FUNCTIONING OF AGING LOW-CONSUMPTION TOILETS IN TUCSON

A FOLLOW-UP WITH REBATE PROGRAM PARTICIPANTS

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PREFACE

The authors and the University of Arizona's Water Resources Research Center gratefully acknowledge the financial support of the U.S. Bureau of Reclamation, Phoenix Area Office, and the City of Phoenix. This research would not have been possible without the assistance and expertise of Tom Babcock of the City of Phoenix. Thanks to the City of Tucson Water Department for their assistance and cooperation, and to Aquacraft Engineering, Inc. Thanks also to Kyle Carpenter of the NSF Center for Sustainability of Semi-Arid Hydrology and Riparian Areas (SAHRA) at the University of Arizona for front cover design and graphics assistance.

The results of this study are based on monitoring of household water use and on customer response to a survey. Ratings of customer satisfaction with toilet function are not to be considered an endorsement of any particular toilet manufacturer, toilet model, or flush valve type. These ratings and the results of data logging are not to be used in advertising, or for any other commercial purposes.

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EXECUTIVE SUMMARY

Toilets in the U.S. have been designed to use less water to help meet water supply planning needs. However, the basic technology employed – that of a siphonic flush – has not changed. When the National Energy Policy Act reauthorized the U. S. Department of Energy in 1992, national standards for water use were included. The included toilet standard matched the industry standard for low-consumption toilets, mandating a 1.6 gallon per flush (gpf) toilet instead of the previous industry standard "Water Saver" toilet which used 3.5 gpf. Most toilet manufacturers adapted by keeping the 3.5 gallon toilet tank to provide the head for a forceful flush, while adjusting the inner workings of the toilet to achieve the 1.6 gallon flush. The two most common adaptations were to install a flush-valve flapper which closes before all the water escapes the tank (early-close flapper) or to install a plastic bucket, or toilet dam, which retains some water in the toilet tank behind the dam, thus lowering the volume of flush. Some manufacturers switched to low-capacity tanks with a standard flapper, and others chose to utilize a new pressurized flush technology.

Since 1.6 gpf, low-consumption toilets became the standard, there have been anecdotal reports of problems with their functioning, including a need for multiple flushes to clear the bowl, and frequent clogging. More anecdotal evidence suggests that the functioning of some early low-consumption toilets has continued to decline as they age. Even though low-consumption toilet performance has improved since the first models, many current models still rely on the same adjustments to the 3.5 gallon toilet. Lack of correct replacement parts seems a likely contributor to a possible decline in toilet performance with age, as early-close flappers are replaced with generic flappers which allow a 3.5 gallon flush, or as toilet dams are removed. Research on the functioning of aging low-consumption toilets can serve as a starting point for discussion of the extent of the problem, especially the decline in performance due to aging and replacement of parts.

Households that participated in the City of Tucson Water Department's low-consumption toilet rebate program in 1991-1992 were selected for study in order to investigate the functioning of older low-consumption toilets. Data loggers were attached to the water meter on the water line going to each house, and four days of data at a 10-second interval were recorded. Data gathered from 170 homes were analyzed using specialized software for identifying toilet flushes. Toilet flushes were measured according to their peak flow, duration and volume of flush and compared to the expected inventory of toilets in the home. A follow-up survey confirmed the number and type of toilets in the household, asked about toilet function problems, and elicited a rating of owner satisfaction with the functioning of these low-consumption toilets.

Results

Data logging revealed that more than half (57.1%) of homes with approximately 7-year-old toilets supplied through Tucson Water's low-consumption toilet rebate program had no detectable problem with their function. While this result is encouraging, considering the alterability of many brands of low-consumption toilet, several types of problems were detected, including high flush volumes, an increase in double flushing compared to 3.5 and 5 gallon toilets, and recurring flapper leaks.

Data-logging revealed the average flush volume for all rebate toilets was 1.98 gallons per flush, or about 24 percent higher than the 1.6 gallons per flush they were designed to use. As is shown in Table ES-1, 26.5 percent of households had at least one low-consumption rebate toilet with a high flush volume, averaging greater than 2.2 gpf.

Double flushing was considered a problem if it occurred once a day or more. Double flushing occurred in 14.2 percent of homes with rebated toilets, or 10.9 percent of rebated toilets. Data logging revealed that occurrence of frequent double-flushing was higher for rebated low-consumption toilets than for non-low-consumption, non-rebate toilets. The difference in proportions between the 10.9 percent of rebated low-consumption toilets requiring frequent double flushing and 6.6 percent of non-rebate, non-low-consumption toilets requiring double flushing is statistically significant, but not large. The small difference in double flushing problems between low-consumption and non-low-consumption toilets underscores the fact that double flushing is not confined to low-consumption toilets, but some models of low-consumption toilet do require more double flushing than non-low-consumption toilets.

A third problem identified was recurring flapper leaks. At least 12.1 percent of households had recurring flapper leaks in their low-consumption rebate toilets. It appears that flapper leaks

Table ES-1. Low-Consumption Toilet Problems by Flush Valve Type

Flush Valve Type	No. of Homes	No. Removed[1]	Double Flush	High Flush Volume	Flapper Leak	Some Problem[2]
Pressurized	14	3	9.1%	9.1%	na	35.7%
Early-close Flapper	61	1	13.3%	25.0%	10.0%	38.3%
Standard Flapper	23	0	21.7%	26.1%	8.7%	39.1%
Toilet Dam/Flapper	41	0	17.1%	26.8%	17.1%	51.2%
Tube and Bell	18	0	11.1%	44.4%	na	55.6%
All Types	170	4	14.2%	26.5%	12.1%	42.9%

[1] Number of homes from which a toilet with this type of flush mechanism was removed.

[2] Calculation of 'Some Problem' includes homes from which toilets were removed due to poor function. Pressurized toilets were removed from three homes due to poor function. A toilet with an early-close flapper was removed from one home because the toilet was rendered inoperable by actions of children in the household, not poor function.

occurred at a higher rate in low-consumption rebate toilets than in non-low-consumption non-rebate toilets, but it was not possible to determine the exact amount of difference in the rate of flapper leaks because of difficulties in determining the source of some flapper leaks.

As a result of these toilet function problems, it appears that water savings projections used in planning by a utility over the expected 20-year life of these 1991-92 year low-consumption toilets would need to be adjusted downwards to accurately accommodate the increase in average flush volume due to deterioration in toilet function over time and persistent toilet leaks. This adjustment should incorporate the 24 percent higher average flush volume measured for low-consumption toilets, as well as the higher rate of recurring flapper leaks and slightly higher rate of frequent double flushing in the rebated low-consumption toilets compared to non-low-consumption toilets.

Despite the ease with which early-close flappers can be replaced with standard flappers, it does not appear that early-close flappers are more likely than other flush valve mechanisms to produce high flush volumes or any other low-consumption toilet problem. Double flushing, high volume flush and flapper leaks in toilets with early-close flappers occurred at a slightly lower rate than for all types of toilet.

Low-consumption toilets with a standard flapper performed about average, with 39.1 percent of homes with some problem compared to 42.9 percent for all types. This type of toilet had the highest rate of frequent double flushing among flush mechanism types, with 21.7 percent of homes. Toilets with a standard flapper had a slightly below average rate of high flush volume (26.1%) and a below average rate of flapper leaks (8.7%).

Toilets with a toilet dam and a standard flapper performed worse, on average, than toilets with an early-close flapper or a standard flapper. Toilets with a toilet dam showed some problems with toilet function in 51.2 percent of homes. Toilets with toilet dams had the second highest rate of double flushing (17.1%) and the highest rate flapper leaks (17.1%) compared to other flush mechanism types. Easy alterability of toilet dams may help to explain worse performance of this type of mechanism.

Toilets with a specialized tube and bell flush mechanism performed the worst. Some toilet function problem was detected in 55.6 percent of homes with toilets with a tube and bell flush mechanism. Toilets with this mechanism had by far the greatest percentage of homes with high flush volume (44.4%). It is possible that some homeowners have installed the 3.5 gallon design of this mechanism in their toilets as a replacement, or have modified the 1.6 gallon mechanism to flush at a greater volume.

Pressurized toilets performed best compared to toilets with other flush mechanisms. Pressurized toilets had the lowest percentage of homes with frequent double-flushing, the lowest percentage of homes with high flush volumes and the lowest percentage homes with some low-consumption toilet problem. The percentage of homes with pressurized toilets with some toilet function problem would have been lower had not some been removed for performance problems. High performance ratings for pressurized toilets revealed that owners were either very happy with their pressurized toilets or dissatisfied enough to remove them.

