Water Conservation

Synthesis Report & Article Summaries

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Synthesis Report

This report is separated into three key topics related to water conservation in buildings: the impact of federal water conservation programs, water fixture design and water use, and drainline impacts. Additional water conservation topics to study in the future related to GSA and commercial buildings include process water, water reuse, and watergy.

To offer a summary and synthesis of the literature reviewed in this topic area, we have organized the following report. The themes provide a high level snapshot of the literature to offer the essence of the articles and a roadmap for where to go for more information. The conclusions are high level summaries of salient information of the literature and encapsulate related and/or contradictory data found in the literature.

### Themes

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
|  | Performance of Fixtures | Impact of User Behavior | Fixture Retrofit Strategies | Drainline Analysis Strategies | Drainline Transport |
| **(Arocha & McCann, 2013)** Provides data on the actual performance of dual flush toilets and defines best practices for design of flush interfaces. | x | x |  |  |  |
| **(Harrison, 2010)** Illustrates the difference in behavior of transient users versus consistent building occupants. | x | x |  |  |  |
| **(Gauley & Koeller, 2010)** Provides evidence that sensor-operating plumbing fixtures, while hygienic, may not be more efficient. | x | x | x |  |  |
| **(Hills, Birks, & McKenzie, 2002)**  Provides evidence on the effectiveness of various water efficient technologies and the implications on ongoing operations and maintenance. | x |  |  |  |  |
| **(Fanney, Dougherty, & Richardson, 2002)**  Provides some evidence on the performance of sensor-operated faucet compared to manual faucets and the influence of aerators. | x |  |  |  |  |
| **(SBW Consulting, 2007)** Provides methods for analyzing current baseline use and outlines efficiency options for the retrofit or replacement of urinals. | x |  | x |  |  |
| **(Koeller & Gauley, 2012)** Provides confirmation of high-efficiency fixture performance, as well as best practices and lessons learned for conducting water use analysis. | x |  | x |  |  |
| **(Gormley & Campbell, 2006)** Presents a validated numerical equation for how to analyze drainline design for low-flow fixtures. |  |  |  | x | x |
| **(Gauley & Koeller, 2005)** Provides evidence of the effects of water-efficient toilets on drainline carry distances. |  |  |  |  | x |
| **(Alliance for Water Efficiency, 2011)** Addresses the key questions and concerns about the impacts of low-flow fixtures on drainlines and municipal water systems. |  |  |  | x | x |
| **(Plumbing Efficiency Research Coalition, 2012)** Summarizes research conducted on drainlines and provides conclusive evidence which should be used to inform building design and existing building retrofits. |  |  |  | x | x |

\*Includes only article summary references. References used in “*Topic Area 1. Impact of Federal Water Conservation*” were not included in the above table.

### Conclusions

Fixture Design, Performance & Retrofit Strategies

The design of high-efficiency water fixtures has sought to reduce water use through reducing volume of flow and increasing pressure. In addition, some fixtures have added features which require an aligned behavior from users in order to achieve efficiency goals, such as dual-flush toilets and sensor operated faucets. Through reduction in water use is often claimed by manufacturers, the articles reviewed illustrated that occupants often do not use fixtures properly and are often installed incorrectly

In the case of sensor operated fixtures, they have been found to use more water than manual faucets (Fanney, Dougherty, & Richardson, 2002; Gauley & Koeller, 2010; Hills, Birks, & McKenzie, 2002). Incorrectly installed sensors, phantom uses, and the requirement to always operate at full flow (instead of the variable flow of manual fixtures) contribute to higher water use. Aerators are likely a more effective, and less expensive, retrofit for reducing water consumption (Fanney, et al. 2002).

In the case of dual-flush toilets, the flush mechanism is most commonly designed for users to pull up for a low-flow and down for a large flush. As users are already conditioned to push the handle down, this is the primary behavior and thus decreases the efficiency of the toilets (Arocha & McCann, 2013; Harrison, 2010). The appropriate use of the handle can be increased through the education of building occupants (Harrison, 2010); some building owners have elected to reverse the handle design to align with user behavior (Koeller & Gauley, 2012).

Several strategies exist for retrofitting existing fixtures to increase performance. The strategy which results in the highest increase in performance is fixture replacement; though, simply retrofitting flush valves and diaphragms can result in significant savings (SBW Consulting, 2007). Installing standard high-efficiency fixtures such as 1.6 gpf toilets and 0.5 gmp faucets can result in water savings of more than 40% (Koeller & Gauley, 2012).

Water Conservation Impact on Drainline Transport

The effort to reduce water use has resulting in the production of toilet fixtures which require considerably less water for flushing. As water volumes decrease, many are concerned with the effects on plumbing infrastructure and the transport of solid waste in drainlines; this has therefore been the topic of recent research. Low-flow toilets using 1.6 or 1.28 gpf have been found to transport waste effectively in drainline designs prevalent in commercial applications; however, 0.8 gpf toilets were not as effective (Plumbing Efficiency Research Coalition, 2012).

