Appendix A
Costing Methods

Contents

Introduction

A thorough examination of utility costs is an integral component of sound utility financial management and ratemaking, serving several purposes.

Because water utilities are natural monopolies, historic regulation has required some form of cost of service analysis to ensure that rates are "just and reasonable" and that rates are not derived on an "arbitrary or capricious" basis. Good efficiency-oriented rate design relies on full cost pricing, which fully recovers the cost of providing water service and which promotes efficient water use by customers. It also emphasizes the principles of cost causation: revenues should be recovered from those who cause costs to be incurred. Understanding these costs associated with different patterns and classes of customer use is a critical step in developing full-cost pricing.

Additionally, marginal/incremental costs reflected in rates can provide more accurate price signals to customers of the cost-causative consequences of consumptive decisions and more effectively encourage conservation. The use of marginal cost of service principles and marginal cost rate design (pricing) to establish utility rates is well documented within the utility industry.

This appendix provides definitions of various cost concepts, an overview of cost allocation methods, and an explanation of the connection of marginal cost pricing to cost-of-service principles. It focuses primarily on production costs.[1]

Cost Concepts

Understanding the costing methods required to estimate a utility's costs involves several basic issues. First, the distinction between **fixed and variable costs,** which is key to many costing methods, depends entirely on the time period under consideration. Second, assigning cost responsibility requires a distinction between **attributable and joint costs**. Third, **data** quality and availability will limit cost analysis. This section defines these basic cost concepts and explains their relevance to costing methods.

Fixed versus Variable Costs: Many costing methods identify costs of water service as either **fixed** or **variable** based on accounting expenditures. **Fixed** costs are expenditures that remain the same, regardless of the volume of water produced. Because large up-front capital costs are required to build capacity for meeting demand, some traditional costing methods classify all system expansion costs as fixed and refer to these costs as "demand" costs. **Variable** costs, also called "commodity costs," are expenditures that vary directly with the volume of water produced or consumed; variable costs include, for example, purchased water, electrical, and chemical costs. Marginal costing methods recognize that the dividing line between fixed and variable depends on the period of time used for the analysis. In the long run, fixed capital expenditures can and do change, thus becoming "avoidable."

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[1] Parts of this appendix were adapted from *"Designing, Evaluating, and Implementing Conservation Rate Structures"*, July, 1997, California Urban Water Conservation Council.

Attributable versus Joint Costs: If all costs could be easily, accurately, and cheaply attributed to specific utility functions, cost-causation would be straightforward. (See Shillinglaw 1963, "The Concept of Attributable Cost.") Attributable cost is directly based on causality. Some costs of water supply are considered "joint" costs because they reflect joint functions. As an example, providing flow capacity sufficient for fire protection simultaneously (or jointly) provides capacity that can be used for any other instantaneous high-flow use. Similarly, providing capacity for peak periods will necessarily provide capacity for nonpeak periods. Joint costs complicate the task of cost analysis.

Data Issues: Costing methods use, and are limited by, accounting and other data generated in the day-to-day operations of the water utility. The quality and availability of these data also affect the accuracy and applicability of avoided-cost methods. Much of the water supplier cost accounting data, for example, is not allocated by utility function—supply, storage, treatment, and conveyance. By improving the process of defining and collecting accounting-cost measures, better decisions can be made using even simple methods. The need for accurate flow data is another data issue. Costs are allocated through this data and many utilities do not have data by class of service beyond monthly data.

Definition and History of Marginal/Incremental Cost Pricing

An important starting point in the discussion of utilizing marginal cost pricing to establish water rates is simply understanding the proper definition of marginal costs. "Marginal" production costs refer to the cost of producing (or not producing) another unit of water supply. Marginal costs taken for an increment of supply are often referred to as "incremental" costs. Marginal or incremental cost pricing refers to setting prices to equal marginal costs.

Marginal cost pricing has a long history of development in the economic literature and has been successfully applied to problems of public utility pricing.[2] The historical evolution of traditional costing in the water industry drew heavily from methods developed for other public utility industries. In the energy and telecommunications industries, where most utilities are subject to economic regulation, average-cost pricing prevailed until roughly the 1980s. Marginal-cost methods have gained some acceptance in the realm of public utility regulation. In fact, the Public Utility Regulatory Policies Act (PURPA) of 1979 required the larger electric and gas utilities to consider these pricing methods.

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[2] In fact, some of the early work on marginal cost pricing for public utilities was focused specifically on hydroelectric reservoirs. See Massé, P. 1944, *Application des probabilités en chaîne à l'hydrologie statistique et au jeu des réservoirs*. Paris. or Boiteux, M., 1949, *"La tarification des demandes en pointe,"* Revue Générale de l'Electricité, 58, 321-40.

Economic Theory and Marginal Cost of Service

Economic theory provides the logic for marginal costs serving as the basis for the marginal cost of service. There is extensive economic background for marginal cost applications in electric cost of service and rate setting as well as other type of utilities.[3] This section provides a summary of the economic theory of using marginal cost as a basis for rate making and cost of service.

One of the main tenants of economics at the individual firm and individual consumer level is that society is better off when the price of a good or service is equal to its marginal cost. The welfare of society is the highest when marginal price equals its marginal cost. Where there is a free market with open competition, this occurs naturally. In the public utility arena where utilities are granted monopolies of service, economic theory would recommend that pricing be based on marginal cost with certain caveats. The analysis behind this finding will be explored in a limited way here, but there is substantial economic literature on the topic.[4][5]

Marginal cost is the cost of producing an additional unit of a good or service at a level of production. The following example is for a firm producing widgets which seeks to maximize profit. Figure B.1 depicts a simple example of a cost of production function for a generic good, "widget", that relates total cost for producing the widgets by the amount of widgets produced. As more widgets are produced the cost per widget increases, an increasing marginal cost example.

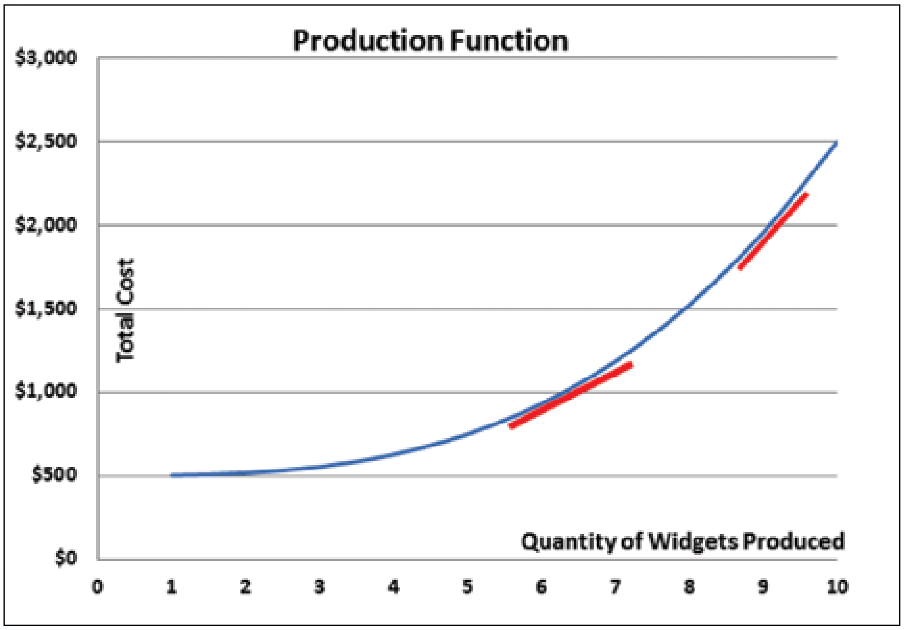

Figure A.1 Total Cost of Production

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[3] Kahn, Alfred, *The Economics of Regulation: Principles and Institutions:* 1970, Wiley & Sons.

[4] Bonbright, James & Danielson, Albert & Kamershen, *Principles of Public Utility Rates:* 1988, Public Utility Reports, Inc.; Mass, A. and others, eds. *Design of Water Resource Systrems,* Cambridge Mass, Harvard University press, 1962. Hufschmidt, M.M. and M. B. Fiering, *Simulation Techniques for Design of Water Resource Systems,* Cambridge Mass, Harvard University Press, 1966. Krutilla, J. V. and O. Eckstein, *Multiple Purpose River Development,* Baltimore: Johns Hopkins Press, 1985. These are seminal works on the role of marginal cost for utility rates and cost of service.

