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Derived Estimation of Willingness-to-Pay to Avoid Probabilistic Shortage

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Abstract

A mathematical programming approach is developed for deriving estimates of the willingness-to-pay of water customers for improvements in water supply reliability. Reliability is represented as a probability distribution of different shortage levels, allowing the valuation of different profiles of water supply reliability. The approach is examined analytically and a two-stage linear programming variant is developed for applied problems. The approach can be applied to estimate the willingness-to-pay for improved reliability of different classes of customers and for suggesting promising water conservation programs for different customer classes. An example application is presented to illustrate the approach.

Introduction

While much effort has been devoted to estimating the reliability of urban water supplies, little effort has been expended in developing methods to value different reliability profiles. Most recent attempts to value urban water supply reliability have been empirical, through the use of direct contingent valuation studies and have examined only one shortage level and frequency combination at a time (CUWA, 1994; Howe and Smith, 1993, 1994; Howe, et al., 1990).

The approach taken here provides somewhat more derived estimates of willingness-to-pay. Two-stage mathematical programming is used to estimate a customer's willingness-to-pay to avoid a particular and complete shortage probability distribution, given estimates of consumer willingness-to-pay to avoid implementing specific short- and long-term water conservation measures and estimates of the water conserving effectiveness of those measures. The method assumes expected value cost-minimizing behavior by the consumer, where the costs of specific conservation activities can be merely financial or include perceived costs (and benefits) as estimated by more focused contingent valuation studies. Additional limitations of these estimates of the willingness-to-pay to avoid a set of probabilistic shortages are discussed. In addition to providing an estimate of customer willingness-to-pay to avoid a given shortage probability distribution, the method also suggests the least-cost mix of long- and short-term water conservation measures for customers to implement in response to such a shortage profile.

This derived approach should have uses for a) estimating customer willingness-to-pay to avoid a set of probabilistic water shortages without the expense of situation-specific contingent valuation surveys of probabilistic situations, b) providing a check on the results of direct contingent valuation estimates of willingness-to-pay to avoid shortages, and c) suggesting promising designs for long- and short-term water conservation programs suitable to local conditions. However, implementation of the proposed approach often will require contingent valuation studies focused on customer willingness-to-pay to avoid implementing specific water conservation measures. Some difficulties with the approach are discussed later in the paper.

The greatest advantage of this method over other approaches to valuing water supply reliability is its ability to value an entire probability distribution of shortage levels. Other approaches to valuing shortages have examined single shortage levels with different probabilities (CUWA, 1994; Howe and Smith, 1993, 1994; Howe, et al., 1990) or merely examine different shortage levels with no frequency distribution. The fuller probabilistic incorporation of shortage levels allowed by the proposed method matches that provided by system planning and operation models (Ng and Kuczera, 1993).

The paper begins with an analytical formulation and solution of the problem and a discussion of the meaning of the solution conditions for this formulation. More practical two-stage linear and integer-linear programming formulations are then developed. The linear programming solution approach is then applied to an example problem. Finally, some implications and limitations of the approach are discussed and conclusions presented.

Analytical Formulation and Solution

The customer is assumed to seek the lowest expected value annualized cost combination of long and short-term water conservation measures that will allow accommodation of each level of a range of probabilistic shortages. The problem is formulated as a two-stage decision process. The decisions in the first stage consist of long-term conservation measures, with enduring water conservation effects, such as xeriscaping, toilet retrofitting, and installing other water-conserving plumbing fixtures. The costs of these measures are expressed by their annualized costs. Second-stage decisions are implementation of short-term water conservation measures for different shortage levels. The costs of these second-stage decisions are accounted for on an annual basis, but accrue only for years they are implemented. The costs of second-stage decisions are weighted by the probability of their corresponding shortage event.

