# HIGH VOLUME FLUSH VS. LOW-FLUSH WATER CLOSETS AND SOLID WASTE TRANSPORT DISTANCE: A COMPARATIVE STUDY

A Thesis

by

MATTHEW DAVID REYES

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements of the degree of

MASTER OF SCIENCE

December 2004

Major Subject: Construction Management

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Approved as to style and content by:

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# ABSTRACT

High Volume Flush vs. Low-Flush Water Closets and Solid Waste Transport Distance:

A Comparative Study.

(December 2004)

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Chair of Advisory Committee: Dr. John Bryant

Upon the enactment by the United States Congress of the 1992 Energy Policy Act, it became mandatory that all water closets in residential and commercial settings reduce the volume of water that they consume per flush. In 1994, after installations began of the new low-flush or low-flow water closets that used less than half the water that their predecessors used, many owners of the new plumbing fixtures began to complain that their performance was sub par. Many complained about plumbing backups and of complete bowl clearance problems. There have been studies conducted to evaluate the new water closets' bowl evacuation properties. This study focuses on what happens to the solid waste that is flushed through the water closet after leaving the bowl, namely how far the solid media is transported down waste piping. The main focus of this study is to compare the performance of the low-flush, 1.6 gallons (6 liters) per flush water closets with the performance of the formerly standard flush 3.5 gallons (13 liters) per flush in regards to how far they transport solid waste through waste lines.

It was found that the media flushed through the high volume water closets traveled significantly farther that the media flushed through the low-flush water closets.

It was often more than double the average distance.  It was also found that media traveled farther down pipes composed of PVC than those composed of cast iron and also traveled farther down three inch pipes than four inch pipes.

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# INTRODUCTION AND BACKGROUND

In 1992, the Energy Policy Act was enacted by the U.S. Congress. This act was a massive piece of legislation and addressed several issues dealing with energy and resource conservation. Located in a subchapter of a subsection of a subtitle of Title I was what appeared to be an insignificant piece of legislation. In reality, it proved to be the bane of many involved in the plumbing industry. Inconspicuously located among the hundreds of other mandates was a brief explanation of how all water closets would be subject to a maximum consumption volume (102nd Congress, 1992).

Exactly how it is that such an apparently inconsequential subtopic has had such far-reaching impact is a bit complicated and requires knowledge of what the act required and of how exactly it affected the plumbing industry.

## *The Statute*

The Energy Policy Act of 1992, also referred to as the EPAct, addressed a very wide range of topics. It covered things such as building energy efficiency standards, alternative fuel incentive programs, electric motor vehicles, radioactive waste, renewable energy, oil pipeline regulatory reform, nuclear plant licensing, and even coal fired diesel engines. In the midst of all this technical jargon related to energy standards, there was one section important to plumbing. It is found in Title I, Subtitle C, Section 123. The section is labeled "Energy Conservation Requirements for Certain Lamps and Plumbing Fixtures" (102nd Congress, 1992).

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This thesis follows the style of the *Journal of Construction Education*.

Part of this section established standards for showerheads and faucets. The volume of water in gallons per minute that each is allowed to produce was reduced with the intention of promoting water conservation. The more controversial subsection is the one that dealt with water closets and the new restrictions it placed on them. The subsection in question states that "the maximum water use allowed in gallons per flush for any of the following water closets manufactured after January 1, 1994, is the following:

-Gravity tank-type toilets 1.6 gpf

-Flushometer tank toilets 1.6 gpf

-Electromechanical hydraulic toilets 1.6 gpf

-Blowout toilets 3.5 gpf" (102nd Congress, 1992, Title I, Subtitle C, Section 123)

The reasoning behind these new rules was to reduce water consumption and save energy. The theory is that it takes energy not only to treat water but also, subsequently, to pump it to consumers. Therefore, by cutting down on water usage, there is a reduction in the energy spent to treat it and to get it out to end users. Another driving force behind water conservation is that it saves on the number of treatment plants that are required. If less water is being used and hence less needs to be treated, then fewer plants will be required and the backlog of treatment plant expansions and upgrades can be reduced (Condon, 1998).

