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From: M.Cubed
To: East Bay Municipal Utility District

Reviewed by: Marcia Tobin (EDAW), Leslie Dumas (RMC), Bill Maddaus, Dr. Michael Hanemann

Re: Proposed Method for Calculating Customer Shortage Costs for Use in WSMP 2040 Portfolio Evaluations

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1 Purpose and Scope of TM

The purpose of this TM is to recommend a practical, informative and defensible approach to calculating customer shortage costs for use in the WSMP 2040 portfolio evaluations. The TM briefly describes WSMP 2040 objectives with respect to EBMUD rationing policy. It then discusses ways in which customer shortage costs are typically represented in planning studies, both in terms of physical impacts and economic costs. Next, the TM reviews alternative approaches to calculating customer shortage costs. Following this review, the TM presents the recommended approach for calculating customer shortage costs for use in the WSMP 2040 portfolio evaluations, discusses the data and modeling requirements to implement the approach, and provides an example calculation of customer shortage costs using the proposed approach.

2 WSMP 2040 Evaluation of District Rationing Policy

One purpose of the economic modeling being done for WSMP 2040 is to evaluate and compare various levels of customer water rationing among the ensemble of water supply portfolios. In this regard, the evaluation will model customer impacts and costs for a range of rationing scenarios. This analysis is to be done within the broader context of water supply portfolio evaluation, such that the combined costs of supply augmentation and customer shortages can be taken into account. At the conclusion of the economic analysis, a rationing policy recommendation is to be made to the Board of Directors. The recommendation will address:

- rationing reduction goals for various levels of projected total system storage;
- water use reduction targets by customer class; and

- the expected frequency and severity of future customer rationing under the recommended rationing policy.

3 Representation of Customer Shortage Costs

Planning studies generally present impacts of water shortages in two ways. One way is to describe and quantify the physical adjustments and impacts resulting from a shortage. The other way is to estimate the economic costs incurred by customers as a result of a water shortage. Both approaches provide useful information for water supply planning and management decisions.

3.1 Physical Characterization of Impacts

Physical characterization of impacts provides policy makers with qualitative and quantitative information about the severity and duration of customer water shortages, customer responses to drought management policies, and the direct and indirect consequences of a shortage to the community. For example, physical characterization of impacts may show that under Portfolio A the likelihood of shortages in excess of 20% is twice that under Portfolio B; or that under Portfolio A the average magnitude of a shortage is 15% whereas under Portfolio B it is 10%. Additionally, likely adjustments in customer water use can be described and quantified. For example, physical characterization of impacts may show that under Portfolio A, shortages within the residential sector are twice as likely to require outdoor water use restrictions than under Portfolio B. Thus, physical characterization of impacts can be used to describe the impacts of alternative rationing policies in terms that are easily visualized and relatable to everyday experience, and therefore is a useful way to convey to policy makers the consequences of different rationing policies.

Physical characterization of water shortages also can be used to generate an ordinal ranking of portfolios in terms of expected shortage costs. That is, it allows for statements such as: “Portfolio A has higher expected shortage costs than Portfolio B.” Importantly, however, it does not allow for statements such as: “Shortage costs under Portfolio A are three times those of Portfolio B.” Nor does it allow one to compare the total cost of different portfolios (i.e. the combined cost of supply augmentation and customer shortages). Evaluating the relative magnitude of shortage costs under alternative rationing policies, or comparing the total costs of different portfolios, requires translating physical impacts into economic impacts.

3.2 Economic Valuation of Impacts

Water users incur economic losses when they reduce their water use in response to rationing policies (Griffin 2006). A measure of this loss widely used in the economics literature is willingness-to-pay, which is defined as the maximum dollar amount individuals would have been willing to pay to avoid the water shortage (Dixon, et al. 1996). The concept of willingness-to-pay is applicable to all sectors of water demand (Griffin 2006). The sum of willingness-to-pay across customer sectors provides a measure of the total amount water users would be willing to invest to avoid similar shortages in the future.