The survey of homeowners showed that 85 percent of those replacing their flappers had done so by going to the hardware store, where proprietary replacement flappers are usually not available. Also, 24 percent of those who knew they had flappers as toilet flush valves used in-tank bowl cleaners, which may play a role in deterioration of rubber or plastic toilet parts. However, no attempt was made in the survey to distinguish between halogenating cleaners, some of which can cause damage, and non-halogenating cleaners, which do not cause damage.

Recommendations

1. **The water industry should collectively press through the ASME/ANSI standards process for toilet designs which are not alterable.** This means casting toilet dams as part of the tank if a toilet dam is used. This also mean using tanks with low-consumption capacity that do not require an early-close flapper. Toilets with specialized flush mechanisms should be made so a 3.5 gallon per flush replacement mechanism will not fit into a toilet that was designed to flush 1.6 gallons.

2. **The water industry should not offer rebates or direct install programs which include toilets with alterable designs or with specialized parts for which replacements may not be readily available later in the life of the toilet.**

3. We endorse Metropolitan Water District of Southern California's recommendations that a warning be included with new toilet packaging about use of halogenating bowl cleaners and that a program be established to inform all homeowners about the possible effect of halogenating bowl cleaners.

4. **Attempts should be made to replicate this study and confirm its findings with other populations of aging low-consumption toilets.** One example of a much larger population of similar-age and model low-consumption toilets are those installed under Los Angeles Department of Water and Power's toilet rebate program.

FUNCTIONING OF AGING LOW-CONSUMPTION TOILETS IN TUCSON

A Follow-Up With Rebate Program Participants

INTRODUCTION

Since its invention in the late 1800's, the siphonic flush has been the dominant toilet flush technology used in the United States and Europe. During the 20th century, the toilet was engineered to use progressively less water. Flush volumes declined over time in the U.S. from more than 7 gallons in early models, to five gallons per flush for much of the mid-20th century. By the 1980's, the standard in the U.S. was 3.5 gallons per flush. Starting with Massachusetts in 1989, some states and communities in the U.S. began requiring 1.6 gallon toilets in new construction and by 1992, 1.6 gallons per flush was the standard nationally.

Since 1.6-gallon, low-consumption[1] toilets started being produced in the U.S. in the late 1980's, there have been anecdotal reports of problems with their functioning, including a need for multiple flushes to clear the bowl and frequent clogging. With improved technology and further research into toilet design, low-consumption toilet performance has improved since the first low-consumption toilets. However, the reputation for the functioning of low-consumption toilets is based largely on experiences with early models, produced a couple years before and after the national low-consumption standard was set.

More anecdotal evidence suggests that the functioning of these early low-consumption toilets has continued to decline as they age. Research on the functioning of these aging low-consumption toilets in homes can serve as a starting point for discussion of the extent of the problem, especially the decline in performance due to aging and replacement of parts.

Achieving the 1.6 Gallon Flush

Some of the problems with the functioning of low-consumption toilets can be traced to the ways manufacturers chose to achieve a 1.6 gallon flush. When the National Energy Policy Act was reauthorized in 1992, the American Society of Mechanical Engineers/American National Standards Institute (ASME/ANSI)[2] standards for 1.6 gallon toilets were adopted by reference, establishing them as the standards across the U.S. The ASME/ANSI standards require that toilets must flush with an average of 1.6 gallons on 5 test flushes, with none of the flushes exceeding 2.2 gallons. The manufacturer must decide how to achieve the standard.

Most manufacturers kept the 3.5 gallon tank to provide the head for a forceful flush, but adjusted the inner workings of the toilet to achieve a flush volume of 1.6 gallons. The two most common ways to achieve the smaller flush with gravity models were to use an early-close flush valve flapper or to install a toilet dam. Other manufacturers chose other options, such as pressurized flush technology or low-capacity tanks with standard flappers.

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[1] Low-consumption toilets have been commonly referred to as ultra-low-flush (ULF) toilets. The term low-consumption is used here because it is the term used when creating the 1.6 gallon standard.

[2] ASME is the author of plumbing standards published by ANSI.

Flush Valve Flappers

The flapper is the rubber or plastic piece that closes the hole (flush valve) through which water flows from the tank to flush the bowl. Standard flappers are designed with air in a bell on the inside so that they will float and close only after the water level has declined enough to seat the flapper on the flush valve. In early-close flappers, a hole is built in the flapper to allow air trapped in the flapper bell to escape early and close the valve before all the water escapes the tank. These early-close flappers are set to allow only 1.6 gallons to flow from the tank into the bowl, instead of the full 3.5 gallons.

Of the low-consumption toilets in this study, one manufacturer, Universal Rundle, chose to use a standard flapper as the flush valve. Toilets made with this design did not use an early-close flapper or a toilet dam to achieve a 1.6 gallon flush. Instead, other modifications were made to the toilet, including using a smaller trapway and a steeper bowl. These toilets use a smaller-capacity tank than most models of toilets in this study, and are generally believed to be more difficult to modify to increase the flush volume.

All flappers inevitably deteriorate over time and must be replaced. While the normal life of a toilet is at least 20 years, the life of a typical flapper under "normal wear and tear" is about five years (MWD 1998). In effect, this means that correct replacement flappers would need to be purchased three times over the expected life of the toilet.

Most early-close flappers can be replaced by standard floating flappers. Customers who are unaware that their toilet has an early-close flapper can unwittingly erase the water savings by replacing a worn-out flapper with a traditional flapper. Identifying an early-close flapper is difficult because they usually are not marked as such and attach to the toilet in the same manner as a traditional flapper. If a traditional flapper is used, the flush volume immediately reverts to the full amount of water held in the tank (3.5 gallons) and the customer may not notice any difference in performance of the toilet. Most hardware and home improvement stores carry only traditional flappers, with customers in need of an early-close flapper having to call the manufacturer to get a suitable replacement.

In addition, the quality of water used in toilets can accelerate deterioration of flappers. Use of bowl cleaners installed in the tank to constantly clean the bowl can lead to rapid deterioration and warping of flappers if the cleaner is a halogenating compound[3]. Accelerated testing done by the Metropolitan Water District of Southern California (MWD) on flappers available in 1994 showed that halogenating bowl cleaning solutions could deteriorate all flappers. Since then, manufacturers have continued to improve the compounds used in constructing their proprietary flappers, and MWD tests on 1998 flappers showed that some new flappers appeared to be either not affected, or much less affected by halogenating bowl cleaners, when compared to effects shown in the 1994 testing.

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[3] In-tank bowl cleaners can consist of halogenating or non-halogenating compounds. Cleaners with halogenating agents generally use either mixed halogenated methyl hydantions or calcium hypochlorite. The non-halogenating type uses detergent and is not known to cause flapper deterioration (MWD 1998).

High concentrations of chloramine, a residual disinfectant used in some water systems, have also been shown to deteriorate rubber toilet parts such as flappers. Chloramine was used to provide residual disinfection in Central Arizona Project (CAP) water delivered to more than half of the City of Tucson Water Department's (Tucson Water) customers from November 1992 to November 1994. Since CAP water deliveries were discontinued, the City of Tucson has switched back to chlorine as the disinfectant.

Toilet Dams

A toilet dam is a plastic bucket or barrier 3 to 4 inches high surrounding the flapper valve in the bottom of the tank. A standard floating flapper and a 3.5 gallon tank are used. When the toilet is flushed, the water outside of the dam and below its top is retained in the tank, maintaining hydraulic pressure to create a more forceful flush, but allowing only 1.6 gallons to be used.

Toilet dams can be easily disabled, although not so easily as to be removed unwittingly. Intentional removal of toilet dams could be prevented if they were cast as part of the tank.

Pressurized Flush

Some manufacturers use pressurized flush technology to achieve the 1.6 gallon flush. The most common of these technologies is the pressurized flush system, with a sealed air bladder contained in the tank using water service pressure to achieve a forceful flush. Pressurized flush toilets are often among the most expensive toilets on the market ($200 - $300) and can be expensive to maintain because parts are more specialized. They are also known for producing a noisier flush accentuated by a rapid flush cycle.