In existing building retrofits, it is important to evaluate current conditions of plumbing infrastructure in order to align the flow rate of high-efficiency toilets. Pipe diameter, slope, length of horizontal runs, as well as presence of drainline defects should be considered, and in some cases modeled using computer software (Alliance for Water Efficiency, 2011; Gauley & Koeller, 2005; Gormley & Campbell, 2006; Plumbing Efficiency Research Coalition, 2012). In new construction, strategies such as decreasing pipe diameter, increasing slope, and shortening horizontal runs could increase the effectiveness of high-efficiency toilets to transport of solid waste (Gauley & Koeller, 2005; Gormley & Campbell, 2006; Plumbing Efficiency Research Coalition, 2012).

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Article Summaries by Topic Area

## Impact of Federal Water Conservation

For this topic area, instead of summarizing complete reports, key statistics were pulled from several publications in order to show the breadth and impact of water conservation efforts.

National Water Use

* An estimated 408 billion gallons of water are used every day in in the U.S.: 195 billion gallons by thermoelectric, 43 billion gallons by public supply, 4 billion gallons by households, 20 billion gallons by industry, and 137 billion gallons by irrigation. ([Whitehead & Melody, 2007](#_ENREF_14))
  + Between 45.3-71 gallons of water are used per household every day in the U.S. ([Whitehead & Melody, 2007](#_ENREF_14))
  + Between 8.2-20.1 gallons water per capita are estimated to be used by toilets in the U.S. every day. ([Whitehead & Melody, 2007](#_ENREF_14))

Impact of Federal Water Conservation Standards

* Federal water conservation standards adopted since 1987 are responsible for an annual savings of 1.5 trillion gallons and a cumulative savings of 11.7 trillion gallons as of 2010. In 2005, the USGS estimated water withdrawals for public supply at 44.2 billion gallons per day. 1.5 trillion gallons in savings equals 9% of the total water withdrawals for the public supply in 2005. ([Meyers, Williams, & Chan, 2011](#_ENREF_12))
* The net consumer impact of federal conservation standards are estimated to have an annual savings, peaking in 2025 at $48 billion. ([Meyers et al., 2011](#_ENREF_12))
  + It is estimated that the typical household is saving approximately $175 as a result of federal conservation standards.([Meyers et al., 2011](#_ENREF_12))
* Water efficient plumbing fixtures are now saving Americans over 6 billion gallons of water daily – enough to fill 200 million bathtubs every night – due to the efficiency standards adopted under the U.S. Energy Policy Act of 1992. ([Efficiency, 2011](#_ENREF_3))

Opportunities for Water Conservation in the Federal Sector

* In the Federal sector alone, a potential 35-50 billion gallons (17%-24% of total Federal water use) per year could be saved by employing “off the shelf” water conservation fixtures. ([McMordie-Stoughton, Solana, Elliott, Sullivan, & Parker, 2005](#_ENREF_11))
  + Half of the total Federal water use is consumed by domestic water consuming fixtures. The remaining half is used by engineered processes such as cooling towers, steam systems, and irrigation. ([McMordie-Stoughton et al., 2005](#_ENREF_11))
  + The energy savings from reducing hot water sue in showers and faucets is estimated to be 602-1550 billion Btus. ([McMordie-Stoughton et al., 2005](#_ENREF_11))
  + If these savings were captured under today’s rates for water and energy, $166-$236 million could be saved annually. ([McMordie-Stoughton et al., 2005](#_ENREF_11))
* Below are life cycle cost analysis results for common fixtures. For more information, see page 4.6 of ([McMordie-Stoughton et al., 2005](#_ENREF_11)).
  + A 1.0 gpf pressure assist toilet, with an estimated installed cost of $344 and installed in a federal office space would have a positive life cycle cost at a combined water and sewer rate of $3.37/kgal and would save 11.96 kgal/year. At the average civilian combined rate of $4.47/kgal (2003), the annual savings would be $53.46.
  + A 0.5 gpf urinal, with an estimated installed cost of $169 and installed in a federal office space would have a positive life cycle cost at a combined water and sewer rate of $1.90/kgal and would save 5.98 kgal/year. At the average civilian combined rate of $4.47/kgal (2003), the annual savings would be $26.73.

## Fixture Design, Performance, & Retrofit Strategies

### Behavioral Economics and the Design of a Dual Flush Toilet

**Authors:** ([Arocha & McCann, 2013](#_ENREF_1))

Justification

Article provides data on the actual performance of dual flush toilets and defines best practices for design of flush interfaces.

Introduction & Methodology

In the effort to conserve water, most fixtures place an emphasis on fixture design for efficiency. Dual flush toilets, however, require users to utilize conservation behavior. Users are provided a choice to utilize low or large-volume flushes. As users have been conditioned to flush a handle down, this is the default behavior; however, dual flush toilets require users to pull the handle up for low-volume flushes making the “correct” behavior more difficult.

