BMP Cost and Savings Study Update

A Guide to Data and Methods for Cost-Effectiveness Analysis of Urban Water Conservation Best Management Practices

June 2016 Update

California Urban Water Conservation Council

Conducted By:

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Preface to the Revision

This 2016 revision of the Cost and Savings Study is a stand alone revision for five topics addressed in prior versions of the study. These topics will be integrated into the Cost and Savings Study during the next revision to the study.

The following topics have been revised or added from the 2005 Study:

- Cooling Tower Controllers
- High Efficiency Toilets and Urinals
- Landscape Labeling and Education
- Pre-rinse Spray Valves
- Self-closing Faucets

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Much of the savings and cost information in this document has been published previously in other sources. Though we are grateful to build on this previous work, the errors that remain are our own.

COOLING TOWER CONTROLLERS: AN UPDATE ABOUT COSTS & SAVINGS

1. BACKGROUND

Central evaporative chilling systems are more efficient at rejecting heat than air-cooled alternatives. As a result, operating and accommodating the former requires less energy and less physical space. However, evaporative cooling systems also cost more and pose greater management and maintenance challenges. The calculus begins to shift in favor of central evaporative cooling systems when cooling demand is large and space for locating the equipment is limited. As a rule of thumb, this begins to occur when floor area exceeds 25,000 square feet and the building has multiple stories, or in large industrial settings requiring both air conditioning and cooling of production machinery.[1] Evaporative cooling systems invariably require a cooling tower to facilitate heat rejection, mainly through evaporation (of water), although convection can also play a limited role.

It is not unusual to encounter commercial sites where water demanded by the cooling tower end use rivals that of all other indoor uses. In others words, water used for cooling can approach as much as half of total indoor water use in many CII settings.

Because water circulating through a cooling tower is warm (up to 95°F) the dissolved solids can precipitate and form scale. The warmth also encourages biofouling and corrosion depending on the circulating water's acidity/alkalinity characteristics (pH). Evaporation of water, key to the functioning of cooling towers, raises the level of total dissolved solids (TDS) in the remaining circulating water, worsening many of the above problems. The crossflow of air and water in a cooling tower also causes contaminants in the air to be scrubbed and transferred to the circulating water, further intensifying its TDS load and modifying its pH. Finally, cooling towers being open, warm and wet invite bugs and birds.

The problems of scale, corrosion and biofouling can be controlled in many ways, including: (1) through chemical additives; (2) through periodic bleeding of a portion of the circulating water and replacement with higher quality makeup water (that is, water with fewer dissolved solids); (3) by running the circulating water through a side-stream filtration system to maintain its characteristics within design specifications; and (4) by filtering and softening the makeup water to improve its quality before introduction into the cooling tower. A cooling tower management program generally includes steps 1 and 2, but may be extended to include steps 3 and/or 4.[2]

The water that a cooling tower loses to evaporation cannot be reduced, since that is how heat rejection works, except, of course, by reducing cooling demand itself through better building insulation and design, but that is another question. Only the water lost to bleed (also called, blowdown), drift and leakage can be minimized. Drift refers to water lost as mist or tiny droplets suspended in the fan-blown

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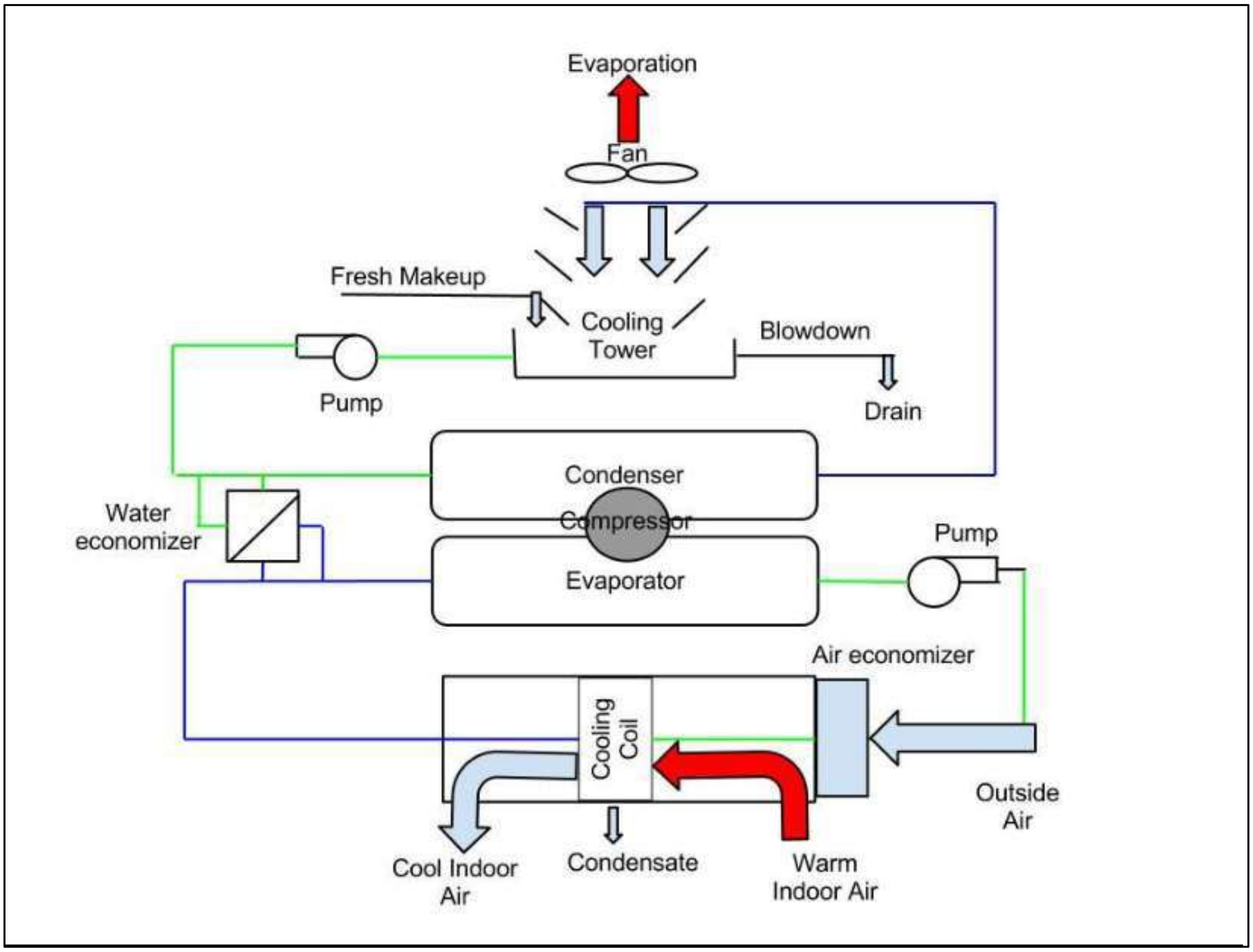
[1] Koeller, J. and J. Riesenberger, *Commercial-Industrial Cooling Water Efficiency*, a Potential Best Management Practice report prepared for the California Urban Water Conservation Council, 2005.

[2] US Department of Energy (FEMP), *Cooling Towers: Understanding Key Components of Cooling Towers and How to Improve Water Efficiency*, DOE/PNNL-SA-75820, 2011.

air exiting the tower. We discuss how to improve water use efficiency in greater detail later, but for now it is sufficient to note that zero liquid discharge technology (ZLD) already exists.[3] Whether ZLD is cost-effective, however, requires a case-by-case assessment.

Figure 1 shows the general operation of an air-conditioning system that uses a chiller for intermediate heat transfer and cooling tower for ultimate heat rejection.



SOURCE: The Environmental Defense Fund has several resources including YouTube videos on the topic of cooling tower efficiency (http://business.edf.org/resources/water/).

Figure 1 Illustration of a Typical HVAC System

Tight control of the chemistry is a pre-requisite for achieving high levels of water use efficiency in cooling tower operations. Because makeup water characteristics can change from day to day, automation of the chemical dosing, bleeding and makeup processes becomes paramount for achieving this tight control. Conductivity controllers (that monitor TDS loads in the circulating water), or the more

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[3] ProChemTech International Inc., *Zero Blowdown Technology (ZBT): Arizona Transportation Center*, (available at www.prochemtech.com). Also see Frayne, C. (*op cit.*) on the subject of ZBT and ZLD.

sophisticated pH/Conductivity controllers (that monitor pH levels in addition to TDS loads) have been available and have been promoted via water supplier rebates for a long time. The latest generation "smart" controllers, however, are more capable because they facilitate two-way communication, heretofore unavailable: Apart from monitoring and automating the key chemical dosing and other functions, "smart" controllers can also transmit key parameters to a distant operator, including fault alerts (e.g., valve and sensor malfunctions, leakage, etc.). An operator can also remotely adjust these "smart" controllers. The availability of real-time operational data, real-time fault indication, and remote control should in theory make these latest controllers all the more water efficient.

Other pathways to reducing potable water demand in cooling towers also exist: These include sourcing makeup water from recycled water,[4] reusing water lost to blowdown for other purposes (including as makeup water after cleanup within a ZLD system), and using cooling towers manufactured from HDPE plastic (or other less corrosive metals) instead of galvanized steel to eliminate corrosion risk, although HDPE towers cost more up front (HDPE towers also weigh less, simplifying the tower foundation's structural engineering).[5]

Nonchemical device-based (NCD) cooling tower management programs are also available, and were discussed by Koeller and Riesenberger *op cit.* in their 2005 Potential Best Management Practice report. NCD technologies, however, remain somewhat controversial.[6]

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[4] San Diego County Water Authority, *Technical Information for Cooling Towers Using Recycled Water*, 2009.
[5] Information about non-metallic cooling towers can be found here: www.deltacooling.com
[6] A few views about NCD technology can be found in the following publications:
Frayne, C., "Green Water Technologies and Resource Management for Water System Heat-Transfer Applications in the Built Environment," *Journal of Greenbuilding*, Vol. 5, No. 1, pp. 56-67, 2010 (available at www.awt.org).
California Department of Toxic Substances Control, E*valuation of Non-Chemical Treatment Technologies for Cooling Towers at Select California Facilities*, OPPGT Document No, 1220, 2009.
Kiester, T., "Non-Chemical Devices: Thirty Years of Myth Busting," based on material presented at the *International Water Conference*, 2004 (available at www.prochemtech.com)
Aquacraft, Inc., *Demonstration of Water Conservation Opportunities in Urban Supermarkets*, a report prepared for the California Department of Water Resources and the US Bureau of Reclamation, 2003.

2. HISTORY OF CODES AND REGULATIONS

The California Energy Commission has instituted new design standards for cooling towers that went into effect from January 1, 2014 as part of Title 24, Part 6 regulations (Building Energy Efficiency Standards).[7] These mandatory regulations apply to cooling towers with a rated capacity exceeding 150 tons in new buildings or in existing buildings seeking to replace their cooling towers. CalGreen (Title 24, Part 11) has not adopted standards for cooling towers that exceed corresponding Part 6 regulations, which means that CalGreen compliant buildings remain subject to requirements of Part 6, but nothing more stringent than Part 6. Title 24, Part 6's mostly prescriptive requirements read as follows:

> **Open and Closed Circuit Cooling Towers.** All open and closed circuit cooling tower installations shall comply with the following:
>
> 1. Be equipped with Conductivity or Flow-based Controls that maximize cycles of concentration based on local water quality conditions. Controls shall automate system bleed and chemical feed based on conductivity, or in proportion to metered makeup volume, metered bleed volume, recirculating pump run time, or bleed time. Conductivity controllers shall be installed in accordance with manufacturer's specifications in order to maximize accuracy.
> 2. Documentation of Maximum Achievable Cycles of Concentration. Building owners shall document the maximum cycles of concentration based on local water supply as reported annually by the local water supplier, and using the calculator approved by the Energy Commission. The calculator is intended to determine maximum cycles based on a Langelier Saturation Index (LSI) of 2.5 or less. Building owner shall document maximum cycles of concentration on the mechanical compliance form which shall be reviewed and signed by the Professional Engineer (P.E.) of Record.
> 3. Be equipped with a Flow Meter with an analog output for flow either hardwired or available through a gateway on the makeup water line.
> 4. Be equipped with an Overflow Alarm to prevent overflow of the sump in case of makeup water valve failure. Overflow alarm shall send an audible signal or provide an alert via the Energy Management Control System to the tower operator in case of sump overflow.
> 5. Be equipped with Efficient Drift Eliminators that achieve drift reduction to 0.002 percent of the circulated water volume for counter-flow towers and 0.005 percent for cross-flow towers.