To see how willingness-to-pay relates to water utility rationing policy, consider some typical actions taken by water utilities during shortages.[1]

- *Type-of-Use Restrictions*. Many water agencies use type-of-use restrictions during shortages, such as prohibiting the washing down of hard surfaces or restricting outdoor watering to certain days or to certain times of the day. Water users observing the restrictions forgo the net benefits of some water uses. Water users choosing not to observe the restrictions typically risk financial penalties or may even have their water service cutoff. Consequently, those water users impacted by such restrictions would be willing to pay some amount to avoid them.
- *Price Increases*. During shortages it is also common for water utilities to increase their water rates both to deter water use and for financial reasons. Increasing water rates impacts water users in two ways. First, water users will reduce water purchases in response to the higher price and forgo the net benefits of this consumption. Second, water users will pay more for a given amount of water than they would have paid before the price increase, thereby further reducing the net benefits of water consumption. To avoid these impacts, customers would be willing to pay up to the sum of the increased water costs on units consumed plus the forgone net benefits of the reduced water use.
- *Quantity Restrictions*. Water agencies may restrict the amount of water a water user or class of users can buy during a shortage. Water users affected by the restriction lose the net benefits of the forgone water use and would be willing to pay a positive amount to avoid the restriction.

Information on willingness to pay can be used to construct economic loss functions. Such loss functions can be used to value water shortage costs associated with different amounts of water supply reliability. Figure 1 illustrates the concept. It shows the average annual customer losses as a function of water delivery reliability. At low levels of reliability, expected customer losses are high. Shortage costs decrease as system reliability increases, reaching zero when the system achieves 100% reliability.

Once shortage impacts are converted into economic losses, it becomes possible to not only rank order water supply portfolios in terms of shortage costs, but to evaluate the magnitude of shortage costs. This is useful in at least two respects. First, it allows policy makers to evaluate the relative magnitude of shortage costs. Looking at Figure 1, for example, it can be determined that shortage costs for Portfolio C are 4.5 times higher than Portfolio A's, which in turn are 2.8 times higher than Portfolio B's. Second, it enables policy makers to assess tradeoffs between imposing costs on customers to increase system reliability versus imposing costs on them through increased frequency and/or severity of water shortages. Policies that increase customer rationing allow customers to avoid costs of developing and providing new supplies to meet dry year demands. The benefits of avoiding system development costs, however, must be balanced against the increase in water shortage costs customers would incur as a result of the policy. For

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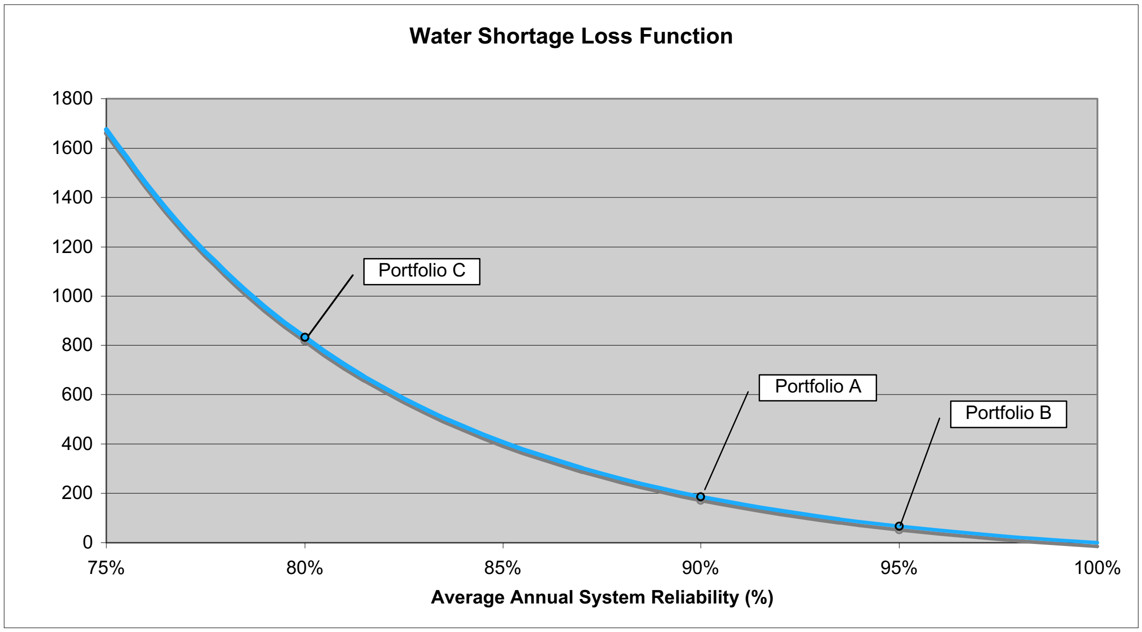
[1] The following discussion is adapted from Dixon, et al., 1996.