This study was performed at two public women’s restrooms in a city hall building using Flushometers during a seven week period. The study evaluated the Sloan Uppercut dual-flush toilet. Researchers hypothesized that the up-to-down ratio would be less than the manufacturer-projected ratio of 2:1 or 66.66%. Researchers also evaluated the effect of educational signage on flush behavior after a control period.

Results & Conclusions

The researchers’ hypotheses were confirmed in the experiment. The ratio of flushes during the control period was 1:4 (1 low-volume flush to 4 high-volume), rather than the manufacturer prediction of 2:1 (26.6% vs. 66.6%). Adding signage increased the ratio slightly to 2:5 (38.8%).

These results are far below manufacturer predictions. For this case, the effect of the increase in large-volume flushes is more than 3,200 gallons of water wasted a year. This result indicates a high-efficiency (1.28 gal) nondual-flush toilet would be more efficient than this particular model.

This study indicates that the design of this dual flush mechanism (utilizing an up and down handle) prevents the realization of predicted water savings. As low-volume flushes are needed for the majority of uses, reversing the mechanism (down for low-volume, up for large-volume) would be more intuitive for users. Alternative designs, using two separate buttons may eliminate confusion altogether.

Key takeaways

* Dual-flush toilets utilizing an up and down lever, with up providing a low-volume flush and down a large-volume flush, have an actual use ratio of 1:4 rather than the manufacturer prediction of 2:1 (26.6% low-volume vs. the prediction of 66.6% low-volume).
* Adding signage increases effectiveness slightly, about 12%.
* Commercial dual flush toilets should be chosen which make it simple for users to choose the correct behavior.

### Flush: Examining the efficacy of water conservation in dual flush toilets

**Author:** ([Harrison, 2010](#_ENREF_8))

Justification

This study provides results which counter the results of Arocha & McCann, illustrating the difference in behavior of transient users versus consistent building occupants.

Introduction & Methodology

Due to the increased focus on water conservation, the use of low-flow water fixtures has become more prevalent. Dual-flush toilets have gained popularity as they are predicted to reduce water usage by 30% compared to standard 1.6 gallon units, assuming a 1:4 flush ratio of large and low volume flushes, respectively. Dual-flush fixtures are unique because they require users to make a decision and distinguish between small and large flush options to execute the correct handle action. In addition to handle design and placement, other factors may influence user decisions including education, signage, gender, age, culture, proclivities to cleanliness, and desire to use foot instead of hand to flush toilet.

The researcher hypothesized that the majority of building occupants would use the “default” large flush option, resulting in less than a 30% reduction in water flush usage. The study was conducted in an LEED certified commercial building. To test the hypothesis, surveys were distributed to building occupants to evaluate their awareness of the water conservation features of their building and their utilization of the dual-flush feature on toilets. Data on actual use of dual-flush toilets were collected in men’s and women’s restrooms over a 12 hour period using a sound data logger which was able to distinguish between large-volume and low-volume flushes.

Results & Conclusions

The results of the flush data collection show that the ratio of large to small flushes was about 2:3. Though this is higher than the manufacturer’s predicted ratio, the water use of the dual flush toilet was still 32% less than a conventional 1.6 gallon toilet, proving the researcher’s hypothesis wrong. The survey conducted on building occupants showed that 98% were aware of the water saving features of their building and 55% indicated that they utilize the small flush option for liquid waste on a consistent basis. In addition, 64% of occupants indicated they use their hand to operate the flush handle, while 31% use their foot. Further, 21% indicated that the flip handle was difficult to use.

The results indicate that the low-flush option is used more consistently than anticipated by the researchers, though still not as prevalently utilized as predicted by the manufacturer. The reason for the higher use could be attributed to the education of building occupants and their familiarity with the system.

Key takeaways

* Water use of the dual-flush toilets in this study was 32% less than conventional 1.6 gallon flush toilets.
* The ratio of small to large-volume flushes in a building with permanent, educated occupants was about 2:3.
* 31% of study participants preferred to use their foot to flush the toilet.

### Sensor-Operated Plumbing Fixtures: Do They Save Water?

**Authors:** ([Gauley & Koeller, 2010](#_ENREF_6))

Justification

This study provides evidence that sensor-operated plumbing fixtures, while hygienic, may not be more efficient.

Introduction & Methodology

There has been much debate among water efficiency professionals on the actual efficiency of sensor operated fixtures, mainly due to the seemingly common occurrence of phantom flushes/running. This project evaluated changes in water demands when manually-operated toilets, urinals, and faucets valves were replaced with sensor-operated valves in the men’s and women’s restrooms in an office building (note: entire toilets were not replaced, only the valves; 1.32 gpm faucets were replaced with sensor-operated 1.21 gpm faucets). A water meter and data logger were installed on bathroom supply piping during the monitoring period before and after valve replacement.

It was discovered during the course of this project that the toilet flush valves were originally incorrectly fitted with 3.5 gpf diaphragms instead of 1.6 gpf diaphragms. These were replaced, cutting water use by 50%. After the replacement of the diaphragms, water was monitored for 12 months. Sensor valves were then installed in three phases: Phase 1 faucets, Phase 2 urinals, Phase 3 toilets. Following each fixture installation, water was monitored for a 4 month period.