Other codes that have attempted to promote cooling tower efficiency include the voluntary LEED program that awards points for installing a submeter on the makeup water line, sourcing makeup water from reclaimed water, and developing a comprehensive cooling tower management plan including automation of chemical dosing, bleed control and biofouling control.[8] Additional LEED points can be earned by opting for the ZLD option.

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[7] http://www.energy.ca.gov/title24/2013standards/index.html

[8] Browning, A. and S. McManis, "Using Automation to Green Your Water Treatment Program," *Facilities Engineering Journal*, pp. 14-15, Nov./Dec., 2010.
Browning, A. and M. Schnepf, "How Water Treatment Meets Green Building Objectives," *Facilities Engineering Journal*, pp. 21-23, Sep./Oct., 2013. (both papers available at www.chemaqua.com)

3. WATER SAVINGS

Savings Estimates from Engineering Formulas

Estimating water savings using pre-versus-post metered water consumption is preferable, but familiarity with engineering basics is also useful in practice.

Evaporation (E) accounts for the bulk of cooling tower water demand. To generate one ton-hour of HVAC cooling requires the evaporation of 1.8 gallons per hour of water (Koeller and Riesenberger, 2005, *op cit.*). When outside air temperature is below the circulating water's temperature, some heat rejection may take place via convection instead of evaporation (when air temperature is higher, obviously convection cannot occur). On an annual basis, cooling towers may reject 20-25% of total heat via convection, which should be subtracted from a tower's evaporative water demand. In other words, if 20% of heat rejection is assumed to occur through convection, then a ton-hour of HVAC cooling should only lead to an evaporative demand of 1.44 gallons per ton-hour. Water treaters should be consulted to pin down this estimate for a given service area.

The ratio of the maximum allowable TDS load in the circulating water to that in the makeup water is called cycles of concentration (C). Water treaters also examine the chemical constituents of the TDS load while determining maximum cycles of concentration. The relative proportion of one or more solids in the circulating and makeup waters may end up generating the upper limit on cycles of concentration instead of TDS. The determination of maximum permissible C is not so straightforward in practice;[9] however, thinking in terms of TDS is sufficient for describing the key engineering concepts.

The maximum allowable TDS limit is set by the water treater to prevent scale formation and to prevent corrosion. Once the TDS load in the circulating water reaches its upper limit, it becomes necessary to remove a portion of this contaminated water (blowdown or B), and to replenish with better quality makeup water (M). As long as the volumetric ratio of M/B is held equal to the cycles of concentration (C), the total TDS load in the circulating water cannot exceed the upper TDS set point. If characteristics of the makeup water were constant, it would be possible to control cooling tower chemistry simply by maintaining a volumetric ratio between makeup water and blowdown (proportional flow control). However, since makeup water chemistry is constantly changing, an automated system capable of measuring TDS loads in the circulating and makeup water, and of making adjustments to the makeup and blowdown rates, becomes necessary. That is where conductivity controllers come in. Before the advent of conductivity controllers, cooling tower chemistry was traditionally managed by maintaining a conservative proportionality between makeup and bleed water flow rates (so as to leave an ample margin of safety against changing makeup water characteristics), which is precisely what led to inefficient water use. Even more primitive versions of proportional control can occasionally still be found (e.g., in a mom-and-pop dry cleaning operation) where a manual bleed valve on the cooling tower

[9] An example (not necessarily endorsed by the CUWCC) of cooling tower management software can be found here: www.frenchcreeksoftware.com

sump is left open at a continuous trickle to maintain tower chemistry without any use of control automation.[10]

Total demand for makeup water can then be calculated as the sum of evaporation (E), blowdown (B), drift losses and leakage. Ignoring drift losses because they are more affected by cooling tower design than day to day management, and also leakage whose detection requires more than just better chemistry control, leads to the following two equations:

$$M = E + B \qquad \text{.................} \quad \text{(Eq. 1)}$$

$$M/B=C \qquad \text{.................} \quad \text{(Eq. 2)}$$

Combining these two equations leads to an estimate of total makeup water as a function of total evaporative demand and achieved cycles of concentration:

$$M=E\ (C/(C\text{-}1)) \qquad \text{.................} \quad \text{(Eq. 3)}$$

In Eq. 3, evaporative demand (E), driven by cooling demand, is a given, but total makeup water (M) used by the tower can be significantly reduced by increasing cycles of concentration through better control of the chemistry. At C=2, makeup water demand is 2 times evaporative demand, at C=4 it is 1.3 times evaporative demand, at C=6 it is 1.2 times evaporative demand, at C=10 it is 1.1 times evaporative demand.

The above discussion demonstrates two key points: (1) increasing cycles of concentration leads to rapidly diminishing returns in terms of water use efficiency after about C equal to 5 or 6; and (2) the most important determinant of cycles of concentration is makeup water quality. One way to determine the maximum cycles of concentration that a cooling tower operator can achieve using a "standard" chemical treatment program (meaning a program mostly focused on conductivity control), is through the use of the Langelier Saturation Index (LSI). The new Title 24, Part 6 regulations require new cooling tower operators to document this maximum achievable cycles of concentration using an LSI calculator provided by the California Energy Commission (CEC). Given the very uneven quality of makeup water across California, the maximum achievable cycles of concentration can vary between as high as 10 for the San Francisco Bay Area and as low as 2.8 for Orange County, California, as per the CEC's analyses.[11] As mentioned earlier, it is possible to exceed this maximum cycles of concentration through more advanced pH control programs. And, of course, blowdown can be minimized or eliminated by opting for side filtration systems or softening of makeup water. So, while the LSI based estimate of maximum cycles of concentration can be seen as a constraint—since the average cooling tower operator by and large still manages tower chemistry on the basis of conductivity alone—it is only a soft constraint.

So, how might one use the above framework to estimate savings from improved conductivity control? Let's work out a hypothetical scenario, say, for an office building with a 500 ton chiller providing air

[10] Personal communication, Mark Gentili, Los Angeles Department of Water and Power.

[11] California Energy Commission, *Cooling Tower Water Savings*, a Codes and Standards Enhancement (CASE) report prepared in support of the 2013 California Building Energy Efficiency Standards, 2011.

conditioning services. Assume the cooling tower is operating at 2 cycles of concentration with proportional flow control but that these cycles could be increased to 4 as per the LSI calculator with a “standard” chemical treatment program and an automated conductivity controller. Further assume that the air conditioning system operates 12 hours a day, 365 days a year, that 20% of the heat rejection takes place through convection instead of evaporation, and that only half of the cooling tower’s maximum evaporative capacity is utilized on average. Under these assumptions makeup water demand (M) at C=2 and C=4 can be calculated as follows using Eq. 3:

> $M_{C=2}$ = (500 tons x 12 hours/day x 365 days/year) x (1.8 gallons/ton-hour x 0.8 convection correction) x (0.5 capacity utilization factor) x (2/(2-1)) = 3,153,600 gallons/year or 9.68 acre-feet/year
>
> $M_{C=4}$ = (500 tons x 12 hours/day x 365 days/year) x (1.8 gallons/ton-hour x 0.8 convection correction) x (0.5 capacity utilization factor) x (4/(4-1)) = 2,102,400 gallons/year or 6.45 acre-feet/year
>
> Water savings from improved conductivity control = 3.2 acre-feet/year or *33% of base use*

Although the algebra shown above is not complicated, obtaining the correct inputs can be tricky. First, evaporative load is not so much a function of the cooling capacity of the tower, but the chillers that are part of the HVAC system. Very often cooling towers are oversized relative to the chillers to provide a margin of safety; the chiller capacity itself may also be oversized for the same reason. Or, a building may have multiple chillers, say, one chiller that runs most of the time to take care of the base load, and a second chiller that comes on during peak loads. To estimate water consumption correctly, it is necessary to account for the run time of each chiller separately. These sorts of inputs are not easily obtained with a high level of accuracy. Furthermore, these engineering calculations cannot take into account improved leakage and fault management that the latest generation of “smart” conductivity controllers can potentially bring about by signaling fault alarms to a remote operator. For all these reasons, submeters on both the makeup and bleed lines can be very helpful for managing cooling tower efficiency. And having reliable baseline usage data can make it that much easier to evaluate the impact of retrofits, or of other modifications to the chemical treatment regimen. Cooling tower operators already have strong incentives to submeter both the makeup and bleed lines—although many perhaps do not appreciate the benefit—because armed with makeup and blowdown data, they can claim a sewer charge credit for the evaporative load of a cooling tower. It is important, however, to select a flowmeter without moving parts (such as, magnetic flowmeters) for bleed-line applications because of continuous exposure to contaminated water.

Savings Results from Field Studies

What do field studies indicate about the potential for improving cooling tower efficiency in California? Several years ago a field study was undertaken to evaluate water savings potential in supermarkets, which was identified as a commercial subsector with one of the largest cooling demands (Aquacraft Inc., 2003, *op cit.*). The study retrofitted six supermarkets distributed across Southern California with Ph/conductivity controllers and flow meters, when prior to this almost all were using proportional flow control between the makeup and bleed water lines. Key findings of this study are as follows: First, NCD technologies did not work well and were replaced with chemical treatment programs. Second, in all cases metered baseline water use was much below what would have been predicted on the basis of rated cooling capacity. In these study sites, average utilization of the cooling capacity was only approximately 46%, something to keep in mind when working up an engineering-savings estimate. Third, pre-retrofit cycles of concentration ranged between 1.8 and 3.5 (for an average of 2.4), and these were successfully raised to between 5 and 6 with advanced chemical treatment including pH control. Fourth, pH control through the use of acids is hazardous, requiring a great deal of vigilance to make sure that the automated controls, valves, flow meters, timers, and sensors are all in sound working order. Pushing up cycles of concentration reduces the margin for error, which makes having controllers with 2-way communication ability all the more important.

The second field study that offers useful results is from Irvine Ranch Water District, California.[12] This study evaluates the feasibility of sourcing makeup water from reclaimed water. The study relied on "standard" chemical treatment for managing cooling tower chemistry (that is, acid was not used to control pH). The level and composition of key solids was similar between reclaimed water and potable water retailed by the Irvine Ranch Water District. With the use of a sophisticated conductivity controller and automated chemical dosing, it was possible to achieve 2.8 cycles of concentration in this study, which is almost exactly what the California Energy Commission's LSI calculator predicts for water found in that part of Orange County, California (California Energy Commission, 2011 *op cit.*). This suggests that the LSI calculator's predictions are both meaningful and achievable.

4. COSTS

Cooling tower controllers are available at different levels of sophistication. At the lower end are conductivity controllers that can measure conductivity and support the automatic operation of the fill and bleed lines and also of one pump relay for dispensing a scale/corrosion inhibitor into the circulating water. Such simple controllers can be found in small to medium sized applications, but they represent a very limited configuration. Having two pump relays, one to administer the scale/corrosion inhibitor and one to administer the biocide, the former on the basis of automated conductivity measurement, the latter on a proportional or timed basis, should be seen as a minimum configuration. To achieve automated and superior biofouling control requires the addition of an ORP (oxidation reduction potential) sensor and usually a third pump relay for automating the biocide and oxidizer feed into the circulating water. A pH/conductivity controller includes a pH sensor and a pump relay for dispensing acid into the cooling water. In other words, a sophisticated cooling tower management system would include three sensors (conductivity, ORP, pH) and four pump relays at a minimum. Inclusion of additional features, such as flow tracking of the makeup and bleed lines, fault detection, and 2-way communication capabilities further increases costs.

A basic conductivity controller with a single pump relay usually costs around $700. Such a controller is suitable for smaller towers where chemical treatment is limited to scale and corrosion control. To add biocides on a timed or proportional basis requires a controller with at least two pump relays; conductivity controllers with two pump relays and somewhat more sophisticated software algorithms

[12] Vargas, G., Sanchez, F. and F. Reinhard, *Irvine Ranch Water District Pilot Study of the Use of Recycled Water in Cooling Towers*, a paper presented at the Water Environment Federation's annual technical exhibition and conference (WEFTEC), Session #76, 2007.

cost roughly $1,400. Addition of an ORP sensor and a pump relay to more finely administer a biocide and an oxidizer raises the cost of the controller to approximately $2,400. Addition of a pH sensor and an additional pump relay for administering acid would bring the price up to roughly $3,400. Including 2-way communication abilities would further boost the cost of the controller system by roughly $1,000.

5. DEVICE LIFE

Good data to determine controller life are not available. Anecdotal evidence suggests that controllers themselves may last for roughly 10 years on average, but many of the other parts such as sensors, relays and alarms may need more frequent replacement. For assessing lifetime savings and cost-effectiveness, we recommend using an average life of 6-8 years, unless equipment manufacturers recommend otherwise.