[5] Freidman, Milton, *Price Theory:* 1976, Aldine Publishing Company and Varian, Hal, Microeconomic Analysis,1978, Norton & Company

The increasing marginal cost in this example is reflected by the two red lines at 6 and 8 widgets. The marginal cost at any point on the production function is the slope of the function/line at that point. For the mathematically inclined the marginal costs is the calculus derivative at the production level of concern. This is represented by the red lines tangent in the above example. Clearly the slope of production at widget 9 is higher than the slope at widget 6. Figure B.2 shows the average cost per unit, the marginal cost per unit and an illustrative demand curve for the above production function. All are a function of cost/price per unit by quantity. Average cost is total cost divided by amount of production.

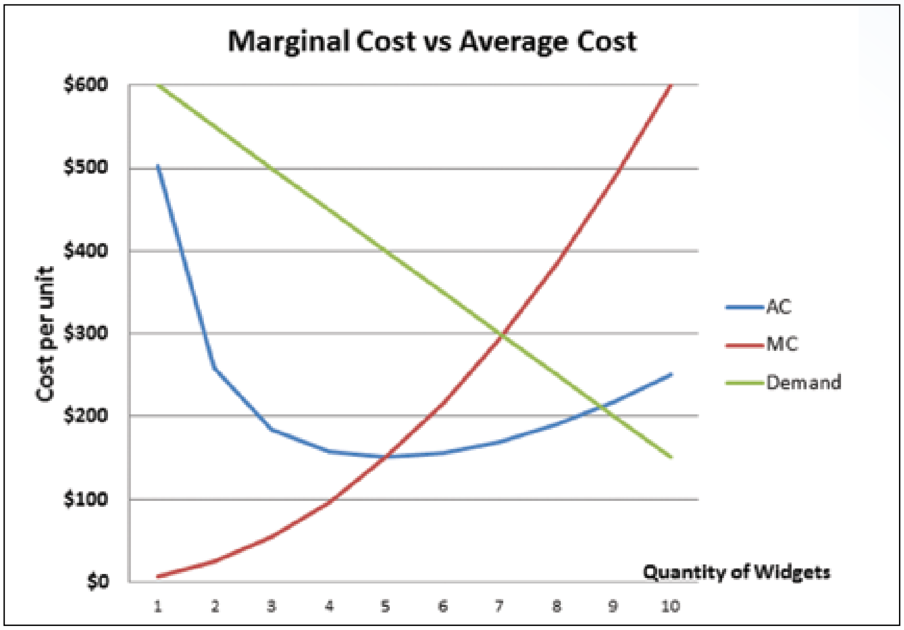

Figure A.2 Marginal Cost vs Average Cost

At 7 units of production, the marginal cost and the price for a demand of 7 widgets is $300 per widget. The average cost is $150 per unit at 7 units of production. At 9 units, the MC = $500 and the price of demand and AC are equal at $200. The profit and overall revenue to the firm is higher at 7 units than at 9 widgets. This is a simple demonstration of how marginal cost equaling demand price results in higher value than at average cost at demand price.

In practice for utility pricing, there are many issues that overlay this simple example such as long term versus short term costs, monopoly pricing and marginal cost revenues are not equal to actual revenue requirements that must be addressed. However, the simple example provides some insight into the economic theory of marginal cost pricing.

The concept of “cost of service” is central to utility rate setting. Federal, state and local regulators, and the courts, generally require rates to adhere to a cost-of-service justification; that is, rates should be designed so that users pay water rates that bear a direct relationship to the costs they impose on the water system. Marginal-cost pricing provides the link between today’s consumptive behavior and the means of satisfying tomorrow’s demand. As such, it can be understood as an expression of cost-of-service methods that brings a closer relationship between costs imposed and cost responsibility.

The concept of marginal cost pricing has also been extended beyond direct production costs. They should be thought of as inclusive of all marginal opportunity costs, including marginal distribution costs, marginal connection costs and marginal environmental costs.[6] By intention, this appendix focuses on marginal production costs.

Two Traditional Cost Allocation Methods: Commodity-Demand and Base-Extra Capacity

Marginal cost methods can be better understood in contrast to the more traditional methods based on embedded average cost. Two traditional methods for allocating embedded costs by demand characteristics have been widely applied by water utilities: the Commodity-Demand method and the Base-Extra Capacity method. Both approaches are extensively discussed and illustrated in the American Water Works Association (AWWA) Manual **M1**, Water Rates.

The **Commodity-Demand method** separates costs into the cost components associated with commodity, demand, customer and direct fire protection. In California, water utilities regulated by the PUC prepare a Fixed Cost and Commodity Cost analysis that is a variation of the Commodity-Demand method. The Commodity-Demand method uses the peak (maximum) demand of each customer class to allocate capacity costs, but does not consider how that peak is related to the overall system peak. In the language of the trade, this approach is termed a "non-coincident" peak responsibility cost allocation. Non-coincident approaches evaluate the maximum day and maximum hour peaking characteristics of customer classes, no matter when the peak occurs. A "coincidental" approach evaluates these peaking factors when the system is peaking. Thus, the Commodity-Demand method could allocate a large proportion of system costs to a customer class with a substantial peak demand at a time other than that of the system peak. By not tying rates to the time of highest system peak, the Commodity-Demand allocation method can miss an opportunity to send an appropriate price signals.

The **Base-Extra Capacity method** is the cost-of-service procedure used by the majority of larger public water utilities, as well as many regulatory utilities. The Base-Extra Capacity method first examines the costs for "Base" or average annual water use. "Extra Capacity" addresses responsibility for the additional costs incurred to meet maximum-day and maximum-hour demands. The base costs of the Base-Extra Capacity method capture all of the commodity costs identified in the Commodity-Demand method plus the portion of demand-related costs necessary to provide capacity for meeting the average-day demands. Extra-capacity costs, then, cover the rest.

Customer related costs under both methods reflect the cost of meters and services, meter reading, customer billing and collection expenditures. These costs are often allocated to customers uniformly by connection or by meter size.

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[6] See for example, R.C. Griffin, 2001, *"Effective Water Pricing,"* Journal of the American Water Resources Association.

PEAK AND LOAD FACTORS

Peak demand is defined as the maximal demand during a specified period of time. Thus, peak/maximum day demand would be the maximum demand observed on any day. Peak/maximum hour demand would be the maximum demand observed in any hour. Peak ratio is the ratio of peak demand to average demand.

A load or capacity factor is defined as the ratio of average demand to peak demand. Thus if a facility is designed to meet some maximal demand, the capacity factor has the interpretation of the percent of total capacity allocated to average demands.

Seasonal Base-Extra Capacity

The Base-Extra Capacity method can be modified to incorporate seasonal time-of-use into the cost assignment. For many systems, water usage (or system "load") will have a seasonal pattern—higher during the warmer months and lower during the cooler months. These seasonal patterns also are reflected in maximum-day and maximum-hour demands. Thus, after developing the average cost per unit of water associated with base and extra capacity requirements, seasonality can be introduced. Under this approach, base and extra capacity costs are allocated to time of year before being assigned to customer classes.

For readers familiar with traditional cost allocation, Table A.1 illustrates a Seasonal Base-Extra Capacity method. First, costs are allocated between base and extra-capacity components Approximately two thirds of the total cost of service of $22,510,348 is deemed necessary to provide capacity for average day demand. (If this allocation applied to a single facility, it would imply that maximal peak demand is about 50 percent greater than average demand) The remaining costs are allocated to extra capacity. (The amounts allocated to maximum day and maximum hour would come from a facility by facility allocation based on the capacity factors.)

The principal departure from the traditional method is the allocation of maximum-day and maximum-hour costs between seasonal and non-seasonal consumption. In this example, a four-month summer period has been defined as the peak season. As in the traditional method, the annual "base" cost of service is divided by total annual consumption, to yield a base cost of $1.60 per CCF. This base amount applies throughout the year. The extra capacity costs, in turn, are further divided by season. The allocation factors for maximum day costs would suggest that 50 percent of the days that exceed average day demand would occur in the eight month off-peak season and 50 percent would occur in the four month peak summer season. Similarly, allocation factors have been developed for maximum hour costs. This procedure results in a non-seasonal rate of $2.22/CCF and a summer rate of $2.72/CCF.

The Seasonal Base-Extra Capacity method results in unit costs and seasonal differential factors that can be applied in the rate design to yield a seasonal rate structure. Seasonal prices signal to consumers the additional cost of the extra capacity needed to provide peak seasons service**. This method alone, however, does not consider the potential for changes in the future costs** of supply alternatives, which would require a forward-looking marginal-cost analysis.

