Defining the Value & Cost of Water & their Uses in Utility Decision Making

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The value of water and the cost of water measure two different types of monetary worth. The value of water depends on how it is used and who is using it, while the cost of water depends on the type of water source and the available technologies that produce and distribute water of a given quality. This article discusses the different values and costs of water and how they can be used to make water supply investment decisions.

Historically, water utilities have been successful in providing safe, reliable water whenever and wherever it was wanted. Water utilities did not need to be concerned about the value of water because the cost of water was relatively inexpensive. In the recent past and currently, however, water utility managers realize they must become proactive in decision making regarding water resources management, water allocation, and economic development. They want to understand the concepts and values of water and how this information can be used in decision making.

Some of the trends that have caused this shift in thinking are:

- To meet the increased demand for improved drinking water quality and reliability, the cost of providing water will increase.
- Dividing the available freshwater sources among competing uses has become more difficult as the population grows and as freshwater is reserved for the environment.
- The rising importance of political-economic interactions when making water-source development decisions has complicated the job of providing safe, reliable water supplies. These interactions result from third-party concerns such as environmental risk or degradation, competition for limited water from the same source, competition for limited funding, and opportunity cost of land.
- In some areas, increasing human impacts on land and water resources have limited the number of new raw-water sources that can be used to meet human needs, or have reduced the quantity and/or quality of raw water available from historic sources.
- In some regions of the United States, subsidizing water supplies and/or economically inefficient water pricing policies for all types of human uses has led to heavy reliance on water as a factor of production in households, agriculture and industries.[1]
- Water utility decision making is constrained by various regulations that govern water supply development, water quality, ratemaking, and water allocation.

As a result, in some areas economic development is becoming constrained by the availability of reliable freshwater supplies or by contaminated freshwater sources. In other areas, water utilities are realizing that the ability to acquire additional freshwater supplies for a growing population is becoming more of a challenge and that the failure to provide adequate water supplies may hinder future economic growth.

Water utilities are realizing that they play an important role in economic development in terms of attracting and retaining businesses and providing essential services to communities. They also understand that their customers, who demand a safe, reliable water supply, also expect sound environmental protection and sound economic development.

Value of Water

Utility policy makers and utility managers across the United States are becoming more involved in debates and decisions regarding the "best" water uses and the "best" water allocation methods. Water utility management in the 21st century will evolve to encompass water allocation decisions and identification of opportunities to optimize water resource development and water use.

"Optimal" is defined as a decision that maximizes the present value of net benefits of water use. Water use includes consumptive, environmental, recreational, and aesthetic uses. Net benefit is the benefit of water use minus the cost of water use. Benefit is measured in monetary terms as the beneficiaries' maximum willingness-to-pay for the water. This is the value of the water to those who will benefit from or use the water. Willingness-to-pay varies by type of water user and type of use.

Willingness-to-pay is an economics term that means the maximum amount of money a person is willing to pay for a good or service of a particular quality. The value of water to individual users can be defined in at least two ways: marginal willingness-to-pay and total willingness-to-pay.

Marginal willingness-to-pay reflects the marginal value of water in a use by a user and is the maximum amount of money that the user is willing to pay for a tiny bit more water in that use. The total value of water in a use by a user is the maximum total amount of money the user would pay for the total block of water purchased for that use. The total value of water in all uses is the sum of the total value of water to all users and uses.

The willingness-to-pay for water can be inferred from estimated water demand equations. A water demand equation represents the amount of water that will be purchased (or produced, in the case of self-supplied water users) by a water-using entity during a certain period of time—typically a year—given water price or cost, weather, and factors

