BY MANUEL P. TEODORO

MEASURING FAIRNESS: Assessing the equity of municipal water rates

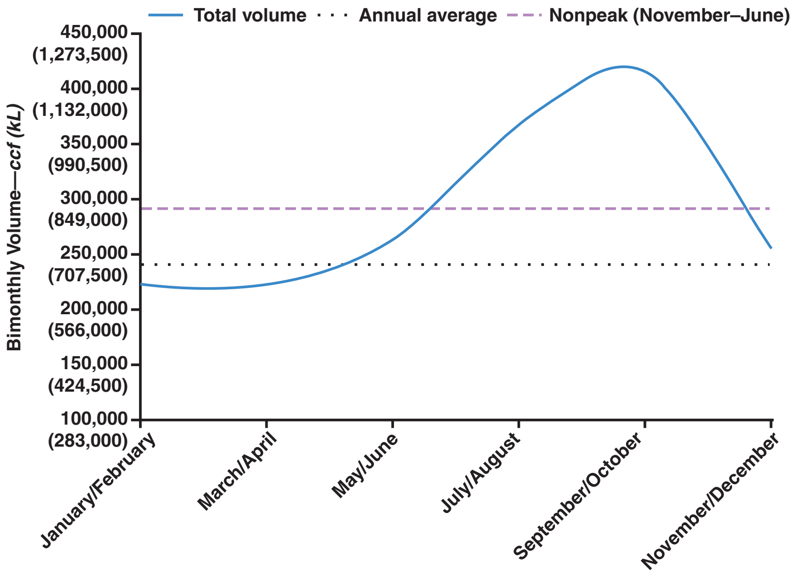
Setting prices for water service is among the most visible and politically sensitive duties that municipal water utility leaders bear. After making the operational and capital investment decisions that establish a utility's costs, policymakers establish a set of rates that its retail customers pay in exchange for water service. Rising operating and regulatory costs are driving ever-greater scrutiny over water utility rates, as AWWA Executive Director Jack Hoffbuhr recently observed (2004). Faced with rate-setting decisions, utility leaders must balance several goals. Reliable metrics for many goals of rate design are readily available: revenue generation is apparent in financial records, and conservation is measurable in terms of time series consumption volumes. Meaningful, scientific measures of rate equity are elusive. The lack of such measures hampers policymakers' efforts to balance equity with other goals.

An eminent scholar once remarked that in matters of public policy, "If you want something to count, find a way to count it" (Axelrod, 2001). Pursuant to that maxim, this study crafts a scientific measure of water-rate equity for individual customers of municipal utilities. This study also develops measurements of water rate equity and the progressivity of rate structures at the whole utility level. The result is a set of empirically grounded, theoretically consistent metrics of equity. Armed with quantitative information about the equity of their water rate proposals, utility leaders can make

EQUITY HAS LONG BEEN AN IMPORTANT PRINCIPLE OF UTILITY RATE DESIGN, BUT UNTIL NOW NO MEASURE OF RATE EQUITY HAS BEEN DEVELOPED AND APPLIED SYSTEMATICALLY TO MUNICIPAL WATER RATE STRUCTURES.

Full rate schedules underlying the comparative rate analyses presented in this article, specifically in Tables 5 and 8, are available from the author on request.

FIGURE 1 Sammamish Plateau Water and Sewer District 2001 utility consumption by billing period



Figures represent volume billed in each bimonthly billing cycle, reflecting water consumed in the prior two months (e.g., July/August bills reflect consumption in the May/June timeframe.

TABLE 1 Sammamish Plateau Water and Sewer District water service customers, 2001

Customer Class	Customers	Percent
Single-family residential	13,486	91.42
Multifamily residential	690	4.68
Commercial	157	1.06
Industrial	1	0.01
Public institution	58	0.39
Irrigation	360	2.44
Total	14,752	100.00

more prudent decisions and articulate those decisions to the public more effectively. Put another way, these equity indexes are a means of softening "rate shock."

Focusing on the cost-of-service concept of equity elaborated in *Principles of Water Rates, Fees, and Charges; Manual M1* (AWWA, 2000), this article applies tailored cost-of-service rates to develop equity scores for individual water customers and aggregate equity and progressivity indexes for rate structures. The theory is then applied to the rates and customer data of a municipal water utility—the Sammamish Plateau Water and Sewer District (SPWSD) in Washington—to demonstrate the mechanics of the equity metrics. Finally, this study analyzes several alternative rate structures for SPWSD and draws inferences about their respective degrees of equitability.

An important distinction between the **cost** and the **price** of municipal water is worth noting before proceeding. Municipal utilities incur costs when providing water service. The cost of water can include simply the cash cost of utility operations, maintenance, and capital, or it can include more abstract notions like economic opportunity cost or the "intrinsic value" of water (Rogers et al, 2002). By contrast, the water price (i.e., the rate) is the structure of charges, or tariffs, that wholesale and retail customers pay. Determining water costs and setting rates are distinct, though related, policy decisions; a utility's natural resource management, capital investment, and operating decisions determine its costs, while its pricing decisions define its rates. Though the assumption that costs are unrelated to rate structure is generally valid for most utilities, there are ways in which rate structure can affect overall utility costs. For example, a highly complex rate structure may drive higher administration and billing costs for a utility, and a utility with very aggressive inclined volume block rates may experience revenue volatility and require larger financial reserves than a comparable utility with a more stable revenue stream. This article addresses water rate design and treats utility costs as exogenous to the discussion.

MEASURING RATE EQUITY

Equity is a normative value on which reasonable people can hold different views (see sidebar beginning on page 114), but *Manual M1* (AWWA, 2000) articulates a standard of equity rooted in the cost of serving customers. How important cost-of-service equity is in designing good water rates may be a matter of one's perspective, but assessments of equity need not be subjective. Objective measures of performance are essential to achieving the normative goals of any public policy. For example, with an eye toward normative goals in water policy, researchers have developed objective, scientific indexes for access to water (Gleick, 1996; Falkenmark 1990; Fallenmark, 1974) and affordability (Hasson, 2002; Saunders et al, 1998).

Though these indexes are value-laden because they stand for specific normative ends, they are objective; they are based on sound data, constructed in a consistent theoretical framework and comparable across time and context.

If the cost-of-service equity principle as articulated in *Manual M1* (AWWA, 2000) is to be an important objective of public policy making, then pursuit of an objective measure of equity is appropriate. Measurements and indexes "define areas of concern" and "galvanize public opinion around a course of action" (Gleick et al, 2002). To date, no such measure of rate equity has been developed or applied systematically to municipal water rate structures.