The result is the following mathematical program, which minimizes the expected value of shortage costs over all shortage levels:

(1) $$\text{Min} \quad z = f(\underline{\mathbf{X}}_1) + \sum_{j=1}^{n} P(s_{ij})\, g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2ij})$$

Subject to

(2) $$h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j}) \quad s_j, \forall j,$$

where z is the minimum expected cost to accommodate (or overall willingness-to-pay to avoid) the entire discrete shortage probability distribution $P(s_j)$, where s_j is the jth of n levels of shortage imposed on the consumer. $\underline{\mathbf{X}}_1$ is the vector of long-term water conservation decision variables, with a total annualized cost of $f(\underline{\mathbf{X}}_1)$. $\underline{\mathbf{X}}_{2j}$ is the vector of short-term (drought) water conservation measures implemented in response to the jth level of shortage, whose total annualized cost is $g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})$, accounting for interaction of these short-term response costs with long-term water conservation decisions. The function $h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})$ represents the water conservation effectiveness of all water conservation measures taken relevant to a particular shortage level j.

The first-order solution conditions for this problem can be found using Lagrange multipliers. The Lagrangian for this problem is:

$$(3) \qquad L = f(\underline{\mathbf{X}}_1) + \sum_{j=1}^{n} P(s_j)\, g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j}) - \sum_{j=1}^{n} \lambda_j \,[h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j}) - s_j] \,.$$

The first-order solution conditions are:

$$(4) \qquad \frac{f(\underline{\mathbf{X}}_1)}{X_{1i}} + \sum_{j=1}^{n} P(s_j) \frac{g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{1i}} = \sum_{j=1}^{n} \lambda_j \frac{h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{1i}} \,, \forall \text{ i, and}$$

$$(5a) \qquad P(s_j) \frac{g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}} = \lambda_j \frac{h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}} \,, \forall \text{ j,k.}$$

Here the index i indicates a specific long-term conservation measure. Rearranging, this becomes:

$$(5b) \qquad \frac{\dfrac{g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}}}{\dfrac{h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}}} = \frac{\lambda_j}{P(s_j)} \,, \forall \text{ j,k.}$$

In words, condition 4 states that the marginal expected cost of implementing a particular long-term conservation measure (X_{1i}) should equal the summed marginal values of water use reductions resulting from implementation. Similarly, for short-term drought conservation decisions, condition 5a states that the expected marginal cost of implementing a particular short-term conservation measure k during a shortage of the jth level should equal the value of water conserved from the marginal implementation. Note that λ_j is the shadow price of water for each shortage level, which is the marginal value the customer or utility should be paying for acquiring additional water during shortages of the jth level, theoretically linking the economics of supply and demand management during drought. Equation 5b further implies that for each shortage level the ratio of marginal cost to marginal effectiveness must be equal for all short-term measures.

The two first-order conditions can be combined and rearranged, beginning with substituting a modified Equation 5 for λ_j in Equation 4 to yield:

$$(6a) \qquad \frac{f(\underline{\mathbf{X}}_1)}{X_{1i}} + \sum_{j=1}^{n} P(s_j) \frac{g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{1i}} = \sum_{j=1}^{n} P(s_j) \frac{h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{1i}} \frac{\dfrac{g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}}}{\dfrac{h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}}} \,, \forall \text{ i,k.}$$

Condition 6a implies that the least-cost implementation of long-term measures occurs where the marginal expected value cost of a long-term measure equals the expected marginal cost of any short-term measure k, when weighted by the ratios of marginal water conservation effectiveness. Where the marginal effectiveness of long-term conservation measures is unaffected by the implementation of short-term measures, $h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})/ \; X_{1i}$ is constant for all j. Under this condition Equation 6a becomes:

$$\text{(6b)} \quad \frac{\dfrac{f(\underline{\mathbf{X}}_1)}{X_{1i}} + \displaystyle\sum_{j=1}^{n} P(s_j) \frac{g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{1i}}}{\dfrac{h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{1i}}} = \sum_{j=1}^{n} P(s_j) \frac{\dfrac{g(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}}}{\dfrac{h(\underline{\mathbf{X}}_1, \underline{\mathbf{X}}_{2j})}{X_{2jk}}} \; , \forall \; i,k.$$

Since this result would hold true for any combination of long-term measures i and short-term measures k, each side of the above condition must equal a constant which applies to any single measure X_{1i} or X_{2jk}. This result implies that the marginal expected cost per marginal demand reduction should be equal for all water conservation measures, regardless of whether they are long-term or short-term conservation measures.