These new restrictions had some serious ramifications in the plumbing community. To put the new restrictions into perspective, it is important to understand the old industry standards. Gravity tank toilets (commonly found in residences), flushometer tank toilets (common in commercial restrooms), and electromechanical hydraulic toilets (also common in commercial settings) previously used 3.5 gallons (13 liters) per flush. This consumption was not a federal requirement because states previously placed their own restrictions on consumption. However, the 3.5 gallons per flush (gpf) had become an industry standard. At one time, blowout toilets (wall mounted toilets designed for heavy use) used eight gallons (30 liters) per flush (Conley, 1998). The act further goes on to say that all water closets being installed in residences must have met the new standards by January 1, 1994. Installations in commercial buildings were held to this new rule starting on January 1, 1997. Furthermore, it was made illegal to sell or install a non-compliant water closet after January 1, 1994.

The new standard enacted by the 102nd Congress was determined with little or no testing or research on various types and classes of water closets (George, 2001). The standard of 1.6 gallons (6 liters) per flush seemed to be arbitrary and the testing as to whether this new volume of water used was adequate to get the job done was lacking.

### *Industry and End User Reactions*

A significant problem with this Act of Congress was that, having been enacted in October of 1992 with the stipulation that the rule on water closets would take effect on January 1, 1994, the manufacturers of water closets had very little time to develop highly effective designs. This was particularly difficult because for years the way water closets were designed had not changed much and manufacturers were suddenly required to drastically redesign their product. Because the law not only applied to all water closets manufactured and installed after the first day of 1994, the development of a new design was even more urgent. Thus, the plumbing fixture manufacturers would have had less than one year to develop a new design, test it, refine the design, start production of the new fixtures, and have them ready to ship to suppliers. Many manufacturers simply tried to adapt their existing designs to meet the new standards. They implemented devices such as early close flappers and toilet dams to reduce the volume of water consumed per flush by, respectively, stopping the flow of water from the tank early and slowing the water's flow from the tank (Tobin, 2001). It is from this rushed design of new water closets and the tweaking of old designs that many problems arose.

It did not take long after New Year's Day of 1994 when the first round of 1.6 gpf water closets, which are also referred to as low-flow or low-flush toilets, were installed for users to begin complaining. The complaints were that residue was being left in the toilets, or that the bowl was not being cleared after flushing, or that the toilet was backing up. Many individuals were claiming that on most occasions they had to flush the toilet two or three times (Conley, 1998). It is not difficult to see that if a new low-flow toilet must be flushed twice then virtually all the water savings are gone and if it must be flushed a third time then it is actually consuming more water than the water closet that it replaced.

Many plumbers were reluctant to install the new, and supposedly underperforming, water closets in new residences. However, since installing water closets that did not comply with the new restrictions had been made illegal, few were willing to do so and risk hefty fines. Rumors began spreading about the development of a black market for the older high volume water closets and of homeowners taking it upon themselves to go to Canada or Mexico to acquire higher volume toilets that were still legal in our neighboring nations (Faloon, 2002). While it is illegal to sell a non-conforming water closet in the U. S., some Canadian plumbing supply retailers near the U. S. border have reported an increase in sales of the old models since the introduction of the new fixtures into American homes (Perman, 2000). This, along with the perception of underperforming water closets, began causing a handful of lawmakers some concern.

### *Legislative Reactions*

With their constituents complaining not only about having to deal with multiple flushing and backup problems but also concerned that it is not the place of the government to regulate how they use the restroom, a few congressmen responded accordingly to the complaints. One congressman in particular seemed to have a vendetta against the regulation. Not long after the passing of the EPAct, Representative Joe Knollenberg, R-Michigan, attempted to have it repealed by proposing House Resolution 623, also known as the Plumbing Standards Improvement Act, in February of 1999. The bill sought to rescind the section of the EPAct that dealt with low-flow water closets. Despite Knollenberg's claims that he had received complaints from thousands of constituents as to the performance of the new fixtures, the bill failed to be passed (United States House of Representatives, 1999).

In 2001, Representative Knollenberg tried to "get the federal government out of our bathroom" (Sticken, 2001) by introducing House Resolution 1479 in April of 2001. The bill made claims similar to his first proposal. His argument was that consumers' right to choose had been restricted and that many had reluctantly become lawbreakers by purchasing black market, high volume toilets (Sticken, 2001). He was able to garner slightly more support for his second attempt but the measure failed as well.