This study develops consistent, scientific measurements of water rate equity. The method developed here compares each customer's calculated cost of service retrospectively with the rate actually paid or with rates that would have been paid under alterative rate structures. The disparity between a customer's cost of service and his or her actual rate paid is the absolute level of inequity because of rate design. With this disparity established, a set of metrics expressing rate equity at the individual customer and utility levels is possible.

This section of the article provides step-by-step explanations of the equity score and equity index calculations and their component parts. Because the discussion draws data from SPWSD to illustrate these metrics, this section begins with a brief description of the district.

Examining a special district. SPWSD serves a fast-growing suburban bedroom community on the Sammamish Plateau, 15 mi east of Seattle, Wash. A five-member board of commissioners governs the special district that served 14,752 water customers and about 9,000 sewer customers in 2001. A large majority of the district's customers are single-family residences, with relatively few multifamily resi-

FIGURE 2 Traditional cost-of-service rate analytical process

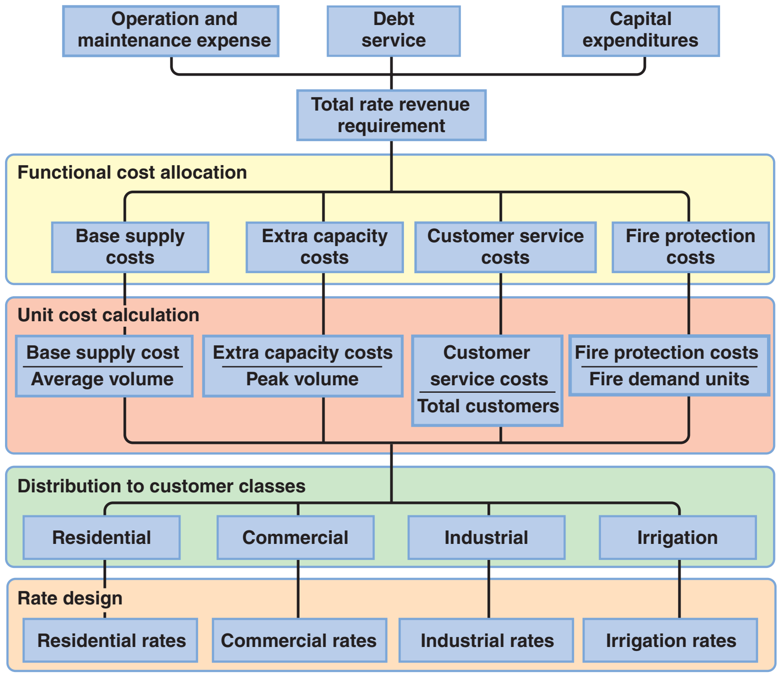
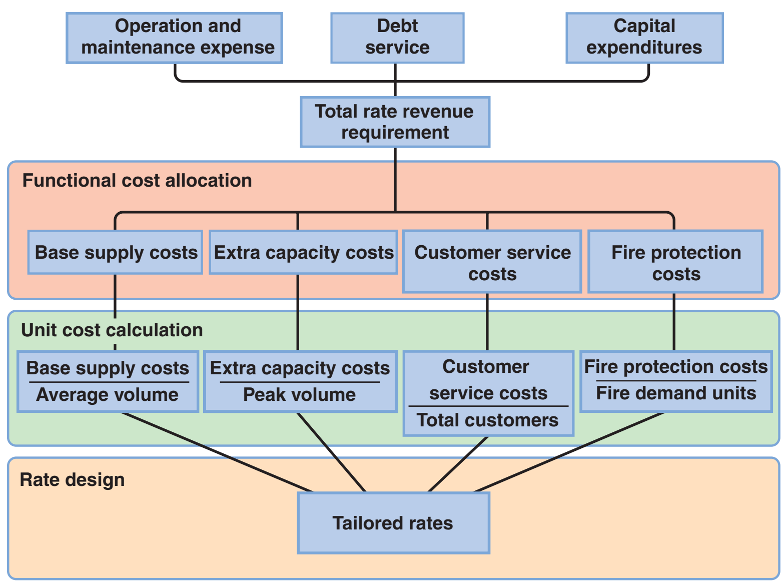


FIGURE 3 Tailored rate analytical process



What's fair?

Normative standards of water rate equity

Assessment of equity in public policy provision is at some level a matter of personal perspective: sound policy to one observer may be unjust to another. Though popular and scholarly discussions of water rates frequently address "equity," few define the term precisely or place it within a broader theoretical framework. Consequently, as Tsur and Dinar (1997) lament, "Equity is a vague concept that changes colors, shapes, and meanings depending on the particular object [against] which it is measured (opportunities, needs, incomes, utilities). It has therefore been pushed aside from mainstream economics (and its associated policy prescriptions), overshadowed by less subjective efficiency concepts."

A brief survey of industry and academic publications on water rate design reveals at least five concepts held up under the banner of "equity": provision of a basic human right, social justice, affordability, efficient resource use, and cost of service.

PROVISION OF A BASIC HUMAN RIGHT

Water is one of a small class of goods essential to human life and therefore a precondition to any other normative or utilitarian good (Maslow, 1954). As such, many observers count potable water service among the fundamental human rights that governments must ensure (Gleick, 1999; McCaffrey, 1992). Under this principle, normative considerations on rate structures are secondary to universal provision of potable water. Taken to its logical conclusion, water as a human right implies that utilities should provide at least some minimal quantity of domestic-use water free of charge to guarantee universal access to water. For rate design purposes, this idea might be best described as a human rights principle.

SOCIAL JUSTICE

The overall distribution of wealth and income in a society is a serious normative consideration for many concerned with social justice (Sen, 1973). Inasmuch as the prices that customers pay for water impact their overall economic status in society, policymakers may be concerned with the income distributional implications of water rate design. Such considerations are particularly important in areas of the world with widespread poverty or where access to irrigation for subsistence farming is a critical concern (Rhodes & Sampath, 1988). Yet evidence suggests that water rates alone can have little overall impact on income distribution, even in developing countries with widespread poverty (Tsur & Dinar, 1997). Thus the possibility that water rates

dential, commercial, or public customers, and only a single industrial customer. Table 1 shows the district's 2001 customer base by class. The district's supply is primarily from groundwater, though it recently finalized plans to connect to a regional wholesale supplier. The climate is temperate and wet during three seasons, but warm weather drives higher demands in the July/August and September/October billing periods, as Figure 1 illustrates.

In 2002 the district hired a consulting firm[1] to conduct a water rate study pursuant to an update of the district's rates in 2003. The rate study employed cost-of-service principles broadly consistent with Manual M1 (AWWA, 2000); that study's findings on the district's finances and cost of service underlie this article's analysis, except as otherwise noted.