While the above derivations yield some theoretical insight into optimal design of conservation plans at the individual consumer level, they are of limited practical use. The functions f(), g(), and h() must be continuous, a problematic condition in real water supply systems. Also, available data on customer preferences, costs, and water conservation effectiveness cannot support the specification of these functions in any complex form. The next section develops a linear programming approach to solving a common, somewhat simpler form of the above problem.

Two-Stage Linear Programming Formulation

The above problem often can be formulated and solved easily as a two-stage linear program. Again, all costs are expressed in annualized terms, representing a year's implementation. The total annualized expected value cost of water conservation measures is represented by Equation 7, the objective function of the mathematical program. This objective is subject to several constraints. Equation 8 requires that the selection of long-term and contingent short-term conservation measures accommodates each shortage level in the shortage probability distribution. As a practical matter, the formulation must include enough water conservation measures to meet the most severe shortage represented, even if extreme conservation measures (such as emigration or importation of bottled water) are required. Equations 9 and 10 ensure that each conservation measure can be implemented only once.

Equation 11 allows some short-term conservation measures to be precluded by implementation of specific long-term measures. This constraint can be modified, as in Equation 12, to allow some short-term measures to be adopted only if accompanied by a particular long-term measure; for instance, drought pricing would be impossible without water metering. These two constraint types allow representation of mechanisms for "demand hardening," where implementation of long-term conservation reduces the effectiveness of short-term water conservation measures.

Equation 13 is added if there is no possibility of a measure being implemented in part, although in many cases this will be possible. With the addition of Equation 13, the problem becomes an integer-linear program; otherwise it can be solved as a linear program.

(7) $$\text{Min } z = \sum_{i=1}^{m} c_i X_{1i} + \sum_{j=1}^{n} p_j \sum_{k=1}^{r} c_{jk} X_{2jk}$$

Subject to:

(8) $$\sum_{i=1}^{m} q_{1i} X_{1i} + \sum_{k=1}^{r} q_{2jk} X_{2jk} \quad s_j, \forall j$$

(9) $X_{1i} \quad 1, \forall i$

(10) $X_{2jk} \quad 1, \forall j,k$

(11) $X_{1i} + X_{2jk} \quad 1$, $\forall$ j and $\forall$ k precluded by implementing i

(12) $X_{1i} - X_{2jk} \quad 0$, $\forall$ j and $\forall$ k requiring implementation of i

(13) Integer X_{1i} , $\forall$ i

where c_i = cost of long-term measure i (annualized),
c_{jk} = the annual cost of short-term measure k during shortage interval j,
m = number of long-term measures,
n = number of shortage levels (events),
p_j = probability of shortage interval j,
r = number of short-term measures,
q_{1i} = annual water saved by long-term measure i,
q_{2jk} = annual water saved by short-term measure k during shortage of interval j,
s_j = shortage amount for shortage interval j,
X_{1i} = 1 if long-term measure i is implemented, = 0 otherwise,
X_{2jk} = 1 if short-term measure k is implemented for event j, = 0 otherwise.

This formulation of the problem has m + r*n decision variables and at least m + r(n+1) + n*v constraints, where v is the number of conflicts or symbiotic relationships between long and short-term conservation measures (v m*n).

To accommodate common situations where shortages vary in duration, as well as magnitude (rate) and frequency, a joint shortage-rate and shortage-duration probability distribution can be employed. Replacing the shortage rate distribution $p(s_j)$ (with an assumed constant duration) with a joint shortage rate-duration distribution essentially adds to the number of shortage events characterized (n). This could be represented by adding another subscript to describe each event probability (p), type of shortage (s), and short-term conservation measure cost (c_k) and decision variable (X_{2k}). However, since the shortage event descriptions (rates, durations, and probabilities) are likely to result from system simulation modeling efforts (Hirsch, 1978), it seems most straight-forward to represent each shortage event as a single event (subscript j in the formulation above), with the effects of duration reflected in the estimation of the relevant cost coefficients c_{jk}, effectively increasing the number of shortage events n.

