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Author
Williams, Alison

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Alison Williams, Camilla Dunham Whitehead, and James Lutz

Energy Analysis Department
Environmental Energy Technologies Division
Lawrence Berkeley National Laboratory
Berkeley, CA 94720

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DISCLAIMER

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Lawrence Berkeley National Laboratory

ABSTRACT

Reducing the water use of plumbing products—toilets, urinals, faucets, and showerheads—has been a popular conservation measure. Improved technologies have created opportunities for additional conservation in this area. However, plumbing products do not operate in a vacuum. This paper reviews the literature related to plumbing products to determine a systems framework for evaluating future conservation measures using these products. The main framework comprises the following categories: water use efficiency, product components, product performance, source water, energy, and plumbing/sewer infrastructure. This framework for analysis provides a starting point for professionals considering future water conservation measures to evaluate the need for additional research, collaboration with other standards or codes committees, and attachment of additional metrics to water use efficiency (such as performance).

INTRODUCTION

Reducing the water use of plumbing products—toilets, urinals, faucets, and showerheads—has long been a popular and effective conservation measure. However, some low-flow plumbing products, especially initially, met with controversy, primarily over their performance. When federal standards were set in 1992, manufacturers released essentially the same products they always had, just adjusting the water level in toilet tanks or restricting the flow on showerheads. These products did not function well and resulted in many customers having bad experiences with “low-flow” products. Since the 1990s, many manufacturers have made great strides in redesigning their products to work effectively at lower flush volumes or lower flow rates. However, many customers still remember their bad experiences and remain skeptical.

These performance issues constitute just one set of factors related to improving the efficiency of plumbing products. As with any product, plumbing fixtures do not exist in a vacuum. Their water use is determined not only by the design of the product, but additional features of the product, how the product is installed, and how users interact with the product. In addition, the water use of the product on-site affects energy use both on-site and in the system, the functioning of the drainage and sewer system, and the sustainability of the source water. Setting standards for water use efficiency of plumbing products offers an opportunity for significant water conservation. At the same time, it also narrows the focus from other opportunities for both water and energy conservation and may cause undesired effects elsewhere in the system. While many of these issues have been addressed in relative isolation, no single source has attempted to review them in combination. This paper provides a literature review regarding plumbing products to establish a framework within which adoption of water conservation measures through standards, codes, or programs could be approached for maximum benefit with the least negative consequences.

This paper does not attempt to address the economics surrounding these issues. It is important to note that water-efficient plumbing products themselves do not have a higher first cost than standard plumbing products (California Energy Commission, 2011) (Federal Energy Management Program) (Flex Your Power). The economics of other system-related issues such as building codes, utility infrastructure, and energy use are too detailed to include in this paper, but would be a useful venue for further research.

BACKGROUND

In the 1970s, due to aging water and wastewater utility infrastructure and shrinking water supply, utilities encouraged manufacturers to design and sell toilets that could flush less water than the five to seven gallons per flush (gpf) common in that time period (Osann & Young, 1998). By the late 1980s, all major toilet manufacturers produced toilet models that flushed 1.6 gpf, and, by the early 1990s, a coalition of plumbing product manufacturers, water and wastewater utilities, environmental organizations, and other interested parties petitioned Congress to enact national efficiency standards for plumbing products (Osann & Young, 1998). Congress did so in 1992 through the Energy Policy and Conservation Act. These efficiency levels were codified in a 1998 final rule (Department of Energy, 1998) and were based on the industry standards published by the American Society of Mechanical Engineers (ASME). The final rule also references the industry test procedures for measuring the water efficiency of these devices. However, the ASME standards also contain additional test procedures for performance not referenced by the federal government, such as waste removal and surface wash.

Some states[1] had set minimum efficiency levels for plumbing products prior to the federal action, but the federal standard pre-empted state standards. A clause in the law stated that, if the standards did not change in five years, the pre-emption would be waived. This waiver did not happen for years, causing uncertainty as to whether state or local jurisdictions could set stricter standards (North Carolina Department of Environment and Natural Resources, 2009), and some did, including California (Assembly Bill 715-Chapter 499) and Texas (HB No. 2667). In December 2010, the federal government finally released a waiver of pre-emption that would allow states to set higher efficiency standards for these products (Department of Energy, 2010).

[1] Seventeen states, in which about half the U.S. population lived, had done so, namely: Arizona, California, Connecticut, Delaware, Georgia, Maryland, Massachusetts, Minnesota, North Carolina, Nevada, New Jersey, New York, Oregon, Rhode Island, Texas, Utah, Washington (Osann & Young, 1998)

California is already considering increasing minimum efficiency for showerheads in its building code (California Statewide Codes and Standards Team, 2011).

While standards address products, codes can address installation. A few states and local entities also regulate efficiency levels through building codes, which often apply primarily to new construction. Furthermore, other entities run voluntary programs that support higher efficiency plumbing products, including the U.S. Environmental Protection Agency's (EPA's) WaterSense program (developed in collaboration with industry stakeholders) and many utilities.

Table 1 provides an overview of maximum water use for plumbing products in the United States, as well as lower voluntary standards set by the U.S. EPA (WaterSense) and the maximum technology levels available on the market.

