The American Water Works Association
Water Conservation Division Subcommittee Report

WATER CONSERVATION MEASUREMENT METRICS

Guidance Report

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GUIDANCE REPORT

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WATER CONSERVATION MEASUREMENT METRICS: GUIDANCE REPORT

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1. PURPOSE

Public water supply utilities need quantitative metrics and benchmarks in order to assess their success in achieving water efficiency goals. Such metrics and benchmarks have to be explicitly and appropriately defined. They also have to be characterized in terms of their value in making comparisons between different periods of time for a single utility or across different utilities.

The purpose of this guidance report is to identify and characterize a set of water use and conservation metrics for public water supply utilities. These metrics could be used as measurement tools to evaluate the effects of water efficiency programs over time in a single utility. Some metrics can also be used to compare water use and conservation effects across different utilities. This report provides guidance on standardized methods of calculating specific metrics and describes their advantages and limitations. The calculation and use of metrics are illustrated using data from seven water utilities in the U.S. that agreed to participate in the project.

2. METRICS VERSUS BENCHMARKS

Before providing guidance on specific metrics it is important to clarify the terminology and potential uses of metrics and benchmarks. While the terms “metric” and “benchmark” are sometimes used interchangeably, for the purpose of this report stricter definitions are adopted in the context of evaluating the use of water. These are described below.

2.1 Definition of a Metric

A *metric* is a unit of measure (or a parameter being measured) that can be used to assess the rate of water use during a given period of time and at a given level of data aggregation (e.g., system-wide, sector-wide, customer level, or end-use level). Another term for a *metric* is *performance indicator*.

Basically, a metric is a formula. In the context of measuring water use, there are very many possible metrics that can be formulated. Some examples of water usage metrics include: total water use per capita per day; residential indoor water use per dwelling unit per day; or average volume of water being used for flushing toilets.

A mathematical formula can be applied to water use and related data from a utility for a defined time period to obtain a *numerical value* of any given metric. This value can be compared to a pre-defined *benchmark* value to assess a relative level of performance. It is important to remember that the calculated value of a metric of water usage is not a benchmark value.

A number of different metrics for measuring water usage rates can be devised. However, the ability to develop the corresponding benchmark values depends on the level of data aggregation and other considerations.

2.2 Definition of a Benchmark

A *benchmark* is a particular (numerical) value of a metric that denotes a specific level of performance, such as a water efficiency target. Sometimes a distinction is made between a *benchmark* (which indicates a current state of achievement) and a *target* which indicates a state of achievement expected at some time in the future.

Basically, *benchmarks* or *targets* are numerical values of the metric to which the calculated metric values are intended to be compared. Metrics and benchmarks can be defined in either absolute or relative terms. For example, some broadly defined benchmarks may reflect conservation goals of water utility, which are often expressed in relative terms, such as a 15 percent reduction of average annual per capita water use in 10 years.

Examples of specific absolute-value benchmarks include: Energy Policy Act of 1992 requirement that all residential toilets had to flush using no more than 1.6 gallons per flush; or Energy Star residential clothes washer standard water factor WF ≤ 8.0 gallons per cycle per cubic foot. Here, the values of 1.6 gallons and 8.0 gallons are benchmarks, which are expressed in absolute terms (i.e., quantity of water being used). Examples of metrics and benchmarks for nonresidential users can be found in Dziegielewski at al. (2000).

Relative-value metrics are ratios without units. For ratio metrics, a value of 1 often represents a target value. An example of the ratio benchmark is the Infrastructure Leakage Index (ILI) developed by the American Water Works Association and the International Water Association (IWA). It is calculated as a ratio of the current annual real losses of water in the distribution system to the unavoidable annual real losses. For most utilities the calculated values of ILI will be greater than 1. Here, the ILI = 1.0 is the benchmark value (or target) which implies that all avoidable losses of water are eliminated. Similar ratio benchmarks can be defined for various end uses of water, where the observed usage rate is divided by an achievable efficient rate of use.

Development of benchmark values for aggregate-level metrics (such as system-wide or sector-wide measures) presents a special challenge for evaluating water efficiency, because the aggregate metrics capture “other-than-efficiency” effects on the calculated unit quantity of water usage. This is a critical point because aggregate-level metrics tend to be interpreted as an indicator of efficiency-in-use, when in reality the calculated values reflect the influence of various other determinants of water use, which are unrelated to efficiency-in-use.

2.3 Defining Efficiency

Improvements in the efficiency of water use are usually undertaken by water providers and water users. A commonly held expectation is that such improvements can free up significant quantities of water by meeting the existing needs of individual users and various purposes of use with less water. Water use metrics and benchmarks are inextricably linked to the concepts of “water conservation” and “water-use efficiency.” Therefore, it is also helpful to define these concepts in the context of evaluating water use.

The term, *efficiency*, derives from engineering practice where it is typically used to describe *technical efficiency*, or the ratio of output to input. The criterion of technical efficiency is useful in comparing various products and processes. For example, one showerhead would be considered more efficient than another if it could accomplish the same purpose (i.e., of showering) by using less water or other inputs (e.g., lower water pressure). The water efficiency gains of low flushing volume toilets over traditional toilets can be substantial without diminishing the completion of the original purpose for which water is used. However, the technical efficiency concept is not useful in making decisions of investing money (or resources) in water conservation unless the inputs and outputs are measured in *value* terms. This expression of efficiency is referred to as *economic efficiency*.

Water conservation can be defined as a reduction in water use or water losses. Baumann, Boland and Sims (1984) developed a practical definition of long-term water conservation as "…any beneficial reduction in water use or in water losses." By adding the term "beneficial" the authors proposed a requirement (consistent with the concept of economic efficiency) that the reduction in water use or losses should result in a net increase in social welfare where the resources used have a lesser value than those saved. In other words, the beneficial effects of the reduction in water use (or loss) must be considered greater than the adverse effects associated with the commitment of other resources to the conservation effort. This definition provided important guidance (through benefit-cost analysis) for long-term conservation; however, it could not be easily applied to short-term conservation measures which are usually aimed at curtailing water demand during a drought.[1]

2.4 Terminology and Acronyms

The purpose of this paper is to define "water conservation metrics" and benchmarks. A necessary intermediate step is to define "water use metrics" so that a reduction in water use can be quantified. However, the term water use has multiple meanings depending on whether it is used in hydrologic, engineering or regulatory contexts. The term water use could mean total water withdrawals from different supply sources, water withdrawn or diverted and put to beneficial use, finished drinking water produced, water sold to customers through metered connections, and many other meanings. In this document the phrase "water use" is used as a generic term with the meaning defined by the context.

Water use metrics (designated by the acronym - UM) can be expressed as "usage ratios" or "usage rates". The "ratio" metric designates the quotient obtained by dividing the volume of water sold over a specified period of time (day, month, season or year) by a scaling factor (e.g., number of accounts, population served or number of employees). Additional letters, superscripts and subscripts can be added to the UM acronym to designate user sector and the scaling variable being used. For example, the annual average usage rate per customer account per day in single family sector can be designated as AUM_a^{SF}, where "A" stands for annual (i.e., average daily), "a" for accounts and "SF" for single family.

For water production and deliveries, the term "production quotient," or PQ is proposed. It represents the total volume of water produced divided by a scaling factor such as number of connections or population served. For example, the annual average rate of water production per service account would be designated as APQ_a.

The term "conservation index" or CI is proposed as the naming convention for denoting conservation metrics. An example could be ICI^{SF} for designating an indoor conservation index for the single-family sector and OCI^{SF} for designating an outdoor (seasonal) conservation index.

[1] Temporary restrictions on water use are usually undertaken in order to prevent adverse impacts of severe shortages in the future if the drought continues and their outcomes cannot be easily analyzed through benefit-cost analysis.

3 DATA FOR CALCULATING METRICS

3.1 Production and Sales Data

The most practicable water usage metrics are those that can be calculated using secondary (i.e., existing) and routinely collected data. Generally, there are two types of existing water measurement records that are routinely collected and maintained by public water supply utilities. These include:

(1) water production records (i.e., amounts of water pumped into the distribution system), and
(2) meter reading and billing records (i.e., amounts of water used by each customer during each billing period and related information).

Water production records show the amount of water delivered to the distribution system and are typically generated daily or hourly. Water production data are almost always available because they represent an essential operating parameter for treatment, distribution and water accounting. Production metering provides measured quantities of water being pumped from treatment plants and other sources to the distribution system. Production meters are usually inserted just before water exits the treatment facility and is delivered to the distribution system. The accuracy of production data is generally good and depends on the accuracy of production meters.

Meter reading and billing records represent the individual customer account data that are maintained by retail water supply agencies. An individual billing record commonly includes: (1) name and address of account holder, (2) type of account (e.g., single-family, commercial, industrial, institutional, irrigation or other), (3) meter size, (4) meter readings and the dates of meter readings, (5) water use between meter readings, and (6) billing information (charges incurred, dates paid, etc.). The customer billing system is usually computerized, and, depending on the database design, individual customer accounts can be sorted and queried by customer type, geographical area, and other characteristics.

Billing records can usually be summarized by aggregating metered consumption and number of billed accounts by the billing cycle (i.e., monthly, bimonthly, quarterly, semiannually, or annually) and by customer type. In essence, water billing data show how much water is being sold to different types of customers, but do not show for which specific purposes the water is being used.

3.2 Data on Scaling Variables

Summaries of billing system data generally contain information on the volume of water being sold and the number of billed accounts. Therefore, other than for the number of billed accounts, data on alternative scaling variables—that is, variables that can be used to standardize per unit rates of water use— have to be obtained from other sources. Some common scaling variables include: population served, number of housing units, number of employees, acreage of irrigated areas, square footage of nonresidential buildings, and other measures of size for specific sectors of water users.

Perhaps the most common scaling variable in public water supply utilities is "population served." In theory, it represents the number of people who are served (through metered connections) by the water utility. However, even this basic scaling variable is very challenging to define (in operational terms) and measure precisely. In the water utility service area, several types of populations can be distinguished. These include such designations as year-round (or resident) population, population in households, population in group quarters, commuter population, seasonal population and others.

Another issue with "population served" is the challenge in measuring these different populations. Relatively accurate estimates of resident population are made every ten years during the decennial census. Estimates of resident population during non-census years are obtained by alternative methods and are less accurate. Even during the census years, population counts available for census tracts and city blocks cannot be matched perfectly with the boundaries of areas served by water utility.

The appropriate measurement of population served is most challenging when it is used in water allocation (through water use permits) or for other regulatory purposes.[2] For the purpose of developing water use and conservation metrics, the only scaling variable that is readily available to water utilities and more accurate than population served (or other measures of size from external sources) is the number of active or billed accounts.

3.3 Special Studies

Other (more disaggregated) data for calculating metrics of water use can be obtained through special measurements (e.g., data logging on customer meters, or installation and reading of special meters), as well as through the use of customer surveys to collect information on important variables that influence water use. Some large U.S. utilities conduct extensive "baseline" studies to collect information on a variety of customer characteristics (such as number of residents or employees, square footage of buildings or size of landscaped areas), as well as prevailing water-using behaviors (e.g., frequency of lawn watering, washing machine use, or the presence of water using features and appliances).

Because these data are not routinely collected by water utilities, the use of metrics that require special baseline data has to be limited to those that support the specific objectives of any particular investigation. Thus, this study employs only data that are routinely collected by water utilities, focusing on summary level production and billing data.

4 CASE STUDY UTILITIES

Ten U.S. water utilities were asked to participate in this study. Seven utilities agreed to participate. The utilities were asked to provide their summary production and billing records for the five most recent data years. Table 1 lists the seven utilities together with the water production, number of customer accounts and estimated population served data for 2008.

[2] Examples of complex methodologies for calculating population served are those developed by the Southwest Florida Water Management District (Gonzales and Yingling, 2008) and New Mexico Office of State Engineer (2009).

Table 1. Water Utility Participants in the Study (2008 Data)

Water Utility	Water Production (MGD)	Number of Customer Accounts	Estimated Population Served
Otay Water District, California	37.1	48,227	196,416
Irvine Ranch Water District, California	88.2	96,019	330,000
Phoenix Water Services Department, Arizona	272.8	403,412	1,566,190
City of Rio Rancho, New Mexico	11.7	29,787	80,000
Seattle Public Utilities, Washington	125.5	186,849	649,286
Philadelphia Water Department, Pennsylvania	250.7	486,664	1,660,500
Tampa Water Department, Florida	76.0	125,260	657,313

Notes: MGD = million gallons per day. The combined retail and wholesale population served in Seattle is 1,312,920.

4.1 Characteristics of Study Sites

The seven study sites differ in size and in prevailing climate and weather patterns. Five of the cities represent arid or semi-arid climates. The remaining two (Tampa and Philadelphia) have humid climates. The following are brief descriptions of each case study site:

- The Otay Water District provides water service to customers within 125.5 square miles of southeastern San Diego County in California which includes the communities of Spring Valley, La Presa, Rancho San Diego, Jamul, eastern Chula Vista, and eastern Otay Mesa. The service area is semi-arid with an average annual precipitation of about 11 inches.
- The Irvine Ranch Water District (IWRD) is located in the south-central Orange County in California and serves the city of Irvine and portions of Costa Mesa, Lake Forest, Newport Beach, Orange and Tustin. It provides potable water as well as tertiary-treated recycled water for landscape irrigation, agriculture and industrial and commercial users. The 179 square mile service area extends from the Pacific Coast and rises to the elevation of 3,200 feet at the foothills of Santa Ana Mountains. The region is semi-arid with an average annual precipitation of about 14 inches.
- The City of Phoenix Water Services Department provides water supply to about 1,566,000 residents within its 540-square mile service area in central Arizona. The city is located in the Salt River Valley, with a desert-type climate with low annual rainfall and low relative humidity, mild winters, and high daytime temperatures throughout the summer months. The average annual precipitation is about 8 inches.
- The City of Rio Rancho in New Mexico is located north of Albuquerque and it borders the Santa Ana Indian Reservation to the north, and the cities of Bernalillo and Corrales to the east. The city has a total area of 73.4 square miles and serves approximately 80,000 people. The climate is arid with warm summers and cold winters, and an average annual precipitation of about 9 inches.
- Seattle Public Utilities (SPU) Water Utility supplies potable water to the City of Seattle and to 21 wholesale customers (with 121 wholesale connections) in King County, Washington (in total, the population served is more than 1.3 million). The City of Seattle service area extends for 143 square miles and includes a population of about 650,000. The city has a mild oceanic climate with wet winters and dry summers with total annual precipitation of 37 inches.

- The Philadelphia Water Department provides water to a 130 square mile service area in the Greater Philadelphia region of Pennsylvania with a population of about 1.66 million. The city has a humid subtropical climate with hot and humid summers and cold winters, although it is at the northern periphery of this Köppen climate zone. Precipitation is fairly evenly distributed throughout the year; with an average annual precipitation of 42 inches.
- The Tampa Water Department delivers drinking water to a service population of approximately 657,000 people in the Tampa Bay area in Florida. The city has a year-round semitropical climate with a remarkable summer thunderstorm season. From June through September, on an average of three out of four days, late afternoon thundershowers occur making Tampa one of the stormiest cities in the United States. Average annual precipitation varies from about 45 inches near Tampa Bay to over 50 inches in the northeast side of the service area.

Table 2 compares the climatic differences among the seven participating utilities. It shows the normal (1971-2000 average) and actual 2008 values of precipitation, maximum temperature and reference evapotranspiration during a defined 5-month growing season (i.e., May to September).[3] The reference evapotranspiration (ET_o) values were obtained from published sources for individual states with the exception of Philadelphia where ET_o was estimated using the Thornthwaite method based on mean monthly temperature (Thornthwaite and Mather, 1955).

Table 2. Growing Season (May-September) Climatic Data for Participating Utilities

Water Utility	Precipitation (inches)		Max. Temperature (deg. F)		Evapotranspiration (inches)	
	Normal	2008	Normal	2008	Normal	2008
Otay	0.6	0.3	74.4	73.3	32.7	28.5
Irvine Ranch	0.8	0.4	80.8	83.6	28.1	28.2
Phoenix	2.9	5.7	99.6	101.6	45.5	43.0
Rio Rancho	5.3	2.1	86.7	88.4	24.2	30.2
Seattle	6.7	6.7	71.0	70.0	18.0	12.9
Philadelphia	19.3	17.6	79.8	81.4	24.1	24.6
Tampa	29.0	25.2	88.8	89.3	25.8	24.5

Source: Annual Climatological Summary, NOAA. The stations used were:` San Diego Lindberg Field and Chula Vista for Otay; Irvine Ranch for IRWD; Phoenix Sky Harbor for Phoenix; Rio Rancho #1 for Rio Rancho; Seattle Tacoma Airport for Seattle; Philadelphia Airport for Philadelphia; and Tampa Airport for Tampa. Reference evaporation obtained from public sources in individual states.

The data indicate that the Otay and Irvine Ranch water service areas receive minimal rainfall during the growing season but tend to have mild temperatures. Phoenix and Rio Rancho receive small amounts of rainfall but experience very high temperatures. Seattle receives about seven inches of rainfall during the identified growing season and has the lowest maximum temperatures among all seven sites. Philadelphia and Tampa have substantially higher rainfall during growing season than the five western sites but in both locations the reference evapotranspiration is close to seasonal precipitation. It is apparent that each site has a unique climate. Only Otay and Irvine Ranch are comparable in terms of all three climatic variables during the growing season.

[3] A customary five month growing season encompasses most areas of the U.S., although a longer season is possible in warmer climate zones.

The data obtained from the participating utilities were used to calculate a number of possible water use metrics, including a subset of metrics for comparing water usage and the associated water conservation effects over time. These metrics are discussed and illustrated with the case study data below.

