# The Economic Value of Water

**By Charles D. D. Howard, P. Eng.**
**Sr. Advisor on Water Management**
**Victoria, BC, Canada**
**cddhoward@shaw.ca**

## Introduction

The value of water has three components:

1. Existence value,
2. Aesthetic and environmental value,
3. Economic value.

To some extent these values overlap, depending on specific circumstances. The purpose of this paper is to examine the economic value of water based on a society's willingness to pay for it. In developing countries this may be a perverse concept that leads to inadequate water development and human hardship. In developed countries where alternatives can be substituted for some level of water consumption, the value of water based on willingness to pay can be a useful tool in establishing objective levels of service and design criteria for new facilities.

Water supplies like other commodities only have economic value in relation to their scarcity. Thus, the value of water is related to the reliability of its supply. And like some other commodities the value stems from its role in the production of other goods and services within society. So, estimates of the economic value of water must include measures of both its reliability and its impact on economic activity. There are well-established methods in water supply capacity expansion planning for estimating reliability and designing facilities to achieve a specified level of service. There are also well-established methods for estimating the impact of rate increases on water consumption. These two methodologies taken together can provide a basis for estimating the value of water within a specific region.

All water supply systems are unreliable to some degree. In practice, compromise leads to an appropriate level of reliability by considering the costs of minimizing inconveniences to customers. A similar situation exists in other industries, such as in telephones, and electric power. The concept of *quality of service* is widely recognized as a practical necessity by public utilities commissions and boards. But such a concept often eludes an objective analysis. Instead, an affordable criterion may be adopted by an industry. For telephones it may be the number of seconds before a dial tone is obtained. For electric power it may be the number of minutes per year without power. For water supply from reservoirs the reliability is often the supplies that substantially can be guaranteed in 49 years out of fifty, unless the costs are prohibitive. For urban water supply, the quality of service may be as high as affordable, or politically acceptable. An acceptable quality of service is particularly relevant when large rate increases are on the table, or plans are afoot to develop a new reservoir and at times of imminent shortage when decisions must be made about temporary curtailment of consumption.

## Reliability and Capacity of Individual Components,

The reliability of a water supply system depends on the reliability and capacity of individual components, the variability of demand, administrative, financial, and management factors, and on the level and pattern of demand for water of specified quality.

The reliability and capacity of individual components collectively contribute to the reliability of the system. This includes the reliability of constructed facilities, like pipelines, pumping stations, reservoirs, treatment plants, distribution channels, and pipe networks and especially the sources of supply –snow in the mountains and rainfall that feeds aquifers, rivers, and lakes. A prime objective of a water supply study is to determine the appropriate level of reliability of the overall system based on the reliability of the individual components of supply, and to specify the corresponding design and operation parameters.

## Demand and Consumption

Reliability also depends on the level of demand for water, and its variability and quality from place to place in the service area, and from hour to hour and from day to day. Storage, water transport, and water treatment capacities are planned and operated in an integrated manner to satisfy the demands at the appropriate level of reliability. Actual water consumption when shortages occur will be different from the latent demand. Thus the concept of "actual water consumption" incorporates consideration for reliability.

## Administrative, Financial, and Management factors

Administrative, financial, and management factors influence the reliability of water supply through their impact on:

- maintenance schedules,
- response time for repairs,
- construction materials,
- data acquisition and analysis,
- information management,
- employee innovation initiatives.

## Level Of Service And Risk Management

The level of service is sometimes a subjective consideration that is talked about but may not be defined rigorously. The level of service is a measure for evaluating the extent to which user expectations and service goals are met with the current infrastructure. In effect, level of service is the scorecard by which the water supply utility manages risks, which are stated in terms of the goals for the system. The level of service is the extent to which the goals will be achieved.

The *appropriate* level of service requires some degree of collective judgment, from utility staff and from a wider community of decision-makers. The factors in this judgment include past experience, knowledge of needs and costs, objective and subjective concerns, and personal and collective values. Once the level of service has been established, the management of risks is a job for utility staff. External and internal factors constantly challenge the system and require continuous readjustment and decision-making on the part of water managers.