Table 1: Water Efficiency by Product

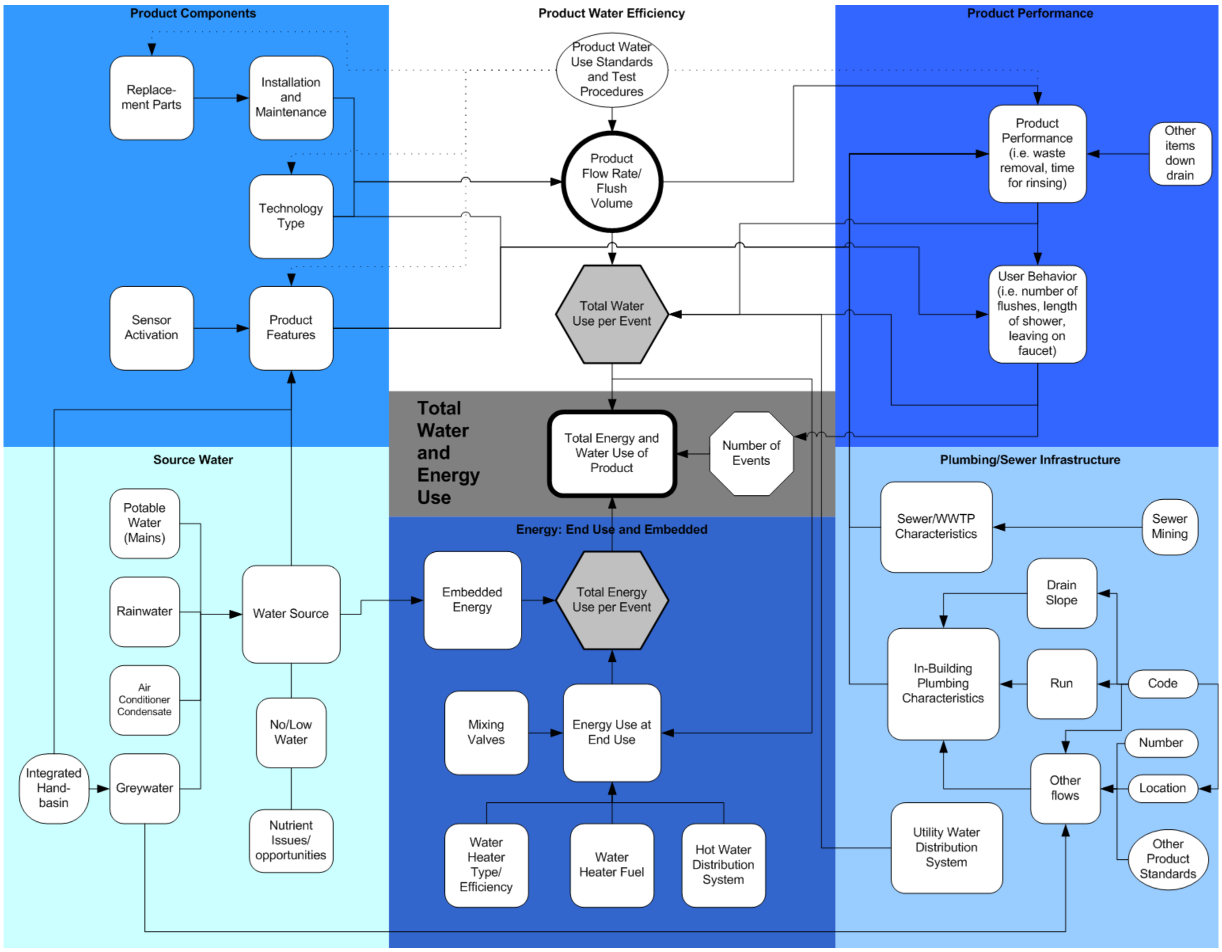
Product	Rating	Federal Standard	WaterSense Maximum	Approximate Max-Tech (Current)
Toilet	Gallons per flush	1.6 (except blow-out)	1.28^	0.8; composting, urine-diverting, foam-flush, etc.
Urinal	Gallons per flush	1.0	0.5	1/8; waterless
Faucet*	Gallons per minute	2.2 (lavatory and kitchen)	1.5 (private lavatory only)	0.5
	Gallons per cycle	0.25 (metering)	N/A	N/A
Showerhead	Gallons per minute	2.5	2.0	1.0

*ASME has a standard of 0.5gpm for public lavatory faucets that is widely regarded as a federal standard, but it has not been formally adopted by the Department of Energy.
^For dual flush, this maximum can be achieved by averaging two reduced flushes and one full flush.

METHODOLOGY

This research effort began with an examination of the federal test procedures for plumbing products in relation to the current industry test procedures (published by ASME) and progressed to include a search for new technologies— and any problems with these technologies—that could affect water savings from these products. Additional, non-referenced industry test procedures were examined, as well as other mandatory and voluntary programs related to the water use of plumbing products in the United States and other countries. The literature search also included studies and presentations that discuss issues or problems with low-flow plumbing products.