Illustrative Example

The approach is illustrated by an example. A particular class of household is assumed to have the following long and short-term conservation measures available:
Long-term measures:

1. retrofit first toilet from 3.5 gallons per flush (gpf) to 1.6 gpf,
2. retrofit second toilet from 3.5 gpf to 1.6 gpf,
3. reduce lawn area by 200 square feet, and
4. install a water-conserving shower head.

Short-term measures:

1. installation of a displacement device in toilet 1,
2. installation of a displacement device in toilet 2,
3. reduce lawn watering,
4. reduce lawn watering, given lawn area reduction,
5. eliminate lawn watering,
6. eliminate lawn watering, given lawn area reduction,
7. take shorter showers, and
8. take shorter showers, given water-conserving shower head.

This numbering of measures will apply to the relevant subscripts in the mathematical program. Some measures are mutually exclusive, both within the short-term measures and between long- and short-term water conservation measures. The costs, water-conserving effectiveness, and mutual interference of each water conservation measure is given in Table 1 and have values representative of those available from the literature (Schulman and Berk, 1994). In practice, estimates of effectiveness have been better studied than the actual and perceived costs of implementing specific water conservation measures. It is likely that contingent valuation studies of willingness-to-pay to avoid implementation would be required to develop cost coefficients for individual water conservation measures. Integer constraints are neglected in this problem, since many of the measures could be partially implemented, or implemented by only a fraction of the households in a particular class.

The mix, costs, and effectiveness of different water conservation measures would vary with different household types. The mix of measures chosen here might apply to existing single-family detached houses with several occupants.

For illustrative purposes, four alternative shortage probability distributions are examined. These might result from different capacity expansion or reservoir operation alternatives. The probability distributions for different shortage amounts appear in Table 2. The form of the shortage distributions has been kept artificially simple for purposes of illustration.

Some results of the linear programming solutions are found in Table 3. Estimates of willingness-to-pay to avoid a particular shortage entirely are given by the objective function value for each solved linear program. In this case, comparing shortage distributions A and B, the more dire shortage distribution (B) increases the estimated household willingness-to-pay to avoid shortage by $35.62/year from the lesser shortage distribution (A). Theoretically, households in this class would be willing to pay an additional $35.62/year to avoid shortage distribution B in favor of the more reliable distribution A. This sum might finance additional water source capacity, water market purchases, or conservation by other water users.

The more frequent shortages in distribution B also encourage significant long-term water conservation measures. The common-sense result is that long-term conservation efforts become more desirable as shortages become more frequent. As a consequence of adopting long-term water conservation measures for shortage distribution B, no short-term water conservation measures are needed for small levels of shortage and lesser reductions are needed for higher shortage levels.

For the most part, the fractional implementation of conservation measures is an artifact of the summed conserved amounts for full measure implementation not equaling the exact shortage amount. Other results are used to examine "demand hardening" effects.

Demand Hardening

A common concern of water conservation planners is the increasing difficulty and expense of achieving high short-term water conservation levels as more long-term conservation measures are implemented. This so-called "demand hardening" is illustrated by the reduced short-term (drought) water conservation potential arising from the implementation of low-flow toilets and xeriscaping. Both measures reduce the amount of normal water use, reducing the potential for water savings from short-term conservation and increasing the user inconvenience and cost of achieving short-term conservation from these water uses.

Demand hardening can be examined with this two-stage mathematical programming approach. The shortages from Table 2 for four increasingly severe shortage distributions are applied to the example household. The results in Table 3 indicate the effect of demand hardening, increased cost for short-term water conservation and increased overall costs with increased optimized long-term water conservation effort. The implementation of long-term measures 3 and 4 (reduction of lawn area and shower-head installation) reduced the ability to employ short-term measures 3 (reduced lawn watering during drought) and 5 (further elimination of lawn watering). This forced adoption of more expensive and less individually cost-effective water conservation measures 4 and 6. This is the economic process of demand hardening.

However, the importance of demand hardening is limited. While both the expected value of shortage and the probability of shortage doubled from scenario A to scenario B (from 25 gpm to 50 gpm and 0.2 to 0.4), the expected cost of responding increased only seventy percent. This less than proportionate increase in cost results from economies gained when long-term water conservation measures are employed; once implemented, long-term measures reduce water use regardless of shortage frequency or level. This effect is seen by the progressive reduction of short-term measure implementation for mild shortages under scenarios B and C, compared with scenario A.