Results & Conclusions

The average daily water demand of the washrooms after faucet replacement was 30% (654 gallons per day to 856) greater than before the installation of sensor faucets. The average daily water demand of the washrooms after urinal and toilets valve replacement was 45% (856 gallons per day to 1,254) higher than before the installation of sensor valves. At the end of the project, water had increased from an average of 654 gallons per day to 1,254 gallons per day.

While it is not expected that sensor-operated fixtures will reduce water use (due to potential of phantom flushes and the guarantee of flushing after each use), the extent water use increased was significant and unexpected. To insure that these results were not due to improperly installed fixtures, maintenance staff were engaged throughout the installation and monitoring periods to confirm that fixtures were operating as designed.

Key Takeaways

* Purchasing agents should be wary of unsubstantiated water savings claims of sensor-operated fixtures.

### The Millennium Dome “Watercycle” Experiment

**Authors:** ([Hills, Birks, & McKenzie, 2002](#_ENREF_9))

Justification

This study provides evidence on the effectiveness of various water efficient technologies and the implications on ongoing operations and maintenance.

Introduction & Methodology

This study was conducted in the UK at the Millennium Dome, where in the year 2000 one of the largest water conservation studies evaluating water-efficient technologies and water reclamation was conducted. This paper details the effectiveness of efficient water closets, urinals, and faucets in the six public restrooms within the Dome. Visitors were measured by infra-red detectors at the entrance to washrooms and data were analyzed using software which was able to calculate the water consumption for each visitor by fixture.

Results & Conclusions

**WCs.** Dual Flush (3 and 6 liter) water closets were compared with standard 6 liter siphonic water closets over the course of a year. Water monitoring software was able to identify flushing problems in original dual flush toilets (continual flushing), which were rectified by researchers in order to enable true comparisons between existing and retrofit fixtures. Before the retrofits, dual flush WCs (n=177) were using more water than siphonic WCs (n=160) in both male and female restrooms. Specifically in male restrooms, dual flush WCs used 8.6 liters while siphonic WCs used 6.2 liters (see Table 1). Researchers believe that as males are more likely to use urinals rather than the dual flush half flush, there is no water saving advantage to installing dual flush WCs in male restrooms. Following retrofits (report did not describe the type of retrofit performed), water use decreased by 11-37%.

**Urinals.** Flushing urinals (n=136) were equipped with a passive infra-red automated flushing system. These retrofitted urinals were compared to waterless urinals. After retrofits, researchers found that the PIR systems were malfunctioning, flushing when washrooms were empty. In addition, cistern filling rates had not been standardized, resulting in water waste. Researchers found that the malfunctioning urinals were using an average of 42% more water than correctly installed urinals. They concluded that correctly positioning PIR sensors was critically important to maintaining water efficiency. The urinal malfunctions were rectified before the data collection period in order to insure valid comparisons. Upon study completion, researchers found that the waterless urinals required considerably less maintenance than sensor operated urinals, but were more costly due to regular cartridge changes.

**Faucets.** Three types of faucets were evaluated, infra-red (n=48), push-top (n=96), and conventional swivel top (n=96). During the monitoring period, problems were discovered with the installation of infra-red and push top faucets and were rectified. In addition, push tops were retrofitted to flow for 7 seconds rather than 15 seconds, resulting in a significant reduction (report does not document the percent savings from the retrofit, nor does it clarify if the final results include data from before or after this retrofit). The final results of the faucet analysis are summarized in Figure 6, illustrating that the swivel top faucets use considerably less water than the push top and infra-red. Infra-red faucets averaged about 1.8 liters per use, push top averaged 1.7-2.0 liters per use, and swivel top averaged 0.9 liter per use.

Finally, a sample of visitors were surveyed to gather their opinion of the Dome’s use of reclaimed water. 95% of respondents agreed that dual water supply was acceptable for use in public areas, while 61% were positive about the use of reclaimed water in their own homes. Respondents who had seen educational signage in washrooms on the Dome’s use of reclaimed water had significantly more positive responses compared to the control group who had not been exposed to the educational signage.

Key Takeaways

* This study highlights the importance of correct installation and maintenance of efficient water fixtures, specifically those with sensor mechanisms. In order to identify problems and fully realize savings, a comprehensive metering system is vital.
* As males are more likely to use urinals rather than the dual flush half flush, there is no water saving advantage to installing dual flush WCs in male restrooms.
* Swivel top faucets use considerably less water than the push top and infra-red. Infra-red faucets averaged about 1.8 liters per use, push top averaged 1.7-2.0 liters per use, and swivel top averaged 0.9 liter per use.
* Retrofitting push tops faucets to flow for 7 seconds rather than 15 seconds resulting in significant water use reduction.

### Field Test of a Photovoltaic Water Heater

**Authors:** ([Fanney, Dougherty, & Richardson, 2002](#_ENREF_4))

Justification

This study provides some evidence on the performance of sensor-operated faucet compared to manual faucets and the influence of aerators.