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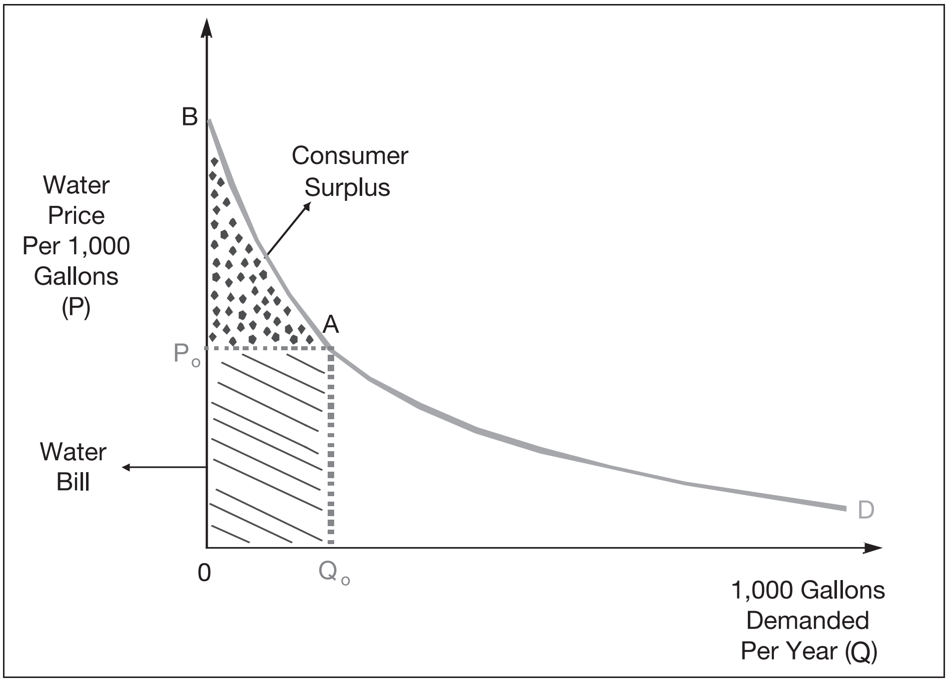

Figure 1: Graphical Representation of a Water Demand Equation for a Single-Family Household – Value of Water Equals Consumer Surplus Plus Water Bill.

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specific to a customer type that determine water use. Water-using entities can be single-family households, multi-family households, commercial businesses, and industries such as agriculture and mining.

The factors that influence water use may include the size of an irrigated area, the amount of commercial or industrial production, the number of employees, the water use efficiency of technologies being used (toilets, water cooling, production processing, cleaning, irrigation, etc.), household income or company profit, and the relative prices of other goods and services purchased by the entity.

Economists statistically estimate these water-demand equations in one of two ways: (1) using passively[2] generated data on water use and the associated values of the factors that determine use and/or (2) using the results of contingent valuation surveys. Separate demand equations are estimated for single-family residential customers, multi-family residential customers, and commercial/industrial/institutional customers providing or producing a specific good or service. The aggregate demand equation is the sum of the demand equations of the individual customers.

Properly estimated water-demand equations can be used to infer the value of water to water users.[3] A demand equation is graphically represented as a downward sloping curve with water price on the vertical axis and quantity demanded per year on the horizontal axis.

Such a representation is provided as Curve D in Figure 1. For the purposes of discussion, assume that this demand equation represents the water demand of an average single-family household customer of a water utility under average weather conditions.

The current variable price of water (price per 1,000 gallons purchased) is represented on the graph as Po. The total amount of water purchased by the household per year when the price is Po is Qo, as indicated on the graph. The area under the demand function between zero water demand and Qo water demand (area 0BAQo) is the total value of water used by the household. Because the value of potable water for drinking is very high, the demand equation crosses the vertical axis at a very high water price, so this area can be a rather large value.

The area represented by 0PoAQo is the annual water bill paid by the household that is collected under the variable rate (does not include the fixed-rate payment). The remaining area under the demand equation (PoBA) is called "consumer surplus" and is the value that the customer receives from water use that he or she gets to "keep" (minus the fixed charge on the water bill, which is typically very low relative to water value). This is the "net benefit" of water use to the customer.

When a household purchases a specific amount of water, we know that the household values that amount of water at least as high as the amount it actually paid for the water. Usually, the value is higher than the amount that was paid. Thus, at a given level of water use at a given price, we know that the net benefit of water at that use level is greater than zero.

Examples of marginal water values are provided in the AWWA Research Foundation Report titled, "Value of Water: Concepts, Estimates and Applications for Water Managers."[4] For residential customers of municipal systems, marginal water values estimated in various regions of the United States range from $4.30 per 1,000 gallons to $7.60 per 1,000 gallons. For commercial, institutional, and industrial customers, marginal water values range from $0.09 per 1,000 gallons to $2.47 per 1,000 gallons. For agricultural water users, marginal water values range from $0.08 to $2.59 per 1,000 gallons. For in-stream recreational uses, marginal water values range from $0.03 to $2.36 per 1,000 gallons.