The level of service may be described in terms of the system reliability and compared with individuals' concepts of the appropriate level of service. Water user's expectations must be determined objectively or deduced by some other means, such as perhaps political insight.

## What Do Water Customers Want?

An industry survey of water users (not water managers) in US cities tried to define "what customers want most from their local water utility", Table 1. Five basic requirements were identified in this survey, in the following order of priority:

- high quality water
- plentiful water at good pressure
- reasonably priced water
- access to information about water quality
- good customer service.

**Table 1. What Customers Want Most from Their Local Water Utility**

| Attribute | Percent |
|---|---|
| Clean water | 34 |
| Safe and healthy water | 34 |
| Good quality water | 16 |
| Water that looks and tastes good | 4 |
| Reasonably priced water | 6 |
| Plentiful water supply | 5 |
| Good customer service | 2 |
| Available on demand | 1 |
| Information on water quality | 1 |
| Good water pressure | 1 |
| Other | 15 |

Although it is not clear from Table 1, the variables of quality, quantity, and price are obviously interdependent. Increasingly, the price charged for sufficient water of good quality must reflect the full costs of delivery. As an example, it may be inexpensive to supply abundant quantities of low-grade water compared to producing large quantities of high-grade treated water. Water users in industry and in cities generally require water of high quality, in sufficient quantities, at a reasonable cost, in that order. Priorities may be different for irrigation.

The expectations of municipal water users also have begun to change regarding reliability of water quantities. Municipalities in the USA and in Canada, such as Vancouver and Victoria, now are accustomed to taking significant measures to curtail consumption during temporary shortfalls in supply.

Customers need to be aware of the aggregate impact their demand patterns have on the water supply system. Information, and price, are the key mechanisms that will heighten awareness to reduce supply costs, influence definition of the appropriate level of service, including quality, and protect the environment.

## Water Supply Quality

Expectations about water quality are in standards, including guidelines published by Health Canada, the Canadian Council of Resource and Environment Ministers, and the Ontario Ministries of Environment and Energy, and Health. A large amount of money has been spent exploring the hazards associated with exposure to a number of parameters in drinking water. These health effects assessments have established a basis for design of water treatment and delivery systems. Where health concerns supersede the need for unlimited supplies of water, they will establish the basic rationale for investments in treatment infrastructure, related supply and distribution works, and alternative sources of supply.

## Establishing Level of Service

Despite the best efforts of a utility to achieve its goals, there is always a probability of shortage, and there are consequences (or impacts) associated with this shortage. The goal should be to avoid a situation in which the cost of investing in measures to minimize risk of shortage will exceed the costs of shortage. To manage the risks of shortage, the municipality first must establish an acceptable level of service where *level of service includes the reliability with which the service goals can be achieved.*

A basic requirement in establishing the appropriate level of service is estimating the probability and costs of water supply shortages, whether caused by deficiencies in supply, delivery capacity, or water quality problems. Shortages seldom occur, data on them are scarce, and when they are over consumers tend to forget the problem until the next shortage occurs.

Many factors, some outside the technical control of the supply system, may affect the probability of shortages in water supplies. Non-technical factors include environmental regulations that influence operations, delays in approvals for developing new supply sources, rigorous water quality standards established by others, municipal budget allocations to water, political constraints on metering, price adjustments, and regional supply cooperation.

## Willingness to Pay to Avoid Shortages

The extent, duration, and frequency of supply shortages affect the average consumer and the commercial and industrial customers that depend on water for output of goods and services. Thus, there is a regional economic impact from shortages. If shortages are large, their cost to the regional economy will be disproportionably large. The value of the region's water supply may be much higher than its cost.

The costs of shortages vary widely. As an example, based on a service goal to meet demand at all times, the need to impose lawn-watering restrictions would constitute a shortage. Yet the economic impact could be reduced substantially with adequate information and warning so consumers have time to adjust. In contrast, without advance preparation, a water shortage during a major fire could result in significant losses to the community.