### *Some Support*

While the initial reaction to the regulation was less than enthusiastic by many, in the 10 years since its passing, it has found more proponents. Manufacturers have now had 12 years to refine or completely redo their designs. It was the first generation of toilets that performed at such a sub par level. A few years after the first production run of the low-flow water closets, an improved second generation was issued. Most of these worked better than the first generation models but still had problems. Recently, a third generation of low-flow toilets has hit the market and the improvements are significant. The newest toilets have thus far performed very well and left many customers quite satisfied (Conley, 1998).

Even some plumbing manufacturers are supportive of keeping the regulation the way it is now and are averse to repealing the law. This stems not only from a knowledge that the technology has improved and is able to perform adequately under the flow restrictions, but also out of concern for the environment. There is an understanding that low-flow toilets do indeed save water which in turn saves energy and helps prevent other problems especially in regions where there are water treatment or supply troubles (Sticken, 2001).

*Background Summary*

While the Energy Policy Act of 1992 covered a wide range of topics, one subsection caused a great deal of controversy. The initial lackluster reviews of the regulated water closets prompted many to call for a repeal of the law. However, since time has passed and technology has been given the opportunity to catch up with the regulations, many opinions have changed. Many have been able to look at the issue more objectively and are able to see the benefits that resulted and are therefore willing to give the regulation a chance to prove its worth (Conley, 1998). However, it is as yet undetermined whether the low-flow water closets do indeed perform as well as their predecessors. There have been many studies to date on water closet behavior in regards to bowl evacuation or clearance, either of which gives a good indication of how a fixture performs during and immediately after flushing. This type of study only tells part of the story and little is known about what happens to media after clearing the bowl.

One such study was conducted by the National Association of Home Builders Research Center in 1999. The intent of their study was to find the potential of different water closets to clog when media were flushed. The testing consisted of flushing a combination of sponges and paper balls through each water closet. A varying number of each was used and both sinking and floating media were modeled. The number of media remaining in the bowl of the water closet after each flush was recorded and a clog potential index was then calculated based on the observed data. Using this calculated index, a comparison of the water closet purchase price versus the clog potential was performed.

The results showed that there was indeed a difference in the performance of the water closets. Only one of the 3.5 gpf style water closets was used and it received the best clog potential score, meaning it was the least likely to leave media in the bowl and clog. The study also found that a relationship between purchase price and the performance of the water closet did not exist (NAHB Research Center, 1999).

An in depth study on solid waste transport distance has yet to be performed and it remains to be seen if there is a significant difference between the two classes of water closet with respect to waste transport. In some residential settings and in many commercial settings, the distance that waste must travel to get to main sewer lines may be substantial. If the waste is not taken far enough then it is possible for backups to occur and cause plumbing problems. The goal of this research is to determine whether the difference in the waste transport through 1.6 gpf and 3.5 gpf water closets is significantly different.

## PROBLEM STATEMENT

Considering the number of claims that the new low-flow water closets are inferior to the old models along with the fact that research data are inconclusive on the matter, a new comparative study needs to be performed. Since the EPAct took effect in 1994, studies on the hydraulic clearing efficiency of water closets have been plentiful. However, studies on what happens after the bowl has been cleared are sparse. Most studies deal only with the water closets themselves and do not address what is going on in the waste pipes or anything that occurs after the solid waste has been evacuated. This begs the question; is it possible that the plumbing backup problems that have been the subject of numerous anecdotal complaints are being caused downstream from the water closet?

Together with the volume of water expended per flush, it is likely that the type of pipe used also affects media transport distance. This is also a subject that has not been thoroughly researched. Therefore, an investigation into how different pipes affect media transport distance, a comparison of the performance of each type should be done.

## RESEARCH OBJECTIVE

The objective of this research is to measure the transport distance of solid waste through two classes of water closets, 1.6 gallons per flush (gpf) and 3.5 gpf, in pipes of differing size and composition. The data collected will be used to determine if there is a statistical difference between the two classes of water closet with regard to solid waste transport distance. The data will also be used to determine whether there is a statistical difference in transport distance from one type of pipe to another.

It is anticipated that experimentation will show that there is indeed a statistical difference between the performances of the two classes of water closet. Data will likely show that each human waste substitute, when flushed through a low-flow water closet, does not travel as far down the discharge pipe as when flushed through an old style water closet.

It is also expected that there will, in fact, be a statistical difference among the different types of pipe in regard to how solid media travel through them. Data will likely show that waste transport distances will be greater for the pipe composed of polyvinylchloride (PVC) than for the pipe composed of cast iron.