example, the loss function depicted in Figure 1 indicates that customers would be willing to pay up to $645 per year to move from Portfolio C to Portfolio A (the difference in annualized shortage costs between Portfolios C and A). Moving from Portfolio C to A would make customers better off only if the annualized cost of doing so were less than this amount. If, on the other hand, avoided shortage costs were less than the costs of moving from C to A, customers would be better off forgoing the system improvements. This comparative assessment of portfolio costs requires not only characterizing the physical impacts of water shortages, but also valuing them.

Figure 1. Illustration of Economic Loss Function for Water Shortages



By combining information on supply costs with information on shortage costs, it becomes possible to evaluate portfolios in terms of the total resource costs to customers (California Department of Water Resources 2007).[2] This is depicted in Figure 2, which shows three separate cost curves. The first is the customer shortage cost curve taken from Figure 1. The second curve shows incremental supply costs as a function of system reliability.[3] The third curve, derived by summing the first two curves, shows the total

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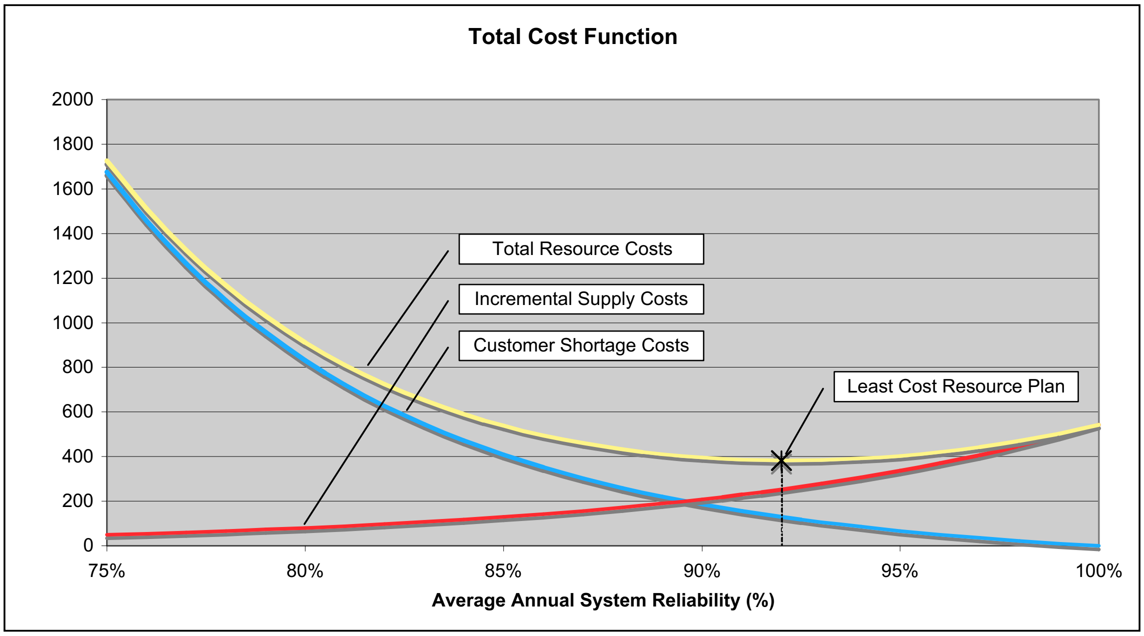
[2] This is the approach used by the Least-Cost Planning Simulation Model (LCPSIM) developed by the California Department of Water Resources. LCPSIM is a yearly time-step simulation/optimization model that was developed to assess the economic benefits and costs of enhancing urban water service reliability at the regional level.

[3] Note that the *incremental* cost is not the same as the *average* rate paid by a utility customer. Water utility rates are usually based on the total *average* cost to supply water, and the *incremental* cost may be only a small portion of these total costs. As a result, a large incremental cost may be reflected in a much smaller increase in the average utility rate.

incremental resource costs associated with each level of system reliability. The low point on this curve identifies the least cost resource plan, which defines the combination of system improvements and rationing policy yielding the lowest overall cost to customers. Portfolios will be located at different points along the total cost curve.