The information obtained was organized into a system framework, with the total water and energy use of the plumbing products shown in the center (Figure 1). The water use efficiency of these products is shown in the top center rectangle, as this is the focal point of the framework and paper. On the top left corner are product components, which include technologies, features, and installation—all of which can either provide additional savings or cause water waste. The top right rectangle addresses product performance and how users interact with plumbing products. Ideally, if a product performs well at its rated water use, users will behave in a way that also minimizes water use. The bottom level addresses the broader interrelationships between plumbing products and such issues as source water, energy use, and plumbing infrastructure. Research at this level is aimed at answering such questions as what type of water is most important to conserve, what are the tradeoffs or synergies between water and energy use, and are there potential problems or benefits associated with plumbing and drainage system design at the household and utility level.



Note: This figure does not include cost or health issues, as they surround nearly every component of the diagram.

Figure 1: Systems Framework for Plumbing Products

In this paper, product components and product performance are primarily addressed in sections dealing with particular products. The bottom-level issues, including source water, energy use, and plumbing/sewer infrastructure, are primarily addressed in a section that covers overarching concerns. As can be seen from the diagram, there are many interactions within the framework, and as a result, many of the individual topics within product components and product performance also affect energy use, and in fewer cases, source water.

TOILETS

Table 2 summarizes the main issues surrounding water conservation with toilets. For readability, the paper has been organized at a finer level than shown in the framework diagram; sections are divided at the category level shown in the table and cover all the topics listed.

Table 2: Issues affecting toilet water use

Framework	Category	Topic
Product Performance	Performance	Waste removal
		Drainline carry
		Surface wash
		Commercial vs. residential
Product Components	Manufacturing Criteria	Tank trim adjustability
		Fill valve integrity
		Chemical durability of flush valve seals
	In-Field Issues	Installation issues
		Replacement flapper valve compatibility
		Sensor-activated flush valve performance
	Water-Saving Devices and Technologies	Dual flush toilet
		Double-action (interruptible) toilets
Source Water		Integral handbasins
		Composting toilets
		Urine-diverting toilets
		Foam-flush toilets
Energy		Air-assisted toilets

Performance. Toilets have likely faced the most customer dissatisfaction of all low-flow products, with the primary problem being solid waste removal. When low-flow toilets first emerged, manufacturers did not generally make changes beyond reducing the quantity of water used, and, as a result, many did not remove waste very well (Henderson & Woodard, Functioning of Aging Low-Consumption Toilets in Tucson, 2000). A few models still don't, but today many models perform even better than the old, higher flow toilets.

Many entities have attempted to address regulation of waste removal in toilets in different ways. The United States and Canadian standards include granule and ball and mixed media tests (American Society of Mechanical Engineers, 2008). However, these tests are widely regarded as being not representative of real-world conditions, and studies show that passing certification with current test media does not mean a toilet will have good performance with realistic media (Vertic Consulting Inc. and Koeller and Company, 2007). Some standards, including those in the United States and Australia, also include paper removal testing for the reduced flush mode of dual-flush toilets (American Society of Mechanical Engineers, 2006) (Standards Australia, 2005).

WaterSense includes flush performance testing with realistic media as part of their high-efficiency toilet specification (EPA WaterSense, 2007). This testing regime is a modification of Maximum Performance (MaP) testing, which has been used by many utilities when specifying toilets for conservation programs and was part of the Uniform North American Requirements (UNAR) for Toilet Fixtures, developed by utilities to provide a voluntary common set of specifications (Gauley & Koeller, 2007). WaterSense requires toilets to pass at least 350g of uncased media. The average MaP score on the market (for tested toilets) is now 675g (Koeller & Gauley, 2010). The U.S. industry standard is currently being revised and will likely follow WaterSense.

Flush performance may also differ between commercial and residential toilets because of the type of use to which they are subjected, such as the use of toilet seat covers in commercial settings. ASME has formed a committee for commercial valve-type toilets that may develop more rigorous performance requirements than those for residential toilets, and MaP may also release a commercial test (MaP Maximum Performance).

Another issue of frequent concern is drainline carry, or the transport of waste to the sewer line. The plumbing industry frequently produces anecdotes regarding the inability of low-flow toilets to reliability transport waste far enough toward the sewer line. However, research to date varies on the extent of the problem. A 2005 study concluded that toilets using as little as 1.1 gpf should meet household drainline carry requirements (Gauley & Koeller, 2005). However, a UK study concluded that in some circumstances reduced toilet flush volume may cause a deterioration in solid removal, particularly in drains taking very little flow (Drinkwater, Chambers, & Waylen, 2008). In addition, the Plumbing Efficiency Research Coalition (PERC) indicates that reduction of other flow rates and discharges, as well as use of gray water systems, could cause problems in the future (Dickinson & DeMarco, 2009). Furthermore, drainline carry may be a problem in commercial applications because of larger pipe diameter, less slope, and fewer supplemental flows (Gauley, High-Efficiency Toilets in Commercial Applications, 2008).

The U.S. and Canadian standards include a drainline transport characterization test (American Society of Mechanical Engineers, 2008), but, as with waste removal, it is widely recognized as not representing real-life conditions. No new tests will be adopted by ASME or WaterSense until a research study is completed by PERC, possibly by the end of 2012. The new PERC test plan notes that pre-programmed, electronically-operated flushometer valves on the upstream end of the drainline in commercial buildings could be flushed at a higher volume once or twice per day to drain solids, and they will test the effectiveness of this in their forthcoming study (Plumbing Efficiency Research Coalition, 2010).