Other Proprietary Mechanisms

Another flush mechanism utilized in achieving a 1.6-gallon flush is the proprietary tube and bell mechanism used by Mansfield in the Allegro model toilet. Mansfield originally licensed the toilet design with the tube and bell mechanism from a Swedish company - Ifö-Sanitar, and later incorporated the mechanism in its Allegro model. In this toilet, a rubber bell slides up a tube to flush and slides back down to close the valve.

Replacement assemblies for this flush mechanism are available from some hardware stores. Both the 1.6 gallon flush and 3.5 gallon flush mechanisms are available and both can be installed in 1.6 gallon toilets. Inadvertently buying the wrong assembly from the hardware store is not likely because the packages are labeled according to flush volume, which is not generally the case with flappers. The 1.6 gallon version of this flush mechanism also could easily be modified to close later with a greater flush volume, but this would require intentional modification. The rubber gasket around the bottom of the flush valve that makes a seal with the bottom of the bell is reported to be the most common piece of the flush valve to wear out, and is also available at some hardware stores.

LITERATURE REVIEW

Most analyses of low-consumption rebate programs show that low-consumption toilets save water compared to conventional fixtures. In Los Angeles and Santa Monica, a study of Metropolitan Water District of Southern California's ultra low flush rebate program for single family residences and multifamily residences found water savings ranging from 30 to 46 gallons per dwelling per day, depending on the dwelling type (Chesnutt et al. 1992). In Tucson, an analysis of Tucson Water's low-consumption rebate program showed that toilet retrofits saved an average of 33 gallons per dwelling per day, or 26 gallons per toilet per day. This study included only single family residences (Woodard and Henderson 1994).

Customer satisfaction surveys show that the majority of customers are satisfied with most brands of low-consumption toilet, when the toilets are relatively new. Homeowners participating in the low-consumption toilet rebate program in New York City were surveyed in 1996 after approximately 7 to15 months of toilet use, and had an average satisfaction rating of 3.16 on a 5-point scale, indicating they were slightly more satisfied with their new toilet compared to the old one. Apartment residents rated their low-consumption toilet on average at 2.94, indicating they were slightly less satisfied with their new toilets (Westat 1997).

In 1992, customers participating in the toilet rebate program offered by the Los Angeles Department of Water and Power were surveyed. How much time elapsed between toilet installation and the survey is unclear. The average satisfaction rating for all brands of toilets was 7.4 on a 10-point scale (Wirthlin Group 1992). This study had toilets of the same model and year as the current study, including the Kilgore/Mansfield Quantum, the Kohler Wellworth Lite, the Universal Rundle Atlas and the Eljer Preserver.

In 1999, Metropolitan Water District of Southern California surveyed customers who installed new low-consumption toilets in 1998 or 1999. Average ratings by model of toilet ranged from 5.91 to 8.37 on a 10-point scale. Most customers preferred the new low-consumption toilets to the old toilets (MWD 1999). Respondents to a 1996 MWD survey provided average ratings ranging from 3.6 to 4.46 on a 5-point scale.

Most customer satisfaction surveys are performed about a year after toilets are installed. There has been anecdotal evidence that functioning of some low-consumption toilets can deteriorate over time, starting as early as a few months after installation. However, no studies have been done of customer satisfaction with low-consumption toilets more than about a year into their expected 20-year life. And, no studies have been conducted that gathered data on the functioning of older low-consumption toilets by measuring the water flow rate at the water meter for the house in which the low-consumption toilet was installed.

METHODS AND PROCEDURES

Households that participated in Tucson Water's low-consumption toilet rebate program in 1991-1992 were selected to study the functioning of older low-consumption toilets. The functioning of rebate toilets approximately 7 years after installation, or about one-third of the way into their expected life, could then be studied. Data from Tucson Water records showing the installation

address, the number of bathrooms, and the type and number of toilets installed were received for 477 households. This number was reduced to the sample size of 200 as follows: one-third of the 477 households were randomly removed from consideration. The 318 households remaining were plotted geographically. Using the geographic center of Tucson, the data set was divided into four quadrants. Approximately 64 homes were randomly selected from each quadrant to assure 50 homes per quadrant, plus several reserve sites in the event of problems obtaining data from selected sites. These sites were well spread-out across an area that is highly diverse in terms of housing age, cost and style.

Data loggers were attached to the water meter on the main water line going to each house for four days[4]. Using fifty loggers at a time, four rounds were necessary to obtain data from 200 homes. The logging was completed over 19 days in December 1998. Data from 30 of the households were not usable due to various problems with the connection to the meter or the functioning of the logger, leaving 170 usable traces to be analyzed. Occupants were not notified that their meter was being logged. As a result, the data are not subject to bias due to the "Hawthorne Effect," when participants change their behavior due to knowledge that their actions are being monitored.

The 170 traces contained data on 20 different models of low-consumption toilet rebated during the program. Table 1 shows the models of toilets and their flush mechanism type.

The data were analyzed using the Trace Wizard™ software for end-use analysis developed by Aquacraft Engineering, Inc.[5] Toilet flushes produce consistent patterns, which can be identified according to their peak flow, duration, and volume of flush (DeOreo et al. 1996). All toilet flushes occurring in the four-day trace were identified and assigned to a particular toilet in the household. The volume of each flush and the number of flushes for each toilet was recorded. The average volume per flush for each toilet and the number of flushes in the trace were then recorded in a database.

A follow-up survey was conducted, initially by phone. The survey asked occupants to confirm the number and type of toilets in their household. Occupants were also asked to state whether any of four common problems were present with any of their toilets: frequent double flushing, toilet runs after flush, flapper leak leading to periodic flushing or refilling, or frequent clogging. Respondents were then asked to rate the functioning of each of their toilets on a 5-point scale with 1 corresponding to very dissatisfied, 2 dissatisfied, 3 neutral, 4 satisfied, and 5 corresponding to very satisfied. The rest of the survey helped assess factors such as whether in-tank toilet bowl cleaners were being used, whether respondents had replaced flush-valve flappers, and the number of adults and children in the household. A copy of the survey is found in Appendix I.

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[4]Meter-Master model 100EL data loggers were used with a 10 second data storage interval. Meter-Master data loggers are manufactured by F.S. Brainard & Co., P.O. Box 366, Burlington N.J. 08016.

[5]Aquacraft Engineering, Inc., 2709 Pine St., Boulder, CO 80304.

Table 1. Low-Consumption Toilet Models and Their Flush Mechanisms

Manufacturer	Model	No. of Toilets	Flush Valve Type
Universal Rundle	Atlas	29	Gravity - standard flapper
Universal Rundle	Saturn	3	Gravity - standard flapper
Universal Rundle	Taurus	2	Gravity - standard flapper
Kohler	Wellworth Lite	76	Gravity - early-close flapper
Briggs	1.5	2	Gravity - early-close flapper
Crane	Cranemeiser	1	Gravity - early-close flapper
Norris	516	1	Gravity - early-close flapper
Santarios Azteca	Lamosa Sahara	11	Gravity - toilet dam with standard flapper
Eljer	Preserver	17	Gravity - toilet dam with standard flapper
Eljer	Ultra	1	Gravity - toilet dam with standard flapper
Eljer	Ultra-One	1	Gravity - toilet dam with standard flapper
American Standard	Plebe	2	Gravity - toilet dam with standard flapper
Aqualine	AquaSaver	13	Gravity - toilet dam with standard flapper
Mansfield/Norris	Allegro	17	Gravity - tube and bell
Kilgore (Ifö)	Cascade	3	Gravity - tube and bell
American Standard	Cadet	3	Pressurized
Mansfield	Quantum	13	Pressurized
Kohler	Rialto Lite	2	Pressurized
Gerber	Ultra-Flush	2	Pressurized
Vitromex	Corinto	5	Manufacturer unable to verify
Unknown		15	
Total		219	

A large percentage of the original participants in the toilet rebate program had moved, and often the phone number of the new occupants was not listed. Also, some households could not be contacted by phone after multiple tries at different times of day or night. Surveys identical to the phone survey were mailed to all households that could not be contacted by phone.

Records from Tucson Water of rebated low-consumption toilets sold to each address, along with the total number of bathrooms and toilets in each household, were combined with surveys of the current residents to inventory toilet types for each household. This expected inventory was compared with the average volume for each toilet identified from the data taken from each household to determine whether low-consumption rebate toilets were flushing at unusually high volumes. When two or more of the same model of low-consumption toilet were being used in a residence, individual low-consumption toilets were often indistinguishable in the data-logging trace. In this case, the average of the same-model low-consumption toilets was reported.