The Seasonal Base-Extra Capacity example shows one limited way that embedded cost methods can be improved for conservation purposes—by incorporating **the time** dimensions of usage patterns into the costing. Seasonal differences in cost responsibility (as defined by traditional methods) provide the basis for seasonal peak pricing. Because future system capacity costs also are driven by peak load, the higher rates during periods of peak load is a step in the right direction.

Table A.1 Analysis of Seasonal Costs - Base/Extra Capacity Method

DESCRIPTION	COST OF SERVICE	PERCENT SHARE	AMOUNT
I. Allocation Between Base and Extra Capacity			
Base	$22,510,348	66.0%	$14,859,250
Max Hour	$22,510,348	15.8%	$3,547,127
Max Day	$22,510,348	18.2%	$4,103,971
II. Base Cost of Service			
Base	$14,859,250	100.0%	$14,859,250
Total Consumption			9,288,311
Base Cost per CCF			$1.600
III. Non-Seasonal Extra Capacity Cost of Service			
Max Hour	$3,547,127	50.0%	$1,773,564
Max Day	4,103,971	40.0%	$1,641,588
Non-Seasonal Extra Capacity Cost of Service			$3,415,152
Non-Seasonal Consumption (8 off-peak months)			5,504,381
Extra Capacity (Non-Seasonal) Cost per CCF			$0.620
Base Cost per CCF			$1.600
Non-Seasonal Extra Capacity Cost per CCF			$2.220
IV. Summer Cost of Service			
Max Hour	$3,547,127	50.0%	$1,773,564
Max Day	4,103,971	60.0%	$2,462,383
Total Summer Cost of Service			$4,235,946
Summer Consumption (4 peak months)			3,783,930
Seasonal Extra Capacity Cost per CCF			$1.119
Plus: Base Cost per CCF			$1.600
Summer Cost per CCF			$2.719

Marginal/Incremental Cost Pricing for Water

Two important components of marginal cost are the change in operating costs caused by a change in the use of existing capacity (short-run marginal operating cost), and the cost of expanding capacity (long-run marginal capacity cost).

- **Short-run marginal operating costs** reflect the cost consequences during time periods in which some inputs are fixed. Short-run marginal costs are comprised mostly of variable operating costs, and are relatively straightforward to estimate.
- **Long-run marginal capacity costs** extend to time periods far enough into the future to be changed by system and resources planning. Long-run marginal costing methods can identify costs that can be avoided through more efficient use or non-use (conservation). Because the long-run concept of marginal costs (1) extends into the future, and (2) reflect all future alternatives, estimation methods must deal with more uncertainty.

Total long run marginal costs include both the short-run operating costs and the long-run capacity expansion/contraction costs.

Marginal costs are computed with respect to two different time periods:

- **Short-run marginal operating costs** constitute a floor for water rates—volumetric rates should never be set below short-run marginal costs.
- **Long-run marginal costs** represent the definition of an efficient price signal—to convey information about the long-run cost consequences, rates should reflect long-run marginal costs.

Applying Marginal Cost Analysis to Water Service

In estimating marginal costs, a central issue is where the next increment of supply will come from and what it will cost. A variety of supply options with different capacity and cost consequences may be available. The identification and quantification of future resource alternatives lies at the heart of water utility planning. Existing water supply/management plans are a good place to start to determine the current set of resource alternatives to which a utility is committed.

The Appropriate Time Horizon: Calculating marginal cost involves projecting capacity costs, operating costs, and water demand over a specified time horizon. These projections require data on the price elasticity of demand, anticipated changes in technology, and the prices of inputs required to provide water service.

Selecting the time horizon directly affects the estimation of marginal capacity cost (long-run marginal cost) and the marginal operating cost (short-run marginal cost). The length of the time horizon or planning period affects both the cost numerator and the output denominator in calculating marginal cost.

Sometimes a shorter time period has been chosen out of a misplaced desire for precision in estimating marginal costs. Though it is often true that shorter time horizons lend themselves to more precise cost and demand forecasts, precision should not be confused with accuracy. Forecasts over long time horizons may contain fewer known and more estimated quantities. These longer term forecasts can be more accurate, because they contain a broader set of alternatives, while necessarily being less precise. The choice of the time horizon also must take into account the span of time required to implement cost-effective changes in the mix, capacity or availability of resources. Most water utilities define a "time horizon" for planning purposes.

Time also matters because forward-looking marginal/incremental costs must necessarily grapple with the economic principles of the time value of money, ongoing inflation, and escalation of future costs in ways that can differ from the general rate of price inflation.

Time Value of Money: It is assumed that most readers are familiar with the concept of the time value of money—most people would prefer to have one dollar today than one dollar a year from today (or ten years from today) because productive things can be done with the dollar within that time. This is the opportunity cost of money. A stream of costs occurring through time can be re-expressed in terms of the present value by using a discount rate that adjusts for the opportunity cost of money.

$$PresentValueCosts = \sum_{t=0}^{n} \frac{Cost_t}{(1 + DiscountRate)^t}$$

In equation A.1, Cost^t are costs in year t; n is years in the period of analysis, and "year" refers to a calendar year.[7] The question of an appropriate discount rate depends on the perspective of analysis (utility direct financial perspective, narrowly defined societal perspective [GDP], and broadly defined societal perspective [inclusive of future generation, for example]) and what constitutes the relevant opportunity costs. For water utilities having to borrow money to build water infrastructure, the cost of borrowing money constitutes a good benchmark of this opportunity cost—that is the "cost of capital".

The discount rate to be applied depends on whether the stream of costs are measured in real (adjusted for inflation) or nominal (not adjusted for inflation) terms. Costs and benefits should be valued in either real or nominal terms—not a combination of the two. If costs are expressed in nominal terms, say a stream of financial payments over time, a nominal discount rate should be used. If costs are expressed in real terms, a real discount should be used.[8]

Marginal Operating Cost

Several techniques can be used to estimate marginal operating cost (MOC) for a water utility. The simplest techniques calculate an average operating cost and thus can deviate from theoretical marginal cost. Additional analysis, using very similar data, can arrive at estimates closer to marginal cost. Both techniques are relatively uncomplicated and involve minimal data requirements.

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[7] For example, costs that occur immediately at the outset of the program accrue in "year zero" (t=0) Costs that occur during the first year of the program accrue in "year one" (t=1), etc.

[8] Real and nominal discount rates, if certain, can be converted as follows: $d = (r - i) \div (1 + i)$
where d is the real discount rate, r is the nominal discount rate, and i is the expected inflation rate. If these rates are uncertain, the "Flaw of Averages" provides several ways that inserting the expected real discount and interest rates would not yield the correct expected nominal discount rates. "Risk-adjusted" discount rates constitute an algebraic "solution" to a problem that is better handled through "probability management" (Savage, 2012).

A Short Method: One technique used to calculate MOC is to forecast the annual operating expenses for the first year that a capacity increment is anticipated to become operational, and then divide that annual cost estimate by the forecast revenue-producing output for the same year (Hanke, 1981) and accounting for the time value of money. When operating costs can be predictably forecast, this technique can be extended over multiple years. The forecast annual operating expenses over the entire planning period in which the capacity increment is anticipated to become operational are divided by the forecast revenue-producing output for the same time period (Hanke, 1978). Water systems exhibiting significant seasonal operating cost differences—due to purchased water prices or electrical power expenses—can adapt this technique to a seasonal basis.

Illustration: Table A.2 illustrates the two calculations of average operating cost. The example assumes that a new treatment plant is operational in Year 1. The projected annual operating expenses and revenue-producing output of a new facility are provided in the table. The first method, using data only from Year 1, generates an average operating cost of $0.47 per CCF. The second method, using data from Years 1 through 5, generates an annual estimate of average operating cost that increases to $0.50 per CCF.

Table A.2 Calculation of Average Operating Cost - Hanke Method

DESCRIPTION	YEAR 1	YEAR 2	YEAR 3	YEAR 4
Operating Expense (millions of dollars)	$4.343	$4.3760	$4.4370	$4.7150
Revenue-Producing Water (CCF)	9,288,311	9,330,170	9,372,302	9,414,711
Average Operating Cost ($/CCF)	$0.468	$0.469	$0.473	$0.501

The primary advantage of this technique is that it has minimal data requirements. The primary disadvantage is that, strictly speaking, this technique produces an estimate of average, not marginal operating cost. Producing an estimate of marginal operating cost can be performed using little additional data and readily available statistical methods.[9]

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[9] Bishop and Weber (1996) provide comparisons of regression-based estimates of marginal operating costs versus average operating costs. Since a regression model can be specified to estimate an "average" operating cost, it is wrong to attribute the difference between the two estimates solely to method. The regression-based method yielded a lower estimate because the model was able to control for the other influences upon operating costs. A simple average, by contrast, forces all variation in operating costs to be explained (caused) by output. Consider the model:

$$\text{Monthly Operating Cost} = a + b \cdot \text{Revenue Producing Quantity}$$

Where a and b are the coefficients to be estimated. If the coefficient a is constrained to be zero, the above regression equation will produce an estimate of b equivalent to an average operating cost. If the fixed cost coefficient a is not constrained and takes on a positive value, the estimated coefficient b will be the estimate of marginal operating cost and will necessarily be less than the average operating cost if a is positive.