For WSMP 2040, WEAP will be used to estimate the incremental supply costs and the frequency, duration, and magnitude of water shortages for each portfolio. A shortage loss function can then be used to translate the physical shortages calculated by WEAP into economic costs. Shortage costs can then be added to incremental supply costs to calculate the total resource cost for each portfolio. Implementing this approach requires that we adopt a method for calculating customer willingness-to-pay to avoid water shortages.

Figure 2. Illustration of Total Resource Costs



4 Alternative Economic Valuation Methods

There are three basic approaches to quantifying the willingness-to-pay to avoid the consequences of water shortages (Brozovic, et al. 2007). One approach is to use survey techniques to directly elicit willingness-to-pay to avoid shortages from a representative sample of water customers. This is commonly referred to as the *stated preference method* in the economics literature. Another approach, the *mathematical programming method*, solves a cost minimization problem to identify the least cost combination of short- and long-term conservation measures that consumers could implement to avoid the impacts of water shortages. Estimated willingness-to-pay can be derived from the model solution values. A third approach uses demand curves to calculate the change in consumer surplus resulting from quantity restrictions or price increases.[4] This approach is sometimes referred to as the *demand curve integration method or the demand point expansion method*. In the discussion that follows, we refer to it as the demand curve integration method.

4.1 Stated Preference Method

This method provides a direct means of estimating willingness-to-pay based on stated preferences of a representative sample of water users. Contingent valuation survey techniques are used to pose various water shortage scenarios to survey participants and to ask them questions about their willingness-to-pay to avoid these shortage events. Econometric analysis is then applied to the survey responses to estimate a willingness-to-pay function.

The stated preference method has been used to estimate residential willingness-to-pay for increased water supply reliability by several previous studies. Two of these studies (CUWA 1994 and Carson & Mitchell 1987) evaluated the willingness-to-pay of Bay Area and Southern California residential water users to avoid probabilistic water shortages. An advantage of this approach is that it directly focuses on the question of interest and can measure willingness-to-pay caused by all different types of shortage impacts (Dixon et al. 1996).

The cost and time required to implement this approach make it infeasible for WSMP 2040. This leaves the possibility of using results from previous stated preference studies to develop shortage loss functions for WSMP 2040. We do not recommend this approach for the following reasons:

- The relatively small set of shortage scenarios evaluated by previous studies is a limiting factor for transferring results outside of the original study context.
- Results of previous stated preference studies may be upwardly biased. Jenkins, et al. (2003) point out that the two studies focusing on California urban water shortages used a survey format that has been shown to upwardly bias estimates of willingness-to-pay. Findings from Hensher et al. (2006) also suggest results from previous stated preference studies may be upwardly biased.
- Griffin and Mjelde (2000), using a contingent valuation survey designed to avoid biased responses, still found significant inconsistencies in their willingness-to-pay estimates. In their study, respondents stated higher *monthly* willingness-to-pay to avoid future, probabilistic water shortages than *total* willingness to pay to avoid

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[4] Consumer surplus is the excess that a consumer would be willing to pay for a commodity over the price that he does pay, rather than go without the commodity. It is a commonly used measure of the benefit consumers derive from consumption. As shown by Willig (1976), consumer surplus closely approximates willingness-to-pay under most circumstances.

immediate shortages of the same duration and severity, indicating that respondents did not have a clear understanding about what they were being asked to value.[5]

4.2 Mathematical Programming Method

The mathematical programming method sets up a cost minimization problem to select the least-cost mix of water savings alternatives to eliminate or manage a water shortage (Jenkins et al. 2003). Estimated willingness-to-pay can be derived from the model solution values. This approach can be combined with supply side cost information to solve the cost minimization problem previously illustrated in Figure 2.[6] Applications of this approach include Jenkins and Lund (2000), Wilchfort and Lund (1997), and Lund (1995).

The mathematical programming method is difficult to implement because it requires specification of the full costs of detailed conservation alternatives and actions, including non-market costs associated with changing habits and behaviors to reduce indoor and outdoor water use during shortages (Jenkins et al. 2003). In the absence of this data it is necessary to specify proxies for these costs. Jenkins and Lund (2000) note that estimates of consumer willingness-to-pay to avoid shortages can be used to approximate near-term shortage management costs. This strategy, however, makes willingness-to-pay an input to rather than output of the model, thereby defeating the purpose of using the method to estimate willingness-to-pay. We do not recommend the approach for this reason.