Introduction & Methodology

\**The scope of this study was primarily focused on the performance of photovoltaic solar hot water system; however, water conservation measures were also employed and monitored which provide data on the performance of fixtures. This summary limits discussion to applicable to this report’s topic.*

In order to evaluate the performance of the solar hot water system and resulting energy and water conservation, four different hot water configurations were investigated utilizing the following fixtures. Note: sensor faucets were not timed.

1. Manually operated faucets with a 4.5 gal/min aerator (baseline)
2. Manually operated faucets with a 2.2 gal/min aerator
3. Sensor operated faucets with 2.2 gal/min aerators
4. Sensor operated faucets with 0.5 gal/min aerators

Configurations were installed in sequence in the years 1996, 1997, 1998, 1999. Data from the months of November through February each year were analyzed. A direct measurement of the number of individual sink draws within the visitor center restrooms was not gathered; however, visitor logs were maintained. Visitor data offers some indication of the effectiveness of fixtures; however, the results (specifically percent change) are difficult to generalize due to issues in the research team’s methodology and lack of statistical analysis.

Results & Conclusions

A full report of monthly hot water use and energy use can be found in Tables 3 and 4 in the full report. For the purposes of this summary report, a table summarizing the results of this study is provided below. The data in this table was pulled from Tables 3 and 4 and from report narratives.

Though the report did not include a statistical analysis comparing visitors to water use, researchers surmise that the addition of aerators in Configuration II resulted in very little savings. The addition of sensors in Configuration III resulted in 58% increase in water use, while visitors only increased 22%. Researchers postulate that the increase in water use could be attributed to sensor faucets always using maximum flow, while users can decrease the flow of swivel, manual faucets. This may negate sensor faucet’s potential decrease in draw time. Configuration IV resulted in the most significant reduction in water use, combining sensors with a 0.5 gpm aerator. Even with a 22% higher attendance, water use was considerably lower than Configuration II.

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| *Summary Table of Results* | | | | |
| **Configuration** | **Daily Average Hot Water Volume** | **Average Daily Visitors & Percent Increase** | **Percent Change in Water Volume** | **Summary of**  **Configuration Performance** |
| I | 351 | 9,356 |  | n/a |
| II | 372 | 10,289 (10%) | 6% increase | Negligible Improvement above CI |
| III | 586 | 12550\* (22%) | 58% increase | Higher Water Use Compared to CII |
| IV | 244 | 12550\* (0%) | 58% decrease | Significant reduction in water use compared to CIII and CII. |
| \*Actual numbers were not reported, only the percent increase above configuration II (22%) | | | | |

Key Takeaways

* Sensor faucets increased water use when compared to manual faucets with the same flow rate.
* Sensor faucets with 0.5 gpm aerators reduced water consumption by more than 58% when compared to a sensor faucet with a 2.2 gpm aerator. The results suggest that the savings might have been higher had the sensor faucet remained a manual faucet.

### Urinal Baseline Study

**Authors:** ([SBW Consulting, 2007](#_ENREF_13))

Justification

This report provides methods for analyzing current baseline use and outlines efficiency options for the retrofit or replacement of urinals.

Introduction & Methodology

This research project was instigated by The Saving Water Partnership of Seattle. The purpose of this study was to determine the baseline characteristics of existing urinals in the SQP service area and investigate the feasibility of retrofitting the existing urinal stock with alternative water efficiency measures. The study also inventoried baseline characteristics of the service area through an equipment inventory and fixture analysis.

Researchers collected a sample of urinals (n=341) from restrooms that were geographically representative of the commercial business districts in Seattle. Researchers surveyed users, tested flush volume and effectiveness, and tested alternative efficiency options in sample urinals. Researchers collected the following characteristics of urinals; urinal location (public or private), wall-mount style of urinal, the style of urinal (wash down, siphon-jet, blowout-ext.), the flush valve type (diaphragm or piston), valve activation (manual or sensor), the urinal condition, the flush volume (minimum, moderate, long), and the vintage (less than 35 years, 35-50, more than 50). The alternative efficiency options tested included; flush valve replacement, diaphragm replacement, and urinal replacement with a high efficiency urinal (HEU). Results of data collection were summarized and the efficiency options were ranked based upon cost, maintenance, longevity, and efficiency.

Results & Conclusions

The average baseline flush volume for the urinals was 1.15 gpf and was measured using a flow meter and vacuum breaker assembly. About 96% of urinals in the study had exposed plumbing and would allow easy urinal replacement; however, only 7 of the 30 urinals targeted for replacement could be replaced with a 1/8 gpf Zurn HEU as the distance between the waste outlet center line and supply height was required to be 31.5-34.5 inches. The flush volume of installed HEUs was tested and the urinals performed as the manufacturer advertised, with flush volumes of 1/8th gpf.

Twenty-seven existing flush valves were replaced with a Toto flush valve with a volume range of 0.3 gpf to 1.5 gps. Flush volumes were tested and the new flush valves reduced volume to an average savings of .52 gpf. Flush valves can be replaced in urinals with exposed, manually operated flush valves. Based on this study, 72% of the market would qualify for flush valve retrofit.