## EXPERIMENTAL SETUP AND METHODOLOGY

The goal of this research is to develop a relative comparison for the two classes of water closet. It is assumed that if the treatment is kept consistent across the two classes, then the comparison will be accurate regardless of how well the test media models human feces. However, there is a sense that if the test media doesn't closely model human feces then, although the results may compare the two water closets on some level, they would be of little interest. Therefore, a primary assumption is that the test media used will accurately simulate the behavior of human excrement as it travels through similar water closets and that reuse does not affect the media's performance or properties.

Other assumptions include that the type of waste pipe used, gallons per flush, and the water closet used are the only things that affect transport distance. Since some of the pipe being used must be altered for observation purposes, it is assumed that the altered pipe accurately simulates non-cut pipe as normally found in residential or commercial construction.

The scope of this study is limited to three water closets of each class. Only tank style water closets that are commonly found in residences are used. The discharge pipe is straight pipe with no turns. The pipe has only one fixture, the water closet being tested, attached to it along its entire length and has no other fixture branches. The pipe is set only at ⅛ inch per foot (1 cm per meter) slope and to achieve the goal of reusable media, only synthetic stool is used. Because the length of all water closet discharge pipes varies according to the building's end use and even the location within the building, an appropriate distance is uncertain. There are no code requirements regarding how far media must travel, so only a quantitative comparison of the two classes of water closet is done and no conclusion is made on whether one or both are performing adequately.

The 1.6 gpf water closets, each from a different manufacturer, were purchased from local vendors. The 3.5 gpf water closets were obtained from residences in which low-flow water closets were being installed.

The independent variables are the class of water closet, the type of pipe, and the actual gallons per flush that each water closet discharges. The dependent variable is the transport distance.

*Experimental Setup*

The laboratory consisted of an eight foot by eight foot (2.4 m x 2.4 m) platform that was ten feet (3.05 m) above finished floor upon which the water closet being tested rested (see Figures 1 and 2). Each pipe had its own flange for the water closet to sit on during use. The flange was connected to an 18 inch (460 mm) vertical section of pipe that was then connected to the horizontal section by a 90° coupling. Each pipe had its own vent stack that branched from this short vertical section. The discharge pipes were set at a 0.01° angle, or ⅛ inch per foot (1 cm per m) slope which is a standard in the industry.

*Figure 1*: Top of the Test Platform

*Figure 2*: Test Platform Viewed from Ground

The discharge pipes were made of polyvinyl chloride (PVC) and cast iron. There were two sizes of each pipe, one three inches (76 mm) in diameter the other four inches (102 mm) in diameter. The three inch PVC pipe was transparent and the transport measurements could be taken without altering the pipe. The other pipes were opaque and a slot had to be cut out of the top of each so that the media could be seen. The cut pipes were covered with clear plastic to simulate an uncut pipe (see Figure 3).

*Figure 3*: Pipes Viewed from Platform

*Figure 4*: Media Capture Tank, Reservoir, and Pump

Each discharge pipe, suspended from the ceiling by hangers spaced at four feet (1.2 m) on center, is 100 feet (30.5 m) long and emptied directly into a two foot by four foot (1.2 m x 0.6 m) media capture tank from which the media was retrieved after testing. Water drained from the media capture tank through a one inch (25 mm) diameter vinyl tube into a 50 gallon (189.3 L) capacity reservoir that was connected to a pressure pump set at approximately 30 pounds per square inch (200 kPa). The pressure pump maintained pressure on the supply line to simulate installed conditions. The water closet was connected to the ¾ inch (19 mm) PVC supply pipe with a valve similar to that which would be found in a residential restroom to further simulate real water closet installation conditions (see Figure 4). See Figures 5 and 6 for schematic diagrams of the experimental setup.

Each water closet had a measurement taken of its flush cycle using a GSE 550 digital scale that is precise to the nearest tenth of a gram to measure the mass of the water discharged by the water closet. The scale was connected to a data acquisition system that recorded measurements 10 times per second. Ten sets of data were gathered for each water closet. The averaged data were then graphed and the resulting flush curve graphs allowed analysis of each water closet's instantaneous flow rate and duration characteristics. These data were used to compare water closets with the same rated flow rate.