The authors of this study advise that the values were estimated at specific locations for specific uses in specific time periods and may

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Table 1
Average Annual Value to Household from Eliminating Water Shortage Scenario
2005 Dollars Per Single-Family Household Per Year,
Water Shortage Duration is One Year

Water Shortage as % of Water Demand	Probability of Water Shortage						
	1%	5%	10%	20%	30%	40%	100%
	Once every 100 years	Once every 20 years	Once every 10 years	Once every 5 years	3 out of 10 years	4 out of 10 years	10 out of 10 years
	Value per Household per Year						
10%			$4.32	$8.65	$12.97	$17.30	$43.25
15%			$7.40	$14.80	$22.19	$29.59	$73.97
20%			$11.59	$23.16			$115.84
30%			$26.03				$260.33
40%	$6.10	$30.47	$60.94				
50%	$14.93	$74.66					
60%	$44.63	$223.13					

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not be directly transferable to other situations; however, this example demonstrates that water values can be successfully estimated.

A water project may have benefits in addition to supplying potable water. Some projects may reduce the use of existing water projects that have detrimental environmental effects, while others may provide additional water for aquifer recharge. The value of these benefits can be estimated and included in a benefit-cost analysis of water supply alternatives.

Table 2
Breakeven Cost of Additional Water Supply to Move from Water Shortage Scenario to No Shortage - Water Shortage Duration is One Year (a)

Water Shortage as % of Water Demand	Probability of Water Shortage						
	1%	5%	10%	20%	30%	40%	100%
	Once every 100 years	Once every 20 years	Once every 10 years	Once every 5 years	3 out of 10 years	4 out of 10 years	10 out of 10 years
	Breakeven Cost of New Project Per 1,000 Gallons						
10%			$0.63	$1.20	$1.71	$2.18	$4.52
15%			$0.68	$1.30	$1.88	$2.38	$4.97
20%			$0.89	$1.67			$6.36
30%			$1.62				$12.16
40%	$0.35	$1.74	$3.33				
50%	$0.78	$3.82					
60%	$2.08	$10.13					

(a) Also represents the user value per 1,000 gallons to move from shortage scenario to no shortage. Breakeven Cost means benefits of additional supply equal to costs of additional supply where the cost is per 1,000 gallons of additional water produced when the project is producing water (Includes 100% of the Capital and O&M Cost in 2005 dollars). Single-family residential households in southwest Florida. Example - To avoid a 10% water shortage once every 10 years, a new water supply project that costs less than $0.63 per 1,000 gallons would be economically feasible (benefits greater than costs).

Use of Water Values in Decision Making

A water utility manager contemplating the affordability of additional water supply to meet increasing water demands, after estimating a marginal water value of $5 per 1,000 gallons, would know that he or she could develop additional water supplies as long as the cost did not exceed $5 per 1,000 gallons. Since the marginal value of water falls as the amount of water use increases, there is a limit to how much additional water the utility should provide before the marginal cost exceeds the marginal value. A water demand study would address this issue.

Water values associated with the direct water users can be used to determine whether water customers are willing to pay the cost of reducing or eliminating water shortages. Using the estimated water demand equation for single-family households in southwest Florida, the average annual household willingness-to-pay to eliminate alternative water shortage scenarios is provided in Table 1.[5]

The willingness-to-pay values presented here are for illustrative purposes, where general assumptions were made regarding customer characteristics and water use. Individual utilities would want to start the model from the beginning with utility-specific water use and customer information to generate utility-specific willingness-to-pay values.

The average household would be willing to pay as much as $4.32 per year to avoid a 10-percent water shortage once every 10 years. This value increases as the frequency and/or extent of the water shortage increases. The value per household increases to $29.59 per year to avoid a 15-percent water shortage every four out of 10 years and $43.25 per year to avoid a 10-percent water shortage every year. To avoid a 30-percent water shortage every year, the average household would be willing to pay as much as $260 per year.

These values translate into the breakeven cost of eliminating water shortages as presented in Table 2.