In addition to replacing flush valves, diaphragms were also replaced in order to achieve the optimal flush rate. The new diaphragms provided an average savings of .39 gpf. Based on this study, 64% of the market may qualify for a diaphragm replacement. Dual filter diaphragm flush valves were found to provide better immediate savings compared to single filter diaphragms and give more consistent savings over their lifetime. Researchers found that the wide variety and unmarked vintage urinals made installing the right diaphragm in every situation complex, and no universal diaphragm exists.

This report concludes with recommendations solutions which would best meet the market conditions and the goals of the SWP program.

* The preferred recommendation is to replace existing urinals with 1/8th gpf HEUs and utilize in all new construction as they have the longest expected life, the greatest water savings potential, good customer acceptance, and the percent of market that qualifies for replacement.
* The second recommendation is to provide direct install replacement of existing manual exposed flush valves with adjustable piston type flush valves with a range of 0.3 – 1.5 gpf, set to optimum efficiency. This option will have a moderate cost, a relatively quick install, and the ability to achieve the lowest gpf possible in existing fixtures.
* The third recommendation is to provide direct install replacement of existing flush valve diaphragms with lower volume diaphragms that have maximum chlorine resistance and minimum gpf drift over time. This option has the lowest equipment cost and good customer acceptance; however, it has a short life, flush volume may increase over time, savings are lower than option A and B, finding the optimal diaphragm for existing urinals may be complex.

Key Takeaways

* Three primary methods exist for lowering water use in urinals: replacement with HEU, retrofit with a new efficient flush valve, or retrofit with lower volume diaphragm.
* This report concluded that 72% of existing installed urinals would qualify for flush valve replacement, and 64% of would qualify for diaphragm replacement.
* The percent of the market qualifying for HEU replacement depends upon products designed to meet the height of existing outlets for water supply and waste. At the time of this study, only 23% of the urinals targeted for replacement could be easily replaced with an HEU urinal.

### Water Use Field Research and Baseline Assessment: U.S. EPA Wynkoop Building, Denver CO

**Authors:** ([Koeller & Gauley, 2012](#_ENREF_10))

Justification

This report provides confirmation of high-efficiency fixture performance, as well as best practices and lessons learned for conducting water use analysis.

Introduction & Methodology

This report summarizes the results of a water evaluation conducted on the EPA’s office building in Denver, Colorado. The purpose of the study was to evaluate the building’s water use compared to estimations made during LEED documentation, and to identify opportunities for greater water efficiency. The building’s fixtures included 1.6/1.1 gpf dual flush toilets in women’s restrooms, and 1.6 gpf toilet and waterless urinal in men’s restrooms. Lavatories utilized 0.5 gpm faucets. Additional fixtures included 0.5 gpm kitchen sink, 2.0 gpm janitor sink, and 1.6-gpm showerhead.

In order to identify further efficiency opportunities, water monitoring was employing utilizing 12 water sub-meters, segregating domestic and non-domestic water use, a whole-building ultrasonic meter to determine if leakage exists. It was determined that the building was not leaking water. In addition, an ultra-sonic sub-meter and data logger was installed on the 7th floor water supply. This provided data on the total water demand for the 7th floor, flush volume characteristics (if dual flush option was utilized), and presence of leakage.

Results & Conclusions

After 24 months of occupancy, users were evaluated and LEED calculations were updated to reflect actual occupancy numbers. An error in the initial baseline calculation was also found and corrected. The final calculation for reduced water use was 40% below baseline, which equals approximately 5.44 gallons per capita per day. Actual water use was measured to be 5.34 gpc in 2010 and 5.25 gpc in 2011.

On the 7th floor, water demand data indicated that users were rarely using the low-flush option on the dual flush toilets. It is hypothesized that the users choose push the handle down as this is the easiest and most common behavior to flush a toilet, pulling the handle up for a low-flush requires awareness and extra effort. As a result, new handles with an opposite design (up for large flush, down for low flush) were installed. Sub-metering data was not able to be collected on this retrofit due to problems with the data logger; however, facility personnel indicated that the valves flush better with the new handles and they received no complaints from occupants concerning fixture performance. Due to these positive results, handles were replaced in the entire building. Though the water demand in the entire building was analyzed, researchers were unable to isolate the savings resulting from the new handles. This is due to the difficulty in determining the full-time equivalent of the building and the relatively small volume reduction compared to the entire building’s water use.

Key Takeaways

* The building’s high-efficiency water fixtures resulted in more than a 40% savings, or the water use of 5.44 gallons per capita per day compared to the baseline of 9.07 gallons per capita per day.
* Water demand data indicated that users were rarely using the low-flush option on the dual flush toilets; therefore, the handles were replaced with opposite behaviors.