4.3 Demand Curve Integration Method

The demand curve integration method uses information on sector water uses, current water prices, and the price elasticity of demand to construct water demand functions. These functions are then used to analytically determine willingness-to-pay (Dixon et al. 1996).[7] This approach provides an economically robust and theoretically rigorous direct assessment of the value of water use (Jenkins et al. 2003). It has modest data requirements and can be implemented more quickly and cheaply than the other methods (Dixon et al. 1996).

The demand curve integration method relies on the basic theory of consumer demand to calculate consumer surplus losses associated with water shortages. Figure 3 illustrates the approach. The downward sloping line, MB(Q), in the Figure represents the demand schedule for water at alternative prices. It shows the quantity of water demanded at any given price P. It also shows the marginal benefit of water use for any usage Q. The area

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[5] The results from Griffin and Mjelde (2000) seem to corroborate Dixon et al. (1996)'s concern that respondents to stated preference surveys may have little experience valuing water shortage impacts and may not give realistic answers.

[6] While this appears to be similar to our proposed use of WEAP, there is a fundamental difference. WEAP is not an optimization model. It is a simulation model. While WEAP can be used to identify the total resource cost of each evaluated portfolio it cannot be used to identify the least-cost option, other than by trial and error.

[7] The price elasticity of demand is defined as the percentage change in demand for a commodity given a one percent change in the price of the commodity.

below the demand schedule and above the price line equals consumer surplus -- the excess that a consumers would be willing to pay for water over what they actually have to pay. Thus, at price P0 consumers would demand Q0 units of water and would derive consumer surplus equal to the area ABC in Figure 3. At price P1 consumers would demand Q1 units of water and consumer surplus would be reduced to area A.

The relationships illustrated in Figure 3 can be used to analytically determine what consumers would be willing to pay to avoid price increases or quantity restrictions on water use. For example, water users would be willing to pay at least an amount equal to the area C in Figure 3 to avoid a quantity restriction (assuming price remains unchanged) requiring them to reduce their usage from Q0 to Q1. Note however that most water agencies during the last drought cycle had to raise water rates either during or after the drought to make up for losses incurred due to quantity restrictions (Dixon et al. 1996). These rate increases would add to consumer losses resulting from a quantity restriction and thus the consumer surplus loss represented by the area C in Figure 3 should be viewed as a lower-bound estimate of willingness-to-pay to avoid the quantity restriction. If one assumes the utility will recover its revenue losses from customers in future periods, an approximate measure of the consumer surplus loss is given by an amount equal to area CE.[8] Willingness-to-pay to avoid a price increase can be assessed in a similar fashion. For example, water users would be willing to pay up to an amount equal to the area BC in Figure 3 to avoid an increase in price from P0 to P1.[9]

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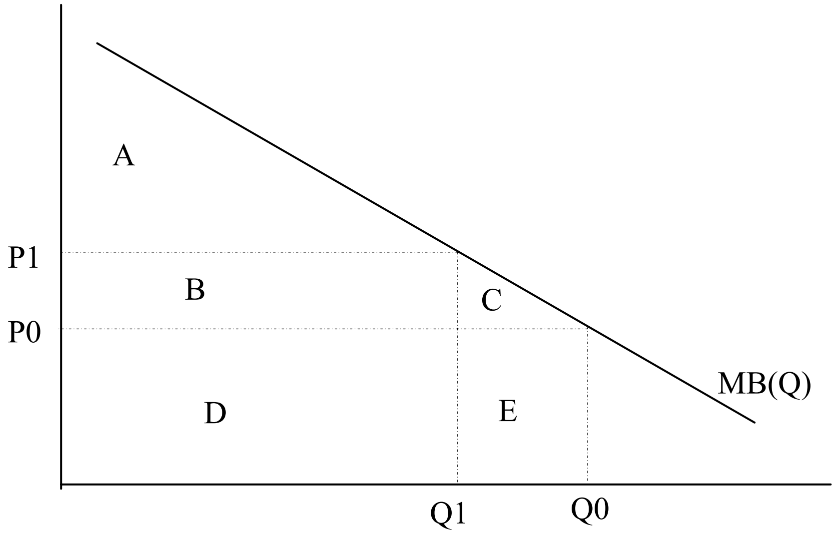
[8] The foregone revenue represented by area E in Figure 3 overstates the amount of revenue the utility would need to recover by an amount equal to the variable operating costs avoided by reducing water delivery from Q0 to Q1. Thus the area CE overstates to some extent customer losses.

