Statistical Model

As described above, many questions pertaining to sociodemographic, attitudinal, and perceptual variables were included in the survey. Responses to many of these questions were included as explanatory variables in the statistical model. By doing this, we can see how these factors affect WTP. Figure S-1 describes the key explanatory variables included in the model.

Two statistical models were estimated. The so-called "detailed" model included all of the key explanatory variables discussed above. A "simplified" model included only those variables that can be obtained from census or agency billing records. These include:

- Age
- Household income
- Education level
- Dwelling type
- Household size

To the extent that this simplified model is statistically valid, it will enable agencies to reestimate willingness to pay in the future without resurveying residential customers.

The approach results in the following expression for the mean WTP for each shortage frequency (FREQ) and magnitude (REDUCE) combination:

$$WTP(REDUCE,FREQ) = \frac{\log(1+\exp(\alpha+\beta_1(REDUCE)+\beta_2(FREQ)+\sum \gamma_n X_{mean_n}+\sum \delta_t Z_{prop_t}))}{-\beta_3}$$

Figure S-1
KEY EXPLANATORY VARIABLES

- **Number of years living in area**
- **Household size†**
- **Age†**
- **Income†**
- **Education†**
- **Housing type†**
- **Concern for other public issues**
- **Perception of drought severity**
- **Perception of water shortages as a long-term problem**
- **Awareness of agency mandates to cut back on water use**
- **Home ownership/rental status and water bill responsibility**
- **Amount and type (private or shared) of external landscaping**
- **Population growth preferences**
- **Average residential water rate for respondent's water agency**
- **Northern California or Southern California agency**

†Included in simplified model.

where:

X_{mean} = the mean of those explanatory variables that are not binary (i.e., either zero or one)

Z_{prop} = the proportion of customers for which each of the binary explanatory variables takes on a value of one.

This expression enables us to derive *customer loss functions* that express average customer willingness to pay as a function of shortage magnitude and frequency. Such functions can be a key tool for agency resource planners.

ANALYTICAL RESULTS

Willingness to pay (WTP) can be interpreted as the losses that residential customers incur as a result of particular shortage scenarios. The amount that a customer is willing to pay to avoid an event is a measure of the losses that customer would incur if that event were to occur. Therefore, we refer to these willingness to pay results as a "loss function."

Tables S-1A and S-1B present the mean WTP for the detailed model and the simplified model for each magnitude and frequency of shortage. WTP figures represent increments to monthly water bills.

WTP for the detailed model varies from a low of approximately $11.60/month to avoid either a 10% shortage every 10 years or a 20% shortage once every 30 years, to a high of about $16.90/month to avoid a 50% shortage every 20 years. The results of the simplified model are almost identical to the results of the detailed model. While results for individual agencies do exhibit some differences, the range of WTP estimates is remarkably consistent across all participating agencies.

Table S-1A
MEAN MONTHLY WILLINGNESS TO PAY, DETAILED MODEL
(Additional $/Month)

Shortage (Percent Reduction From Full Service)	Frequency (Occurrences/Years)				
	1/30	1/20	1/10	1/5	1/3
10%			$11.63	$11.98	$12.12
20%	$11.62	$12.33	$13.06		
30%	$13.05	$13.80	$14.57		
40%	$14.56	$15.34	$16.13		
50%	$16.12	$16.92			

Blank cells in the table reflect scenarios that were not part of the survey.

Table S-1B
MEAN MONTHLY WILLINGNESS TO PAY, SIMPLIFIED MODEL
(Additional $/Month)

Shortage (Percent Reduction From Full Service)	Frequency (Occurrences/Years)				
	1/30	1/20	1/10	1/5	1/3
10%			$11.67	$12.00	$12.14
20%	$11.71	$12.39	$13.08		
30%	$13.13	$13.84	$14.56		
40%	$14.61	$15.35	$16.10		
50%	$16.15	$16.92			

Blank cells in the table reflect scenarios that were not part of the survey.