## Water Conservation Impact on Drainline Transport

### Modeling Water Reduction Effects: Method and Implications for Horizontal Drainage

**Authors:** ([Gormley & Campbell, 2006](#_ENREF_7))

Justification

For those considering retrofitting existing buildings with low-flow water closets, the size and slope of drainlines must be considered as existing plumbing systems were designed for higher water flows than provided by low-flow water closets. This paper presents a validated numerical equation for how to analyze drainline design for low-flow fixtures.

Introduction & Methodology

Standard design practice has utilized outdated statistical models for estimating drainline design, leading to oversized pipes and overestimation of water flow, causing blockages and often expensive maintenance issues. Improving modeling techniques is essential as many developed countries (Australia, US, UK< Singapore, Scandinavia) have passed legislation requiring low-flow water closets. These reductions pose significant implications for existing drainline design as they reduce the water available for drain cleansing.

Researchers defined a new numerical equation, updating current statistical equations. Current statistical models fail because they assume a steady flow of water and do not consider the influence of solids of flow, leading to increased pipe size and overestimation of water depth, both of which compound problems.

The paper presents a refinement to the modeling technique used in DRAINET. The resulting modeling technique is included in the new computer program INTERACT, to assess the effects of multiple solids in drain lines.

Results & Conclusions

Researchers designed a new numerical modeling technique, predicted flows, and tested their predictions against physical experiments. Figure 14 in the paper illustrates the travel distance of solids in three pipe sizes (75mm, 100mm, and 150mm). The results indicate that travel distances are greatest in the 75mm pipe and least in the 150mm pipe. Their predictive modeling, confirmed in measured experiments, is a method for realistically determining the solid deposition distances in above-ground building drainage systems. This new method is critical to the successful adoption of water conservation fixtures. The use of computer simulations to inform designers and regulatory policy is essential as water conservation systems cannot be assessed in isolation from the system in which they connects.

“The conclusion of much research into solid transport (Swaffield and McDougall, 2000) has been that above-ground building drainage systems would benefit from reduced pipe size because of the reduction in available water to move waste into the public network. This paper confirms that this is a valid conclusion”.

Key Takeaways

* Low-flow water closets require pipe sizes which are likely smaller than current assumptions.
* Existing building drainline design should be modeled using INTERACT in order to confirm the system can perform under lower water conditions produced by low-flow water closets.

### Evaluation of Water-Efficient Toilet Technologies to Carry Waste in Drainlines

**Authors:** ([Gauley & Koeller, 2005](#_ENREF_5))

Justification

This report provides evidence of the effects of water-efficient toilets on drainline carry distances.

Introduction & Methodology

In order to provide evidence to Canadian policy and manufacturers concerned with the effects of water-efficient toilets on drainline carry distances, this project was developed to examine the ability of water-efficient toilets to transport waste through drainlines under laboratory conditions. Variables studied included; flushing system, volume, drainline slope and diameter, etc. Drainline flows were examined under the worst-case scenario, where all the flow in a drainline is supplied by toilet flushing. Drainline conditions were designed to a best case scenario, with plastic piping, unobtrusive couplings, and a straight and true layout.

Results & Conclusions

Researchers confirmed assumptions that there is a positive correlation between flush volumes and carry distance and drainline slope and carry distance. They found carry distances in 3” diameter drainlines are 50% greater than 4” drainlines at a 2% slope, and 25% greater at a 1% slope. They found that the drop height from the vertical waste outlet to the horizontal drainline had little effect on carry distance.

Researchers concluded that for commercial installations using 4” piping at 1% slope, water efficient toilets can transport 200g of test media approximately 20-34ft, depending on the type of flushing system. Under the conditions of this study (clean drain pipes, straight runs, proper slopes) all high efficiency toilets would be expected to meet or exceed the waste carry distances typical of *household* plumbing installations, even with no supplemental flows. Installations with extremely long drainage distances (shopping malls, industrial sites, etc.) may require evaluation on a site-by-site basis, especially if no supplemental flows are available.

Key Takeaways

* There is a positive correlation between flush volume and carry distance; for example, in a 4” diameter drainline with a 1% slope, a 1.6 gpf pressure-assist toilet has a carry distance of 33 ft., while a 1.0- gpf pressure-assist toilet has a carry distance of 22 ft.
* Smaller diameter drainlines will increase carry distance, as will increased slope of drainline.

### The Impacts of High-Efficiency Toilets on Plumbing Drainlines and Sewers

**Authors:** ([Efficiency, 2011](#_ENREF_3))

Justification

This article addresses the key questions and concerns about the impacts of low-flow fixtures on drainlines and municipal water systems.

Article Summary

Due to national policy, such as the U.S. Energy Policy Act of 1992, sales of high-efficiency toilets have increased such that 1.28 gpf HET fixtures, particularly for homes, have begun to outpace 1.6 gpf fixtures. Though the increased use of low-flow fixtures does reduce wastewater flows, there are no authoritative instances of high-efficiency toilets causing building drainlines or municipal sewer systems to experience blockages, despite anecdotal reports. EPA’s WaterSense Program, responsible for high-efficiency fixture standards, reports: “With regard to municipal sewer lines, the transport of waste has not proven to be an issue of concern in those areas with a concentration of high-efficiency toilets”. They go on to say that a reduction of wastewater flows is beneficial in some cases, leading municipal utilities to sponsor the replacement of fixtures.