6. THE CHALLENGE AHEAD

Water suppliers do not seem to have good data about baseline water use efficiency in the cooling tower end use (i.e., baseline cycles of concentration on average) because it is difficult to pin down this estimate without submeters on the makeup and bleed lines. Most small to medium sized cooling towers still do not have such submeters. A provisional answer, however, can be offered to the other related question—what is the upper limit on cycles of concentration given water quality in a given area through improved conductivity control?—by using the California Energy Commission's LSI calculator. Undertaking a full blown end use metering study is one way to improve baseline information. However, short of such an endeavor, suppliers can survey and collect other sorts of easily observed data to improve information about cooling tower efficiency in their service area. These include addressing the following types of questions:

- What is the relative proportion of cooling tonnage in a service area that relies on proportional flow control, conductivity control, pH/conductivity control, or pH/ORP/conductivity control?
- What are the characteristics of the controllers in use (type of sensors, number of pump relays, 2-way communication ability, etc.)?
- What proportion of cooling towers have makeup and bleed-line submeters? At what cycles of concentration do such cooling towers operate?
- What proportion of cooling towers source makeup water from recycled water?

Although answers to the above questions do not directly yield an estimate of baseline cycles of concentration, they nonetheless would go a long way in highlighting the size and scope of the remaining inefficiencies.

Education of cooling tower customers is also necessary to sensitize them to the full cost of operating a cooling tower, including water and sewer costs, energy costs, and chemical treatment costs. Management of cooling towers is often fragmented across multiple entities, which makes adoption of a holistic view difficult. Many operators focus inordinately on minimizing chemical treatment costs—the most easily observed cost component—which may not lead to the lowest operational cost overall.

Two trade associations can serve as useful sources of information about cooling tower design, operation and management. These are the Association of Water Technologies (www.awt.org) and the Cooling Technology Institute (www.cti.org). Water suppliers may wish to reach out to these associations for additional information and expertise.

HIGH EFFICIENCY TOILETS (HET) AND HIGH EFFICIENCY URINALS (HEU) IN RESIDENTIAL AND COMMERCIAL SETTINGS: AN UPDATE ABOUT COSTS & SAVINGS

1. BACKGROUND

Toilet water use was, and remains, the single largest indoor end use in the residential sector. Although comparable data are not available for the commercial sector, it is safe to surmise that in commercial settings with minimal process water needs (e.g., office buildings) water used in restrooms probably comprises an even greater proportion of total indoor use. As a result, a great deal of attention has been paid to improving water use efficiency in this plumbing fixture category.

2. HISTORY OF CODES AND REGULATIONS

California first attempted to improve toilet water use efficiency through the use of regulations during the late 1970s. Until then toilets used between 5 and 7 gallons per flush (gpf), and urinals between 1.5 and 5 gpf.[1] Effective January 1, 1978, California law required toilets sold in California to have a flushing volume below 3.5 gpf. In the early 1990s, two pieces of legislation further tightened California laws: Assembly Bill 2355 (passed in 1989) went into effect on January 1, 1992 requiring toilets installed in new or renovated buildings to use no more than 1.6 gpf, and Senate Bill 1224 (passed in 1992) went into effect on January 1, 1994 limiting the sale and installation of toilets and urinals in California to not exceed 1.6 gpf and 1.0 gpf respectively (with some exceptions). Many other states also followed suit during the 1980s and 1990s. This patchwork of state-specific regulations was rationalized when mandatory federal standards for toilets, showerheads, urinals and faucets were incorporated into the Energy Policy Act passed by Congress in 1992 (EPAct 1992): From the time this federal law spearheaded by the Department of Energy (DOE) came into force, tank type gravity fed toilets, tank type pressure assisted toilets (also called flushometer tank toilets), or flushometer valve type toilets (found mostly in commercial settings), were required to use no more than 1.6 gpf (ultra-low-flush toilets, or ULFTs). Blowout toilets could use up to 3.5 gpf. Wall and floor-mounted urinals were limited to no more than 1.0 gpf. EPAct 1992's requirements went into force on January 1, 1994 for tank type ULFTs and urinals, and on January 1, 1997 for flushometer valve type ULFTs.[2] EPAct 1992 also included labeling requirements to properly identify compliant from non-compliant fixtures.

Although the DOE has not amended its 1992 efficiency requirements (by efficiency we mean maximum allowable gpf requirements), it has periodically updated the testing and certification procedures that manufacturers have to follow so that DOE's product testing guidelines remain consistent with those

[1] D&R International, *Plumbing Fixtures Market Overview: Water Savings Potential for Residential and Commercial Toilets and Urinals*, a report prepared for the US Environmental Protection Agency, 2005.
California Energy Commission, *Staff Analysis of Toilets, Urinals and Faucets*, Report # CEC-400-2014-007-SD, 2014.

[2] Details about water closet and urinal federal standards and test procedures can be found here, respectively: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/29 and https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/30.

adopted (and refined over time) by the American Society of Mechanical Engineers (ASME) and the American National Standards Institute (ANSI).

EPAct 1992 required DOE to waive federal preemption of state law regarding plumbing-fixture efficiency if after 5 years of EPAct 1992's coming into force states wished to adopt more stringent standards than the federal ones, and ASME had by then not further tightened federal efficiency standards. Given this built-in waiver provision, and ASME's inaction, California legislature adopted Assembly Bill 715 (AB 715) in 2007 requiring manufacturers to start offering high-efficiency toilets (HET) with flushing volume under 1.28 gpf and high-efficiency urinals with flushing volume under 0.5 gpf from 2010 onward in the State. And from January 1, 2014, AB 715 required that water closets and urinals sold or installed in California be exclusively limited to HETs and HEUs. DOE also formally adopted EPAct 1992's waiver provision in late 2010.

HETs were first introduced in the US marketplace in 1999,[3] and are defined either as single-flush toilets with an effective flushing volume below 1.28 gpf, or dual flush toilets with an average effective flushing volume below 1.28 gpf (where the average is based on the composite of one full flush and two reduced flushes). There are several single-flush HET designs that use significantly less water than the permissible maximum (1.28 gpf), some as little as 0.8 gpf. Among dual flush designs there are some that use 1.6 gallons for a full flush and 1.1 gallon for a reduced flush, and other designs that use 1.28 gallons for a full flush and 0.8 gallons for a reduced flush. Dual flush designs are available in both tank type and flushometer valve type product lines; the latter is mostly found in commercial settings. In other words, AB 715's requirements apply to tank type gravity fed, tank-type pressure assisted, and flushometer valve type water closets: However, it exempts water closets found in certain institutional settings such as prisons, daycare facilities, historical sites, etc., or where blowout toilets are presently in use; it also exempts blowout urinals.

The requirements of AB 715 were incorporated into the California Plumbing Code (coming into force from July, 2011) and the California Green Building Code (coming into force more directly from January, 2013, although indirectly they have been in force since January 2011), thus becoming AB 715's enforcement vehicles. California building and plumbing codes, however, are listed under Title 24 of the California Code of Regulations:[4] These only apply at the point of installation in new construction or remodels of existing construction requiring a permit, not at the point of sale. Regulations influencing what can and cannot be offered for sale in California are covered by Appliance Efficiency Standards (Title 20 of the California Code of Regulations). This loophole was closed when AB 715's efficiency standards were incorporated into Title 20 regulations in 2015, coming into force on January 1, 2016. From 2016, only HETs and HEUs can be offered for sale in California (prisons and mental health institutions excepted). Although the sale and installation of non-HETs and non-HEUs has been banned in California since January 1, 2014 per the California Health and Safety Code, Section 17921.3 (which was used as a

[3] Koeller, J., *A Bit of Plumbing History*, prepared for the Alliance for Water Efficiency and the California Urban Water Conservation Council, 2008.
[4] California Code of Regulations can be found here: www.oal.ca.gov

temporary vehicle for implementing AB 715's requirements), this ban is likely to become fully effective from 2016 onward as Title 20 enforcement swings into full gear.

Although mandatory federal standards pertaining to toilet and urinal efficiency have not changed over time, the Environmental Protection Agency (EPA) has undertaken a voluntary labeling and testing program, WaterSense, analogous to the EnergyStar program, to promote water use efficiency in the US. To earn a WaterSense compliant certification, HETs and HEUs have to meet certain efficiency and performance requirements. The WaterSense specification for HETs was finalized in 2007 (which stimulated California's desire to adopt more stringent standards in 2007 via AB 715) and for HEUs in 2009. The efficiency requirements are designed to test that flushing volume is below a certain threshold (1.28 gpf in the case of HETs and 0.5 gpf in the case of HEUs) while the performance requirements test whether a toilet can clear a minimum test load (350 grams of cased or uncased soybean paste) in a single full flush. WaterSense's testing requirements piggyback on another voluntary product testing and reporting program (MaP)[5] that a consortium of 22 water suppliers first put in place in 2003 to assure that their incentive programs were steering customers only toward those toilet models that performed well, so as to avoid the consumer backlash that occurred with the first generation of ULFTs during the mid-1990s because of subpar performance. Ultra-low-flush urinals introduced after 1994 did not suffer performance problems to the same degree, so consumer backlash was less of an issue. Nonetheless, MaP and WaterSense test HEUs as well.

A key difference between the MaP and WaterSense testing protocols is that the former reports the maximum test load that a toilet make and model is able to clear in a single full flush, while the latter only certifies that a toilet make and model is able to meet WaterSense's efficiency and performance criteria. MaP testing thus offers consumers greater granularity with regards to toilet performance. Water suppliers today generally limit their incentive programs to MaP or WaterSense labeled toilets—several thousand makes and models have been tested according to either protocol. One important difference is that the EPA released WaterSense specifications for flushometer valve type commercial HETs only recently (December 2015), whereas MaP has already tested several hundred of these types of commercial HETs (albeit according to MaP's residential toilet testing protocol). MaP is now beginning to indicate which of their previously tested commercial flushometer HETs also meet the new WaterSense specifications.

Another piece of legislation—Senate Bill 407 (SB 407 enacted in 2009)—also has some bearing on calculation of savings from codes and regulations pertaining to toilets. Although SB 407 does not deal with toilet efficiency or performance, it requires all single-family homes with toilets using greater than 1.6 gpf to be retrofitted with water conserving fixtures (defined as fixtures compliant with current building or plumbing codes) by January 1, 2017, and multifamily and commercial buildings by January 1, 2019. SB 407 requires sellers or transferors of property to declare whether non-conserving plumbing fixtures are present at the time of sale or transfer, which constitutes this legislation's primary enforcement mechanism. In other words, in spite of SB 407's wording it is doubtful that saturation of

[5] Additional details about these certification programs can be found here: www.epa.gov/watersense and www.map-testing.com

toilets using greater than1.6 gpf will go to zero in 2017 for the single-family sector, and in 2019 for the multi-family and commercial sectors. More than likely, this legislation's effect will be more gradual over time depending on the rate at which property is sold or transferred in a given service area. Estimation of code-related savings shall need to account for the implications of this legislation.

Table 1 shows the current and future standards that apply to toilets and urinals offered for sale or installation in California. These standards are consistent with the California Plumbing Code and the California Green Building Code, except in the case of wall mounted urinals where the California Energy Commission saw it appropriate to aim for more stringent standards than either AB 715 or WaterSense currently specify. From January 1, 2016, wall-mounted urinals offered for sale in California will need to comply with the lower 0.125 gpf threshold (waterless urinals would also qualify). The reason for this is the rapid transformation of the HEU market. Almost a third of all WaterSense compliant HEUs available in the market can already meet the post-2016 Title 20 urinal standards, and that too at little extra cost compared to the 0.5 gpf HEUs.[6]

Two other features of the latest Title 20 standards are noteworthy. First, plumbing fixture manufacturers have to comply with these standards regardless of the equipment manufacture date (In the past, retailers have been allowed to continue to sell already-manufactured inventory, but not in this instance). Second, water closets offered for sale or installation in California after January 1, 2016 also have to meet a minimum waste extraction requirement of 350 grams of test material. The testing is to be performed according to the following protocol: ASME A112.19.2, which also forms a core component of WaterSense's and MaP's product testing programs.

Table 1 Standards Controlling Sale of HETs and HEUs in California

Plumbing Fixture	**Maximum Gallons Per Flush or Dual Flush Effective Flush Volume**	
	Sold or Offered for Sale on or after January 1, 2014‡	**Sold or Offered for Sale on or after January 1, 2016†**
Water Closets	1.28	1.28
Trough Type Urinals[1]	Trough Length (inches) ÷ 16	Trough Length (inches) ÷ 16
Wall Mounted Urinals	0.5	0.125
Other Urinals	0.5	0.5

‡ California Health and Safety Code, Section 17921.3

† Appliance Efficiency Standards (Title 20)

[1]The standard for trough type urinals is in terms of gallons per minute, not gallons per flush.