Breakeven Cost means the benefits of additional water supply are equal to the costs of additional supply where the cost is per 1,000 gallons of additional water produced when the project is producing water. The breakeven cost represents 100 percent of the capital and O&M costs in 2005 dollars. Breakeven cost also represents the user value per 1,000 gallons to move from a water shortage scenario to no shortage.

Each cell in the table represents the breakeven cost of the water project that eliminates the water shortage, given the magnitude of the shortage and the probability that the water shortage will occur. For example, to avoid a 10-percent water shortage once every 10 years, a water supply project that costs less than $0.63 per 1,000 gallons in 2005 dollars and eliminates the water shortage would be economically feasible and worthy of consideration. This breakeven cost does not include all other costs associated with delivering water to customers; it just represents the cost of the new project.

As the probability of a given water shortage increases, the breakeven project cost increases because customers are willing to pay more to eliminate more frequent shortages. For example, the breakeven cost increases to $4.52 per 1,000 gallons when the frequency of the 10-percent shortage occurs every year.

As the size of the water shortage increases, the breakeven project cost also increases. For example, the breakeven cost is $0.89 per 1,000 gallons if the magnitude of the water shortage increases to 20 percent shortage every ten years. If the 20-percent water shortage were to occur every year, then the breakeven cost is $6.36 per 1,000 gallons.

The breakeven cost of 40-percent and 50-percent water shortages that occur once every 100 years is relatively low ($0.35 to $0.78 per 1,000 gallons) until the magnitude of the water shortage increases to 60 percent. In this case, the breakeven cost increases to $2.08 per 1,000 gallons.

The circumstances of such a severe shortage under current conditions may not exist, so planning for such an event may not be necessary; however, while a utility may not choose to build a water supply project just to use once every 100 years, this value should be considered when determining the future "optimal" mix of water supply and water conservation projects that have as a benefit the elimination of severe yet infrequent shortages.

The breakeven costs of each water shortage scenario presented in Table 2 are not additive unless each water project can eliminate only one water shortage scenario without changing the probability of the other potential

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Table 3
Average Cost of New Water Projects in Southwest Florida

Type of Water Project	Cost per 1,000 Gallons in 2005 Dollars (includes capital and O&M costs)
Conservation	
Agriculture	$0.45 per 1,000 gallons saved
Public Supply	$0.67 per 1,000 gallons saved
Non-Public Supply	$0.11 per 1,000 gallons saved
Desalination	
Seawater	$2.56 to $4.55 per 1,000 gallons produced (a)
Brackish Water	$2.55 per 1,000 gallons produced
Reclaimed Water	$1.30 per 1,000 gallons produced
Surface Water	
Potable	$1.67 to $2.72 per 1,000 gallons produced (b)
Urban Irrigation	$2.08 to $2.72 per 1,000 gallons produced (b)

(a) Costs are sensitive to quality of water source and availability of effluent disposal methods.
(b) Costs are sensitive to water source quality and storage methods.
Source: Hazen and Sawyer, "Statement of Estimated Regulatory Costs for the Southern Water Use Caution Area II Rule-making", prepared for the Southwest Florida Water Management District, Brooksville, Florida, February 6, 2006, Table 5.2-2 on page 5-9.

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shortage scenarios. In practice, water projects change the probabilities of all or most of the potential water-shortage magnitudes.

For example, a project that eliminates a 15-percent shortage every five years will likely also eliminate a 10-percent shortage every five and 10 years. To estimate the breakeven cost of multiple water shortage scenarios, the model must be rerun considering the initial probability distribution of water shortages without the project and the resulting probability distribution of water shortages with the project.

Cost of Water & Its Use in Decision Making

The cost of water includes the capital cost to construct water supply projects or the upfront cost associated with water conservation programs and the annual operations and maintenance (O&M), or annual recurring costs.

A water project may have costs in addition to the direct costs of supplying potable water. These costs are called external costs. Examples of external costs include loss of wetland functions, the drying of private wells, soil subsidence, lost recreation opportunities, and lowered property values from lowered lake levels.

The value of these costs can be estimated and included in a benefit-cost analysis of water supply alternatives. When all benefits and costs of a water project are considered, recommendations regarding the types of new water sources that should be developed may be different from those chosen based on direct benefits and costs to the utility and its water customers.