Though no evidence of building drainline blockages have been found in the United States, research from Australia indicates that a combination of factors such as drought, absence of supplemental flows, and low fixture use could result in drainline blockages. However, these blockages are likely to occur regardless of the presence of high-efficiency fixtures.

Authors of this article point to the age and inadequacy of existing infrastructure as of higher concern than reduced flows from high-efficiency toilets. Therefore, achieving water conservation goals includes thinking system-wide and evolving plumbing infrastructure to align with these conservation goals.

In order to meet drainline requirements in existing building drainlines, authors suggest these actions:

* Determine the minimum wastewater flow requirements for solid waste transport in existing drainlines prior to the installation of new high-efficiency fixtures.
* Pay specific attention to isolated fixtures responsible for carrying solid waste down long horizontal drainline runs. If appropriate, install higher-volume fixtures in these problem areas.
* Change the type of toilet paper provided in restrooms to a product with a higher rate of disintegration.
* For new buildings, predict wastewater flows of new fixtures and update design criteria to align (pipe size, slope, etc.).
* For drainlines with combined flows, model the impact of reduced flows from multiple sources.

Key Takeaways

* No authoritative evidence exists that high-efficiency toilets have been responsible for blockages in building drainlines or municipal sewer systems.
* In some municipalities, reduced wastewater flows are desired to reduce demand on treatment facilities; therefore, incentives for fixture replacement are likely to exist.
* Before installing high-efficiency fixtures, existing plumbing infrastructure must be evaluated in order to identify the impact of reduced wastewater flows.

### The Drainline Transport of Solid Waste in Buildings

**Authors:** ([Coalition, 2012](#_ENREF_2))

Justification

This report summarizes research conducted on drainlines and provides conclusive evidence which should be used to inform building design and existing building retrofits.

Introduction & Methodology

When the Energy Policy Act of 1992 passed, requiring all toilets to use no more than 1.6 gpf, many consumers reported poor flush performance in new models. Research conducted on the performance of toilets has increased effectiveness, but little research was conducted on the ability of low-flow models to transport waste through drainlines. As manufacturers continue to improve flush performance and volume required, many have been concerned about the increasing effect low-flow fixtures will have on existing drainline systems and municipal sewers. In 2009, the U.S. EPA requested the five prominent plumbing and water efficiency associations to collaborate to provide research on water conservation and drainline transport.

Researchers designed a testing scenario to mimic long building drains in commercial buildings and examined variations in configuration, length, materials, fittings, and slope. Utilizing a surge injector apparatus to create precise flush characteristics, researchers were able to control variables related to toilet performance and focus solely on drainline impacts. Researchers used simulated solid waste made from soybean paste and high-tensile strength toilet paper balls in test runs. A total of 40 test runs were conducted, with each run consisting of 100 flushes. The surge injector controlled flushes to use the required volume (0.8, 1.28, or 1.6 gpf), flush rate, and percent trailing water. The research team utilized ANOVA to isolate the significance of variables.

Results & Conclusions

The study found that toilet hydraulics (percent of trailing water and flush rate) had minimal significance on drainline transport of solid waste. Flush volume, toilet paper, and pipe slope were found to have a very significant effect upon drainline transport of solid waste.

1.28 and 1.6 gpf toilets were found to perform well under test conditions, resulting in an orderly and predictable movement in the test drainline. As a result, no problems are anticipated with the use of 1.28 gpf HET in new commercial construction. However, in retrofit applications the committee suggests inspecting drainlines for defects, root intrusions, sagging or other physical conditions which could result in clogging with lower flush volumes.

0.8 gpf toilets had a major difference in performance, resulting in large plugs in 5 of the 16 test runs. Though the plugs eventually cleared themselves prior to water overflows, the conditions skewed the data and made it unusable to statistical analysis.

Toilet paper was found to be a variable with high significance in the transport distance in drainlines. The tensile strength of toilet paper impacted distance. In test runs using only paper (with no solid waste media), low-tensile strength paper traveled 135 feet and high tensile strength traveled 45 feet. Therefore, toilet paper selection has the potential to be very significant in terms of drainline performance – even more significant than flush rate and percent trailing water. The committee suggests that buildings with chronic drainline blockages utilize a toilet paper with a lower wet tensile strength.

Key Takeaways

* 1.28 and 1.6 gpf toilets were found to consistently transport media through test drainlines; as such, the researchers anticipate no issue with their use in commercial building applications.
* Researchers were not able to find conclusive data regarding 0.8 gpf toilets’ ability to transport waste in drainlines due to occasional blockages.
* When switching to a lower-flow fixture in a building retrofit, this report recommends evaluating drainline conditions (presence of defects, slope, diameter, etc.) to determine if HETs can be utilized successfully.
* For buildings with concerns about drainline blockages, the first step in best management practice is to utilize a toilet paper with a low wet tensile strength.

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