A report on

Potential Best Management Practices

Prepared for

The California Urban Water Conservation Council

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Annual Report - Year Three

January 2007

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And a very special thanks to Gary Klein of the California Energy Commission for his valuable insights and for contributions to the Residential Hot Water Distribution chapter:

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I. Introduction

General Background

Signatory water suppliers to the *Memorandum of Understanding Regarding Urban Water Conservation in California (MOU)* agree to make good faith efforts to implement 14 urban water conservation Best Management Practices (BMPs). In addition to the current 14 BMPs, Exhibit 1 of the MOU includes a list of 11 potential BMPs (PBMPs)[1]. Under the terms of the MOU, the California Urban Water Conservation Council (Council) is responsible for maintaining a dynamic BMP/PBMP assessment process, which includes the following commitments:

1. The assumptions of reliable savings for BMPs and PBMPs will be updated at least every 3 years.
2. The economic reasonableness of a BMP or PBMP will be assessed by the Council using the economic principles in Sections 3 and 4 of Exhibit 3 of the MOU.
3. A PBMP will be moved to the BMP list and assigned a schedule of implementation if, after review of data developed during research and/or demonstration projects, the Council determines that the PBMP is economically reasonable and otherwise conforms to the definition of BMPs.

Project Background

To assist in meeting these commitments, the Council secured a three-year grant from the United States Bureau of Reclamation to evaluate and research PBMPs. Over a three-year period, the Council is required to prepare three annual reports summarizing water savings and cost information for the original PBMPs listed in the MOU as well as for other emerging technologies, products, and practices that might be candidate PBMPs.

The original 11 PBMPs drafted in 1991 and included in the MOU are as follows:

(a) Rate structure and other economic incentives and disincentives to encourage water conservation
(b) Efficiency standards for water using appliances and irrigation devices
(c) Replacement of existing water using appliances (except toilets showerheads, and washers which are already addressed by BMPs) and irrigation devices
(d) Retrofit of existing car washes
(e) Graywater use
(f) Distribution system pressure regulation
(g) Water supplier billing records broken down by customer class
(h) Swimming pool and spa conservation including covers to reduce evaporation
(i) Restrictions or prohibitions on devices that use evaporation to cool exterior spaces

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[1] Refer to *Summary of Best Management Practices* and list of Potential Best Management Practices from Exhibit 1 of the MOU. A complete copy of the MOU may be found at http://www.cuwcc.org/memorandum.lasso

(j) Point of use water heaters, recirculating hot water systems and hot water pipe insulation

(k) Efficiency standards for new industrial and commercial processes

In January 2003, the Council issued a Request for Proposal (RFP)[2] seeking a consultant to "evaluate potential Best Management Practices for urban water conservation." On May 19, 2003, the Council entered into a contract with Koeller and Company (consultant) to perform the scope of services outlined in the RFP.

In Year One of the three-year scope of work, the Council's Research and Evaluation Committee (Committee) and the consultant performed a simple assessment of 11 candidates in each of three areas-

(a) Availability of the data necessary to evaluate as a PBMP
(b) Magnitude and coverage of potential water savings that could result from the practice if implemented
(c) Marketability to the end-user/customer and ease of implementation

Point ratings were assigned to each candidate in each of the three areas. From this assessment and in consultation with the Committee, eight candidates were ultimately evaluated in Years One and Two:

(a) Weather-based irrigation controllers (including ET controllers)
(b) Pre-rinse spray valves for food service
(c) X-ray film processor recycling units
(d) Steam sterilizer retrofits (medical industry)
(e) On-Premise Laundries
(f) High Efficiency Plumbing Fixtures - Toilets and Urinals
(g) Submetering of Multi-Family Residential Properties
(h) Commercial-Industrial Cooling Water Efficiency

The Year One final report covering the first four candidates is available for download from the Council's website with the following link:

www.cuwcc.org/uploads/tech_docs/PBMP_Report_Year_1_FINAL_August-2004.pdf

The Year Two final report covering the second four candidates is also available for download from the Council's website at this link:

www.cuwcc.org/uploads/tech_docs/PBMP_Report_Year_2_FINAL_Jan-2006.pdf

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[2] Request for Proposals by the California Urban Water Conservation Council, January 2003.

II. Selection of Evaluation Candidates for Year Three

Continuing with the process that commenced in Year One, the Committee worked with the consultant to consider a range of candidates for evaluation in Year Three:

(a) Car (vehicle) washes
(b) Ice making machines
(c) Point-of-use water heaters, recirculating hot water systems, and hot water pipe insulation
(d) Residential dishwashers
(e) Boilerless steamers for the food service industry
(f) Plan review for new commercial, industrial, and institutional projects
(g) Distribution system pressure regulation
(h) Submetering (follow-on to Year Two analysis)
(i) Highway/road speed sweeper
(j) Soil moisture sensor technology
(k) Drip and high-efficiency irrigation systems and equipment (other than controllers)
(l) Synthetic/artificial turf
(m) Water saving pool filter
(n) On-site graywater re-use
(o) Evaporation suppression (cooling and other applications)
(p) New construction (residential) guidelines
(q) Process water efficiency standards
(r) Customer classification of water supplier billing records
(s) Residential shower systems

As a result of the process, the following four candidates were selected for Year Two evaluation[3]:

(a) Residential dishwashers
(b) Vehicle wash systems
(c) Synthetic turf
(d) Residential hot water distribution

The results of those evaluations are included in Sections 4 through 7 of this report.

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[3] Some candidates were deferred to a Year Three or possible Year Four analysis

III. Summary of Evaluation Results

Descriptions of each of the four selected Year Three PBMP candidates, together with analyses of the water savings potential and other factors, are included within the following four sections of this report. The essential findings are summarized in Table 3.

Table 3. Summary of Year Three PBMP Characteristics and Results of Evaluations

	Residential Dishwashers	Vehicle Wash Systems	Synthetic Turf	Residential Hot Water Distribution
Gross lifetime water savings potential for California (millions of acre-feet – over expected life of equipment)	At water factor (WF) reduction of (see Note a): 1.0 – 0.06 2.0 – 0.13	Reclaim (regulatory) ordinance (30 yrs) – 0.69	School sporting applications only – 0.88 to 1.17 (see Note d)	Existing (2005) housing in Calif - 6.15 (see Note f)
Gross annual water savings potential for California (millions of acre-feet per year)	At WF reduction of: 1.0 – 0.006 2.0 – 0.013	Reclaim - 0.023 AFY Certification - 0.005 AFY	School sporting applications only – 0.088 to 0.117 AFY	20 yrs of new construction (2005-25) – 0.029 AFY in 2025 (see Note g)
Readily feasible for state regulation?	Yes, for new construction	Yes	No	Yes, for structured plumbing in new construction
Projected cost to the water utility of water saved under the measure (per acre-foot)	Negligible if through green building voluntary guidelines or regulatory mandate for new construction	Reclaim ordinance or state regulation - $42 Certification program - $225	$6,000 to $15,000	Negligible if through green building voluntary guidelines or regu-latory mandate for new construction
Applicable customer class(es)	Residential	Commercial	Institutional & large comm'l	Residential & commercial
Type of water use reductions	Average and peak period	Average and peak period	Average and peak period	Average and peak period
Ancillary benefits of the measure	Wastewater reduction; energy use reduction due to reduced volume of high tempera- ture water needed for sanitizing; reduced greenhouse gas emissions	Significant wastewater reduction	Use of pesticides and chemicals reduced or eliminated; significantly reduced urban runoff is likely	Wastewater reduction; significant energy use reduction due to reduced waste of warm and hot water; reduced greenhouse gas emissions
Cost-effective scale of measure implementation by water suppliers	Cost-effective for new residential green building guidelines and construction; not cost-effective to establish and operate rebate or other incentive programs unless partnered with energy utility programs	Very cost-effective for reclaim ordinances or state regulation for all new dis-charge permits and/or new construction	Doubtful cost-effectiveness, due to high cost of product vs. relatively low amount of water saved	Cost-effective for new residential green building guidelines and construction; probably not cost-effective to retrofit all of existing housing inventory unless partnered w/wastewater & energy utilities

	Residential Dishwashers	Vehicle Wash Systems	Synthetic Turf	Residential Hot Water Distribution
Barriers to implementation	No barriers to inclusion in new construction green building guidelines; economically unfeasible to establish customer incentive programs	Possible physical limitations to retrofits at some car washes; high cost of facility renovation & equipment replacement	Some anecdotal information indicates leaching of chemicals into soil; in certain climates, water required to "cool down" turf for use for sports; high cost of installation vs. life expectancy	Possible building industry reluctance to change time-worn plumbing designs & practices; requires plumbing code changes and training & education of contractors and plumbers
Technical skills required of water utility conservation coordinator (b)	1	3	2	4
Viable candidate for PBMP status? (c)	Yes	Yes	Not until more information is available on life expectancy, maint. & water requirements, and potentially adverse environmental effects (see Note e)	Yes. Full BMP status, however, awaits further field trials of structured plumbing designs and technologies.

Notes:

(a) Assumes 10-year life of typical residential dishwasher

(b) Some measures require significant technical analysis and assessment at a customer site prior to implementation. Others, such as simple rebate programs, do not. Each measure is subjectively rated on a scale of 1 to 5, with a rating of "5" indicating that specialized technical expertise is required to understand and effectively implement the measure, while a rating of "1" would indicate that little, if any, technical understanding is necessary. On this scale, for example, a showerhead replacement program would be assigned a "1" rating.

(c) Reflects the recommendation of the consultant only.

(d) Assumes a 10-year physical life of synthetic turf. However, anecdotal information indicates that under intensive sporting use, the life may be as short as 6 years. Such situations occur where school sporting fields are also used in "off hours" by municipal recreation programs, some of which utilize the lighted fields to as late as 10 PM.

(e) Decisions on status and viability await studies currently being conducted by the Metropolitan Water District of Southern California and by the Santa Clara Valley Water District.

(f) Based upon an estimate of 123,000 AFY currently being wasted in existing housing times a 50-year life of typical residential housing

(g) Estimate is only for new future housing constructed after 2005; does not include the retrofit of any existing housing.

IV. Residential dishwashers

1. Background

History

The first hand-operated dishwashing machine was patented in 1850. However, a powered dishwasher with permanent plumbing hookups was not developed until 1920, according to the Whirlpool Corporation[4]. In 1947, household dishwashers went into production and soon became a feature in the American home[5]. Numerous technological advances since then have significantly improved the cleaning, energy, and water efficiency of residential dishwashers in the North American marketplace.

Over the past 20 years, the percentage of all U.S. housing units with automatic dishwashers has grown steadily, from only 42 percent in 1985 to nearly 58 percent by 2003. Of special note is the fact that about 88 percent of all new housing units constructed in the period from 2000 to 2003 were equipped with builder-installed automatic dishwashers.[6] Figure 1 displays annual data on installed product in the U.S. for the 1985 to 2003 period.

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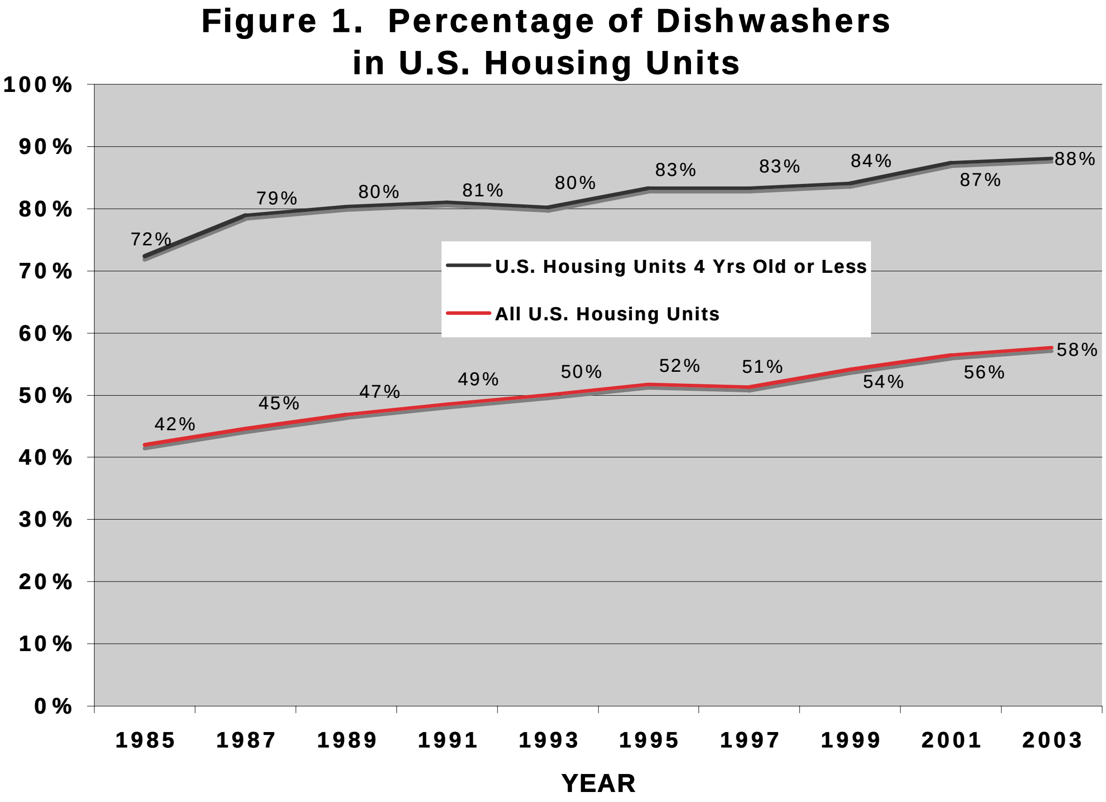
[4] Whirlpool Corporation, 1993. *How to make a home run with clean-up appliances.*

[5] Lindsay, F.D., 1980. *Dishwashers: A look at the past while pondering the present with an eye to the future.* Proceedings of the Detergents in Depth 1980 Symposium.

[6] U.S. Departments of Commerce and Housing and Urban Development, various dates. *American Housing Survey for the United States* (Multiple reports: 1985 through 2003)



Efficiency Standards

In 1987, the U.S. Congress passed the National Appliance Energy Conservation Act (NAECA). The NAECA led, in 1988, to the first Federal residential dishwasher standard, which required these appliances to provide the option to dry without heat. In 1994, the first Federal standard and test procedure was adopted that was based on an Energy Factor (EF)[7,8].

In 1997, the voluntary Energy Star program was expanded to include residential dishwashers. Under the direction of the U.S. Department of Energy (DOE), dishwasher energy use criteria are developed and maintained for the Energy Star program.

Within these two areas, the minimum EFs for residential dishwashers have been established as follows:

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[7] Karney, Richard H., 2005a. *Energy Star Criteria for Dishwashers*, U.S. Department of Energy, July 13 (powerpoint presentation)

[8] For dishwashers, the energy factor is defined as the number of cycles per kWh of input power.

Federal standard (NAECA)[9] - mandatory:	0.46 and 0.62[10]
Energy Star (DOE)[11] – voluntary:	0.52 (1997 to 2000) 0.58 (2001 to today) 0.65 and 0.88[12] (beginning 2007)

None of the above efficiency standards contain any requirements directly related to water use by the dishwasher. During the DOE's deliberative and comment process for the proposed increases in the EF, comments from water utilities and from the Steering Committee for Water Efficient Products[13] clearly advocated for the addition of a water factor (WF) within the Energy Star criteria. While some appliance manufacturers argued that energy use is well-correlated with water use and, thus, a WF is unnecessary, others representing water utilities argued that such is not necessarily the case. Therefore, they concluded, a measure of water use is meaningful and necessary in order to promote the most water-efficient products. At this point, however, there is no indication that a WF, or some equivalent measure or threshold, will be included by the DOE.

While a WF is absent in the standards, water use data from the Energy Star work is gathered, made available, and used by a few water utilities operating water efficiency programs. The State of Oregon's Department of Energy Residential Tax Credit Program provides credits of up to $50 for energy-efficient residential dishwashers with a EF of at least 0.61 and WF of no more than 6.5 gallons of water use per cycle. Qualifying washers (as of April 2006) are listed on the department's website, which is frequently updated:

http://oregon.gov/ENERGY/CONS/RES/tax/appdish.shtml

Natural Resources Canada (NRC) provides energy and water use[14] data for all residential dishwashers qualified for Energy Star. NRC's website permits the viewer to sort machines by water use per cycle as well as by energy use. The website is frequently updated and may be accessed at:

http://oee.nrcan.gc.ca/energystar/english/consumers/dishwashers-search.cfm

Both sites provide valuable and usable information for those organizations developing residential green building programs and water-efficiency subsidy (rebate) programs for dishwashers.

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[9] McNary, Bill, 2005. *Energy Star Criteria for Dishwashers, Market Impact Analysis*, D&R International, July 13 (powerpoint presentation)

[10] Requirement is a 0.46 EF for standard dishwasher models and 0.62 for compact models.

[11] Karney, Richard H., 2005b. Letter to Energy Star Partners and Stakeholders, U.S. Department of Energy, December 20.

[12] Final version of requirements (dated March 2, 2006) calls for a 0.65 EF for standard dishwasher models and 0.88 for compact models.

[13] The Steering Committee and its constituent membership is comprised of representatives from the water utility industry, appliance manufacturers, and other interested parties. This ad hoc organization represents the interests of water efficiency before both the DOE and the U.S. Environmental Protection Agency (EPA), as well as other stakeholder groups.

[14] Residential dishwashers are connected only to the hot water side of the plumbing in a typical installation. As such, the "hot water" use shown for each machine on the NRC website constitutes the total water consumption. All water and energy consumption data is provided by the manufacturers of the machines.

Market

The U.S. market for new dishwashers is currently supplied by 17 different manufacturers that produce a total of 565 dishwasher models under 47 different brand names. Of those models, 486 are Energy Star-compliant, or 86 percent of the total.[15] This indicates that while Energy Star has very successfully influenced the marketplace by encouraging the development of efficient product, the distinctiveness of the label for dishwashers has largely disappeared. As such, the actions being taken by the DOE to "raise the bar" on efficiency are necessary and welcome.

According to DOE data, and consistent with the marketplace inventory of Energy Star models cited above, nearly 86 percent of all dishwashers sold in the last quarter of 2004 met Energy Star qualifications.

Of the 486 Energy Star-qualified dishwasher models, 346 meet the requirements of the State of Oregon (a maximum WF of 6.5 gallons per cycle) and thereby qualify for their $50 tax credit.[16]

Dishwasher Use

Two important factors are worthy of note when considering the potential for a Best Management Practice related to residential dishwashers:

a) The household use of automatic dishwashers is declining.

   Energy Star and DOE have reduced the number of cycles of dishwasher use per year from 322 to 264 in 2002, then subsequently to 215 as the current estimate.[17] Oregon uses 215 cycles per year as well for their measure of water use.[18] This phenomena of reduced activity is attributed by many experts to the strong trend to dining outside the home (particularly in California, which leads the nation in restaurants per capita). It can also be attributed, in part, to the downward trend in household size (of those households that have dishwashers), which leads to a reduced use of dishware.

b) The pre-rinsing of dishes prior to loading the dishwasher is an unknown behavioral issue.

   Most automatic dishwasher manufacturers today recommend that the consumer load their machine without pre-rinsing. However, a certain (unidentified) number of people not only remove large food scraps but also rinse their dishware under the faucet or in the sink unnecessarily before loading. Of course, this is a behavioral issue that is largely unrelated to the water use in the automatic dishwasher and, as such, is not addressed in this paper. Authoritative studies on consumer habits related to pre-rinsing are necessary to establish the extent to which this frequently unnecessary practice is consuming water.

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[15] _______2005. *Market Impact Analysis on the Potential Revision of the Energy Star Criteria for Dishwashers*, June 10 (author unidentified)

[16] Oregon Department of Energy, 2006a. Qualifying Dishwashers, Apr 06. As viewable at: http://oregon.gov/ENERGY/CONS/RES/tax/appdish.shtml Note: Oregon sets the EF at a minimum of 0.61, which is below that that will be required by Energy Star beginning in 2007. As such, some of the models currently qualifying under the Oregon program would not be Energy Star-qualified after January 1, 2007.

[17] McNary, 2005.

[18] Oregon Department of Energy, 2006b. Qualifying Dishwashers as of March 1, 2006.