Marginal Capacity Cost

Most of the marginal capacity cost (MCC) estimation techniques used in water system cost analysis are variations of two basic MCC approaches: (1) the avoided cost approach, and (2) the Average Incremental Cost (AIC) approach.[10] A brief description and discussion of each of these techniques is provided below.

Marginal Capacity Cost as an Avoided Cost:[11] As explicated by Turvey, this approach expresses MCC as either the cost incurred by an acceleration in growth of demand, or as the cost avoided by a deceleration of demand. A plan for system expansion is taken as a given, and only the timing of that expansion is varied; plans for system expansion are not re-optimized, only rescheduled. The original Turvey method examined the savings associated with slowing down system expansion through conservation. The cost numerator was formed by the change in the present value of capacity expenditures by moving the capacity increment forward into the future. The usage denominator was the annual change in demand that allowed the postponement of the capital facility. The original method focused on the change in cost associated with a postponement or acceleration of the construction period.

Clearly, the avoided capital cost calculated by the Turvey method applies directly to valuing the worth of water use efficiency programs. WUE programs directly attempt to affect the growth of expected water demand. This change to water demand, if quantified, constitutes the quantity denominator of the marginal capital costs estimate. The more difficult part of the task would then be calculating what capital costs could then be postponed or avoided.

ILLUSTRATION OF TURVEY MCC METHOD

The following example illustrates the calculation of MCC under the Turvey method. Assume that the utility planned to construct a treatment facility in three years (Year 3). As a result of demand management and conservation programs, annual demand decreases by 1,000 CCF per day (838 acre-feet per year). This decrease in demand allows the construction of a treatment facility to be postponed for one year (from Year 3 to Year 4.) The treatment facility costs \$17.0 million. Taking the utility's planning discount rate of four percent (at a real or inflation-adjusted level), the \$17.0 million spent three years from today would have a present value of (PV = \$17.0 million ÷ $(1+.04)^3$ =) \$15.113 million. By comparison, an additional year's delay would yield a present value of (PV = \$17.0 million ÷ $(1+.04)^4$ =) \$14.532 million. The cost numerator is the difference in the present value of capital expenditures by delaying the capital project from year three to year four (\$15.113 million - \$14.53 million =) \$0.581 million. (Methodical analysts might also include a small adjustment for the residual difference in scrap value, due to a finite facility project life.) Dividing the change in cost of \$0.581 million by the change in annual demand produces a MCC of 1.59 \$/CCF. This estimate added to the MOC for the new facility produces the estimated total long-run marginal cost estimate.

Several notable characteristics of the original Turvey method (1976) are:

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[10] Both approaches were summarized in Chapter 15 of the AWWA Manual M-1 Principles of Water Rates, Fees, and Charges, 5th Edition, 2000. (The reader should beware the error in equation 15-1.) The more recent 6th Edition of the Manual M-1 provides an entirely less coherent summary of Marginal Cost Pricing—caveat lector.

[11] Turvey, R. (1976) *"Analyzing the Marginal Cost of Water Supply,"* Land Economics, 52, 158-168, May 1976.

1. The method produces an annual (not seasonal), estimate of MCC that changes each year. (Marginal costs are the same in the peak and off peak season.)
2. The size of the planned system expansion only enters into the cost numerator. The quantity denominator is strictly determined by the change in annual demand that allows the deferral. Both of these quantities are empirically difficult to estimate and are associated with considerable uncertainty. If the postponement period, in the above example, were expressed as a range from 0 to 2 years, then the MCC would vary between zero and 3.12 $/CCF.
3. The Turvey MCC gets larger as the system gets closer to its capacity limitations and is zero otherwise. Since water projects involve large discrete changes in system capacity, the resulting Turvey marginal cost estimates could be volatile. The Turvey MCC focuses only on the next capacity increment, ignoring the cost consequences of subsequent increments.

Different variants of the Turvey approach have been proposed:

1. To produce a seasonal estimate of MCC, Hanke (1975) suggested categorizing cost data into facility costs designed to meet peak demands and system costs designed to meet average demands. Hanke (1981) implemented a seasonal variant of a Turvey avoided capital cost by disaggregating cost and consumption data into peak and off-peak periods.
2. Several applications have stressed quantifying the demand expected in the future and linking changes in this expected demand to the corresponding sizes of the deferrable facilities. (For an illustration, see Hanke, 1981). These variants of the Turvey approach will use the same numerator (the difference in the present value costs of two differently timed but otherwise identical system expansions) while substituting the planned usable facility capacity (that matches the avoided demand) into the denominator. The denominator is also adjusted downward to account for the effect of system loss; due to distribution leaks, more than one gallon must be produced to deliver one gallon of water.
3. Several variants of the Turvey method use an averaging of the marginal cost over several years for different rationales:
    - as the long run consistent strategy that results when an administrative feasibility constraint is included in an optimal planning framework (Dandy, 1984),
    - to produce a consistent price signal for long-term decision making (Boiteux, 1959), and
    - as a more appropriate tradeoff between short-run allocative efficiency (efficient use of existing capacity) and long-run resource efficiency (efficient capacity-sizing decisions) (Mann et al., 1980).

The original Turvey method (1976) is direct, relatively straightforward, and requires only data available in the existing water system plan. As such, it is easily interpretable as the direct cost of additional (or avoided) water use. Though directly appropriate for assigning value to conservation (demand-side management), strict implementation of the original Turvey method has several shortcomings: it does not reflect the higher cost of using water during peak periods (without an additional seasonal allocation step), it becomes erratic when capacity increments are lumpy, and it does not look beyond the next capacity increment. The reader should note that CUWCC and the U.S. EPA developed avoided costing models that avoid the above deficiencies. Though models will be discussed later, they should be understood as building on these simple methods while applying more realism and rigor.

Marginal Capacity Cost as an Average Incremental Cost: The Average Incremental Cost (AIC) approach for estimating MCC involves the annualization of incremental cost. Sometimes also referred to as a "Levelized Cost," the AIC approach first involves calculating annualized capacity cost *(K)*, which is defined as the annual payment, over the useful service life of the new capacity *(n)*, required to recover both financing costs and the additional capacity costs:

$$K \equiv \frac{C \cdot i \cdot [1+i]^n}{[1+i]^n - 1}$$

where: K = total annualized incremental capacity costs,

C = total capital expenditure required,

N = useful service life of the capacity increment, and

i = appropriate financing (interest) rate.

"*K*" must be calculated for each system function (that is, source development, transmission, treatment, distribution, etc.) in which a capacity increment is planned, since service lives will vary across these functions. "*K*" can be disaggregated into peak/off-peak components. The output (quantity) denominator is based on the expected annual delivery capacity, adjusted for system losses.[12]

The output (quantity) denominator is based on the designed annual capacity (annual firm yield). The planned capacity, however, should be adjusted to account for losses due to leakage in the system. System losses mean that more than one gallon must be produced to deliver one gallon to the customer. For example, a system loss of 10 percent implies that 1.11 gallons must be produced for each gallon delivered. The output denominator can be expressed as revenue- producing annual capacity (annual planned delivery capacity averaged over the life of the plant).[13]

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[12] Incremental costing for each service element required for production are more common with other utility services that use "unbundled" ratemaking, such as Telcom. The FCC refers to this approach as TELRIC: Total Element Long Run Incremental Cost.

[13] Some AIC calculations take the accounting an additional step, separately accounting for the capacity that is used and the capacity that is held in reserve. Analysts should avoid using "expected capacity utilization" as the output denominator; this sends the exact wrong short run signal. (Since the expected utilization is low immediately after construction of a capacity increment and is high as the maximum capacity is approached, AIC with expected utilization in the denominator would send a high/low price signal when capacity is plentiful/scarce.) This handbook therefore recommends use of expected capacity utilization averaged over the life of the project, adjusted for system loss.