The "loss function" is shown graphically in Figure S-2. In examining the tabular and graphical results, two major conclusions can be drawn:

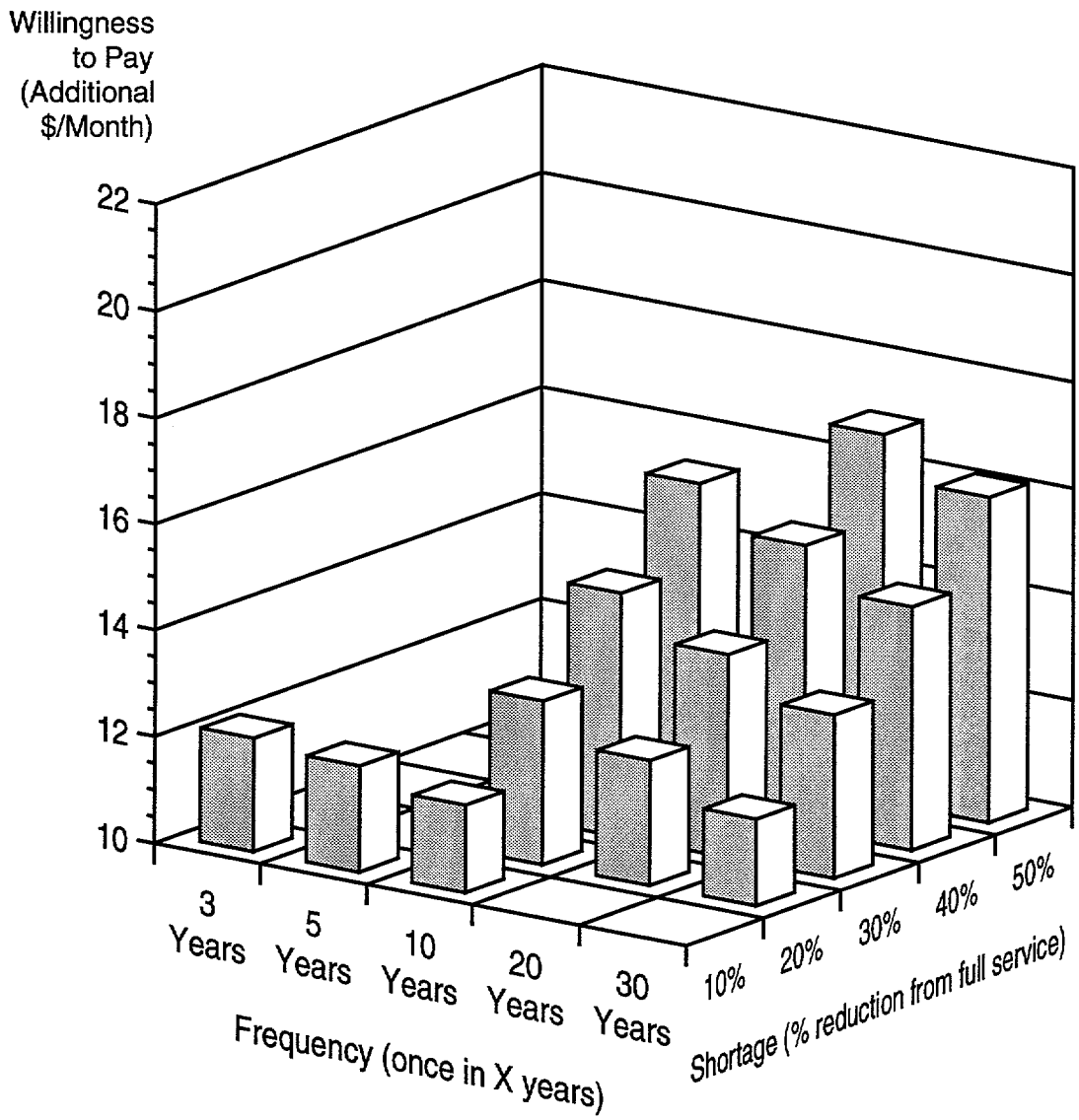
- As expected, respondents are willing to pay more to avoid larger shortages and for shortages that occur with higher frequency. However, the impact of frequency variations is considerably smaller than the impact of shortage magnitude on consumers' responses.