2. California Installations

Existing inventory

The only reliable, publicly available data[19] that exists regarding the installed base of automatic dishwashers is that provided through the Census data in the American Housing Surveys. This national data must be applied to California housing data on a percentage basis to arrive at an estimate for the state.

As of January 1, 2006, California's housing inventory amounted to 13.139 million units. Growth since 2000 has been as follows[20]:

Table 1. Housing Unit Inventory

January 1 of….	Housing Unit Inventory[21] (millions)	Inventory Growth in prior year (millions)
2000	12.215	
2001	12.307	.092
2002	12.448	.141
2003	12.599	.151
2004	12.758	.159
2005	12.942	.184
2006	13.139[22]	.197

Using figures from the 2003 American Housing Survey[23], we estimate that approximately 7.4 million automatic dishwashers are currently installed in California derived as follows:

Pre-2000 housing: 12.215 housing units x 54.1 percent =	6.608 million dishwashers
2000 to 2005: 0.925 housing units x 88.1 percent =	0.815 million dishwashers
Total installed base =	7.423 million dishwashers

According to estimates by various authorities, the older units (greater than 6 years old) are likely functioning within the range of 7.0 to 12.0 gallons per cycle[24], with an average we estimate at about 9.5 gallons.[25] The newer units (installations from 2000 through 2005) are functioning at an estimated 7.5 gallons per cycle. At these levels of efficiency, and with a use of 215 cycles per

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[19] It is very likely that individual appliance manufacturers and/or the Association of Home Appliance Manufacturers (AHAM) have substantial data on the installed base of residential dishwashers in the state, as well as current information on sales into the replacement and new construction markets. This information, however, is deemed proprietary and is not generally made available to water utilities or other "outsiders".

[20] California Department of Finance (DOF), 2006. *Report E-5a.xls, 1/1/2006*, May 1.

[21] Includes all types of housing units: occupied, unoccupied, single family, multi-family, group quarters, and mobile homes.

[22] California DOF reports population as of January 1, 2006 at 37.172 million, or 2.83 persons per total dwelling unit.

[23] U.S. Departments of Commerce and Housing and Urban Development, 2003. *American Housing Survey for the United States: 2003.*

[24] Vickers, Amy, 2001. Handbook of Water Use and Conservation, p131. WaterPlow Press, May.

[25] McNary (2005) estimates that the new non-efficient models are using 10 gallons per cycle. Vickers estimates that the older models (1990 to 1995 and 1995 to present) function at 7.0 to 12.0 gallons per cycle.

year, annual water use in California currently approximates 45,500 acre-feet (exclusive of any pre-rinsing by hand).

Annual additions to the inventory

Annual additions of housing units to the California inventory during the 6-year period of 2000 to 2005 averaged 154,000 units.[26] While this figure will vary significantly as the economic and housing cycles occur, it is fairly consistent with the projected housing unit additions through 2040.

The California DOF estimates that state population will reach 51.5 million persons by 2040.[27] At the current persons per housing unit ratio, such an increase would indicate that an additional 5.1 million housing units will be required by that date. Data from the 2003 American Housing Survey reveals automatic dishwasher installations were found in 88.1 percent of the new residential housing units (4 years old or less – see Figure 1). Using this data, we can project that about 4.4 million new dishwashers will be installed in new construction during the 34-year period from 2006 to 2040, or a average of about 130,000 annually. By 2040, the number of installed dishwashers will have grown from 7.4 million to nearly 12 million.[28]

The addition of 130,000 new dishwashers to the inventory each year will add about 600 acre-feet to the water demand. At the same time, existing dishwashers will be replaced with units of higher efficiency. (The normal physical life of a residential dishwasher is about 10 years.) As water factors decline and units are replaced, the overall demand for water is expected to decline as well. By 2025, water demand is predicted at slightly over 40,000 acre-feet per year, a reduction of 5,500 acre-feet of demand based solely on natural replacement with more efficient machines.

Figure 2 illustrates the demand profile for the period from 2005 to 2025. It should be noted that while demand has declined over the 20-year period, it is beginning to rise again by 2020. No projections beyond 2025 were attempted due to our inability to predict the marketplace WF for these appliances.

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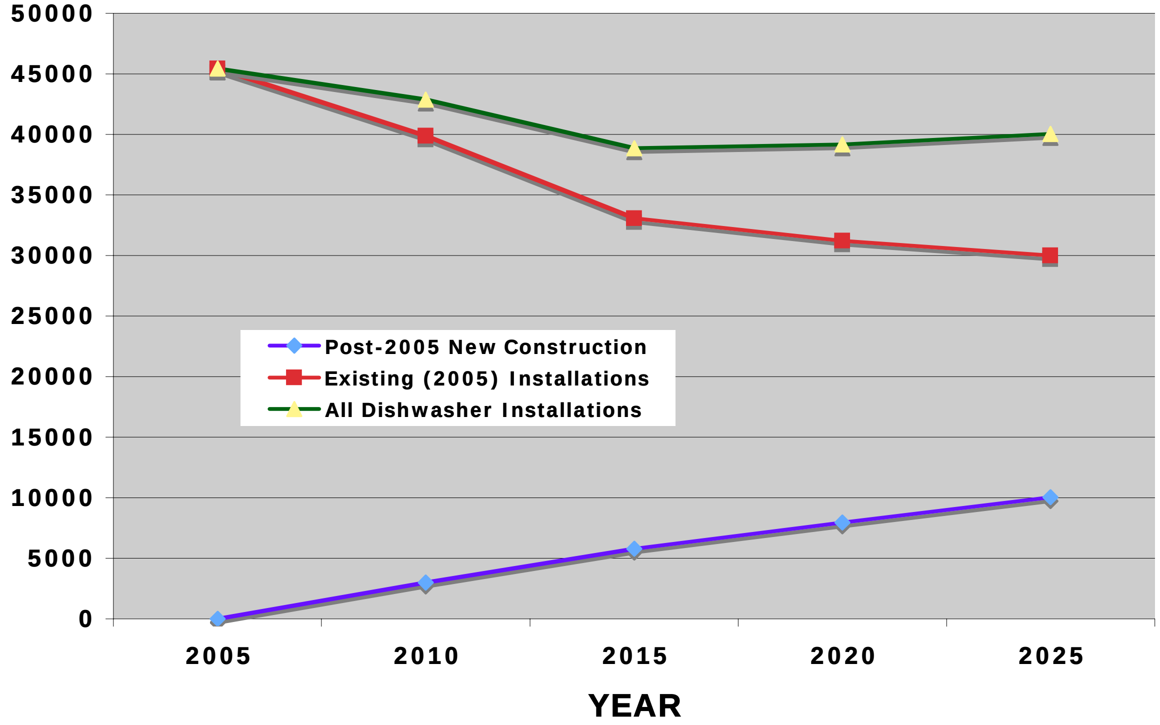
[26] 925,000 new housing units over 6 years = 154,000 units per year.

[27] California DOF, 2005. *P-1 Tables.xls*, November 7.

[28] This assumes that the installation rate of 88.1 percent prevails through the entire period.

Figure 2. Projected Annual Water Use by Residential Dishwashers -



3. Water Savings Estimates

Water savings through the implementation of a BMP for residential dishwashers will be achieved entirely through reductions in the WF. Because WFs appear to already be on a general decline due to energy efficiency initiatives by the DOE and the Energy Star program, water use will naturally decline as older machines are replaced. For the purpose of developing Figure 2, WFs were assumed as follows:

Table 2. Projected Water Factors for Dishwashers

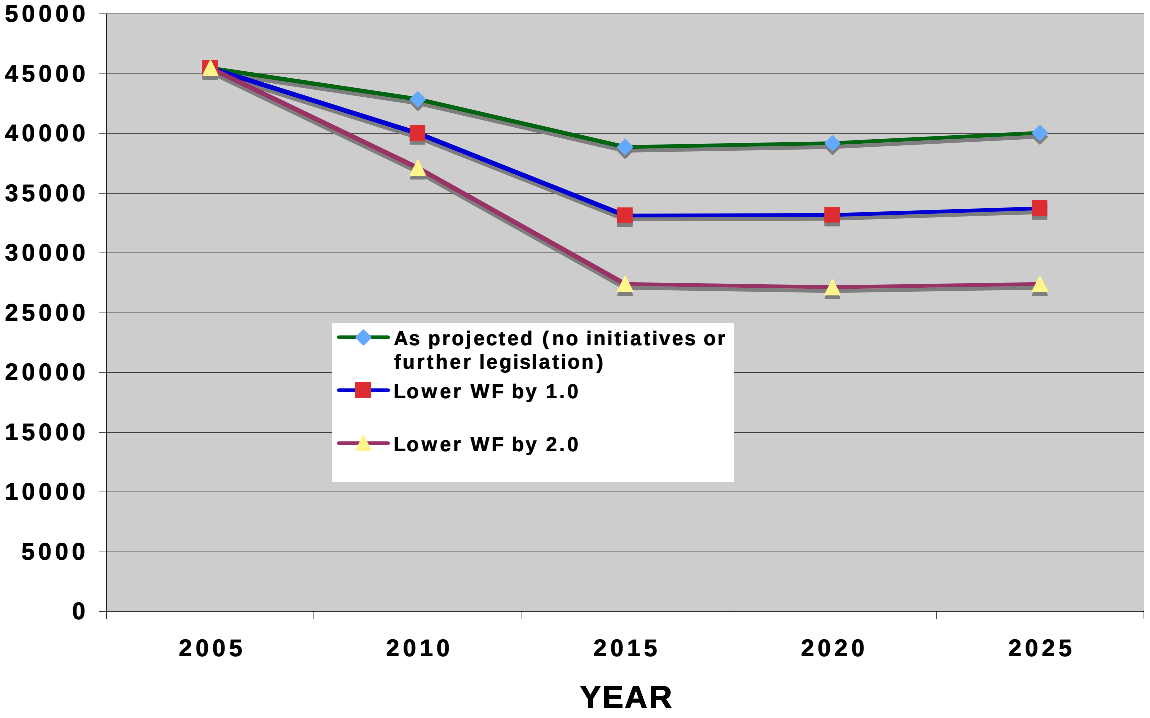
Dishwashers delivered to market in…	Assumed Average Water Factor
2006-2010	7.00
2011-2015	6.50
2016-2020	6.25
2021-2025	6.00

A reduction in the maximum WF through legislation (mandatory) to something less than these figures would yield savings in 2025 estimated as follows:

- Reduction in the average WF by 1.0 – reduction of 6,300 AFY
- Reduction in the average WF by 2.0 – reduction of 12,700 AFY

Figure 3 illustrates the water demand by dishwashers at the projected efficiency without any mandated changes, as well as the demand that would result with the above reductions in the WF.

Figure 3. Projected Annual Water Use With Reduced Water Factors



Those who might advocate the elimination of automatic dishwashers as a means to save water would, in fact, probably be encouraging an increase in household water use, since at least one such study indicated that the "water factor" for hand washing is as high as 18![29] The study found that to clean 12 place settings of dishes, an average of 27 gallons of water was used. (Converting this to the 8-place setting criteria of the DOE, for example, would mean that the water use was 18 gallons per "cycle".)

4. Cost Effectiveness

The cost of implementing a mandatory WF through legislation is difficult to estimate. If such an initiative were undertaken and legislation approved today with an implementation date 10 years hence (when overall water demand from dishwashers begins to increase), costs might be negligible. If, on the other hand, appliance manufacturers were pressed through legislation to comply with an aggressive WF within 2-4 years, the costs would probably escalate as industry resisted.

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[29] Home Energy Magazine, 2004. *Is a machine more efficient than the hand?* by Rainer Stamminger, University of Bonn, May/June 2004.

Because of the minimal water use of residential dishwashers (only 1.4 percent of water use in a single family home is attributed to dishwashing[30]), the short 10-year physical life, and the improving efficiencies of these machines, it is not recommended that the water providers attempt to develop rebate structures directed at today's installed base of machines. Figure 4 displays what subsidy (rebate or other financial incentive) could be "justified" at various values of water and with three different WF reduction thresholds.

Figure 4. Justifiable Financial Subsidy (Rebate) at Various Reductions

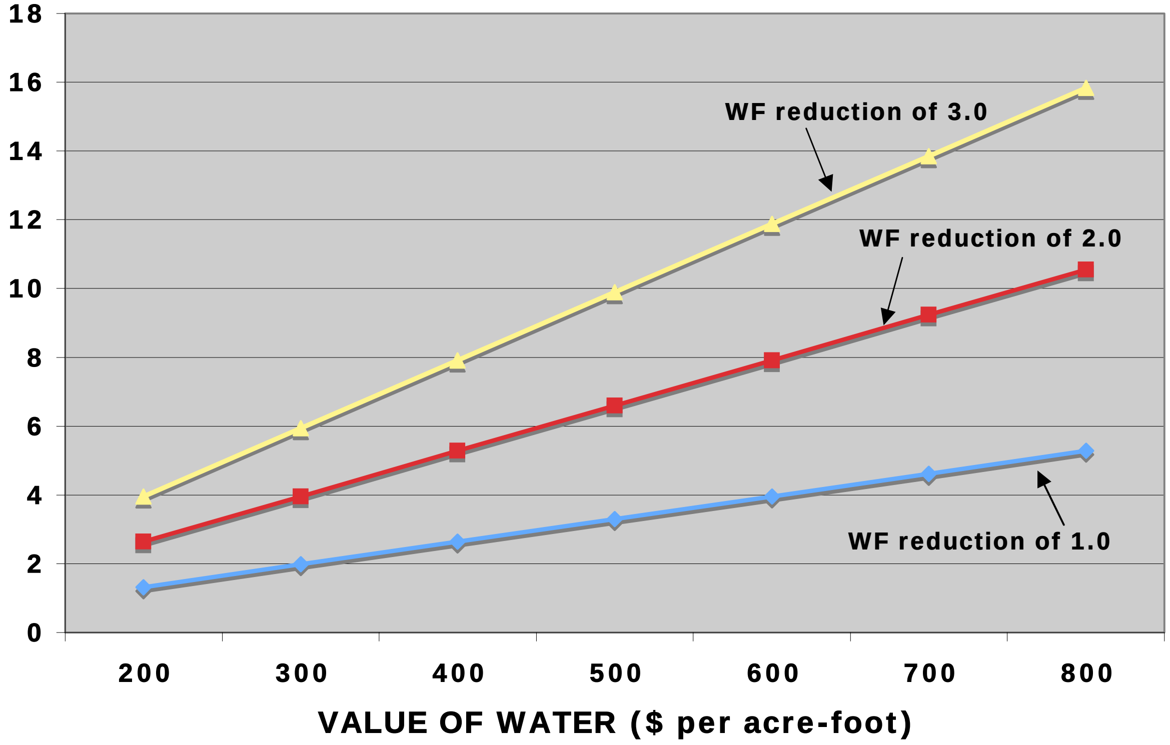

Figure 4 illustrates that even with an aggressive WF reduction of 3.0, the subsidy by the water utility would not exceed $16 per dishwasher replacement where the value of the water is $800 per acre foot. This small subsidy is probably insufficient to even market and administer a program, much less provide a financial incentive to a customer. Furthermore, it is likely that such a rebate would be largely consumed by freeriders, although there is no data to indicate that such is the case with energy rebates for dishwashers.

The only area where a Potential BMP appears feasible in the short-term is through the green building approach, directed at new construction. Here, the water providers have the opportunity to influence the various national and regional green building programs to incorporate a WF into

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[30] Mayer, P. et al., 1999. *Residential End Uses of Water Study*, American Water Works Research Foundation, Denver, Colorado

their guidelines and criteria. The costs to do so are negligible, inasmuch as the water interests are already working with these programs and organizations to incorporate water efficiencies in other areas of new homes. Including residential dishwashers with a WF of 6.5 or less, for example, would be relatively easy to implement for most of the programs in existence today.

5. California Potential

The additional initiatives on dishwashers that might be taken through or because of a BMP will probably not yield the savings that BMPs associated with other indoor appliances and fixtures might. Therefore, while the magnitude of potential savings (as noted above and in Figure 3) appears to be meaningful and worthwhile to pursue, the other areas in the residential sector probably deserve more attention than dishwashers.

Overall, the water savings potential for California that might be achieved with more resource-efficient residential dishwashers is estimated at between 6,000 and 12,000 AFY if legislation mandating aggressive WFs is implemented. On a voluntary basis (through green building programs[31]), we project that less than 20 percent of this potential could be captured. However, in both cases, the cost to the water providers to seek out either or both of these avenues for increased efficiencies would be minimal and, in most cases, would be encompassed within existing advocacy programs directed toward legislation and green building.

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[31] A few new home green building programs are beginning to incorporate WFs for residential dishwashers into their guidelines or standards, although it is not yet a widespread practice. The usual focus by these programs is instead upon the higher water-using elements of the new home, such as landscape and plumbing.

V. Vehicle Wash Systems

1.0 Background

Commercial vehicle washes present a two-part opportunity for water conservation based both upon differences in construction and upon operator preferences. In this chapter, the functional difference between vehicle wash systems and categories are examined first, followed by a discussion of the operational measures employed by these businesses. The water savings potential and cost benefit estimates are presented for each of the different types of vehicle washes.

Commercial carwashes are categorized as either conveyor, in-bay automatic or self-serve, and include those carwashes that are available for public use at stand-alone carwash facilities, as well as those alongside convenience store, lube shops or gasoline stations. The three basic types of equipment within those categories are also used for truck and bus washing and for washing vehicles at dealerships and rental agencies. Some truck washes are available commercially, but many are for washing fleets and are typically located on private property. Conveyor and in-bay automatic carwashes can be constructed as friction or touch-less, which further affects water use. All these basic types of carwashes can be retrofitted for or built with water reclaim systems.

The International Carwash Association summarizes the "Steps in a Professional Car Wash Process"[32] that affect water use as follows:

- Pre-soak. An automated nozzle or hand held spray.
- Wash. High pressure spray or brushes with detergent solution.
- Rocker panel/undercarriage. Brushes or high pressure sprays on sides and bottom of vehicle.
- First Rinse. High pressure rinse.
- Wax and Sealers. An optional surface finish is sprayed on the vehicle.
- Final Rinse. Low pressure rinse - with fresh or membrane-filtered water.
- Air Blowers. Air is blown over the vehicle to remove water and assist in drying.
- Hand Drying. The vehicle is wiped down with towels or chamois cloths on site. In full-service washes these are then laundered in washing machines on-site.

To differentiate among the three categories, in a professional conveyor car wash, these steps are performed by separate spray arches and/or brushes. In the professional in-bay automatic, there is a set of nozzles through which all processes are performed, except in some cases where brushes may be used for the wash cycle. In professional

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[32] Brown, C., 2000. *Water Conservation in the Professional Carwash,* International Carwash Association.

self-service car washes there may be a brush for the wash cycle, but all other functions are performed through a hand-held wand.

In addition to the three basic carwash types, mobile washing services, detailing services including hand washing, and some industrial vehicle washing systems exist with unique challenges and opportunities for water-use efficiency. These will be dealt with at the end of this chapter.

1.1 Conveyor Carwash

The conveyor carwash is usually installed in a tunnel, and includes a series of cloth brushes or curtains and arches from which water is sprayed while the car is pulled through the tunnel on a conveyor chain. In some "touchless" carwashes, only spray nozzles are found. In full service conveyor carwashes, hand drying usually follows the conveyor, and often the pre-soak is done by hand-held wands like those found at self-service carwashes.

In friction carwashes, the wash cycle is accomplished with brushes or soft cloth curtains. Conveyors with friction components use less water than frictionless washes because the brushes or curtains pick up water and detergent from the pre-soak of cars as the day proceeds.[33]

The most recent national survey of carwash businesses reported that 73 percent of conveyors use friction components in the wash.[34] California specific data were not available and, thus, not separated out in the report.

Timing is a critical component in carwash water efficiency. In properly calibrated conveyors, nozzles are timed to turn on as the vehicle passes under the arch, and shut off as exits each arch. Each arch is on for a matter of seconds, as conveyors can process 90 or more cars an hour. Efficiency is also maintained by proper nozzle alignment and pressure.

Additional water efficiency is obtained by the orientation of blowers after the final rinse to push water back into the tunnel, or to construct a longer length of tunnel after the final rinse arch. Water that otherwise would be carried out of the tunnel can flow back into sump, and be reused in the carwash with a reclaim system.