The traditional cost-of-service rate design. Five basic analytical steps comprise the cost-of-service analysis used in water rates as outlined in Manual M1 (AWWA, 2000); they are summarized briefly here and represented graphically in Figure 2.

(1) Revenue requirement calculation. The revenue requirement is the amount of revenue that the utility's service rates must generate. The utility's annual operating, capital, and debt service expenses are added and adjusted for nonrate revenue that the utility receives. The revenue requirement may be calculated according to any conventional method (e.g., cash or utility basis) or with a more inclusive method that accounts for water's economic value. Billing data indicate that in 2001 SPWSD generated $4.65 million in water rate revenue.

(2) Functional cost allocation. This step allocates the utility's revenue needs into functional components. According to standards cited in Manual M1 (AWWA, 2000), costs typically are divided into four universal functions of municipal water utilities: (a) base supply, (b) peak demand, (c) customer service, and (d) fire protection. Alternatively, Manual M1 (AWWA, 2000) offers another functional allocation method, "commodity-demand," with a similar process. However, cost pools might be developed for other kinds of utility functions, too. For example, a utility might serve several pressure zones at different distances from the treatment facility or with disparate needs for pumping and storage. It is also possible to develop cost pools for these special functional costs if sufficient financial and capital records are available. SPWSD's rate study found that its 2001 revenue requirements were 29.3% attributable to base supply costs, 47.8% to peak demand, 15.7% to customer service, and 7.2% to fire protection.

(3) **Unit cost calculation.** Functional costs are divided by appropriate service metrics to determine functional unit costs of service. For example, annual base water-supply costs are divided by annual average volume sales. The result is the annual cost-per-unit of supplying water at or below the utility's average annual demand; customer costs are divided by the total number of customers. Appropriate units apply for each function. Table 2 shows the unit cost calculation SPWSD used to develop its 2003 rates.

(4) **Distribution of costs to customer classes.** Customers are grouped into classes and assigned portions of the revenue requirement according to the class's relative share of functional units. In the end, each class is assigned a portion of the utility's total revenue requirement to be recovered through rates designed for that specific class. In theory, customers are grouped into classes because they share similar consumption patterns and cost characteristics. In practice, customer classes are typically based on land use designation (e.g., single-family residential, commercial, or industrial) rather than on explicitly common water consumption patterns. Indeed, customers within classes often use water in widely varying patterns. *Manual M1* (AWWA, 2000) calls for utilities to

might affect wealth and income distribution in the United States seems remote, and US policymakers rarely cite this end as a consideration in rate design.

AFFORDABILITY

Closely related to water's status as a basic human right and concepts of social justice, the decidedly more pragmatic end of affordability is frequently cited by the equity-conscious. Affordability is a relative and contextual quality of water rates; that is, water's affordability is a function of a utility's water rate, a customer's income, and the prices of other goods that customer purchases (Saunders et al, 1998). In the interest of affordability, policymakers must make judgments about how much customers can afford to pay and set rates accordingly. Thus the notion of "affordability" hints at a basic human right for water, but it may be broader, recognizing aesthetic, economic, commercial, or other values of water. Moreover, though affordability is commonly associated with residential customers, it is a principle applied to other customers, too. Municipalities sometimes accommodate large commercial or industrial customers with low and/or declining rates in the interest of luring or retaining jobs in a community. When policymakers design rates to promote economic development, they are effectively making appeals to the affordability principle.

Thus there is an important distinction between affordability and other notions of equity. Rate affordability is meaningful at the level of a customer's ability to pay whereas equity connotes fairness across many customers; the price of a good or service can be affordable but not equitable, or vice-versa. Suppose two children with $1 each pool their money to buy a candy bar for 50 cents, with the first child contributing 10 cents and the second child 40 cents toward the purchase. Suppose then that the two children split the candy bar exactly equally, with each receiving half the candy. For both children the half candy bar is affordable inasmuch as each has enough money to pay for his contribution. However, the prices that the two children paid are not equitable inasmuch as the prices paid do not reflect the equal benefit that each child receives.

The point is that affordability may be conditionally important as a quality of water rate design but that ultimately affordability is an instrumental principle (i.e., desirable only pursuant to some other goal, like social justice or economic development).

RESOURCE EFFICIENCY

Water is a natural resource belonging to the entire community. When rates promote resource efficiency, they ensure that the community's water is put to good use and that no one wastes water with impunity. With this understanding, an "equitable" rate structure charges moderate prices for efficient water use and punitively high prices for wasteful use.

Some utilities have introduced water budget-based rates with this ideal in mind (Chesnutt & Pekelney, 2002). Under these schemes utilities assign an allotment of water to each customer, based on an assessment of the customer's need for water. For residential customers this assessment can include the number of persons in the household, the home size, the lot's landscaping, and other variables. Relying on the professional judgment of scientists, engineers, and economists, these water budgets are paragons of resource efficiency. This notion of efficiency is explicitly different from typical notions like economic efficiency, an allocation of resources to achieve an optimal level of welfare or utility (Tsur & Dinar, 1997).

Yet under a resource efficiency-oriented water budget structure, two residential customers with identical consumption records but different landscaping and family sizes might pay significantly different rates for water. So while resource-efficient, such rates are discriminatory inasmuch as they charge different prices to different customers for the same service.

COST OF SERVICE

Rates based on cost-of-service principles strive to make each customer pay exactly what it costs to serve him or her. An equitable rate structure by cost-of-service standards levies charges that approximate as closely as possible the costs of serving customers; resource, capital, operating, maintenance, customer service, and any other discrete cost pools are assigned as practicable to customers or groups of customers. This principle of ratemaking has cost-of-service equity at its core—proportionate sharing of costs by customers according to each customer's demands. Cost-of-service equitable rates may not necessarily be efficient, affordable, or socially just; cost-of-service equity is a distinct normative goal in itself. This understanding of equity underlies *Manual M1*'s (AWWA, 2000) guide to ratemaking, which remains the preeminent industry standard statement on equitable water rate design (Mumm & Matthews, 2004). The cost-of-service equity principle also informs the discussion in this article.

analyze their customers' demand patterns to ensure that classes are reasonably homogenous in their consumption characteristics; in practice such assessments are rare. Table 3 shows the allocation of functional costs to SPWSD's single-family residential class in 2003; a similar allocation applies to all customer classes.