A final performance issue for toilets is surface wash, as consumers want a clean bowl. The size of the water spot is often small for low-flow toilets, which can cause cleanliness issues.

The U.S. standard includes a surface wash test (American Society of Mechanical Engineers, 2008).

Manufacturing criteria. Other issues, including tank trim adjustability, fill valve integrity, and chemical durability of flush valve seals, can affect the water use of toilets. WaterSense includes a tank trim adjustability protocol and a high-efficiency toilet (HET) fill valve integrity test (EPA WaterSense, 2007). These protocols restrict the maximum flush under maximum trim adjustment and maximum pressure conditions, respectively. The U.S. industry standard also has a flush valve seal chemical durability test, a version of the previous Los Angeles Department of Water and Power Supplementary Purchase Specification, which was used by many utilities in their programs as part of UNAR (American Society of Mechanical Engineers, 2005). This test ensures water savings by preventing leaks caused by cleaners.

In-field issues. Studies show that, when used in the field, toilets may not always use as little water as they are designed to use. One study found that flush valve toilets rated for a certain flush volume had higher gpf diaphragms installed that used more water (Gauley & Koeller, 2010). Several other studies found that observed flush volumes can be higher than rated (ECONorthwest, 2010) (Aquacraft, Inc., 2011) (Mohadjer, 2003) (Independent Toilet Testing Program) (Aquacraft, Inc., 2011). Low-flow toilets installed in the early 1990s were found to experience several problems seven years later including high flush volumes, flapper leaks, and the need for double flushing (Henderson & Woodard, Functioning of aging low-consumption toilets in Tucson, 2000). Some of these problems result from the need to replace flappers, as customers may not choose the correct replacement. In an attempt to deal with issues in replacements, WaterSense has a separate tank trim adjustability testing protocol for the maximum volume of water discharged when the original flush valve seal or flapper is replaced with a standard replacement seal (EPA WaterSense, 2007). The use of sensor-activated flush valves, often installed for hygiene and convenience purposes, may increase water use through ghost flushing (Gauley & Koeller, Sensor-Operated Plumbing Fixtures: Do They Save Water?, 2010).

Water-saving devices and technologies. Dual-flush toilets are one of the most common devices now being used to increase water savings of toilets. The U.S. industry standard specifies a performance requirement of 1.1 gallons for the reduced flush mode (American Society of Mechanical Engineers, 2006). The European Union includes design requirements for double-action mechanisms (interruptible) and double-control (dual-flush) mechanisms (CEN, 2010). Use of dual-flush toilets can potentially save more water than standard high-efficiency toilets, but as some toilets on the market have full flush volumes as low as 0.8 gallons with a high waste removal score, the future of the dual-flush market is unclear.

Other types of toilets, which are not in as widespread use, may also significantly reduce the use of water. Composting toilets do not use any water, while foam-flush toilets, a variation, use a small amount of water. Urine-diverting toilets do not use water for liquid waste but require behavior change (Schlunke, Lewis, & Fane, 2008). Air-assisted toilets, which are different from pressure-assisted toilets, use air displacement with a small amount of water. Although they require an electric motor, the net energy use including embodied energy is supposed to be less than standard toilets (Schlunke, Lewis, & Fane, 2008).

Finally, another water-saving feature is an integral handbasin that allows a person to wash his or her hands with water that flows into the tank and that then can be used for the next flush. The Australia and New Zealand water labeling programs give five stars to toilets only if they have these integral handbasins (Standards Australia/Standards New Zealand, 2005). It is important to note that the use of these products has implications for drainline carry issues as they reduce other flows in the pipe.

URINALS

Table 3 summarizes the main issues surrounding water conservation with urinals.

Table 3: Issues affecting urinal water use

Framework	Category	Topic
Product Performance	Performance	Surface wash
Product Components	Water-Saving Devices and Technologies	Operation of flush valve
		Waterless urinal

Performance. The primary performance issue for urinals is surface wash. The United States, Canada, Australia, and New Zealand have test procedures to address this issue (American Society of Mechanical Engineers, 2008) (Standards Australia/Standards New Zealand, 1996).

Water-saving devices and technologies. With traditional urinals, flush valve operation can be improved to provide water savings. Australian technical standards prevent the use of automatic or set-cycle flushing and require that for flush on-demand operation the motion sensor prevents interference[2] (Standards Australia, 2005). The Australia and New Zealand water-efficient label requires smart demand operation to get more than three stars, and to get six the urinal must also have a urine-sensing device (Standards Australia/Standards New Zealand, 2005). Use of sensors for urinals may actually increase water use if the sensors are not installed correctly or do not operate properly (Hills, Birks, & McKenzie, 2002) (Gauley & Koeller, 2010). A urine-sensing device may be less prone to ghost flushing than sensors that detect humans, but no studies on this subject were found.

[2] While interference is not defined in the standard, it is presumed to be erroneous flushing caused by people not actually using the urinal.