5 METRICS OF AGGREGATE USE

Several different metrics of aggregated water use (system-wide) can be defined. All three characteristics portrayed in Table 1 above (i.e., average daily production, number of customer accounts, and population served) can be used to represent the size of the water system and its service area. However, these measures of system size do not convey information on the intensity (or average rates) of water use. The average rates of use can be obtained by dividing average daily production or total customer sales by a scaling variable. As mentioned before, the most commonly used scaling variable is population served. A popular metric of aggregate use is known as "per capita use" in gallons per capita per day. This metric is obtained by dividing average daily production (in gallons) by total population served. The appropriate use and limitations of this metric and the availability of alternative aggregate metrics are discussed below.

5.1 Per Capita Daily Production Metric

When calculating the per capita daily production (PQ_c) metric (where subscript *c* indicates per capita), the reported annual volumes of water produced should be matched with the population served in the retail service area. This requires that all wholesale water deliveries outside of the retail service area are metered and deducted from the production volume.[4] Also, any water imported into the distribution system should be added to production records.

Total population served is usually defined as total year-round resident population of the retail service area (urban planners sometimes define resident population as the number of people occupying space in the community on a 24 hour per day, seven-day-per-week, 52 weeks per year basis). Different water utilities use different definitions of population served and, regardless of the definition, in most cases the reported population served estimates represents best guesses of the actual but unknown number. Therefore, the annual per capita per day production (PQ_c) metric that is calculated by dividing annual water production by population served is usually inaccurate due to "definitional noise" in both the numerator and denominator of the metric.

Table 3 illustrates the values of the PQ_c metric that were calculated using data from the seven case study utilities. The values of the metric were obtained by dividing the average daily production numbers by population served.

The values in Table 3 show that per capita production rates change from year to year and differ greatly across the seven utilities. The last column and the last row show the average absolute deviation in the respective row and column data from the mean in each row or column. The average deviations across the utilities are generally six times greater than average deviations of annual data for each utility. Over relatively short time intervals, the year to year changes in a

[4] Alternately, if the population served by wholesale customers is known, the PQ value can be calculated by dividing total production by the sum of retail and wholesale population served.

single utility are caused primarily by changes in weather conditions. The differences across utilities are caused by two main factors: climate and the composition of water users. Figure 1 shows a plot of annual per capita values for 2008 versus the difference between reference evapotranspiration and effective precipitation during the 5-month growing season (only the 2008 data were available for all seven utilities). For six utilities the per capita values are more or less aligned with the theoretical irrigation water requirement during the growing season. The value for Irvine Ranch lies farther away from the regression line. Water production in Irvine Ranch district includes about 8 mgd of water delivered to agricultural customers and 2.6 mgd in wholesale deliveries.[5] If these two quantities are subtracted from 2008 production, the per capita production would be 214 gpcd and the data point would be moved closer to the regression line.

Table 3. Calculated Per Capita Production Metric (PQ_c) for Participating Utilities

Utility/Year	2002	2003	2004	2005	2006	2007	2008	Average Deviation
Otay	227	206	212	207	209	203	189	7.2
Irvine Ranch	--	--	--	252	279	268	267	7.3
Phoenix	228	211	207	197	198	196	174	11.8
Rio Rancho	--	--	--	--	--	--	146	--
Seattle	109	111	112	100	102	97	95	6.0
Philadelphia	160	166	162	157	153	155	151	4.2
Tampa	--	--	130	112	117	124	116	5.8
Avg. deviation	46.5	35.0	35.9	47.8	52.3	48.5	40.7	44.7

GPCD = gallons per capita per day, -- = data not available. Seattle numbers are based on the sum of both retail and wholesale population.

The data points for Rio Rancho and Phoenix lie below the regression line. In the case of Rio Rancho, the seemingly outlying per capita production value may be partly related to a possibly imprecise estimate of population served. The U.S. Census estimate of the 2007 population for the City of Rio Rancho is 75,978 while the number used in Table 1 (obtained from Rio Rancho's website) is 80,000. Using this population, the per capita production would be 154 gpcd vs. the value of 146 shown on the graph. In Phoenix, the low 2008 value of 174 gpcd could not be explained by any possible imprecision in population or production.

According to the regression equation on Figure 1, per capita production increases by about 3.0 gpcd for each inch of irrigation requirement during growing season. The regression equation displayed on Figure 1 indicates that at zero requirement (when effective rainfall is equal to evapotranspiration) during the growing season the expected value of per capita production would be about 96.2 gallons per capita per day (gpcd). However, the 96.2 gpcd number has no practical value for deriving benchmark usage rates because of the differences in base climate. For example, it is unlikely that Phoenix would experience 96.2 gpcd during a growing season if precipitation was adequate for maintaining the urban landscapes. In essence, each locale or region should have its own regression line that best relates water use with local weather conditions.

[5] It is important to note that while removing wholesale water from total production makes intuitive sense, removing agricultural deliveries would affect the difference in the composition of demand which tends to be unique in each utility.

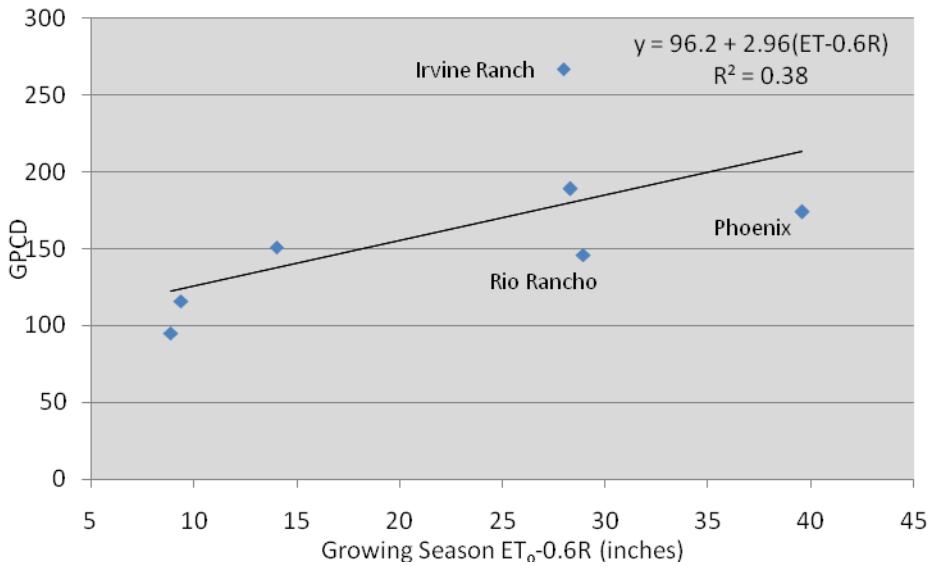

Figure 1. Relationship between Per Capita Production and Evapotranspiration minus Effective Rainfall during Growing Season

5.2 Alternatives to the PQ_c Metric

Because population served is difficult to measure (even if it is precisely defined), a more accurate measure of system size is needed. One measure of system size that is universally available is the number of water service connections. This measure can be defined precisely by making distinctions between specific characteristics of the various types of connections.

For example, a distinction can be made between retail and wholesale connections, metered and unmetered connections and connections with different meter sizes. Alternative definitions include active and inactive customer accounts, customer accounts with non-zero consumption or number of billed accounts. Table 4 compares the average water use per account (i.e., the PQ_a metric where subscript *a* stands for accounts) in the seven utilities. The advantage of this metric is that the data on the number of connections (or accounts) are available on an annual basis. The number of billed accounts is also available for each billing period (i.e., monthly, bimonthly or quarterly). Billed accounts would include all accounts receiving a bill including connections with no metered use – only fixed charges.

Table 4. Calculated Production per Account (PQ_a) Metric for Participating Utilities

Utility/Year	2002	2003	2004	2005	2006	2007	2008	Average Deviation
Otay	832	773	802	781	794	801	769	16.1
Irvine Ranch	--	--	886	868	943	908	892	20.9
Phoenix	865	799	775	743	753	738	659	44.0
Rio Rancho	--	--	--	--	--	--	393	--
Seattle	--	--	--	--	--	--	670	--
Philadelphia	554	570	557	552	539	543	515	12.7
Tampa	--	--	643	596	603	647	607	20.6
Avg. deviation	130.9	96.0	106.1	107.2	124.2	106.0	118.9	119.7

PQ_a = production per account per day in gallons, -- = data not available

As with the per capita production, the PQ_a metric can be used for comparing year-to-year changes in production per account in a single utility. The PQ_a metric is still inappropriate for inter-utility comparisons. The calculated values of the PQ_a metric in Table 4 for 2008 ranged from 393 gpad in Rio Rancho to 892 in Irvine Ranch. However, the 2008 values of PQ_a include wholesale deliveries of water in Otay, Irvine Ranch, Tampa and Seattle, while for Phoenix and Rio Rancho they do not. Therefore, the PQ_a metric can be standardized by narrowing down its definition to include only "water deliveries to the retail area" which would exclude the part of water production sold wholesale.[6] For example, if wholesale deliveries in Seattle are excluded, the value of the 2008 PQ_a metric would be 302 gpad. The PQ_a metric can also be refined further by using total metered sales as the numerator. This modification will remove the effect of non-revenue water, which is usually addressed by separate metrics. Furthermore, wholesale deliveries and agricultural sales can be removed from total metered sales.

Another improvement to the PQ_a would be to convert the total number of connections or accounts (which represent different types of customers or connection sizes) into the number of "equivalent connections" or "equivalent accounts", with reference to single-family accounts. The weights for converting non-single-family accounts into equivalent single-family accounts can be based on average annual consumption by customer type or by meter size (in utilities without customer type designation). The main reason for creating a number of equivalent accounts for each utility is to develop a scaling variable which is similar to population served. Table 5 compares possible weights for calculating the number of equivalent accounts in the six study areas. The city of Philadelphia does not use customer categories and the only feasible weights are those based on average consumption by meter size category.

The weighing ratios in Table 5 illustrate the differences in the composition of demands at the sectoral level. For example, it is important to understand why an industrial customer is on average equal to 106.5 single-family customers in Phoenix, but equal only to 19.6 single-family customers in Irvine Ranch. Also, it is worth determining why a multifamily customer in Tampa is equivalent to 28.6 single-family customers and equates only to 3.1 single-family customers in Rio Rancho. It was determined that in Rio Rancho the multifamily sector includes only tri- and four-plexes. Apartments with five and more units are classified as commercial. Apparently, in Tampa all residential customers other than single-family are included in the multifamily sector. These examples of customer class definitions indicate another source of definitional noise introduced by unique customer classifications schemes.

Table 6 shows the calculated weights based on the 2008 sales data for accounts with different meter sizes in Philadelphia. The single-family sector is assumed to be represented by the meter size of 5/8 of an inch.

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[6] However, the removal of the wholesale deliveries from the production data is not straightforward. Total production is metered accurately on the daily basis while the wholesale deliveries may be reported on monthly basis. Also, line losses between the production meter and the wholesale connection cannot be easily measured.

Table 5. Weighting Ratios and Equivalent Accounts Based on 2008 Sales Data

User Category	Otay	Irvine Ranch	Phoenix	Rio Rancho	Seattle	Tampa
Single-family	1.0	1.0	1.0	1.0	1.0	1.0
Multifamily	8.4	5.9	6.8	3.1	4.4	28.6
Commercial	3.9	11.9	4.9	9.1	--	4.8
Industrial	--	19.6	106.5	229.7	--	59.7
Governmental	--	36.6	14.5	9.1	--	2.4
Public/institutional	19.0	--	7.7	--	--	--
Irrigation (urban)	8.6	--	8.0	--	--	--
Construction	12.7	--	--	--	--	--
Other nonresidential	--	8.7	1.4		5.9	--
Recycled water	14.7	--	--	--	--	--
Fire service	0.03	--	12.2	12.8	0.03	--
Total production, mgd	37.1	88.2	272.8	11.7	125.1	75.9
Total retail sales, mgd	35.5	70.6	258.6	9.9	56.4	66.4
Total accounts	48,202	85,202	413,783	29,787	186,849	125,139
Total equivalent accounts	80,718	201,174	693,277	45,276	277,711	252,853
Retail sales per account (SQ_a), gpad	736	829	625	331	302	519
Sales per equivalent account (SQ_{ea}), gpad	440	351	373	218	203	257

Note: Agricultural deliveries are removed from the retail sales data for Otay and Irvine Ranch.

Table 6. Weighting Ratios Based on Meter Size for Philadelphia

Meter Size (Inches)	Number of Accounts	Gallons/ Account/Day	Consumption Weight
5/8	473,904	189	1.0
3/4	71	466	2.5
1	5,526	856	4.5
1-1/2	2,026	1,998	10.6
2	2,562	3,835	20.3
3	1,227	9,312	49.3
4	920	17,214	91.1
6	331	42,499	224.8
8	66	85,203	450.8
10	29	389,606	2,061.2
12	2	761,826	4,030.5
All accounts	486,664	347.3	--
Equivalent accounts	889,899	189.9	--

The equivalent weights in Table 6 approximately double for each increment in meter size with the exception of 10-inch meter where the weight more than quadruples. Because meter size information is available in all systems, the conversion based on meter sizes would provide a more standard measure of equivalent accounts than the conversion based on customer types; however, this depends on the assumption that accounts are appropriately metered.

5.3 Inter-utility Comparisons of Aggregate Metrics

Table 7 compares five aggregate consumption metrics. The first three metrics are based on total production; the other two are based on total retail sales of water. The five aggregate metrics shown in Table 7 vary among the seven utilities and would result in different ranking of the utilities. For example, Tampa has the lowest PQ_c value but it ranks as the fourth lowest according to SQ_{ea}.

Table 7. Calculated Aggregate Metrics for Participating Utilities for 2008

Utility	Production per Capita (gpcd)	Production/ Account (gpad)	Production/ Equivalent Account (gpad)	Retail Sales/ Account (gpad)	Retail Sales/ Equivalent Account (gpad)
Acronym	PQ_c	PQ_a	PQ_{ea}	SQ_a	SQ_{ea}
Otay	189	769	460	736	440
Irvine Ranch	267	919	438	829	351
Phoenix	174	676	393	625	373
Rio Rancho	146	393	258	331	218
Seattle	193	672	452	302	203
Philadelphia	151	515	282	347	190
Tampa	116	607	300	519	257
Average deviation	34	124	76	174	84
Coeff. of variability, %	27	26	24	40	34

gpcd = gallons per capita per day, gpad = gallons per capita per day

The average deviation and coefficient of variation (c.v.), shown in the bottom two rows of Table 7, indicate that the conversion of the PQ and SQ metrics to the equivalent account shows some improvement in these measures of dispersion over the metric values calculated based on the actual number of total accounts. Also, the coefficients of variation are nearly identical for per capita production (PQ_c) and production per account (PQ_a and PQ_{ea}). However, it is clear that the values obtained for these alternative aggregate metrics are unique to each water utility and their only appropriate use is for comparing trends in annual water usage over time at a single utility.

The problems with the definition and measurement of population served are among several reasons which make the aggregate use metrics inappropriate for comparing the calculated numbers among different utilities (i.e., inter-utility comparisons). The following is a brief listing of the shortcomings of the PQ and SQ metrics:

1. In order to compare PQ_c values across different water utilities, it would be necessary to standardize the measurement of "populations served." For example, the estimates of population served may account for commuters and part time residents (e.g., hotel guests, students, and seasonal residents). The term "functional" population served is used by

some utilities to describe the population served which is adjusted for hotel populations, commuter population and population in group quarters. However, regardless of its definition, population served cannot be measured precisely during each calendar year and will likely be a crude estimate of actual population, however it is defined.

2. The number of accounts used in calculating the PQ_a and SQ_a metrics can also be standardized, possibly through the use of equivalent accounts. Although, the number of accounts or equivalent accounts will be more accurate than population served, the aggregate production or sales metrics cannot be compared across different utilities, because of differences in the composition of sectoral demands.
3. Because the PQ and SQ values will change in response to weather condition, even the utility-specific year-to-year values cannot be meaningfully compared unless the annual water production or total sales are normalized for weather conditions. Adjustments for weather conditions would also be required in order to make the values of aggregate metrics comparable across different utilities, however no meaningful “weather normalization” for multiple locations is generally possible because of fundamental differences in prevailing climate.
4. An absolute benchmark value of the PQ_c or SQ_a metric for all utilities would be impossible to develop even if a precise definition/measurement of population served is used and the adjustments in total production for actual weather conditions are made. The main confounding factor is the difference in the composition of municipal demands which stems from different housing types and a different mix of industrial and commercial activities. For example, a utility with a higher share of commercial and industrial activity in total demand would be expected to have a higher PQ_c value than a utility in which total demand is almost entirely for residential use.
5. Even if two different utilities have the same per capita production rate or average sales per account, and the same sectoral make-up, it would be difficult to judge their relative efficiency if they differ in terms of the determinants of water use that are unrelated to efficiency–such as type of housing stock, average lot size, family incomes, and several other factors. Therefore, without additional information and analysis, one cannot simply assume that a lower (higher) per capita rate is indicative of higher (lower) water using efficiency.

A meaningful comparison of per capita production or average annual sales per account should attempt to account for these types of influences on water use within and among communities. However, the aggregate nature of the PQ and SQ metrics and the infeasibility of developing a single benchmark value for all utilities make these metrics inappropriate for inter-utility comparisons.

6. SECTOR-WIDE ANNUAL USE METRICS

Year-to-year changes in the annual average values of aggregate metrics at a given utility are a result of different weather conditions and changes in the “structure” of total demand. For example, total demand will decrease (or increase) if there is a decline (or increase) in nonresidential customer accounts with water-intensive activities. Some structural changes can also take place in the residential sector. For example, there could be a substantial increase (or decrease) in the number of residences with automatic sprinkling systems or swimming pools.