An economically sound method for calculating the value of water is to evaluate the consumer's willingness to pay for additional water supplies. In theory, the cost of a shortage would equal the amount that consumers would be willing to pay to offset it. Historical data on the effect of price increases on consumption can be used to make such estimates.

If shortages continue for extend periods of time, or are frequent, the consumers will make adjustments that are similar to those which would be made when faced with price increases. If shortages are unexpected, consumers will be caught unprepared and many would be willing to pay more to avoid such an event. How much more remains an open question. They would pay at least as much as indicated by historical price-consumption data.

Some types of shortage may have a greater level of acceptability than others. As noted by the waterworks industry survey, a failure to achieve the quality goals would be received less favorably than a failure to achieve quantity objectives. And the temporal and geographical extent of a shortage is important. Failing to meet pressure targets in a residential pressure zone for a few hours would be more publicly acceptable than uninterrupted low pressures for days or weeks in a hospital zone. These considerations affect how the customers perceive the goals of the utility, and therefore reflect the priorities for investing funds in infrastructure that is designed to make the system "more reliable".

Building redundancy into the water system reduces the probability of a water shortage. But how much redundancy is enough? Priorities for investments in redundancy within the water system may consider the risks they would offset.

## Inherent Risks – the Cost of Shortages

The probability of a shortage, and its associated economic costs - the product of shortage probability and cost is the *risk of the shortage*, expressed in dollars. For each type and level of shortage there is an associated risk. Consideration of all possible shortages will describe the probability distribution of the risk.

The annual expected value (the average annual value) of the regional economic losses during supply shortages, or facilities failures, is an inherent expense in operation and maintenance of the water supply. This risk is difficult to measure, and immune from GST, but nevertheless it is there. Making the appropriate capital investment in facilities that are redundant for normal operations could reduce this expense. The annual cost of capital invested to offset risks can be compared to the risk it would offset.

How much risk to offset? That depends on the level of service that is deemed appropriate. From an economic perspective, the *optimal level of risk* could be chosen as the risk that *minimizes* the expected value of *annual costs of shortages plus the appropriate capital investment*. An optimization analysis will estimate the optimal level of risk and the associated reliability for each component of the system, and for the overall system.

## Isoquants

Graphs of storage versus supply capacity show equal levels of reliability connected together by smooth curves, Figure 1. In the field of economics, these curves are called *isoquants*. These curves define the system's overall reliability in meeting the variability of demands and they can be used to evaluate the economic aspects of reliability.