ILLUSTRATION OF AVERAGE INCREMENTAL COST (AIC) MCC METHOD

Continuing the previous example, the AIC method can be used to estimate the marginal capital cost of the same new treatment facility. Assuming that the treatment plant has a useful service life of 25 years (n=25), and that the real annual interest rate is 4 percent (7 percent nominal financing rate and a 3 percent rate of inflation), the AIC method produces an annualized capacity cost (K) of $1,088,203. Dividing by the planned capacity of 10,000 CCF per day, the AIC method estimates the MCC of the treatment plant to be:

$$\$1{,}088{,}203 \div 10{,}000 \text{ CCF/day X } 365 \text{ days } =) \; 0.298 \text{ \$/CCF}$$

This AIC is then added to the MOC to yield the total marginal cost. Because the AIC method involves averaging, it's results are less sensitive to changes in the assumptions than other methods. A service life of 20 years produces an estimated AIC of 0.343 $/CCF and a real interest rate of 5.0 percent changes the estimated AIC to 0.330 $/CCF.

The example is simplistic because not all components of a treatment plant will have the same service life. More importantly, a treatment plant is of little use if a utility does not have a corresponding raw water source, pumping and transmission capacity to move the water, and storage facilities to handle fluctuations in system load.

A more realistic example of the AIC method for a major system expansion is illustrated in Table B.3. Supply, treatment, pumping and storage capital improvements all are required for a major system expansion. Any costs related to expansion of the distribution system are considered customer costs and are not included in the AIC calculation. An analysis of each function determines the capital cost, useful physical life, and annual capacity cost. Annual capacity costs are summed by function and totaled. To derive the AIC estimate, the total annual capacity costs are divided by the output measure to arrive at a AIC per CCF. The summary at the bottom of **Table A.3** shows the effect of accounting for a 12 percent system loss by comparing marginal capital costs using the planned firm yield of the system expansion and the deliverable water (88 percent of the firm yield.) The AIC method produces an estimate of $ 1.91 per CCF for the system expansion.

Table A.3 Illustration of AIC Method for calculating the MCC of System Expansion

DESCRIPTION	TOTAL CAPITAL EXPENDITURE (C)	LIFE (N)	ANNUALIZED INCREMENTAL CAPACITY COST (K)	
Supply				
Wells	$15,000,000	40	$757,852	
Reservoirs	$30,000,000	40	$1,515,705	
Transmission Mains to Dist. System	$5,000,000	100	$204,040	
Land	$18,500,000		$740,000	
Total Supply Capacity Cost	$68,500,000		$3,217,597	
Treatment				
Facilities	$10,000,000	25	$640,120	
Equipment	$5,000,000	20	$367,909	
Land	$2,000,000	-	$80,000	
Total Treatment Capacity Cost	$17,000,000		$1,088,028	
Pumping				
Structures	$18,000,000	50	$837,904	
Equipment	$5,750,000	20	$423,095	
Total Pumping Capacity Cost	$23,750,000		$1,260,999	
Storage				
Facilities	$10,000,000	50	$465,502	
Land	$2,500,000	-	$100,000	
Total Storage Capacity Cost	$12,500,000		$565,502	
Summary	Annualized Capacity Costs (K) $		Marginal Capacity Costs (K / Yield) $ per CCF	Marginal Capacity Costs (K / Delivery) $ per CCF
Supply Capacity Costs	$3,217,597		$0.882	$1.002
Treatment Capacity Costs	$1,088,028		$0.298	$0.339
Pumping Capacity Costs	$1,260,999		$0.345	$0.393
Storage Capacity Costs	$565,502		$0.155	$0.176
Total Capacity Costs	$6,132,126		$1.680	$1.909
Increment to Supply (CCF/year), Planned Yield = 10,000 CCF/day * 365 days/year Delivery Capacity = Yield* (1-SystemLoss(12percent))			3,650,000	3,212,000

The average costs for additional capacity increments can be used to calculate a downsizing avoided cost attributable to reduced demand. This relatively straight forward process involves comparing two average incremental capacity costs—the AIC designed without the effect of conservation programs and the AIC of a system designed with conservation. Though the calculation of avoided capacity costs due to downsizing is less common, it is mentioned here for several reasons. First, it is a valid method that has found use in the water industry. Second, these costing methods also provide the basis for the determination of a "good" price signal to be provided by water rates. Last, calculation of average incremental costs by function can serve as a useful benchmark for other costing methods.

CUWCC Avoided Cost Models – Water and Wastewater

CUWCC — with the Water Research Foundation and the US EPA as partners — historically developed two companion models to estimate costs that are avoided on the water supply and wastewater systems as a result of water use efficiency (WUE)-induced demand reductions.

A complete picture of the costs and benefits of WUE include the costs avoided by the water supply utility, avoided environmental degradation from water not supplied, wastewater system costs avoided due to more efficient water use, and avoided stormwater management costs. The primary use of these models is to assist in valuing the economic benefits of WUE (conservation) programs; The typical users of the model are water and wastewater system staff, managers and decision makers.

Model Characteristics. Both avoided cost models are characterized by a two period time step (peak/off peak), a long planning horizon (over fifty years), and an annual summary of both short and long run avoided costs over the entire planning horizon. A set of common assumptions are imposed for a consistent economic logic—projected interest rate, projected inflation rate, a consistent planning time horizon, and user-selectable units of measure for inputting flow and volume.

Both of these avoided cost components are differentiated by season, so that the avoided costs in the peak-demand season may differ from those in the off-peak season. They also may change over time, as cost components escalate and as system configurations change. Thus, avoided costs are expressed annually—in tabular form or as a chart.

Figure A.3 is the flow chart of the *US EPA/CUWCC Wastewater Avoided Cost Model* where clicking on a flow object takes the user to the model input or output sheet.

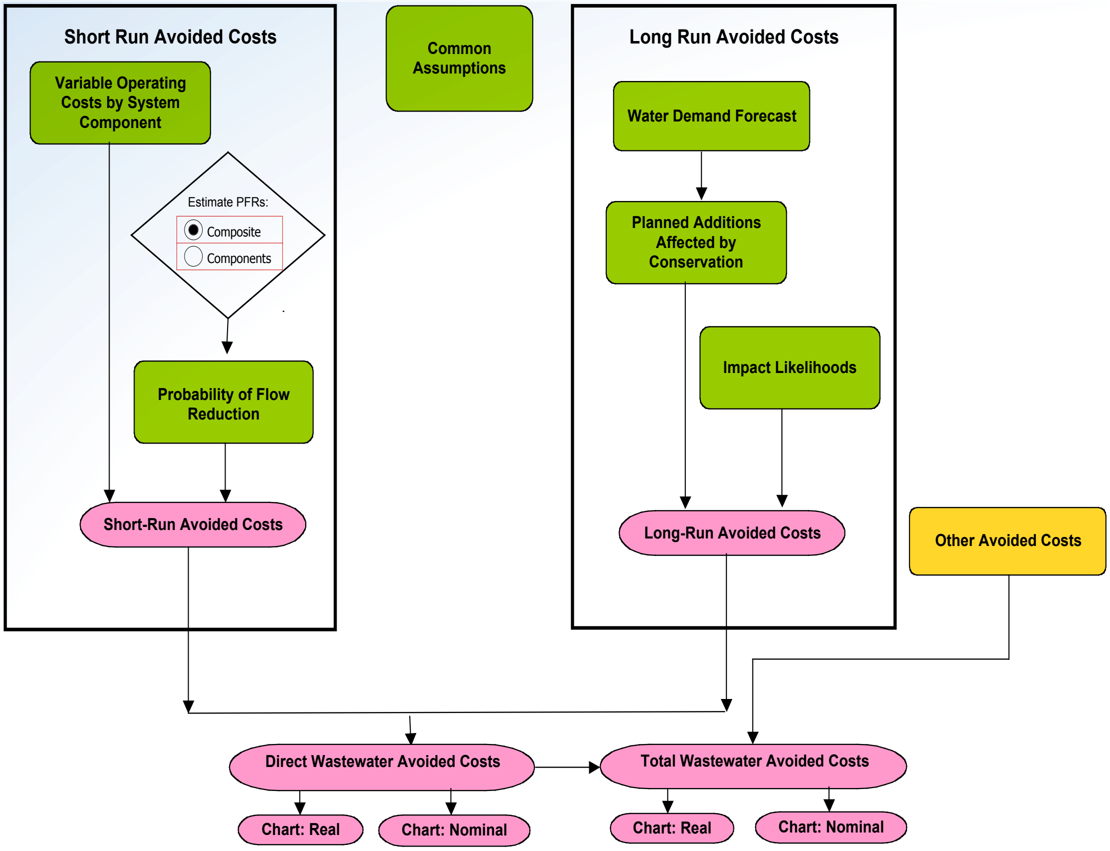


Figure A.3 USEPA/CUWCC Wastewater Avoided Cost Model Flow Chart

Table A.4 and Figure A.4 show typical tabular and graphical outputs of the *WaterRF/CUWCC Direct Utility Avoided Cost Model*. This model and the instructions for use can be found on the CUWCC website.