Generally, metrics based on disaggregated demands (i.e., water sales separated into groups of similar users) are expected to provide a better basis for comparing usage rates over time than aggregate metrics. This section compares several metrics that are derived based on annual sectoral water use. All metrics use the number of accounts (for each sector) as the scaling variable. The most commonly used definition of the number of accounts is the number of "billed accounts." In some cases, a water utility may prefer to use a subset of billed accounts, excluding accounts with zero consumption reads during the billing period.

6.1 Single-Family Residential Use

Single-family residential customers represent the most homogeneous sector of urban water use. Usually, the single-family account represents a land parcel with a free-standing building containing one dwelling unit which is connected to the city water supply through a single water meter. Possible exceptions to this definition include lots with a secondary building or the presence of secondary meter for irrigation water, with a few locations not requiring the use of meters.

Billing data can be used to calculate average daily rate of usage in all single-family residential accounts. Table 8 compares average annual single-family residential water use per account (AUM_a^{SF}) in gallons per account per day within the seven study sites.

Table 8. Annual Single-Family Residential Use per Account (Gallons per Account per Day)

Utility/Year	2002	2003	2004	2005	2006	2007	2008	Avg. Deviation
Otay	435.4	435.6	435.9	436.1	436.3	436.5	436.7	0.4
Irvine Ranch	--	--	313.4	313.0	331.1	321.4	321.4	5.5
Phoenix	457.2	429.9	413.3	396.7	402.8	400.9	372.5	19.7
Rio Rancho	--	--	--	--	--	--	217.5	--
Seattle	166.3	166.2	161.0	149.4	154.6	147.7	141.4	7.9
Philadelphia	--	--	--	--	--	--	189.0	--
Tampa	--	--	246.7	263.6	269.5	259.4	256.7	6.1
Average deviation	124.4	118.5	88.4	84.2	85.3	87.7	86.1	96.2

-- = data not available

Per account usage rates in individual utilities show relatively small year-to-year changes but very large differences across different utilities. Between 2002 and 2008, the usage rates changed very little in Otay WD but show a declining trend in Phoenix and Seattle. There are large differences across different utilities which reflect the effects of local climatic conditions and the influence of other factors that are known to affect water use (such as housing density or average lot size, average number of persons per household, marginal price of water, availability and cost of reclaimed irrigation water, median household income, and other characteristics of the single-family residential sector).

6.2 Multifamily Residential Use

Table 9 illustrates the annual multifamily residential water use per account (AUM_a^{MF}) in gallons per account per day within six study sites.

Table 9. Annual Multifamily Residential Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	3,155	3,294	3,427	3,555	3,677	158
Irvine Ranch	1,843	1,989	1,990	2,039	1,994	51
Phoenix	2,821	2,773	2,789	2,711	2,536	82
Rio Rancho	--	--	--	--	679	--
Seattle	--	--	--	--	1,243	--
Philadelphia	--	--	--	--	--	--
Tampa	7,471	7,012	7,602	7,403	7,338	152
Average deviation	1,824	1,623	1,825	1,738	1,731	1,715

Both the year-to-year fluctuations in annual average water use per account and the large differences across the utilities are likely the result of different utility definitions of multifamily structures and variation in the types of multifamily properties, and possibly less the result of weather conditions. For example, in Otay WD the per account usage shows an increasing trend which may suggest that the new multifamily accounts tend to serve more dwelling units. Therefore, a more appropriate scaling variable for the multifamily sector may be the number of dwelling units that are represented by the multifamily accounts.

6.3 Nonresidential Use

The nonresidential sector of water use can be defined to include all customers other than residential (both single-family and multifamily). Other user types such as agriculture or wholesale can also be excluded. Table 10 shows the annual nonresidential water use per account (AUM_a^{NR}) in the study sites.

Table 10. Annual Nonresidential Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	4,304	2,863	3,188	3,258	3,169	379
Irvine Ranch	2,714	3,719	2,811	3,609	1,949	563
Phoenix	2,616	2,596	2,633	2,641	2,415	66
Rio Rancho	--	--	--	--	2,777	--
Seattle	--	--	--	--	1,675	--
Philadelphia	--	--	--	--	--	--
Tampa	1,975	1,724	1,711	1,807	1,707	85
Average deviation	701	566	437	605	505	557

Because the composition of user types in the combined nonresidential sector should be expected to differ among water utilities, the cross-utility comparisons of usage rates are not appropriate. However, if the sector is defined consistently in a given utility (i.e., its definition does not change over time) then the nonresidential usage rate per account can be used to track changes over time.

7. SEASONAL AND NONSEASONAL USE METRICS

7.1 Estimation of Seasonal/Nonseasonal and Outdoor/Indoor Use

Urban water demand varies over time depending on weather conditions and it is possible to distinguish seasonal and non-seasonal components of water use.

Seasonal, or weather-sensitive, water use varies with weather conditions over the calendar days and months of the year. In the residential sector, nearly all seasonal use is outdoor use. Non-seasonal use is assumed to be relatively constant throughout the days and months of the year, and in the residential sector it generally represents indoor use.

When calculating the metrics of seasonal and nonseasonal use an indoor and outdoor designation is used, although some of the indoor use can be seasonal (e.g., cooling use) and some of the outdoor use could be non-seasonal (e.g., cleaning of concrete surfaces).

The separation of seasonal and non-seasonal components of water use can be performed using the *minimum-month method* or its modifications. The basic assumption of the minimum-month method is that during the month of lowest consumption water use represents only indoor use. Therefore, seasonal use during the remaining 11 months of the year can be estimated by subtracting the minimum-month use from total use during each month. As a rule of thumb, in the U.S., the lowest use occurs during the month of December, January, February or March. Indoor use is calculated using the following formula:

$$I = \frac{V_{Min-M} / d_{Min-M}}{N} \tag{1}$$

Where:

I = erage indoor (non-seasonal) water use in gallons per customer (i.e., account) per day

V_{Min-M} = lowest monthly water use (i.e., volume during the minimum-use month)

d_{Min-M} = number of calendar days during the minimum month

N = number of billed accounts during the minimum use month

One modification to the minimum-month method is to use three winter months in calculating nonseasonal use. Using data from three months, the winter-season use for a given sector can be calculated as:

$$W = \frac{(V_{Dec} + V_{Jan} + V_{Feb})/90}{(N_{Dec} + N_{Jan} + N_{Feb})/3} \tag{2}$$

Where:

W = average winter season water use in gallons per customer (i.e., account) per day

V_{Dec} = total volume of water sold (to all billed accounts in a given sector) during the month of December, with the other two subscripts designating the months of January and February,

N_{Dec} = total number of billed accounts (in a given sector) during the month of December[7], with the other two subscripts designating the months of January and February, and

90 = number of calendar days from December 1 to February 28.

Once the indoor (or winter season) use is estimated, then the outdoor (or spring/summer/fall season) use for a calendar year can be calculated as:

$$O = \frac{V_{Annual}}{365 \cdot N_{Annual} / 12} - I \quad (3)$$

Where:

O = average outdoor (seasonal) water use in gallons per customer (i.e., account) per day

V_{Annual} = total volume of water sold (to all billed accounts in a given sector) during the year,

N_{Annual} = total number of billed accounts (in a given sector) during the year

I = average indoor water use in gallons per customer per day which can be calculated using Equation 1 above.

Metrics of seasonal and nonseasonal use should represent an improvement over average annual usage rates because they are designed to include more narrowly defined subsets of purposes (i.e., end uses) of water use.

7.2 Single-Family Indoor (Nonseasonal) Use Metrics

A single family indoor use metric (IUM^{SF}) can be calculated using Equation 1 above. When the number of billed single-family accounts is used as a scaling variable, this metric is equivalent to the indoor water use (I) in gallons per account per day. Two alternative variants of the IUM^{SF} metric can also be used.

One variant is average indoor use per single-family housing unit (IUM_h^{SF}) which would require the substitution of the number of occupied single-family housing units for the number of billed single-family accounts in Equation 1. However, the data on the number of occupied single-family housing units are available only for the Census years and have to be estimated for other calendar years based on the number of new building permits and the number of demolitions or conversions of single-family buildings. Monthly data on building permits and demolitions or conversions may not be readily available, and, if available, may not be reliable because of the significant lapse of time between the date of the permit and the time the building is completed (and connected to water) or the date it is occupied. Therefore, the use of billed single family accounts in calculating the IUM^{SF} metric is preferable to the use of single-family housing units.

The other variant of the metric uses the resident population in single-family homes as the scaling variable. This alternative metric can be designated as IUM_c^{SF}(where subscript *c* stands for per capita). Because an accurate estimate of the total population in single-family housing is rarely available, a better way to calculate this metric is to use an estimate of the average number of persons per single-family housing unit. Technically, the gallons per person per day (IUR_c^{SF})

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[7] Note that because the billing data for December often contain extra end-of-year billings and adjustments, the months of January, February and March can be used instead.

metric is preferable to the IUM_a^{SF} metric when making comparisons between different utilities because it takes into account differences in average number of persons per housing unit.[8]

Table 11 below illustrates the calculation of the IUM_a^{SF} metric for the seven study sites in 2008. The values for individual months represent average usage rates in gallons per account per day. The usage rate during the minimum month is taken to represent indoor (or nonseasonal) water use. The minimum month and average annual values of per account use can also be used to calculate the percentage of nonseasonal and seasonal use according to the formula:

$$NS = \frac{Q_{Min-M}}{Q_{Annual}} \cdot 100 \tag{4}$$

Where:

NS = percent of annual use that is nonseasonal,

Q_{Min-M} = average per account use during the minimum-use month and

Q_{Annual} = average annual use in gallons per account per day.

The seasonal use is obtained by subtracting the percent nonseasonal use from 100 percent.[9]

Table 11. Monthly and Seasonal Single-Family Water Sales per Account in 2008 (Gallons per Account per Day)

Month	Otay	Irvine Ranch	Phoenix	Rio Rancho	Seattle	Phila-delphia	Tampa
January	318	245	255	173	127	203	288
February	281	253	248	160	124	254	266
March	271	244	278	161	120	165	229
April	381	297	350	223	124	175	219
May	467	322	412	245	139	163	258
June	481	340	451	302	164	172	300
July	507	379	489	308	184	220	315
August	558	363	455	322	180	175	217
September	544	370	412	277	157	182	229
October	480	354	410	231	136	201	229
November	471	330	398	185	128	182	282
December	363	287	311	149	127	172	246
Annual average	427.5	321.4	372.5	217.5	142.4	188.9	256.7
Minimum month (IUM_a^{SF})	271.4	243.6	247.8	149.4	120.3	163.4	217.3
Percent nonseasonal	63.5	75.8	66.5	68.7	84.5	86.5	84.7
Percent seasonal	36.5	24.2	33.5	31.3	15.5	13.5	15.3

[8] However, this metric will require more data that are bound to contain some error.

[9] The minimum-month formulas and calculations provided here produce annual estimates of weather-sensitive demands. However, it is important to note that outdoor use varies by month, and that the majority of use in any given month and locale during the peak irrigation season can be considered seasonal.

The minimum-month method is readily applicable to utility data, but the method has some significant practical shortcomings. For example, in warmer climates in the U.S. there is a year-round watering of urban lawns, such that the designated minimum month includes outdoor water use. Also, the method essentially estimates and treats indoor use as a constant. One should not expect the true indoor use to be constant during all months of the year, though it is likely much less variable than outdoor use.

Using the minimum-month method, the calculated annual values of the IUM_a^{SF} metric in Table 11 show a range from 120.3 gallons per single-family account per day in Seattle to 271.4 gpad in Otay WD. Also, the estimated percentage of 2008 annual use that is nonseasonal varies among the seven sites from 63.5 percent in Otay to 86.5 percent in Philadelphia.

Table 12 compares the values of the IUM_a^{SF} metric over time and across the study utilities. In four utilities the data were available for the period from 2004 to 2008. The dispersion statistic across the utilities for 2008 is more than twice the dispersion of the values over time in individual utilities. The differences across utilities are likely a result of differences in end-use composition and socioeconomic characteristics of individual service areas. The values also show significant year-to-year fluctuations, possibly due to response to weather conditions as a result of residual seasonal use in the minimum-month estimates.

Table 12. Single Family Indoor Water Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	223	248	285	299	271	24
Irvine Ranch	232	226	275	225	244	15
Phoenix	288	238	309	268	248	23
Rio Rancho	--	--	--	--	149	--
Seattle	--	--	--	--	120	--
Philadelphia	--	--	--	--	163	--
Tampa	194	235	223	225	217	11
Average deviation	27	6	25	29	49	34

-- = data not available

7.3 Single-Family Outdoor (Seasonal) Use Metrics

The single-family outdoor usage rate (or the OUM_a^{SF} metric) can be calculated by subtracting the indoor usage rate from average annual rate. Table 13 compares the values of OUM_a^{SF} for the seven study sites.

There are large differences in average daily seasonal use per residential account. These differences reflect climatic and weather conditions as well as other factors. For example, both Otay and Irvine Ranch districts have similar evapotranspiration and very low precipitation during the growing season but the estimated outdoor use in Otay is twice that in Irvine Ranch. Possibly, other factors than weather contribute to the difference (e.g., average lot size or proportion of homes with swimming pools). A scatter plot of estimated outdoor use versus the difference between reference evapotranspiration and effective rainfall during growing season is shown on Figure 3. The slope of the regression line on Figure 2 indicates an average increase of 3.52 gpad in aoutdoor use per inch of irrigation water requirement.

Table 13. Single Family Outdoor Water Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	199	176	159	156	156	15
Irvine Ranch	81	88	57	97	78	10
Phoenix	125	159	94	133	125	15
Rio Rancho	--	--	--	--	68	--
Seattle	--	--	--	--	22	--
Philadelphia	--	--	--	--	26	--
Tampa	53	29	47	34	39	8
Average deviation	48	55	37	40	40	46

-- = data not available

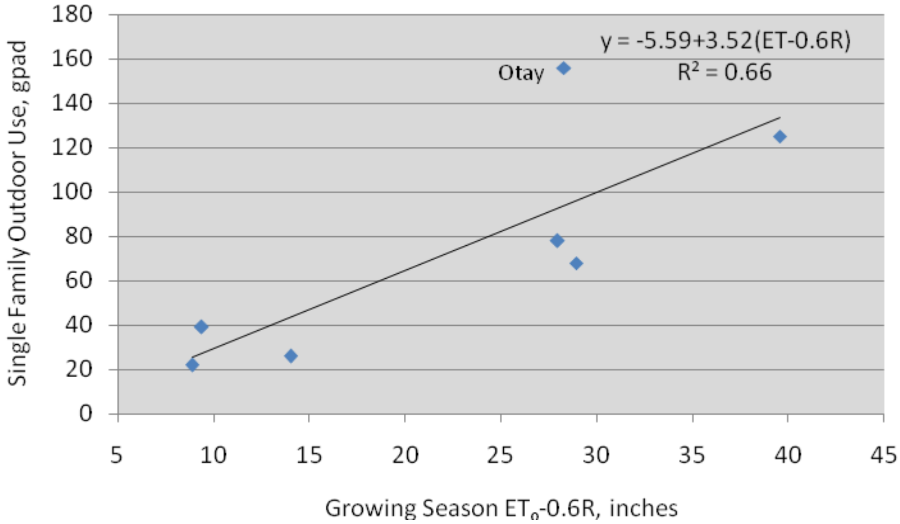

Figure 2. Estimated Single-Family Outdoor Use vs. Theoretical Irrigation Demand during Growing Season

7.4 Multifamily Indoor Use Metrics

Table 14 compares minimum-month use in multifamily sector. The IUM_a^{MF} metric shows relatively small average deviations within each utility and order of magnitude higher deviations across the utilities.

The wide range of numbers in Table 14 would likely be narrowed if the number of housing units was used as a scaling variable. However, the estimates of housing units are difficult to obtain and were not available for this study.

Table 14. Multifamily Indoor Water Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	2,793	2,628	2,492	3,066	3,041	200
Irvine Ranch	1,657	1,781	1,648	1,868	1,853	87
Phoenix	3,541	3,291	3,625	3,400	3,184	140
Rio Rancho	--	--	--	--	563	--
Seattle	--	--	--	--	822	--
Philadelphia	--	--	--	--	--	--
Tampa	6,675	6,732	6,830	6,666	6,849	71
Average deviation	1,504	1,562	1,591	1,458	1,639	1,550

-- = data not available

7.5 Multifamily Outdoor Use Metrics

Table 15 compares outdoor water use per account per day based on the minimum-month use method in multifamily sector. The OUM_a^{MF} metric shows significant variability over time within each utility. It also varies across the utilities. In 2008 the average values ranged from 69 gpad in Seattle to 567 gpad in Otay.

Table 15. Multifamily Outdoor Water Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	503	427	758	581	567	82
Irvine Ranch	186	208	342	171	141	53
Phoenix	555	734	416	508	471	86
Rio Rancho	--	--	--	--	117	--
Seattle	--	--	--	--	69	--
Philadelphia	--	--	--	--	--	--
Tampa	797	280	776	742	493	185
Average deviation	166	168	194	165	201	192

-- = data not available

Because the outdoor water use in the multifamily sector depends primarily on the size of irrigated area in multifamily housing developments (and less on the number of housing units in each development)**,** the best scaling variable for this metric would be the sum of square footage of the irrigated landscape for all multifamily accounts.

7.6 Seasonal and Nonseasonal Nonresidential Metrics

Table 16 illustrates the calculated values of the IUM_a^{NR} metric for nonresidential sector in gallons per nonresidential account per day.