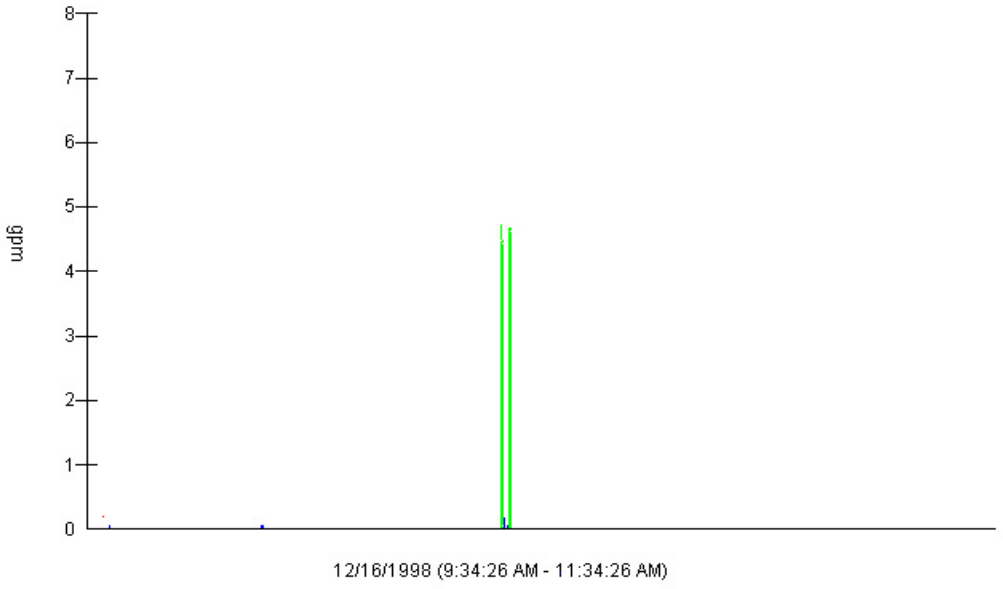
In addition, several common problems with toilet function could be detected from the traces, including high flush volume, double flushing, and flapper leaks. If the average volume of a low-consumption toilet was greater than 2.2 gallons per flush, it was recorded in the database as having a high flush volume.

Only low-consumption rebate toilets with average flush volumes greater than 2.2 gpf were counted as having high flush volumes. Because flush volumes greater than 2.2 gpf were not allowed in testing for meeting ASME/ANSI standards, this seemed an appropriately conservative cutoff volume to account for normal variations in toilet flush volume. Toilet flush volumes can vary slightly depending on human factors such as how long the handle of a gravity flush model is held down and the water pressure at each residence. Officials with Tucson Water state that the average water pressure varies by 5 to 10 psi across pressure zones in the central city, and by 10 to 20 psi in the higher elevation portions of the service area. Differences in pressure of 20 psi would be large enough to cause small systematic variations in flush volume in some toilets, but not enough to cause flush volumes of 1.6 gallon toilets to consistently be measured above 2.2 gpf.

The number of times that each toilet was flushed in succession was recorded as an indication of a possible multiple flushing event to clear one load of waste. Toilet flushes from the same device within four minutes of each other were counted as multiple flush events. Figure 1 shows a sample trace of a multiple flush event.

The proportion of possible multiple flushing events to total flushing events for each toilet in each home was recorded. Toilets with double-flush percentages greater than or equal to 15 percent were counted as having a problem with double flushing. This is a conservative standard. With an average of 28 flushes per toilet over a four day period during the study, this means at least four multiple flushing events, or one per day, were needed for multiple flushing to be considered a problem.

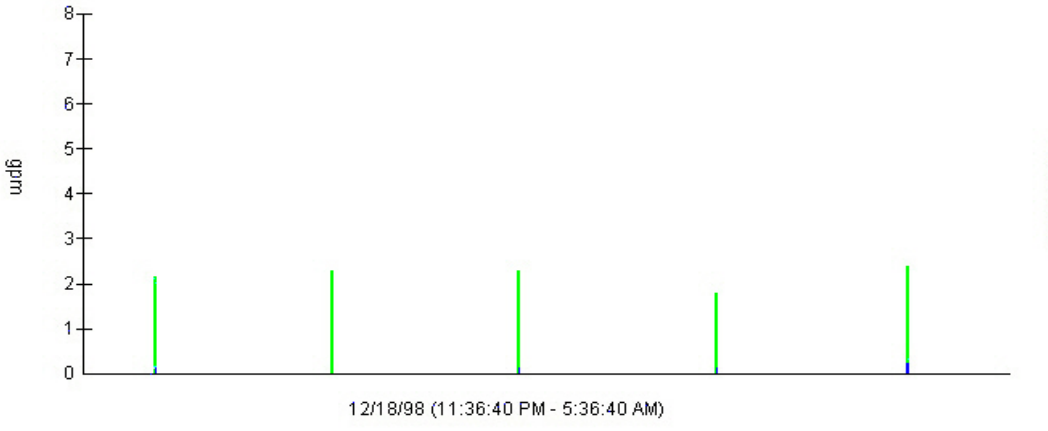
Figure 1. Example of Double Toilet Flushing



Toilet flush volumes: 2.13 gallons, 1.63 gallons; interval between flushes: < 2 minutes

The traces also revealed some toilets flushing or refilling on their own. Flapper leaks result in a slow draining of the water in the tank of toilets. As the water drains, the refill valve eventually turns on. As a flapper leak continues, it is detectable on a trace as a recurring pattern of water use spikes at regular intervals. Figure 2 shows a flapper leak recurring at a particular interval. This pattern is easiest to detect at night, when there is little other water use. Only recurring, regular interval leak patterns that were detectable at night were counted as flapper leaks.

Figure 2. Example of Recurring Toilet Flapper Leak



Average leak volume: 0.57 gallons, Average interval between leaks: 1 hour 13 minutes

RESULTS: DATA LOGGING

The data logging revealed a range of water fixture leaks and problems, including constant leaks and toilet flushing at a repeating, constant interval. Although all water use events were identified in each trace to make sure that no toilet use events were misidentified, analysis of problems was restricted to those specifically related to toilet functioning.

Problems discovered for toilet models installed in 10 or more households are shown in Table 2, along with a listing of toilet problems according to flush valve type used in the toilet and the total for all households.

High Flush Volume

There were 219 low-consumption rebate toilets found in 166 houses (in four of the 170 sample homes the low-consumption rebate toilets had been replaced). These toilets had an average flush volume of 1.98 gallons per flush (gpf), or approximately 24 percent higher than the 1.6 gallons per flush they were designed to use.

Investigation by Aquacraft Engineering, Inc. into the functioning of data loggers and the end-use-analysis software, using simultaneous flow traces on the main water meter and a meter installed on the hot water line, indicates that small faucet usage on the order of 0.1 gallons can be hidden in the volume recorded for the toilet flush event. This faucet usage occurs as people wash their hands after using the toilet. However, Aquacraft reports that inclusion of an extra 0.1 gallons in the toilet flush volume does not occur every time faucet use immediately follows a toilet flush. In addition, the impact of a possible inflation of toilet flush volume depends on the frequency with which faucet use follows a toilet flush. Observation of traces in this study indicates that faucet use follows toilet use only some of the time.

Another measure of the frequency of low-consumption toilets with high flush volumes is the percentage of homes with a low-consumption toilet with an average flush volume greater than 2.2 gpf, or the highest allowed flush volume allowed for any of the flushes used in meeting the AMSE/ANSI low-consumption testing protocol. The average flush volume of at least one low-consumption rebate toilet was found to be greater than 2.2 gpf in 26.5 percent of homes.

Low-consumption toilets with the tube and bell flush mechanism were shown to have the highest percentage homes with high flush volumes at 44.4 percent, which was well above the average of 26.5 percent for all homes. There were two models of toilets included in this category, the Mansfield Allegro and the Kilgore (Ifö) Cascade. The Allegro was the more numerous of the two toilet models, with 15 of the 18 total homes in which a toilet with a tube and bell style mechanism was installed. The Allegro had the second highest percentage of homes with high flush volumes compared to other individual toilet models, at 40 percent.