  Put another way, it appears that residential customers believe that infrequent large shortages impose higher losses than more frequent small shortages. This result is also consistent across all of the individual agencies. This type of conclusion may be important to agencies as they plan supply-side or demand-side resource additions and make system operations decisions.

- To avoid even apparently minor shortage scenarios (e.g., 10% once every 10 years), respondents are willing to pay substantial amounts. This type of "threshold" response is not uncommon in surveys of this type and may indicate that respondents regard even a mild shortage scenario as an inconvenience that they want to avoid. They may make a greater distinction between "shortage" and "no shortage" than between different magnitude or frequencies of shortages. Again, this pattern of responses holds for all participating agencies.

Figure S-2

Mean Monthly Willingness to Pay to Avoid Particular Shortage Frequencies and Magnitudes



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Impact of Key Explanatory Variables on Willingness to Pay

As described previously, the statistical model includes many variables that could potentially explain the variation in willingness to pay. For example, the variable "RATE" was included to determine if the average residential rate charged by the respondent's water agency affected WTP. The impact of this variable was not statistically distinguishable from zero. The following discussion selects three explanatory variables that are statistically significant and illustrates their impact on WTP.

Figures S-3 to S-5 show the variation of WTP at various shortage magnitudes when all other variables, other than the one in question, are held constant.

Landscape Area

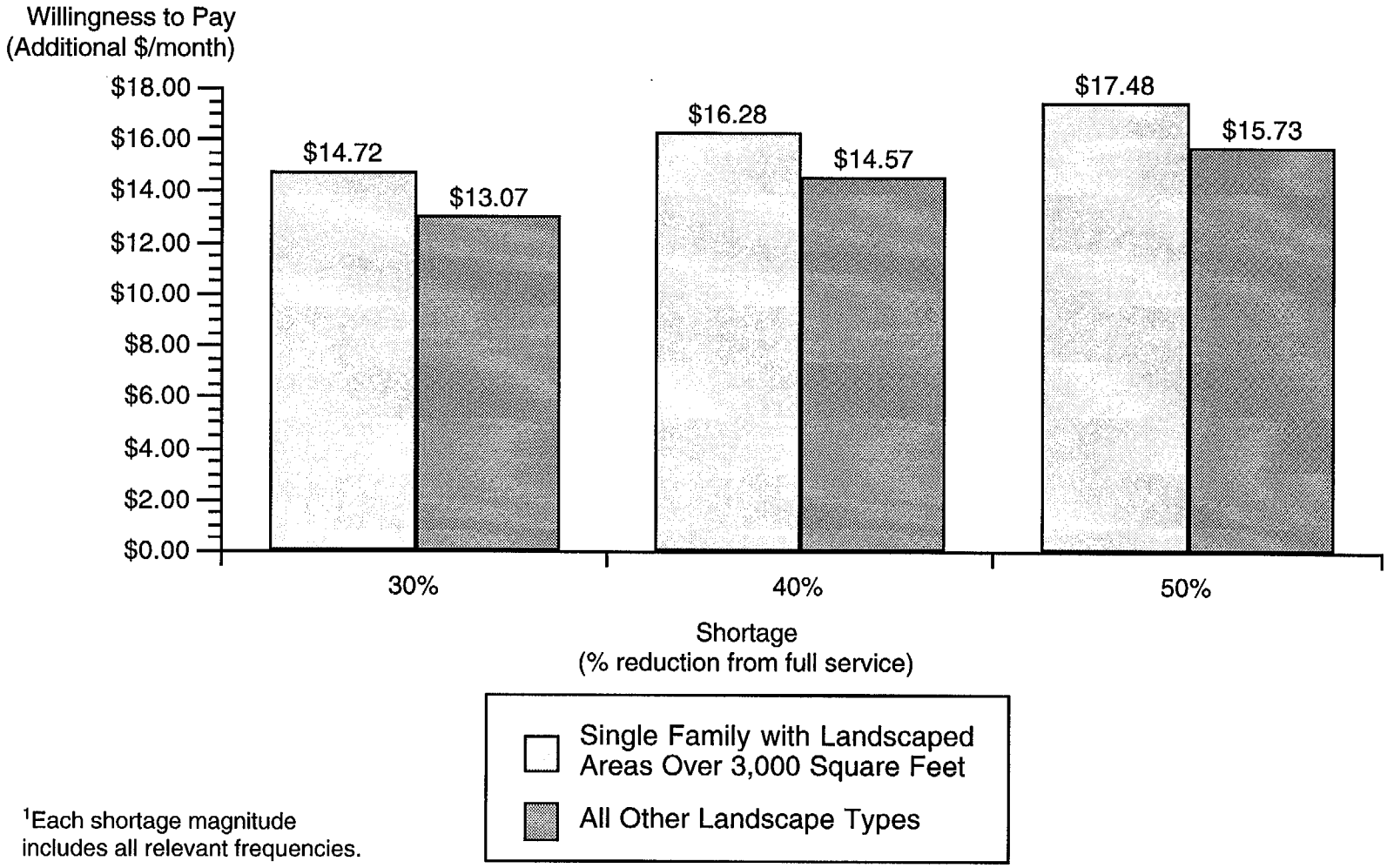
Not unexpectedly, the quantity and type of outdoor landscaping has a statistically significant influence on respondents' willingness to pay to avoid future shortages. Figure S-3 illustrates this by using the variables in the model that capture variations in landscaped area. The results show that respondents who have private lots with landscapes larger than 3,000 square feet have higher WTP than families with other types of landscaping.