As an example, the average capital and annual O&M (or recurring) costs associated with new alternative source projects in southwest Florida are provided in Table 3. Alternative source water projects are those that do not rely on already-stressed ground and surface water sources in Southwest Florida.

Comparison of the new water project costs in Table 3 to the value of water under various water shortage scenarios in Table 2 shows that the benefits of water conservation outweigh the costs of conservation for all but one shortage scenario. That is, the breakeven costs of Table 2 are greater than the estimated new project costs presented in Table 3, except for the scenario of a 10-percent water shortage once every 10 years.

In this scenario, public-supply water conservation programs cost about $0.67 per 1,000 gallons, while the water-use value per 1,000 gallons is $0.63. In this case, if the less-expensive non-public supply or agricultural conservation can free up water for other uses, then this 10-percent water shortage scenario can be eliminated through conservation programs.

It is likely that large water shortages can not be prevented with additional water conservation only. A combination of water conservation programs and one or more water supply projects would be needed.

To evaluate a combination of projects, the utility begins with a table of the breakeven costs of all existing potential water shortage scenarios. The breakeven cost of each scenario is compared to the new water project costs per 1,000 gallons at increasing levels of water shortage frequency and extent until the new project cost is greater then the breakeven cost. Then the least cost combination of projects that eliminate the largest economically feasible water shortage scenario is chosen.[6] To determine the resulting potential water shortage scenarios by frequency and extent, the water shortage model is rerun considering the new project combination.

Using Table 2 as an example (which is not meant to be a realistic table of potential water shortage scenarios for a utility, but a table of values associated with different scenarios), the most severe water shortage scenario included in the table is a 30-percent water shortage every year. The value to households of eliminating this shortage is $12.16 per 1,000 gallons (or $260 per year).

Fortunately, the highest cost project that could eliminate this water shortage is desalination at $4.55 per 1,000 gallons, so it is economically feasible to eliminate this water shortage. As a result, other potential water shortages would be eliminated as well. The utility's water shortage model would be rerun with the 30-percent increase in water supply provided by the least-cost combination of water sources that cost less than $12.16 per 1,000 gallons to determine the potential water shortages that would still exist after the new projects are implemented.

The last column of Table 2 and Table 3 demonstrate that households are willing to pay a significant amount of money to avoid any magnitude of water shortage that occurs every year, such that most, if not all, of the current technologies for producing water would be economically feasible.

Summary & Conclusions

Today water utilities are realizing that the ability to acquire additional freshwater supplies for a growing population is becoming more of a challenge and that the failure to provide adequate water supplies may hinder economic development and slow future economic growth.

The challenges facing many water utilities today stem from many external influences. These include the increased demand for improved drinking water quality and reliability, competition among available freshwater sources, public concerns about environmental risk and degradation, increased human impacts on water resources, inefficient water pricing policies, and regulations.

Water utilities are realizing that they need to play a greater role in decisions regarding economic development and growth in terms of attracting and retaining businesses and providing essential services to communities. They also understand that their customers, who demand a safe, reliable water supply, also expect sound environmental protection and sound economic development. As a result, utilities want to understand the concepts and values of water and how this information can be used in decision making.

The value of water to water users is their willingness-to-pay, or the maximum amount of money a person is willing to pay for a good or service of a particular quality. The value of water to individual users can be defined in at least two ways: marginal willingness-to-pay and total willingness-to-pay.

The factors that influence household willingness-to-pay may include the size of an irrigated area, the water use efficiency of technologies being used and frequency of use (toilets, appliances, irrigation, etc.), household income, and the relative prices of other goods and services purchased by the household.

The factors that influence commercial and industrial willingness-to-pay may include the amount of commercial or industrial production, the number of employees, the water use efficiency of technologies being used (water cooling, production, processing, cleaning, irrigation, etc), company profit, and the relative prices of other goods and services purchased by the company.

Properly estimated water demand equations can be used to infer the value of water to water users. A demand equation is graphically represented as a downward sloping curve with water price on the vertical axis and quantity demanded per year on the horizontal axis. In the case of household water use, the demand equation crosses the vertical axis at a very high water price because the value of potable water for drinking is very high. The value of water in the graphical representation of the demand equation is the sum of the water bill and consumer surplus. Consumer surplus is the value that the customer receives from water use that he or she gets to "keep."