Table 16. Nonseasonal (Indoor) Nonresidential Water Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	2,478	1,720	2,290	2,431	2,057	245
Irvine Ranch	2,422	2,285	2,178	2,054	1,698	201
Phoenix*	1,057	969	1,107	1,112	962	61
Rio Rancho	--	--	--	--	1,691	--
Seattle	--	--	--	--	1,139	--
Philadelphia	--	--	--	--	--	--
Tampa	1,385	1,572	1,398	1,277	1,260	88
Average deviation	615	366	491	524	348	458

-- = data not available; *Phoenix data include only General Commercial user type

Table 17 shows the calculated values of the OUM_a^{NR} metric for nonresidential sector in gallons per nonresidential account per day.

Table 17. Seasonal Nonresidential (Outdoor) Water Use per Account
(Gallons per Account per Day)

Utility/Year	2004	2005	2006	2007	2008	Avg. Deviation
Otay	1,826	1,143	898	827	1,112	266
Irvine Ranch	537	626	584	564	683	45
Phoenix*	459	523	448	467	457	21
Rio Rancho	--	--	--	--	1,086	--
Seattle	--	--	--	--	180	--
Philadelphia	--	--	--	--	--	--
Tampa	509	236	217	338	136	109
Average deviation	497	256	204	147	351	288

-- = data not available *Phoenix data include only General Commercial user type

The nonresidential metrics of seasonal and nonseasonal use cannot be compared across different utilities because of different composition of the nonresidential sector. Improved metrics of nonseasonal use (IUM^{NR}) should be obtained by using a standardized composition of the sector (i.e., definition of user types to be included) and by using the number of employees as the scaling variable. For the seasonal use metrics (OUM^{NR}) the best scaling variable would be the sum of square footage of the irrigated landscape for all nonresidential accounts.

8. NORMALIZING METRICS FOR COMPARABILITY

In order to ensure that water use metrics obtained for a single utility at different time periods or from different utilities are comparable it is necessary to “normalize” the calculated value of the metric by adjusting for differences in climate and weather conditions and other characteristics. However, it is helpful to track the raw numbers to determine how water production and use change in response to departures from normal weather.

8.1 Single Utility Comparison

When comparing metrics for a single utility over time it should be sufficient to adjust the calculated metrics for weather conditions. Year-to-year changes in the number of users are accounted for by the scaling variable, while any small changes in other determinants of water use can be neglected over relatively short time intervals. The weather adjustment can be performed directly on the calculated value of any metric with the use of parameters that capture the sensitivity of water use to weather. The two key variables which are used in modeling the effects of weather on urban water demand are precipitation and air temperature. The weather-normalized value of the metric can be calculated as:

$$OUM_{atn}^{SF} = OUM_{at}^{SF} \cdot \left(\frac{T_n}{T_t}\right)^{\alpha} \cdot \left(\frac{R_n}{R_t}\right)^{\beta} \qquad (5)$$

Where:

OUM_{atn}^{SF}	=	weather-normalized single-family outdoor use metric in gallons per account in year t
OUM_{at}^{SF}	=	calculated value of the metric in gallons per account in year t
T_t	=	average daily air temperature during the growing season of year t
T_n	=	normal value of average daily air temperature during the growing season
R_t	=	total rainfall during growing season in year t
R_n	=	normal value of total rainfall during growing season
α, β	=	constant elasticities of temperature and precipitation, respectively
atn	=	subscripts designating per account use *a* and normal year weather *tn*

Normalizing water use for changes in socioeconomic conditions in a single utility is possible using essentially the same normalizing technique as for weather. All metrics can be normalized for socio-economic conditions. For example, when comparing the OUM_a^{SF} metric between two different years, the adjustments for differences in average housing density and average home value can be made using the formula:

$$OUM_{ant2}^{SF} = OUM_{ant1}^{SF} \cdot \left(\frac{D_{t2}}{D_{t1}}\right)^{\lambda} \cdot \left(\frac{V_{t2}}{V_{t1}}\right)^{\eta} \qquad (6)$$

Where:

OUM_{ant2}^{SF} = weather-normalized residential single-family outdoor use per account/day in t2

OUM_{ant1}^{SF} = weather-normalized residential single-family outdoor use per account/day in t1

D = average housing density

V = average home value

λ, η = constant elasticities of housing density and home value variables, respectively.

The elasticities that are used in calculating the adjustments should accurately reflect the responsiveness of water use to changes in the values of determinants of water use. Elasticities will vary by user sector. Ideally, the elasticities of the determinants should be obtained from water demand studies for the utility in which the comparisons over time periods are to be made. However, if such studies are not available, then it is possible to derive “generalized” values of elasticities based on the available published studies of water demand.

8.2 Cross-Utility Comparison

Metrics for comparing efficiency of water use across different utilities would have to ensure that all external factors which influence and confound the unit quantity of water used, but are outside the control of water users, are “corrected for.” This means that additional data collection and analysis would be required in order to differentiate between the effects of water efficiency improvements and other factors that can affect average rates of water use.

For example, even when comparing a relatively homogeneous sector of single-family residences, because of local conditions, one community could have smaller single family parcels and fewer swimming pools than another community. Per capita residential usage in a more densely developed area would likely be lower than in an area with lower density of single-family housing. Also, the denser urban community could have a greater opportunity to increase indoor water efficiency through the replacement of plumbing fixtures, whereas less dense suburban counterparts might have a greater opportunity to increase the efficiency of landscape watering practices. Because it is possible these situations could be independent of water-use efficiency levels, the unadjusted usage rates cannot be used to infer water efficiency levels. Without additional information, simple comparisons of average water usage rates cannot reveal underlying technological or behavioral practices regarding water efficiency or differentiate among the several market and non-market forces that shape residential demand.

Normalization for weather and other confounding factors across different utilities is problematic. Because of fundamental differences in normal weather within particular climatic zones and the relative presence of particular water end uses even within the same climatic zone, there is no easily accessible way to use such normalization procedures for inter-utility comparisons. Thus, the best approach is to derive a benchmark value of a metric for each utility and divide the weather-normalized value of the metric by a theoretical (derived) value of the benchmark (representing an efficient level of water use).

Therefore, a practical approach to developing metrics for comparing water use efficiency between utilities would be to use metered account-level information for homogeneous groups of customers and the same dimensions of water use (i.e., total annual, seasonal, non-seasonal), then convert the values of the calculated metrics into ratio benchmarks for each utility before making a comparison.

9. WATER CONSERVATION BENCHMARKS

9.1 Water Loss Metrics and Benchmarks

A number of metrics and one ratio benchmark are available for assessing the level of water losses in the water supply and customer billing systems. Several are listed in Table 18 and are briefly discussed below.

Table 18. System-Wide Metrics of Water Losses

Description of Metric	Acronym	Calculation	Notes on Feasibility of Efficiency Benchmarks
Annual non-revenue water by volume, %	NRW%	Total annual system input volume of finished water (i.e., production) to the distribution system minus total annual billed authorized consumption; Expressed as percent of system input volume (production)	Moderate. Feasible for a single utility as a high level financial target only, NRW = 0 % is not achievable. Misleading as an operational indicator
Apparent losses	APL	The volume of apparent losses quantified in the water audit divided by the number of customer service connections	Basic but meaningful performance indicator for apparent losses
Current Annual Real Losses	RL	Current annual real losses (CARL) divided by the number of customer service connections. CARL is a volume derived from the water audit (system input volume minus authorized consumption minus apparent losses); or quantified from component analysis or field measurements	Highly effective for target-setting for a single utility, CARL = 0 % is not achievable. Not reliable for performance comparisons among utilities
Infrastructure Leakage Index	ILI	Current annual real losses (CARL) divided by unavoidable annual real losses (UARL)	Feasible ratio benchmark with the target of 1.0

The non-revenue water (NRW) metric, as a percentage by volume, is the fraction of water delivered to the distribution system which is not accounted for through metering individual connections and measurement or estimation of other authorized uses. In the past, the term *unaccounted-for-water* (UAW) was used but is no longer recommended because it is considered imprecise. While this metric offers limited high level financial insight, simple percentage indicators for water loss are greatly limited for operational purposes since they do not identify where specific loss volumes occur and they are distorted when customer consumption levels vary significantly.

Table 19 below shows the eight components of non-revenue (NRW) water. The apparent losses include all types of customer metering inaccuracies, unauthorized consumption and systematic data handling errors typically occurring in customer billing systems. The real losses include the annual volumes of water lost from overflows at service reservoirs and through all types of leaks and breaks on mains, and service connections, up to the point of customer metering.

A simple method for calculating the NRW value is to divide the difference between the annual system input volume (water production) and total billed authorized consumption by annual system input volume. A possible source of error in this calculation is the “mismatch” between the annual (365 day) period of production and the uneven and continuous periods of customer meter readings. The mismatch error can be minimized by performing a special query of the billing system based on meter reading dates (e.g., by totaling metered consumption for all meter readings between January 1 and December 31).

The breakdown of NRW into its components is necessary for calculating apparent losses and real losses (CARL) which are used to calculate the performance indicators and ILI benchmarking indicator.

Table 19. IWA/AWWA Standard Water Balance Terms

System input volume (corrected for known errors)	Authorized consumption	Billed authorized consumption	Billed metered consumption (including water exported)	Revenue water
			Billed unmetered consumption	
		Unbilled authorized consumption	Unbilled metered consumption	Non-revenue water (NRW)
			Unbilled unmetered consumption	
	Water losses	Apparent losses	Unauthorized consumption	
			Customer metering inaccuracies	
			Systematic data handling errors	
		Real losses	Leakage on transmission and/or distribution mains	
			Leakage and overflows at utility's storage tanks	
			Leakage on service connections up to point of customer metering	

Source: Kunkel at al. and AWWA Committee, 2003

Apparent losses are quantified in the water audit by estimation followed-up by field testing of customer meter accuracy, number of meters tampered, stopped or missing, fire hydrants misused, or billing system discrepancies identified in detailed auditing functions. The annual volume of apparent losses can be divided by the total number of customer service connections to give the performance indicator, APL. The real losses include water lost through leaks and breaks on transmission mains, distribution mains, customer service lines as well as other measured and background leakage. Real losses can be quantified roughly from the water audit as the volume that remains when authorized consumption and apparent losses are subtracted from the system input volume. More reliable, but more detailed methods to quantify real losses include component analysis and field measurements in discrete zones of the water distribution system (minimum hour analysis). (AWWA, 2009) The annual volume of real loss (CARL) can be divided by the total number of customer service connections to give the performance indicator, RL.

Finally, the ILI metric is calculated by dividing the current annual real losses (CARL, as defined in Table 19) by unavoidable annual real losses (UARL). The UARL is a reference value that represents the theoretical low limit of leakage that would still exist in a water distribution system even if the best of today's leakage management interventions were exerted in system operations. The UARL (in gallons per day) is calculated using the following formula (AWWA, 2009):

$$UARL = (5.41L_m + 0.15N_c + 7.5L_p) \cdot P \tag{7}$$

Where:

L_m = length of water mains, miles

N_c = number of service connections

L_p = total length of private pipe, miles (obtained by multiplying Nc by the average distance from curbstop to customer meter

P = average pressure in the system, psi

For average system pressure of 60 psi, the UARL formula indicates unavoidable losses for 1.0 psi of average system pressure of 0.09 gallons per day per mile of water mains, 0.0025 gallons per day per service connection and 0.125 gallons per day per mile of private pipe.

The ILI metric has a benchmark value of 1.0. This means that at a value of 1.0 the real losses are equal to the unavoidable losses.

Table 20 shows the metrics calculated for Philadelphia based on the IWA/AWWA water audit methodology. Note that a discernable trend of reduction in real losses is shown in the average daily volume of real losses, the RL metric and the ILI benchmark.

However, the less reliable NRW% indicator shows relatively little variation over the same time span. This occurs since Philadelphia's customer consumption has decreased at the same time that its leakage losses have been reduced. This illustrates the limitations of percentage indicators in representing operational performance regarding water loss. The values of nonrevenue water metric are compared for five utilities in Table 21.

Table 20. Examples of Water Loss Metrics for Philadelphia

Year	NRW, %	Apparent loss, mgd	APL, gal/conn/day	Real loss, mgd	RL, gal/conn/day	ILI
2000	33.1	18.6	33.9	70.1	127.7	12.3
2001	32.1	14.5	26.3	68.9	125.1	12.7
2002	32.2	13.1	23.9	69.2	149.8	13.1
2003	32.1	13.3	24.2	70.5	154.6	11.9
2004	35.4	11.1	22.8	72.6	132.5	12.1
2005	34.6	14.1	25.5	66.9	121.2	11.0
2006	32.2	15.1	27.4	59.2	107.3	8.9
2007	36.3	21.8	39.6	61.6	112.0	10.3
2008	32.4	19.0	35.2	53.8	96.7	8.9

Table 21. Comparison of Nonrevenue Water Metric
(Percent of Production)

Year	Otay	Irvine Ranch	Phoenix	Rio Rancho	Seattle	Tampa
2001	--	--	10.7	--	8.6	--
2002	6.6	--	12.5	--	7.2	--
2003	7.6	--	10.4	--	6.7	--
2004	5.4	6.6	10.7	--	9.8	16.3
2005	10.5	6.3	10.5	--	6.1	11.3
2006	6.7	8.1	9.7	--	4.8	9.3
2007	3.8	8.5	8.6	--	4.1	15.8
2008	4.3	9.1	5.2	15.8	6.4	9.4

9.2 Indoor Conservation Indices

A concept similar to unavoidable leakage can be applied to the indoor and outdoor use of water in different sectors. A ratio benchmark similar to ILI can be defined for each utility by developing an estimate of an efficient level of water use to be achieved. For example, the indoor conservation index for the single-family residential sector in a given utility can be defined as:

$$ICI_a^{SF} = \frac{IUM_a^{SF}}{IUM_{aG}^{SF}} \tag{8}$$

Where:

ICI_a^{SF} = indoor conservation index for single-family sector as a ratio-type benchmark

IUM_a^{SF} = estimated residential single-family indoor use per account per day[10]

IUM_{aG}^{SF} = efficiency goal (G) for residential single-family indoor use per account per day

The value of IUM_{aG}^{SF} can be obtained by disaggregating indoor water demand into its specific components or end uses. A rational representation of each end-use can be made using a structural end use equation of the following form (Dziegielewski, 1996):

$$EU_G^i = [(\sum_j M_j S_j) * U + K * F] * A \tag{9}$$

where

EU^i_G = quantity of water in end use *i* representing an efficiency goal *G*

M_j = efficiency classes of the end use (set of mechanical or design parameters)

S_j = fraction of end uses within efficiency classes j =1, 2 …k

U = usage rate per event (or intensity of use) in end use *i*

K = average flow rate of leaks

F = fraction of end uses with leaks (incidence of leaks)

A = proportion of users with end use *i* in a given sector of users

An application of Equation 9 to the toilet end-use in the residential sector would require the knowledge of all end-use parameters. An example of the application of this equation for the toilet end use is presented in Table 22.

The efficiency classes for toilets are defined using the typical values for the design parameter M_i of 5.5, 3.5, 1.6 and 1.28 gallons per flush . The corresponding fractions of end uses within each class under current conditions are assumed to be 0.20, 0.50, 0.30, and 0.00. Also, with a typical value of 5 flushes per person per day and average household size of 2.8 persons the usage rate for the toilets would be 14 flushes per day per home. An average leakage rate of 20 gallons per day can be assumed with the incidence of leaks of 0.15. The presence parameter for toilets is 1.0. Using the equation (9), the average quantity of the current end use of water for toilet flushing would be 48.2 gallons per account per day.

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[10] Depending on climate characteristics it may be appropriate to weather-normalize the estimated indoor use to account for residual seasonal use that may be present in a minimum-moth estimate of indoor use.

Table 22. Example of Calculations for Toilet End Use

Symbol	Parameter Description	Current	Goal
M_1	Inefficient class 1 rate	5.00	5.00
S_1	Inefficient class 1 fraction	0.20	0.00
M_2	Standard class 2 rate	3.50	3.50
S_2	Standard class 2 fraction	0.50	0.00
M_3	Efficient class 3 rate	1.60	1.60
S_3	Efficient class 3 fraction	0.30	0.00
M_4	Efficient class 4 rate	1.28	1.28
S_4	Efficient class 4 fraction	0.00	1.00
U	Intensity (or frequency) of use, fpd	14.00	14.00
K	Leakage rate, gpd	20.00	20.00
F	Incidence of leaks	0.15	0.15
A	Presence of end use	1.00	1.00
EU	End use quantity, gpad	48.2	20.9

An efficiency goal for toilet flushing may be defined by a water utility by assuming that all non-conserving and standard toilets are replaced with the 1.28 gpf model that is recommended by WaterSense®. Then, at the same intensity of use (i.e., same number of flushes per day) and the same rate and intensity of leaks, the toilet end use that represents an efficiency goal would be 20.9 gallons per account per day.

Other end uses and their efficiency goals can be estimated using similar parameters and assumptions. Once all significant indoor end uses are estimated, the total value of the indoor efficiency goal can be calculated as:

$$IUM_{aG} = \sum_{1}^{n} EU_{aG}^{i} \qquad (10)$$

where, EU^{i}_{aG} is efficiency goal for end use i where i = 1…n.

9.2.1 Single Family Indoor Use

Table 23 shows the results of the AWWA residential end use study of a sample of single-family homes (DeOreo et al, 1999). The table compares the average rates of use at the time of the study and the estimated usage with the most efficient fixtures and appliances (M_3) existing at that time. The actual average indoor use in the AWWA study was 69.3 gallons per person per day.