Growth Preferences

Another interesting relationship is demonstrated in Figure S-4, which shows the relationship between participant feelings about community growth and their willingness to pay to avoid water shortages. Individuals who indicate a desire for their communities to grow in size have a higher WTP than do people who want their communities to stay the same size or to get smaller. Many in the latter group may perceive a relationship between water resource development and growth and are therefore more likely to prefer enduring more severe and/or frequent water shortages rather than adding to the resource base.

Figure S–3

Effect of Landscape Characteristics on Willingness to Pay[1]



[1]Each shortage magnitude includes all relevant frequencies.

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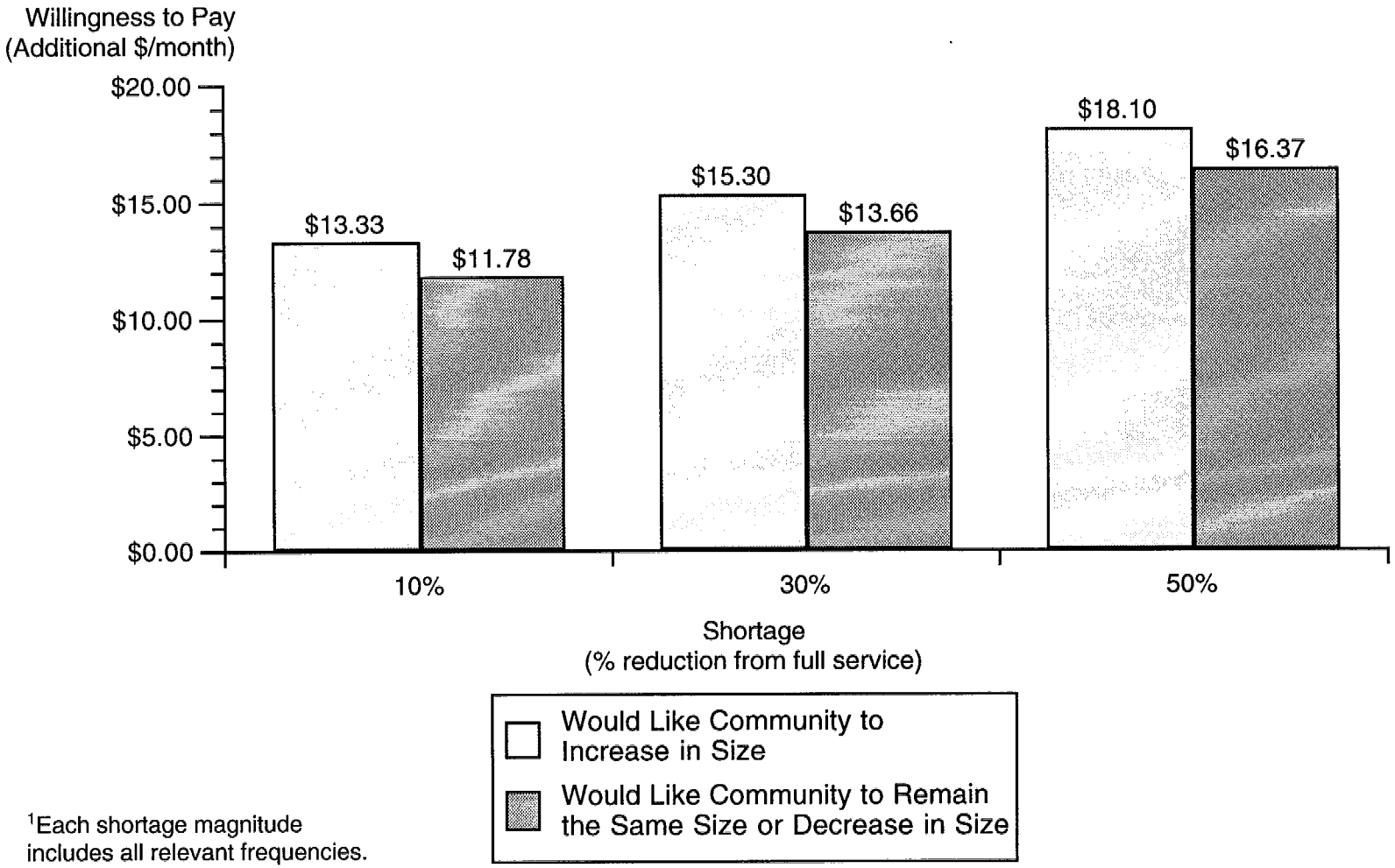
Figure S–4

Effect of Population Growth Preferences on Willingness to Pay[1]



[1]Each shortage magnitude includes all relevant frequencies.