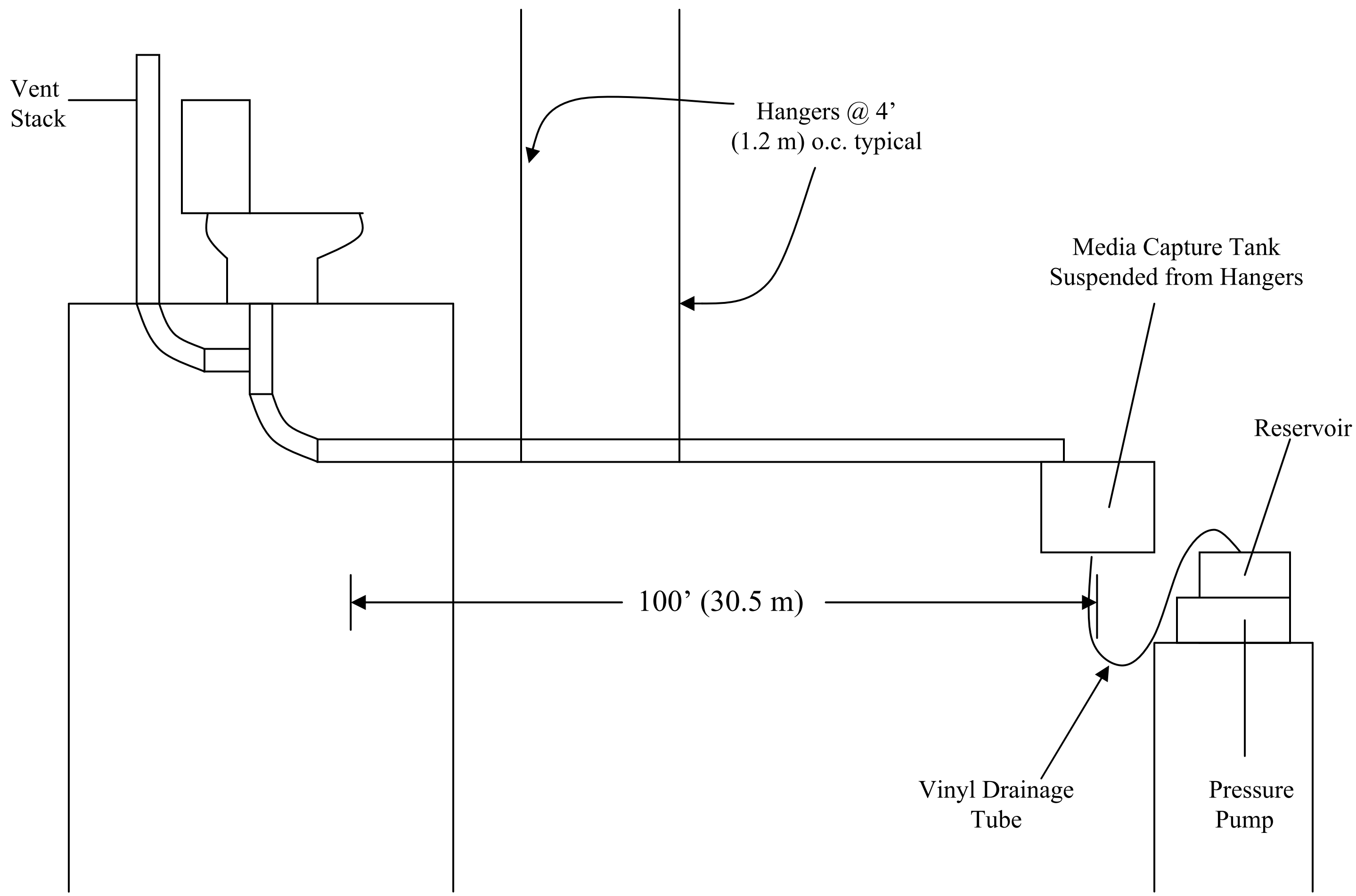



*Figure 5*: Experimental Setup Diagram - Section View

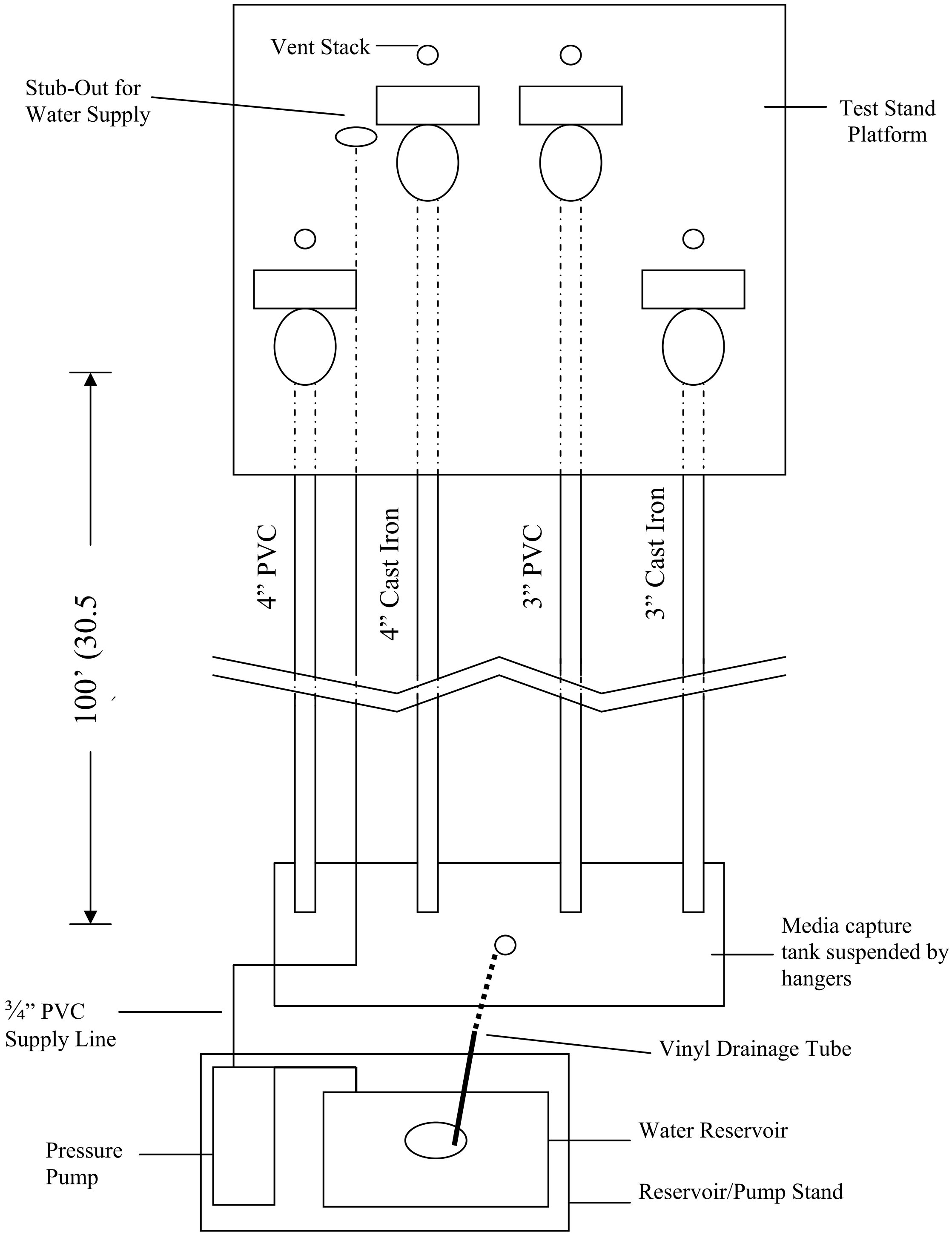



*Figure 6*: Experimental Setup – Plan View

The media transport distance measurement process consisted of five test cycles for each water closet on each pipe for a total of 20 test cycles for each water closet. Each test cycle consisted of seven flushes of the water closet being tested (see Appendix B for an example of the table used to record observed data) and used both wet flushes and load flushes. A wet flush is defined as a flush of the water closet when no media are put in the bowl and a load flush is a flush after media have been loaded into the bowl. The order of each cycle was as follows: one wet flush (zero flush); one load flush (first flush); two wet flushes (second and third flushes); one load flush (fourth flush); two wet flushes (fifth and sixth flushes). The cycle order is based on research conducted by Roy B. Hunter in the 1930's (Hunter, 1940). On each load flush, two pieces of media were flushed and the location center of mass is recorded.

Cylindrical media were used that have a mass of approximately 4.4 ounces (125 g) and a volume of 8.5 cubic inches (140 cc). They are approximately 4.75 inches (120 mm) long with a diameter of 1.5 inches (38 mm). The travel distance measurements were taken after each flush and there was a five minute interval between each flush. The media have a latex exterior and are filled with water giving them a size and density similar to that of human stool.