In a full-service conveyor, towel-drying of the car is one of the services offered. In many older car washes, towel washing sinks are designed for a constant flow of water through the sink. Installation of a float ball valve to halt the flow of water when it reaches an optimum level is one water efficiency measure. Replacement of older flow-through sinks, or top loading washing machines with new front loading machines will cut water consumption by 40% or more. Some conveyor washes, referred to by the industry as "exterior-only," do not offer drying or detailing services, so visual confirmation of the existence of towel washing machines is necessary.

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[33] Kobrick, J.D., et. al., 1997. *Water uses and conservation opportunities in automatic carwashes: A City of Phoenix study,* June.

[34] Billings, A., ed, 2000. *Almanac for the Year 2000,* Auto Laundry News, Vol. 48, No. 14.

1.2 In-Bay Automatic Carwash

In-bay automatics are characterized by a wash bay in which the customer stays in their car as the carwash equipment uses either spray nozzles or brushes, or a combination of both to process the individual cycles. The car remains stationary within the carwash bay during the process. The carwash machinery is moved over the car by a gantry. In-bay automatics also have the greatest variety in basic design with some machines comprising an entire moveable arch, others having vertical and horizontal arms suspended from the gantry, and yet other designs including spinning arms that are attached to the gantry.

Nozzle size, number and alignment, flow rates and timing all affect water use in the in-bay automatic carwashes. Since all water flows to one pit, and all chemicals mix together, reclaim systems can be more costly and a bigger challenge to maintain than in conveyor carwashes. In addition to water used in the pre-soak and wash cycles, many in-bay automatic operations offer a spot-free rinse. This is typically obtained with reverse osmosis (RO) or deionization (DI) equipment. A more detailed discussion of water treatment systems found in commercial carwashes is covered later.

As with the conveyor car wash, in-bay automatics that use brushes or cloth use less water than frictionless or “touch-free” car washes. Some in-bay automatics also reduce water use by employing laser sensors to identify the length of the vehicle being washed, and limiting the gantry movement and timing of wash based upon the sensor signals.

1.3 Self-Service Carwash

Self-service car washes are typically coin-operated with spray wands and brushes operated by the customer. The wash facility typically contains a central equipment room, in which water process equipment is housed, along with four to six wash bays. The customer controls whether and for how long low-pressure or high-pressure settings are used. Thus, the carwash owner/operator does not have direct control over the water use at the facility. But with a fixed pricing structure for the initial purchase of several cycles, plus the ability to purchase additional time (usually at a 25¢ per unit), the customer has a direct monetary incentive to move as quickly as possible, thus conserving water. Studies of car wash water use efficiency have shown that self-service carwashes use the least amount of water on average per vehicle.

In addition to water used in the pre-soak and wash cycles, many self-service operations also offer a spot-free rinse. Like the in-bay automatics, reject water from the RO unit can be utilized in landscape watering where landscape exists.[35] Because customers wash their own cars unattended, self-service operators sometimes find evidence of oil dumping, or organic materials in the waste water. These provide very difficult and expensive insults to filters, and are a disincentive to the use of reclaim in self-service washes.

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[35] However, since reclaim is not typically used in self-service washes, except where required by law, reuse of RO reject water is not typically an option.

1.4 Truck, Bus and Fleet Washes

The type of equipment used to wash trucks, buses utility vehicles and heavy equipment is the same as described above except for scale. If in an industrial or construction-related use, potentially much greater amounts of dirt and grease must be removed. As such, water use per vehicle is higher than in a typical carwash. Some commercial truck wash operators are coin operated and charge customers by the length of the vehicle, usually at a unit cost per foot length. Due to differences in vehicle size and shape, hand held wands are prevalent in truck washes. One modified type of equipment is a drive through arch, similar to those found in conveyors, but where the driver controls the speed at which they move under the arch. These are referred to as "drive through tunnels", although sometimes the arch is found without a surrounding building. Electronic or magnet sensors are used to turn the arch on and off as the vehicle enters and leaves the arch. Thus the speed of the vehicle driving under the arch controls the amount of water used.

Fleet washing of light passenger vehicles (such as in an auto dealership or at a rental agency) is typically done with either in-bay automatic or hand held wands and brushes found at self-service facilities. The Irvine Ranch Water District (District) surveyed 24 automobile dealerships to determine the carwashing equipment being used.[36] They found that 87.5 percent of automobile dealers have on-site car wash facilities in their service areas. Examining the dealerships by type of carwashes found that 62.5 percent had self-service type wands, 20.8 percent had in-bay automatics or drive-through type washes[37] and 4.2 percent had conveyors. Fleet washes such as these were not included in the ICA Study, but could reasonably be estimated to use about the same amount of water per vehicle as their commercial counterparts.

Another technique, which is not well studied, includes the amount of water used by detailing or handwashing businesses. A survey of commercial car washes in 1999 found 5% of respondents operating hand washes.[38] Anecdotal observation suggests that hand washing and detailing businesses have grown as a sector of the carwash industry, although there are no firm numbers on water use or size of market.

Other equipment which is washed such as airplanes, boats, farm equipment, trailers, construction equipment such as dozers, backhoe loaders, excavators, dump trucks, and military equipment may also be considered for inclusion in this BMP, but like the examples above, water use has not been quantified.

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[36] Sanchez, Fiona, 2006. Personal communication, Conservation Manager, Irvine Ranch Water District, April 28.

[37] No studies of water use in drive-through facilities have been published, but due to the slower speed of the vehicle proceeding through a drive-through arch, an industry representative anticipates water use to resemble an in-bay automatic more than a conveyor. Bill Sartor, former Chair of ICA, personal communication, April 2006.

[38] Billings, ibid, 2000.

1.5 Opportunities and Practices for Water-Efficiency

Two program approaches have been used by utilities seeking to promote efficiency in the car wash sector. One approach is to promote the use of reclaim systems, and the other is to promote the use of lower flow nozzles and other proven conservation practices. The second approach, sometimes combined with the first, is typically offered as a voluntary certification program for those carwash operators that agree to operate and maintain their facility to water efficiency standards. Both approaches to carwash water efficiency are examined here.

Reclaim Systems

Water reclamation in the professional carwash covers a wide range of practices and equipment. Numerous manufacturers produce full reclaim systems with all components included, or operators can instead purchase filtration and de-odorizing components and construct a site-specific system for their facility. Treatment levels need to be appropriate to the number and level of cycles in which reclaim water is used. The least amount of filtration is needed for the water used to wash dirt and grime from the undercarriage and lower parts of the vehicle carriage (rocker panel). As wash and rinse cycles are added to the list of cycles using reclaim water more filtration and water quality treatment measures are required. Additional challenges exist in in-bay automatic and self-service washes. The general process of reclaim and some of the challenges common to many systems are explained below. Information specific to a particular manufacturer's product or reclaim approach is not included.

Prior to filtering water and reusing it in the carwash, grit, oil and grease must be removed from the wash water. This can be accomplished in a series of tanks or separate compartments within a large separator tank. Settling and separation tanks must be large enough to allow water flow to slow and large particles to settle to the bottom of the tank. The first separation step is to remove oil and grease, allowing water to flow under a baffle or through a pipe placed low in the tank wall, with its upstream aperture open toward the bottom of the tank. The settling compartment is next, and water will flow over a barrier, or through a pipe located near the top of this compartment to the third compartment from which reclaim water is pumped for reuse or further filtration and treatment before reuse.

Some reclaim systems use the water after the separation tank with no further treatment. In these systems the water may be used in an under carriage or a rocker panel cycle, and to wash down the carwash tunnel or bay. Some reclaim system use simple cyclonic filtration systems to remove suspended particles in order to protect pumps and the finish of vehicles. Such systems can use the reclaim water in initial pre-soak cycles. Where reclaim water is to be used more extensively in the wash, additional filtration and treatment are performed. These can include bag or media filtration to remove particles above 10 microns in size, so the reclaim water may be used with high pressure pumps to perform the wash cycle. Filter media can include sand, diatomaceous earth, glass, or olivine. Absorption filters used in this stage of the wash process include cloth, paper or other synthetic materials. Carwash employees must be trained and regularly maintain the filter media.

Such filtration allows the reuse of water which would otherwise cause a variety of problems for the carwash operator. Larger suspended particles can scratch the vehicle's finish while smaller particles, including dissolved solids, can cause spotting. For operators wishing to recycle a larger percentage of their water, or who are restricted from discharging to the sewer, more sophisticated treatment is needed. Oils, soaps and finish products entrained in the wash water that are not caught by the multi-media filter require additional treatment steps. For example, an activated charcoal filter can remove organic compounds including hydrocarbons from the water prior to return to the wash system.

Most modern carwash reclaim systems do not bother with separate flocculation chambers, pulling water from the clarifier section of the carwash separation tank after baffles have intercepted most of the floating and sinking waste. Some reclaim systems may use additives to assist in flocculation of suspended particles. Simple bag or media filtration or cyclonic separators may be used to remove additional contaminants before reuse.

Filter maintenance is crucial, for either particle or cloth media. Backwashing cleans and reactivates granular media. Closed loop systems direct the backwash water into the separation tank of the car wash. If available and permitted, the reclaim system may send the backwash water to the sanitary sewer system. Overflow from some reclaim systems is also piped to the sanitary sewer system where available.

Carwash operators occasionally have problems with reclaim water, including issues of odor and color. In in-bay automatics, or in a self-service environment, where the customer is more likely to come into contact with the water, these can create perception concerns. On the other hand, when the customer is not exposed to the reclaim water (as in a conveyor wash where the customer is not in the vehicle), this issue is less critical.

Color and odor problems with reclaim water may be caused by bacterial or algal growth, or from hydrocarbons washed off the vehicles. Oxidation is the solution to this problem. Several methods of treating for color and odor are available: aeration, including running air through the tanks; recirculating the water after filtration; chemical solutions such as chlorine or chlorinated products; or, in some cases, a deodorant may be used to mask the odor.[39] Some systems use ozone.

Since ozone can be hazardous, and is very reactive, it needs to be used in such a way as to prevent exposure to carwash operators. The oxidizing reaction neutralizes the ozone while removing the odor and color problems.[40]

A technology growing in use in commercial car washes in the United States, and found in Europe and in industrial settings is enzyme technology. Known as bio-systems or biological control, it requires a reaction tank where organic contaminants can be digested.[41] These systems are already in use in reclaim systems found in some industrial settings in the U.S. The industrial setting permits aerobic bacteria to do the job, as tanks can be left open to the air when sited at a distance from public access. Closed systems have been developed for use in facilities where the public may be nearby.

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[39] Anderson, Shane, 1999. Gin-San, Personal communication, September 27.

[40] Pero, S, 1999. *A declaration for water reclamation,* Carwashing & Detailing, August.

[41] Duplantis, J., 1998. *Where ozone meets your water,* Carwashing & Detailing, March.

Whatever type of reclaim system is used, several practices must be implemented by the operator to prevent fouling and/or failure of the system. Cleaning and finish products need to be chosen for compatibility with each other and with the reclaim systems components to prevent entraining of emulsified oil, and fouling of filters. The employees responsible for operating the equipment must be properly trained and regular maintenance must be performed on all reclaim system components. Failure to perform any of the above practices will lead to problems with the reclaim system, and possible abandonment of its use.

Conveyors and Reclaim

In conveyor systems, the length of the tunnels can provide opportunities to reclaim rinse water separately from wash water, necessitating different levels of treatment. This can create more cost-effective reclaim opportunities. For example, more difficult-to-treat chemicals, such as those in waxes or finish products, which are used in small quantities, are routed away from the principal reclaim system, which picks up water from earlier in the wash. Final rinse water can also be reclaimed and reused with less treatment. The wide variety of ways that reclaim can be performed in conveyor carwashes results in a broad range of reclaimed water usage measured as a percentage of total water used per vehicle in the 2002 ICA study. The lowest amount of reclaim water used in a conveyor wash with reclaim was 9 percent per wash and the highest was 74 percent. The 2002 study also found that 56 percent of conveyor washes in the United States have a reclaim system[42].

In Bay Automatics and Reclaim

Reclaim equipment companies generally acknowledge that in-bay automatics provide a more expensive challenge to reclaim systems, since all chemical products, from cleaning to finish, as well as oil and grease, and contaminants from the road, winds up in the same separator tank. The water needs to be treated to remove all constituents that would interfere with its eventual reuse in the wash. The 2002 ICA water use study also found a wide variation in reclaim usage rates in in-bay automatics with a low of 12 percent per wash and a high of 82 percent per vehicle washed. The 2002 study found that 25 percent of in-bay automatic washes in the United States have a reclaim system[43].

Self Serve and Reclaim

Reclaim systems are not usually used by self-service carwashes due to the relatively few gallons per vehicle used by self-service customers. However, a closed loop reclaim system is used in self-service carwashes where no discharge to sanitary sewer is available, and all discharge is restricted.[44] In these situations, it is not uncommon for the self-service to be staffed on-site in order to prevent misuse of the facility by customers dumping contaminants in the pits.

Large Vehicles and Reclaim

Reclaim also has an important role in industrial uses and for large vehicles as noted above. The controlled access to such facilities allows for more innovative treatment of the water, such as

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[42] Brown, C., 2002. *Water Use in the Professional Carwash Industry,* International Carwash Association.
[43] Brown, ibid., 2002.
[44] Anderson, ibid., 1999.

longer residence times, and use of enzymes, with lower cost systems. Rainfall can be captured to replenish systems, and thus closed loop systems can approach 100 percent nonpotable water use. A bus wash reclaim system in Seattle, for example, which was partially funded by the Seattle Public Utilities, achieved in excess of 80 percent efficiency and saved more than 200 gallons per vehicle. Similar results could be expected for other large vehicle reclaim systems, but studies on this sector have not been performed.

Water Softeners and Spot-Free Rinse Equipment

Water softeners and additional filters for spot-free rinses are found in carwashes where hardness or high TDS levels in the water supply can cause spotting as the vehicle dries. Softening can also reduce the need for detergents in the wash process, and spot-free rinse leads to lower costs for treatment in a reclaim system. Because conveyor washes often use hand-drying, water softening and spot-free rinse equipment are more often found instead at in-bay automatic or self-service facilities. Two of the more common means of achieving a spot-free rinse are the use of reverse osmosis (RO) and deionized (DI) water systems. A 1999 survey of the carwash industry found that 60 percent of self-service carwashes have water softeners, 48 percent offer spot-free rinse with RO and 7 percent offer spot-free rinse with DI[45].

All three of these processes have potential impacts on water quality and water quantity, both of which need to be considered as part of either a certification program or a reclaim system. Reject water from the RO unit can be utilized in landscape irrigation where a car wash operation has landscaping, or can be discharged to the carwash reclaim system. DI ion beds require periodic regeneration, and the process must be performed properly to avoid producing excessive contaminants in the carwash discharge stream. Water softeners place salts into the discharge water, and use water in backwashing the ion bed. Recharging of both water softeners and DI systems should be performed based upon the amount of water treated, not upon a fixed time schedule. During a site compliance review, the machinery should be examined to determine if a timer or a meter is used to trigger regeneration.

Certification

Certification of carwash businesses has been pursued in a number of cities in the west and southwest, Denver and San Antonio being the largest. Certification involves an initial audit to determine compliance with typical carwash best management practices (BMPs), followed by annual inspections to determine continued eligibility. Certification incentives have included: signage, promotion by the utility, ordinance provisions requiring charity car washes be performed at certified facilities (provides businesses with an opportunity to self-promote while helping non-profits), and relief from certain drought provisions as in day-of-week or time-of-day operating restrictions.

Requirements for certification have included an average freshwater (potable water) gallons per vehicle usage ceiling, specific nozzle size requirements, regular replacement of nozzles, prompt repair of leaks, and/or the use of reclaim water. Due to the variability in water use based upon differences in carwash configuration and equipment, the limits of freshwater usage per vehicle

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[45] Billings, ibid., 2000.

have typically been 40 to 50 gallons per vehicle (gpv) range. By establishing upper limits on freshwater use per vehicle, it has avoided situations in which utilities could be accused of favoring one brand of equipment over another. The 2002 ICA water use study has had an impact on manufacturer perception of the need to reduce water use, causing them to redesign some in-bay automatic equipment to increase efficiency. However, that study was performed without identification of specific branded equipment; as a result, utility conservation staff do not currently have a brand-specific source of normative data similar to studies of toilets and other water using equipment.

The 2002 ICA study also showed that freshwater use is held to ≤30 gpv in in-bay automatics and conveyors with most equipment and with the use of a reclaim system.[46] Since self-service facilities rarely approach the use of 30 gpv and the actual gallons used is at the discretion of the customer, a 3.0 gpm nozzle is required in San Antonio. (Since a number of the cycles in a self-service wash are at low-pressure, this limitation leads to a gpv of less than 14.5 gallons on average.)

Certification programs can also require RO reject water to be recycled or used in landscape irrigation where local regulations allow. One of the benefits of a reclaim system is the reduction of waste constituents in the discharge to the sewer. Where sanitary sewer fees include surcharges based upon water quality, the local staff of the wastewater treatment utility should be consulted to determine if they would like to participate in design and implementation of a car wash certification program in order to provide incentives to reclaim water.

Municipal Ordinances and State Regulation

A number of cities and the state of Florida have used legal restrictions on carwashes to achieve greater efficiency goals. The city of El Paso, Texas requires all new car wash facilities constructed after June 2002 to use no more than 50 gpv of freshwater, but does not specify reclaim systems as a requirement. The state of Florida, the cities of San Antonio, Texas, Denver and Centennial, Colorado and a number of California cities, all require new in-bay and conveyor carwashes to be constructed with reclaim systems. The State of Florida is concerned about discharges and maintaining water quality in the state's ground and surface water systems. The Florida Administrative code requires an industrial general permit for all carwashes that recycle water[47]. One result of this approach has been to limit the number of self-service facilities constructed in Florida since the law was passed, because self-service sites with reclaim systems need staffing 24 hours per day to prevent customers from dumping motor oil or other materials that would foul the filters.

Florida's Division of Environmental Protection has published a best management practice focused on water quality to assist carwash operators with the zero discharge requirement.[48] The BMP deals with truck washing as well as car washing issues. "Residential" carwashes in Florida that use less than 4,000 gallons per week are exempt from the reclaim requirement.

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[46] Brown, ibid, 2002..

[47] Section 62-660.803

[48] Florida Department of Environmental Protection, 2005. *Guide to Best Management Practices: 100% Closed-Loop Recycle Systems at Vehicle and Other Equipment Wash Facilities,* Industrial Wastewater Section, October.

The Florida BMP focused on water quality points out another potential avenue for designing a vehicle wash conservation BMP. Vehicle wash facilities are typically regulated as to their type and quantity of discharge. The separation tanks, which are essential to properly operating reclaim systems, are also a requirement for operations discharging to publicly owned water treatment works (POTW). Federal and state limits on discharge are also imposed by regulators, especially if a facility discharges to surface or ground water rather than a POTW. Reclaim systems assist reducing discharge quantities by removing more contaminants from the waste stream. Local water quality personnel should be consulted to determine if common BMPs for carwashes can be developed which assist in reducing contaminant discharges as well as reducing water use.

System Retrofits

Adding a reclaim system to an existing carwash can be cost-prohibitive, in large part due to problems with the configuration of the existing building and plumbing. This includes issues such as: separation tanks being too small for additional storage, insufficient room for additional storage tanks, key pipes running through walls or beneath concrete or asphalt floors and driveways where connections to the reclaim system need to be added, and similar impediments. As a result, the costs to renovate the facility can be quite high. For this reason, some communities have required reclaim systems on new carwashes only, and have not addressed retrofit of existing car washes.

The difficulty in quantifying retrofit potential in existing carwashes stems from three separate factors, relating to location, equipment, and costs. These factors result in site-specific constraints on accurate estimating costs and potential water savings. For example, some fully skid-mounted reclaim systems exist (with all significant components included) and are marketed to carwash operators. However, due to equipment room configurations, these systems do not fit all carwashes. Therefore, it is necessary for some carwash operators to retrofit with a reclaim system by separately installing the each of the system components required, e.g., filtration, pump and treatment equipment. In addition, some systems require additional water storage capacity for the treated reclaim water, for which there may not be room in either the original facility building or within the facility's property boundary.