(5) **Rate design.** With class cost pools established, utilities design rates for each class to recover the class's share of the revenue requirement. Municipalities typically charge customers some combination of periodic fixed and volumetric rates for service. Table 4 shows SPWSD's 2001 rates. All customers within a class pay according to the same rate schedule, but rate schedules may vary considerably across classes. Table 5 lists several other rate structures developed for the district's single-family residential customers to mimic structures common among US utilities; all are designed to generate equal revenue based on SPWSD's 2001 customer data. Ultimately, rate design decisions are influenced by a myriad of factors, many of which have little to do with scientific considerations of cost of service. For example, in the name of affordability or economic development, policymakers may design rates that favor particular groups of customers regardless of cost of service.

This kind of analysis underlies SPWSD's 2001 rate structure, and most US municipal water utilities employ some similar cost-of-service analysis in developing their rates.

Tailored rates are designed for individual customers. Assessing a rate structure's equity at the individual customer level requires measuring it against a cost-of-service yardstick. Thus the most equitable rate possible for each customer—the cost-of-service "tailored rate"—is the calculation upon which the measurement of rate equity rests. This section presents a method for calculating cost-of-service tailored rates for a water utility and its customers.

Consistent with the methodology described in earlier work on tailored rates, this calculation proceeds according to a four-step process (Teodoro, 2002). The first three steps—revenue requirement calculation, functional cost calculation, and unit cost calculation—are identical to those used in the traditional cost-of-service analysis described earlier. A new fourth step compiles analytical results directly into rates that apply to individual customers. Essentially, this analysis eliminates steps four and five of the traditional cost-of-service analysis by recognizing customers as individual consumers of water service, rather than as members of different classes. With consumption data for each customer it is possible to calculate what each would have paid for water over the course of the year if rates were tailored to reflect actual individual demands, rather than presumably homogenous class demands. Figure 3 illustrates the analytical process underlying tailored rates. Tailored rates are a simple aggregation of the functional unit costs multiplied by customers' individual service units, without a class cost-allocation step. Table 6 shows a 2001 cost-of-service tailored rate for SPWSD single-family residential customer number 10086, developed using the four-function cost-of-service framework.

This tailored rate is a close approximation to an equitable rate, derived with data generally available to a water utility. Teodoro (2002) provides a more thorough theoretical discussion of the tailored rate calculation. In this case the tailored rate is entirely retrospective; calculations are based on a full year's metered consumption data along with the same year's financial and engineering information. With actual and cost-of-service tailored rates in place, assessment of rate equity can proceed.

Figuring a rate equity score. The difference between an individual customer's tailored rate and the rate that the customer actually paid is the absolute cost-of-service inequity in the utility's rates for that customer. Converting this inequity value into an equity score allows for more analytical flexibility. Unlike an absolute dollar value, an equity score is validly comparable across time and across rate structures. In other words, it is possible to make meaningful comparisons between a customer's equity score today and his or her equity score 10 years ago, even when the utility's overall rate revenue requirements have changed considerably. Likewise, it is possible to compare the equity scores of two different rate structures for a particular customer, or the equity scores of two or more customers with one another.

The equity score for a customer is the difference between the rate actually paid and the tailored rate, divided by the tailored rate. Mathematically, the equity score e for customer i is:

$$e_i = \left(\frac{a_i - \tau_i}{\tau_i}\right) \qquad (1)$$

in which τ_i is the tailored rate as described and a_i is the actual rate paid by customer i over a given year. For customer i, e_i is a value that varies about zero, where a score of 0.00 reflects a water rate that is perfectly equitable for i.

There is no theoretical upper bound on an equity score, as a customer may actually pay many times the individual cost of service; the score is effectively limited at –1.0 on the negative end of the scale. There is no logical lower bound on the equity score either; however, an equity score can only be > –1.0 if the utility pays its customers for the privilege of providing service. This equity score is a mathematical expression of rate equity at the individual customer level and is useful when individual customers or groups of customers within a utility are the relevant units of analysis. A negative equity score indicates that the actual rate paid by i is lower than his or her calculated cost of service; a positive equity score indicates that the customer pays more than the calculated cost of service.

Returning to customer number 10086 from Table 6, the actual rate of \$295.98 paid in 2001 is \$57.77 greater than the cost-of-service tailored rate of \$238.21. The result is an equity score of 0.243, indicating this customer paid 24.3% more than the calculated cost of service in 2001. Table 7 shows rate equity score calculations for 10 SPWSD customers in 2001. The disparity between cost-of-service-based tailored rates and the actual rate differs considerably across the SPWSD customer base; scores for the district in 2001 range from a low of –0.591 to a high of 5.646. These scores allow rate equity analysis of individual customers within a utility.

Establishing a rate equity index. Analysis of an entire utility requires a metric of equity for an entire rate structure. A utility's managers and policymakers may want to compare the overall equity of two or more rate structures or compare rate equity today against equity in prior years. The rate equity index (REI) developed here is an aggregated utility-level indicator of the degree to which a utility's water rates differ from the calculated cost-of-service for all customers. Mathematically, the REI is the total absolute difference between actual and tailored rates, divided by total actual rate revenue, subtracted from one and multiplied by 100. Symbolically, the REI for utility U is

$$\text{REI}_U = 100\left[1 - \left(\frac{\sum_{i=1}^{n} |a_i - \tau_i|}{R_U}\right)\right] \qquad (2)$$

in which R_U is the total rate revenue requirement for utility U. The result is a value for utility U bounded by zero and 100 (inclusive), representing the absolute percentage deviation of actual rates from calculated cost-of-service for all the utility's customers. Higher values of REI represent more-equitable rates, and lower values of REI reflect less-equitable rates. A utility with perfectly equitable rates (theoretically possible, though extremely unlikely under conventional rate structures) would have an REI of 100. An REI of zero is possible only for a utility that does not charge for water. In 2001 SPWSD's rate structure produced an REI of 71.0.

A progressivity analysis. A final component of the utility-level equity investigation is an analysis of the degree to which a utility's rate structure favors high cost-of-service customers or low cost-of-service customers. Rates that result in negative equity scores for low cost-of-service customers and positive equity scores for high cost-of-service customers are **progressively** inequitable. Conversely, if a utility's low-cost-of-service customers tend to have positive equity scores and its high-cost-of-service customers negative scores, then we may describe its rates as **regressively** inequitable. In other words, if a utility's costliest customers pay relatively more than the low-cost customers of a utility, then its rates are progressive. If the costliest customers pay relatively less than the low-cost customers, then its rates are regressive.