The efficiency goal in Table 23 represents a condition requiring the installation of water efficient fixtures and appliances and requires no change in water using behavior. For example, the average volume of water used to flush the toilet was measured to be 3.7 gallons. However, 13.9 percent of recorded flushes used approximately 1.6 gallons per flush, which was then the current efficiency standard in toilet design. If all toilet flushes would use 1.28 gallons per flush, then without changing the frequency of toilet flushing, the efficient usage goal would be 6.5 gpcd instead of the previous average of 18.5 gallons. Similar assumptions can be made for the remaining seven end uses. The efficient single-family sector indoor use goal in this example is 43.5 gpcd.

Using the average and the goal values of indoor use in Table 23, the calculated value of the ICI metric for single family indoor use can be calculated as:

$$ICI_a^{SF} = \frac{IUM_c^{SF}}{IUM_{cG}^{SF}} = \frac{69.3}{43.5} = 1.59 \qquad (11)$$

Table 23. Examples of Average and Efficient Levels of Indoor Residential End Uses

Purpose of Use	Average Frequency of Use (U) (events/person/ day)	Average Usage (M_i*S_i) (gallons per event)	Average Use (EU^i) (gpcd)	Efficiency Assumption (M_3*1.0) (gallons per event)	Efficient Use Goal (EU^i_G) (gpcd)
Toilet flushing	5.05	3.7	18.5	1.28	6.5
Clothes washing	0.37	40.6	15.0	25.8	9.5
Showering	0.70	16.6	11.6	14.4	10.1
Bathing	0.05	23.8	1.2	18.6	0.9
Faucet use	17.60	0.6	10.9	0.5	9.3
Dishwashing	0.10	10.0	1.0	8.0	0.8
Leaks	0.46	20.7	9.5	20.7	4.8
Other domestic	--	--	1.6	--	1.6
Total indoor use	--	--	69.3	--	43.5

gpcd = gallons per person per day

It is important to note that each water utility would likely develop its own efficiency goal by selecting realistic assumptions about achieving the adoption of the efficient fixtures and appliances. Also, the intensity (U) and presence (A) of end uses may vary among different utilities.

9.2.2 Multifamily Indoor Use

The ICI^{MF} benchmark for multifamily use can also be developed for each utility. In absence of a locally derived efficiency benchmark, an approximate benchmark value for indoor use can be derived based on the AWWA end use study by assuming different rates of presence of washing machines and dishwashers in multifamily housing units.

The national submetering study (Mayer, 2004) found that only 52 percent of apartments had a washing machine. Eighteen percent of residents without a washing machine reported washing clothes at an off-site laundry (or through other arrangements). This implies that only about 85 percent of multifamily residences are expected to have the clothes washing end use. Also, 78.8 percent of respondents reported having a dishwasher.

Table 24 shows the adjusted average indoor use per person in multifamily housing based on the AWWA end use study. The estimates in the table indicate that the average indoor use in multifamily residences would be 62.2 gpcd and the efficiency goal would be 40.3 gpcd. Accordingly the value of the ICI_c^{MF} metric would be 62.2/40.3 or 1.54.

Table 24. Examples of Average and Efficient Levels of Indoor Residential End Uses in Multifamily Sector

Purpose of Use	Average Use (EU^i) (gpcd)	Average Multifamily Use (EU^i) (gpcd)	Efficient Use Goal (EU^i_G) (gpcd)
Toilet flushing	18.5	18.5	6.5
Clothes washing	15.0	12.75	6.46
Showering	11.6	11.6	10.1
Bathing	1.2	1.2	0.9
Faucet use	10.9	10.9	9.3
Dishwashing	1.0	0.8	0.64
Leaks	9.5	4.8	4.8
Other domestic	1.6	1.6	1.6
Total indoor use	69.3	62.2	40.3

[a] MF use assumes 85 percent of clothes washing use and 80 percent of dishwasher use and 50% reduction of leaks.

9.3 Outdoor Conservation Indices

In order to define a meaningful efficiency benchmark for the OUM metric, it would be necessary to determine total irrigated area in the sector and assume an agronometric theoretical value of irrigation demand for each water utility.

According to Bennett and Hazinski (1993) a theoretical irrigation water requirement can be calculated using the following irrigation water budget formula:

$$WB = 0.8 \cdot \frac{ET \cdot K_s \cdot K_m \cdot K_d}{IE} \cdot A \qquad (12)$$

Where:

- WB = theoretical irrigation water requirement
- ET = reference evapotranspiration
- K_s = crop coefficient
- K_m = microclimate factor
- K_d = canopy density
- IE = irrigation efficiency, typically 0.80
- A = irrigated area
- 0.8 = assumption for supplying only 80 percent of ET

Another option is to use the method developed by the EPA's WaterSense® Water Budget Approach (EPA, 2009). On May 8, 2009, EPA released a revised draft of the tool (file name: WaterSense Water Budget Tool_050809.xls) in a Microsoft Excel spreadsheet format that facilitates the water budget calculation for urban landscapes. This calculation can determine how much water the designed landscape requires based on climate, plant type, and irrigation system design.

According to EPA, the landscape water requirement (LWR) can be calculated for each hydrozone and the sum of these values is the LWR for the site. The LWR is based on ET_o, the landscape coefficient (K_L), the area of the hydrozone, the lower quarter distribution uniformity (DULQ) of the associated system, and a portion of local rainfall designated as allowable rainfall (R_a):

$$LWR_H = RTM \cdot [(ET_o \cdot K_L) - R_a] \cdot A \cdot C_u \tag{13}$$

Where:

LWR_H = landscape water requirement for the hydrozone (gallons/month)

RTM = run time multiplier, equal to 1/lower quarter distribution uniformity (dimensionless); this factor is used to increase zone run time to account for lack of distribution uniformity within the root zone

ET = local reference evapotranspiration (inches/month) which represents the rate of evapotranspiration from an extensive surface of cool-season grass cover of uniform height of 12 centimeters (4.7 inches), actively growing, completely shading the ground, and not short of water

K_L = landscape coefficient for the highest water-using plant in that hydrozone (dimensionless), this coefficient is used to modify reference ET, which includes species factor (K_s), density factor (K_d), and microclimate factor (K_{mc}) where K_L = K_s x K_d x K_{mc}) but for the purposes of this tool, WaterSense is assuming K_d and K_{mc} are both approximately equal to one to reduce the complexity of the calculations

R_a = allowable rainfall, designated by WaterSense as 25% of the site's peak monthly rainfall

A = area of the hydrozone (square feet) which represents the grouping of plants with similar water and environmental requirements for irrigation with one of more common station/zone valves

C_u = conversion factor (0.6233 for results in gallons/month)

For a water utility, Equation 12 could be used to determine landscape water requirements for hydrozones and then entire parcels for residential and nonresidential customers to determine average water requirements per customer in a given service area. The outdoor conservation index for single family sector would then be calculated as:

$$OCI_a^{SF} = \frac{OUM_a^{SF} \cdot (365/153)}{LWR_{Gs}^{SF} / 153} \tag{14}$$

Where:

OCI_a^{S} = outdoor conservation index for single-family sector as a ratio-type benchmark

OUM_a^{SF} = weather-normalized residential single-family outdoor use per account per day

$LWRG_{gs}^{SF}$ = efficiency goal (G) for residential single-family outdoor use per account per day represented by average irrigation water requirement during the growing season (*gs*)

153 = number of calendar days during the May-September growing season.

Similar calculations could be performed for landscapes in multifamily and nonresidential sectors.

Unfortunately, the detailed data and assumptions required to provide an example could not be derived for this study.

10. SUMMARY RECOMMENDATIONS

10.1 Applicability of Metrics

This examination of the potential for developing water use and conservation metrics for public water supply utilities revealed several limitations as well as some possibilities for using various metrics to track water use and monitor progress in achieving efficiency goals. Table 25 provides a list of metrics that were considered, together with brief statements on their advantages, shortcomings, and appropriate use.

Table 25. Metrics of Water Use and Conservation

Category of Metric	Symbol	Description	Selected Advantages	Selected Limitations
Aggregate Production Based	PQ_c	Per capita production	Good availability of data on water production	Population served defined differently by water utilities and cannot be measured accurately.
	PQ_a	Production per account	Number of billed accounts known for each billing period	Cannot account for differences in the composition of water use among primary sectors.
	PQ_{ea}	Production per "equivalent" account	Number of equivalent accounts is more precise than population served	Number of equivalent accounts depends on sectoral water use characteristics
Aggregate Metered Sales Based	SQ_a	Retail sales per account	Separates out system losses	Cannot account for differences in the composition of water use among primary sectors.
	SQ_{ea}	Retail sales per equivalent account	Number of billed accounts known for each billing period	Number of equivalent accounts depends on sectoral water use characteristics
Disaggregate -- Sector Sales Based	AUM_a^{SF}	Annual single-family usage metric per account	Definition of single-family sector generally consistent	Influenced by seasonal and weather-sensitive components of water use
	AUM_a^{MF}	Annual multifamily usage metric per account	Number of accounts available and more accurate that housing unit counts.	Large variance in number of units served per multifamily account
	AUM_a^{NR}	Annual nonresidential usage metric per account	Number of accounts available and more accurate than employment and other counting variables.	Large variance in types of businesses and corresponding water uses
Disaggregate -- Sector and Seasonally Based	IUM_a^{SF}	Indoor (nonseasonal) single family use metric per account	Indoor use is considered relatively homogenous	Difficulty in estimating indoor/outdoor use distinction in areas with year-round outdoor and/or cooling uses. Classification of irrigation meters can confound estimates. Regularly collected data on
	IUM_c^{SF}	Indoor (nonseasonal) single family use metric per capita	Scales indoor use for average number of people residing in households.	
	OUM_a^{SF}	Outdoor (seasonal) single family use metric per account	Isolates weather-sensitive uses	
	IUM_a^{MF}	Indoor (nonseasonal) multi-family use metric per account	Indoor use is considered relatively homogenous	

Category of Metric	Symbol	Description	Selected Advantages	Selected Limitations
	IUM_c^{MF}	Indoor (nonseasonal) multi-family use metric per capita	Scales indoor use for average number of people residing in households.	irrigated acreage would improve use of account-level data Heterogeneity of customers and class definitions for multifamily and nonresidential categories limits inter-utility comparisons
	OUM_a^{MF}	Outdoor (seasonal) multi-family use metric per account	Isolates weather-sensitive uses	
	IUM_a^{NR}	Indoor (nonseasonal) nonresidential use metric per account	Indoor use perhaps less variable than sector-wide use	
	OUM_c^{NR}	Outdoor (seasonal) nonresidential use metric per account	Convenient measure of weather-sensitive uses	
Leakage and Loss	NRW	Nonrevenue water	Easily computed from commonly available data	Combines real and apparent water losses
	CARL	Real resource loss	Focuses on real (physical) losses	Does not provide any allowances for unavoidable leaks
	ILI	Infrastructure leakage index	Can be used for inter-utility comparisons	Rigid formula for assessing unavoidable leaks
Conservation Indices	ICI^{SF}	Indoor single-family conservation index	Ratio benchmarks with 1.0 target/goal value Can be tailored to reflect service area end use and weather characteristics Can be used for inter-utility comparisons	Indoor use measure may include outdoor uses using minimum month estimation methods Requires definition and calculation of benchmark usage rates for indoor and outdoor use Outdoor benchmark values require multiple assumptions to reflect service area characteristics
	ICI^{MF}	Indoor multifamily conservation index		
	OCI^{SF}	Outdoor single-family conservation index		
	OCI^{MF}	Outdoor multifamily conservation index		

All metrics in Table 25 except the conservation indices are best suited for making comparisons of water use at a single water utility. The ILI, ICI and OCI metrics can be used (with some fundamental caution) in cross-utility comparisons.

10.2 Key Findings

The analysis and comparison of the values of different metrics for the seven case study utilities resulted is several relevant findings. The following is a summary of key findings.

1. Available water production and sales records can be used to calculate both system-wide and sector-specific metrics of water use. However, the only accurate and regularly updated measure of system size is the number of connections or customer accounts. Other measures of system size such as population served, number of housing units, or the number of employees are not precisely defined and at best are updated only on annual basis. For this reason the commonly used metric representing annual production per capita, or GPCD, should not be used as a benchmark.

2. Useful sector-specific metrics can be defined and calculated precisely. However, each water utility uses a different system for classifying customer accounts. This makes it difficult to consolidate the existing customer types into user sectors such as residential, commercial, industrial, and institutional and others. Even if such sectoral groupings are made, their customer characteristics and composition may vary across different utilities.

3. Both system-wide and sector-wide metrics can be used to track water usage per account over time. However, the year-to-year changes of the values of each metric have to be carefully interpreted. These changes may have different causes; oftentimes changes in water use that are related to weather conditions and/or the composition of water users can mask or overwhelm changes in use resulting from water conservation efforts.

4. No metrics of water use (measured in absolute terms) should be used for judging relative water use efficiency across different utilities. Different utilities will likely display uniqueness in terms of the climate and composition of demands in their respective service areas. Only ratio metrics such as the Infrastructure Leakage Index (ILI) with a benchmark value of 1.0 could be used (although with some caution) for inter-utility comparisons.

5. Ratio-type benchmarks can be formulated for different components of sectoral water use. These benchmarks can be compared across different utilities; however the absolute benchmarks on which such ratios are based should be unique to each utility. For example, the proposed Indoor Conservation Index (ICI) would be based on an efficiency goal of indoor use that would take into account specific conditions of each utility.

6. A promising way for developing metrics, absolute benchmarks, and efficiency goals is to disaggregate sectoral demands into specific end uses. End-use specific benchmark values can be formulated based on technological standards and assumptions regarding the intensity or frequency of use. Measurement of water use at an end-use level would naturally improve the indoor and outdoor metrics discussed in this report. Unfortunately, highly disaggregated end use data are not available in most water utilities.

10.3 Recommendations

The results of this study lend support to two major recommendations: one pertains to the data and water use records and the other to the development of supportive information for the conservation benchmarks.

1. Significant improvements in the ability of water utilities to reduce definitional noise and monitor water usage rates over time would be achieved if the water supply industry adopted a standard set of customer types and customer classification procedures. This ability would be enhanced further if water utilities collected and maintained additional characteristics for each customer. These would depend on customer type and could include such measurements as irrigated area, number of dwelling units, number of employees and the presence of specific end uses such as swimming pools or evaporative coolers.[11]

[11] The authors of this report and some members of the study review committee are currently developing a tailored collaboration study approach for determining information management needs for utility planning.

2. The suggested conservation indices for indoor and outdoor use (i.e., ratio benchmarks ICI and OCI) should be further investigated through a pilot study in a sample of water utilities. The indoor component of the study could include end-use measurement similar to the 1999 end use study conducted by AWWA for both single family and multifamily sectors, in particular to improve upon the limitations of the minimum-month method for estimating indoor use, as well as to establish baseline conditions and conservation benchmarks. The outdoor component of the study could include measurement of irrigated areas and watering requirements through advanced remote sensing techniques and on-site measurements of actual water use for irrigation and outdoor purposes in a sample of residential and nonresidential parcels.