As a result of these facility-specific circumstances, a utility considering funding retrofits may be faced with: some customers who are unable to retrofit without major renovation to facility buildings and plumbing; others who are able to use all-in-one skid mounted systems; and yet others who can only install some of the necessary equipment – thus limiting the amount of water they can successfully reclaim. This results in an inability to accurately estimate the quantity of water saved through reclaim retrofits in the scale of this analysis. At a utility scale, each facility would need to be analyzed on a case-by-case basis for the cost-effectiveness of a proposed rebate or other subsidy.[49]

The data from the 2002 ICA study showed that the lowest amount of water recycled in a carwash was 9 percent of total gpv, with the highest being 82 percent of water used per vehicle[50]. This

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[49] Such as would be the case in evaluating process water system improvements in certain unique applications, such as in the manufacturing or commercial laundry sectors.

[50] Brown, ibid., 2002, p. 39.

large range of reclaim water percentages demonstrates the difficulty in providing accurate estimates without more detailed on the type s of reclaim systems anticipated, and the associated costs of modifications to the existing facility.

On the other hand, adding an RO system to an existing car wash can be accomplished very easily - most systems require little room and in a crowded equipment room can be installed on the wall. The associated storage tanks, however, need sufficient space and this can prove to be difficult in some circumstances. RO systems increase the amount of water used in final rinse, due to their reject water. However, in a vehicle wash with a reclaim system, the reject water can be used in initial pre-wash rinse or undercarriage cycles in the wash.

2.0 California Potential

Due to the nature of the sample and survey data – small sample size and market data based upon voluntary survey response – the results of the water savings analyses are presented here with caution. Census data typically only identifies conveyor type systems as carwash businesses. In-bay automatics, on the other hand, are typically linked with combined convenience store/gasoline station businesses or with lube shops and, as such, do not show up in the census data. Furthermore, self-serve operations are typically owned by businesses or proprietors with other primary business activities, and without an office on site.[51] Thus, they, too, are uncounted in the census.

For this analysis, conveyor carwashes are considered to be represented by U.S. census data for California, which counted 1,555 such businesses in 2002[52]; this constituted 11.1 percent of total carwash businesses listed in the U.S. Economic Census.

The estimated number of self-service carwashes was determined by multiplying the national estimates of self-serves by 11.1%, which results in approximately 1,600 such facilities in California in 2002. Potential growth in the conveyor and self-service sectors is based upon growth from 1997 to 2002 in these business sectors in California.

In-bay automatics were estimated at a similar percentage of the total estimated in-bay facilities in the U.S. as estimated by the carwash industry in 2000. This calculation results in approximately 2,700 in-bay automatics in California in 2002. However, growth in the in-bay market is estimated based upon growth rates in gasoline stations, since most in-bay automatics are co-located with gasoline/convenience store businesses. In 2002, the 2,700 in bay automatics estimated for California represented 46.7 percent of the gasoline stations reported by the U.S. Census Bureau for California.

The number of estimated vehicles washed is based upon a 2002 market study performed by the ICA. An annual average of 82,019 vehicles were washed in conveyor-type systems, 54,184 in in-bay automatics, and 92,093 at self-service carwashes.[53] Water use estimates for both the freshwater and reclaim water use per vehicle were derived from the ICA's *Water Use in the Professional Carwash Study*.[54]

2.1 Reclaim Ordinance Scenario

The reclaim ordinance scenario assumes that, beginning in year 2010, ordinances statewide will require all new in-bay automatic and conveyor carwashes to install reclaim systems, that growth in the industry is reflective of growth found in California from 1997 to 2002, and that there is a natural replacement rate of 30 years for a commercial car wash. To eliminate overestimation of savings due to changes in ordinances, existing reclaim rates for the two types of carwashes (25 percent for in-bay automatics and 56 percent for conveyors) were deducted from the potential savings. With an average 30-year physical or economic life of carwash equipment, an estimated

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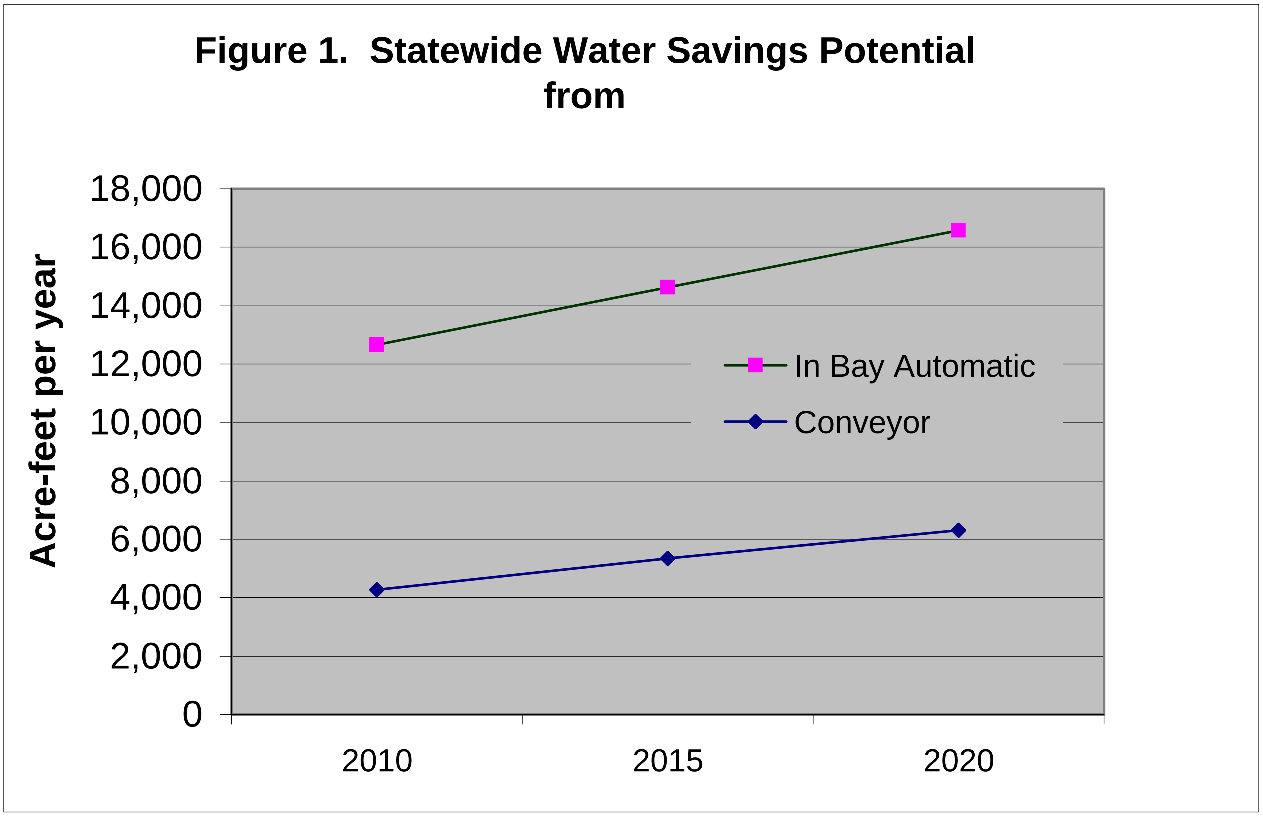
[51] Billings, ibid., 2000

[52] 2002 Economic Census, http://www.census.gov/econ/census02, U.S. Census Bureau

[53] Smith-Bucklin, 2003. 2002 Cost of Doing Business Report, International Carwash Association.

[54] Brown, ibid., 2002.

3.33 percent of the carwash equipment existing in 2010 will be replaced with new equipment each year in this scenario. Figure 1 shows a potential water savings totaling 22,877 acre-feet per year (AFY) in 2020. In-bay automatics make up more than two-thirds of the potential savings at 16,580 AFY, and conveyors represent 6,297 AFY potential savings, in 2020. Because of difficulties in the use of reclaim systems in self-service carwashes as discussed earlier, this category is not included in this scenario.



2.2 Carwash Certification Scenario

The carwash certification scenario assumes an approximate 10 percent savings from all three types of carwashes. This figure is derived from water savings calculated by the City of Denver in 2005. That year saw a 25 percent reduction in total water use by all 247 carwashes that participated in the certification program. However, Denver's program is not voluntary and was first implemented in 2002 during a critical drought period. The mandatory aspect of the Denver program requires a 10 percent reduction in water use overall, and after discussion with local carwash owners, the Denver staff that implemented the program estimated that additional savings were obtained as a result of reduced use of the carwashes by the public, probably related to public awareness of the need to reduce citywide water consumption.[55] Due to these two factors, a lower estimate of savings has been chosen to represent potential water savings for this California scenario.

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[55] Reed, Jim, 2006. Personal communication, carwash conservation certification coordinator, Denver Water, May.

The water savings estimate includes only the three types of commercial carwashes that are represented by the professional industry and does not include fleet or truck and bus washing facilities. The annual water savings in 2020 for the 10 percent savings scenario from carwash certification is estimated as totaling approximately 4,700 acre-feet per year for all three types of car washes. In-bay automatics make up more than one-half the potential savings at 2,549 acre-feet per year, while conveyor systems represent 1,497 acre-feet potential annual savings, and self-service car washes represent 722 acre-feet of potential savings in 2020. Refer to Figure 2.

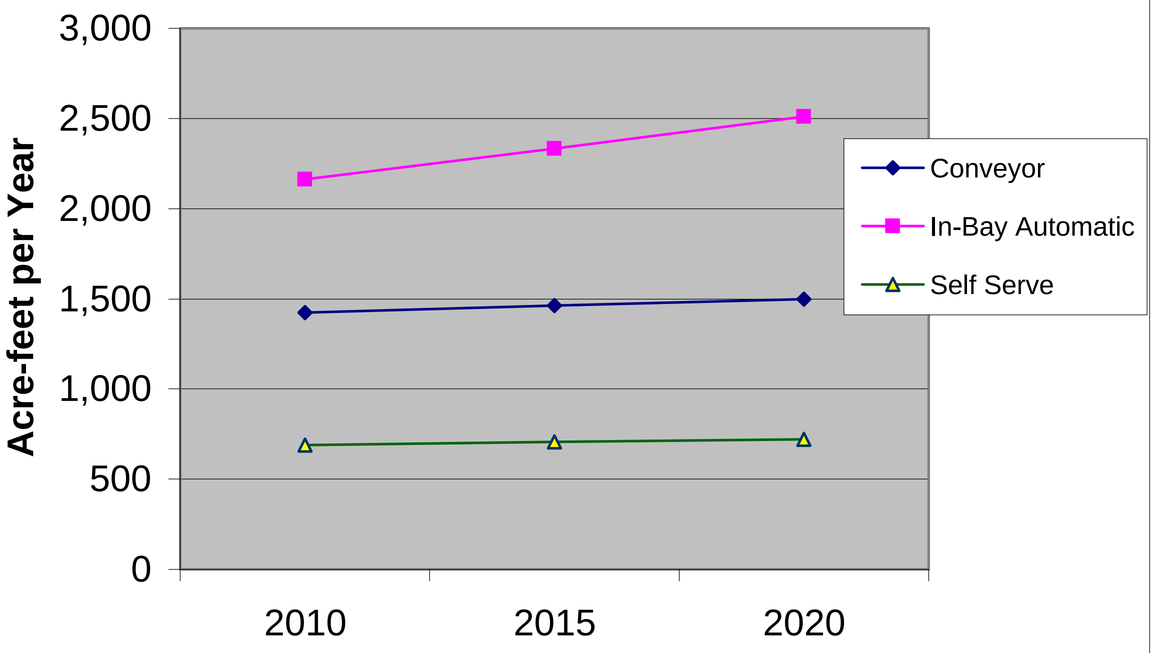

Figure 2. Statewide Water Savings Potential from Carwash Certification

3.0 Cost-Benefit Analysis

In both of the above scenarios, minimal costs would be incurred on the part of the water utility. In the ordinance/legislation and the certification scenarios, annual site visits are necessary to ensure that compliance is maintained. Such visits should be accomplished in less than three hours per site, paperwork included. Enforcement structures for ordinance violations such as fines should be designed to pay for the cost of enforcement. In certification programs, an annual fee charged to all participants in the program can pay for signage and promotional expenses on the part of the utility. A certification fee of $25 to $50 per year per facility could provide enough funds to produce both attractive signage, and paid media placements such as radio spots or newspaper adds encouraging utility customers to use the water saving carwash facilities. The ordinance approach would avoid this fee, but would also not require the utility to promote certified carwashes through the media. The monetary value of advertising in the certification model is market specific, and is not estimated in this report.

The cost per visit is estimated at a value of $51 per hour or approximately $153 per visit based upon utility conservation staff performing the visits. Using these assumptions, the average annual cost per acre-foot of water saved in 2010 in the reclaim ordinance/legislation approach is $42 and in the certification program is estimated at $225.

4.0 Additional Considerations

Additional challenges for water efficiency and storm water management include (a) mobile carwash systems, almost all of which use pressure wash machines with wands similar to self-service carwashes; and (b) detail shops that offer "hand-washing". In some communities, strict discharge prohibitions have led to the creation of mobile reclaim systems.

Another type of vehicle wash that is not well quantified is the industrial or commercial wash systems for trucks. Some, such as cement and concrete trucks require daily cleaning and have strict prohibitions on discharge. This has led to creation of wash water recycle systems using hoses with spray nozzles, and external reclaim pits designed to capture and separate all wash water. If the wash pads at these sites are properly designed, rainwater also collects in the pits and can serve to replenish water lost to evaporation and drag-out on the trucks. Construction sites and quarries also include tire-washing systems that typically recycle water from a catchment basin or pond as a truck exits the site. Driven by air quality regulations that prohibit particulate emissions from dirty tires, these systems are almost all recirculating and use non-potable water. This use of non-potable water suggests another potential resource management tool for future water efficiency in the use of non-potable water for vehicle washing.

As mentioned earlier, the ICA water use study was the first comparison of car wash water use by type and region to use data collected in the field. The study did not reveal the make and manufacturer of the carwash equipment. However, the wide variability of in-bay automatic data (mean = 43gpv, Stdev = 26gpv) suggests that differences in equipment as well as operation may be responsible for higher than average water use in some facilities. Utility-funded studies of specific equipment may be of some use in implementing a BMP, similar to MaP testing studies of toilets, by identifying carwash equipment that performs at or better than the industry average. For conveyor carwashes (mean = 34gpv, Stdev =15gpv), studies that identify the length, timing, use of reclaim, and type of equipment in a multivariate approach would assist in clearer guidelines for efficiency and would assist greatly in the drafting of a clearly defined and fair BMP.

VI. Synthetic Turf

1.0 Introduction

Synthetic turf has evolved considerably since it was first introduced in 1965 under the trade name *Astroturf*. *Astroturf* never really became popular with players (except perhaps in the sport of field hockey), who found the surface exceptionally hard (compared to natural turf), altering ball bounce characteristics in unfavorable ways, and also leading to more serious sports injuries. Successive innovations have thus been aimed at making synthetic turf resemble as much as possible the softness and ball handling characteristics of natural turf. The latest generation of synthetic grass uses a combination of synthetic fiber woven into a mat with sand/rubber infill to simulate the look and feel of natural turf, which is markedly superior to the earliest generation products.

Several organizations have approved the use of synthetic turf in their respective sporting activities. These include the Federation International Football Association (FIFA), the international governing body for soccer; Federation of International Hockey (FIH) for field hockey; and the International Rugby Association. These organizations have published detailed specifications (downloadable from their websites) for what characteristics an synthetic pitch should possess, as well as detailed testing protocols. In addition, the Synthetic Turf Council (www.syntheticturfcouncil.org), a trade association of synthetic turf manufacturers, also has a set of testing guidelines for synthetic turf products that could be used for applications outside the purview of specific sports governing bodies.

Why synthetic turf?

The world of sports has historically been the primary market for synthetic turf. In sporting applications, many factors enter into the decision to choose synthetic over natural turf. These include:

1. Climate. Some areas may not enjoy a climate conducive for growing natural turf on a year-round basis because of either severe summers or severe winters. Synthetic turf provides a more consistent playing surface.
2. Covered sports arenas. Often designed to increase spectator comfort, they also limit natural sunlight making cultivation of natural turf more difficult.
3. Reduced downtime. Although periodic maintenance and cleaning is necessary even in the case of synthetic turf, these surfaces are more available since they do not require seasonal fertilization and aeration as natural turf does. This is an important factor not only for professional sports, but also for expanding school districts where increasing uptime of existing playing fields through installation of synthetic turf may be more cost-effective than new land acquisition.
4. Cost. Although upfront costs of synthetic turf are many times greater than natural turf[56], over its life cycle synthetic turf may be cost-effective when one factors in reduced

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[56] Irvine Ranch Water District reports that installed synthetic turf can cost between $6 and $9 per square foot (www.irwd.com/Conservation/synturf.php). The cost of sod is usually less than $1 per square foot. A do-it-yourselfer could thus install a natural turf landscape quite inexpensively, although professional installation would narrow the cost difference between natural and synthetic turf somewhat. Natural turf-based high-end sporting

maintenance, reduced downtime, and reduced irrigation bills. Unfortunately, reliable data about costs and benefits are not available at present to permit this assessment. Many of the synthetic turf manufacturers are privately held businesses that are loathe to sharing such data openly.

5. Optimization for multiple sports. Since the properties of the latest generation synthetic turf can be altered to some extent, it is possible to engineer a pitch that may be acceptable for many different sports. For example, football players may prefer natural turf, while field hockey players may prefer *Astroturf*, but both could perhaps find a properly optimized infilled synthetic pitch acceptable, obviating the need for two playing fields.
6. Recruiting. Choices made by competing institutions can play a part in whether a given institution chooses natural or synthetic turf ("perception is reality"). This bandwagon effect has probably worked both for and against synthetic turf at different points in time.[57]

Apart from sporting applications, synthetic turf is also suitable for residential and commercial applications assuming the cost benefit calculus is favorable. Again, anecdotal evidence suggests that residential applications are increasing rapidly in arid areas where water providers have taken aggressive measures to limit outdoor water use. An example is the Southern Nevada Water Authority (www.snwa.com), which limits residential turf to no more than 50 percent of landscaped area, limits summer watering to alternate days, and has inclining water rates. A recently completed synthetic turf study in the City of Anaheim[58], California, found that residential customers that replaced their natural turf with synthetic turf were quite satisfied with the result (mainly due to reduced maintenance and bugs), but the study included only five customers, so it is difficult to generalize to all residential applications. Of the two commercial sites included in this study (roadway median and public park) the park official was not enthusiastic about synthetic turf's appearance. The Anaheim Pilot Study estimated the cost of saved water to be $7,000 per acre-foot (savings were derived using engineering estimates, not billed data).

Overall, irrigation considerations do not appear to be a significant decision driver in sporting applications, but could be more so in other applications[59]. In other words, water providers probably enjoy very limited opportunity for influencing synthetic turf use in sporting applications (although they could still show support via rebates up to the value of saved water), but perhaps could have greater impact in residential and commercial applications.

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applications are likely to cost more than residential lawns. These are very rough figures based on anecdotal evidence, and a lot more investigation and history is required to really pin down these cost estimates across different settings.

[57] Rosenberg, B., "Greatest turf on show," NCAA news, September 29, 2003 (accessible at www.ncaa.org)

[58] *Astrolawn Synthetic Turf Pilot Project*, conducted by the City of Anaheim Public Utilities and H2O-Less Lawns and Turf, LLC, October, 2004 (under the auspices of MWDSC's Innovative Conservation Program).

[59] Anecdotal evidence indicates that, for summer sporting applications, water is used to "cool down" the synthetic turf prior to play.