Rate progressivity may be measured systematically with a Spearman's ρ correlation between customers' relative cost-of-service tailored rates and their equity scores. Mathematically, this progressivity correlation ρ_U is:

$$\rho_U = \frac{\Sigma e_i r_i - \frac{\Sigma e_i \Sigma r_i}{N}}{\sqrt{\left(\Sigma e_i^2 - \frac{(\Sigma e_i)^2}{N}\right)\left(\Sigma r_i^2 - \frac{(\Sigma r_i)^2}{N}\right)}} \qquad (3)$$

in which N is the number of customers utility U serves and the val-

TABLE 2 Sammamish Plateau Water and Sewer District 2003 functional unit costs from district rate study

	Utility Function				
	Base Supply	Peak Demand	Customer Service	Customer Accounts	Fire Protection
Revenue requirement	$1,509,443	$2,486,385	$213,690	$729,407	$371,276
Percentage	28.4	46.8	4.0	13.7	7.0
Service unit	Winter average volume	ME	MSE	Accounts	Total annual volume
2003 units*	249,254 ccf (7.06e+05 kL)	19,086 ME	15,728 MSE	14,512	1,859,300 ccf (5.26e+06 kL)
Unit cost (revenue requirement/2003 units)	$6.06/ccf	$53.87/ME	$13.59/MSE	$50.26/account	$0.20/ccf

ME—meter equivalents, MSE—meter service equivalents
*Based on rate study projections

TABLE 3 Sammamish Plateau Water and Sewer District 2003 revenue requirement allocation—single-family residential

Function	Units	Unit Cost $	Single-family Residential 2003 Units*	2003 Allocated Revenue Requirement (cost · unit) $
Base supply	Winter average volume (ccf)	6.06/ccf	193,452 ccf (5.48e+05 kL)	1,171,517
Peak demand	ME	53.87/ME	13,453 ME	1,679,856
Customer accounts	Accounts	50.26/account	13,226	664,767
Customer service	MSE	13.59/MSE	13,310 MSE	180,838
Fire protection	Annual volume	0.20/ccf	1,424,130 ccf (4.03e+06 kL)	304,810
Total				4,001,788

ME—meter equivalents, MSE—meter service equivalents
*Based on rate study projections

ues of r are the cost-of-service ranks for all customers of U. That is, if all customers are ordered from 1 to N according to their tailored rates, the value of r_i is i's rank position in that sequence. This rank-ordering of the tailored rate distinguishes the Spearman's ρ from the more common Pearson's correlation. By using the Spearman's ρ, the progressivity correlation essentially compares the way a rate structure treats customers within a utility relative to one another. The advantage (and disadvantage) of this approach is that it reduces the influence of extreme values, or outliers, relative to the simple Pearson's correlation. For utilities with extreme variation in consumption pattern and equity scores, this procedure will tend to mute progressivity or regressivity compared with a Pearson correlation. Bounded by –1.0 and 1.0, this progressivity correlation ρ_U indicates the linear relationship between customers' cost-of-service rank and their equity scores in utility U. The progressivity correlation between cost-of-service tailored rates and equity scores will be positive under a progressively inequitable rate structure; ρ_U will be negative under regressively inequitable rates. The progressivity correlation would be mathematically undefined for a perfectly equitable rate structure, because all equity scores would be equal to zero, leaving a zero in the denominator of the Spearman correlation equation. Values of ρ approaching zero are generally neutral—that is, they indicate little systematic relationship between customers' equity score and their cost of service. Values of ρ_U approaching the extremes of –1.0 and 1.0 indicate that rate structures systematically favor either high- or low-cost-of-service customers. In 2001 the SPWSD progressivity correlation ρ was –0.715, indicating a fairly regressive rate structure.[2]

Figures 4 and 5 offer illustrations of the equity impact that the district's 2001 water rate structure had on its customers by calculated cost of service. Each figure depicts the experience of 100 SPWSD customers drawn at random from the customer base. Figure 4 shows a generally downward-sloping relationship between equity scores and cost-of-service ranking. This plot demonstrates that the district's costliest customers tend to experience negative equity scores—(mostly those ranked greater than 10,000, toward the right side of the scatter plot in Figure 4) meaning that most of these customers paid less than the cost of their water service—whereas the majority of customers ranked below 10,000 show positive scores, indicating that most of those customers with lower cost-of-service paid more than their actual service costs. This sample of 100 customers is consistent with the whole district; in 2001, customers with positive equity scores outnumbered those with negative equity scores more than two to one (10,468 positive equity scores versus 4,284 negative equity scores).

Figure 5 translates the equity scores in Figure 4 into dollar values, illustrating the way that the 2001 rates distributed financial burdens across the customer base. In this sample of customers, the area above zero shows the effective "markup" relative to cost of service that the lower cost-of-service customers pay (generally shown at the left two thirds of the graph). Offsetting this markup is the effective "discount" that high cost-of-service customers receive (illustrated in the area below zero toward the right side of the graph). Across the entire utility the values of these markups and discounts net to zero, so the cost paid across the entire customer base provides a de facto subsidy to most high cost-of-service customers. Under the 2001 rate structure the average markup over cost of service was $64.40 whereas the mean effective discount relative to cost of service was $157.37.

The implication of the progressivity correlation and the information illustrated in Figures 4 and 5 is that under the district's 2001 rate structure the costliest third of the customer base was the greatest beneficiary of the structure's inequity. Put another way, from a cost-of-service perspective, the district's least costly 10,468 customers subsidized the water service of the district's costliest 4,284 customers in 2001 by an aggregated amount of $674,162, or 14.5% of total rate revenue.

TABLE 4 Sammamish Plateau Water and Sewer District 2001 retail water rates

Meter Diameter (All Classes) *in. (mm)*	Bimonthly Fixed Charge *$*	Volume		
		Block 1 *ccf (kL)*	Block 2 *ccf (kL)*	Block 3 *ccf (kL)*
0.625 and 0.75 (15.63 and 18.75)	15.63	0–15 (0–42.5)	15–60 (42.5–169.9)	>60 (>169.9)
1 (25)	21.61	0–38 (0–107.6)	38–150 (107.6–424.8)	>150 (>424.8)
1.50 (37.5)	33.09	0–75 (0–212.4)	75–300 (212.4–849.5)	>300 (>849.5)
2 (50)	47.11	0–120 (0–339.8)	120–480 (339.8–1,329.2)	>480 (>1,329.2)
3 (75)	82.36	0–240 (0–679.6)	240–960 (679.6–2,718.4)	>960 (>2,718.4)
4 (100)	126.90	0–375 (0–1,061.9)	375–1,500 (1,061.9–4,247.5)	>1,500 (>4,247.5)

Customer Class	Volume Block Charges per ccf (kL)—$		
	Block 1	Block 2	Block 3
Single-family residential	1.49 (0.53)	1.81 (0.64)	3.85 (1.36)
Multifamily residential	1.15 (0.41)	1.40 (0.49)	3.85 (1.36)
Commercial	1.15 (0.41)	1.40 (0.49)	3.85 (1.36)
Industrial	1.15 (0.41)	1.40 (0.49)	3.85 (1.36)
Public institution	1.30 (0.46)	1.57 (0.55)	3.85 (1.36)
Irrigation (with audit)	1.92 (0.68)	2.13 (0.75)	4.82 (1.36)
Irrigation (without audit)	3.73 (1.32)	4.14 (1.46)	8.42 (2.98)

ANALYSIS

Equity scores, rate equity indexes, and progressivity correlations calculated for multiple rate schedules allow comparison of equity for several rate-structure alternatives. The following section demonstrates how these equity metrics can help investigate the equity implications of different rate structures for a single utility.