Another option for saving water in urinals is the use of waterless urinals. However, these urinals have experienced some problems with crystallization of urine. The U.S. industry standard provides for testing for resistance to stoppage from debris and ammonia detection in the air near the waterless urinal, but does not address crystallization (American Society of Mechanical Engineers, 2006). Australia and New Zealand do address crystallization by requiring a minimum of two additional water-using fixture units upstream of every waterless urinal (Cummings, 2009). Another possible solution to alleviate the crystallization problem is to use a very small amount of water, such as one cup, with these urinals.

FAUCETS

Table 4 summarizes the main issues surrounding water conservation with faucets.

Table 4: Issues affecting faucet water use

Framework	Category	Topic
Product Performance	Performance	Minimum flow rate
		Wetting/rinsing (kitchen)
Product Components	Other Criteria	Non-adjustability
	Faucet Accessories and Features	Automatic faucets (sensor or time delay)
		Flow rate regulators, controllers, restrictors
		Spray tap performance
		Water-saving/water brake feature
		Foot pedals
		Variable controls (kitchen)
Energy	Energy Use/Savings	Double lever valves
		Hot/cold water management
		Mixing valves
		Compatibility with tankless water heaters
		Water waste with traditional water heaters

Performance. The main performance issue for low-flow faucets is their ability to provide enough pressure for rinsing or other tasks. For this reason, WaterSense specifies a minimum flow rate to ensure satisfaction at low pressure (EPA WaterSense, 2007). Kitchen faucets may be more likely to cause performance issues at low flows, but current federal standards are the same for bathrooms and kitchens. WaterSense has chosen to provide certification only for lavatory faucets at the moment. They note that, for kitchen faucets, a wetting or rinsing performance test might be useful and that the maximum flow might need to be greater than for lavatory faucets (EPA WaterSense, 2007).

Other criteria. Many faucets are designed to be low-flow through the use of a flow restrictor or aerator, which may be easily adjusted. For this reason, the WaterSense specification prevents the inclusion in the packaging of instructions on how to override the maximum flow rate of the faucet (EPA WaterSense, 2007). This can save water by limiting after-market tampering.

Faucet accessories and features. Automatic faucets that switch on or off in response to motion sensors or time delays are commonin non-domestic premises. Some studies show that the inclusion of a sensor increases water use (Hills, Birks, & McKenzie, 2002), (Gauley & Koeller, 2010). Hills *et al.* note that conventional swivel-top taps used less water than both push-tops and infrared taps, although push top use was reduced after switching from a 15- to a 7- second delay.

Japan has a test procedure for measuring the time until water stops, and the European Union has a standard regarding electronic opening and closing tapware (Japan Environment Association Eco Mark Office), (CEN, 2006). The European Union also has a test procedure for flow duration of automatic shut-off valves (CEN, 1996). The UK Green Public Procurement criteria require that, for faucets activated by sensors, supply must be terminated within three seconds of user intervention being removed, and, for faucets controlled by timers, the flow duration cannot exceed 20 seconds (ECOTAPWARE). Australia and New Zealand water labeling requires that flow be automatically turned off after 15 seconds and that faucets controlled by sensors must shut off within two seconds after the end of user activity (Standards Australia/Standards New Zealand, 2005). Singapore requires self-closing taps in all non-domestic premises and limits the delay (Cheng, 2010).

Faucet accessories are also available to reduce the flow of existing faucets. These include flow-rate regulators, controllers, restrictors, and aerator devices. The European Union and Australia include separate test procedures for these devices, while WaterSense includes them in the faucet specification (CEN, 2003) (Standards Australia, 2008) (EPA WaterSense, 2007). The federal government includes replacement aerators in its definition of faucet, so they are already regulated in the existing standard.

A spray tap can also potentially provide water savings. British standards include test procedures for flow rate and divergence of spray (British Standards Institute, 1976). The UK Market Transformation Programme notes that a water-saving or water brake feature exists for single-lever mixer taps in which resistance is felt at a low flow rate, and force must be increased to achieve a higher flow rate (Market Transformation Programme, 2008). Finally, foot pedals may be used, primarily with kitchen faucets, to shut off water during intermittent activities without having to remix hot and cold water (Federal Energy Management Program, 2011). No studies regarding the water use implications of these devices have been identified.

Water efficiency for kitchen faucets might also be enhanced through the use of variable controls. For example, WaterSense notes that a multi-position control level would offer users high and low settings for different activities (EPA WaterSense, 2007). The UK Market Transformation Programme discusses a type of flow restrictor that enables the tap to deliver a spray at low flow rates and unrestricted flow at higher flow rates in order to fill pots (Market Transformation Programme, 2008).

Energy use and savings. Faucets also provide an opportunity for energy savings, and faucet design can affect energy use. The EU Ecolabel and Green Public Procurement programs for tapware report that, because double-lever valves require adjustment of cold and hot water, they can increase water volume used and energy consumption (Kaps & Wolf, 2011). The same report notes that single-lever taps can be designed with a mid-position that does not allow warm water flow and can therefore avoid wasted energy. Sweden has also noted the energy savings of single-lever taps as compared to double-lever taps, and has further explored a rinse test and activity test to determine the energy efficiency of these single-lever mixers (Wahlstrom, 2009). These tests take into account the time required for the activity, the temperature of cold water and mixed water, and the volume of cold water and hot water.