Pros and cons of synthetic turf

Some of the key reasons why synthetic turf has found favorable reception in sporting applications were mentioned above (climate, covered arenas, reduced downtime, lack of land in urbanized areas). They may, in many circumstances, outweigh synthetic turf's considerably higher initial cost, and possibly its other technical deficiencies (such as a harder surface). But where the above factors are less important, synthetic turf may not turn out to be as cost effective as manufacturers claim. Here are some views offered by stakeholders within the natural turf industry:[60]

1. Natural turf advocates argue that synthetic turf is not maintenance free, and usually requires acquisition of specialized equipment to meet the manufacturer's maintenance specifications.
2. Synthetic pitches can become very hot during summer months and need to be sprayed with water to cool them down. They may also need to be regularly sanitized to reduce the possibility of viral/bacterial infections being transmitted to players when they suffer cuts and burns. All of these activities use water, making the irrigation savings perhaps not as large as one might think (especially in sporting applications).
3. Natural turf is friendlier for the environment. It effectively bio-filters rainwater as it moves from surface to aquifer. It also has a cooling effect on properties that it surrounds, reducing air conditioning related energy use, a factor that would need to be considered in residential/commercial applications.
4. While fertilizers and pesticides used with natural turf can run off into streams and rivers, synthetic turf uses infill materials (ground rubber tires) that could also leach toxic materials into the groundwater while in use[61]. Safe post-use disposal of synthetic turf also remains an issue.

Some of the above criticisms speak to the technical efficacy of synthetic turf relative to natural turf (such as greater chance of sports injuries, unusually hot playing surfaces, etc.); the others speak to whether a full accounting of direct and indirect environmental costs would still lead one to favor synthetic turf. As stated earlier, data to sort through these claims and counterclaims appear to be spread across multiple sources, many proprietary, which would need to be collated before one could draw any definitive conclusions. Given that synthetic turf has been approved by several sports governing bodies and that its penetration is steadily increasing in sporting applications, we would surmise that the negatives associated with synthetic turf are not so great in those situations.

However, the operational history of the latest versions of synthetic turf is limited. With useful lifetimes projected at as low as six years and as high as ten years, enough "real world"

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[60] Several articles are cited at www.westcoastturf.com/architects/keepitreal.html and at www.turfgrasssod.org (click on "resources"). Also see a University of California, Riverside publication on this subject, "Davis, William, Natural versus Synthetic Turf: An Economical Alternative," *California Turfgrass Culture*, Vol. 31, No. 1, 1981 (ucrturf.ucr.edu/publications/CTC/ctc31_1.pdf).

[61] Although the Synthetic Turf Council's guidelines proscribe the use of toxic materials, it remains unclear exactly what each manufacturer is, in fact. using. The Santa Clara Valley Water District is examining this issue in greater detail, although no published report is as yet available from them.

experience is not yet available. To balance the picture, at present we can only suggest that interested readers also familiarize themselves with the generally favorable testimonials about synthetic turf included at the National Collegiate Athletic Association's (NCAA) website.[62]

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[62] Search www.ncaa.org using keywords "synthetic turf" and "artificial turf".

2.0 Target Market

Synthetic turf's primary market is in sporting applications. While residential and commercial applications are also technically viable (and rapidly growing in Nevada according to anecdotal evidence), synthetic turf's cost-effectiveness in these latter applications will depend upon climate, water availability, and water rates. Certainly, one could envision the use of synthetic turf becoming more common in California's rapidly developing, hotter, inland regions.

Schools

Table 1 provides the total number of K through 12 public schools in California, which account for roughly 90 percent of all student enrollments (the remainder are enrolled in private schools). We were unable to find data about the size and type of playing fields that each type of school has, but school design is a highly regulated activity, subject to several codes and guidelines[63]. Thus, it is possible to develop estimates about synthetic turf's potential target market among K through 12 schools.

Table 1 California's Public Schools (FY 2004-05)

Type	Number
Elementary	5558
Middle/Junior High	1254
High	1128
K-12 (integrated)	96
Other‡	1339
TOTAL	9375

‡Includes alternative schools, special education schools, continuation schools, community day schools, etc.
SOURCE: California Department of Education (www.cde.ca.gov/ds/)

Colleges and Universities

Table 2 shows the total number of colleges and universities in California. Again, information about their athletic facilities is not available. It should be noted, however, that out of the 399 colleges located in California, only roughly 50 are members of the National Collegiate Athletics Association. These members include all the University of California campuses, the California State University campuses, and other well known private universities. Perhaps, only these 50 campuses have advanced athletic programs, and represent potential users of synthetic turf.

Table 2 California's Colleges and Universities (FY 2004-05)

Type	Number
2 year colleges	173
4 year colleges	226
TOTAL	399
Members of NCAA	50

SOURCE: National Center of Education Statistics (nces.ed.gov/programs/stateprofiles) and
National Collegiate Athletics Association (www.ncaa.org).

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[63] For example, see California Department of Education's publication entitled, *School Site Analysis and Development, 2000 edition* (www.cde.ca.gov/ls/fa/sf/documents/schoolsiteanalysis2000.pdf). This document provides empirical guidelines about all aspects of school design, including playing fields, as a function of school size and enrollment.

Residential applications

Estimating synthetic turf's potential market in residential and commercial applications is extremely difficult. Given the price differential between natural and synthetic turf, only areas where water agencies aggressively aim to reduce outdoor use is synthetic turf likely to catch on. One can only construct "what if" scenarios at this stage. Which of these areas might be candidates in the future? To shed some light on this issue we present estimates of the indoor/outdoor split among single-family residences by County. Outdoor use as a proportion of total use varies considerably, exceeding 90 percent in Inyo County. If one focuses only on counties that are located in the southern district (since they are more dependent upon imported water), with very high outdoor water use (say, over 75 percent), one can shortlist San Diego, Imperial, Riverside, Ventura, San Bernardino, and Inyo counties as most promising markets for synthetic turf. According to the California Department of Finance, there were roughly 1.7 million single-family detached homes in these six short-listed counties.

Table 3. Outdoor Water Use Patterns By County

County	District	Single-family internal use	Single-family external use
Santa Barbara	SD	61.17%	38.83%
San Luis Obispo	SD	56.71%	43.29%
Humboldt	ND	55.00%	45.00%
Monterey	SJD	51.10%	48.90%
Siskiyou	ND	46.86%	53.14%
Kern	SD	41.60%	58.40%
Kern	SJD	37.51%	62.49%
Tulare	SJD	37.03%	62.97%
Orange	SD	37.00%	63.00%
Los Angeles	SD	36.45%	63.55%
Lake	ND	36.33%	63.67%
San Benito	SJD	35.15%	64.85%
Madera	SJD	34.31%	65.69%
Santa Cruz	SJD	34.07%	65.93%
Butte	ND	33.00%	67.00%
Del Norte	ND	32.00%	68.00%
Kings	SJD	30.45%	69.55%
Santa Clara	CD	30.12%	69.88%
Alameda	CD	30.10%	69.91%
Contra Costa	CD	30.08%	69.92%
Calaveras	CD	30.04%	69.96%
Yuba	CD	30.04%	69.97%
Marin	CD	30.02%	69.98%
Amador	CD	30.02%	69.98%
San Francisco	CD	30.01%	69.99%
Placer	CD	29.73%	70.27%
El Dorado	CD	29.67%	70.33%
Fresno	SJD	29.64%	70.37%
Nevada	CD	29.54%	70.46%
Mono	SD	29.00%	71.00%
Mono	CD	28.57%	71.43%
Sonoma	CD	26.22%	73.78%
Modoc	ND	26.00%	74.00%
Sacramento	CD	25.00%	75.00%
Mendocino	CD	24.82%	75.18%

County	District	Single-family internal use	Single-family external use
Solano	CD	24.01%	75.99%
San Diego	SD	23.17%	76.83%
Tuolumne	CD	22.57%	77.43%
Shasta	ND	22.50%	77.50%
Sierra	CD	22.15%	77.85%
Imperial	SD	22.08%	77.92%
Merced	SJD	21.52%	78.48%
San Joaquin	CD	21.46%	78.54%
Yolo	CD	21.45%	78.55%
Sutter	CD	20.04%	79.96%
Napa	CD	20.01%	79.99%
San Mateo	CD	20.01%	79.99%
Tehama	ND	19.75%	80.25%
Stanislaus	SJD	19.72%	80.28%
Mariposa	SJD	19.50%	80.50%
Lassen	ND	18.11%	81.89%
Riverside	SD	18.04%	81.96%
Alpine	CD	17.74%	82.26%
Ventura	SD	17.25%	82.75%
Plumas	ND	17.00%	83.00%
Colusa	ND	15.20%	84.80%
San Bernardino	SD	12.50%	87.50%
Trinity	ND	10.00%	90.00%
Glenn	ND	6.86%	93.14%
Inyo	SD	6.21%	93.79%

SOURCE: Indoor/Outdoor splits were obtained from the California Department of Water Resources website. The data are for 2001: www.landwateruse.water.ca.gov/docs/annualdata/2001/Urb_IO_2001_by_Co.xls
Housing units data can be obtained from the California Department of Finance's website. These are for 2006: http://www.dof.ca.gov/HTML/DEMOGRAP/E-5a.xls
Finally, CIMIS maps California by climate zone based upon annual ET, a potentially useful tool for identifying target markets: wwwcimis.water.ca.gov/cimis/images/etomap.jpg

3.0 California Potential

Estimating residential and commercial water conservation potential at this stage is very difficult. So we do not attempt it. Instead, we focus only on sporting applications and provide rough estimates of that potential. As noted earlier, we lack rigorous estimates about how much acreage ought to be considered viable for synthetic turf installation in schools and colleges. In order to approximate the savings, however, we have relied on anecdotal evidence provided to us by a knowledgeable conservation professional, who suggests that an average estimate of three acres per school site may be reasonable.[64] These water savings are very uncertain for two reasons: (a) school playing fields often are deficit irrigated and (b) some amount of water is usually necessary to cool as well as clean synthetic turf. We assume that irrigation savings may only be in the range of 3-4 acre-feet per acre per year. We also assume product life to be roughly 10

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[64] Maddaus, William, 2006. Personal communication. Mr. Maddaus states that "elementary schools normally have about 3 acres of turf, enough for one soccer field. Middle schools have about 7 acres and high schools about 15 acres. Colleges show a wide variation since many colleges are small urban campuses. We've used 10 acres in the past as an average. This is the amount of turf we feel is being irrigated now. But for replacement with artificial turf, because of the high cost, it will probably be limited to playing fields. So to be conservative you could use 3 acres per school and have a figure that is not too overly optimistic."

years in sporting applications based upon anecdotal evidence that synthetic turf manufacturers generally offer an eight year product guarantee[65]. Table 4 shows the results, suggesting the gross conservation potential (from turf replacement in all schools in the state) may roughly lie in the range of 88 to 117,000 acre-feet per year, and over the product lifetime between 880,000 and 1,170,000 acre-feet. For reasons cited earlier, the potential "capture" rate of that savings cannot be determined at this time.

Table 4 Water Conservation Potential in School Sporting Applications

Site type	No. of sites	Potential for synthetic turf replacement per site on average	Annual savings potential		Lifetime savings potential (10 year product life)	
			At 3 AFY per acre	*At 4 AFY per acre*	*At 3 AFY per acre*	*At 4 AFY per acre*
K-12 schools	9,375	3 acres	84,375	112,500	843,750	1,125,000
2 and 4 year colleges	399	3 acres	3,591	4,788	35,910	47,880
TOTAL			87,966	117,288	879,660	1,172,880

4.0 Cost effectiveness

Given lack of reliable data and unresolved environmental issues, we are unable to provide comparative cost-effectiveness analyses to evaluate how natural and synthetic turf would fare against one another in similar settings. Instead, we only provide illustrative estimates of what the cost of saved water would be from a synthetic turf installation. Once again we assume product life to be 10 years, water savings to range between 3 and 4 acre feet per acre per year, and the cost of installed synthetic turf to vary anywhere between $6 and $10 per square foot. Table 5 shows that the cost of saved water could vary anywhere between $6,000 and $15,000 per acre foot, which significantly exceeds the current cost of water in most, if not all, California jurisdictions.

Table 5 Cost of Water Saved Through Synthetic Turf Installation

Savings per acre per year	Product life	Installed cost of synthetic turf per square foot	Installed cost per acre	Total lifetime water savings per acre	Cost per acre-foot saved
3 acre-feet	10	$6	$261,360	30 acre feet	$8,712
3 acre-feet	10	$8	$348,480	30 acre feet	$11,616
3 acre-feet	10	$10	$435,600	30 acre feet	$14,520
4 acre-feet	10	$6	$261,360	40 acre feet	$6,534
4 acre-feet	10	$8	$348,480	40 acre feet	$8,712
4 acre-feet	10	$10	$435,600	40 acre feet	$10,890

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[65] However, anecdotal information also suggests that where heavy sporting use exists (e.g., school playfields shared with local municipal recreation programs), the physical life of the synthetic turf may be as short as six years.

5.0 Conclusions

Our brief survey of the literature on the topic of synthetic turf shows that at present information about this technology is distributed across many sources, and that these disparate pieces of information have not been collated in a way that would allow one to observe trends, offer general guidelines about product suitability in different applications, estimate the size of potential markets for this product in California, and ultimately assess its broader impact on water use and the environment. It is feasible to generate this information, especially in the context of sporting applications, since the user community is fairly well defined.[66] While some of this information would also translate to residential and commercial applications, identifying the target market in these latter applications will remain very difficult. Decisions to go synthetic or natural in the residential and commercial sector are much more dependent upon water agency policies, and the cost differential between natural and synthetic turf, than appears to be the case in the sporting sector. The only estimate of the cost of saved water in residential and commercial applications that we were able to find (City of Anaheim Pilot Study cited earlier) suggests that this may be as high as $7,000 per acre-foot. Much more research is needed to refine this estimate to fully account for all the costs and benefits associated with natural vis-à-vis synthetic turf.

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[66] The Metropolitan Water District of Southern California also has roughly 10 pilot projects underway under the auspices of their synthetic turf program. However, no reports are available from these projects at present to shed light on the various issues surrounding synthetic turf.

VII. Residential Hot Water Distribution

1.0 Background

The purpose of this PBMP analysis is to address the waste of water that occurs in a typical household between the time one turns on a tap or a fixture and when the water arrives at the same location at the desired useful hot water temperature. The key question that needs to be answered in order to properly frame the discussion is:

> How much water can or should be wasted while waiting for hot water to arrive?

The amount of water that is wasted is directly related to the volume and temperature of water that is in the pipe between the source of hot water and point of need, i.e., the fixture or appliance. That volume of waste can be either cold or warm water. That water is not at the desired useful hot water temperature at the beginning of the hot water event and can vary from practically zero to many gallons.

The amount of water waste also relates to time and energy. For a given flow rate, the smaller the volume that needs to be purged from the line, the less the wait. Less wait generally increases customer satisfaction.

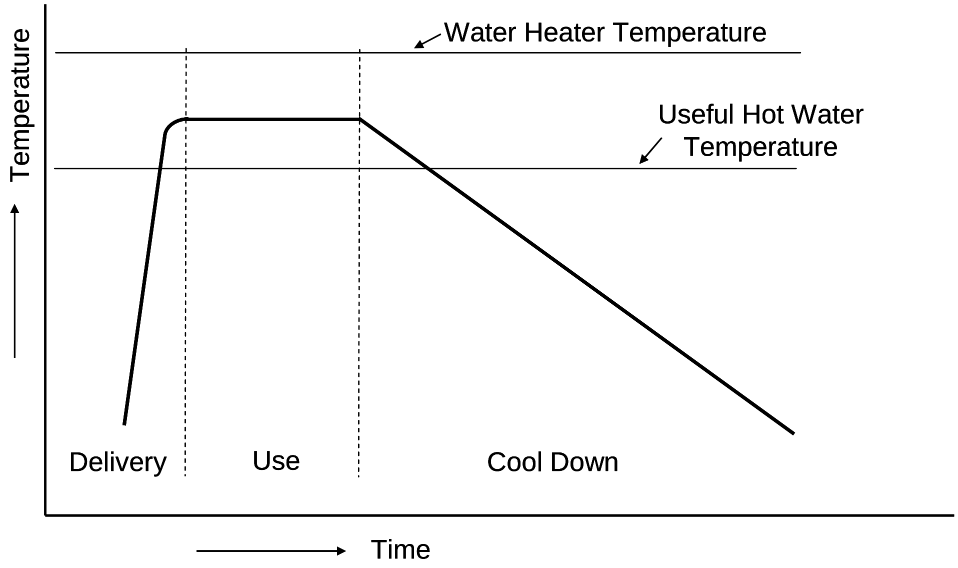
Energy is used in buildings both to pressurize and heat the water. When needed, cold water is pressurized, e.g., using well pumps in remote locations and using pumps to lift the water in tall buildings. The energy so-consumed needs to be accounted for in the building and in the water and wastewater treatment systems. The energy required for heating the water is based on the delivery volume, the use volume, the volume of water that cools off between hot water events and on the efficiency of the water heater. The configuration of the hot water distribution system – length, diameter, environmental conditions, insulation, etc. – is directly related to its water delivery performance and to the energy needed to support this level of performance.

Every gallon that is not wasted while waiting for hot water to arrive means that a gallon does not need to be delivered to the water-using customer and that same gallon does not need to be treated as wastewater. The energy intensity of the water use cycle has been studied by the California Energy Commission (CEC). In their staff report (CEC-Klein, 2005), the CEC reported that energy intensity can vary from 2,000 to 20,000 kilowatt-hours/million gallons (kWh/MG). In northern California the typical energy intensity is roughly 4,000 kWh/MG and in southern California it is roughly 13,000 kWh/MG. Saving a gallon of water - hot or cold - in southern California typically saves more energy than in northern California.

1.1 What is a Hot Water Event?

Before going further, we need to define a hot water event. A typical hot water event is depicted in Figure 1. Each hot water event has three phases: delivery, use, and cool down. When a fixture valve is opened, hot water leaves the water heater and heads through the hot water piping toward the fixture. Ideally, we want this delivery time to be as short as possible. In practice, there are probably two parts to the delivery phase. The first part is technical or structural and depends upon the plumbing system configuration, the location of the pipes, the volume of the water in the pipes between the water heater and the fixture, whether the piping is insulated, the fixture flow rate, the temperature of the water in the pipes compared to the temperature in the water heater, etc. The second part is behavioral and depends upon when the occupant decides the water is hot enough to use and "gets in." The behavioral waste can be significantly longer than the structural waste.

Figure 1. Hot Water Event Schematic



The delivery phase may be short at some fixtures and long at others. It may be short or long at the same fixture depending on when hot water was last needed on the same line serving the fixture elsewhere in the building. Some people hover near the fixture, checking to see when it is hot enough, while others know from experience that it takes a long time, so they leave, returning when they are good and ready! From the occupant's point of view this may appear to be totally random and hard to "learn", in which case their behavior may likely default to the worst case condition at all fixtures.

The use phase needs to be whatever length it takes to perform the task for which hot water is desired. The cool down phase begins the moment the fixture is turned off. If the time until the next hot water event is short enough, the water in the pipes all the way back to the water heater will be hot enough to use. If it is too long, water coming from the water heater for that next event will be run down the drain until water hot enough to use arrives at the fixture.

At the fixture, hot water is generally mixed with cold water to reach the desired useful hot water temperature. The thermostat on the water heater needs to be set high enough to overcome the heat losses in the piping system and still provide water that is hot enough to be mixed with cold water at the furthest fixture to obtain the highest desired useful hot water temperature. For purposes of the experiments, 105°F was arbitrarily selected as the nominal useful hot water temperature. The actual useful hot water temperature depends in large part on the purpose of the hot water event: rinsing hands, taking a shower, sterilizing dishes, etc.

1.2 Recent Research

What follows is a synopsis of what was learned from the CEC-sponsored research into hot water flow (CEC-Hiller, 2005).