NOTATION

Acronyms for metrics:

PQ = water production quotient

SQ = water sales quotient

UM = usage metric

CI = conservation index

Dimensions of water use (added in front of the acronyms for metrics):

A = annual average (daily) water production, sales or usage

I = indoor (nonseasonal) water use

O = outdoor (seasonal) water use

Sectors of water users (added as a superscript after the acronyms for metrics):

SF = single-family sector

MF = multifamily sector

NR = nonresidential sector

Scaling variables (added as a subscript after the acronyms for metrics):

c = per capita based on population served or number of residents

a = per account based on the number of billed accounts

ea = equivalent account

also

G = goal or benchmark value

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APPENDIX A

CASE STUDY TABLES

CASE #1
OTAY WATER DISTRICT, CALIFORNIA

Table O1. Annual Production (MG), Sales (CCF) and Billed Accounts Data for Otay Water District, California

Description	2002	2003	2004	2005	2006	2007	2008	C.V.	Trend
Population Served	149,132	160,252	171,373	177,634	183,895	190,156	196,416	9.5	4.48
Production (Potable)	36,856	35,857	39,378	39,932	41,740	39,359	36,821	5.5	0.86
Production (Recycled)	1,119	1,209	1,275	1,227	1,228	1,206	1,202	3.9	0.58
Purchase (Recycled)						2,759	3,524	17.2	27.74
Total metered sales:	15,456,498	14,916,586	16,761,288	16,048,790	17,459,150	18,155,769	17,324,974	7.0	2.80
Total Residential	9,147,579	9,172,475	9,646,201	9,983,730	10,778,272	11,080,760	10,475,434	7.6	3.24
Single-family	8,145,112	8,106,525	8,447,007	8,837,155	9,428,653	9,655,479	9,045,979	6.9	2.79
Multifamily	1,002,467	1,065,950	1,199,194	1,146,575	1,349,619	1,425,281	1,429,455	14.0	6.51
Commercial	759,669	744,443	1,527,960	861,316	871,767	922,899	939,562	28.2	0.91
Irrigation	2,470,244	2,027,714	2,231,341	2,038,685	2,158,727	2,316,057	2,217,028	7.0	-0.41
Agricultural	89,272	77,013	68,852	53,043	50,344	57,972	48,502	24.1	-9.85
Public	919,553	919,033	901,744	911,968	963,747	960,105	946,271	2.6	0.86
Recycled water	1,141,825	1,284,886	1,608,699	1,639,477	1,806,359	1,989,596	2,020,373	20.4	9.94
Construction	928,356	686,364	766,060	412,846	659,057	639,370	553,672	24.3	-6.99
Fire Services		4,608	10,185	0	52	10,615	4,012	95.0	-0.95
Sales to other agencies		50	245	147,725	170,825	178,395	120,120	79.8	55.85
Total billed accounts:	40,726	42,802	45,233	47,072	48,283	48,289	48,227	6.6	2.90
Total Residential	37,652	39,515	41,763	43,386	44,344	44,307	44,175	6.3	2.73
Single-family	36,931	38,785	41,017	42,622	43,557	43,506	43,363	6.3	2.74
Multifamily	722	731	746	764	787	801	812	4.6	2.13
Commercial	989	991	1,040	1,086	1,135	1,154	1,183	7.3	3.03
Irrigation	1,022	989	986	1,082	1,120	1,170	1,188	7.7	2.55
Agricultural	24	38	33	32	32	30	24	16.6	-2.11
Public	204	216	216	222	228	232	233	4.7	2.15
Recycled water	182	324	470	484	557	589	628	34.3	17.71
Construction	226	266	266	252	240	201	162	16.6	-5.33
Fire Services	426	462	460	526	626	604	633	16.3	7.55
Sales to other agencies	1	1	1	1	1	1	1	0.0	0.00

Table O2. Calculated Metrics Using the Number of Accounts and Population Served as Normalizing Variables for Otay Water District, California

Description	2002	2003	2004	2005	2006	2007	2008	C.V.	2002-2008 Trend
Per account metrics (gpad):									
Total Residential	480	483	486	488	490	493	495	1.1	0.49
Single-family	435	436	436	436	436	437	437	0.1	0.05
Multifamily	2,858	3,010	3,155	3,294	3,427	3,555	3,677	9.0	4.27
Commercial	1,908	1,923	1,849	1,786	1,724	1,712	1,685	5.4	-2.39
Irrigation	4,484	4,613	4,611	4,183	4,024	3,836	3,761	8.5	-3.60
Agricultural	5,220	4,915	4,598	4,267	3,921	3,561	3,184	17.3	-7.84
Public	8,966	8,844	8,728	8,616	8,510	8,407	8,309	2.7	-1.26
Recycled water	9,636	8,512	7,788	7,283	6,910	6,624	6,398	15.2	-6.62
Construction	6,165	6,087	6,001	5,906	5,799	5,680	5,545	3.8	-1.73
Fire Services		23	21	19	18	16	15	14.9	-7.73
Sales to other agencies		41,368	109,165	176,962	244,759	312,557	380,354	60.2	55.85
All sales/all accounts	745	744	743	742	742	741	740	0.2	-0.10
Per capita metrics (in gpcd):									
Per capita production	227.3	206.5	211.8	206.9	208.6	203.4	188.8	5.5	-2.13
Total sales per capita	204.4	200.2	196.3	192.6	189.3	186.3	183.4	3.9	-1.79
Residential sales per capita	122.0	120.2	118.7	117.2	115.9	114.7	113.5	2.6	-1.19
Commercial sales per capita	12.4	11.9	11.5	11.1	10.7	10.4	10.0	7.5	-3.43
Construction sales per capita	10.8	9.7	8.7	7.7	6.9	6.1	5.4	24.7	-11.21
Nonrevenue water (%)	6.6	7.6	5.4	10.5	6.7	3.8	4.3	35.3	-7.18

Table O3. Metrics Based on Socioeconomic Data for Otay California

Description	2004	2008
Population served	171,373	196,416
Employment (civilian)	38,778	52,838
SF housing units	44,646	44,830
MF units	9,394	16,388
SF persons per households	3.445	3.490
SF population	153,805	156,457
MF population	17,568	39,960
SF sales per housing unit	393.2	435.9
MF sales per housing unit	251.8	182.8
SF sales per capita	114.1	124.9
MF sales per capita	134.7	75.0
NR sales per employee	139.2	95.0

Table O4. Monthly and Seasonal Single-Family Residential Usage Rates in Otay, California.

Month	2002	2003	2004	2005	2006	2007	2008
Per account use (gpad):							
January	330.0	318.7	297.5	265.9	391.2	343.7	318.4
February	363.4	387.6	307.8	303.6	378.0	362.2	280.7
March	359.0	268.7	223.1	248.4	332.0	299.1	271.4
April	394.6	377.0	339.6	316.9	284.9	370.0	380.9
May	427.2	358.8	409.7	419.0	337.0	385.3	466.8
June	543.0	490.2	564.5	520.1	463.5	588.5	481.0
July	536.7	508.0	511.6	505.2	567.1	556.2	506.8
August	588.0	531.4	595.1	556.3	564.9	553.5	558.4
September	594.4	582.5	610.3	552.9	598.6	643.5	544.0
October	477.6	508.9	494.9	510.0	514.8	487.1	480.2
November	431.0	459.7	366.4	428.9	448.0	494.3	470.7
December	370.5	340.2	320.5	433.7	437.3	373.0	362.9
Annual average	452.0	428.3	422.0	423.9	443.6	454.8	427.5
Minimum month	330.0	268.7	223.1	248.4	284.9	299.1	271.4
Percent nonseasonal	72.7	62.8	52.7	58.5	63.2	66.7	60.5
Percent seasonal	27.3	37.2	47.3	41.5	36.8	33.3	39.5

Table O5. Monthly and Seasonal Multifamily Residential Usage Rates in Otay, California.

Month	2002	2003	2004	2005	2006	2007	2008
Per account use (gpad):							
January	2,557	2,615	3,127	2,628	3,316	3,431	3,489
February	2,752	2,933	3,356	3,168	3,106	3,311	3,404
March	2,419	2,458	2,793	2,801	2,900	3,066	3,041
April	2,724	2,711	3,220	2,825	2,492	3,290	3,426
May	2,640	2,671	3,129	3,111	2,694	3,130	3,506
June	3,051	3,158	3,697	3,460	3,212	4,168	3,736
July	2,938	3,111	3,180	3,171	3,517	3,775	3,605
August	3,170	3,228	3,638	3,324	3,719	3,809	3,939
September	3,360	3,480	3,761	3,244	3,947	4,420	4,257
October	2,876	3,328	3,353	3,255	3,667	3,845	3,806
November	2,939	3,177	3,292	2,945	3,482	4,005	3,687
December	2,739	3,011	3,021	2,724	3,013	3,474	3,390
Annual average	2,846	2,990	3,296	3,055	3,250	3,647	3,608
Minimum month	2,419	2,458	2,793	2,628	2,492	3,066	3,041
Percent nonseasonal	86.4	83.4	85.7	85.9	75.7	82.4	85.5
Percent seasonal	13.6	16.6	14.3	14.1	24.3	17.6	14.5

Table O6. Monthly and Seasonal Nonresidential (Commercial/Public/Construction) Usage Rates in Otay, California.

Month	2002	2003	2004	2005	2006	2007	2008
Per account use (gpad):							
January	2,537	2,617	4,234	2,284	2,749	2,728	2,222
February	3,075	3,045	4,534	2,189	2,644	2,851	2,473
March	3,221	2,576	4,218	2,008	2,476	2,431	2,057
April	3,797	2,599	4,762	2,465	2,290	2,637	2,540
May	4,211	2,758	6,520	3,622	2,450	2,744	3,027
June	4,487	3,518	3,547	3,684	3,281	3,791	3,349
July	4,335	3,585	3,739	4,013	3,647	3,803	3,802
August	4,249	3,800	4,279	4,293	3,862	3,623	4,035
September	4,382	4,080	4,376	2,920	4,314	4,372	3,889
October	3,686	4,093	5,786	2,706	3,797	3,674	3,900
November	3,864	3,619	3,248	2,451	3,332	2,587	3,542
December	3,260	2,867	2,478	1,720	3,259	3,836	3,098
Annual average	3,766	3,271	4,304	2,863	3,188	3,258	3,169
Minimum month	2,537	2,576	2,478	1,720	2,290	2,431	2,057
Percent nonseasonal	66.4	78.0	60.7	62.4	69.6	76.2	65.4
Percent seasonal	33.6	22.0	39.3	37.6	30.4	23.8	34.6

Table O7. System-wide Production, Consumption and Losses in Otay WD

Description	Units	2006	2008
Water imported:	acre-ft/yr	42,329.50	43,260.80
Water exported:	acre-ft/yr	393.80	281.40
WATER SUPPLIED:	acre-ft/yr	41,935.70	42,979.40
AUTHORIZED CONSUMPTION			
Billed metered:	acre-ft/yr	37,940.30	40,350.70
Billed unmetered:	acre-ft/yr	58.80	135.40
Unbilled metered:	acre-ft/yr	295.80	221.40
Unbilled unmetered:	acre-ft/yr	524.20	537.24
AUTHORIZED CONSUMPTION:	acre-ft/yr	38,819.10	41,244.74
WATER LOSSES	acre-ft/yr	3,116.60	1,734.66
Apparent Losses			
Unauthorized consumption:	acre-ft/yr	104.84	107.45
Customer metering inaccuracies:	acre-ft/yr	3.82	4.06
Systematic data handling errors:	acre-ft/yr	58.80	135.40
Apparent Losses:	acre-ft/yr	167.46	246.91
Real Losses = Water Losses - Apparent Losses:	acre-ft/yr	2,949.14	1,487.75
WATER LOSSES:	acre-ft/yr	3,116.60	1,734.66
NON-REVENUE WATER:	acre-ft/yr	3,936.60	2,493.30
Length of mains:	miles	750.00	750.00
Number of active and inactive service connections:		46,874.00	46,874.00
Connection density:	conn./mile main	62.50	62.50
Average length of customer service line:	ft	22.00	22.00
Average operating pressure:	psi	95.00	95.00
Apparent Losses per service connection per day:	gallons/connection/day	3.19	4.70
Real Losses per service connection per day:	gallons/connection/day	56.17	28.34
Real Losses per service connection per day per psi pressure:	gallons/connection/day/psi	0.59	0.30
Unavoidable Annual Real Losses (UARL):	million gallons/year	435.29	435.29
Infrastructure Leakage Index (ILI) [Real Losses/UARL]:	--	2.21	1.11

CASE #2
IRVINE RANCH WATER DISTRICT, CALIFORNIA

Table I1. Reported Production and Sales Data for Irvine Ranch Water District, California

Description	2004-05	2005-06	2006-07	2007-08	2008-09	C.V.	Trend
Production (AF)	86,906.1	89,279.4	100,721.3	98,978.2	98,826.7	6.7	3.60
Metered Sales (AF) to:							
Total Residential	30,689.4	31,851.3	34,442.9	34,307.1	34,799.8	5.5	3.27
Single-family	26,103.5	26,739.6	29,187.0	28,738.3	29,131.7	5.2	2.92
Multifamily	4,585.9	5,111.7	5,255.9	5,568.8	5,668.1	8.2	5.15
Commercial	7,663.1	8,095.4	8,772.0	8,824.3	8,524.7	5.9	2.97
Industrial	6,047.3	5,754.4	5,441.7	5,358.9	5,009.6	7.2	-4.39
Governmental	2,841.8	2,795.1	2,474.2	2,588.3	2,571.0	5.9	-2.78
Irrigation							
Agricultural	7,222.7	8,225.5	8,660.3	7,559.5	7,856.0	7.1	0.76
Urban	22,806.9	23,897.5	29,302.0	28,701.2	27,888.2	11.2	5.83
Public	0.0	0.0	0.0	0.0	0.0		
Combined nonresidential	564.0	897.7	835.9	808.2	279.5	37.8	-9.38
Wholesale to other agenc.	3,309.3	2,145.2	2,647.7	2,399.6	2,945.0	17.0	-1.75
Total sales	81,144.5	83,662.1	92,576.7	90,547.1	89,873.8	5.6	2.82

Table I2. Customer Classification and Number of Accounts in Irvine Ranch, California

Customer Classification/Fiscal Year	2004-05	2005-06	2006-07	2007-08	2008-09	C.V.	Trend
Total Residential							
Single-family (10, 11, 12, 18, 71, 91)	46,891	48,148	50,059	50,668	51,542	3.8	2.42
Separately Metered Condo (13, 16)	22,133	22,770	23,292	23,804	24,030	3.3	2.10
Separately Metered Apt (14, 17)	5,345	5,345	5,345	5,345	5,346	0.0	0.00
Master Metered Condo - Multifamily (80, 83)	732	804	830	838	850	5.8	3.40
Master Metered Apts - Multifamily (81, 82)	1,489	1,490	1,527	1,600	1,687	5.4	3.30
Other							
Commercial - Potable (20, 22, 72, 92)	1,821	3,723	4,258	4,632	4,840	31.5	20.76
Commercial - Untreated (21, 23)	3	3	2	2	2	25.4	-13.67
Commercial - HOA (27)							
Commercial (28)							
Commercial - Recycled Water (29)	13	13	19	36	48	60.0	56.79
Industrial - Potable (30,38)	880	876	870	865	858	1.0	-0.62
Industrial - Recycled (32)	1	1	2	2	1	34.5	12.26
Public Authority (40, 46, 47, 48, 94)	221	227	252	262	269	8.7	5.50
Irrigation - Potable (60, 76, 93)	1,751	1,765	1,783	1,799	1,811	1.4	0.87
Irrigation - Untreated (61)	106	134	234	214	167	31.4	12.91
Irrigation - Recycled (62, 63, 65)	3,636	3,801	3,925	4,202	4,374	7.5	4.84
Irrigation - Lake Fill (64)							
Ag - Potable (66)	21	21	23	23	19	7.7	-1.47
Ag - Untreated (67, 69)	40	35	35	35	31	8.5	-4.78
Ag - Recycled (68)	17	13	13	14	19	17.5	2.79
Construction - Temporary Potable (50, 75, 95)	181	212	261	197	126	25.2	-6.20
Construction - Temporary Recycled (51)	5	4	4	3	2	30.6	-16.97
Hydrants (90, 98)	2,294	2,429	2,572	2,756	2,931	9.8	6.40
Wholesale Water to Other Agencies							
Total billed accounts	87,579	91,813	95,306	97,297	98,953	4.8	3.05

Table I3. Summary of Billed Accounts in Irvine Ranch Water District, California.

Fiscal Year/ Customer Classification	2004-05	2005-06	2006-07	2007-08	2008-09	C.V.	Trend
Total Residential	76,590	78,557	81,053	82,255	83,455	3.5	2.19
Single-family	74,368	76,263	78,696	79,817	80,918	3.4	2.16
Multifamily	2,221	2,294	2,357	2,438	2,537	5.2	3.33
Commercial	1,834	3,736	4,277	4,668	4,887	31.6	20.93
Industrial	880	876	870	865	858	1.0	-0.62
Governmental	221	227	252	262	269	8.7	5.50
Irrigation							
Agricultural	78	70	71	72	69	5.2	-2.24
Urban	5,492	5,700	5,943	6,215	6,352	6.0	3.84
Combined nonresidential	186	216	266	200	128	25.0	-6.39
Total Sales	85,281	89,380	92,731	94,536	96,019	4.7	2.95

Table I4. Calculated Metrics Using the Number of Accounts as Normalizing Variable

Fiscal Year/ Customer Classification	2004-05	2005-06	2006-07	2007-08	2008-09	C.V.	Trend
Water Use per Account (gpad)							
Total Residential	358	362	379	372	372	2.4	1.08
Single-family	313	313	331	321	321	2.3	0.77
Multifamily	1,843	1,989	1,990	2,039	1,994	3.8	1.80
Commercial	3,729	1,935	1,831	1,688	1,557	41.7	-20.42
Industrial	6,134	5,868	5,587	5,531	5,211	6.2	-3.79
Governmental	11,480	11,001	8,759	8,831	8,525	14.4	-8.05
Irrigation							
Agricultural	82,315	105,532	109,407	94,168	101,398	10.9	2.76
Urban	3,708	3,743	4,402	4,123	3,920	7.2	2.04
Combined nonresidential	2,714	3,719	2,811	3,609	1,949	24.5	-5.41
Total sales/total accounts	849	836	891	855	836	2.7	-0.10

Table I5. Monthly and Seasonal Single-Family Residential Usage Rates in Irvine Ranch, California.

Month	2004-5	2005-6	2006-7	2007-8	2008-9
Per account use (gpad):					
January	250.0	266.7	280.1	259.2	244.6
February	232.2	267.9	274.6	224.6	253.2
March	237.7	255.5	275.4	251.6	243.6
April	275.3	225.5	289.6	297.4	297.2
May	306.6	265.2	305.9	325.1	321.8
June	355.6	330.1	362.0	347.1	340.4
July	375.9	375.1	384.5	378.9	379.4
August	425.1	375.6	382.4	367.2	363.4
September	389.5	378.0	389.1	386.2	370.4
October	381.4	353.8	348.2	338.3	354.0
November	265.1	303.7	321.0	324.2	329.9
December	279.0	292.1	287.6	286.2	286.8
Annual average	313.4	313.0	331.1	321.4	321.4
Minimum month	232.2	225.5	274.6	224.6	243.6
Percent nonseasonal	75.3	73.9	84.8	71.3	77.4
Percent seasonal	24.7	26.1	15.2	28.7	22.6

Table I6. Monthly and Seasonal Multifamily Residential Usage Rates in Irvine Ranch, California.

Month	2004-5	2005-6	2006-7	2007-8	2008-9
Per account use (gpad):					
January	1,743	1,860	1,915	1,956	1,853
February	1,657	1,869	1,932	1,868	1,857
March	1,796	1,863	1,958	1,899	1,862
April	1,730	1,781	1,767	1,984	1,897
May	1,800	1,865	1,909	1,956	1,910
June	1,832	2,045	2,114	2,032	1,988
July	2,061	2,092	1,648	2,100	2,083
August	2,020	1,991	2,017	2,017	2,011
September	1,925	2,079	2,141	2,079	2,065
October	1,995	2,076	2,046	2,091	2,040
November	1,744	1,986	2,027	2,008	1,985
December	1,841	1,923	1,962	2,023	1,945
Annual average = (a)	1,843	1,989	1,990	2,039	1,994
Minimum month = (b)	1,657	1,781	1,648	1,868	1,853
Percent nonseasonal, (b)/(a)	89.9	89.5	82.8	91.6	92.9
Percent seasonal, 100-(b)/(a)	10.1	10.5	17.2	8.4	7.1

Table I7. Monthly and Seasonal Nonresidential Usage Rates in Irvine Ranch, California.