Homes with toilets having a toilet dam and a standard flapper had the second highest percentage of problems compared to other flush mechanisms, with 26.8 percent or just above average for all homes. Of the brands for which there were traces from 10 or more homes, the Lamosa Sahara had the highest percentage of homes with high flush volumes, at 60 percent. This toilet uses a

Table 2. Low-Consumption Toilet Problems by Flush Valve Type and by Toilet Model

Flush Valve Type	No. of Homes	No. Removed[1]	Double Flush	High Flush Volume	Flapper Leak	Some Problem[2]
Pressurized	14	3	9.1%	9.1%	na	35.7%
Early-close Flapper	61	1	13.3%	25.0%	10.0%	38.3%
Standard Flapper	23	0	21.7%	26.1%	8.7%	39.1%
Toilet Dam/Flapper	41	0	17.1%	26.8%	17.1%	51.2%
Tube and Bell	18	0	11.1%	44.4%	na	55.6%
Toilet Model [3]						
Wellworth Lite (E)	57	1	12.5%	23.2%	10.7%	35.7%
Quantum (P)	10	3	10.0%	10.0%	na	38.5%
Atlas (S)	20	0	20.0%	30.0%	10.0%	40.0%
Aqua Saver (D)	10	0	20.0%	20.0%	20.0%	40.0%
Allegro (T)	15	0	13.3%	40.0%	na	53.3%
Preserver (D)	13	0	30.8%	23.1%	23.1%	61.5%
Lamosa Sahara (D)	10	0	0.0%	60.0%	20.0%	80.0%
All Models/Types	170	4	14.2%	26.5%	12.1%	42.9%

[1] Number of homes from which this toilet model or toilet with this type of flush mechanism was removed.

[2] Calculation of Some Problem includes homes from which toilets were removed due to poor function. Pressurized Quantum toilets were removed from three homes due to poor function. A Wellworth Lite with an early-close flapper was removed from one home because the toilet was rendered inoperable by the actions of children in the household, not due to poor function.

[3] Toilet models for which there were data from at least 10 households.

E = Early-close Flapper, P = Pressurized, T = Tube and Bell, D = Toilet Dam and Standard Flapper
S = Standard Flapper

toilet dam and a flapper. Homes with other toilet models with a toilet dam performed much better than the Lamosa Sahara. The Eljer Preserver had 23.1 percent of homes with high flush volumes. The Aqualine Aqua Saver, had 20.0 percent of homes with high flush volumes.

The generally poor performance of some brands of toilet with the toilet dam and flapper flush mechanism such as the Lamosa Sahara compared to other brands is an interesting finding. It is possible that toilet dams dislodge in the tank easier with some models than with others, or that dams are intentionally removed. Also, the flappers originally provided with the toilet may perform better in those toilets than generic replacement flappers. It is difficult to single out a cause with the information gathered in this study.

Low-consumption toilets with a standard flapper as the flush mechanism had the next highest percentage of homes with high flush volumes at 26.1 percent, or just below average for all homes. All toilets in this category were made by Universal Rundle, and Atlas was most numerous of the toilets, with 20 of the 23 total homes. Thirty percent of households with the Atlas had high flush volumes.

Homes with low-consumption toilets with early-close flappers had the next lowest percentage of high flush volumes, at 25.0 percent. The Wellworth Lite is the only model installed in 10 or more households which uses an early-close flapper. Twenty-three percent of households with Wellworth Lite toilets had high flush volumes, which was below the average for all households (26.5%). This implies early-close flappers, despite the ease with which they can be replaced with standard flappers with 3.5 gallon flush volumes, may not be worse than other mechanisms in allowing higher flush volumes after seven years of service.

Pressurized toilets were the most successful at delivering low-volume flushes. Only 9.1 percent of homes with pressurized toilets recorded high flush volumes. The Quantum was the only pressurized toilet brand installed in 10 or more homes. Compared to all other individual toilet models, the Quantum had the lowest percentage of homes (10%) with flush volumes greater than 2.2 gallons per flush.

Double Flushing

Chronic double flushing of low-consumption rebate toilets occurred in 23 of 211 toilets in the 162 homes for which there were data[6]. This means there were toilets requiring chronic double flushing in 14.2 percent of homes, constituting 10.9 percent of rebated low-consumption toilets studied. This is roughly equivalent to 10.9 percent of rebated low-consumption toilets needing to be double flushed once a day. For reference, a 1992 survey of Los Angeles Water and Power toilet rebate customers with many of the same models of low-consumption toilet when they were new, reported that 9 percent of low-consumption toilets required double flushing several times a week, 4 percent said their low-consumption toilet required double flushing once a day, and 5 percent said double flushing was required several times per day (Wirthlin Group 1992).

The rate of double flushing can be influenced by human factors, such as habits formed over time, as well as toilet construction. This may be reflected in the fact that double flushing occurs in non-low-consumption toilets as well as low-consumption toilets. A comparison of the rate of chronic double flushing between rebate low-consumption toilets and non-low-consumption toilets can give an indication of the increase in the rate of double flushing attributable to low-consumption construction.

There were 76 non-low-consumption toilets functioning in 72 of the 163 homes for which there were readings. Five of the these non-low-consumption toilets showed chronic double flushing,

[6]There were four homes where it could not be determined whether a toilet with a high flush volume was the expected low-consumption toilet. Therefore, these four homes were not used in calculating the percentage of homes with low-consumption toilets with high flush volumes. As a result, data were available for 162 homes instead of 166.

or 6.6 percent of non-low-consumption toilets. The difference between the 6.6 percent of non-low-consumption toilets requiring double flushing and the 10.9 percent of low-consumption rebate toilets requiring double flushing, although not large, is statistically significant at the 95 percent confidence interval.

Low-consumption toilets with a standard flapper as the flush valve had the highest percentage of homes with double flushing problems, at 21.7 percent. These toilets did not use either a toilet dam or an early-close flapper, but instead incorporated other design changes to achieve the 1.6 gallon flush. The most numerous toilet in this category, the Atlas, had the third highest percentage of chronic double flushing among toilet models, at 20.0 percent.

Homes with toilets with a toilet dam and standard flapper as the flush mechanism had the second highest percentage of homes with double flushing problems, at 17.1 percent. There was a wide variation in performance between the Preserver, the Lamosa Sahara, and the Aqua Saver. The Preserver had the highest percentage of chronic double flushing among toilet models, at 30.8 percent of homes, while none of the homes with a Lamosa Sahara had a problem with chronic double flushing. Twenty percent of homes with an Aqua Saver had double flushing problems.

Early-close flapper toilets showed a below average percentage of homes with chronic double flushing at 13.3 percent (compared to 14.2% average). Toilets with a tube and bell mechanism had problems in 11.1 percent of homes.

Pressurized toilets had the lowest percentage of homes with chronic double flushing, at 9.1 percent. Among individual toilet models, the Quantum had the second lowest percentage of chronic double flushing at 10 percent of homes in which they were installed.

Flush-Valve Flapper Leaks

A total of 24 homes had recurring flapper leaks out of the 140 which had low-consumption rebate toilets that used flappers instead of some other flush mechanisms. In 17 of these instances it could be verified that a Tucson Water rebate program low-consumption toilet was responsible for a regular-interval flapper leak. In three of the cases, another toilet in the house had the flapper leak, not the Tucson Water low-consumption toilet. In the remaining four instances, there was no way to determine whether the leak was due to the rebate toilet, or to another toilet in the household.

The average volume per tank refill due to a flapper leak was 0.48 gallons. The period of time between refills ranged from 6 minutes to 4 hours, and averaged 85 minutes.

Flapper valve leaks occurred somewhat more often in toilets with a toilet dam and a standard flapper (16.1% of homes) than in those with an early-close flapper (13.3% of homes). Toilets with a standard flapper without the toilet dam design had the lowest percentage of flapper leaks, at 8.7 percent of homes.

The Preserver, which has a toilet dam, had the highest percentage of homes with flapper leaks, at 23.1 percent. Homes with the Atlas had the lowest percentage of flapper leaks, at 10.0 percent.

Homes With Some Toilet Function Problem

Seventy-two of the 165 households for which there was a reading had one or more problems with the functioning of their low-consumption toilets, or 42.9 percent of homes. Four households were disregarded because it could not be determined whether a flapper leak was from the rebated low-consumption toilet or another toilet in the household. However, three homes in which the low-consumption rebate toilets had been replaced because of poor functioning were included in the calculation for this category, leaving 165 homes.