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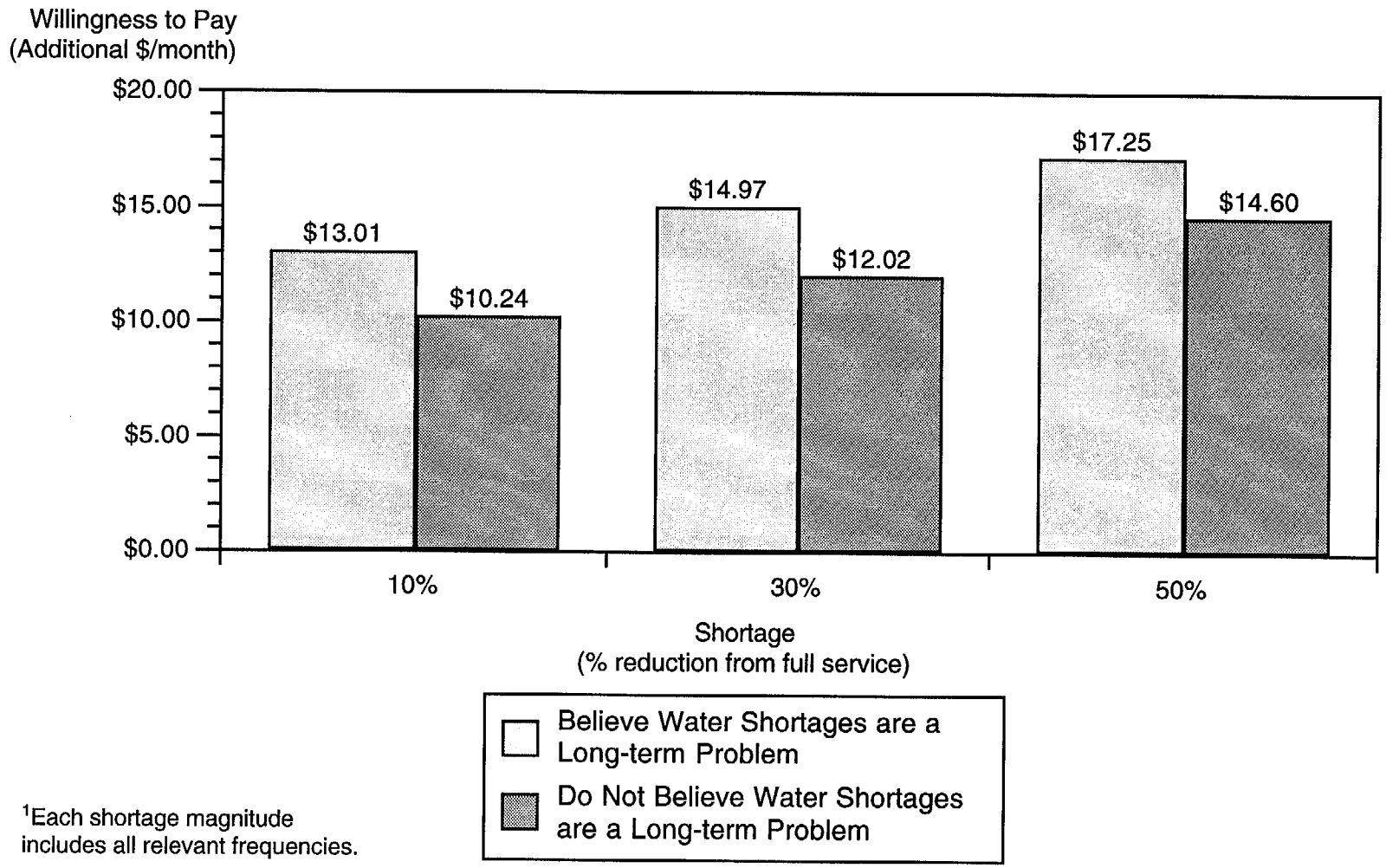
Figure S–5

Effect of Perception of Water Shortages as a Long-term Problem on Willingness to Pay



[1]Each shortage magnitude includes all relevant frequencies.

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Perception of Water Shortages as a Long-Term Problem

Survey respondents were asked to what extent they considered water shortages to be a long-term problem in their area. Those who considered the water shortages to be a long-term problem have higher WTP than those who do not. WTP for these two groups is illustrated in Figure S-5.

Regional Comparisons

An analysis was done to determine whether Northern California respondents had different WTP than Southern California respondents. To isolate the variation that is due to regional differences, a variable NORTH was included in the model. The variable was set equal to 1 if the respondent was in the service area of:

- Alameda County Water District
- Contra Costa Water District
- San Francisco Public Utilities Commission
- Santa Clara Valley Water District

The variable was set to 0 if the respondent was in the service area of:

- Los Angeles Department of Water and Power
- Metropolitan Water District of Southern California
- Municipal Water District of Orange County
- Orange County Water District
- San Diego County Water Authority
- City of San Diego

Although all Southern California mean values are slightly lower than the corresponding Northern California mean values, the variable "North" was not statistically different from zero.