Month	2004-5	2005-6	2006-7	2007-8	2008-9
Per account use (gpad):					
January	2,422	2,399	2,178	2,054	1,698
February	2,465	2,571	2,421	2,115	1,972
March	2,466	2,500	2,379	2,161	1,939
April	2,489	2,285	2,435	2,420	2,256
May	2,832	2,532	2,603	2,574	2,338
June	3,241	3,105	2,929	2,609	2,440
July	3,315	3,177	2,986	2,922	2,784
August	3,867	3,250	3,249	2,905	2,694
September	3,465	3,775	3,253	3,084	2,683
October	3,496	3,177	2,869	2,811	2,583
November	2,866	2,787	2,771	2,670	2,507
December	2,730	2,743	2,482	2,506	2,158
Annual average = (a)	2,959	2,911	2,762	2,618	2,381
Minimum month = (b)	2,422	2,285	2,178	2,054	1,698
Percent nonseasonal, (b)/(a)	81.8	78.5	78.9	78.5	71.3
Percent seasonal, 100-(b)/(a)	18.2	21.5	21.1	21.5	28.7

CASE #3 -- PHOENIX WATER SERVICES DEPARTMENT, ARIZONA

Table P1. Number of Accounts by Customer Category in Phoenix Water Services Department, Arizona

Customer Type - Description	2001	2002	2003	2004	2005	2006	2007	2008	C. V.	Trend
1 Commercial -unit - pools, landsc. sprinklers, warehouse, vacant lots, public restrooms	11,717	11,908	12,051	12,211	12,443	12,634	12,820	13,048	3.8	1.54
1 Family residence	305,827	310,348	316,848	325,119	335,810	345,904	352,959	354,101	5.8	2.37
1 Family residence & 2 commercial units	17	16	15	16	16	16	16	16	3.1	-0.20
1 Family residence and 1 commercial unit	446	446	442	439	434	429	420	412	2.9	-1.13
2 Commercial units	494	495	496	497	494	488	484	482	1.2	-0.41
2 Family residences - duplex	4,046	4,042	4,047	4,048	4,040	4,030	4,006	3,966	0.7	-0.24
2 Family residences & 1 commercial unit	56	56	55	55	52	53	52	51	3.9	-1.51
2-1 Family residences	665	665	664	666	661	654	650	639	1.4	-0.52
3 Commercial units	297	298	301	304	304	304	301	299	0.9	0.18
3 Family residences - triplex	1,662	1,659	1,655	1,647	1,674	1,691	1,689	1,681	1.0	0.30
3-1 Family residences	86	87	87	86	85	83	82	82	2.3	-0.87
4 Stores	776	788	794	796	799	796	796	798	0.9	0.30
Apartments - 4 units or more, condos	8,375	8,505	8,586	8,670	8,752	8,813	8,866	8,918	2.2	0.88
Car wash	112	116	119	118	118	121	126	130	4.7	1.82
Church rate	886	896	902	911	913	907	911	917	1.1	0.40
City of phoenix	592	607	618	625	638	658	664	682	4.9	2.00
Federal	46	47	47	46	46	48	50	49	3.1	0.94
Fire hydrant meter	525	480	507	555	623	762	758	582	18.1	5.41
Governments	225	226	229	226	225	223	220	220	1.4	-0.44
Heavy industry	174	175	180	185	187	186	186	183	2.9	0.95
Hotel, motel	415	414	418	419	414	410	404	406	1.3	-0.41
Institutions	358	358	361	362	362	365	370	377	1.7	0.66
Killed or inactive taps	455	360	273	163	95	31	7	4	99.1	-176.77
Laundry - commercial	50	49	49	49	48	47	51	51	2.7	0.26
Laundry - self service	75	76	76	79	78	79	82	81	3.0	1.16
Mortuary	27	27	27	27	26	26	26	26	1.9	-0.66
Office/bank building (non-dining), medical building, nursing home	1,371	1,379	1,385	1,393	1,397	1,407	1,416	1,426	1.3	0.55
Restaurant, bakery	1,371	1,403	1,425	1,441	1,447	1,460	1,469	1,478	2.5	0.99
Schools	747	780	811	839	856	881	903	928	7.3	3.04
Service station, auto repair	647	644	640	633	628	626	619	617	1.8	-0.72
Trailer courts	313	312	311	309	306	301	296	295	2.3	-0.92
Irrigation	7,507	7,918	8,302	8,689	9,143	9,524	9,909	10,465	11.4	4.79
All user types (sum)	350,357	355,580	362,720	371,620	383,113	393,956	401,605	403,412	5.5	2.26

Table P2. Average Water Use per Account (GPAD) by Customer Category in Phoenix Water Services Department, Arizona

Customer Type - Description	2001	2002	2003	2004	2005	2006	2007	2008	C. V.	Trend
1 Commercial -unit - pools, landscaping, sprinklers, warehouse, vacant lots, public restrooms	1,622	1,578	1,544	1,516	1,492	1,555	1,579	1,419	4.1	-1.09
1 Family residence	452	457	430	413	397	403	401	372	6.9	-2.65
1 Family residence & 2 commercial units	603	538	487	538	453	445	444	428	12.5	-4.53
1 Family residence and 1 commercial unit	648	632	611	561	544	542	544	504	8.9	-3.43
2 Commercial units	882	874	902	904	786	813	814	759	6.6	-2.17
2 Family residences - duplex	583	568	543	511	498	501	486	439	9.1	-3.55
2 Family residences & 1 commercial unit	963	783	803	681	642	700	586	586	17.8	-6.49
2-1 Family residences	733	732	675	646	615	623	617	572	8.9	-3.41
3 Commercial units	1,415	1,301	1,305	1,313	1,277	1,260	1,247	1,140	6.0	-2.19
3 Family residences - triplex	863	834	795	736	694	703	680	625	11.1	-4.36
3-1 Family residences	999	1,046	972	963	960	918	915	815	7.2	-2.62
4 Stores	2,957	2,896	2,775	2,701	2,625	2,617	2,547	2,388	6.9	-2.75
Apartments - 4 units or more, condos	4,532	4,392	4,235	4,096	4,025	4,041	3,908	3,655	6.7	-2.64
Car wash	6,119	6,275	5,941	5,909	6,421	6,643	6,416	5,613	5.5	-0.04
Church rate	1,530	1,507	1,429	1,328	1,307	1,340	1,353	1,229	7.5	-2.70
City of phoenix	6,590	5,865	5,312	5,584	5,659	5,426	5,607	5,053	8.1	-2.43
Federal	4,320	4,402	3,969	3,777	4,222	3,816	3,917	3,643	6.9	-2.11
Fire hydrant meter	5,592	4,774	4,150	4,240	3,811	4,574	4,427	4,537	11.7	-2.16
Governments	8,922	9,037	8,952	8,587	7,442	7,128	6,984	6,846	12.2	-4.62
Heavy industry	45,950	43,344	42,253	40,943	40,842	41,657	42,135	39,715	4.5	-1.45
Hotel, motel	9,676	9,337	9,890	9,873	10,379	10,715	10,604	9,879	4.7	1.28
Institutions	4,577	4,634	4,713	4,582	4,460	4,295	4,173	3,845	6.6	-2.35
Killed or inactive taps	1,017	1,048	1,029	1,180	2,340	2,449	2,409	1,219	42.7	11.30
Laundry - commercial	6,769	6,890	6,827	6,690	7,386	7,481	6,783	6,541	4.8	0.09
Laundry - self service	8,690	8,652	8,331	8,157	8,508	8,678	7,910	6,630	8.4	-2.41
Mortuary	1,485	1,642	1,650	1,656	1,694	1,751	1,814	1,784	6.1	2.36
Office/bank building (non-dining), medical building, nursing home	3,777	3,691	3,497	3,283	3,268	3,304	3,296	3,074	7.0	-2.60
Restaurant, bakery	3,300	3,168	3,128	3,084	3,089	3,195	3,169	2,943	3.3	-0.87
Schools	5,040	4,849	4,391	4,288	4,084	3,980	4,088	3,770	10.1	-3.85
Service station, auto repair	839	841	767	765	817	735	739	640	8.7	-3.00
Trailer courts	9,625	9,422	9,128	8,783	8,731	8,856	8,934	8,138	5.1	-1.81
Irrigation	3,385	3,382	3,142	3,097	2,923	3,207	3,294	2,976	5.5	-1.22
All user types (sum)	775	771	731	707	681	695	691	641	6.4	-2.68

Table P3. Monthly and Seasonal Single-Family Usage Rates per Account per Day in Phoenix, Arizona

Month	2001	2002	2003	2004	2005	2006	2007	2008
January	319.7	314.2	298.5	294.5	269.2	308.6	286.4	255.0
February	277.1	320.5	294.9	287.8	237.7	310.3	268.0	247.8
March	290.8	360.1	272.2	291.5	244.8	313.6	296.9	278.4
April	369.1	417.9	346.9	357.5	341.3	329.3	349.5	350.4
May	472.6	499.3	448.0	453.6	422.8	425.0	413.4	411.9
June	603.0	590.9	565.5	545.7	510.7	513.6	500.5	451.0
July	615.3	626.9	619.3	570.4	562.3	547.1	546.9	489.1
August	565.4	571.9	568.0	531.7	501.8	504.1	481.4	455.5
September	559.0	545.5	508.5	505.0	472.9	435.3	487.6	412.0
October	523.1	480.0	471.6	450.6	450.7	412.5	441.9	409.8
November	467.7	416.1	428.5	376.8	403.9	395.8	421.2	398.4
December	358.2	342.7	337.2	294.4	342.8	338.9	317.2	310.5
Average	451.8	457.2	429.9	413.3	396.7	402.8	400.9	372.5
Minimum month	277.1	314.2	272.2	287.8	237.7	308.6	268.0	247.8
Maximum month	615.3	626.9	619.3	570.4	562.3	547.1	546.9	489.1
Percent nonseasonal	61.3	68.7	63.3	69.6	59.9	76.6	66.8	66.5
Percent seasonal	38.7	31.3	36.7	30.4	40.1	23.4	33.2	33.5

Table P4. Monthly and Seasonal Apartments Usage Rates per Account per Day in Phoenix, Arizona

Month	2001	2002	2003	2004	2005	2006	2007	2008
January	4,082	3,841	3,692	3,544	3,526	3,667	3,525	3,208
February	3,802	3,779	3,624	3,541	3,291	3,625	3,400	3,184
March	3,819	3,870	3,488	3,573	3,305	3,649	3,469	3,227
April	4,084	4,084	3,772	3,803	3,648	3,680	3,636	3,484
May	4,502	4,411	4,128	4,124	4,009	4,014	3,900	3,709
June	5,040	4,855	4,673	4,548	4,340	4,396	4,228	3,911
July	5,261	5,138	5,048	4,798	4,660	4,657	4,446	4,163
August	5,205	5,053	5,016	4,719	4,698	4,626	4,417	4,099
September	5,038	4,939	4,749	4,570	4,497	4,333	4,304	3,927
October	4,763	4,493	4,394	4,198	4,263	4,043	3,967	3,730
November	4,674	4,337	4,367	4,106	4,195	4,036	3,997	3,763
December	4,118	3,903	3,871	3,626	3,870	3,761	3,613	3,451
Average	4,532	4,392	4,235	4,096	4,025	4,041	3,908	3,655
Minimum month	3,802	3,779	3,488	3,541	3,291	3,625	3,400	3,184
Maximum month	5,261	5,138	5,048	4,798	4,698	4,657	4,446	4,163
Percent nonseasonal	83.9	86.0	82.4	86.5	81.7	89.7	87.0	87.1
Percent seasonal	16.1	14.0	17.6	13.5	18.3	10.3	13.0	12.9

Table P5. Monthly and Seasonal General Commercial Usage Rates per Account per Day in Phoenix, Arizona

Month	2001	2002	2003	2004	2005	2006	2007	2008
January	1,145	1,117	1,052	1,057	1,009	1,107	1,112	962
February	1,094	1,120	1,078	1,061	969	1,138	1,123	995
March	1,105	1,178	1,031	1,098	997	1,183	1,185	1,058
April	1,267	1,366	1,201	1,320	1,215	1,251	1,329	1,255
May	1,669	1,599	1,442	1,597	1,459	1,561	1,585	1,450
June	2,035	1,899	1,903	1,898	1,803	1,921	1,845	1,649
July	2,176	2,148	2,120	2,097	2,085	2,129	2,140	1,901
August	2,166	2,113	2,144	2,035	2,006	2,082	2,057	1,917
September	2,078	2,012	2,007	1,917	1,916	1,884	2,065	1,718
October	1,867	1,742	1,799	1,651	1,734	1,693	1,757	1,577
November	1,607	1,458	1,569	1,383	1,489	1,476	1,543	1,423
December	1,252	1,177	1,187	1,080	1,222	1,237	1,203	1,119
Average	1,622	1,578	1,544	1,516	1,492	1,555	1,579	1,419
Minimum month	1,094	1,117	1,031	1,057	969	1,107	1,112	962
Maximum month	2,176	2,148	2,144	2,097	2,085	2,129	2,140	1,917
Percent nonseasonal	67.4	70.8	66.8	69.7	65.0	71.2	70.4	67.8
Percent seasonal	32.6	29.2	33.2	30.3	35.0	28.8	29.6	32.2

CASE #4
RIO RANCHO WATER DISTRICT, NEW MEXICO

Table R1. 2008 Production, Sales (KGAL) and Number of Accounts for Rio Rancho, New Mexico

Customer Classification	Annual Total	No. Accounts	Per Account Use
Population Served	80,000		
Production	4,267,139	--	
Per Capita production, gpcd	146		
Metered Sales to:			
Total Residential	2,301,612	28,686	219.8
Single-family	2,265,659	28,541	217.5
Multifamily	35,953	145	679.3
Commercial	440,795	613	1,969.0
Industrial	200,569	11	49,954.9
Governmental	20,989	29	1,977.2
Urban irrigation	532,120	352	4,144.6
Fire hydrant meters	98,118	96	2,790.5
Total sales/Total accounts	3,594,203	29,787	330.6

Table R2. 2008 Monthly and Seasonal Water Use in Rio Rancho

Month/Season	Monthly Use, 1000s Gal.	No. of Billed Accounts	Per Account Use, GPAD	Percent Annual Use
Single Family Sector				
January	149,791	27,969	172.8	6.61
February	126,077	28,147	160.0	5.56
March	140,967	28,229	161.1	6.22
April	189,632	28,315	223.2	8.37
May	216,070	28,409	245.3	9.54
June	257,727	28,449	302.0	11.38
July	276,646	28,951	308.2	12.21
August	250,930	25,122	322.2	11.08
September	249,144	29,956	277.2	11.00
October	107,852	29,938	116.2	4.76
November	164,441	29,559	185.4	7.26
December	136,382	29,442	149.4	6.02
Annual average = (a)	2,265,659	28,541	217.5	100.00
Minimum month = (b)	107,852		116.2	4.76
Percent nonseasonal, (b)/(a)			53.4	57.1
Percent seasonal, 100-(b)/(a)			46.6	42.9
Multifamily Sector				
January	3,675	139	852.9	10.22
February	2,201	137	573.8	6.12
March	3,650	139	847.1	10.15
April	2,865	153	624.2	7.97
May	2,700	148	588.5	7.51
June	2,876	146	656.6	8.00
July	3,115	147	683.6	8.66
August	3,487	145	775.8	9.70
September	3,124	144	723.1	8.69
October	3,013	146	665.7	8.38
November	2,683	149	600.2	7.46
December	2,564	147	562.7	7.13
Annual average = (a)	35,953	145	679.3	100.00
Minimum month = (b)	2,201		562.7	6.12
Percent nonseasonal, (b)/(a)			82.8	73.5
Percent seasonal, 100-(b)/(a)			17.2	26.5
Nonresidential Sector				
January	31,504	601	1,690.9	4.76
February	29,863	618	1,725.8	4.51
March	33,665	628	1,729.2	5.08
April	40,796	636	2,138.2	6.16
May	51,956	670	2,501.5	7.84
June	53,398	670	2,656.6	8.06
July	60,557	665	2,937.5	9.14
August	76,538	660	3,740.9	11.56
September	101,796	672	5,049.4	15.37
October	89,714	674	4,293.8	13.54

Month/Season	Monthly Use, 1000s Gal.	No. of Billed Accounts	Per Account Use, GPAD	Percent Annual Use
November	37,802	674	1,869.5	5.71
December	54,764	673	2,624.9	8.27
Annual average = (a)	662,353	653	2,777.2	100.00
Minimum month = (b)	29,863		1,690.9	4.51
Percent nonseasonal, (b)/(a)			60.9	54.1
Percent seasonal, 100-(b)/(a)			39.1	45.9

CASE #5
SEATTLE PUBLIC UTILITIES, WASHINGTON

Table S1. Reported 2008 Production and Sales Data for Seattle, Washington

Description	2008 Production/ Sales (CCF)	Number of Accounts	Per Account Use GPAD	Per Capita Use GPCD
Population served	649,286	--	--	--
Production, mgd	45,797	--	--	193.2
Total residential,	16,520,306	169,313	200.0	52.1
Single-family	11,252,896	160,630	143.6	--
Multifamily	5,267,410	8,683	1,243.2	--
Non-residential	11,001,448	13,461	1,674.9	34.7
Other: Fire service	16,556	4,075	8.3	--
Wholesale water to other agencies	29,752,271	121	503,899.0	--
Total metered sales	57,290,581	186,970	627.9	180.8

Table S2. Monthly Water Use in Single-Family Sector in Seattle in 2008.