SOURCE: *2015 Appliance Efficiency Regulations*, California Energy Commission, CEC-400-2015-021

The Alliance for Water Efficiency's website offers additional valuable resources about the evolution of various codes and standards over time.

[6] California Energy Commission, *Analysis of Standards Proposal for Toilets and Urinals Water Efficiency*, Codes and Standards Enhancement Report, Docket # 12-AAER-2C, July 29, 2013

3. WATER SAVINGS

Residential Toilets

Back in the early 1990s water resource planners were often skeptical about the water savings potential of ULFTs. Complaints about subpar ULFT performance, possibly leading to double flushing, were behind the fear that perhaps switching to ULFTs may save no water at all compared to 3.5 gpf toilets, and much less than anticipated savings compared to the older 5-7 gpf toilets. Planners did not have much faith in water savings projections based on engineering calculations because the behavioral element (flushes per person per day) and relative mix of 5-7 gpf and 3.5 gpf toilets, both remained wild cards. These fears were finally laid to rest when a rigorous pre- versus post-retrofit statistical evaluation of a very large toilet retrofit program using customer billing histories was completed in Los Angeles and Santa Monica, California.[7] This study's statistical modeling approach overcame the need to make assumptions about behavior and pre-retrofit toilet characteristics to calculate savings, although fears were expressed at the time that estimated savings were biased upward because not only did they include savings from higher efficiency of the new toilets, but also savings from elimination of leaks plaguing the older removed toilets (more on this later). Although this large study demonstrated that toilet retrofits generate significant savings, it is not possible to continue to use these 20+ year old estimates. The current stock of toilets has become more efficient because of the triple effect of codes and regulations, natural turnover, and retrofit incentives offered by water suppliers since the early 1990s. Moreover, HETs being promoted through codes and current incentive programs are more efficient than ULFTs; prior retrofit programs targeted the latter, as did many earlier impact evaluations.

Although statistical model-based approaches require far fewer assumptions for evaluating retrofit programs, end-use metering studies have in fact become more common over the past two decades because of the latter's ability to allocate total household demand to each end use, which is also of great value to water planners. Using results from these end-use studies to project toilet retrofit savings requires reverting back to engineering calculations built up from assumptions. But, for two reasons, an engineering approach may be more reliable going forward than it was in the past. First, because of the tremendous effort that has gone into toilet efficiency and performance testing, water resource planners are far less worried about performance problems, such as, double flushing, drain line transport problems, etc.[8] Second, many end-use metering studies have become available giving us insights into flushing behavior and actual water use of different types of toilets, including the latest generation HETs. The one wild card that still remains, and was so in years past as well, is the average flushing volume of the installed stock of toilets at any given point in time, which because of natural turnover, incentive-based retrofit programs, and plumbing codes no longer skews toward 5-7 gpf toilets like it did in the early 1990s: To generate an estimate of baseline average flushing volume, water suppliers will need to rely on toilet turnover models assuming they are unwilling to fund end-use metering studies in their service area. And to evaluate savings from their retrofit programs, suppliers will need to institute a

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[7] Chesnutt, T.W., Bamezai, A. and C.N. McSpadden, *The Conserving Effect of Ultra Low Flush Toilet Rebate Programs*, a report prepared for the Metropolitan Water District of Southern California, 1992.

[8] The following webpage offers a good list of studies that evaluate efficiency and performance of HETs: http://www.allianceforwaterefficiency.org/1Column.aspx?id=878&terms=het

process by which the flush volume of old retrofitted toilets and urinals is determined and collected under the auspices of their rebate programs so that engineering estimates of savings are better grounded in reality (assuming suppliers are unwilling to undertake statistical model-based evaluations of their retrofit programs).

Let us first review findings from some of the key end-use metering studies (Table 2). These studies are separated into two groups: (1) end-use metering studies that evaluate the impact of retrofits on water use first by measuring baseline end use followed by post-retrofit end use, and (2) end-use metering studies that offer a single snapshot in time. The data lead to several conclusions.

Table 2 Summary of End Use Metering Studies

Retrofit Studies						
	Fieldwork Years	**Pre-Retrofit**		**Post-Retrofit**		
		Gallons per Flush	**Flushes per Capita per Day**	**Gallons per Flush**	**Flushes per Capita per Day**	**Type of Retrofitted Toilets**
SWEEP	1999-2000	3.9		1.3		Dual flush HETs
Seattle	1999	3.6	5.2	1.4	5.5	Mix of ULFTs and dual flush HETs
EBMUD	2001	3.9	5.1	1.5	5.6	Mix of ULFTs and dual flush HETs
Tampa	2002	3.5	5.0	1.6	5.0	Only ULFTs
Albuquerque	2009	2.3	n.a.	1.4	n.a.	Only HETs
Snapshot-In-Time Studies						
REUWS 1999	1996-1998	3.5	5.0			Mix of all types of toilets
CA Single Family	2006-2008	2.8	4.8			“”
REUWS 2015	2010-2013	2.6	5.0			“”
New Single Family Homes study	2009	1.4	n.a.			Mix of single flush and dual flush HETs

SOURCES:
Pacific Northwest National Laboratory, *The Save Water and Energy Education Program (SWEEP): Water and Energy Savings Evaluation*, a report prepared for US Department of Energy, 2001.
Mayer, P. et al., *Seattle Home Water Conservation Study*, a report prepared for Seattle Public Utilities and US Environmental Protection Agency, 2000.
Mayer, P. et al., *Residential Indoor Water Conservation Study*, a report prepared for East Bay Municipal Utilities District and US Environmental Protection Agency, 2003.
Mayer, P. et al., *Tampa Water Department Residential Water Conservation Study*, a report prepared for Tampa Water Department and US Environmental Protection Agency, 2004.
Aquacraft Inc., *Albuquerque Single Family Water Use Efficiency and Retrofit Study*, prepared for Albuquerque Bernalillo County Water Utility Authority, 2011.
Mayer, P. et al., *Residential End Uses of Water*, published by the American Water Works Research Foundation, 1999.
DeOreo, W. et al., *California Single-Family Water Use Efficiency Study*, a report prepared for the California Department of Water Resources, 2011.

DeOreo, W. B. et al., *Residential End Uses of Water Update*, published by the Water Research Foundation (forthcoming). DeOreo, W. B. et al., *Analysis of Water Use in New Single Family Homes*, a report prepared for the Salt Lake City Corporation and the US Environmental Protection Agency, 2011.

Predictably, studies where the fieldwork was undertaken later in time show that average flush volume has declined over time for all the reasons discussed above. Flushes-per-capita-per-day (fpcd) has remained fairly steady over time, however. In the earlier retrofit studies where replacement toilets included ULFTs, fpcd rises somewhat after retrofits because of performance problems with early-generation ULFTs. However, the retrofit study from Tampa, the original REUWS study published in 1999, the California Single Family study, and now the 2016 REUWS update show that toilet flushing behavior has remained fairly steady at roughly 4.8-5 flushes per capita per day. Scanning the average flush volume data show that among snapshot-in-time studies where only HETs were present in the metered sites (New Single Family Homes Study) , or only HETs were used as replacement toilets during the post retrofit phase (SWEEP and Albuquerque), HETs used approximately 1.3 to 1.4 gallons per flush. This is a little higher than their rated volume (1.28 gpf), but close enough to give us confidence that if savings are calculated on the basis of rated flushing volumes and a behavioral assumption of 5 flushes per capita per day, the savings estimate should be quite robust for planning purposes.[9] A key unknown remains the average flushing volume of the installed stock of toilets in a service area, which will need to be estimated via turnover models, taking into account past incentive programs, codes and regulations and natural turnover, or by undertaking end-use metering studies.

A couple of recently completed studies have tried to compare savings derived from engineering calculations with those derived from analysis of pre- versus post-retrofit billing data.[10] Both have found engineering estimates to be lower. The engineering estimates were calculated from the difference in rated flushing volumes of old and new toilets and assumptions (well grounded, by now) about per-capita flushes per day. The billing data analysis compared quarterly use before and after the retrofit without fitting statistical models to control for other factors, such as weather. The use of statistical models may have narrowed the gap between the two estimates, but the authors of these studies think the gap is better explained by misattribution of leak reduction to the toilet retrofits and possibly performance problems with the older replaced toilets leading to unnecessary extra flushing. The former should not be counted as a program benefit because leakages will likely re-emerge with age. However, if newer

[9] Although end use metering studies can identify and separate leaks, they can sometimes run into difficulty separating water use associated with concurrent events, such as toilet tank filling and hand washing. Improvements in software and algorithms has reduced the salience of this issue somewhat over time, but probably has not eliminated the problem altogether. For an early discussion, see: Koeller, J. and Gauley, W., *Effectiveness of Data Logging Residential Water Meters to Identify and Quantify Toilet Flush Volumes: A Pilot Study*, prepared for the Metropolitan Water District of Southern California, 2004.

[10] Koeller and Company and Veritec Consulting Inc., *Evaluation of Water Use Reduction Achieved through Residential Toilet Fixture Replacements*, a report prepared for Elsinore Valley Municipal Water District and Eastern Municipal Water District, 2011.

Koeller and Company and Veritec Consulting Inc., *Evaluation of Water Use Reduction Achieved through Residential Toilet Fixture Replacements: Mendelsohn House San Francisco*, 2011.

toilets indeed have fewer performance problems because they are fundamentally better designed, that is a locked-in benefit that should be attributed to a retrofit program.

The key point that emerges from the studies that have been reviewed here is that there is no perfect evaluation method. Therefore, exclusive reliance on a single savings estimation method is not advisable. Engineering estimates, if based on real data about flushing volumes of old and new toilets, may generate conservative estimates that are adequate for planning purposes. However, field studies using alternative methods should also be performed from time to time to ground-truth such estimates.

Commercial Toilets and Urinals

Although several field studies have evaluated water savings from HET and HEU retrofits in commercial settings, their results usually only report what a certain program achieved in retrospect but not how to use the results to either project savings from future incentive programs or estimate remaining conservation potential. An old study commissioned by the Council to address savings from ULFT retrofits in commercial settings is no longer usable because savings are expressed per retrofitted toilet, but the installed stock of toilets no longer skews toward the 5-7 gpf toilets like it did during the early 1990s. Projecting savings from current and future HET retrofits based on this early study's results may generate very biased results.[11]

While many analyses have been undertaken to assess savings potential of HET and HEU retrofits in the commercial sector (D&R International, 2005, *op cit.* and California Energy Commission, 2013, *op cit.*), these have relied mostly on engineering estimates built up from assumptions. Unfortunately, not much guidance can be provided here except to repeat the key assumptions made by these prior studies. First, these studies assume that female inhabitants flush a toilet 3 times in a working day, whereas male inhabitants flush a toilet 1 time and a urinal 2 times in a working day. These assumptions appear to be more appropriate for office-like settings with a steady workforce. For other settings with a transient throughput of people, such as airports, retail stores, etc. some guidance is available from the US Green Building Council, but the reliability of their assumptions remains unclear.[12] While working up an engineering estimate, the number of working days should be allowed to vary by type of commercial site. Office buildings are assumed to be operational for 260 days a year, but many other types of commercial sites operate every day. And finally, to work up an engineering estimate the analyst needs to know the specification of the old toilets and urinals being removed, and similar information for the new toilets and urinals taking their place. An engineering approach requires collecting a fair amount of detailed information from each commercial participant in a retrofit program since the commercial sector is so heterogeneous. The need to improve our information about plumbing fixture prevalence and flushing behavior for different types of commercial sites is quite acute.

4. COSTS

The retail cost of residential tank type HETs falls roughly between $100-$2,000 dollars (before taxes and installation). However, the vast majority of the available models fall within a much narrower range

[11] Hagler Bailly Services, *The CII ULFT Savings Study*, a report prepared for the California Urban Water Conservation Council, 1997.

[12] US Green Building Council, *Water Use Reduction Additional Guidance*, Version 7, July 6, 2012.

($200-$600) with several WaterSense labeled residential HETs with high (MaP reported) performance scores being available at list prices between $200 and $250.. These cost data are derived from product listings advertised on websites of big box retailers, such as Lowes and Home Depot combined with expert judgement.[13] Bulk purchase of toilets by a water supplier for a direct install program would reduce these estimates considerably. There is also likely a cost difference between toilets favored by owner-occupied single-family residences and renter-occupied apartments, which may need to be factored into the design of incentive programs.