[9] In the case of the price increase, the change in utility revenues equals B-E in Figure 3. When price elasticity is greater than -1, as is the case for water, this net change in revenue will be positive.

Figure 3. Illustration of Demand Curve Integration Method



Several studies have used the demand curve integration method to evaluate California urban water users' willingness-to-pay to avoid water shortages. Brozovic et al. (2007) estimated the willingness-to-pay of residential water users served by the Hetch Hetchy water system to avoid prolonged disruption of water service caused by natural or man-made catastrophes. Hanemann et al. (2006) used the method to evaluate water shortage impacts for San Joaquin Valley agricultural water users and Southern California urban water users under alternative climate change scenarios. Jenkins et al. (2003) used the approach to develop monthly economic loss functions for major urban water users throughout California. Dixon et al. (1996) used the method to evaluate shortage impacts of the 1987-92 drought for residential water users served by Alameda County Water District.

While the demand curve integration method is theoretically robust and pragmatic, it has several limitations. First, the method only provides a lower-bound estimate of willingness-to-pay because it implicitly assumes that rationing policies result in water users curtailing their lowest value water uses first. This is a reasonable assumption when pricing policies are used to curb demand, but may understate the willingness-to-pay to avoid quantity or type-of-use restrictions (Dixon et al., 1996). Second, the method relies on two-parameter specifications of demand – either linear or constant elasticity. While these specifications are mathematically convenient, it should not be presumed that water demand actually exhibits linearity or constant elasticity across the full range of water use (Griffin 2006). Third, the method requires price elasticity estimates for all water demand sectors. While there is a large body of research on residential price elasticity, estimates for commercial and industrial water demand are more limited (Jenkins et al. 2003).[10]

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[10] However, an implicit WTP method was developed for the commercial and industrial sector in the Bay Area for a previous shortage cost study (Brozovic et al. 2007), and this

5 Recommended Approach

Of the three methods considered, we believe the demand curve integration method is the best approach for estimating customer shortage costs for WSMP 2040. While the method has several important limitations, as described in the previous section, it has fewer drawbacks than the other two methods reviewed. Moreover, it has three key advantages over the other approaches. First, it has been used in several urban water planning studies with specific application to California urban water use. Second, it is straightforward to implement and can be easily integrated into the WEAP modeling framework. And third, it has modest data requirements that can be easily satisfied with EBMUD system data.

A draft of this memorandum was provided to Dr. Michael Hanemann, Chancellor's Professor of Agricultural and Natural Resource Economics at UC Berkeley and member of the CLAC, on October 5, 2007. We requested Professor Hanemann review our proposed methodology, indicate if he agreed with the approach, and suggest modifications if he had any. A conference call with Professor Hanemann was held on October 18, 2007 to discuss his review. Professor Hanemann indicated he agreed with the recommended approach and offered the following comments:

1. The analysis should use short-run demand elasticities to account for the immediacy and more limited response options of unpredictable and temporary shortage events.
2. Adjusting the demand forecast for variations in weather conditions would improve the shortage estimates. Higher demand generally correlates with years with higher than average temperatures and dry conditions. Hence use of normalized demands may bias downward to some extent shortage magnitude and cost estimates. Professor Hanemann indicated that the additional complications in modeling this would entail might not justify this refinement, however.
3. Consider truncating the shortage cost functions so that zero shortage costs are counted below some shortage threshold. He suggested 5%.