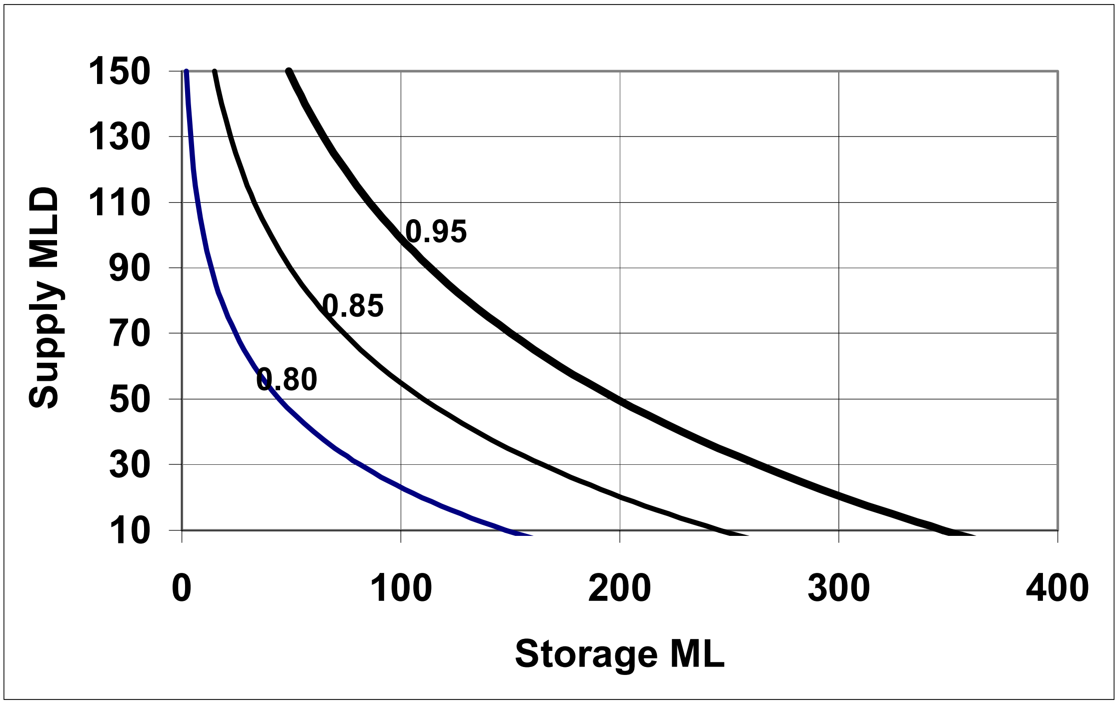

**Figure 1. Hypothetical Isoquants**
**Note: Numbers beside lines show reliability.**

Each point on an isoquant corresponds to a different cost for storage and supply capacity. The total cost for a particular level of Reliability is the sum of costs for storage, supply capacity, and for the shortage probability implied by any selected combination of facilities. The implied shortage cost is a constant along an isoquant because the reliability is constant - but a minimum total cost is associated with each isoquant because the costs for expanding storage capacity tend to be offset by reduced costs for the corresponding smaller supply capacity. There is therefore an optimum water supply reliability that can be objectively determined from the characteristics of the supply system and the service area's response to shortages.

A budget isoquant (line with constant total cost over the range of alternatives) can be placed on the reliability isoquants. The budget isoquant shows combinations of spending on expanded supply or treatment capacity, and storage. The highest reliability isoquant that the budget isoquant comes in contact with shows the highest reliability that the budget can achieve. This provides guidance on how much to spend on supply capacity, and how much to spend on storage to achieve that reliability.

## The Value Of Water - The Cost Of Being Unreliable

The cost of water supply shortages is reflected in the cost to society if supplies are inadequate to meet demands. The costs to society of a shortage can be estimated from economic concepts of demand elasticity and consumer surplus. The probability of a shortage can be estimated from an analysis of past operation of the water supply system. The expected value of the annual costs of incipient shortages is estimated by combining the economic analysis with the statistics of supply capability.

The cost of a shortage depends on its economic impact on the community at large. One way to make this estimate is to assume a public response and its associated costs. Another way is to assume that the consumer surplus is the marginal value of water supply. The consumer surplus is obtained from the demand curve of cost per unit of water versus volume of water sold, Figure 2.

The consumer surplus associated with a percentage shift from the current demand level depends on the current price of water and the elasticity, which is the logarithmic slope of the demand curve.

Tables can be prepared to show the cost of shortages for various durations and levels of demand, say the three days encompassing the maximum day. For longer durations the average level of demand is lower, and so to are the costs per day that would result from a shortage at a given percentage of that demand.

The probability of a shortage multiplied by its cost if it occurs is the weighted cost. The sum of all weighted costs over all probabilities is the expected value of the annual cost of shortages. It would be worthwhile to consider constructing a facility, or reducing demands for water, to the point where the annual cost of the remedy equals the expected value of the annual cost of the shortages that are thereby offset.

The costs of water shortages to the community can be estimated from the elasticity of the demand curve. The demand curve shows how demands for water were reduced by past increases in price. A common use for a demand curve is to estimate how revenues would be affected by increases in water rates. The curves can also be used inversely, to estimate how reductions in supplies will reduce the benefits that consumers receive from the water supply. The area under the demand curve, between two levels of supply, provides an estimate of the total cost to the producer and to the consumer.