The limitations of "demand hardening" effects for severe shortage conditions are illustrated by results for scenarios C and D. Here, demand hardening has no effect on measure selection, particularly since the most severe shortages are of equal severity (but different frequency). The only rise in expected value cost results from the more frequent implementation of short-term conservation measures. While some of these effects can result from the common range of shortages chosen for this example, both the consequences and limitations of demand hardening effects are illustrated by application of this mathematical programming approach. Greater "demand hardening" effects would result where water saved by long-term conservation were used to serve exogenous growth in water demands, effectively worsening the range of shortages seen by individual customers. With growth, long-term demand hardening effects must be traded against their short-term effectiveness at reducing short-term total demand and improving overall reliability. The current formulation of the problem takes a static view of this situation; long-term conservation measures are implemented without regard to potentially worsening or improving shortage conditions in the future. This longer-term feedback between reliability and demand might be addressed by stochastic dynamic programming formulations of the problems.

Discussion

The willingness-to-pay interpretation of the result rests on the assumption that the model's cost coefficients are estimates of the willingness-to-pay of customers to avoid implementing specific water conservation measures. For commercial and industrial customers, cost coefficients can be estimated directly based on financial costs of implementing specific water conservation measures. For residential customers, these implementation costs include both financial and inconvenience costs (and perhaps benefits from participation in a conservation ethic). Estimation of this full range of costs and benefits would likely require a contingent valuation or other non-market valuation technique. Such specific contingent valuation studies might be an improvement over direct contingent valuation studies of willingness-to-pay to avoid probabilistic shortages since the contingent valuation questionnaires would not require subjects to evaluate probability statements, but would only solicit evaluations of direct water conserving actions that subjects might take in response to shortages. Such a conservation measure-specific contingent valuation study is currently underway by Dr. Richard Berk at UCLA. These cost coefficients should also include the benefit of annual reduction in water bills from implementation of conservation measures.

In some cases, the proposed method should provide potentially useful information in the absence of rigorous, but probably more expensive, contingent valuation-based estimates of customer willingness-to-pay to avoid specific conservation measures. The use of purely financial methods for estimating model cost coefficients should provide a lower bound estimate of customer willingness-to-pay to system reliability, if inconvenience costs for implementing water conservation measures are thought to exceed any benefits customers perceive from fulfilling some environmental or community ethic. If the reverse is true, then the financially-derived willingness-to-pay to avoid shortages would be an upper bound on the true willingness-to-pay.

A further technical and behavioral limitation of the linear programming formulation is its assumption of few economies of scope and scale in implementing water conservation measures. It assumes implementation costs of water conservation measures are largely independent, whereas it is probably less than twice as inconvenient to retrofit two toilets as one. This problem can be remedied by adding additional constraints or moving to more of a dynamic programming formulation. These add only computational and formulation difficulties beyond the linear programming approach employed here.

Valuation of cost coefficients is almost always an estimation problem in itself. One advantage of the linear programming method applied here is its provision of some useful sensitivity analysis information, allowing the user to estimate the sensitivity of results to uncertainty in cost coefficient values. For example, sensitivity analysis results from the linear program solver indicate that, for case B, less than a sixty-percent increase in the cost of installing a water-conserving shower head (all else remaining the same) would not change the solution. For case A, the cost of retrofitting the first toilet would have to decrease from an annualized $9/yr to $5.60/yr to merit implementation. More complex and flexible sensitivity results can emerge from re-running the linear program for different sets of parameter values. Such sensitivity analyses are typically unavailable from direct empirical estimates of willingness-to-pay for system reliability.

Another advantage of the mathematical programming approach is its reliance on more detailed cost and willingness-to-pay estimates for specific water conservation measures. Such detailed costs should be more transferable between situations than aggregate estimates of willingness-to-pay for system reliability. This should allow the less costly estimation of willingness-to-pay for system reliability for a wider variety of household and land-use characteristics and shortage probability distributions with a more limited set of cost parameter estimates (perhaps empirically-derived by contingent valuation studies of willingness-to-pay to avoid specific conservation measures).