Flushometer valve type HETs for commercial settings are usually more expensive, averaging approximately $700 for valve/bowl combined units,[14] where the valve is sensor operated, thus "hands free." Sensor operated valves are increasingly preferred in commercial applications for reasons of hygiene. It has led to concerns about "phantom flushes," which merits monitoring and greater research although manufacturers claim that they have considerably improved the design of sensor-operated valves to overcome this problem. Manually operated flushometer valves are also still available and cost more in the range of $500 for a manual valve/bowl combination.

The average retail cost of WaterSense approved 0.125 gpf urinals is estimated to be $277, $614, and $884 for fixtures, valves, and fixture-valve systems, respectively (California Energy Commission, 2013, *op cit.*).

5. DEVICE LIFE

Prior studies have generally assumed that the average life of a residential toilet is 25 years, which translates into a natural turnover rate of 4% per year. Data are available to support a 25 year average life assumption {add link to "natural turnover" section in wiki} for residential toilets. Very little is known about the average life of toilets and urinals in commercial settings. Some studies have assumed an average life of 20 years (D&R International, 2005, *op cit.*), while others have assumed an average life of 12 years (California Energy Commission, 2013, *op cit.*). More research is required to tighten this large range.

6. THE CHALLENGE AHEAD

Toilets have been extensively studied in the residential sector. The efficiency and performance reporting programs that have been put in place since 2003 have made it possible to have greater confidence in water usage of HETs, much more so than was the case with ULFTs. The principal hurdle in estimating savings from retrofit programs, or in estimating remaining conservation potential in the residential toilet end use category, remains knowledge of the average flushing volume within the installed stock of toilets at any given point in time. Toilet turnover models that account for past and current codes, natural turnover, and the effect of rebate programs can help in estimating this key parameter, but it is necessary to periodically ground-truth these turnover model-based results using household surveys or end-use metering studies.

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[13] Personal communication with John Koeller.

[14] US Environmental Protection Agency, *WaterSense Draft Specification for Flushometer-Valve Water Closets Supporting Statement*, Version 1.0, 2014.

The commercial sector, on the other hand, poses greater challenges. Here all the key inputs required to estimate savings remain shaky, including plumbing fixture prevalence, flushing behavior, and device life. The greater heterogeneity of the commercial sector further complicates matters, requiring greater granularity than is necessary in the residential sector.

Although water suppliers do undertake saturation surveys and end-use metering studies from time to time, it would be better to have an institutionalized framework for implementing residential and commercial saturation surveys at a predetermined frequency, say, every 4 years. The California Energy Commission's Residential Appliance Saturation Survey perhaps could serve as a model for mounting such an effort.

A FRAMEWORK FOR IMPROVING SUSTAINABLE LANDSCAPE MESSAGING

Introduction

In order to reach future per-capita water demand targets, water suppliers recognize the need to aggressively turn their attention to improving outdoor water use efficiency as their legacy indoor conservation programs plateau in terms of effectiveness. Water conservationists are also aware of the multiple ways in which landscape design impinges on other environmental goals beyond water-use efficiency.

The Council has been playing a leading role in promoting steps that would transform the choices customers make while installing or modifying their landscapes, discussed in a 2015 report entitled, *Sustainable Landscaping: Market Transformation Framework*. The phrase "sustainable landscaping" refers to "an integrated, holistic, watershed based approach to landscape design, construction, and maintenance that transcends water-use efficiency to reflect a site's climate, geography, and soils to address the related benefits of cost savings, runoff reduction, green waste reduction, pesticide and fertilizer reduction, habitat improvement, and energy/Green House Gas reduction."

The Council has identified nine key barriers that have prevented landscape designs from moving in a sustainable direction, including:

1. Lack of "Watershed Approach"
2. Lack of Unified Leadership, Collaboration and Outreach
3. Inadequate Economic Incentives
4. Fear of Breaking Social Norms and Culturally Established Aesthetics
5. Ineffective, Inconsistent Messaging/Branding/Marketing
6. Lack of High Quality, Required Workforce/Public Education and Training
7. Lack of Consensus on Quantification and Comparison of Different Approaches
8. Insufficient Codes, Standards, Regulations and Enforcement
9. Too Many Unknowns

The present paper focuses only on one identified barrier, item #5, pertaining to ineffective landscape messaging, branding and marketing. The intended audience of messaging that item #5 refers to is the average residential customer or property manager, not so much the professional landscaper. Inadequacies in the education, training and certification of the latter have also been identified as a barrier (item #6 above), and certainly there can be overlaps between programs targeted at the homeowner versus the professional landscaper. The present paper, however, focuses mainly on the residential customer or property manager.

Overview of Approaches to Messaging

Water suppliers have used many of the following approaches to spread the sustainable-landscaping message among their customers, including:

1. Use of demonstration gardens and redesigned landscapes at municipal properties to showcase the attractiveness of landscapes that maximize native vegetation, permeable hardscapes, and other water entrapment features that help to minimize runoff
2. Developing and offering guidelines in the form of downloadable documents to aid in the design and upkeep of sustainable landscapes
3. Showcasing the work of certified green-industry professionals, especially those that specialize in the design and installation of sustainable landscapes
4. Promoting branding strategies at retailers of gardening equipment and nurseries to influence customer purchasing decisions in favor of low water-using plants
5. Offering landscape education classes to residential customers and residential property managers
6. Offering landscape retrofit incentives and adopting inclining or budget-based rate structures to promote outdoor water-use efficiency

Not all of the above approaches are directly related to messaging (e.g., financial incentives and conservation-oriented rate structures are identified as barrier #3 per the Council's list mentioned above), but they do belong in the overall package of messaging measures. The impact of pro-sustainability messaging is probably heavily conditioned by pocketbook and other broader environmental concerns, which play an influential contextual role in the background.

1. Use of Demonstration Gardens

There are many examples of dedicated sites being used to showcase the design of low water-using landscapes, and these can serve as useful tools for educating customers about the virtues of sustainable landscaping. Increasingly, water suppliers are also experimenting with using municipal properties distributed across their service area to showcase sustainable landscapes. The presence of such resources can be advertised through the water supplier's website[1] and through education programs targeted at homeowners, property managers, and schools. The demonstration gardens can also be used to disseminate literature about sustainable landscaping, and about useful resources for locating certified landscape design professionals and landscape equipment retailers and nurseries.

2. Develop and Offer Sustainable Landscape Design Guidelines

Water suppliers in concert with other stakeholders have promoted the development of sustainable landscape guidelines for some time. The focus and scope of these guidelines has evolved over time. While the earlier versions did promote environmental benefits over and above water-use efficiency, they tended to do so in a piecemeal fashion depending on local concerns. For example, coastal areas perhaps gave greater credence to the benefits that accrue from storm runoff reduction ("Offshore

[1]The following two links offer examples: (1) http://www.ieua.org/use-water-wisely/landscaping/ and (2) http://ci.santa-rosa.ca.us/departments/utilities/conserve/Pages/default.aspx

Friendly Garden" initiative of the Surfrider Foundation). On the other hand, fire prone areas perhaps emphasized reduction in fire risk as a key benefit accruing from native vegetation-based landscapes, etc.[2] However, there seems to be greater recognition that these guidelines must demonstrate sustainable landscaping's full panoply of environmental benefits for maximizing their educational value. The latest guidelines[3] now emphasize a watershed approach and discuss in a comprehensive manner all the environmental benefits, including:

- Reduced energy use and consequently reduced Green House Gas emissions
- Reduced pesticide and fertilizer use
- Reduced irrigation runoff leading to less polluted rivers and other water bodies
- Reduced storm runoff through improved soil infiltration and less polluted storm runoff because of improved bio-filtration of precipitation
- Reduced green waste going to landfills
- Reduced natural fire risk and improved post-fire soil stability in erosion-prone areas
- Protection (and often creation) of wildlife habitat

This trend toward greater comprehensiveness should be encouraged.

3. Showcasing the Work of Certified Green Industry Professionals and Homeowners

A comprehensive messaging plan should consider including a component that showcases the work of certified green industry professionals that follow sustainable landscaping guidelines in their work practice. Sonoma County offers a useful template for how this can be done in a way that invites participation instead of resistance from the green industry. Water suppliers in Sonoma County have partnered with a volunteer organization called the Master Gardner Program of Sonoma County,[4] whose volunteers are trained and certified by the University of California. Homeowners can request a free consultation with these certified volunteers when considering modifications to their landscape. Apart from offering an unbiased evaluation, these volunteers are also able to recommend WaterSense qualified professionals and local nurseries to homeowners that are considering making modifications to their landscape.

Promoting local nurseries that specialize in native, low water-using vegetation, and providing links on their website to help locate certified green industry professionals are two steps that just about all water suppliers can take to bring this information to the attention of their customers.[5]

Finally, homeowners with sustainable landscape designs may be willing to have their property pictures with location address posted on the water supplier's website. If so, this can become yet another

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[2] http://www.ieua.org/wp-content/uploads/2014/04/FireWiseLandscapes.pdf

[3] *Russian River-Friendly Landscape Guidelines*, developed with the assistance of several stakeholders and available at (www.rrwatershed.org) and *San Diego Sustainable Landscape Guidelines*, also developed with the assistance of several stakeholders and available at (http://www.watersmartsd.org/news/sustainable-landscape-guidelines)

[4] www.sonomamastergardeners.org

[5] An alternative template to the Sonoma County approach can be found here: http://watersavinggardenfriendly.com/

messaging technique for showcasing the ways available to customers for improving their existing landscapes.

4. Promote Branding Strategies at Nurseries

It is quite common now, especially because of the recent drought, to walk in a nursery and find several aisles devoted to low water-using plant species. Often labels, such as, “Water Wise,” “California Friendly,” or “Smart Planet” are used to advertise these plant species. The “Smart Planet” label was pioneered by Home Depot in partnership with water suppliers, and has continued to gain in popularity. These branding efforts while a step in the right direction need to be linked with broader attempts at customer education. Some efforts are underway to use nurseries as dissemination points for brochures and literature about sustainable landscaping, a type of message integration that is probably necessary to improve the impact of these branding efforts.

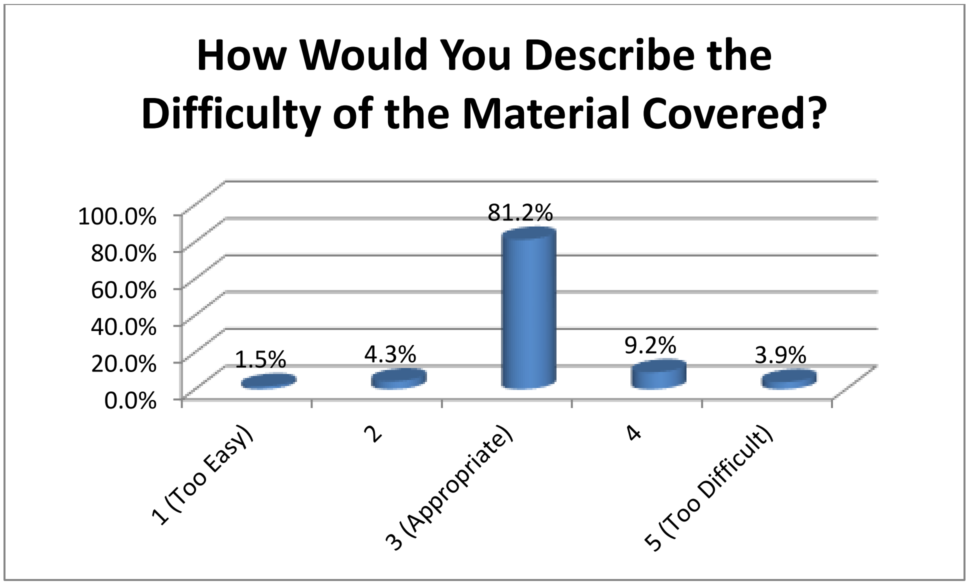
5. Offer Landscape Education Classes

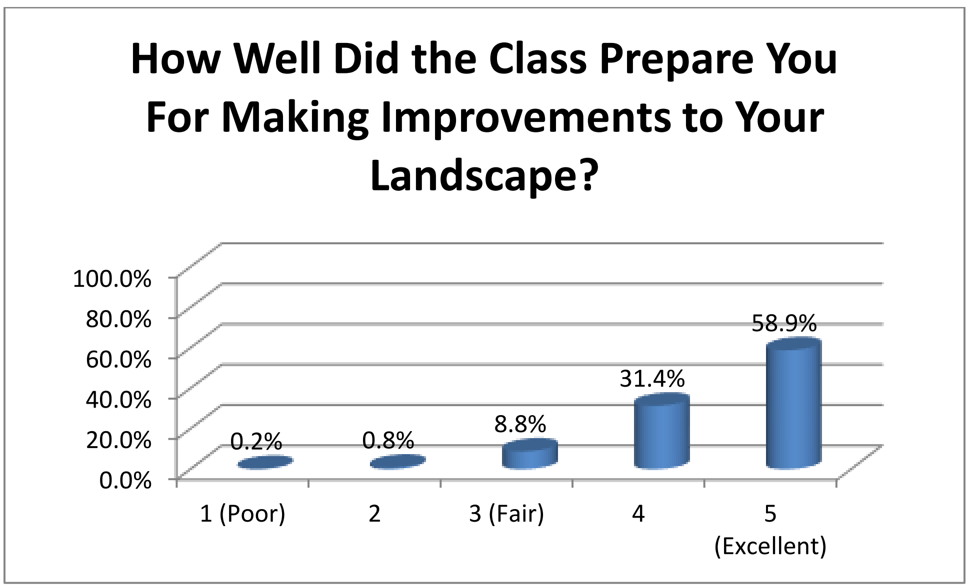
Many water suppliers offer free landscape education classes (online and in-class) to their residential customers. The Metropolitan Water District (MWD) of Southern California’s California Friendly Landscape Training (CFLT) program is one example of a large scale effort at customer education.[6]