The Delivery Phase

The CEC learned three things about the delivery phase:

1. During the delivery phase, hot water acts differently than cold water
2. Low flow rates (< 1 gpm) waste much more water than high flow rates (> 4 gpm).
3. At typical fixture flow rates (1-3 gpm), sharp (standard) 90^o elbows increase turbulence, heat loss and water waste

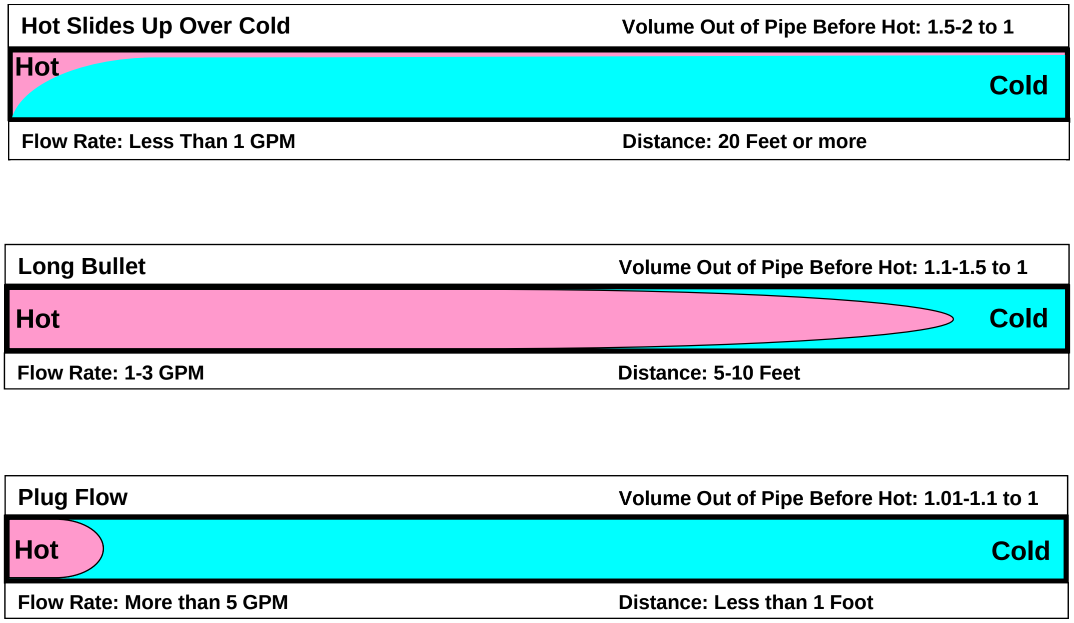
Perhaps one of the most surprising things researchers learned is that it is possible for significantly more water to come out of the pipe before hot water gets from the water heater to the fixture than is actually in the pipe. During the tests, their researcher found that the temperature sensor on the first turn was getting hot sooner than was theoretically possible assuming perfect plug flow. The difference in time was significant. To determine what was actually occurring, the researcher used his hands to feel the pipe and found that there was a thin stream of hot water riding on top of the cold water that was running many feet ahead of the plug of hot water coming from the water heater. After some time, mixing would occur, but until that happened, there was a much greater surface area of hot water touching both the cold water and the relatively cold pipe than would normally have been expected.

This is depicted in the top portion of Figure 2. At the beginning of a hot water event, the cold water is much more viscous than the hot water. The length of the thin stream of hot water could be more than 20 feet long and would go around the elbows. The volume of water that would come out of the pipe (or past a given temperature sensor) before hot water arrived could be twice the volume that was in the pipe.

This condition was most prevalent at flow rates less than 1 gpm. Such low flow rates are typical of commercial lavatory sinks, low flow showers and the hot water portion of the flow in a single lever faucet when the valve is opened halfway between hot and cold. In fact, for a given length of pipe in a given environment there is a flow rate at which hot water will never get to the fixture.

As the flow rate increased into the range typical of many sinks and showers (1-3 gpm), the thin stream gave way to a more normal mixing front, which is depicted as a long bullet (see Figure 2). The length of the bullet was several feet ahead of the hot water plug. The extra volume of water that came out of the pipe before hot water arrived was generally 10 to 50 percent more than the volume of water in the pipe. The waste was larger for a given flow rate in the hard-piped test rig that had standard elbows than it was in the flexible pipe test rig which used wide-radius bends in the pipe itself to make the 180 degree turns.

Figure 2. Delivery Phase Schematics (Not to scale)



At higher flow rates, typical of those found in garden or Jacuzzi tubs, some laundry sinks, washing machines and dishwashers, researchers saw what looked like plug flow, the idealized type of flow covered in engineering school. In these cases, the length of the much shorter bullet was only a very short distance ahead of the hot water plug (see bottom illustration in Figure 2). The extra volume of water that came out of the pipe before hot water arrived was generally much less than 10 percent more than the volume of water in the pipe. This condition was seen some of the time at high flow rates in the hard-pipe test rig with hard elbows. It was seen much more often and at lower flow rates in the flexible test rig with wide-radius bends.

The Use Phase

Researchers learned four things about the use phase:

- Uninsulated flexible PEX-Al-PEX[67] piping has a greater temperature drop at a given flow rate than does copper piping of the same nominal diameter. Insulating the pipes minimized the difference.
- The temperature drop at a given flow rate is less in ½-inch piping is less than in ¾-inch piping.
- The temperature drop over a given distance is greater at low flow rates than at high flow rates. There is a significant difference in the rate of change of the temperature drop at flow rates below 1 gpm.
- Insulation decreases the temperature drop at a given flow rate.

Figure 3 shows the comparison between nominal ¾-inch PEX-Al-PEX and ¾-inch copper piping over a length of 100 feet. The figure is based on steady-state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F. The

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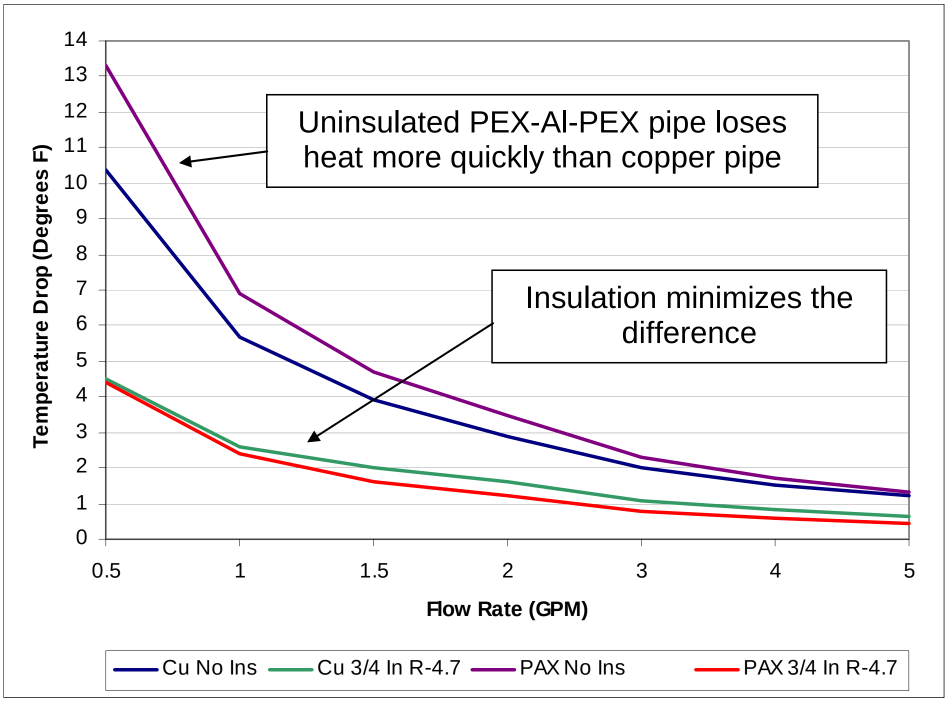
[67] PEX piping is cross-linked polyethylene and Al is Aluminum. PEX-Al-PEX is a type of PEX pipe that has a layer of aluminum sandwiched between two layers of PEX.

water in the uninsulated PEX-Al-PEX pipe lost more temperature at the same flow rate than did the water in the copper pipe. This additional heat loss is probably due to a combination of two effects: first, the nominal ¾-inch PEX-Al-PEX pipe has a larger surface area than the nominal ¾-inch copper pipe - once it is hot, there is more surface area to lose heat. Second, because the PEX-Al-PEX has a larger internal diameter than the copper piping, the face velocity of the water in the PEX-Al-PEX is slower and the rate of heat loss is greater than it is in copper. Once the pipes were insulated, the difference in temperature drop essentially disappeared.

Figure 3. Comparison of Nominal ¾-Inch PEX-Al-PEX and ¾-Inch Copper Piping

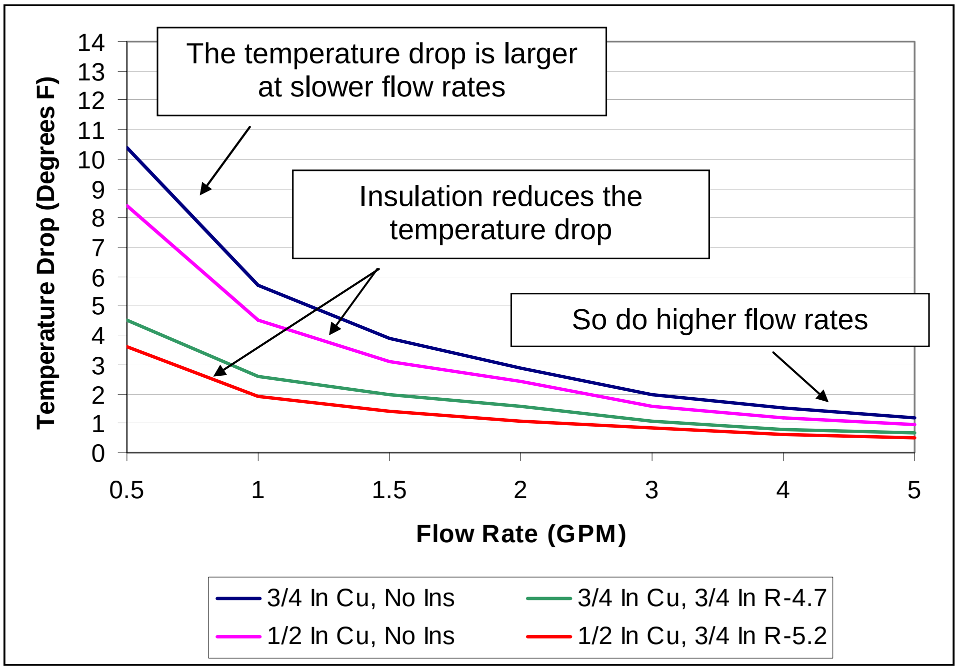


The CEC did not have enough funding to run tests on ½-inch PEX-Al-PEX. Based on the fact that uninsulated copper performed better than PEX-Al-PEX, and with insulation, the performance was very similar, it is possible to use the performance of copper pipe at ½- and ¾-inch (with and without insulation) as a reasonable first order proxy to better understand what generally happens in hot water piping.

Figure 4 compares the performance of nominal ½- and ¾-inch diameter copper piping, both insulated and uninsulated. As in the prior figure, the graph is based on steady-state flow rates with the hot water entering the pipe at 135°F and the ambient air temperature surrounding the pipe at 67.5°F over a length of 100 feet.

At a given flow rate, the temperature drop in ½-inch nominal piping is less than in ¾-inch nominal piping. This is due to the increased face velocity of the water, which reduces the heat loss rate. The issue is that frictional losses increase exponentially with increased face velocity and results in increased pressure drop over a given length.

Figure 4. Comparison of Nominal ½- and ¾-Inch Copper Piping



The temperature drop over a given distance is greater at low flow rates than at high flow rates. At 2.5 gpm, the highest flow rate allowed for showerheads, the temperature drop in uninsulated copper piping is between 2° and 2.5°F. At 1 gpm, the temperature drop in uninsulated pipe climbs to between 4.5° and 5.5°F. At 5 gpm, the temperature drop goes down to roughly 1°F, and the difference between ½- and ¾-inch diameter essentially goes away.

There is a significant difference in the rate of change of the temperature drop at flow rates below 1 gpm. At 0.5 gpm, the temperature drop more than doubles. As discussed earlier, the curve will get even steeper if the flow rate is reduced still further and <u>for a given length at some low flow rate, hot water will never reach the fixture</u>. The same thing would happen if length was increased while flow rate was held constant, or if the piping was located in a higher heat loss environment, say in damp soil under a slab or between buildings in a campus situation.

As shown in Figure 4, insulation reduces the heat loss overall. For a given flow rate, insulation causes the temperature drop to be roughly halved. Insulation also reduces the difference in temperature drop between ½- and ¾-inch diameter piping.

The Cool Down Phase

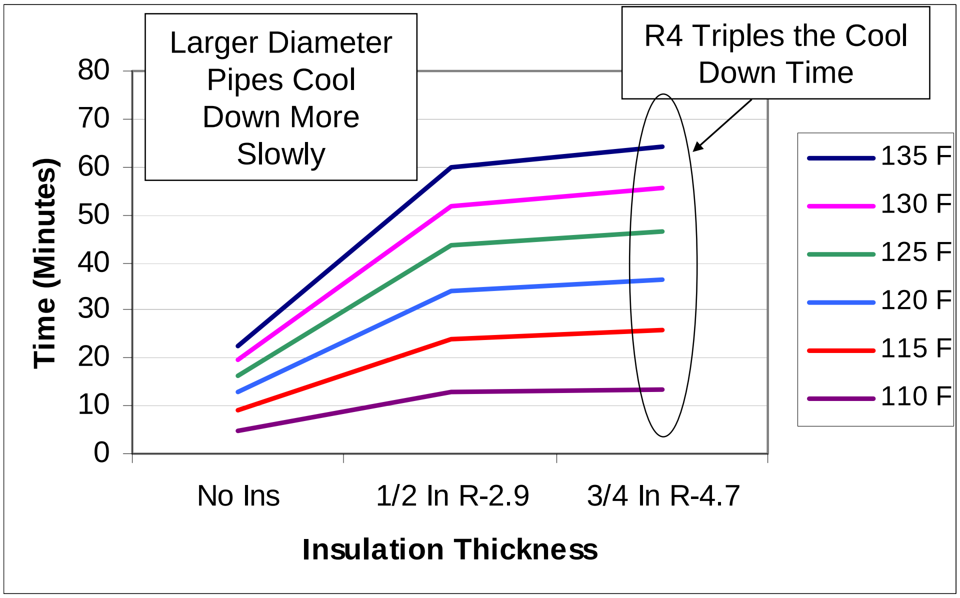
Three things were learned about the cool down phase:

- If the time between hot water events is long enough, the pipes cool down to below the useful hot water temperature for the next hot water event.
- Larger diameter pipes cool down more slowly than smaller diameter pipes.
- Insulation extend the time it takes for the pipes to cool down to a given temperature.

The first point seems obvious, since if you wait long enough, the temperature of the water in the pipes will eventually reach equilibrium with the ambient temperature surrounding the pipes. The real question is: how long does it take to cool down to a non-useful hot water temperature? This depends upon the starting temperature of the water in the pipes, the diameter of the pipes, the amount of pipe insulation, the environmental conditions in which the pipes are located, and the temperature of water needed for the next hot water event.

Figure 5 compares how long it took for the water in ¾-inch diameter copper pipes to cool down from a given starting temperature to 105°F. The ambient temperature surrounding the pipes was between 65° and 70°F and the pipes were located in air. Without insulation, it took between 5 and 22 minutes for the temperature to reach 105°F. The hotter the water began, the longer it took.

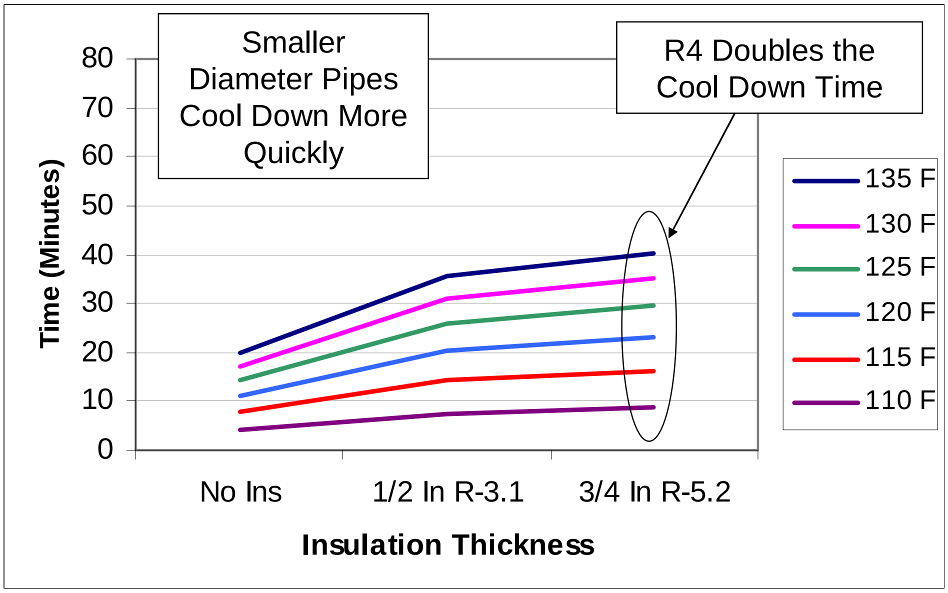
Figure 5. Time Required for ¾-Inch Diameter Pipes to Cool Down to 105°F With and Without Pipe Insulation



When ½-inch wall thickness and ¾-inch wall thickness insulation was added, it took significantly longer for the water to cool down to 105°F. Use of the ¾ inch thick insulation (>R-4) roughly tripled the cool down time. The ½-inch wall thickness insulation did almost as well.

Figure 6 compares how long it took for the water in ½-inch diameter copper pipes to cool down from a given starting temperature to 105°F. As with the tests on ¾-inch diameter pipe, the ambient temperature surrounding the pipes was between 65° and 70°F and the pipes were located in air. Without insulation, it took between 5 and 20 minutes for the temperature to reach 105°F, almost exactly the same as for the uninsulated ¾-inch piping. Use of the ¾-inch thick insulation (>R-4) roughly doubled the cool down time. The ½-inch wall thickness insulation did almost as well.

Figure 6. Time Required for ½-Inch Diameter Pipes to Cool Down to 105°F With and Without Pipe Insulation



Although the time it took the water in the uninsulated pipes to cool down was very similar for the ½-inch and ¾-inch diameter pipes, when insulation was added, the water in the ¾-inch pipes took roughly 1.5 times as long to reach the same temperature as the ½-inch pipes.

If the pipes were located in a colder environment, such as in a crawl space or an attic, at night or early in the morning, or throughout much of the winter, they would have cooled down much more quickly. If the pipes were in a high heat loss environment, such as in the damp soil under a concrete slab, they would cool off even faster. If the ambient temperature were higher, such as in an attic in the middle of a summer afternoon, it would take much longer to cool down. (On the other hand, the water in the cold water pipes might be too hot to use!)

2.0 Improving Hot Water Events

The concept behind the original elements in the PBMP was to save water. From the research results provided above, it is possible to define improvements in hot water events that save both water and energy and increase customer convenience and satisfaction. The key to understanding how to improve a hot water event is recognizing that unless the water in the pipes is hot enough to use at the fixture where it is desired, it always takes more water than is in the pipe to get the water to the fixture at the desired temperature.

The volume of water in the pipes between the source of hot water and the fixture(s) that is **not** hot enough for the next hot water event determines the **minimum** volume of water that will be wasted before water that is hot enough to use arrives at the fixture(s). (Conversely, if you know the maximum amount of water or time that you want to waste while waiting for hot water to arrive, you can back calculate the volume of water that will be in the pipe.) Once you know the volume, you can determine the **maximum** length for any pipe diameter, or any configuration of multiple pipe diameters. Other factors, such as the temperature of the water in the pipes at the start of the event, the temperature of the hot water coming from the water heater, the additional restrictions in the plumbing run (joints, abrupt changes in direction, valves and other fitting) that increase the “effective length” of the pipe, the ambient temperature surrounding the pipe, other environmental conditions, etc., increase the volume of water that comes out of the pipe before hot water arrives at the fixture.

Before going into the details, it is necessary to introduce the concept of “trunks, branches and twigs”. A twig serves one fixture, a branch serves more than one twig and a trunk serves many twigs or a combination of branches and twigs. These descriptions apply to plumbing in single family and multifamily residential applications as well as to non-residential applications. While a slight departure from the terms used in the plumbing industry, this nomenclature has proven useful in discussing how to improve hot water events.