Examples of marginal water values are provided in the AWWARF Report titled, "Value of Water: Concepts, Estimates and Applications for Water Managers." For residential customers of municipal systems, marginal water values estimated in various regions of the United States range from $4.30 per 1,000 gallons to $7.60 per 1,000 gallons. For commercial, institutional and industrial customers, marginal water values range from $0.09 per 1,000 gallons to $2.47 per 1,000 gallons. For agricultural water users, marginal water values range from $0.08 to $2.59 per 1,000 gallons. For in-stream recreational uses, marginal water values range from $0.03 to $2.36 per 1,000 gallons.

The authors of this study advise that the values were estimated at specific locations for specific uses in specific time periods and may not be directly transferable to other situations, but this example demonstrates that water values can be successfully estimated.

The direct cost of water includes the capital cost to construct water supply projects or the upfront cost associated with water conservation programs and the annual operations and maintenance (O&M) or annual recurring costs.

When external benefits are considered, then the value of these benefits, such as aquifer recharge, improved environmental quality, etc., are included in the benefits of water supply. When external costs are considered, then the values of lost benefits from environmental degradation, lost recreation opportunities, etc., are included in the cost of water supply. The values of these benefits and costs can be estimated and included in a benefit-cost analysis of alternative water projects.

When all benefits and costs of a water project are considered, recommendations regarding the types of new water sources that should be developed may be different from those chosen based on direct benefits and costs to the utility and its water customers.

A water utility manager contemplating the affordability of additional water supply to meet increasing water demands, after estimating a marginal water value of $5 per 1,000 gallons, would know that he or she could develop additional water supplies as long as the cost did not exceed $5 per 1,000 gallons. Since the marginal value of water falls as the amount of water use increases, there is a limit to how much additional water the utility should provide before the marginal cost exceeds the marginal value. A water demand study would address this issue.

Water values associated with the direct water users can be used to determine whether water customers are willing to pay the cost of reducing or eliminating water shortages. Using the estimated water demand equation for single-family households in southwest Florida, the average annual household willingness-to-pay to eliminate water shortage scenarios was calculated and converted to the breakeven cost of additional water supply per 1,000 gallons of water produced (or saved in the case of conservation).

Breakeven cost means the benefits of additional water supply are equal to the costs of additional water supply where the cost is per 1,000 gallons of additional water produced when the project is producing water. The breakeven cost represents 100 percent of the capital and O&M costs in 2005 dollars. Breakeven cost also represents the user value per 1,000 gallons to move from a water shortage scenario to no shortage.

The breakeven costs of water shortage scenarios that vary by frequency and extent were compared to the average estimated costs of water conservation and alternative water supply projects contemplated in southwest Florida. Alternative source water projects are those that do not rely on already-stressed groundwater and surface water sources in southwest Florida. The analysis showed that single-family households in southwest Florida are willing to pay more than the cost of most, if not all, types of alternative water supply projects that eliminate potential future water shortages.

This article described the values and costs of water—particularly publicly supplied water—and demonstrates that single-family households place high values on reliable water supplies. These values are higher than the costs of most new water supply projects. Such information is useful in decision making by utilities as they face a variety of challenges in their mission to provide safe, reliable water supplies.

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References

[1] *Economic efficiency is achieved when the allocation of productive resources creates as much value as possible from a given quantity of resources. An action moves the economy toward efficiency if the benefits of the action are greater than the costs of the action.*

[2] *Passively generated data is data collected from observing human behavior. The data are not generated from an experiment where factors can be controlled to conform to the model being estimated; therefore, much care is needed to obtain valid statistical estimates using passively generated data.*

[3] *See also Scott J. Callan and Janet M. Thomas, "Environmental Economics and Management, Theory, Policy and Applications", Richard D. Irwin, a Times Mirror Higher Education Group, Inc., 1996, pages 61-62.*

[4] *Stratus Consulting, Inc., "The Value of Water: Concepts, Estimates and Applications for Water Managers", #2855, sponsored and published by American Water Works Association Research Foundation, Denver, Colorado, 2005.*

[5] *This example is from Grace Johns, Hazen and Sawyer, "Customer Preferences for Water Supply Reliability", Conference Proceedings, Florida Section American Water Works Association, 2002.*

[6] *A project is economically feasible if the benefits are greater than the costs.*