Homes with pressurized toilets had the lowest percentage of overall problems, with 35.7 percent. Among individual toilet brands, the Quantum had the second lowest percentage at 38.5 percent. The rating for pressurized toilets in general and the Quantum specifically would have been significantly better, had not Quantums in three homes been removed for performance-related problems.

Toilets with early-close flappers had the second lowest percentage of homes with some problem. Among individual models of toilets, households with the Wellworth Lite had the lowest percentage of problems, with 37.5 percent.

Low-consumption toilets with a standard flapper also had a below average number of homes with some problem, at 39.1 percent of homes. The most numerous toilet in this category, the Atlas, had some problem in 40 percent of homes.

One or more problems were detected in 51.2 percent of homes with toilets with toilet dams. This figure is similar to the 55.6 percent of homes with the tube and bell mechanism that had some problem. The two worst performing individual models of toilets used a toilet dam. The Preserver had the second highest percentage of homes with problems at 61.5 percent, while the Lamosa Sahara had the highest percentage of homes with some problem at 80.0 percent.

RESULTS: SURVEY

There were 79 complete responses to the phone survey. An additional 10 households contacted by phone refused to participate and 2 gave incomplete responses. Thirty-three of the 80 households receiving the mail survey gave responses. However, due to a clerical error, 17 of the mail responses received could not be identified with a home or toilet. A follow-up letter convinced four of the mail respondents to re-submit a survey, however 13 did not respond. This leaves 20 usable responses from the mail survey, for a total of 99 usable responses from both phone and mail.

Seventy-eight percent of the survey respondents were the occupants at the time that the rebate toilets were purchased for the house. Based on phone book listings and tax records it appears that 66 percent of all possible respondents were the occupants at the time the rebate toilets were purchased.

A comparison of participation rates for original occupants versus new owners confirms that homes with respondents who were the original purchasers of the low-consumption rebate toilets

responded to the survey at a greater rate than homes with new owners since the rebate program expired. Of the possible respondents identified as not being the occupants at the time the toilets were installed, 39 percent responded to the survey. Sixty-eight percent of original occupants gave responses. This difference is large and statistically significant.

Possible Sources of Bias

The finding that original occupants responded at a greater rate than those who moved in later is not surprising, since those who participated in the toilet rebate program are familiar with questions about toilets purchased under the rebate program, while those who were not the original occupants may know nothing of the rebate program or even which toilets in their house are 1.6 gallon models. Also, phone numbers for original occupants were given in the data from Tucson Water, while phone numbers for those who were not original occupants were available only if they were listed in the phone book.

Survey results from original occupants may be susceptible to bias in favor of water conservation. All of the homes selected had owners who willingly participated in a water conservation program. To the extent that they were motivated to save water over the need to replace a toilet they would have needed to replace anyway, these participants may be said to be biased towards viewing water conservation programs and water saving devices favorably. They may ignore minor inconveniences in the functioning of their low-consumption toilets because they are more influenced by the thought that they are saving water. Comments provided by respondents confirm that this attitude is true for at least a couple of participants.

However, many of the homeowners from the time of the rebate program have since moved out of the homes. The new occupants are less likely to be biased towards viewing water conservation favorably. Also, earlier investigations into the toilet rebate program revealed that at least some of the program participants were motivated by the fact that they needed to replace their toilets, and would have done so anyway without the toilet rebate program. These two factors serve to balance against the possible bias in favor of water conservation.

Survey Responses

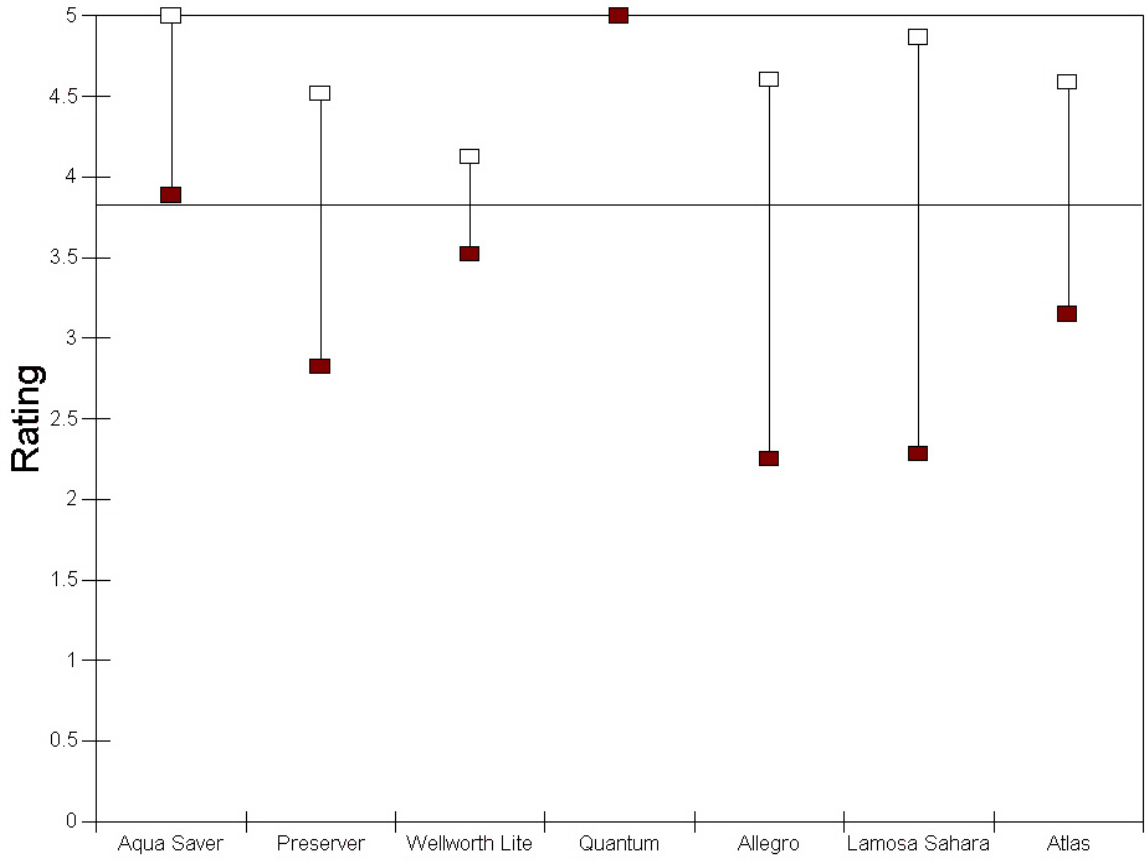
On average, respondents had 1.89 adults and 0.53 children occupying their households on a regular basis. The average persons per household of 2.42 is only slightly lower than the average persons per household reported in the 1990 census for the Tucson Metropolitan Area and is consistent with the trend of decreasing household size.

The average rating for all respondents of low-consumption toilets purchased through the Tucson Water toilet rebate program was 3.83 on a five point scale (131 toilets). This shows that respondents on average were satisfied with the functioning of their rebate program toilets. By comparison, the overall rating for toilets in the Los Angeles Department of Water and Power Survey in 1992 was 7.4 on a 10 point scale (Wirthlin Group 1992). If this rating is halved to correspond to a five-point scale, the overall rating was 3.7, or slightly lower than in the current survey.

Respondents overall rated their non-rebate toilets slightly higher than the rebate toilets at 3.92 (53). Of the non-rebate toilets, respondents rated their non-rebate, non-low-consumption toilets (those using 3.5 gallons per flush or greater) (3.93, 44 toilets) slightly higher than their non-rebate low-consumption toilets (3.88, 8 toilets).

There was only one toilet for which more than 30 responses were received. The average rating of the Wellworth Lite was 3.82 (51 toilets). Other models with ratings for more than 5 toilets are the Atlas at 3.87 (15 toilets), the Aqua Saver at 4.44 (9 toilets), the Quantum (5.0, 7 toilets), the Allegro (3.43, 7 toilets), the Lamosa Sahara (3.57, 7 toilets), and the Preserver (3.67, 6 toilets). These ratings are shown with 95 percent confidence intervals around the means in Figure 3. Only the rating for the Aqua Saver and the Quantum can be said to be greater than the mean for all rebate toilets at the 95 percent confidence level. However, it must be kept in mind that the ratings for these toilets are based on small numbers. Also, none of the ratings for each toilet are

Figure 3. 95 Percent Confidence Interval Around Mean Toilet Ratings



statistically different from each other, except for the Quantum which can be said to be significantly better rated than all other brands for which there were at least 5 toilets except the Aqua Saver. The sample size for the survey would need to be significantly increased for toilets other than the Wellworth Lite in order to rank toilet ratings in a statistically significant manner.