Table A.4 WaterRF/CUWCC Direct Utility Avoided Cost Model: Sample Water Supply Avoided Cost

Total Direct Utility Avoided Costs: Nominal Dollars

($/mg)

Year	**Peak Season**			**Off-Peak Season**		
	Short-Run	Long-Run	**Total**	Short-Run	Long-Run	**Total**
2007	$228	$0	**$228**	$225	$0	**$225**
2008	$234	$0	**$234**	$232	$0	**$232**
2009	$241	$0	**$241**	$238	$0	**$238**
2010	$247	$0	**$247**	$245	$0	**$245**
2011	$254	$0	**$254**	$251	$0	**$251**
2012	$274	$923	**$1,197**	$267	$0	**$267**
2013	$281	$924	**$1,205**	$274	$0	**$274**
2014	$289	$924	**$1,213**	$282	$0	**$282**
2015	$297	$1,469	**$1,766**	$289	$0	**$289**
2016	$305	$1,469	**$1,775**	$297	$0	**$297**
2017	$361	$1,470	**$1,831**	$321	$0	**$321**
2018	$372	$1,470	**$1,842**	$330	$0	**$330**
2019	$382	$1,470	**$1,852**	$339	$0	**$339**
2020	$393	$1,471	**$1,863**	$349	$0	**$349**
2021	$404	$1,471	**$1,875**	$359	$0	**$359**
2022	$409	$1,472	**$1,881**	$369	$352	**$721**
2023	$421	$1,472	**$1,893**	$379	$352	**$731**
2024	$433	$4,645	**$5,078**	$389	$353	**$742**
2025	$445	$4,654	**$5,098**	$400	$353	**$753**
2026	$457	$4,662	**$5,119**	$411	$353	**$764**
2027	$497	$4,671	**$5,167**	$420	$353	**$773**
2028	$511	$4,679	**$5,190**	$431	$353	**$785**
2029	$525	$4,689	**$5,214**	$443	$354	**$797**
2030	$540	$3,898	**$4,437**	$456	$7	**$463**
2031	$555	$3,794	**$4,349**	$468	$7	**$476**
2032	$573	$3,804	**$4,377**	$478	$9	**$487**
2033	$589	$3,815	**$4,404**	$491	$9	**$500**
2034	$606	$3,825	**$4,431**	$505	$9	**$515**
2035	$623	$3,291	**$3,914**	$519	$10	**$529**
2036	$641	$3,302	**$3,943**	$534	$10	**$544**
2037	$659	$3,314	**$3,973**	$549	$10	**$559**
2038	$678	$3,326	**$4,004**	$564	$11	**$575**
2039	$697	$3,338	**$4,035**	$580	$11	**$591**
2040	$717	$3,351	**$4,068**	$596	$11	**$608**

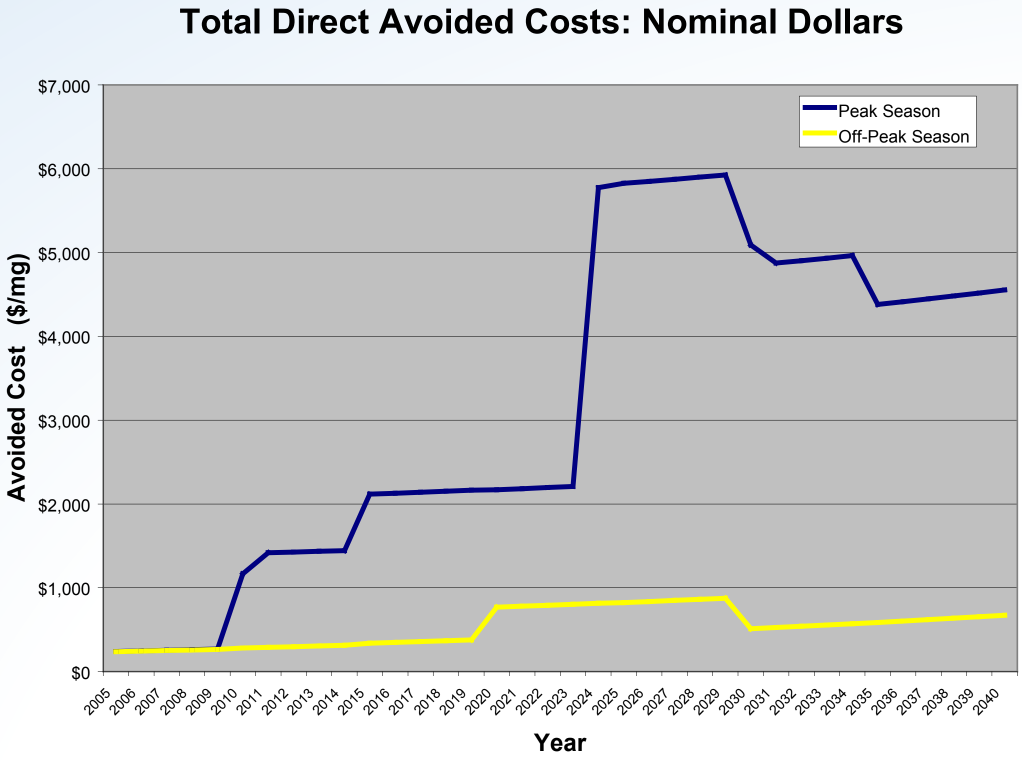
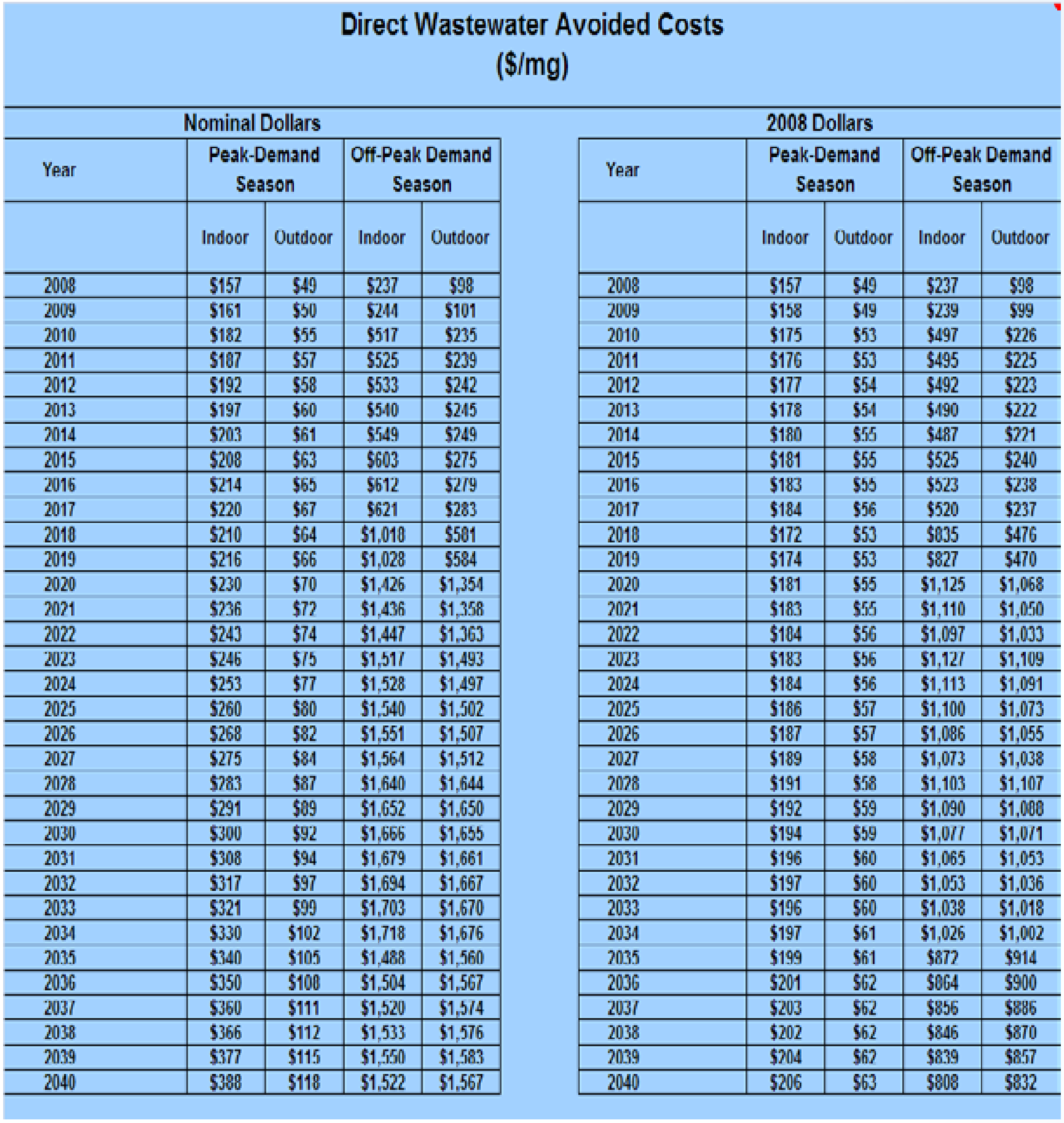