Establishing an effective method. Equity scores, REIs, and progressivity correlations were developed for SPWSD's 2001 rates, as described previously. In order to test the equity implications of rate structure changes, seven hypothetical alternative class-based rate schedules were developed for the district's 2001 customer data and revenue requirements. Another four alternative rate structures without customer class distinctions were also created. All 12 rate structures are "revenue neutral"; that is, each is designed to recover the $4.65 million that the district actually collected through rates in 2001. The alternative rate structures were designed to mimic some of the structures elaborated in *Manual M1* (AWWA, 2000) that are common to many US utilities. All the alternatives analyzed here are consistent with *Manual M1* (AWWA, 2000); however, it is important to note that many other results could have been developed for each alternative shown in Table 5. The

TABLE 5 Single-family residential water rate structures*

Structure	Description	Example Using Bimonthly Rate for 0.75 in. (18.75 mm) Meter
Fixed only	Customers pay a fixed charge each period for service, regardless of the volume consumed.	$45.91
Fixed + volume	Customers pay a fixed charge each period for service with an additional volume charge for each unit consumed.	$15.63 + $1.80/ccf (+$0.64/kL)
Fixed + volume with allowance	Customers pay a fixed charge each period for service with additional volumetric charges beyond a basic volume allowance.	$40 + $0.00/ccf for 0–20 ccf (+ $0.00/kL for 0–56.6 kL) $40 + $2.50/ccf for >20 ccf, (+ $0.88/kL for >56.6 kL)
Fixed + two-block inclined volume	Customers pay a fixed charge each period for service with additional volumetric charges. Charges increase for volumes above a set first-block level.	$15.63 + $1.50/ccf for 0–20 ccf (+ $0.53/kL for 0–56.6 kL $15.63 + $2.25/ccf for >20 ccf (+ $0.80/kL for >56.6 kL)
Fixed + four-block inclined volume	Customers pay a fixed charge each period for service, with additional volumetric charges. Charges increase at progressively higher volumes at set block levels.	$12.00 + $1.00/ccf for 0–10 ccf (+ $0.35/kL for 0–28.3 kL) $12.00 + $2.25/ccf for 10–20 ccf, +$0.80/kL for 28.3–56.6 kL) $12.00 + $3.25/ccf for 20–40 ccf ($1.15/kL for 56.6–113.3 kL) $12.00 + $4.50/ccf for >40 ccf ($1.59/kL for >113.3 kL)
Fixed + declining-block volume	Customers pay a fixed charge each period for service with additional volumetric charges. Charges decrease at progressively higher volumes at set block levels.	$12 + $2.25/ccf for 0–10 ccf (+ $0.80/kL for 0–28.3 kL) $12 + $1.50/ccf for 10–20 ccf (+ $0.53/kL for 28.3–56.6 kL) $12 + $1.25/ccf for 20–40 ccf (+ $0.44/kL for 56.6–113.3 kL $12 + $0.75/ccf for > 40 ccf (+ $0.27/kL for >113.3 kL)
Fixed + seasonal volume	Customers pay a fixed charge each period with additional volumetric charges. Charges vary by season, with higher rates applying during peak demand periods and lower rates applying during periods of low demand.	$15.63 + $1.25/ccf November–June (+$0.44/kL November–June) $15.63 +$2.50/ccf July–October (+ $0.88/kL July–October)

*All rate structures designed to recover Sammamish Plateau Water and Sewer District's 2001 rate revenue requirement.

TABLE 6 2001 tailored rate for single-family residential customer number 10086

Utility Function	Unit Cost c	Units for Customer i u_i	Annual Tailored Rate $c \cdot u_i = \tau$
Base supply	$0.78/ccf ($0.276/kL) total annual consumption	127.2 ccf (360.2 kL)	$99.40
Peak capacity	$4.71 per ccf ($1.66/kL) July/August billed volume over utility nonpeak average	6.9 ccf (19.5 kL)	$32.44
	$5.56 per ccf ($1.96/kL) September/October billed volume over utility nonpeak average	6.2 ccf (17.6 kL)	$34.40
Customer service	$12.00 per meter service equivalent	1 meter service equivalent	$12.00
Customer accounts	$37.45 per customer account	1 account	$37.45
Fire protection	$23.31 per fire service unit	0.966 fire unit	$22.52
Total			$238.21

alternatives presented are intended to illustrate the sensitivity of the equity metrics to rate design decisions. Table 5 shows the single-family residential rates for seven of the nine alternative structures.

With alternative rates established, a full set of equity metrics including individual scores, REIs, and progressivity correlations were calculated for each alternative rate structure for comparison.

Interpreting the findings. Analysis of alternative rate structures for SPWSD's 2001 customers indicates that differences in rate structures cause considerable differences in equity and progressivity. Table 8 shows the REI and progressivity correlation results for all eight class-based rate structures (actual 2001 rates plus nine hypothetical alternatives). Table 8 also shows the equity score outcomes for customer number 10086 under each rate structure to illustrate the effect that rate structures can have on equity at the individual customer level.