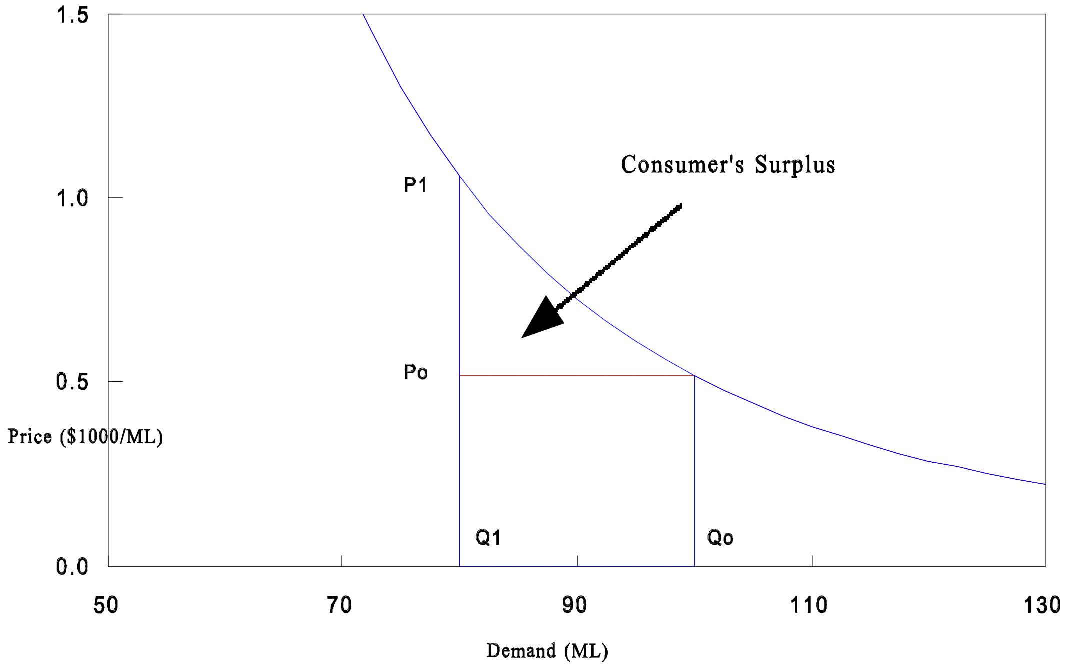

**Figure 2 The Economic Demand Curve for Water Supply**

The cost to the producer is the rectangular area under the curve between the normal demand level, $Q_0$ and the reduced demands $Q_1$ that can be met during the period of shortage. Producer costs include revenue lost because of reduced water sales during periods of shortage. The producer's costs can be considerable as it may take consumers many months, or years, to adjust to the availability of water when the period of shortage is ended. In the meantime the utilities fixed costs can be burdensome, especially if a drought occurs soon after a period of major expansion to the supply system.

The consumer's costs can be equated to the value of the water supply between the normal demand level and the reduced demands that can be met during the period of shortage. Since the curve was defined from actual responses to price increases it may be assumed that it reflects the value of the water supply. Hence, the intangible costs of reductions in supply are reflected in the "consumer surplus", which is the triangular area under the curve.

The costs of shortages rise steeply for larger shortages - conversely the benefits are small from providing only a limited relief from shortages. This behavior is important in determining the optimal level of reliability. A 1996 study of the Ottawa-Carleton Region showed that for the overall Region, a loss of 90 percent of the supply capability, say by losing one of the two treatment plants and part of the conveyance capacity from the remaining treatment plant, could cost the community approximately $25 million per day.

The analysis showed that, with either plant out of service, it would be optimal to construct approximately 100 ML if no storage currently existed (the existing storage is 260 ML).

## Reliability of Water Supply and Distribution Facilities

Shortages can be caused by failures of transmission mains, treatment facilities, or pumping capacity. The probability of an equipment failure has two aspects. The first is its probability of occurrence. The second is the probability of the length of time it will take to repair and return to full service. Thus, estimating *Facilities Reliability* requires estimation of the three-way joint probability describing failure likelihood, the level of demand, and the duration of the failure (which determines the extent of the shortage and the requirements for emergency storage).

The minimum cost point on each isoquant can be plotted against the isoquant's Reliability. There is a minimum cost on each isoquant because as the capital costs go up, the shortage costs go down. Their sum has a minimum, which identifies the optimum level of Reliability for a particular failure scenario, Figure 3.