Faucets can have compatibility problems with tankless water heaters, affecting water heating energy use. Some tankless water heaters require a minimum flow rate of 0.5 gallons per minute (gpm), which might not be met with some low-flow faucets (Consortium for Advanced Residential Buildings, 2009). For example, faucets equipped with faucet aerators at 0.5 gpm, which many utilities offer, may prevent the switching on of these water heaters. However, this interference may not be as problematic as it first seems, because the average lavatory sink use is 30 seconds and often hot water won't arrive at that fixture in that time period, no matter what type of water heater is being used, (Klein, 2009). In fact, hot water may never reach a fixture in 90% of all draws in which a hot water tap is used (Schoenbauer, 2011). Drawing hot water into pipes, where it then cools off without ever being used, wastes energy.

SHOWERHEADS

Table 5 summarizes the main issues surrounding water conservation with showerheads.

Table 5: Issues affecting showerhead water use

Framework	Category	Topic
Product Performance	Performance	Pressure compensation
		Spray force
		Spray coverage
		Temperature drop
	Thermal Shock	Automatic compensating mixing valves
		Package labeling
Product Components	Water Saving Devices and Technologies	Automatic shut-off valves (commercial)
		Temporary shutoff valves/trickle valves
		Temperature based automatic shut-off
		Cullector
		Recycling/recirculating showers
	In-Field Issues	Accuracy of rated flow values
		Measured flow rates less than rated
	Other Issues	Showerhead definition/multiple showerheads
Energy	Energy Use/Saving	Drainwater heat recovery
		Energy efficiency of mixing valves
		Double lever valves

Performance. As with toilets, performance has been a large issue for low-flow showerheads. When the devices emerged, consumers complained about low pressures. The inability to rinse in a reasonable amount of time possibly led to increased showering time, potentially offsetting some gains from conservation, as well as removal of the showerheads, which would eliminate all gains from conservation. There is not much, if any, data to clearly support these claims, but bad press and consumer distrust have led many entities to begin addressing performance through pressure compensation, spray force, spray coverage, or drops in the temperature of the water that lands on the person showering compared to the temperature of the water entering the showerhead. The WaterSense specification for showerheads includes tests for the first three features (EPA WaterSense, 2010). Australia and New Zealand currently regulate mean spray spread angle, limit temperature drop to three degrees, and plan to incorporate a force of spray test when available (Standards Australia/Standards New Zealand, 2005). British standards include spray form and spray trajectory tests (British Standards Institute, 1984). In addition, some researchers have been attempting to develop a test for skin pressure (Critchley & Phipps, 2007). While these attempts to capture the performance of showerheads are a step in the right direction, there are still doubts about how effective the requirements are in the real world. Test results do not necessarily line up with consumer satisfaction (Mowris & Woody, Consumer Satisfaction and Laboratory Test Results of New Showerhead Standards and Labels, 2010).

Thermal shock. Issues have been raised regarding showerheads and thermal shock. In showers without automatic compensating mixing valves, when water is used in another location, such as flushing the toilet, the shower's water can become suddenly hot or cold, potentially resulting in burning or falls. This risk becomes greater as the shower's flow is reduced and it becomes more sensitive to pressure changes. The valves that can prevent this occurrence – either pressure-compensating or temperature-compensating valves – are tested at a different pressure from the showerhead test procedure and assume a 2.5 gpm flow rate. When tested at a flow rate less than 2.5 gpm, fewer valves pass the industry temperature fluctuation test. (California Statewide Codes and Standards Team, 2011) Only 77% of pressure-balancing valves pass at 2.0 gpm and only 31% pass at 1.0 gpm. Thermostatic valves fare even worse, with fewer than one-third passing the test across flow rates less than 2.5 gpm (California Statewide Codes and Standards Team, 2011). The industry test procedure is currently being revised to require testing at appropriate flow and pressure for low-flow showerheads (American Society of Sanitary Engineering, 2005). WaterSense requires manufacturers to mark packaging with a minimum flow rate at the valve testing pressure to help customers match showerheads and mixing valves

(EPA WaterSense, 2010). Portugal's voluntary standards require a warning regarding the risk of scalding unless the showerhead is equipped with an automatic device (ANQIP, 2009).

Water-saving devices. In addition to limiting the flow of showerheads, additional water saving devices and technologies are available for these products that may help further reduce water use. The first is an automatic shut-off valve, primarily time-based, which is generally used for non-domestic purposes. In fact, Ecotapware is recommending that these valves be required for non-domestic uses (Kaps & Wolf, 2011). To ensure real reductions in water use, British standards include testing of flow duration for time delay valves (CEN, 1996).

Temporary shutoff valves or trickle valves can also help save water. U.S. industry standards prevent complete shut-off for showers, in response to concerns about the thermal shock issue mentioned previously (American Society of Mechanical Engineers, 2005). However, a trickle valve can reduce flow for periods of time, such as while lathering. Portugal's voluntary program allows for a higher rating for use of an "eco-stop" but does not recommend them for flows of less than five liters per minute and requires a written notice about the need for check valves to prevent direct communication between hot and cold water during withdrawal flow (ANQIP, 2009). Watersense has chosen not to require these, because that would restrict the design of plumbing products, actual savings have not been determined, and possible impacts on plumbing system and health and safety issues have not been determined (EPA WaterSense, 2010).