6 Specification of Shortage Cost Functions

Using the demand curve integration method, shortage cost functions can be derived from linear or constant elasticity demand curve specifications. Figure 4 provides an example of both demand curve specifications for an average residential water user. The curves assume baseline consumption of 304 gallons/day, baseline price of $1.72/CCF, and a price elasticity of -0.25. From Figure 5 it is seen that marginal values of water are higher under the constant elasticity specification than under the linear specification, and that this difference increases with water scarcity. Consequently, willingness-to-pay estimates derived from the linear and constant elasticity specifications will diverge as water shortages increase in magnitude. As will be discussed in a following section, this fact

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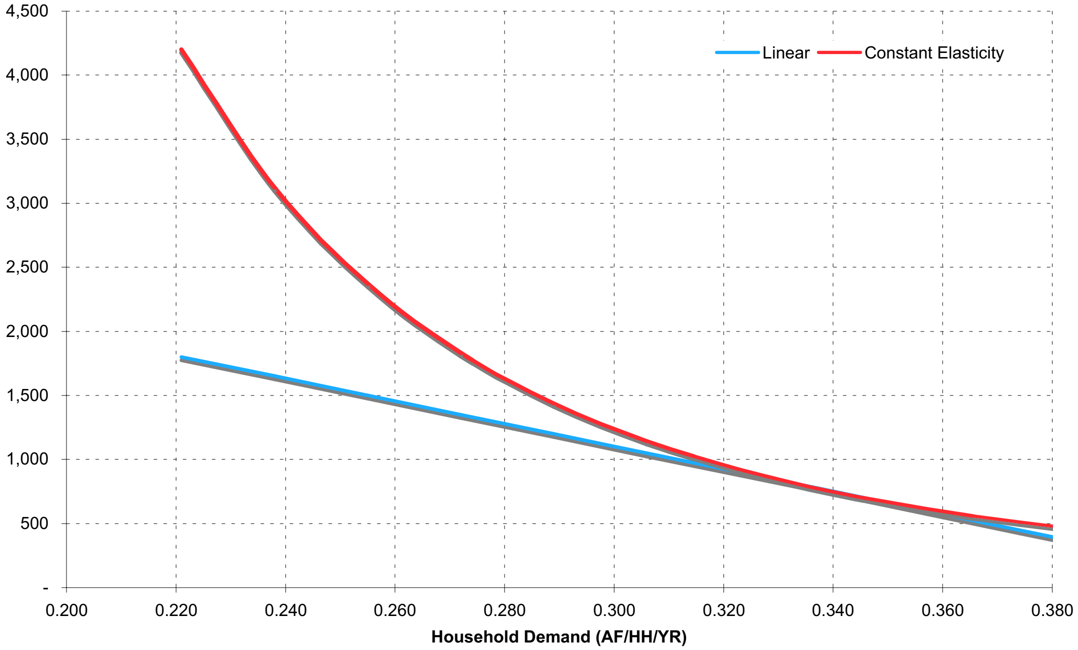
method may be an appropriate alternative if we are unsuccessful identifying suitable elasticity estimates for the commercial and industrial sectors. This method relied on estimates of regional economic output and the "resiliency" of specific industries to accommodate extended water shortages.

can be usefully exploited to construct lower and upper bound estimates of willingness-to-pay for use in WEAP.

Figure 4. Illustration of Linear and Constant Elasticity Household Demand Curves



6.1 Constant Elasticity Demand Specification

The price elasticity of demand for water at any price P and quantity Q is given by:

$$(1)\qquad \eta = \left(dQ \middle/ dP \right)\left(P \middle/ Q \right)$$

Rearranging terms in equation (1) and integrating gives an inverse demand function for water:

$$(2)\qquad P(Q) = e^{\frac{\ln Q}{\eta} + C},$$

where C is the integration constant, which can be expressed as a function of P0, Q0, and η:

$$(3)\qquad C = \frac{P0}{Q0^{\frac{1}{\eta}}}$$

The willingness-to-pay to avoid reducing water use from Q0 to Q1 is found by integrating equation (2) over the range [Q1,Q0]:

$$(4)\qquad WTP(Q1,Q0,P0,\eta)=\int_{Q1}^{Q0}P(Q)dQ=\frac{\eta}{1+\eta}P0Q0\left[1-\left(\frac{Q1}{Q0}\right)^{\frac{1+\eta}{\eta}}\right]$$

6.2 Linear Demand Specification

Under a linear specification of demand, the willingness-to-pay function to avoid reducing water use from Q0 to Q1 is given by equation (5)