The analysis can be repeated for as many scenarios as desired until all of the scenarios with appreciable shortage costs have been identified. The sum of the expected value of these costs is the overall expected value of the shortages that are implicit in the existing system at the current level of demand. This seems like a tedious process but in fact only a limited number of scenarios need to be examined. There are only a limited number of possible major failures and minor failures contribute very little to the expected value of shortage costs.

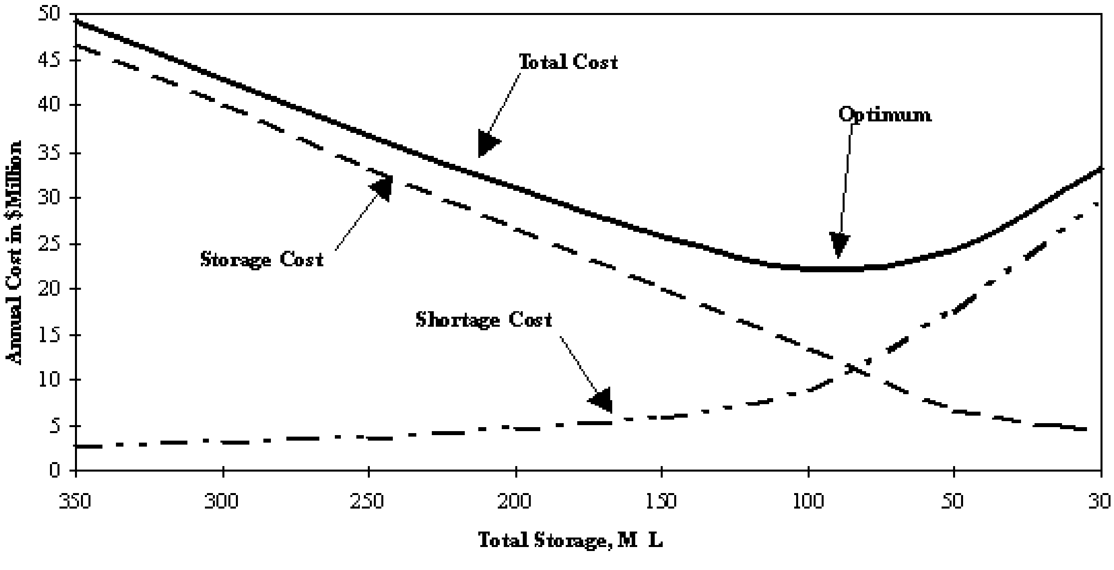

**Figure 3. The Optimum Capacity.**

**Note: For each value of storage there is a corresponding optimum supply capacity and level of reliability.**

## Conclusion

The reader is invited to draw conclusions, make observations, and develop ideas for improving ways in which municipal officials and water consumers can be fully informed about benefits and costs of various measures, regulations, and standards. For example, if a shortage appears imminent, knowledge of the costs of various levels of shortage may provide an objective basis for deciding when to ask the public to curtail consumption.

All water supplies inherently incorporate some level of risk in economic terms. Understanding this risk is an important first step to defining a sustainable supply – one that avoids increasing risks as demands and competition for water increases.

The economic approach described here may be most useful as a mechanism for communicating an objective way of thinking about the level of service for water supplies. This includes the required reliability, operations during drought, and alternative plans for expansion to meet future "demands" in the context of sustainable development.

## Related Reading

Howard, C.D.D., *Sustainable Development – Risk and Uncertainty.* Journal of the American Society of Civil Engineers, Water Resources Planning and Management Division, Sept/Oct, 2002, p1

Charles Howard & Associates, Ltd. and Resource Futures International, *Water Supply Reliability*, report to Regional Municipality of Ottawa Carleton, January 1996.

Shamir, U. and Howard, C.D.D., *Reliability and Risk Assessment for Water Supply Systems,* Proc. ASCE Specialty Conference on Water Resources Systems, Buffalo, New York, June 1985.

Shamir, U. and Howard, C.D.D., *Water Supply Reliability Theory,* Journal of the American Waterworks Association, July 1981.