Calendar Month	Water Sales, CCF	Number of Billed Accounts	Per Account Use GPAD	Percent Monthly Use	Allocated Water Use, CCF	Alloc. Per Account Use GPAD	Alloc. Percent Monthly Use
January	749,320	69,492	132.6	6.66	832,730	127.3	7.40
February	930,163	91,540	124.9	8.27	810,110	123.9	7.20
March	721,274	69,086	128.4	6.41	789,181	120.3	7.01
April	867,730	91,961	116.0	7.71	812,405	123.5	7.22
May	699,988	69,644	123.6	6.22	914,414	138.8	8.13
June	981,912	92,120	131.1	8.73	1,079,125	163.6	9.59
July	993,843	69,976	174.6	8.83	1,212,772	183.6	10.78
August	1,346,901	92,349	179.3	11.97	1,192,367	180.4	10.60
September	1,163,443	70,123	204.0	10.34	1,036,909	156.9	9.21
October	1,095,682	92,554	145.6	9.74	897,788	136.2	7.98
November	792,830	69,571	140.1	7.05	840,443	127.6	7.47
December	909,810	92,379	121.1	8.09	834,653	127.1	7.42
Total/average	11,252,896	160,630	143.6	100.00	11,252,896	142.4	100.00
Minimum	--	--	116.0	6.22	--	120.3	7.01
Nonseasonal	--	--	--	74.7	--	--	84.2
Seasonal	--	--	--	25.3	--	--	15.84

Table S3. Monthly Water Use in Multifamily Sector in Seattle in 2008.

Calendar Month	Water Sales, CCF	Number of Billed Accounts	Per Account Use GPAD	Percent Monthly Use	Allocated Water Use, CCF	Alloc. Per Account Use GPAD	Alloc. Percent Monthly Use
January	422,762	5,832	891.4	8.03	427,903	865.0	8.12
February	437,464	6,371	844.3	8.31	416,978	845.6	7.92
March	413,922	5,753	884.7	7.86	405,580	822.2	7.70
April	402,604	6,374	776.7	7.64	419,562	851.3	7.97
May	403,191	5,758	861.0	7.65	449,414	912.5	8.53
June	469,262	6,348	909.0	8.91	473,092	960.2	8.98
July	455,939	5,767	972.2	8.66	485,398	986.4	9.22
August	511,227	6,347	990.4	9.71	470,181	956.6	8.93
September	463,199	5,739	992.5	8.79	441,799	903.9	8.39
October	443,098	6,346	858.6	8.41	426,411	874.3	8.10
November	417,802	5,600	917.4	7.93	423,611	856.9	8.04
December	426,940	6,442	814.9	8.11	427,482	858.9	8.12
Total/average	5,267,410	160,630	892.8	100.00	5,267,410	891.2	100.00
Minimum	--	--	776.7	7.64	--	822.2	7.70
Nonseasonal	--	--	--	91.7	--	--	92.4
Seasonal	--	--	--	8.3	--	--	7.6

Table S4. Monthly Water Use in Nonresidential Sector in Seattle in 2008.

Calendar Month	Water Sales, CCF	Number of Billed Accounts	Per Account Use GPAD	Percent Monthly Use	Allocated Water Use, CCF	Alloc. Per Account Use GPAD	Alloc. Percent Monthly Use
January	822,779	8,010	1,263.1	7.48	827,880	1,187.6	7.53
February	848,759	9,244	1,129.0	7.71	803,156	1,158.2	7.30
March	791,221	7,784	1,249.9	7.19	790,461	1,138.5	7.19
April	781,421	9,293	1,034.0	7.10	839,888	1,211.0	7.63
May	807,779	7,775	1,277.5	7.34	938,533	1,350.7	8.53
June	962,574	9,267	1,277.3	8.75	1,066,554	1,529.7	9.69
July	1,021,206	7,853	1,599.0	9.28	1,163,065	1,668.8	10.57
August	1,261,229	9,311	1,665.6	11.46	1,112,770	1,599.4	10.11
September	1,108,596	7,802	1,747.2	10.08	970,701	1,407.9	8.82
October	972,658	9,298	1,286.3	8.84	856,194	1,249.8	7.78
November	828,893	7,464	1,365.6	7.53	810,085	1,157.6	7.36
December	794,333	9,483	1,030.0	7.22	822,163	1,164.0	7.47
Total/average	11,001,448	13,461	1,674.9	100.00	11,001,448	1,318.6	100.00
Minimum	781,421		1,030.0	7.10	--	1,138.5	7.19
Nonseasonal				85.2	--	--	86.2
Seasonal				14.8	--	--	13.8

Table S5. Historical Water Use in Single-Family and Multifamily Sectors in Seattle

Year	Single-Family Sector			Multifamily Sector		
	Water Sales, CCF	Billed Accounts	Use per Account, GPAD	Water Sales, CCF	Billed Accounts	Use per Account, GPAD
1994	13,834,558	144,989	195.5	6,954,628	118,307	120.5
1995	13,505,753	145,307	190.5	6,992,254	120,023	119.4
1996	13,111,222	145,476	184.7	7,020,046	121,739	118.2
1997	12,796,245	146,070	179.5	7,023,046	123,455	116.6
1998	13,463,537	146,586	188.2	7,114,778	125,172	116.5
1999	12,700,811	147,176	176.8	7,026,526	126,888	113.5
2000	13,171,348	147,849	182.6	7,091,105	128,604	113.0
2001	11,728,965	148,476	161.9	6,661,524	130,885	104.3
2002	12,103,025	149,131	166.3	6,386,505	133,165	98.3
2003	12,148,677	149,786	166.2	6,240,051	133,662	95.7
2004	11,827,349	150,524	161.0	6,126,420	135,671	92.5
2005	11,040,749	151,403	149.4	5,949,379	136,281	89.5
2006	11,517,353	152,623	154.6	5,996,091	138,306	88.8
2007	11,070,245	153,620	147.7	5,868,082	140,331	85.7
2008	10,733,747	155,581	141.4	5,786,559	144,930	81.8
Trend	-1.69	0.48	-2.16	-1.61	1.36	-2.95

CASE #6
PHILADELPHIA, PENNSYLVANIA

Table L1. System-wide Production, Consumption and Losses in Philadelphia in 2008

No.	Description	Calculations	MGD
	Water supply:		
1	System input		258.30
2	Correction for master meter and data handling error		7.59
3	Corrected system input	(1)-(2)	250.70
4	Minus exports		19.40
5	Water supplied (city only)	(3)-(4)	231.30
6	*Authorized consumption:*		
7	Billed metered		162.40
10	Unbilled unmetered		2.09
11	Registered authorized consumption sub-total	(7)+(10)	164.49
12	Customer billing over-statement adjustment		-6.02
13	Authorized consumption total	(11)+(12)	158.49
	Apparent losses:		
14	Customer meter inaccuracies		0.52
15	Unauthorized consumption		5.70
16	Systematic data handling error		12.77
17	Total apparent losses	(14)+(15)+(16)	18.99
	Real losses		
18	Reported & unreported leakage**		
19	Transmission main leaks/breaks		1.00
20	Distribution main leaks/breaks		1.76
21	Customer service lines		18.49
22	Hydrant & valve leaks		1.60
23	Measured leakage		1.92
24	Background leakage		29.05
25	Total real losses	Σ (19)…(24)	53.82
26	Total water losses	(25)+(17)	72.82
	Unavoidable annual real losses:		
27	Total pipeline mileage (miles)	3,207	
28	Average pressure (psi)	55	
29	Unit pipeline losses (gal./mile/day/psi)	5.4	
30	Unavoidable pipeline losses (mgd)	(27)*(28)*(29)	0.95
31	Number of service connections	547,932	
32	Unit connection losses (gal./service/day/psi	0.15	
33	Unavoidable connection losses (mgd)	(28)*(31)*(32)	4.52
34	Service line per connection (feet)	12	
35	Unit service line losses (gal./mile/day/psi)	7.5	
36	Unavoidable service line losses (mgd)	(28)*(34)*(35)	0.51
37	Total unavoidable real losses (mgd)	(30)+(33)+(36)	5.99
38	Nonrevenue water (%)	(26)*100/(5)	32.4
39	Real resource losses (%)	(25)+100/(5)	23.3
40	Infrastructure leakage index	(25)/(37)	9.0

Table L2. Historical Production, Consumption and Water Losses in Philadelphia

Description	2000	2001	2002	2003	2004	2005	2006	2007	2008	C.V.	2000-08 Trend
Service area population (1000)	1,671.6	1,653.3	1,640.8	1,629.4	1,622.7	1,653.3	1,656.2	1,642.6	1,660.5	0.9	-0.02
Water supplied from rivers, mgd	308.7	294.3	286.5	294.3	286.0	283.0	276.9	278.7	273.6	3.8	-1.26
Water system input, mgd	277.7	267.5	263.0	270.2	263.0	260.3	253.8	255.3	250.7	3.3	-1.09
Per capita water supplied, gpcd	184.7	178.0	174.6	180.6	176.2	171.2	167.2	169.7	164.8	3.7	-1.23
Billed consumption, mgd	185.8	181.7	178.2	183.4	176.9	176.9	177.0	169.5	175.8	2.7	-0.80
Unbilled unmetered, mgd	3.0	2.3	2.4	3.1	2.4	2.3	2.4	2.3	2.1	13.7	-2.93
Authorized consumption, mgd	188.8	184.0	180.6	186.4	179.3	179.2	179.4	171.8	177.9	2.8	-0.82
Per capita water consumed, gpcd	111.2	109.9	108.6	112.6	109.0	107.0	106.9	103.2	105.9	2.6	-0.77
Apparent losses, mgd	18.6	14.5	13.1	13.3	11.1	14.1	15.1	21.8	19.0	22.0	3.06
Real losses (leakage), mgd	70.1	68.9	69.2	70.5	72.6	66.9	59.2	61.6	53.8	9.5	-2.78
Non-revenue water, mgd	91.8	85.7	84.7	86.9	86.1	83.3	76.7	85.7	74.9	6.2	-1.72
Non-revenue water, %	33.1	32.1	32.2	32.1	35.4	34.6	32.2	36.3	32.4	4.9	0.62
Unavoidable real losses (mgd)	5.7	5.4	5.3	5.9	6.0	6.1	6.7	6.0	6.0	6.8	0.73
Infrastructure Leakage Index (ILI)	12.3	12.7	13.1	11.9	12.1	11.0	8.9	10.3	8.9	14.0	-4.41

Apparent losses include billing data error, unauthorized consumption, and customer metering inaccuracies.
Non-revenue water volume = unbilled, unmetered consumption + apparent loss + real loss.

CASE #7
TAMPA WATER DEPARTMENT, FLORIDA

Table T1. Annual Production, Sales and Billed Accounts Data for Tampa Water Department, Florida

Description	2004	2005	2006	2007	2008	C.V.	Trend %/year
Population served	605,073	655,993	647,131	656,837	657,313	3.5	1.65
Production (mgd)	28,721.8	26,924.8	27,725.50	29,761.7	27,725.5	3.9	-1.46
Total metered sales (mgd):	24,034.4	23,882.2	25,161.62	25,745.0	25,123.7	4.0	2.54
Total residential	14,867.9	15,462.4	16,386.02	15,982.1	15,666.3	3.7	1.43
Single-family res.	9,700.1	10,502.6	10,908.35	10,550.7	10,317.7	4.3	1.34
Multifamily res.	5,167.8	4,959.8	5,477.68	5,431.4	5,348.6	4.1	1.6
Commercial	5,357.6	5,491.0	5,522.23	5,444.2	5,334.9	1.4	-0.21
Industrial	1,416.6	1,181.3	1,328.57	1,312.6	1,190.6	7.8	-2.16
Governmental	282.5	3.7	3.01	131.4	57.1	122.4	--
Public							
Mixed nonresidential			1,257.03				
Wholesale deliveries		439.3	664.76	1,439.4	1,439.4	42.0	52.78
No. of billed accounts:	122,340	123,801	125,887	126,089	125,139	1.3	0.82
Total residential	109,612	111,105	112,886	113,455	112,257	1.4	0.69
Single-family res.	107,717	109,167	110,912	111,445	110,140	1.3	0.65
Multifamily res.	1,895	1,938	1,974	2,010	1,997	2.4	3.09
Commercial	11,936	11,926	11,969	12,056	11,956	0.4	0.14
Industrial	204	201	203	201	213	2.4	0.88
Governmental	11	12	257	18	252	120.0	--
Public	227	226	226	225	223	0.7	-0.4
Combined nonresidential	337	332	333	346	345	1.9	0.89
Wholesale deliveries	13	13	13	13	13	0.0	0

Table T2. Calculated Metrics Using the Number of Accounts and Population Served as Normalizing Variables

Description	2004	2005	2006	2007	2008	C.V.	Trend %/year
Per account metrics (gpad):							
Total residential	372	381	398	386	382	2.5	0.69
Single-family	247	264	269	259.4	256.7	3.3	0.63
Multifamily	7,471	7,012	7,602	7,403	7,338	3.0	-1.38
Commercial	1,230	1,261	1,264	1,237	1,223	1.4	-0.35
Industrial	19,025	16,102	17,931	17,892	15,315	8.8	-2.99
Governmental	70,361	845	32	19,993	621	164.8	--
Mixed nonresidential	--	--	0	--	--	--	--
Total nonresidential	213	1,005	10,342	482	1,051	50.4	0.79
Wholesale deliveries		92,582	140,096	303,345	303,345	42.0	52.78
Al sales/all accounts	538	529	548	559	550	2.9	2.6
Per capita metrics (in gpcd):							
Pr capita production	130.1	112.5	117.4	124.1	115.6	5.9	-3.25
Total sales per capita	108.8	99.7	106.5	104.1	110.8	4.5	0.8
Residential sales per capita	67.3	64.6	69.4	66.2	65.7	1.5	-0.24
Nonresidential sales per capita	32	33.3	34.3	34.2	33.4	2.4	1.12
Nonrevenue water (%)	16.3	11.3	9.3	15.8	9.4	84.3	-61.44

Table T3. Monthly and Seasonal Single-Family Residential Usage Rates in Tampa, Florida.

Month	2004	2005	2006	2007	2008
Per account use (gpad):					
January	221.2	290.0	271.4	275.9	264.5
February	329.3	277.9	257.3	250.7	319.4
March	289.2	264.2	233.0	226.6	240.4
April	322.2	272.7	256.3	247.8	237.0
May	239.7	264.2	325.0	249.1	212.5
June	228.9	265.0	320.1	294.5	266.3
July	194.1	272.0	316.2	289.5	291.1
August	235.4	234.9	234.0	303.8	315.5
September	240.4	257.9	247.7	241.1	225.6
October	194.2	238.7	223.3	225.3	220.8
November	235.2	278.6	275.9	243.9	238.7
December	240.4	249.2	272.6	244.9	273.1
Annual average	246.7	263.6	269.4	257.8	258.4
Minimum month	194.1	234.9	223.3	225.3	212.5
Percent nonseasonal	80.2	91.0	82.9	89.2	84.0
Percent seasonal	19.8	9.0	17.1	10.8	16.0

Table T4. Monthly and Seasonal Multifamily Residential Usage Rates in Tampa, Florida.

Month	2004	2005	2006	2007	2008
Per account use (gpad):					
January	6,833	8,340	7,950	8,074	7,940
February	8,833	8,263	7,534	7,494	7,878
March	7,478	7,509	6,874	7,034	6,928
April	8,255	7,787	6,942	7,251	6,849
May	7,305	7,534	7,808	7,876	7,062
June	7,763	7,554	8,065	7,759	7,754
July	6,735	7,935	8,430	7,222	7,573
August	7,650	7,423	7,199	6,764	6,856
September	7,393	7,715	7,629	7,583	7,235
October	6,675	6,732	6,830	6,666	7,306
November	7,691	8,064	8,230	7,340	7,524
December	7,263	7,423	7,784	7,840	7,203
Annual average	7,472	7,012	7,606	7,409	7,342
Minimum month	6,675	6,732	6,830	6,666	6,849
Percent nonseasonal	91.4	94.3	89.8	90.0	93.3
Percent seasonal	8.6	5.7	10.2	10.0	6.7

Table T5. Monthly and Seasonal Nonresidential Usage Rates in Tampa, Florida.

Month	2004	2005	2006	2007	2008
Per account use (gpad):					
January	2,007	1,816	1,496	2,806	1,417
February	2,365	1,839	1,640	1,596	1,495
March	2,084	1,658	1,398	1,277	1,260
April	2,114	1,748	1,593	1,569	1,432
May	2,034	1,782	1,634	1,518	1,368
June	1,816	1,824	1,812	1,705	1,579
July	1,873	1,831	1,676	1,486	1,414
August	1,783	1,676	1,544	1,588	1,380
September	1,985	1,572	1,543	1,436	1,295
October	1,385	1,725	1,578	1,375	1,456
November	1,565	1,821	1,724	1,404	1,277
December	1,711	7,423	1,739	1,620	1,374
Annual average	1,894	1,722	1,615	1,615	1,396
Minimum month	1,385	1,572	1,398	1,277	1,260
Percent nonseasonal	73.1	69.9	86.6	79.1	90.3
Percent seasonal	26.9	30.1	13.4	20.9	9.7