Figure A.4 WaterRF/CUWCC Direct Utility Avoided Cost Model Sample Water Supply Avoided Cost Chart

Table A.5 and Figure A.5 show typical tabular and graphical wastewater avoided cost results by year and season. As with the Water Avoided Cost Model, the results are generated as a vector over time, rather than as a scalar. Avoided costs outputs are summarized in both nominal dollars (as used in financial plans) and real dollars (as used for economic decision making).

Table A.5 USEPA/CUWCC Wastewater Avoided Costs



Direct Wastewater Avoided Costs
($/mg)

Nominal Dollars					2008 Dollars				
Year	Peak-Demand Season		Off-Peak Demand Season		Year	Peak-Demand Season		Off-Peak Demand Season	
	Indoor	Outdoor	Indoor	Outdoor		Indoor	Outdoor	Indoor	Outdoor
2008	$157	$49	$237	$98	2008	$157	$49	$237	$98
2009	$161	$50	$244	$101	2009	$158	$49	$239	$99
2010	$182	$55	$517	$235	2010	$175	$53	$497	$226
2011	$187	$57	$525	$239	2011	$176	$53	$495	$225
2012	$192	$58	$533	$242	2012	$177	$54	$492	$223
2013	$197	$60	$540	$245	2013	$178	$54	$490	$222
2014	$203	$61	$549	$249	2014	$180	$55	$487	$221
2015	$208	$63	$603	$275	2015	$181	$55	$525	$240
2016	$214	$65	$612	$279	2016	$183	$55	$523	$238
2017	$220	$67	$621	$283	2017	$184	$56	$520	$237
2018	$210	$64	$1,018	$581	2018	$172	$53	$835	$476
2019	$216	$66	$1,028	$584	2019	$174	$53	$827	$470
2020	$230	$70	$1,426	$1,354	2020	$181	$55	$1,125	$1,068
2021	$236	$72	$1,436	$1,358	2021	$183	$55	$1,110	$1,050
2022	$243	$74	$1,447	$1,363	2022	$184	$56	$1,097	$1,033
2023	$246	$75	$1,517	$1,493	2023	$183	$56	$1,127	$1,109
2024	$253	$77	$1,528	$1,497	2024	$184	$56	$1,113	$1,091
2025	$260	$80	$1,540	$1,502	2025	$186	$57	$1,100	$1,073
2026	$268	$82	$1,551	$1,507	2026	$187	$57	$1,086	$1,055
2027	$275	$84	$1,564	$1,512	2027	$189	$58	$1,073	$1,038
2028	$283	$87	$1,640	$1,644	2028	$191	$58	$1,103	$1,107
2029	$291	$89	$1,652	$1,650	2029	$192	$59	$1,090	$1,088
2030	$300	$92	$1,666	$1,655	2030	$194	$59	$1,077	$1,071
2031	$308	$94	$1,679	$1,661	2031	$196	$60	$1,065	$1,053
2032	$317	$97	$1,694	$1,667	2032	$197	$60	$1,053	$1,036
2033	$321	$99	$1,703	$1,670	2033	$196	$60	$1,038	$1,018
2034	$330	$102	$1,718	$1,676	2034	$197	$61	$1,026	$1,002
2035	$340	$105	$1,488	$1,560	2035	$199	$61	$872	$914
2036	$350	$108	$1,504	$1,567	2036	$201	$62	$864	$900
2037	$360	$111	$1,520	$1,574	2037	$203	$62	$856	$886
2038	$366	$112	$1,533	$1,576	2038	$202	$62	$846	$870
2039	$377	$115	$1,550	$1,583	2039	$204	$62	$839	$857
2040	$388	$118	$1,522	$1,567	2040	$206	$63	$808	$832

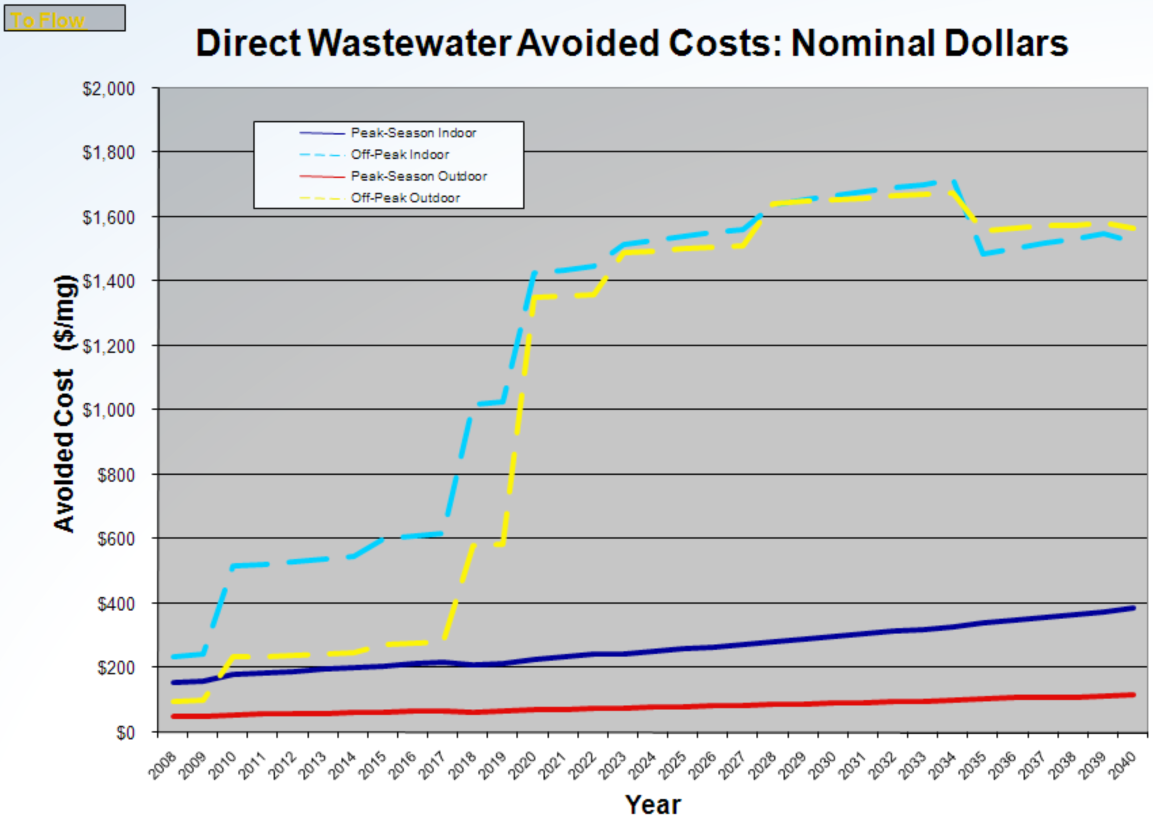


Figure A.5 USEPA/CUWCC Wastewater Avoided Cost Chart Output

These two models constitute an approach that incorporates the requisite analytical rigor in fashion that is usable by and adaptable to the needs of different water utilities. The avoided cost models provide a motion picture of the real economic cost consequences of consumption over time. The pat answer to the question as to which price signal—short-run or long run—should be used is: “In the short-run, prices should reflect short run marginal costs and in the long run, prices should reflect the long run marginal costs.” This principle may not provide the necessary guidance. If the long term expansion path of the water utility displays increasing avoided costs, then current customers need to be provided this information for efficient decision to be made. Utilities managers can decide how to shape the avoidable costs into feasible price signals in water rates over time.