Other water savings options include a sensor with auto shut-off that shuts off the water when the desired temperature has been reached. For users who turn a shower on and then walk away while the water warms up, this feature stops water from being wasted until the user returns to the shower. Once the user is ready for the shower, he or she can activate the full flow at the desired temperature. Australia and New Zealand will require a feature like this to get their highest ratings (Standards Australia/Standards New Zealand, 2005). Another product collects cold water until it reaches the desired temperature and then slowly feeds it back into the shower (cullin innovation). Recycling showers, currently available in the UK, can filter, treat, reheat, mix, or recirculate water, or provide some combination of these features (ECOTAPWARE). Recirculating systems are common in water-short countries such as Australia, although they also can be used with high-flow spa systems, although this feature would likely not save water compared to a single-head shower (California Statewide Codes and Standards Team, 2011).

In-field issues. Flow-rate testing by researchers found that many showerheads flowed at a rate that exceeded their manufacturer-specified flow rate and sometimes the federal maximum of 2.5 gpm (Mowris, Woody, & Jones, Development and evaluation of new testing protocols for measuring the performance of showerheads in the United States and Canada, 2010). However, on average, a 1 gpm reduction in rated flow corresponded to a 1 gpm reduction in measured flow; thus, although an individual showerhead rated at less than 2.5 gpm may not accrue savings, on average, the expected savings should accrue across the board (California Statewide Codes and Standards Team, 2011). However, some researchers found that in the field, fixtures rated at 2.5 gpm actually flow at 2.38 gpm (California Statewide Codes and Standards Team, 2011). Other researchers found that at full throttle, 2.5 gpm-rated showerheads flowed at 2.5 gpm on average, while 2.0 gpm rated showerheads flowed at 1.8 gpm on average (Schuldt & Tachibana, 2008). Furthermore, users often operate their showerheads at less than full throttle. These issues make it difficult to accurately predict water savings without monitoring in-field use pre- and post-retrofit.

Multiple showerheads. Another potential roadblock to achieving expected water savings is the trend toward multiple showerheads (Biermayer, 2005). Based on limited evidence, approximately 15% of the new construction market may include showers with two or more heads supplied from one pipe or two or more heads supplied from different pipes (California Statewide Codes and Standards Team, 2011). The Department of Energy received complaints that certain showerheads exceeded the federal maximum (Department of Energy, 2011). The Department found that manufacturers had interpreted existing legislation to allow for water being expelled from multiple nozzles to constitute multiple showerheads, and, therefore, water use in total could exceed the federal limit. In 2011, the Department released guidance noting that "a showerhead with multiple nozzles constitutes a single showerhead for purposes of EPCA's water conservation standard," but provided an enforcement grace period of two years. WaterSense requires that each showerhead must meet all specifications individually, and the entire system must meet the maximum flow rate in all possible operating modes (EPA WaterSense, 2010). However, as noted previously, many homes now have custom installed showers that contain multiple shower outlets. In this case, federal standards cannot limit the flow in combination, as the guidance states: "The Department *does not regulate the behavior of consumers* or how they, an architect, or a homebuilder may wish to design a shower." However, many green building codes have recently begun to address this issue by setting limits on flow per square inch of shower compartment (Pape, 2010) (Koeller, 2010). California is proposing that showerheads must be placed no closer than 4 feet from each other (California Statewide Codes and Standards Team, 2011).

Energy savings. Showerheads provide an opportunity for energy savings in addition to water savings and are frequently used in energy conservation programs. Besides directly reducing overall water use and, thus, domestic hot water use, other related opportunities for energy savings exist. Drainwater heat recovery is a potential method of saving energy in which a heat exchanger wrapped around the shower drain pipe captures heat, which is then used to pre-heat cold water entering the water heater, the showerhead, or both. Some studies—both in the lab and very limited field studies—have identified potential energy savings from this device (Gusdorf, 2009) (Dumont, Dery, Le Bel, & Laperriere, 2010) (James, 2009). However, savings are dependent on numerous factors including configuration, water temperature, shower flow rate, and heat exchanger length (Gusdorf, 2009) (Velan, 2010).

Other potential avenues for energy savings or waste are similar to those for faucets. As noted previously, Sweden has a test procedure for determining the energy efficiency of mechanical basin and mixing valves (Wahlstrom, 2009), and an Ecotapware report notes that double-lever valves can increase energy consumption compared to single-lever products (Kaps & Wolf, 2011).

OVERARCHING CONCERNS

Table 6 lists some of the overarching concerns related to water conservation with plumbing products.

Table 6: Overarching Concerns

Framework	Category	Topic
Source Water	Relationship of plumbing products to source water	Rainwater
		Gray water
		Economics
	Environmental benefits	Reduced raw water withdrawals
Energy	Embedded energy	Water use treatment and distribution
	Relationship of plumbing products to water heaters	Hot water systems
		Tankless water heaters
		Solar hot water
Plumbing/Sewer Infrastructure	Relationship of plumbing product standards to building codes	Hot water distribution systems
		Drainlines
	Relationship of plumbing product standards to utility equipment	Sewers
		Wastewater treatment plants

Source water. Water for indoor use can be provided by a variety of sources including potable water, rainwater, or gray water, depending on the use. The use of these different types of water may affect the cost-effectiveness or the need for water conservation. For example, in some retrofit situations, installing a rainwater tank might be much cheaper than ripping out old fixtures (Bucknum, 2011). Some planners may also consider it less important to save non-potable water. Another potential source of water for toilet flushing in warm, humid climates is air conditioner condensate, but this has primarily been limited to commercial and industrial applications (East Bay Municipal Utility District, 2008) (U.S. Environmental Protection Agency, 2011).