There were four brands of pressurized toilets for which data was collected in the survey - the Quantum, the Rialto Lite, the Cadet, and the Ultra-Flush. The survey yielded ratings for 14 pressurized toilets. Every pressurized toilet was given a rating of 5, the highest rating. However, the survey also revealed that 4 Quantum pressurized toilets in 3 households were removed due to bad performance or lack of available replacement parts. By contrast, only 2 other toilets in 1 household were reported to be removed. They were yielded inoperable by actions of children in the household. It appears from this limited sample that when pressurized toilets work well, residents are very happy with them, but when they do not perform correctly, residents are sufficiently dissatisfied to remove them.

Respondents were asked specifically about their flush mechanisms. Of those respondents who knew whether or not their toilet had a flapper as the flush valve, 58 percent had replaced the flapper on their rebate toilets. Eighty-five percent of those replacing their flappers had gone to a hardware store for a replacement flapper. Nine percent got replacement flappers from their plumbers, while six percent got replacement flappers from a specialty toilet supply store.

Respondents were asked whether or not they use in-tank bowl cleaners. However, no attempt was made to distinguish between halogenating cleaners and non-halogenating cleaners. Twenty-four percent of those who knew they had flappers as toilet flush valves used in-tank bowl cleaners. Several respondents stated they could notice the deteriorating effect of using in-tank bowl cleaners on their flappers and had stopped using this type of cleaner for that reason, or that plumbers or toilet salespeople had warned them not to use in-tank bowl cleaners.

Reported Problems

In the survey, respondents were asked whether there were chronic or recurring problems with any of their toilets. Four possible problems related to toilet functioning were suggested: frequent double-flushing, clogging, toilet flushes or refills on its own, or toilet runs after flush and then stops. The most numerous problem reported with both rebated low-consumption toilets and non-low-consumption, non-rebated toilets was double flushing. Multiple flushing was reported as necessary in 38 percent of rebate toilets and 16 percent of non-rebate, non-low-consumption toilets. This difference is statistically significant. Clogging was reported in 28 percent of rebate toilets and 8 percent of non-rebate, non-low-consumption toilets. This difference is also statistically significant. A toilet flushing or refilling on its own was reported in 16 percent of rebate toilets and 18 percent of non-rebate, non-low-consumption toilets, which is not a statistically significant difference. Running after the flush and then stopping was reported in 25 percent of rebate toilets and 16 percent of non-rebate, non-low-consumption toilets. This is not a statistically significant difference.

Reports of double flushing in a rebate toilet match the data logging record in 67 percent of the cases. This percentage stays the same whether the double flush percentage used in the data logging is 15 or 10 percent of flush events. The percent of toilets requiring double flushing as reported in the survey (38%) is higher than the percentage requiring double flushing obtained from the data logging (10%).

Table 3. Percent of Toilets Reported to Have Chronic Toilet Function Problems

Toilet Function Problem	Low-Consumption Toilets	Non-Low-Consumption
Frequent Double Flushing	38%	16%
Refills/Flushes On Its Own	16%	18%
Runs After Flush	25%	16%
Frequent Clogging	28%	8%

SUMMARY AND CONCLUSIONS

Data logging of homes with approximately 7-year-old toilets supplied through Tucson Water's low-consumption toilet rebate program, combined with surveys of more than half the households, revealed that nearly half of aging low-consumption toilets had problems with high flush volumes, frequent double flushing, and/or flapper leaks.

Data logging revealed that the average flush volume for all low-consumption rebate toilets was 1.98 gallons per flush, or about 24 percent higher than 1.6 gallons per flush they were designed to use. In addition, 26.5 percent of households had at least one low-consumption rebate toilet with an average flush volume greater than 2.2 gpf.

Frequent double flushing, which was defined as occurring in at least 15 percent of possible flushing events during a trace (on average about once a day), occurred in 14.2 percent of homes with rebated low-consumption toilets, or 10.9 percent of rebated toilets. Data logging also revealed that occurrence of frequent double flushing was higher for rebated low-consumption toilets than for non-low-consumption, non-rebate toilets. The difference in proportions between the 10.9 percent of rebated low-consumption toilets requiring frequent double flushing and 6.6 percent of non-rebate, non-low-consumption toilets requiring double flushing was statistically significant, but not large. The small difference in double flushing problems between low-consumption and non-low-consumption toilets underlines the fact that double flushing is a problem that is not confined to low-consumption toilets, but that some models of low-consumption toilet do require more double flushing than non-low-consumption toilets.

The survey respondents also reported problems with frequent double flushing. Thirty-eight percent of all rebate low-consumption toilets versus 16 percent of non-rebate, non-low-consumption toilets were reported to require frequent double flushing. This difference was also statistically significant. The rate of frequent clogging was also significantly higher in rebated low-consumption toilets (28% of toilets) than in non-rebate, non-low-consumption toilets (8% of toilets).

In the survey, homeowners were allowed to use their own standard to determine what was frequent double flushing. For interpreting the results from the data loggers, double flushing once per day or more was used to define frequent double flushing. The survey suggested a greater problem with double flushing than did the data loggers. This result indicates that many homeowners considered double flushing to be a problem even if it occurs less than once per day.

Also, at least 12.1 percent of households had recurring flapper leaks in their low-consumption rebate toilets. Flapper leaks were also identified in non-low-consumption toilets. It appears that flapper leaks occurred at a higher rate in low-consumption toilets compared to non-low-consumption toilets, but it was not possible to determine the exact amount of increase in the rate of flapper leaks in rebated low-consumption toilets than in non-low-consumption toilets because of difficulties in determining the source of some flapper leaks.

It appears that water savings projections used in planning by a utility over the expected 20-year life of these 1991-92 year low-consumption toilets would need to be adjusted downwards to accurately accommodate the increase in average flush volume due to the deterioration in their function over time. This adjustment should incorporate the 24 percent higher average flush volumes measured for low-consumption toilets, as well as the higher rate of recurring flapper leaks and slightly higher rate of frequent double flushing in these low-consumption toilets compared to non-low-consumption toilets. However, the combined effect of flapper leaks and frequent double flushing is smaller than the increase in average flush volume.

Overall ratings of the performance of low-consumption toilets purchased under the rebate program showed that their owners currently view their functioning positively. The average rating of low-consumption rebate toilets of 3.83 was above "neutral" (3) and just shy of "satisfied" (4). The rating for low-consumption rebate toilets was only slightly lower than the average rating given for all non-rebate toilets (3.92) and non-rebate, non-low-consumption toilets (3.93) and is similar to the overall rating of many of the same toilets when they were new as reported in the Los Angeles Department of Water and Power survey of rebate program participants in 1992 (overall rating 7.4 out of 10, or 3.7 out of 5).

Despite the ease with which early-close flappers can be replaced with standard flappers, it does not appear that early-close flappers were more likely than other flush valve mechanisms to produce high flush volumes or any other low-consumption toilet problem. Double flushing, high volume flush and flapper leaks in toilets with early-close flappers occurred at a slightly lower rate than for all types or models of toilet. The most common toilet in the study was the Wellworth Lite, which is the only toilet model in 10 or more households which uses an early-close flapper. The Wellworth Lite had the smallest percentage of households with toilets with a problem detectable through data logging (38.2%), as well as below average percentages of homes with frequent double flushing (12.5%), high flush volumes (23.2%) and flapper leaks (10.7%). The Wellworth Lite received an average satisfaction rating of 3.82, which was not statistically different from the mean rating for all rebate toilets.

Low-consumption toilets which use a standard flapper for the flush valve have been designed to a achieve a 1.6 gallon flush without using a toilet dam or an early-close flapper. Some problem with toilet function was found in 39.1 percent of homes with these toilets, which was slightly

worse than toilets with an early-close flapper, but below the average for all toilet types or models (42.9%). Toilets with a standard flapper had the highest rate of double flushing of any flush mechanism type, at 21.7 percent. These toilets had the lowest rate of flapper leaks (8.7%) and a slightly below average percentage of homes with high flush volumes (26.1%).

The Atlas is the most numerous of toilets with a standard flapper. This model had above average rates of double flushing (20.0%) and high flush volume (30.0%), and a below average rate of flapper leak (10.0%). The customer satisfaction rating for the functioning of the Atlas was slightly above the mean rating for all low-consumption toilets (3.87, 15 toilets).