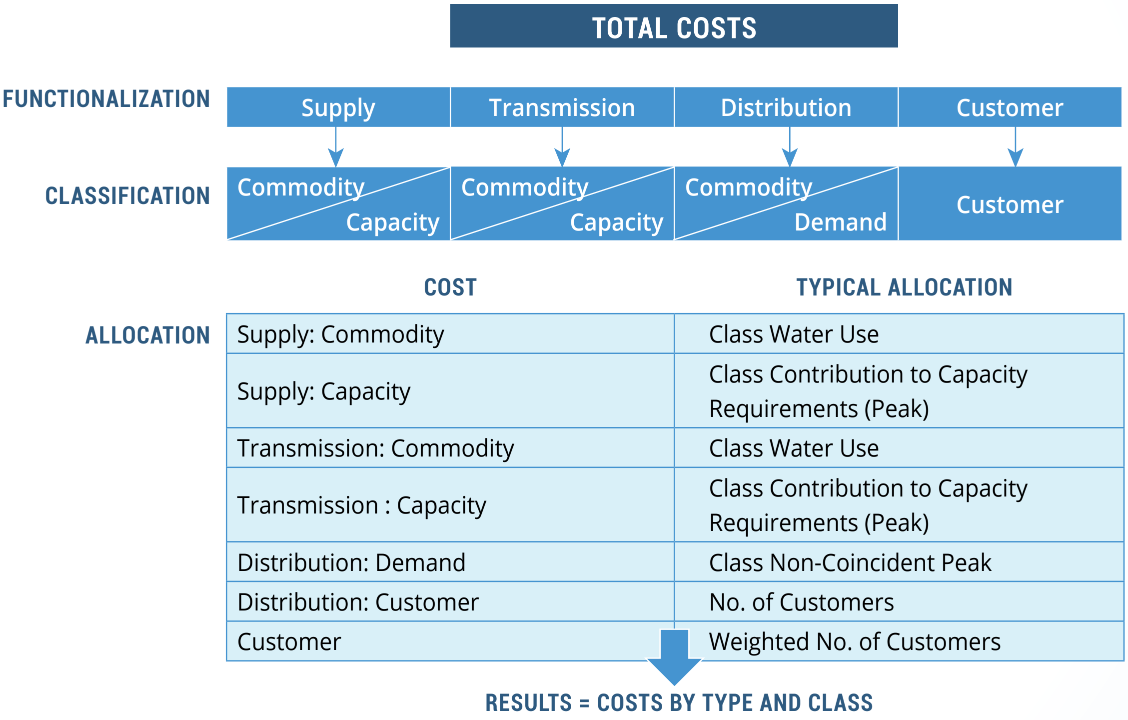
Comparing Cost of Service Analyses: Average/Embedded vs. Marginal/Incremental

Cost of Service Analysis (COSA) can be conducted on a traditional average/embedded approach or on a marginal/incremental approach. The alternative methods are not substitutes for one another and are often combined. This section outlines the alternative approaches and suggests how they might be combined.

- Cost Functionalization
- Cost Classification
- Cost Allocation

Figure A.6 shows the "top down" steps of an Average/Embedded Cost of Service Analysis, beginning with the total costs (total revenue requirements) being separated into smaller bins: 1) the total costs are placed into functionalized cost bins—supply, transmission, distribution, and customer costs; classified into cost types—either commodity/demand or base/extra capacity; allocated to customer classes by an allocation factor.

Figure A.6 Average/Embedded Cost of Service Approach



COST	TYPICAL ALLOCATION
Supply: Commodity	Class Water Use
Supply: Capacity	Class Contribution to Capacity Requirements (Peak)
Transmission: Commodity	Class Water Use
Transmission : Capacity	Class Contribution to Capacity Requirements (Peak)
Distribution: Demand	Class Non-Coincident Peak
Distribution: Customer	No. of Customers
Customer	Weighted No. of Customers

Figure A.7 shows the “bottom up” steps of a Marginal/Incremental Cost of Service Analysis that begins with identification of the marginal/incremental unit costs per function and allocates cost responsibility to individual customer classes. Class specific cost responsibility determines the class share of the total costs (total revenue requirements):

- Cost Functionalization
  - Assign costs (revenue requirements) to major functional categories based on cost drivers:
    - Supply, Distribution, Transmission, Customer, or A&G.
- MC Unit Cost Definition & Development
  - Determine the choice of units to allocate costs within functional categories (e.g., average usage, peak usage (capacity), number of customers).
  - Develop marginal unit costs by function.
- Customer Class Cost Allocation
  - Develop marginal costs by customer class by allocating functional costs to stable customer classes based on applying the marginal cost to the classification units for each class.
  - Compare the marginal costs to the current revenues.

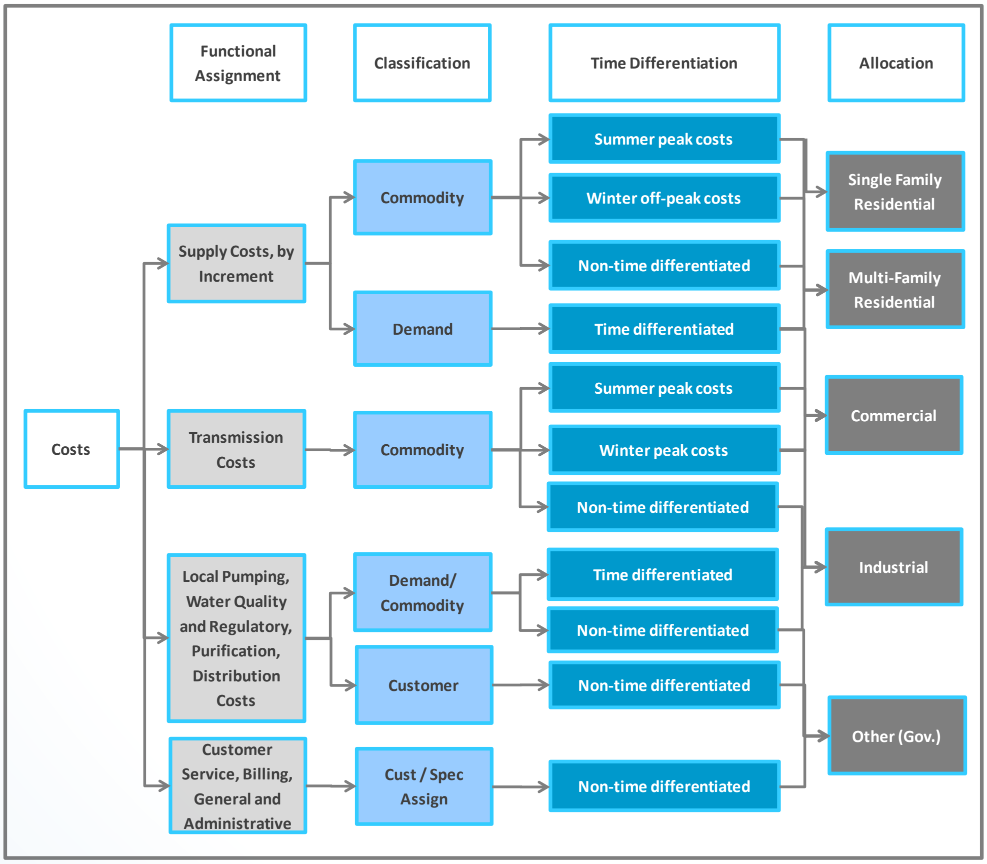


Figure A.7 Steps of a Marginal/Incremental Cost of Service Analysis

Table A.6 sets forth the different dimensions along which these two methods can be contrasted.

Table A.6 Cost Methods Contrasted

AVERAGE/EMBEDDED	MARGINAL/INCREMENTAL
Allocation of total revenue requirements to smaller and smaller “buckets” (top-down)	Identification of unit costs (bottom-up)
Cost allocated to classes using some measure of cost causation	Costs by demand load level
Based on history	Forward-looking
Rarely time-differentiated (Non-Coincident Peak)	Detailed time-differentiation
Capital costs often treated as completely capacity/demand-related	Not all capital costs are capacity/demand-related
Allocated costs total to overall revenue requirement (more or less)	“Revenue gap” is likely

It should be noted that a Marginal/Incremental COSA does not provide the total revenue requirement for the test period. Thus, a Marginal/Incremental COSA does not replace the traditional definition of the revenue requirement. It does provide information for rate design on the cost consequences for the water utility of customer consumption in different time periods.

Conclusion

All of the foregoing approaches shed light on the issues that must be addressed in estimating utility costs for ratemaking. Traditional costing methods are still required to generate the utility revenue requirement and avoid monopoly rents. Marginal/Incremental costs provide more accurate price signals to customers of the cost-causative consequences of consumptive decisions.