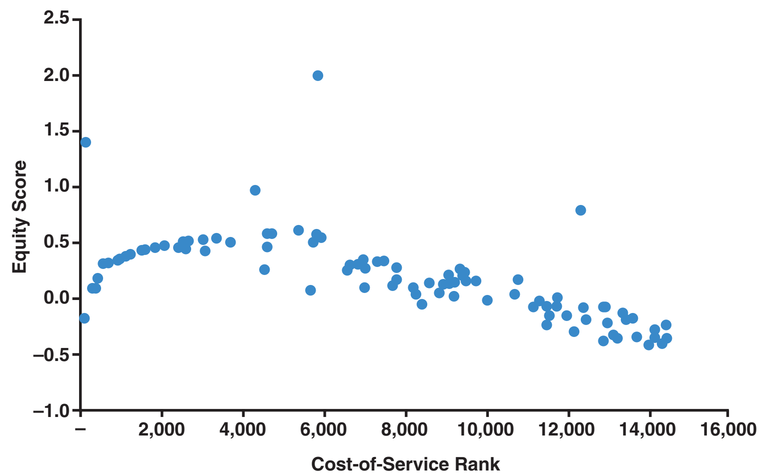
As Table 8 indicates, REIs and progressivity correlations were lowest for the fixed-rate only and fixed-plus-volume with allowance structures. The fixed-plus inclining four-block rate structure generated the highest REI value (79.4) and progressivity correlation (–.288) among the class-based structures in Table 8; that is, among the class-based rate structures assessed here, structure 6 is the most cost-of-service equitable and least regressive. These results indicate that structures that are relatively insensitive to customers' demand patterns drive lower aggregate equity whereas structures that are more sensitive to customers' consumption behavior drive greater equity. This finding is consistent with the principles articulated in *Manual M1* (AWWA, 2000).

Moreover, these findings offer tantalizing evidence that, at least for one utility, rate structures normally considered "conservation-oriented" (with lower fixed charges, inclining volume block charges, and smaller consumption intervals) are also more cost-of-service equitable than their more conventional cousins. Put simply, in this case, conservation rates are more equitable rates.

Four alternative rate structures without customer class distinctions were developed to investigate whether the district's classes enhanced or inhibited equity in 2001. The REI and progressivity correlations for these non-class-based rates are shown at the bottom portion of Table 8. For both the four-block inclined volume and seasonal structures, elimination of customer classes improved equity and progressivity. Elimination of graduated fixed charges for larger meter sizes improved REI and progressivity even further. Indeed, of the 12 rate structures considered in Table 8, the fixed-plus-inclining four-block rate structure without classes or meter size charges generated the highest REI (80.0) and progressivity (–.189).

These results lead to two important observations. First, the improvement in aggregate equity with elimination of classes reinforces suspicions that land-use-based classes are poor proxies for individual demand patterns. In the case of SPWSD, existing customer class distinctions actually reduce aggregate rate equity. Second, the improvement in progressivity with elimination of meter-size charges suggests that many customers with larger meters do not demonstrate the correspondingly higher demands that graduated fixed rates suggest. Overall, it seems that

FIGURE 4 SPWSD equity scores by cost-of-service rank*



SPWSD—Sammamish Plateau Water and Sewer District

**Random sample of 100 SPWSD customers*

TABLE 7 2001 equity scores for 10 Sammamish Plateau Water and Sewer District single-family residential customers

Customer Number	Tailored Rate *t*	Actual Rate *a*	Difference *a–t*	Equity Score *[(a–t)/t]*
10086	$238.21	$295.98	$57.77	0.243
10091	$534.89	$373.97	($160.91)	(0.301)
10118	$295.02	$299.76	$4.74	0.016
10119	$190.86	$257.17	$66.31	0.347
10121	$226.60	$270.26	$43.65	0.193
10125	$182.37	$249.27	$66.90	0.367
10127	$200.17	$235.03	$34.86	0.174
10129	$529.41	$390.24	($139.17)	(0.263)
10132	$224.64	$291.56	$66.92	0.298
10133	$198.82	$243.70	$44.89	0.226

for SPWSD, classes and meter size are not valid indicators for demand patterns.

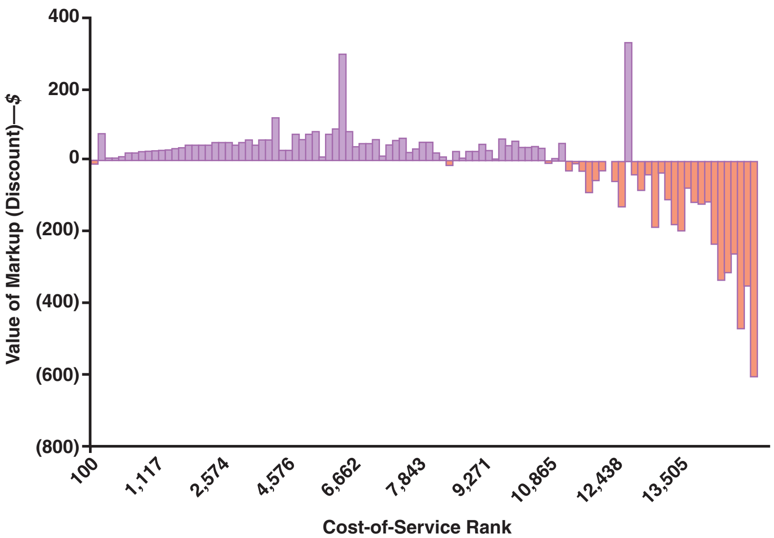
Finally, all of the rate structures analyzed as part of this study have negative progressivity correlations and so are regressive in the aggregate. That is, in all cases, the highest cost-of-service customers tend to enjoy negative equity scores (effective discounts) whereas low cost-of-service customers tend to suffer positive equity scores (effective markups). Thus even under fairly aggressive conservation-oriented rate structures such as 7 and 10, low-cost customers subsidize high-cost customers to some extent.

CAUTIONS AND CLARIFICATIONS

The intuitive ease of the equity score, equity index, and progressivity correlation developed here may obscure their limitations. Researchers and policy analysts must bear in mind a number of potential pitfalls when performing equity analyses using these metrics.

First, the metrics of water rate equity developed here rely on two critical inputs: a valid set of customer-level meter data and a sound cost-of-

FIGURE 5 Value of 2001 rate markup (discount) by cost-of-service rank*



***Random sample of 100 Sammamish Plateau Water and Sewer District customers**

service analysis. Corrupted meter data may cause distortions in equity scores, and systematically inaccurate data may bias utility-level equity indexes and progressivity correlations. Careful data management is therefore an important prerequisite to an equity analysis. Further, meter readings must be sufficiently frequent for utilities to infer demand patterns. The bimonthly billing schedule SPWSD employs probably is the minimum billing frequency necessary for inference of individual demand patterns. More frequent meter data—or ideally, real-time consumption data—are preferable for inferring demand patterns. Similarly, equity metrics are only as valid as the cost-of-service analyses upon which they rest. Reliable cost-of-service analyses are frequently quite complicated, even for relatively small and ordinary utilities. To the extent that a cost-of-service analysis is shoddy or inaccurate, the equity analyses that follow will also be inaccurate.