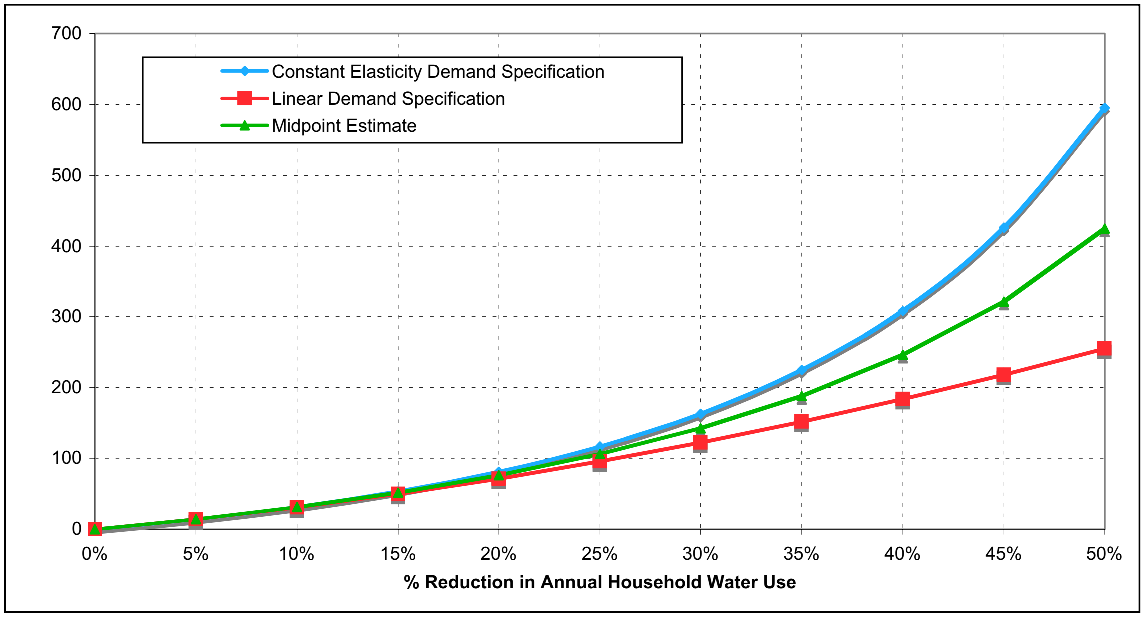
$$(5)\qquad WTP(Q1,Q0,P0,\eta)=P0\left(1-\frac{1}{\eta}\right)(Q0-Q1)+\frac{P0}{2\eta Q0}\left(Q0^2-Q1^2\right)$$

6.3 Example Shortage Cost Curves

Figure 5 shows illustrative shortage cost curves for residential water users using the same baseline assumptions that were used to derive the demand curves in Figure 4. Shortage costs are expressed in Figure 5 in dollars per household per year, but they could just as easily be expressed in dollars per acre-foot of shortage per year. WSMP 2040 modeling and presentation requirements can dictate choice of units.

The divergence in shortage cost estimates can be usefully exploited to construct low, medium, and high shortage cost estimates, as shown in the figure. Information on shortage impacts for very large shortages (> 35%) is very limited and uncertainty about the magnitude of impacts is much greater. The increasing spread between the low and high estimates serves as a proxy for this uncertainty in the shortage cost modeling.

Figure 5. Illustration of Residential Shortage Cost Curves



7 Data Requirements

Implementing the recommended approach for calculating water shortage costs requires information on baseline water use (Q0) and water rates (P0), the reduction in water use during a shortage (Q1), and an estimate of demand elasticity (η). Sources for these data are discussed below.

7.1 Baseline and Shortage Event Water Use

The WSMP 2040 demand forecast will used to construct the schedule of annual demands over the planning period for each customer sector and pressure zone. WEAP model output will be used to calculate deviations from baseline water use during shortages.

7.2 Water Rates

Baseline water rate assumptions will be developed in consultation with EBMUD staff. Rate assumptions for each customer class will be required. Rate assumptions may also need to be differentiated by pressure zone if analysis shows average rates paid by customers significantly differ by zone.

7.3 Price Elasticity of Demand

Price elasticity estimates will be drawn from the urban water demand literature. Espey et al. (1997), Renzetti (2002), Jenks et al. (2003), and Griffin (2006) provide good reviews on residential water demands and elasticity. Renzetti (2002) also summarizes past research on commercial and industrial water demand price elasticity. Final assumptions about elasticity to be used in the modeling of shortage costs will be developed in consultation with EBMUD staff.

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