Being the largest education program of its kind in California, we requested MWD for participant feedback regarding their CFLT program, since each participant fills out an evaluation questionnaire at the end of the course. Slightly over 8,000 individuals had participated in the CFLT program between summer of 2013 and fall of 2015. Figure 1 shows tabulations of responses for three of the key questions included in the course evaluation questionnaire. These data suggest that CFLT participants found the material both comprehensible and useful and are willing to modify their landscapes to conform to the sustainability guidelines they learned about during the course.

It may also be beneficial to target small mom-and-pop landscape maintenance businesses with education programs that are designed mainly for the residential customer because such small businesses often fall through the cracks of the more professional-oriented training and certification programs.

[6] http://www.bewaterwise.com/gardenspot.html


How Would You Describe the Difficulty of the Material Covered?
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
1.5%
4.3%
81.2%
9.2%
3.9%
1 (Too Easy)
2
3 (Appropriate)
4
5 (Too Difficult)


How Well Did the Class Prepare You For Making Improvements to Your Landscape?
100.0%
80.0%
60.0%
40.0%
20.0%
0.0%
0.2%
0.8%
8.8%
31.4%
58.9%
1 (Poor)
2
3 (Fair)
4
5 (Excellent)

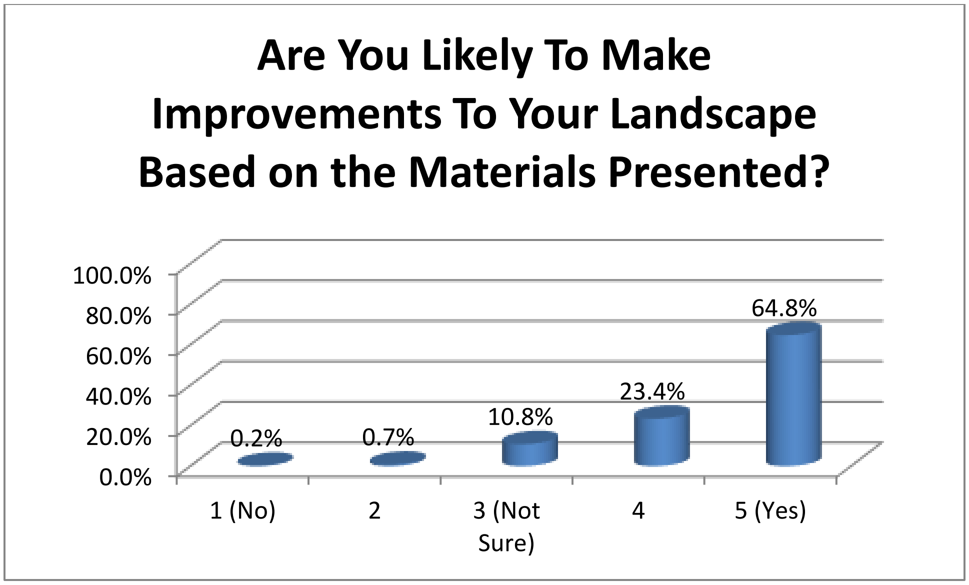


Figure 1 Tabulations of CFLT Student Evaluations

6. Offer Landscape Retrofit Incentives and Inclining Rate Structures

It is self-evident that to create a fertile ground for landscape messaging to work, especially after the current drought is declared over, it will be necessary to continue to use economic incentives to encourage customers to look for alternatives to their current landscapes. The use of carrots (turf removal rebates) and sticks (inclining rates) will likely both be required to help customers realize that there is a business case to be made for why investing in sustainable landscapes is cost-effective for them in the long run.[7]

The Property Assessed Clean Energy (PACE) program (known as the Home Energy Renovation Opportunity (HERO) program in California), a program that provides 100% upfront financing for energy efficiency improvements, which the property owner then repays over several years through assessments added to their property tax bill (transferable to a new owner at time of sale), has also now been extended to water-use efficiency, including drought-tolerant landscapes. Water suppliers can make their sustainable landscape messaging more effective by promoting the use of this newly available financing mechanism.

[7] A recent report entitled *Investing in Landscape Water-Use Efficiency: A Companion Guidebook to the Landscape Water Management Return on Investment Calculator*, is an example of products being developed to help make the business case for investing in sustainable landscapes. This report and calculator were developed by a consortium of stakeholders, with the City of Santa Rosa and the Municipal Water District of Orange County in the lead. Copies of the report may be directly requested from either lead agency.

The Challenge Ahead

A lot of experimentation is taking place at present across different water suppliers to develop a landscape messaging approach with long-run transformative power. It will be necessary to periodically review these efforts in order to distill best practices that can then be scaled to a statewide level.

COMMERCIAL PRE-RINSE SPRAY VALVES: AN UPDATE ABOUT COSTS & SAVINGS

1. BACKGROUND

Commercial pre-rinse spray valves (PRSV) are handheld spraying devices with a normally-closed valve that can be squeezed open by pressing a lever. Pre-rinsing involves manual spraying with hot water under pressure to remove loose or sticky food residue from food service items, such as, plates, dishes, utensils, and so on, before final cleaning in a commercial-grade dishwasher. PRSVs are often marketed along with dishwashers designed for commercial and institutional use (in very small scale commercial settings the entire cleaning process may be performed by a PRSV with no dishwasher present). Since PRSVs use a lot of water (usually more than the dishwasher), that too hot water, improved efficiency in this end use has received considerable attention from both energy and water utilities that have often partnered to implement direct-install PRSV retrofit programs.[1] PRSV design, however, must balance minimized water and energy use with its ability to remove food residue. Failure to meet the latter goal only increases pre-rinse times (or rejection of new equipment altogether), which in turn lessens achieved water and energy savings.

2. HISTORY OF CODES AND REGULATIONS

California water suppliers first attempted to improve PRSV efficiency under the auspices of CUWCC's Pre-Rinse Spray Head Distribution Program in 2002.[2] PRSVs in the past used over 3 gallons per minute (gpm) on average, with some models using over 5 gpm. Working in concert with the Food Service Technology Center (FSTC), which undertook laboratory testing of PRSVs available in the market back in the early 2000s, PRSVs with flow rates under 1.6 gpm but a different spray pattern (knife-like) were found to be as effective as non-efficient PRSVs (with a showerhead-like spray pattern). Effectiveness was measured in terms of time required to rinse tomato paste off of a plate ("cleanability"). This lower flow rate of 1.6 gpm then became the standard that was used by CUWCC to promote efficient PRSVs through rebate programs, but non-efficient PRSVs still remained available for sale in California.

The availability of PRSVs became restricted nationwide to models that use no more than 1.6 gpm when federal efficiency standards were extended to commercial pre-rinse spray valves by the Department of Energy (DOE) via the Energy Policy Act of 2005 (EPAct 2005), coming into force on January 1, 2006.[3] The

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[1] Additional details can be found here: http://www.allianceforwaterefficiency.org/1Column.aspx?id=992&LangType=1033&terms=pre-rinse+spray+valves

[2] SBW Consulting, Inc., *Evaluation, Measurement and Verification Report for the CUWCC Pre-Rinse Spray Head Distribution Program*, a report prepared for the California Urban Water Conservation Council, 2004.
SBW Consulting, Inc., *Impact and Process Evaluation Final Report for California Urban Water Conservation Council 2004-05 Pre-Rinse Spray Valve Installation Program (Phase 2),* a report prepared for the California Urban Water Conservation Council, 2007.
Tso, B. & J. Koeller, *Pre-Rinse Spray Valve Programs: How are They Really Doing?,* 2005.

[3] Details about federal PRSV standards can be found here: https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/54

federal standard included in EPAct 2005 does not include a test for performance, however, just efficiency; this is expected to change in the near future. The DOE has not waived federal preemption of state law in the case of PRSV efficiency standards, so California's Appliance Efficiency Standards (Title 20 of the California Code of Regulations)[4] have to remain consistent with federal law, which means that PRSVs using up to 1.6 gpm can be sold or offered for sale in California. However, California's Title 20 regulations for PRSVs do include a performance component (a PRSV must be able to remove food residue from 60 plates in 30 seconds a plate or less, on average; the "cleanability" test originally developed by the FSTC). The California Plumbing Code and the Green Building Code (Title 24 of the California Code of Regulations) are consistent with the federal standard in terms of efficiency. However, since it is Title 20 regulations that control what can be offered for sale in California, PRSVs installed in buildings subject to the Plumbing Code or Green Building Code also become subject to California's performance standard.

Several organizations have attempted to promote greater PRSV efficiency through voluntary certification programs. For example, the Environmental Protection Agency (EPA) has undertaken a voluntary labeling and certification program, WaterSense, analogous to the EnergyStar program, to promote water use efficiency in the US. A WaterSense specification for PRSVs was adopted in 2013, which lowered the maximum permissible flow rate to 1.28 gpm,[5] and also includes tests for PRSV performance and longevity based on EPA's field research. According to this research, "spray force" is a more objective and reliable indicator of user satisfaction than California's "cleanability" performance metric.[6] WaterSense compliant PRSVs must be able to deliver a "spray force" exceeding 4 ounces during laboratory testing. The DOE has already initiated rulemaking procedures to incorporate this "spray force" performance metric into the mandatory federal standard for PRSVs. Once this is approved, the California Energy Commission will likely follow suit by substituting the "spray force" performance standard in place of the existing "cleanability" standard in its Title 20 regulations.

Table 1 Various Standards Influencing Sale or Installation of PRSVs in California

Mandatory or Voluntary Standard	Efficiency and Performance Standard	Effective Date
Federal Standard (mandatory)	≤1.6 gpm at 60 psi; no performance standard	January 1, 2006
California Title 20 Standard (mandatory)	≤1.6 gpm at 60 psi; "cleanability" performance standard	January 1, 2006
WaterSense Standard (voluntary)	≤1.28 gpm at 60 psi; "spray force" performance standard; also includes life cycle testing standard	September 19, 2013
Food Service Technology Center (voluntary)	≤1.15 gpm at 60 psi; "cleanability" performance standard	Fall 2014

[4] California Code of Regulations can be found here: www.oal.ca.gov
[5] www.epa.gov/watersense
[6] US Environmental Protection Agency (WaterSense), *Pre-Rinse Spray Valves Field Study Report*, March 31, 2011.

Table 1 summarizes PRSV standards in California. The FSTC's recommendation is also shown because they have been an important player in improving water and energy use efficiency in commercial kitchens.[7] FSTC recently modified its recommendation and limits rebates to PRSV models that use under 1.15 gpm. As mentioned earlier, most existing standards that rely on "cleanability" to judge performance will more than likely switch to the "spray force" performance metric once DOE includes this criterion in the mandatory federal standard. The Alliance for Water Efficiency's website offers additional valuable resources about the evolution of codes and standards over time.

PRSVs using as little as 0.65 gpm are now available for food service applications. Performance of these ultra-low-flow PRSVs, however, is quite sensitive to inlet water pressure (more on this later).