Separate models were then run for the Northern California and Southern California agencies to determine whether, apart from a difference that could be attributed to living in Northern or Southern California, there were demographic and attitudinal differences that were captured in other model variables and that resulted in different estimates of WTP for the two populations. The results, illustrated in Table S-2, indicate no significant differences in WTP.

Table S-2
MEAN MONTHLY WILLINGNESS TO PAY, BY REGION
(Additional $/Month)

Shortage (% Reduction from Full Service)	Frequency (One Occurrence in X Years)	Northern California	Southern California
10%	10	$12.32	$11.13
10%	5	$12.70	$11.50
10%	3	$12.85	$11.64
20%	30	$12.10	$11.19
20%	20	$12.85	$11.93
20%	10	$13.63	$12.68
30%	30	$13.40	$12.75
30%	20	$14.19	$13.52
30%	10	$14.99	$14.32
40%	30	$14.75	$14.38
40%	20	$15.57	$15.20
40%	10	$16.40	$16.02
50%	30	$16.15	$16.09
50%	20	$16.99	$16.93

The confidence interval for the Southern California model is +/- $0.51; the confidence interval for the Northern California model is +/-$0.63. Except at the 10% shortage magnitude, the differences all fall within the overlapping confidence intervals. Given that the confidence interval is underestimated at that level because there are fewer observations, it is likely that the actual confidence intervals overlap at the 10% shortage as well and that there is therefore no statistically significant difference in WTP between Northern and Southern California respondents.