Environmental benefits. Urban water conservation results in reduced raw water withdrawals; this environmental benefit can be assigned an economic value through avoided costs (Coughlin, 2006) (Coughlin, Bolduc, Chan, Dunham-Whitehead, van Buskirk, & Hanemann, 2006).

Embedded energy. Water saved at the tap provides additional system savings. Most, if not all, water conservation saves energy at various points in the treatment and distribution system. The energy required to deliver treated water to a household is generally known as embedded energy. Recent studies have identified ranges of numbers regarding this energy usage that vary with geographical location, water source, type of treatment required, and the size of the distribution system, among other things (GEI Consultants/Navigant Consulting, 2010) (GEI Consultants/Navigant Consulting, 2010) (ECONorthwest, 2010) (American Council for an Energy-Efficient Economy, 2010).

Water heaters. As noted previously, showerheads and faucets also affect hot water usage and the water heater, depending on the type used. There may be tradeoffs between water and energy savings. A combination of tank and tankless water heater might provide a good opportunity for both water and energy savings; a modest tank would provide hot water at the beginning of every draw and a burner or element could be sized for some amount of continuous use. In addition, efficiency could be increased by preheating and using a very efficient booster (Klein, 2009).

Tankless water heaters also demonstrate additional interactions with plumbing products. As noted previously, low-flow faucets might not meet the minimum draw requirements for these units. If they do, hot water may take five to 15 seconds longer to get to a faucet, which could increase water use if users wait for that hot water (Consortium for Advanced Residential Buildings, 2009). However, one study found that consumers actually modify their behavior with a tankless water heater and use fewer, longer hot water draws than they do with a storage water heater, resulting in no significant changes in hot water use (Bohac, Schoenbauer, Hewett, Lobeinstein, & Butcher, 2010). Tankless water heaters could theoretically increase water and energy use by enabling people to take longer showers or encouraging the use of high-flow custom showers, because, unlike tank water heaters, they can provide enough hot water (Bohac, Schoenbauer, Hewett, Lobeinstein, & Butcher, 2010) (Biermayer, 2005).

The amount of water used for showering can also affect the economics of installing a solar hot water system (California Statewide Codes and Standards Team, 2011). For example, use of low-flow showers could reduce water consumption, therefore reducing the required area for solar collection and making such systems more feasible.

Building codes. The use of plumbing products is correlated with the design of hot water distribution systems and the choice of hardware, such as mixing valves, and drainlines. These are all often regulated separately, but have obvious impacts on each other, providing opportunities for collaboration between standards development committees and building codes committees.

Showerheads and faucets also interact with the hot water systems. For example, as mentioned previously, the average lavatory sink use is 30 seconds, and often hot water never arrives (Klein, 2009) (Schoenbauer, 2011). Lag time prior to hot water arrival at the desired temperature wastes water that is not accounted for when comparing flow rates only (Binsacca, 2011). One small-scale field study showed that this lag time could result in water waste on the order of 18% to 39% and energy waste on the order of 24% to 69% (Lutz, 2011). As the flow requirements for showerheads and faucets are reduced, supply pipe diameters could be reduced accordingly to capture reductions in this structural waste (California Statewide Codes and Standards Team, 2011). In addition to smaller supply pipe diameters, for hot water to arrive sooner requires shorter length pipes, pipe insulation, and on-demand recirculation (Klein, 2009). Others recommend a centralized water heater, shorter and insulated pipe runs, and a closed-loop recirculation configuration with a pump activated by occupancy sensors or manual switches in the bathroom (Binsacca, 2011).

The paper previously discussed issues with drainline carry. Changing drainage design standards to include smaller diameter pipes, pipes with steeper gradients, and pipe layouts with fewer pipes taking very little flow could reduce the likelihood of problems (Drinkwater, Chambers, & Waylen, 2008).

Utility equipment. While the issue of drainline carry relates to the household level, reductions in water flow also have implications for sewers or wastewater treatment. Some researchers note that in addition to lower flows from products, rainwater harvesting and removal of storm water from sewers may contribute to problems with sewer blockages or odors. These researchers also note that future plant design and operational procedures should address potential decreases in household wastewater discharge and resultant effluent concentration (Drinkwater, Chambers, & Waylen, 2008).

CONCLUSIONS

The 1992 federal water use efficiency standards set an aggressive bar and resulted in significant water conservation. As these standards are now nearly 20 years old, opportunities to gain additional savings abound. However, approaching lower water use levels requires extra care to ensure that negative consequences do not occur. These consequences could include user dissatisfaction and offsetting behavior, drainage issues, and energy waste, among others. This research identifies the systems framework in which plumbing products operate. By paying attention to product performance, product components, source water, energy use, and plumbing and sewer infrastructure, in addition to water use efficiency, practitioners can create a more comprehensive arena for water conservation.

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