According to the research, <u>water</u> is wasted:

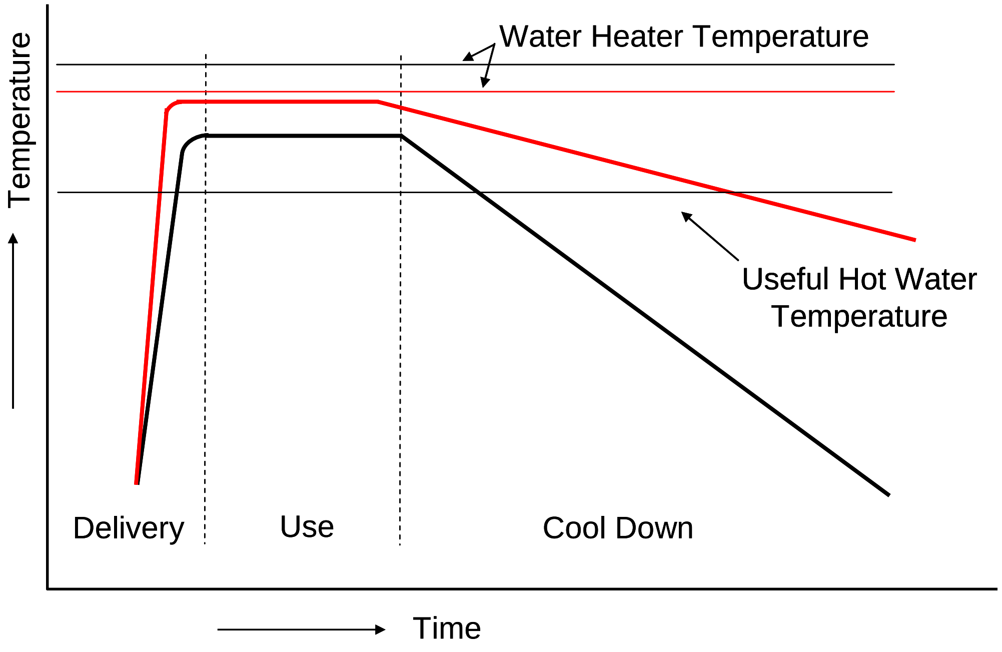
1. Based on the volume of water between the source of hot water and the fixture.
2. At low flow rates (really low face velocities). The lower the flow rate, the more water that is wasted.
3. When there are restrictions to flow in the piping.

According to the research, <u>energy</u> is wasted:

1. When water is wasted. This is true both in the building (pressurizing and heating) and in the water use cycle.
2. When overcoming the heat losses in the piping. The longer the pipe, the larger the diameter, the slower the face velocity, the less the insulation, the worse the ambient environment surrounding the pipes, the more energy that is lost.

The goal is to improve hot water events. Figure 7 depicts an improved hot water event.

Figure 7. Improved Hot Water Event Schematic



Improving the Delivery Phase

Improving the delivery phase means getting hotter water more quickly by minimizing the waste of water, energy and time. For a given fixture flow rate, there are three ways to do this:

- Reduce the volume of water in the pipe
- Reduce the number of restrictions to flow
- Increase the flow rate

Reducing the volume of water in the piping between the source of hot water and the fixture means paying attention to both the diameter and the length. Smaller diameters and shorter lengths contain less water. However, for a given flow rate, the pressure drop due to friction is larger in smaller diameter pipes. If not carefully engineered, it is possible to reduce the pressure at the fixture to a point where the fixtures will not operate properly or provide the desired effect. The problem is exacerbated at low municipal water pressures and longer length piping.

One of surprising results of the research was the impact of standard elbows on the waste of water. In the tests on copper piping, standard radius elbows were used to make the changes in direction. There were no couplings on the straight sections, but there were two elbows at each end to change direction 180 degrees. There was also a tee to create a well for the temperature sensor. In the tests on PEX-AL-PEX, the pipe itself was bent to make the changes in direction, so that there were no elbows. In addition, there were no tees for the temperature sensors (a new method had been found to insert them directly into the pipe). In short, the “effective length” of the PEX-AL-PEX was much shorter than it was in the copper piping.

The general solution is to reduce the effective pipe length as much as possible. The first step is to reduce the actual length as much as practical, then reduce the restrictions to flow that increase the pressure drop in the line disproportionately to their actual length. The idea is to make the pipe appear like a "super highway" to the water. To do this, the number of joints (couplings, elbows, tees and valves) between the source of hot water and the fixtures need to be minimized.

The configuration with the fewest joints would be one with a smooth, flexible pipe running from the water heater to the fixture. The minimum is two connections, one at the water heater and one at the fixture and no shut off valves. Since we generally want to be able to turn off the water on each individual line, and most code jurisdictions require it, the practical minimum is four connections (two connections at the shut off valve, one on each side).

While this sounds good, in buildings with many hot water fixtures and appliances and only one water heater, this would mean that the water heater would need to have as many outlets as the number of fixtures. It is not likely, however, that water heater manufacturers would be willing to produce such a design!

Assuming that water heaters will continue to have one outlet for the hot water exiting the heater, then there will be a main trunk line coming out of the water heater. This trunk line can be short or long, but there needs to be a tee to get water from the trunk line into the branch lines or twigs. In general, there is more pressure drop when the water makes a 90 degree turn through a tee than if it made the same turn through an elbow. The fewest joints would be on a line that had one tee. This means that the fixture was served by a twig attached directly to the trunk. From the trunk line, the practical minimum number of connections is still four; one at the tee, two at the shut off valve and one at the fixture.

A tee can be defined as a one-port manifold. There are three joints for this type of tee. Each requires labor to make the joint and each joint is a potential source of leaks. It is common to use tees with the same dimension on all three joints. However, when a twig is connected to a trunk, the through diameter will be larger by one or more sizes than the diameter of the joint serving the twig (for example ¾-inch through diameter trunk line serving a ½-inch diameter twig. For a given flow rate at the fixture served by the twig, the face velocity of the water in the twig is greater than the face velocity of the water in the trunk line. This results in somewhat less pressure drop than if the water went through the 90 degree turn in a tee with equal dimensions.

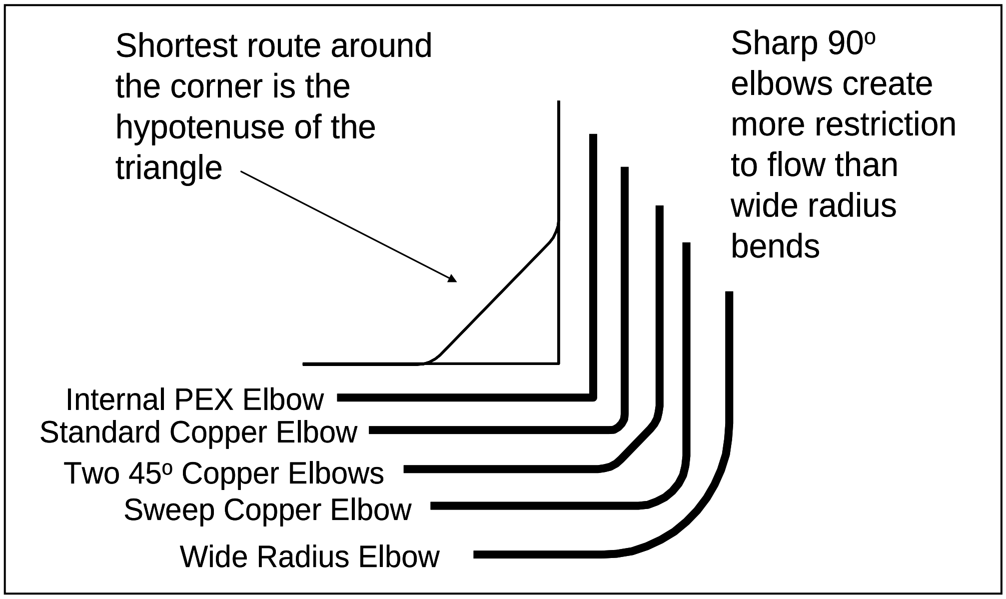
It is possible to reduce the number of joints (and labor and potential leaks) by joining two or more tees into a manifold. If manufactured correctly, this reduces the number of joints by two for every additional "tee" connected to the manifold. Most of these manufactured multi-port tees already have smaller diameter openings compared to the trunk line, providing an additional benefit for their use.

Figure 8 compares the radius of various elbows. The larger the radius of the bend, the more it appears to the water like a banked curve on a race track, and the less resistance there is to flow. Using larger radius bends also results in the use of less piping.

Internal elbows, such as those used in PEX or PEX-Al-PEX systems have the most restriction to flow. External standard elbows such as those used in copper and CPVC systems are next. Two

45 degree external elbows are next, but because of the extra joints, are not quite as good as sweep elbows. Wide radius elbows provide the least restrictions. Making these elbows with flexible piping (copper, PEX, PEX-Al-PEX, CPVC) means that no joints are needed for the elbows. Based on the radius of the elbows in the tests by the CEC, it appears that the radius should be no less than 10 times the nominal diameter (larger is better), but this really needs to be further tested.

Figure 8. Changing Directions Smoothly



It is also possible to improve the delivery phase by increasing the flow rate. The research showed that moving water faster got it there sooner and at a higher temperature. It is possible to see this effect at tub/shower combinations where the flow rate through the tub spout is greater than it is through the shower (when the tub spout diverter is used). Even though hot water will get to the tub/shower combination sooner with somewhat less water waste, you still waste the water if you run it down the drain. One solution to this dilemma is to find a way to prime the trunk line serving the fixture shortly before hot water is desired and then turn on the fixture. The only water that needs to be drained is the volume that is between the trunk line and the fixture. The smaller that volume, the quicker the hot water will arrive.

Improving the Use and Cool Down Phases

Insulation is the best way to improve a hot water event during the use and cool down phases. Assuming you have already improved performance by reducing the volume of water in the pipe, reducing the effective pipe length and getting the hot water to the fixture more quickly, then the insulation will help maintain the temperature during the event and reduce the rate at which the pipes cool down when the fixture is turned off.

The benefits during the use phase are primarily energy related; once the hot water is at the fixture, the flow rate is what it is. What can change is the amount of hot water that is needed to reach the desired mix temperature. The energy benefit derives from the fact that there are fewer heat losses in the piping for the water heater to overcome. Referring again to Figure 7, the red line shows the improved hot water event and the black line shows the typical event. During the use phase, the temperature indicated by the black line was hot enough to create the desired mixed temperature. In the improved event, the temperature indicated by the red line is hotter. Since the water at the fixture is hotter than it would have been without the insulation, then less hot water is needed to reach the same mixed temperature.

There are three ways to capture the energy benefit. One is to keep the temperature of the water heater the same and change the mix temperature. This will reduce the volume of hot water used. If the water heater is of the tank type, standby losses will remain the same, but total available hot water will effectively increase since there will be more hot water in the tank to mix with cold water. If the water heater is tankless, there will be no changes to overall capacity. Second is to reduce the temperature setting of the water heater. For tank-type gas-fired water heaters this will reduce the standby losses roughly two percent for every degree the tank temperature is reduced. For tankless water heaters this will increase the effective capacity so that more fixtures can be used simultaneously. The third way is to combine both strategies. While lowering the tank temperature provides the greatest energy benefits, the consumer benefits from any of the three options.

The longer the distance between the source of hot water and the fixture, and the slower the flow rate, the greater the benefit of the insulation. Looking back at Figure 4, insulation will become even more important if the trend to lower fixture flow rates continues. We already have many sink and shower fixtures with flow rates less than 1 gpm (rated at 80 psi). For a given amount of insulation on the pipes, the temperature drop will increase as the flow rate is decreased. If we do not simultaneously reduce the volume of water in the pipes between the source of hot water and the fixture, the potential water and energy savings benefits will be reduced and might actually be reversed.

In the cool down phase, insulation increases the time that the pipes stay hot enough to use for the next hot water event, thereby increasing the likelihood that the temperature in the pipes is hot enough for the next use. There are four major issues.

- Where is the location of the hot water event in relation to the source of hot water?
- How long is the time until the next hot water event?
- What is the temperature of the hot water needed for that subsequent event?
- What is the volume of water in the pipe that eventually cools down?

Going back to trunks, branches and twigs, all hot water distribution systems have some combination of these. The worst configuration from the water and energy perspective is to have a high volume system characterized by long, large diameter trunks, long, large diameter branches and long twigs. The best configuration would be a low volume system characterized by short, small volume trunks, no branches and short twigs. To achieve this configuration means carefully determining the location of all fixtures in relationship to one water heater, or having multiple water heaters as will be described in the section on Point-of-Use Water Heaters. The next best system would be to have a reasonable volume trunk and short twigs. This provides for greater flexibility in the relationship between the water heater(s) and the fixtures, while still minimizing the volume of water in each twig.

Standard main and branch systems generally have large volume trunks, medium volume branches and relatively small volume twigs. The distance (volume) from the water heater to the fixtures varies from close to far (small volume to large volume). If the first hot water event is close to the water heater, then hot water will flow through the trunk line to the branch line to the twig serving that fixture. If the next hot water event is located at the far end of the trunk line, then the source of hot water will be the point on the trunk line where the water branched off to serve the first event, assuming, of course, that the water in the pipe hasn't cooled to below the temperature needed for the second hot water event. If the first hot water event was at the furthest fixture, then the hot water would already be at the branch line serving the closest fixture, assuming that the time between hot water events is short enough that the temperature in the pipes was still hot enough.

Once the temperature in the pipes drops below the desired temperature for the next hot water event, it is necessary to replace all of the water in the pipes that is not hot enough with water that is. As was discussed earlier, **at a minimum**, this will be the volume of water that is in the pipe between the source of hot water and the fixture. The amount that needs to be removed can be significantly more than this, both for structural reasons and for behavioral ones…if people have to wait long enough, they leave, coming back to see if the water is hot when they are good and ready to do so.

While the examples given above are based on single family dwellings, the principles are equally applicable to multi-family and non-residential applications. For example, in multi-family buildings with recirculation systems, depending on how the plumbing is configured, there may be a branch line serving each apartment or there may be individual twigs serving each fixture off a trunk line.

The time between hot water events, the location of the next hot water event and the temperature needed for the next hot water event are all unknowns. They are essentially random and the possibilities are practically infinite. However, all of the possibilities default into two choices; either the temperature of the water in the pipes is hot enough for the next hot water event or it is not. Since it is unknown what the desired temperature for the next event will be, it makes sense to design systems to provide for hottest typical event, say 105° to 110°F, suitable for a shower.

The volume of water in the pipes is determined by the location of the fixtures and appliances in relationship to the water heater(s). The greater the length, the higher the flow rate and the more fixtures served by the same pipe, the greater the volume that pipe needs to be. Plumbing codes must be followed when determining the diameter of the pipes supply hot water to the fixtures. The purpose of good engineering and the codes is to ensure that there is enough pressure at each fixture so that it operates properly under a variety of conditions.

Given these considerations, the volume of water on the supply side of a hot water distribution system is effectively predetermined. As shown earlier in Figures 5 and 6, the same amount of insulation keeps a larger diameter pipe hotter longer than a smaller diameter pipe. However, the larger the diameter, the more water that will eventually cool down if the time between hot water events is long enough. The energy it took to heat this water will effectively be lost.

A balance needs to be struck between the volume of the water that is in the supply piping and the fact that the energy it took to heat that water will be lost when the water in the pipes eventually cools down (which it will always do if the time between hot water events is long enough). While this can be addressed relatively easily in new construction (or a major remodel where the piping configuration can be changed), it is much harder to do so in retrofit.

Single trunk and branch systems are the simplest to fix and the ones where the benefits in terms of water and energy will be greatest. This is because once the trunk line is primed with hot water, the volume to the fixture is reduced to what remains in the branch and twig that serves the fixture. Since all fixtures are served by some combination of branches and twigs that emanate from the main trunk line, all fixtures will benefit to a greater or lesser degree by priming the main trunk line.

The most difficult plumbing configuration to fix will be manifold systems. These systems are characterized by a trunk line of some volume, hopefully small, and twigs serving individual fixtures. If there are many fixtures with relatively large volume twigs, there will be many problem areas that need to be addressed.

In new construction, it is possible to address both the location of the fixtures and the layout of the plumbing that will serve those fixtures. Stacking hot water fixtures, locating them back-to-back and grouping them close together and near the water heater minimizes the total plumbing required. This is true for the hot and cold water supply as well as for the drain system. However, efficiently locating the plumbing fixtures is often not the primary criteria when designing a building layout.

The key to reducing the waste of water for the next hot water event is to minimize the volume of water between the source of hot water and the fixture that is not hot enough to perform the task at hand. Insulated trunk lines, which are relatively large in diameter, stay hot a relatively long time. Once the trunk line is hot enough, then the volume of water between the trunk line and the individual fixtures becomes the next critical value. The smaller the volume of the water contained in these sections of pipe, the less water that will be wasted at the beginning of the next hot water event.

3.0 Technologies and PBMPs

3.1 Point-of-Use Water Heaters

The principle behind point-of-use water heaters is to locate the heater(s) close to each fixture or appliance so that when hot water is desired, the waste of water, energy, and time until hot water arrives is minimized. Each point-of-use water heater needs to be sized properly for the one or more fixtures that it will serve. Many people are familiar with the devices that are intended to heat a small amount of water at the kitchen sink. While appropriate for that use, they are not capable of supplying one or more gallons per minute of hot water for continuous use at a sink or shower and they do not have the capacity to provide the hot water for a dishwasher or washing machine cycle.

Hiller (ASHRAE-Hiller, 2005) reports that beyond a certain distance, adding another water heater may be more energy-efficient than running the plumbing from a single water heater. This conclusion is based on the results of laboratory tests that studied the heat loss characteristics of ½- and ¾-inch piping. This paper compares the energy lost in the piping to the energy lost by the water heater, both over the course of the day. Hiller found that larger diameter pipe, less insulation on the pipe, and more efficient water heaters translate into a shorter distance before the energy losses from another water heater are equal to the energy losses of the intervening piping. This was true for both trunk and branch piping layouts and for recirculation system layouts.

The CEC approaches the question somewhat differently. In the 2005 Title 24 Building Energy Efficiency Standards Residential Compliance Manual (CEC-Shirakah, 2005) a point-of-use hot water distribution system is one with no more than eight (8) feet of horizontal distance between the water heater and hot water fixtures, except in the laundry. The CEC considers this type of distribution system to be somewhat more efficient than the standard hot water distribution system. To get credit for this when building a house, there can only be one such system in the building - one water heater serving all fixtures and appliances.

There are several issues with installing point-of-use water heaters. These have been well described by Klein (IAPMO-Klein, 2005b) as follows:

1. The cost of running gas piping or electrical wiring to each point-of-use water heater instead of running plumbing pipe to the same location. In general it always costs less to install the same length of plumbing.
2. The cost of installing additional flues if gas is the water heating fuel.
3. The related problems of how to install a flue for the island sink in the kitchen when the floor is a slab-on-grade.
4. The cost of each additional water heater. If the additional water heater(s) serve loads such as a shower, then they need to be essentially the same capacity as the single water heater that is generally chosen to serve an entire house. This capacity either needs to be in a tank with a volume large enough to provide hot water for the intended application or it needs to be in the form of a tankless water heater with a burner or element large enough to keep up with the hot water demand. Small tank water heaters may be an option for remote sinks, but if they need to serve a shower, dishwasher or a washing machine, the volume need increases rather quickly. For example, to supply enough hot water for a 10 minute shower, the tank needs to have 30 gallons of stored hot water. If the shower is longer, the tank needs to be larger. In the tankless case, assuming 55°F incoming cold water and 120°F outgoing hot water, it takes roughly 10 kW electric or 40,000 Btu gas to continuously heat 1 gpm. This flow rate is fine for most sink uses, but it is not enough for a shower, which needs roughly 2 gpm. This doubles the instantaneous energy consumption.
5. The space required by each water heater. Typical practice in single family residential applications in California is to install the water heater in the garage. In multi-family applications, either a large mechanical room serving many individual dwelling units or a smaller mechanical room in each individual apartment is used. In commercial buildings,

there is generally a mechanical room. As an example, a typical tank-type water heater needs roughly 10 square feet of space, including the walls that surround it. At sales prices for single family homes of more than $200 per square foot, this means that the value of the space for the water heater is more than $2,000. While tankless water heaters take up much less space, the space they take within the building needs to be considered.

6. Finally, the future maintenance that will be needed by each water heater. Most homeowners don't adequately maintain the one water heater they have today. Should they be expected to properly maintain more than one?

Do multiple water heaters make sense? The short answer is that it depends on an interrelated set of variables. The variables include the volume of hot water or flow rate that is needed at each fixture and appliance, the distance between fixtures or groups of fixtures and appliances, and the intermittency of the use pattern. The more intermittent and the smaller the demand in flow rate or volume, and the further the fixtures are apart, the more a point-of-use water heater makes sense.