Water Shortages as a Public Concern

In the survey, respondents were asked to rate the importance of various public problems, including water shortages, as "not at all important," "somewhat important," or "very important." There were three reasons for asking this question:

- To analyze the extent to which concern with any given set of issues (e.g., financial issues) affected willingness to pay.

- To test the perceived importance of water shortages relative to other public issues.

- To see how respondents categorized water shortages. With what other issues are water shortages associated?

Overall, the mean response for each issue is illustrated in Table S-3.

Water shortages fall in the middle of the list of concerns.[2]

The factor analysis showed that respondents grouped issues as illustrated in Table S-4. Water shortages fall into the category that includes issues that can best be described as having public service components. The factors are ranked within each category according to the strength of their rating in the factor analysis.

Each of the four factors was included in the model as a binary variable to test its explanatory impact on WTP.[3] Each of these variables was assigned the value of 1 if the mean value of all of a respondent's ratings for the issues included in that factor exceeded the value assigned to the water shortage issue, and zero otherwise. For the combined CUWA results, the social concerns, quality of life, and financial factors are statistically significant in explaining WTP. Respondents who placed any of those concerns above their concern for water shortages had lower WTP.

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[2]It is possible that had this survey been conducted a year earlier, when the state was still in the grip of a serious drought, water shortages would have been viewed as much more of a concern.

[3]The "public services/environmental" factor included in the model excluded the water shortages variable.

Table S-3
ISSUE RANKING AND MEAN RESPONSE

Issue	Mean Rating	Standard Error
Economy	2.66	.0095
Drug abuse	2.38	.0126
Education	2.35	.0136
Housing costs	2.32	.0122
Taxes	2.31	.0123
Traffic	2.29	.0122
Crime	2.26	.0122
Drinking water quality	2.18	.0138
Water shortages	**2.17**	**.0129**
Air pollution	2.08	.0124
Homelessness	1.98	.0130
Overcrowding	1.92	.0129
Trash disposal	1.88	.0138
Racial issues	1.73	.0126

Table S-4
FACTOR ANALYSIS OF PUBLIC ISSUES

Public Services Concerns	Social Concerns	Quality of Life Concerns	Financial Concerns
Trash disposal	Crime	Overcrowding	Taxes
Education	Racial issues	Traffic	Economy
Water shortages	Drug abuse	Air pollution	
Homelessness			
Drinking water quality			

SUMMARY OF KEY CONCLUSIONS

The important conclusions that can be drawn from the analysis are as follows:

- Monthly willingness to pay higher residential water bills to avoid shortages ranged from $11.60 to $16.90. Individual agency results, while exhibiting some variation, are generally consistent with this range.

- As expected, respondents' willingness to pay increases with increasing magnitude and frequency of shortages.

- To avoid even apparently minor shortage scenarios (e.g. 10% once every 10 years), respondents are willing to pay substantial amounts. This type of "threshold" may indicate that respondents regard even a mild shortage scenario as an inconvenience that they want to avoid. They may make a greater distinction between "shortage" and "no shortage" than between different sizes or frequencies of shortages.

- Shortage frequency is not as important a determinant of willingness to pay as shortage magnitude. Residential customers appear to be more willing to tolerate frequent small shortages than infrequent large ones.

- There are no significant differences in willingness to pay between Northern California and Southern California respondents.

- The simplified model has virtually the same predictive power as the detailed model. Participating agencies who wish to replicate this type of analysis in the future can therefore use the simplified model rather than resurveying their customers to gather data on the remaining variables required for the detailed model.