3. WATER SAVINGS

Several studies have evaluated water and energy savings, and user satisfaction, associated with efficient PRSVs (Table 2). Only the subject of water savings is highlighted here. All these studies have estimated PRSV savings by physically metering water usage, before and after a retrofit. Except for the CUWCC Phase 2 evaluation, they all suggest that PRSVs save a significant amount of water and energy, so much so that the cost of a retrofit pays for itself within a year or less, on average. For this reason, many utilities (often energy and water utilities in partnership) run direct install programs at no cost to the program participant. The cost-effectiveness of PRSV retrofits is, therefore, largely a settled question. What is less settled is figuring out how to use results from the existing studies to estimate savings from future PRSV retrofit programs where conditions may be different from what was evaluated by aforementioned studies?

Field studies have identified several drivers of water savings, mostly self-evident, such as the flow rate difference between the existing and replacement PRSVs, length of time per day in use (and whether this changes after switching to an efficient PRSV), inlet water pressure, and retention rate (dependent on user satisfaction). Additional drivers of energy savings include inlet cold water temperature and output spray water temperature desired by the PRSV operator. All of these factors likely vary across service areas.

A key driver of savings is obviously the difference between the flow rate of existing PRSVs and what they are replaced with. Data in Table 2 show that both can fluctuate considerably across field studies. Not surprisingly, earlier studies generally indicate a higher pre-retrofit average flow rate (except for the CUWCC Phase 2 evaluation that stands apart on this and other key metrics). Once the 1.6 gpm federal standard for PRSVs went into effect in 2006, natural turnover alone would be expected to improve efficiency. Therefore, taking the average of pre-retrofit flow rates across existing studies to estimate savings from a future program would not be a sensible strategy. Water suppliers would be better off performing field measurements in their service area to estimate this parameter. A similar recommendation applies for estimating post-retrofit flow rates.

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[7] Additional details about PRSVs certified by FSTC can be found here: www.fishnick.com/equipment/sprayvalves

Table 2 Key Savings Parameters from PRSV Evaluations

Study & Fieldwork Year	Measured Flow Rate (gpm)		Site Pressure (psi)	Measured Usage (hours/day)		Rated Flow Rates of Replacement PRSVs	Estimated Savings per PRSV Retrofit (gpd)
	Pre-Retrofit	Post-Retrofit		Pre-Retrofit	Post-Retrofit		
CUWCC Phase 1, 2002-03	3.35	1.11	61	n.a.	1.27	1.6 gpm[1]	171
CUWCC Phase 2, 2004-05	2.23	1.12	n.a.	0.54[3]	0.73[3]	1.6 gpm[1]	23
Waterloo, Canada, 2004	2.75	1.22	66	0.65	0.77	1.6 gpm[1]	51
Calgary, Canada, 2005	3.62	1.48	81	0.78	0.83	1.6 gpm[1]	96
WaterSense, 2010[4]	2.32	0.89	62	1.29	1.32	<1.0 gpm[2]	108
	"	1.32	68	"	1.50	1.0-1.24 gpm[2]	61
	"	1.33	65	"	1.42	1.25-1.6 gpm[2]	67
SoCal. Gas Company, 2013	1.61	0.91	63	1.30	1.63	0.65-1.15 gpm[2]	37
Santa Cruz, CA, 2014	2.15	0.96	78	n.a.	n.a.	0.65-1.15 gpm[2]	

NOTES:
[1]Flow rated at 80 psi. [2]Flow rated at 60 psi. [3]Usage times exclude grocery stores, which are minimal users of PRSVs, but were included accidentally in the CUWCC Phase 2 study. [4]This study tried three different PRSVs of varying efficiency at each of the 10 test sites, which is why there are three sets of post-retrofit results.

SOURCES:
SBW Consulting, Inc., *Evaluation, Measurement and Verification Report for the CUWCC Pre-Rinse Spray Head Distribution Program*, a report prepared for the California Urban Water Conservation Council, 2004.
SBW Consulting, Inc., *Impact and Process Evaluation Final Report for California Urban Water Conservation Council 2004-05 Pre-Rinse Spray Valve Installation Program (Phase 2),* a report prepared for the California Urban Water Conservation Council, 2007.
Gauley, B., *Region of Waterloo: Pre-Rinse Spray Valve Pilot Study*, a report prepared by Veritec Consulting Inc. for the Regional Municipality of Waterloo, Canada, 2005.
Gauley, B., *City of Calgary: Pre-Rinse Spray Valve Pilot Study*, a report prepared by Veritec Consulting Inc. for the City of Calgary Waterworks and Wastewater, Canada, 2005.
US Environmental Protection Agency (WaterSense), *Pre-Rinse Spray Valves Field Study Report*, March 31, 2011.
Valmiki, M.M. & M. Esser, *Low Flow Pre-Rinse Sprayer Field Testing*, a report prepared by NegaWatt Consulting for the Southern California Gas Company, 2013.
Liske, K. & L. Sotomayor, *2014 Pre-Rinse Spray Valve Direct Installation Program: Final Report*, a report prepared by Ecology Action for the City of Santa Cruz Water Department, 2015.

Measuring PRSV flow rates and site pressure at each participating food service establishment before the retrofit, and from a random sub-sample of participants after the retrofit, need not be very expensive; collection of these metrics may need to become standard practice for implementing these programs in the future anyway. The reason for this is that the latest generation PRSVs (ultra-low-flow PRSVs using less than 1.0 gpm) are much more sensitive to inlet water pressure. The latest field studies (Table 2) that have experimented with ultra-low-flow PRSVs (WaterSense, Southern California Gas Company, and the City of Santa Cruz) have all shown that if these types of PRSVs are used at pressures much below 60 psi (laboratory test pressure), the risk of user dissatisfaction increases greatly. FSTC also recommends using PRSVs between the 1.0-1.15 gpm range if inlet pressure is too variable or too low. Assuming that a supplier allocates PRSVs based on site pressure, and that the distribution of pressures is similar to what was encountered in the Southern California Gas Company or City of Santa Cruz studies, suggests that a post–retrofit flow rate assumption between 0.9-1.0 gpm may be reasonable (depending on average inlet pressure). But, as stated earlier, field verification would be preferable. WaterSense discovered several PRSVs in their field study (EPA WaterSense, 2011, *op cit.*) that were operating at significantly higher flow rates than their rated flow rates.

Measuring average usage time is a significantly more complicated task than measuring flow rates, because it requires installing submeters. We have known since the CUWCC Phase 1 study that usage time measured in the field is much lower than what planners originally anticipated, and that actual metered usage hours is poorly correlated with self-reported usage hours (SBW Consulting Inc., 2004, *op cit.*). So, just asking food service establishments about their PRSV use is not a viable strategy for estimating usage time. Table 2's data can offer some guidance on this issue. Ignoring the CUWCC Phase 1 and 2 studies (the former because it does not report pre-retrofit usage time, the latter because its key results set it apart from all the other studies), it appears PRSVs are used about 1 hour per day, on average; and that usage time increases by roughly 13%, on average, after switching to an efficient PRSV. In the absence of field data, we recommend water suppliers use both of these parameters for projecting savings from their PRSV retrofit programs.[8]

The final issue that savings calculations have to deal with is the issue of retention. The CUWCC Phase 1 and 2 evaluations examined this issue and found that retention was not a problem. Only about 5% of efficient PRSVs had been removed after 1 year from retrofit. Data about retention over a longer time period are not available. However, going forward, now that ultra-low-flow PRSVs have become available, this issue deserves greater scrutiny. Retrofit programs that fail to evaluate inlet water pressure may end up recommending ultra-low-flow PRSVs to those food service establishments for whom it may not be suitable, causing user dissatisfaction and subsequent equipment removal.

[8] Additional useful data that could help water suppliers develop water savings projections can be found in the following document: US Environmental Protection Agency (WaterSense), *WaterSense Specification Pre-Rinse Spray Valves Supporting Statement*, September 19, 2013.

Table 2's last column shows estimated savings per PRSV retrofit that prior evaluations have yielded. These estimates are computed from flowrate and usage time data shown in Table 2's earlier columns, assuming a 100% retention rate.

How might a water supplier project savings from their PRSV retrofit program using results from existing field studies? The Santa Cruz field study is a good way to illustrate a potential methodology because this field study measured pre- and post-retrofit flow rates, but not usage times. Pre- and post-retrofit water use could be calculated as follows:

Pre-Retrofit Water Use per PRSV = (2.15 gallons per minute) x (60 minutes per day of average use)

Post-Retrofit Water Use per PRSV = (0.96 gallons per minute) x (60 minutes per day of average use) x (1.13 to account for 13% usage time increase at lower flow rates)

Net Water Savings = 64 gallons per PRSV retrofit per day

A further down-correction could be applied to the 64 gpd estimate to account for less than 100% retention over time.

4. COSTS

The FSTC has tested and recommends several PRSV models on their website. We searched for internet retail prices for as many of these models as we could find. In general, there appears to be a negative correlation between price and flow rate, but the correlation is weak. That means within each efficiency band (<1.0 gpm, 1.0-1.28 gpm, >1.28 gpm) a wide variety of PRSVs are available. The median retail price within each efficiency band works out to roughly $70-80, although it is possible to find models as cheap as $35 and as expensive as $110 (excluding taxes and shipping). The price variation reflects differences in features, ergonomics, materials and performance (over and above efficiency), which may influence retention. Water suppliers that purchase in bulk for a direct install program would be able to do better than the above estimates suggest.

5. DEVICE LIFE

Many of the published studies that have performed cost-effectiveness analyses use an average device life of 5 years (implying a natural turnover rate of 20%) for PRSVs. The basis for this estimate appears to be largely anecdotal, however, so merits improvement through additional field research.

6. THE CHALLENGE AHEAD

Although a high natural turnover rate is causing the installed stock of PRSVs to become more efficient over time, we expect these retrofit programs to remain cost-effective because of the steep increases in water and energy rates over the past few years.

A key issue that may be emerging, that did not exist before, is the need for better program targeting. Earlier, one could promote a 1.6 gpm PRSV with greater confidence across many different kinds of food service establishments. With the advent of ultra-low-flow PRSV designs, greater care is required in choosing an efficiency level appropriate for a particular kind of food service establishment, which implies that measurement of water pressure will need to become an integral component of PRSV retrofit programs. Otherwise, program savings may be compromised due to customer dissatisfaction. Additional field research is required to develop these water pressure based allocation rules so as to assure high retention rates.

SELF-CLOSING FAUCETS: AN UPDATE ABOUT COSTS & SAVINGS

1. BACKGROUND

Self-closing faucets come in two broad flavors: (1) faucets that dispense water for a fixed, pre-determined length of time (also called metering faucets); and (2) faucets that are triggered open, and remain continuously open, as long as hand motion is detected within the faucet's sensory field (or until finger pressure is applied to the actuator stick of the "instant-off" faucet,[1] which is an example of a mechanical, non-metering self-closing faucet). Metering faucets can be mechanical spring-loaded devices, or triggered via electronic sensors. Non-metering, self-closing faucets in public lavatories almost always rely on electronic sensors and controls, barring exceptions, such as the "instant-off" faucet. Historically, majority of self-closing faucets were found in public lavatories, to a lesser extent in common areas of group quarter residential settings, where user carelessness is a greater risk. However, self- closing faucets are increasingly seen as effective ways of improving hygiene in commercial kitchens, food processing applications, the health industry, etc. They are also finding applications in the residential sector, especially for kitchen applications, as a convenience and lifestyle product—these can be touch based (touching the faucet with the back of the palm or forearm can start or stop the faucet, helpful when fingers are engaged in food preparation or degreasing chores) or "hands free" (infra-red sensor based), or both, or of the "instant-off" variety.

Another dimension on which sensor faucets can vary is whether the sensors receive power from a battery or from a hardwired connection. The former require greater vigilance from building maintenance staff.

2. HISTORY OF CODES AND REGULATIONS

Although self-closing faucets are more prevalent in public lavatories, the evolution of codes and regulations for all faucets is covered first, before turning specifically to public lavatory faucets.

California first attempted to improve faucet water use efficiency through the use of regulations during the late 1970s. Until then some faucets used as much as 7 gallons per minute (gpm).[2] Effective January 1, 1978, California law required faucets sold in California to have a maximum flow rate not exceeding 2.75 gpm. Many other states also followed suit during the 1980s and 1990s. This patchwork of state-specific regulations was rationalized when mandatory federal standards for toilets, showerheads, urinals and faucets were incorporated into the Energy Policy Act passed by Congress in 1992 (EPAct 1992): From the time this federal law spearheaded by the Department of Energy (DOE) came into force (January 1, 1994), only faucets and replacement aerators with a maximum flow rate of 2.5 gallons per minute (gpm) tested at 80 psi could be sold in the US. Subsequent revisions to ASME's testing protocol caused DOE to modify the federal standard to 2.2 gpm tested at 60 psi, which remains the federal standard in effect today.[3] EPAct 1992 also included labeling requirements to properly identify compliant

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[1] www.instant-off.com

[2] California Energy Commission, *Staff Analysis of Toilets, Urinals and Faucets*, Report # CEC-400-2014-007-SD, 2014.