Engineering design and planning in water resources have long required estimates of willingness-to-pay (Dupuit, 1844). In engineering and planning practice, the mathematical programming approach for estimating willingness-to-pay for system reliability has additional applications and advantages. This quasi-derived approach is likely to be less expensive than direct contingent valuation alternatives. More importantly, the approach has a flexibility to examine a wide variety of explicitly stated shortage probability distributions, similar to those generated from water resource systems models (CUWA, 1993; Hirsch, 1978). The mathematical programming approach also might find use for the design of cost-effective water conservation programs for particular water use sectors, using the method to estimate explicitly the package of water conservation measures which is most for local shortage conditions.

There is a long-standing literature regarding behavioral problems with cost-minimizing expected-value decision-making assumed by this method (Khanemann and Tversky, 1979). Nevertheless, this approach should apply more strictly to estimating the willingness-to-pay of commercial, industrial, and institutional customers. The method also would have use for checking the reasonableness of direct empirical estimates of willingness-to-pay for system reliability and as a basis for the rational design of water conservation programs. From a public policy perspective, it may be desirable to act as if water users are rational. For public policy purposes, the use of expected-value decision making for such public policy problems, where losses are small relative to the societal scale and where individual losses are typically small relative to household incomes, is well-supported (Arrow and Lind, 1970).

Conclusions

A mathematical programming approach has been developed to estimate the willingness-to-pay of customers to avoid particular probability distributions of water shortages. If model cost coefficients are estimated as the willingness-to-pay to avoid implementing specific water conservation measures and consumers behave to minimize the expected value of perceived costs (without economies of scale and scope), then the mathematical programming results should be fair estimates of consumer willingness-to-pay to avoid a given set of probabilistic shortages. The approach has both advantages and disadvantages compared with direct contingent valuation approaches to estimating willingness-to-pay to avoid probabilistic shortages. The major advantages of this approach are an ability to explicitly consider a probability distribution of shortage levels, greater flexibility in examining a wide variety of shortage distributions with a relatively parsimonious data set, and derived rigor. The major disadvantages are assumption of expected value behavior and the difficulties of estimating customer willingness-to-pay to avoid implementing specific water conservation efforts. The approach also might find application in the design of water conservation programs.

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Table 1: Characteristics of long- and short-term measures for example problem

Number of short-term measure	c_{2jk}	q_{2jk}	Number of Long-term measure 1	2	3	4
1	1	4	X	-	-	-
2	1	2	-	X	-	-
3	150	80	-	-	X	-
4	100	60	-	-	R	-
5	400	160	-	-	X	-
6	350	120	-	-	R	-
7	20	2	-	-	-	X
8	25	1	-	-	-	R
c_{1i}:			9	9	25	1
q_{1i}:			12	6	50	2

X = measures are mutually exclusive, R = short-term measure requires long-term measure.

Table 2: Alternative Shortage Probability Distributions for Example

Shortage Interval	Shortage Amount (gpd)	Probability A	B	C	D
1	0	0.8	0.6	0.4	0.2
2	50	0.05	0.1	0.15	0.2
3	100	0.05	0.1	0.15	0.2
4	150	0.05	0.1	0.15	0.2
5	200	0.05	0.1	0.15	0.2

Table 3: Costs and Implemented Measures for Each Example Shortage Probability Distribution (partial implementation in parentheses)

	A	B
Estimated WTP ($/household-year)	51.03	86.65
Implemented long-term measures	none	4; 3 (88%)
Implemented short-term measures for each shortage level:		
No shortage	none	none
50 gpd shortage	1; 2; 3 (55%)	1
100 gpd shortage	1; 2; 3; 5 (9%)	1; 2; 4 (80%)
150 gpd shortage	1; 2; 3; 5 (40%)	1; 2; 3 (12%); 4 (88%); 5 (12%); 6 (14%)
200 gpd shortage	1; 2; 3; 5(71%)	1; 2; 3 (12%); 4 (88%); 5 (12%); 6 (55%)