3.2 Recirculating Hot Water Systems

The primary alternative to point-of-use water heaters is to install a recirculating hot water system. There are several issues with installing hot water circulation systems. These have been well described by Klein (IAPMO-Klein, 2005b and 2005c)

There are six types of recirculation systems:

1. Thermosyphon (gravity convection with no pump),
2. Continuously pumped systems,
3. Timer controlled,
4. Temperature controlled,
5. Time and temperature controlled, and
6. Demand controlled.

Thermosyphon-based recirculation systems use the temperature difference between the hot and cold water and the height of the building to drive the water around the loop. They work because heat is lost from the time the water leaves the water heater until it returns at some colder temperature to the water heater, often 5–10^{o}F less than when it left the water heater. It takes energy to reheat the water; how much depends on the heat loss and the flow rate, which is in the range of 0.5–1 gpm. Pipe insulation is often neglected, which means that there is even more heat loss as the water moves around the loop.

A ***continuously pumped*** recirculation system is thermally very much like a thermosyphon system, with the addition of a small pump that runs 24 hours per day. In most residential systems the pump draws roughly 40 watts. In multifamily and commercial systems the pump can draw significantly more energy.

In ***timer-controlled*** recirculation systems a timer determines the hours of operation of the pump. This has the effect of reducing the costs of operating the recirculation system in proportion to reduced hours of operation. In residential applications, a timer is often set to run for all of the waking hours, or roughly 16 hours per day. In this case, it would use roughly two-thirds as much energy as the continuously pumped system for both the pump operation and for heating the water needed to maintain the temperature in the loop.

Another method of controlling the pump is to install an aquastat, which is a method of ***temperature control*** similar to that used in an automobile radiator. The aquastats that are often used in single family applications are set to open when the temperature drops to 95° F and to close when the temperature rises to 115° F—a 20° F bandwidth. Assuming that the minimum desired hot water temperature is 105° F, the temperature in the recirculation line is colder than desired at least half the time. A better choice from a water temperature perspective would be to use an aquastat with a minimum set point of more than 105° F. However, with a bandwidth of 20° F, the lowest water heater setting must be above 125 ° F, otherwise the pump will never shut off. An aquastat controlled system can be installed without a timer, and if set up properly, will run roughly half the time, or 12 hours a day. If set up incorrectly with the water heater temperature too low to overcome the temperature drop in the recirculation loop, the upper temperature limit of the aquastat will never be reached and the pump will continue to run 24 hours a day.

Time- and Temperature-Controlled recirculation system combine the use of a timer and an aquastat. Assuming a 16-hour time clock, the aquastat will allow the pump to come on roughly half that time, or eight hours per day.

Demand control is the last method of operating a recirculation system. This system uses one or more consumer-activated devices (button, remote, flow switch, door switch, motion sensor) located where convenient near the hot water fixtures to "tell" the pump to come on. A thermo-sensor, looking for a small (5–10 °F) rise in temperature above the ambient pipe temperature, tells the pump to shut off. In typical residential applications, the pump is activated 10-20 times and runs for 10–20 minutes a day, the duration depending on the configuration of the plumbing system (volume and restrictions). Unlike typical recirculation systems which usually have a ½ inch diameter return line, demand controlled systems have a return line that is no smaller than ¾ inch. This is to accommodate the higher velocity found in demand pumps, since they are intended to "prime the line" quickly and then shut off.

Given the same plumbing layout (meaning the same diameter trunk line supplying hot water to the fixtures and same volume in the lines serving each fixture), all of these systems will waste the same amount of water at the beginning of a hot water event. The difference in these systems is in the energy it takes to keep the trunk line primed with hot water.

Rosenthal (Rosenthal, 2005) measured water savings using a time and temperature controlled retrofit water circulation system. The small pumps were located in the room that was determined to have the longest wait for hot water. Based on a sample of ten single family homes, Rosenthal found that the average decrease in water waste per hot water use event in these test rooms was 2 gallons (68 percent). There was a large variation in the water waste, however, and therefore the savings per household varied significantly as well. The smallest measured decrease was 0.8 gallons and the largest was 5.4 gallons. The percent reduction in waste was also very variable, ranging from 5 to 96 percent. Rosenthal then estimated whole house savings from the savings measured in the test room. Based on this estimate, the potential water savings compared very favorably with the savings from high efficiency washing machines and from showerhead replacements. Although the water utility does not see the entire benefit, Rosenthal points out that the customer benefits from the savings in both water and wastewater costs. The study did not measure the energy costs or savings from using these time and temperature controlled circulation systems. Although most customers were satisfied with the system's performance, some pointed out that they often had warm water in the cold water lines and had to run this out before they could get cold water. Rosenthal plans to start a new study in 2006 with Proposition 50 funding to look at this question.

As documented the articles and papers by various green building programs and more recently by the U.S. Environmental Protection Agency (U.S. EPA-Chinery, 2006), demand controlled circulation is the most energy-efficient. In fact, demand controlled circulation systems use less energy, and waste less water than current practice where water is run down the drain at the beginning of a hot water event. Green building programs such as the City of Austin, Build-It-Green and the U.S. Green Building Council's LEED for Homes all give the most credit for using a demand controlled circulation. EPA released a draft report in early June 2006 (the final report is due to be released in late June) that recognizes demand controlled pumping as suitable for inclusion in Energy Star for homes programs. The EPA is in the process of defining a category for all circulation systems.

The EPA report states that demand controlled pumping systems can conservatively save 15 percent of the daily hot water consumption when used in retrofit or new construction on trunk and branch systems where no special consideration has been given to optimizing the plumbing layout or to insulating the pipes. This reduction in water consumption translates to energy savings equivalent to a 12-17 percent energy factor coefficient enhancement to the water heater.

When demand controlled circulation is combined with Structured Plumbing, in which the volume of water in the branches or twigs serving individual fixtures has been minimized (less than 10 feet of ½ inch diameter or less piping) and all hot water pipes have been insulated with at least R-4 pipe insulation, the water and energy savings will be even larger. The EPA conservatively estimates that water savings will increase to 20 percent of the daily hot water use (due primarily to the small volume in the twigs) and an additional savings will be due to the insulation on the piping, which increases the likelihood that the water in the pipes will be hot enough for the next hot water event. The combined energy savings are estimated to be equivalent to a 27 to 42 percent increase in the energy factor of the water heater.

The California Department of Water Resources recently awarded a Proposition 50 grant to Lawrence Berkeley National Laboratory to compare the performance of Structured Plumbing systems to standard plumbing systems. The study will work with one or more builders so that different plumbing configurations can be applied to the same floor plan and the water and energy performance of each type measured. This study will begin in the second half of 2006.

3.3 Hot Water Pipe Insulation

The benefits of hot water pipe insulation were discussed earlier in this report. The research results were based on relatively mild ambient temperatures surrounding the pipes. These temperatures are close to the temperature found in most buildings, 65°-70°F. This means that hot water piping should be insulated even when the pipes are located within the conditioned building envelope.

In general, it will be much more difficult to insulate the pipes in retrofit than it will be in new construction. This is due primarily to the fact that hot water pipes are often buried, hidden in walls or floors or are located in other hard-to-reach places such as crawl spaces. However, given the benefits, wherever possible, they should be insulated. The focus of any retrofit insulation effort should be to insulate the main trunk line(s) that serve(s) many fixtures. Then focus on insulating the longest, most used branches and twigs. These recommendations apply to all building types.

Insulation of all hot water pipes should be required in new construction for all building types.

If the cold water pipes run in locations where they get warm or hot, they should also be insulated. The idea is to deliver hot water to the hot fixtures and cold water to the cold water fixtures, not lukewarm water to either of them.

4.0 California Potential

There is a large base of existing buildings in California with water- and energy-inefficient hot water distribution systems. There is also a large number of new buildings constructed each year also with water- and energy-inefficient hot water distribution systems.

Klein (ASHRAE-Klein, 2005) estimated the magnitude of the waste and therefore the benefit for the United States. This paper estimated the scope of losses of water and energy caused by the poor design and installation of hot water distribution systems. The emphasis was on residential buildings, both single family and multifamily. The purpose for the estimate was to assess whether or not the waste of water, energy and time associated with waiting for hot water to arrive at fixtures was large enough to warrant further study and possible remediation. The base year for the estimates was 2005.

The paper estimated that the daily waste of water was 10 gallons per household per day, recognizing that the standard deviation around this number is quite large. This level of waste is roughly 17 percent of daily average hot water consumption and is consistent with the waste report by Rosenthal. This volume of wasted water while waiting for hot water to arrive results in a waste of energy in each home as well. If the water is heated electrically, the energy waste is 2.9 kWh per household per day. If it is heated with natural gas, the energy waste is 0.14 therms per household per day.

The waste of water was estimated to be 415 billion gallons (almost 1.3 million acre-feet) in 2005, continuing to grow proportional with household growth unless something was done specifically to prevent that waste. The paper looked at the United States as a whole and did not separate out California. The number of households in California is roughly 10 percent of the national total. Assuming that the average plumbing configuration is the same as the national average, and that behavior while waiting is essentially the same, then roughly 40 billion gallons (123,000 acre-feet) of the waste occurs in California.

The energy consequences of this waste depend on the relative amount of water heating that is done by natural gas or electricity. In California, this is roughly 85 percent natural gas (or propane) and 15 percent electric. Applying these percentages to the waste of water, the energy impact is 476,000,000 therms and 1,740,000,000 kWh per year.

Costs can be estimated assuming $0.005 per gallon for water and wastewater costs combined, $1.00 per therm for natural gas and $0.10 per kWh for electricity, all of which are conservative given today's prices.

The total cost in California in 2005 can then be estimated to be at least $850 million ($200 million for water and wastewater, $476 million for natural gas and $174 million for electricity). There are additional costs associated with the inefficient operation of multifamily circulation systems and non-residential applications, which brings the total estimated costs to more than $1 billion per year for existing residential applications.

Nationally, the waste is growing by at least the rate of growth in the number of households or roughly one percent per year. In California, the rate of growth of new dwelling units (single family, multifamily and manufactured) is estimated to be approximately 130,000 per year through 2025. Conservatively assuming that the average waste per household remains the same, (in fact the waste is likely to be larger, since dwelling unit square footage is increasing), the expected **increase** in water waste will be 475 million gallons (1,475 acre-feet) per year. These water and energy inefficiencies cost Californians $10 million ($68 per household) per year.

To express it differently, every year that serious improvements in construction practices are delayed will result in an increase in annual waste of about 1,475 acre-feet of water. In the 20 years from 2005 to 2025, the waste will grow to 9.5 billion gallons (29,000 acre-feet) per year, an increase almost 25 percent on the current waste occurring in existing homes. The total waste is growing even faster when ones takes into account the other non-residential buildings that are being constructed in California.

5.0 Possible Actions

5.1 Single Family - New Construction

Water providers have the opportunity to dramatically impact the future water efficiency of hot water distribution systems in single family (SF) new construction by requiring that all new plumbing be installed to take advantage of what has been learned about how to improve performance. In general, new homes are being built with structural water waste that is significantly larger than the average waste in existing households, as discussed above. The costs and potential savings are proportional to the actual waste. The key to obtaining future water savings is to improve the hot water distribution systems so that the volume wasted at the beginning of each hot water event is minimized. Minimizing the water waste will also reduce water and wastewater treatment agency expenditures on embedded energy costs while also reducing the energy costs for water heating.

One strategy is to require that all builders change the layout of their houses so that all hot water fixtures are located within less than a given number of plumbing feet of a single water heater. While the concept of better plumbing fixture layouts should be encouraged through incentives such as points in a green building program, water providers risk a great deal of strong resistance from builders and consumers if it is mandated. Similarly, mandating more water heaters, given the additional installation costs and other issues, should be avoided. Where appropriate, water providers can encourage the use point-of-use water heaters.

The installation of Structured Plumbing systems is the most cost-effective and buildable strategy in single family new construction, since it requires the fewest changes to standard practice. A Structured Plumbing system includes a properly sized trunk line located such that the distance from the trunk line to each fixture is no more than 10 feet of ½ inch diameter or smaller piping. All hot water lines must be insulated. In most cases there will be a dedicated return line from the last fixture back to the water heater, but there are some circumstances in which the cold water line may be used as the return. The pump used to circulate the water must be demand controlled, not continuously operated or controlled by time, temperature, or time and temperature. As of June, 2006 there are at least three manufacturers of demand controlled pumping systems: ACT Inc., Metlund Systems (www.gothotwater.com); TACO (www.taco-hvac.com); and Uponor Wirsbo (www.wirsbo.com).

Installing Structured Plumbing in new construction often requires no more piping (even including the dedicated return line that is recommended) and labor than typical plumbing installations, the only difference is the layout for where the pipes are located. There are additional costs for pipe insulation, but sometimes it may be possible for the pipes to be buried in attic insulation for much of their length, and the cost of insulation for this portion of the system is zero. For purposes of this paper it can be assumed that there will be an additional cost for the installed pipe insulation of $100. The primary additional costs are for the demand controlled pump and the activation mechanisms and for the additional outlet where the pump is to be connected. These costs range from $325 to $725. What is essential to note is that there is practically no increase in cost to install the piping, the pipe insulation and the extra outlet in a Structured Plumbing configuration. If this is done, then the homeowner has a choice of including the pump and activation mechanisms in the original purchase or of waiting until after they have lived in the house for some time and completing the system as a retrofit. Since the plumbing was laid out efficiently, the retrofit will have the same performance characteristics as if it were installed during construction.

Structured Plumbing systems can either be mandated or encouraged. Mandated programs are often difficult to implement, but once past the political battle prior to adoption, they generally provide the most savings at the least cost. The most effective strategy will probably be to start by developing a joint incentive program with the local energy utility that is responsible for selling the energy used for water heating. The program should include assistance with plumbing layouts before the builders have the plumbers bid on the projects, work with the plumbers so they understand how to bid and install the systems properly, discussions with the local building officials so they understand how the systems meet the code requirements, validation that the systems were installed properly and measurement that they perform as intended. A feedback loop needs to be established so that customer satisfaction, and water and energy performance are tracked and improvements made to the program to maximize the benefits at the lowest delivered cost. After a few years of incentives, it will then be much easier to make the use of Structured Plumbing a requirement.

Given the water and corollary energy issues in Southern California, there is a confluence of events that strongly indicates that a large scale program should be started in all growing communities south of the Tehachapi Mountains. The reason for this focus is that the embedded energy in the water is generally the greatest in Southern California, so the ancillary benefits to the state are the largest. Similar programs should be started in all growing communities in the state.

5.2 Single Family - Retrofit

While there are many more existing homes that have inefficient plumbing systems than what is built new each year, the key to a retrofit program is to identify the homes with the greatest structural waste without spending a great amount of money doing so. The key is to identify those homes with single trunk and branch plumbing configurations, since priming the trunk line with hot water will reduce the waste to the amount remaining in the branches and twigs serving individual fixtures. The next best homes to target are those with two trunk lines, one of which serves the kitchen and the master bathroom, the two most used hot water rooms in a house. The City of San Diego Water Department will be testing a simple audit technique in the Proposition 50 program that they will implement in the second half of 2006, where they will also demonstrate and measure the water and energy performance of demand controlled pumps.

Demand controlled pumps are the only type of circulation pump that will save the customer both water and energy. There are two other types of pumps sold for use in retrofit, both of which have time and temperature based controls. Neither of them saves energy because they need to run many hours per day to provide hot water when needed by the occupants. If the number of hours is restricted, then whenever hot water is needed between circulation cycles, the water savings are reduced.

The water and energy savings from a retrofit program are likely to be somewhat less than that attainable in a new construction program. The reason for this is that it is extremely unlikely that such a program can or would attempt to reconfigure or insulate the existing piping. Even with this caveat, a retrofit program can be cost effective. The cost to retrofit with a demand controlled pump is between \$300 and \$700 depending on the model and features. In addition to the cost of the pump and activation mechanisms, there is installation, which takes about one hour if there is electricity available under the sink (e.g., kitchen) and another hour if it is necessary to run a short line from the outlet near the bathroom sink to a location down under the cabinet.

As in new construction, the program should be run in cooperation with the local energy utilities, to share both program costs and benefits. One way to think of the magnitude of the incentives is to look at the joint programs that were run to support the introduction of high-efficiency clothes washers. Since the water savings are similar, the incentives should be similar.

5.3 Multi-Family - Retrofit and New Construction

There are two types of multi-family buildings, those with central water heaters and circulation systems and those with individual water heaters serving each dwelling unit. In existing multifamily buildings with central systems, unless the circulation loop is non-existent or inoperative, the savings are primarily energy and the role for water providers is limited. In those buildings with individual water heaters serving each dwelling unit, the plumbing systems must be looked at the same way as would be done in a single family home. The key is to identify those buildings with single trunk and branch systems that serve the whole apartment and to install a demand controlled circulation pump at the furthest fixture from the water heater on the trunk line that serves the most used fixtures. Also, install insulation on the pipes if they are accessible.

In new construction or major renovation, programs should assist the builder or developer with the design of the plumbing layout in order to minimize the volume of water between either the circulation loop and the fixtures or the water heater and the fixtures. The concept of Structured Plumbing should be fully employed, adjusted as applicable to the type of water heating system. In buildings with central hot water, the activation mechanism will probably need to be a flow control, rather than the buttons or motion sensors that are typically used in single family homes. An excellent example of how to implement this concept in a major renovation can be found in a 35 unit apartment building owned by Bob Mayer in San Francisco (Mayer, 2006, personal communication). He plans to complete the renovations in late 2006 and will be measuring the water and energy performance.

Even though many of the savings to be found in multifamily buildings are energy, not water, it still makes sense to share programs with the energy utilities. Working closely with multifamily building owners, operators, management companies and developers will be key to the success of these programs. Builder, plumber and code official education need to be part of the program as will validation of system performance and feedback to the program designers so that the program can be improved.

5.4 Non-Residential - New Construction and Retrofit

Most of the efforts to understand how to improve hot water distribution systems have gone into residential applications, so less is known about non-residential situations. Point-of-use water heaters have greater application in buildings that are more spread out. This is particularly true when the hot water demand is both small and intermittent. When non-residential applications looks like those found in single and multifamily residences, then the solutions will probably be similar as well.

Recent discussions with the Food Service Technology Center indicate that there are many opportunities to save water by improving the plumbing systems in food service facilities. Improving the plumbing will result in the more the rapid availability of hot water at kitchen and lavatory sinks, which will help the industry meet its health code requirements.

6.0 Cost Effectiveness

Based upon the potential savings per household data presented in Section 4.0 and the rough costs for new construction and retrofit installations discussed in Section 5.0, the cost effectiveness of the two scenarios was determined to be approximately as follows:

Estimated lifetime savings: 10 gallons per day per household x 365 days x 25 year life =
91,250 gallons = 0.28 acre-feet of water
Approximate cost: $425 to $825 per installation
Cost per acre-foot saved: $1,500 to $2,900

It appears that, by itself, the cost of the saved water does not justify an incentive program that pays for the entire cost of a residential installation. However, by coupling such a program with similar incentive programs that might be offered by water and/or wastewater utilities, feasibility may be achieved. However, structured plumbing requirements are being "written into" various green building programs today. Therefore, the implementation of a BMP directed at these voluntary green building programs would have minimal cost to the water utilities and could achieve savings in a large number of new residential dwelling units in California.

7.0 Conclusions

In the quest to realize genuine water use reduction, the amount of water to be saved will depend on first developing an answer to the question posed at the beginning of this paper:

> How much water can or should be wasted while waiting for hot water to arrive?

Deciding how much residual waste is acceptable after making changes to the plumbing system is the key to making significant reductions in the structural waste in buildings. Specialists in the field of residential hot water distribution know how to get the waste down to less than two cups per hot water event. Doing this will require a significant effort, but the effort will be rewarded in terms of reductions in water, wastewater, energy and air pollution and increases in customer satisfaction. As we proceed along this path, we recommend partnering with the California Energy Commission and others in the water-use aspects of their initiatives to better understand the most effective ways to obtain the potential savings represented from the technologies discussed in this paper.

Based on the evidence provided in this paper, we recommend that the PBMP relating to this topic be defined to encompass Structured Plumbing in new construction as well as encompassing the technologies contributing to it.

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