[3] Details about faucet federal standards and test procedures can be found here:

from non-compliant fixtures. The federal standard is the same for private and public lavatory faucets, kitchen faucets, and replacement aerators. Metering faucets, however, are subject to a maximum gallons-per-cycle, not a maximum gallons-per-minute standard: These are required to dispense no more than 0.25 gallons per cycle (gpc), but their maximum flow rate is otherwise unregulated. In the mid-1990s the ASME/ANSI testing protocols reduced the maximum permissible flow rate for public lavatory faucets to no more than 0.5 gpm. Since the federal standards have not been revised to reflect this change, many remain unaware of this difference between public and private lavatory faucets.[4]

Although mandatory federal standards pertaining to faucet efficiency have not changed over time, the Environmental Protection Agency (EPA) has undertaken a voluntary labeling and certification program, WaterSense, analogous to the EnergyStar program, to promote water use efficiency in the US. A WaterSense specification for private lavatory faucets was adopted in 2007, which lowered the maximum permissible flow rate to 1.5 gpm.[5]

California has opted for more stringent faucet standards than the federal ones, because DOE formally waived federal preemption of state law regarding faucet efficiency in 2010, although provisions contained in EPAct 1992 allowed for this waiver much earlier. State faucet standards are now incorporated in the California Plumbing Code and the California Green Building Code that apply both to new construction and to alterations of existing construction requiring a permit (Title 24 of the California Code of Regulations).[6] Regarding what types of faucets and replacement aerators can be offered for sale in California, these are covered by Title 20 regulations. Faucet standards included in Title 20 regulations up until now reflected the federal efficiency standard (2.2 gpm), but these were recently revised by the California Energy Commission.

Table 1 Standards Controlling Sale or Installation of Faucets and Replacement Aerators in California

Plumbing Fitting	Maximum Flow Rate Criterion	
	Installed in New or Renovated Construction after January 1, 2014‡	**Sold or Offered for Sale on or after January 1, 2016†**
Private Lavatory Faucets and Replacement Aerators	1.5 gpm at 60 psi	1.2 gpm at 60 psi
Kitchen Faucets and Replacement aerators	1.8 gpm with optional temporary flow of 2.2 gpm at 60 psi	1.8 gpm with optional temporary flow of 2.2 gpm at 60 psi
Public Lavatory Faucets	0.5 gpm at 60 psi	0.5 gpm at 60 psi
Metering Faucets	0.25/0.20 gallons/cycle[1]	0.25 gallons/cycle

‡ Title 24 standards, from California Plumbing Code and California Green Building Code, 2013

† Title 20 standards, from *2015 Appliance Efficiency Regulations*, California Energy Commission, CEC-400-2015-021

https://www1.eere.energy.gov/buildings/appliance_standards/product.aspx/productid/64

[4]Additional details about evolution of federal standards can be found here: http://www.allianceforwaterefficiency.org/1Column.aspx?id=1822&LangType=1033&terms=faucet+standards

[5]www.epa.gov/watersense

[6] California Code of Regulations can be found here: www.oal.ca.gov

[1]California Green Building Code Supplement, 2015, reduced allowable delivery to 0.20 gallons/cycle for non-residential settings. For residential settings, the maximum allowable delivery remains 0.25 gallons/cycle.

Table 1 summarizes faucet efficiency standards in California. A notable change is the revised Title 20 standard for private lavatory faucets, which requires faucets and replacement aerators sold in California for this application to not dispense any more than 1.2 gpm after January 1, 2016. What do these standards mean for self-closing faucets, however? The maximum flow rate for non-metering, self-closing faucets in public lavatories remains 0.5 gpm. Leading manufacturers have already introduced CalGreen compliant faucets that use as little as 0.35 gpm (to gain a competitive advantage among those clients that wish to comply with higher tiers of CalGreen or LEED codes). What about metering faucets in public lavatories? Do these need to comply with the 0.5 gpm or the 0.2 gpc standard? Strictly speaking, metering faucets are subject only to gpc standards, but leading plumbing manufacturers have introduced CalGreen compliant metering faucets that comply with both the gpm and gpc requirements, some limiting their maximum flow rate to 0.35 gpm, and water dispensed per cycle to as little as 0.05 gpc. The emergence of these latest, ultra-low-flow self-closing faucets is partly driven by codes and partly by competitive dynamics in the faucet marketplace. The Alliance for Water Efficiency's website offers additional valuable resources about the evolution of codes and standards over time.

Another piece of legislation—Senate Bill 407 (SB 407 enacted in 2009)—also has some bearing on calculation of savings from codes and regulations pertaining to faucets. Although SB 407 does not deal with faucet efficiency or performance, it requires all single-family homes with faucets using greater than 2.2 gpm to be retrofitted with water conserving faucets or appropriate replacement aerators (defined as fittings compliant with current building or plumbing codes) by January 1, 2017, and multifamily and commercial buildings by January 1, 2019. SB 407 requires sellers or transferors of property to declare whether non-conserving faucets (as also non-conserving toilets and urinals) are present at the time of sale or transfer, which constitutes this legislation's primary enforcement mechanism. In other words, in spite of SB 407's wording it is doubtful that saturation of faucets using greater than 2.2 gpm will go to zero in 2017 for the single-family sector, and in 2019 for the multi-family and commercial sectors. More than likely, this legislation's effect will be more gradual over time depending on the rate at which property is sold or transferred in a given service area. Estimation of code-related savings shall need to account for the implications of this legislation.

3. WATER SAVINGS

Mechanical self-closing (metering) faucets have been favored for use in highly trafficked, lightly supervised, public lavatories where carelessness, abuse and vandalism can lead to high levels of water wastage. The new breed of electronic-sensor operated faucets (metering or non-metering) offer the added benefit of greater hygiene on account of the "hands free" operation. Although self-closing faucets may have several ancillary virtues, do they actually help to conserve water (as many manufacturers have claimed in the past)?

Three field studies can shed some limited light on this question.

The first study implemented during the late 1990s ran a four stage experiment in a single facility spanning several years.[7] In stage 1, water use was metered in lavatories fitted with manually operated swiveling faucets using 4.5 gpm aerators; in stage 2, the manual faucet aerators were replaced with 2.2 gpm aerators; in stage 3, the manual faucets were replaced with electronic self-closing faucets using 2.2 gpm aerators; and finally in stage 4, the electronic self-closing faucets were fitted with 0.5 gpm aerators. Comparing measurements over time periods that represent an apples-to-apples comparison, the study showed that between stages 1 and 2, water use remained roughly the same even though aerator nominal flow rates were cut by half. Between stages 2 and 3, water use increased by roughly 23%, suggesting that the self-closing feature caused more water to be used in spite of aerator flow rates being the same.[8] Finally, between stages 3 and 4, downsizing to 0.5 gpm aerators from 2.2 gpm aerators reduced consumption by 58%. In other words, the self-closing feature squandered water. Reducing aerator flow rates from 4.5 gpm to 2.2 gpm had no significant effect. The real savings came from going all the way down to 0.5 gpm aerators (more on this later).

The second study compared swiveling manual faucets to both mechanical metering faucets as well as electronic-sensor self-closing faucets.[9] This study found that both types of self-closing faucets used approximately twice the amount of water than used by manual swiveling faucets. However, the paper acknowledges several problems with the installation of infra-red sensors, so the results of this study may not be very representative. The paper also acknowledges that the mechanical metering faucets were initially set for an excessively long cycle time of 15 seconds. When this was reduced to 7 seconds, water consumption reduced significantly, although the paper includes no data to demonstrate this.

The third, a much more recent study, evaluated the efficacy of sensor-operated self-closing faucets (and also sensor operated toilets and urinals) in a Florida office building.[10] Water consumption was measured by installing a submeter and datalogger on the supply line to the test restrooms. Pre-retrofit water consumption was first measured with manual swiveling faucets in the test restrooms for roughly ten months. These had an average flow rate of 1.32 gpm. The manual faucets were then replaced with electronic-sensor operated faucets with an average flow rate of 1.21 gpm—consumption metering was resumed for another four months. Comparison of the pre- and post-retrofit average daily consumption suggests that daily faucet use increased after the retrofits, by roughly 30%.

To make sense of the above findings, two observations may be useful to keep in mind. First, there is no reason to believe that a non-conserving faucet will always be operated at full blast with the valve fully open. Users do not wish to splash themselves while washing their hands in a sink. Second, sensor-based faucets are designed to operate with the valve fully open. These two observations may explain

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[7] Fanney, A.H. et al., *Field Test of a Photovoltaic Water Heater*, 2002 (available at www.map-testing.com)
[8] In deriving this estimate we have accounted for greater building occupancy reported during stage 3 and 4 by Fanney et al., 2002, *op cit*. Other studies that have cited this paper often fail to include the higher reported building occupancy, wrongly concluding that self-closing faucets increased water consumption by 58%.
[9] Hills, S. et al., "The Millenium Dome "Watercycle" Experiment: to Evaluate Water Efficiency and Customer Perception at a Recycling Scheme for 6 Million Visitors," *Water Science and Technology*, Vol. 46, No. 6-7, pp. 223-240, 2002 (available at www.map-testing.com)
[10] Gauley, B. & J. Koeller, *Sensor Operated Plumbing Fixtures: Do They Save Water*, 2010.

the anomalous findings of the above studies. If a user only opens a manual faucet part way, perhaps it is not too surprising that reducing aerator nominal flow rates from 4.5 gpm to 2.2 gpm makes little difference. If users are happy with a flow rate below 2.2 gpm, switching from one to the other ought not to make much of difference. It might also explain why comparing manual and sensor-operated faucets with aerators rated at fairly high output levels leads to the conclusion that sensor operated faucets squander water (perhaps the manual faucets were being operated at well below their nominal flow rating, but the sensor-operated faucets by design deliver their full flow rate).

A true test of the water savings potential of sensor-based self-closing faucets thus requires that this comparison be performed when flow-rates have been throttled back to a point where users of manual faucets are likely to fully open the valve. Otherwise, the comparison remains between apples and oranges. Such a study was completed in a Southern California hotel under the auspices of Metropolitan Water District of Southern California's Innovative Conservation Program a few years ago, and this conclusively showed that self-closing faucets installed with code-compliant aerators achieve significant savings in public restrooms.[11]

The design specification of the new breed of CalGreen-compliant sensor faucets looks quite a bit different from what prior studies have evaluated. Their maximum flow rates have been throttled back considerably (to as little as 0.35 gpm), and many of these also have a (electronic instead of mechanical) metering feature built in. Field testing of this new faucet breed may demonstrate even greater conservation potential.

4. COSTS

Although a brand new electronic sensor faucet can cost several hundred dollars per piece, using low-flow aerators is the key to generating savings, for which replacement of the entire faucet is unnecessary, unless of course the faucet's age makes it incapable of accommodating the latest aerator designs. In other words, it is more important to ensure that public lavatory faucets have aerators at or below 0.5 gpm, instead of investing in brand new faucets. It is also important that metering faucets be programmed to match cycle times to user behavior. Shorter cycle times may potentially lead to greater efficiencies. The cost of retrofitting aerators and adjusting cycle times is quite minimal. Replacement aerators can usually be purchased for under $5 a piece, and for a lot less than that, if purchased in bulk.

5. DEVICE LIFE

To support revisions to residential faucet standards, the California Energy Commission used an average life of 10 years for faucet accessories (aerators). Perhaps, a similar assumption can be used for public lavatory settings until better data become available,[12] although aerator life probably varies considerably across regions because of differences in water hardness.

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[11] West Basin Municipal Water District and EcoGreen Services, LLC, *Field Study Findings Report: Restroom Retrofit Self-Closing Sensor Faucet Retrofit*, a report prepared for the Metropolitan Water District of Southern California, 2010.

[12] California Energy Commission, *Analysis of Standards Proposal for Residential Faucets and Faucet Accessories*, a report prepared under CEC's Codes and Standards Enhancement Initiative, Docket #12-AAER-2C, August 6, 2013.

6. THE CHALLENGE AHEAD

CalGreen-compliant self-closing faucets available in the market today appear to be quite different from what previous studies have evaluated. It may be a good idea for water suppliers to mount a carefully designed field study to evaluate the latest CalGreen-compliant self-closing faucets to be able to reliably quantify their savings potential and identify performance shortcomings, if any.