Second, because the equity metrics are based on a cost-of-service analysis of a specific utility, researchers and policymakers should be careful about comparing equity metrics for different utilities. The data that underlie cost-of-service analyses can include billing records, financial records, capital plans, engineering designs, municipal ordinances, state regulations, and myriad other records. The availability and quality of these data vary widely across utilities. Moreover, even for seasoned experts applying state-of-the-art techniques, cost-of-service analysis remains as much a craft as a science. Two reasonable, competent professionals may arrive at somewhat different cost-of-service findings for the same utility because of subtle differences in methodology. Any comparison of equity metrics—and, by implication, cost of service figures—across utilities should be made with great caution.

Third, analysts should be cautious when evaluating equity across classes of customers. In utilities accustomed to grouping customers by land-use class (e.g., single-family residential, commercial, irrigation) it may be tempting to analyze aggregate equity by customer class to discover which classes fare best and worst under different rate structures. But a chief premise of the tailored rate used to develop equity scores is: "actual consumption pattern, not customer class, is the phenomenon driving service costs." To the extent that consumption patterns vary considerably within customer classes—as they do in SPWSD—equity disparities within classes may be as great as those observed across the entire utility. In such cases, assessing rate equity by customer class may simply perpetuate and legitimize a poor assumption that the cost of serving water customers is primarily driven by customer class.

It is possible to make meaningful comparisons between a customer's equity score today and his or her equity score 10 years ago, even when the utility's overall rate revenue requirements have changed considerably.

Fourth, the equity analyses developed here are retrospective; that is, they look at a past year's consumption and financial data and assess the equity that various rate structures would have produced under identical conditions. Analyses of potential future rate changes should bear in mind the possible sensitivity of utility costs and consumption patterns to changes in the rate structure.

Finally, this analysis relies on short-term costs and demands whereas utility systems inherently require long-term investments to accommodate long-term demands. Utility costs that are unbalanced over time because of uneven capital investment, fluctuating real operational costs, or other factors, introduce potential "temporal" or intergenerational inequity over time. That is, in many cases today's customers partially bear the costs incurred to serve yesterday's and/or tomorrow's customers. This temporal inequity is one of the persistent difficulties in designing cost-of-service rates, and the equity metrics developed here do not capture this kind of inequity.

CONCLUSION

This article develops a theoretical model for quantifying cost-of-service equity in water rates, demonstrates the viability of equity metrics, and uses them to analyze several rate structures for a small municipal utility. These metrics having been established, researchers and policy analysts may explore a number of important questions about municipal water rates.

A policy analyst's tool. With equity metrics in place, investigators can answer several questions: Are equity scores more or less normally distributed across a utility, or are there patterns of inequity? Do relatively conservative customers consistently pay more than their fair share, while profligate customers pay less, or vice-versa? Are there deeper social implications to patterns of inequity? That is, do rich and poor customers experience systematically different levels of equity? Do different racial or ethnic groups experience different levels of equity?

TABLE 8 2001 equity metrics for rate structures

Rate Structure	Equity Score for Customer Number 10086	Rate Equity Index (REI)	Progressivity Correlation (ρ)
Equity standard*	0.000	100.0	0.000
Class-based rate structures			
(1) Actual rates (see Table 2)	0.243	71.0	–.715
(2) Fixed rates only	0.156	33.6	–.906
(3) Fixed + volume	0.355	66.8	–.700
(4) Fixed + volume with allowance	0.161	58.0	–.950
(5) Fixed + inclining two-block	0.241	71.9	–.715
(6) Fixed + inclining four-block	0.250	79.4	–.288
(7) Fixed + declining four-block	0.277	62.3	–.568
(8) Fixed + seasonal	0.287	70.7	–.710
Non-class-based rate structures			
(9) Fixed + inclining four-block	0.265	79.9	–.275
(10) Fixed + inclining four-block, no meter size charges	0.132	80.0	–.189
(11) Fixed + seasonal volume	0.198	74.1	–.520
(12) Fixed + seasonal volume, no meter size charges	0.310	73.4	–.554

*Values representing ideal cost-of-service equity, given data and computational constraints

At the utility level, the rate equity index allows comparisons of equity in a utility over time. Do some kinds of rate structures (e.g., inclined block, flat rate, or water budgets) carry systematic equity consequences for different kinds of customers? Are some kinds of rate structures more or less progressive than others? The results here suggest that, at least for one utility, different rate structures result in significantly different degrees of equity and progressivity. Perhaps most intriguing is the initial finding that conservation-oriented rates may be much more cost-of-service equitable and less regressive than other traditional rate structures, indicating that conservation and equity are complementary, not opposed, values. The results here also reaffirm *Manual M1*'s (AWWA, 2000) call for frequent analyses to confirm the homogeneity of customer classes and meter-size groups for rate-making purposes. The substantive findings of this study are limited but offer enticing possibilities for broader studies of utilities elsewhere.

A guide for policymakers. Particularly exciting are the possibilities that these equity metrics hold out for policymakers. If a utility has a cost-of-service analysis and has customer-level consumption data, it has all the pieces it needs to perform an equity analysis. Though the equity metrics developed in this article are time consuming, analysis of a statistically valid sample of customers could be easier and reasonably valid. Metrics of rate equity provide policymakers with a means of making more informed judgments about rate design. With equity metrics before them, utility leaders can assess the relative equity of various rate structures. Equity metrics will

From a cost-of-service perspective, the district's least costly 10,468 customers subsidized the water service of the district's costliest 4,284 customers in 2001 by an aggregated amount of $674,162, or 14.5% of total rate revenue.

allow policymakers to make explicit judgments about the trade-offs between equity and other goals of rate design. Moreover, equity analyses will help the managers and governing boards that run utilities make their cases for rates to their customers with greater clarity and confidence.

These equity metrics are equally applicable to wholesale utilities, too. With functional cost analyses and customer consumption data available, the theoretical framework developed here allows equity analysis of a wholesale water supplier's charges to other utilities. In this way equity metrics hold out the potential to cool with science the often heated negotiations between wholesale suppliers and their customers.

The claim here is not that cost-of-service equity should be the primary goal of rate design. Rather, the argument here is that cost-of-service equity as advanced in *Manual M1* (AWWA, 2000) is an important ethic, and inasmuch as it is important to policymakers, sound measures of equity are essential to making good policy. To put it simply, rate equity will count more now that there's a good way to count it.

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FOOTNOTES

[1]Financial Consulting Solutions Group Inc. (FCS Group), Redmond, Wash.

[2]Progressivity correlation calculations were made using Stata 8.0 for Windows, StataCorp LP, College Station, Texas.

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