Toilets with a toilet dam and a standard flapper performed worse, on average, than toilets with an early-close flapper or a standard flapper. Toilets with a toilet dam showed some problem with toilet function in 51.2 percent of homes, compared to 40 percent of homes with a toilet with an early-close flapper. Compared to other flush mechanism types, toilets with toilet dams had the second highest rate of double flushing (17.1%), the highest rate of flapper leaks (17.1%), and an average rate of homes with high flush volumes (26.8%).

However, there were large variations in the functioning of individual models of toilet with a toilet dam. The Lamosa Sahara had the highest percentage of homes with high flush volumes (60%), but had no homes with frequent double flushing. On the other hand, the Preserver had the highest percentage of homes with frequent double flushing (30.8 %) and an about average percentage of homes with high flush volume (23.1%). Both of these toilet models had higher than average rates of flapper leaks. Customer satisfaction ratings for these toilets were below the mean for all toilets (Lamosa Sahara 3.57, 7 toilets; Preserver 3.67, 6 toilets).

Toilets with the tube and bell flush mechanism were rated worst in overall function of all toilet mechanism types. Some toilet function problem was detected in 55.6 percent of homes with toilets with a tube and bell flush mechanism. Toilets with this mechanism had by far the greatest percentage of homes with high flush volume (44.4%).

The Allegro, which uses a proprietary tube and bell flush mechanism design, had the second highest percentage of homes with high flush volume (40%). It is possible that some homeowners have installed the 3.5 gallon design of this mechanism in their toilets when it was necessary to replace the old mechanism or have modified the 1.6 gallon mechanism. The Allegro had among the lowest customer satisfaction ratings (3.43, 7 toilets).

It appears that toilets with a pressurized flush technology perform best compared to toilets with other flush mechanism types. Pressurized toilets had the lowest percentage of homes with frequent double flushing (9.1%) and the lowest percentage of homes with high flush volumes (9.1%). Pressurized toilets also had the lowest percentage of homes with some low-consumption toilet function problem (35.7%). These results are reflected in the function of the Quantum, which had a small percentage of households with toilets with detectable problems (38.5%), and had the lowest percentage of households with high flush volumes (10%) or multiple flushes (10%). Good pressurized toilet performance also was reflected in the customer satisfaction ratings. All 14 rebate toilets with pressurized flush technology that were still in service were rated as very satisfactory (5).

The percentage of homes with pressurized toilets with some toilet function problem would have been lower, had not some of the pressurized toilets been removed for performance problems. Four Quantum pressurized toilets in 3 households had been removed due to bad performance or lack of available replacement parts. It appears from this limited sample that when pressurized toilets work well, residents are very happy with them, but when they do not perform correctly or need major repairs, residents can be dissatisfied enough to remove them.

Of survey respondents who knew whether or not their toilet had a flapper as the flush valve, 58 percent had replaced the flapper on their rebate toilets. Eighty-five percent of those replacing their flappers had done so by going to a hardware store to get a replacement flapper. The fact that such a high percentage of toilet owners get their flappers from a hardware store underlines the fact that the correct early-close flappers must be available at a hardware store in order for toilet owners to maintain the low-water-use design of their toilets. Production of a standardized early-close flapper that will work with all 1.6 gallon toilets may be necessary to allow hardware stores to efficiently supply the correct replacement flappers for low-water-use toilets.

Use of halogenating in-tank bowl cleaners also has been a factor in flapper performance and durability. The survey revealed that 24 percent of those who knew they had flappers as toilet flush valves used in-tank bowl cleaners. However, no attempt was made to distinguish between halogenating cleaners and non-halogenating cleaners. Tests conducted by MWD in 1994 and 1998 show that some toilet manufacturers are making their flappers more resistant to halogenating compounds. MWD's recommendations that a warning be included with new toilet packaging about use of halogenating bowl cleaners and a program be established to inform all homeowners about the possible effect of halogenating bowl cleaners on flappers seem appropriate, especially if the finding that a quarter of those with toilets with flappers use in-tank bowl cleaners holds for other communities besides Tucson.

RECOMMENDATIONS

- **The water industry should collectively press through the ASME standards process for toilet designs which are not alterable.** This means casting toilet dams as part of the tank if a toilet dam is used. This would also mean using tanks with low-consumption capacity that do not require an early-close flapper. Toilets with specialized flush mechanisms should be made so a 3.5 gallon per flush replacement mechanism will not fit into a toilet that was designed to flush 1.6 gallons.

- **The water industry should not offer rebates or direct install programs which include toilets with alterable designs or with specialized parts for which replacements may not be readily available later in the life of the toilet.**

- **We endorse MWD's recommendations that a warning be included with new toilet packaging about use of halogenating bowl cleaners and that a program be established to inform all homeowners about the possible effect of halogenating bowl cleaners.**

- **Attempts should be made to replicate this study and confirm its findings with other populations of aging low-consumption toilets.** One example of a much larger population of similar-age and model low-consumption toilets are those installed under Los Angeles Department of Water and Power's toilet rebate program.

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APPENDIX I. Mail Questionnaire.

How many bathrooms do you have?_____
How many toilets do you have? _____
Do you know how many of these toilets are 1.6 gallon per flush, water-saving toilets?_____ ☐ don't know
Do you know how many of these were purchased under the Tucson Water toilet rebate program?_____ ☐ don't know

Listed below are common problems found with toilets. We would like to know whether they apply to **any** of your toilets. We recognize that you may be fixing most of these as they occur, but we want to know if you think they are recurring or chronic problems. If you know the manufacturer of each of these toilets, please indicate the manufacturer in the space provided above the list of common problems for that toilet. (A stamp somewhere visible on the toilet often indicates the manufacturer).

Manufacturer _____	Manufacturer _____	Manufacturer _____	Manufacturer _____
Water Saver? ☐	Water Saver? ☐	Water Saver? ☐	Water Saver? ☐
Rebate Toilet? ☐	Rebate Toilet? ☐	Rebate Toilet? ☐	Rebate Toilet? ☐
Problems: (check any that apply)			
☐ Frequent double flush	☐ Frequent double flush	☐ Frequent double flush	☐ Frequent double flush
☐ Runs after flush then stops	☐ Runs after flush then stops	☐ Runs after flush then stops	☐ Runs after flush then stops
☐ Flushes or refills on its own periodically	☐ Flushes or refills on its own periodically	☐ Flushes or refills on its own periodically	☐ Flushes or refills on its own periodically
☐ Frequent plugging or overflow problems	☐ Frequent plugging or overflow problems	☐ Frequent plugging or overflow problems	☐ Frequent plugging or overflow problems
Please rate your satisfaction with the functioning of your each of your toilets: (check one)			
Very satisfied ☐	Very satisfied ☐	Very satisfied ☐	Very satisfied ☐
Satisfied ☐	Satisfied ☐	Satisfied ☐	Satisfied ☐
Neutral ☐	Neutral ☐	Neutral ☐	Neutral ☐
Dissatisfied ☐	Dissatisfied ☐	Dissatisfied ☐	Dissatisfied ☐
Very dissatisfied ☐	Very dissatisfied ☐	Very dissatisfied ☐	Very dissatisfied ☐

Do you have any other comments on functioning of any toilets in your home?

_____

_____

_____

Do any of your water-saving 1.6 gallon toilets have flappers? ☐ yes ☐ no ☐ don't know

If yes, have you replaced a flapper for any low-consumption toilet since you've had the toilet? ☐ yes ☐ no ☐ don't know

If yes, where did you buy the flapper? ☐ From hardware store or general home supply store ☐ Direct from manufacturer

☐ From specialty toilet supply store ☐ Other _____

Do you use in-tank bowl cleaners in your toilets? ☐ yes ☐ no ☐ don't know

Do you have a water treatment system? ☐ yes ☐ no ☐ don't know

If yes, what type of treatment device?

☐ Softener ☐ Whole house filtration unit ☐ Filtration unit under sink ☐ Other (please describe)_____

_____

How many showers do you have? _____

How many showers have water-conserving, low flow shower heads? _____ ☐ Don't know

How long have you lived at your present address? _____

Do you rent or own your home? ☐ own ☐ rent

How many adults permanently reside in your home? _____

How many children permanently reside in your home? _____

Thank you for completing the survey! All responses will be kept confidential.