The transport distances were measured to the nearest hundredth of a foot (30mm) from the end of vertical discharge pipe (directly below the water closet) where it was connected by the 90° coupling to the horizontal discharge pipe to where the media come to rest in the pipe. The measurement was to the tip of the media closest to the water closet. After each use, the media were inspected for damage. Each media piece was used an equal number of times as a means to eliminate the individual media as a source of variation. Before loading media into the water closets, a plastic plate with a hole in the middle was placed over the bowl. The media were dropped through the hole into the bowl to ensure that the water closets were loaded in a consistent manner thus removing another source of variation (see Figure 7).

After several tests were carried out with each water closet, a descriptive analysis of the observed data was performed using the software program Statistical Processing for Social Sciences (SPSS) version 11.5 for Windows. Preliminary experimentation had shown that each piece of media behaves differently depending on when in the cycle it is flushed. Since two load flushes were done with each test cycle, the loads were treated independently. Five test cycles were performed on each water closet on each pipe for a total of 20 test cycles for each water closet and a total of 120 test cycles overall.

*Figure 7*: Water Closet Bowl with Plastic Plate and Media

Each water closet yielded two sets of data. Both sets come from the first load that is flushed. The sets of data are referred to as “first flush” and “last flush” throughout the data analysis. The first flush data is a measurement of the distance that the media traveled after being flushed once. Because two observations were used from each test cycle (each load is considered) for the first flush analyses, each water closet had 10 observations that make up the first flush means.

The last flush data were taken from the measurement of the resting position of the first media load that was flushed after a test cycle is complete. Because only one observation was used from each test cycle for the last flush analyses, each water closet had five observations that make up the individual means for the last flush data.

Both the first flush and last flush data are measurements of the same load but at different times during the test cycle. One is at the beginning and one is at the end. See Appendix A for a graphical representation of how the media behaved from flush to flush within a test cycle and how the location differs from the first flush to the last flush. The reasoning behind using two sets of data was to measure the initial performance of each water closet and also to measure what happens to a piece of media that has been in a pipe for a period of time and had more media behind it that may affect the way it continues down the pipe. This piece of media is represented by the first load that was flushed during each test cycle.

The data were tested using a one way analysis of variance (ANOVA). This method compares several means and evaluates whether there is a statistical difference among the means by measuring the variation of observations by comparing the sum of squares between (SSB) and the sum of squares within (SSW) the groups. The mean square (MSB and MSW, respectively) for each of these values is calculated by dividing by the degrees of freedom for each. When MSB is divided by MSW, the result is the F-statistic for the observations being tested. This F-statistic is then compared against the F-distribution to find the level of evidence that there is against the null hypothesis. The null hypothesis in this case is that all the water closets being compared are equal and that the true means of the transport distance associated with the individual water closets is in fact the same and that any differences observed are merely due to sampling variation. The alternative hypothesis is that there is indeed a difference between the types of water closets and that the means are not equal. The larger the F-statistic is, the more evidence there is against the null hypothesis.

A confidence level of 95% is used for this and therefore the significance level, $\alpha$, of the test is 0.05. The significance level is the proportion of time that a test of this kind will reject a null hypothesis is true.

When an ANOVA is run on multiple means, it is often the case that while not all the means are the same, they are at the same time not all different but rather form groups of indistinguishable means. The test places these means into homogeneous subsets. If two or more means are indistinguishable then, statistically speaking, it is possible that they came from the same population mean and therefore are not considered to be different (see Appendices I and J for a list of the generated homogeneous subsets) . In the case of comparing water closets' transport distance performance, two indistinguishable water closets would mean that there is no statistical difference between the performance of the two and they can be considered to have equivalent performance.

The same statistical analysis was done when comparing the different pipes. However, the data were grouped differently. For each pipe, two different means were calculated. One mean is from the observations for all the 1.6 gpf water closets on that particular pipe. The other mean is from the observations from the 3.5 gpf water closets. The two classes were divided in this manner to reduce variation and also to determine if the pipes behave differently relative to one another depending upon the class of water closet. The pipes were analyzed using first flush and last flush sets of data as with the water closet comparison. Since the water closets were grouped together in the pipe analyses, the number of observations for each pipe was larger. The first flush analyses had 30 observations and the last flush analyses had 15 observations.

The results of this study will give insight into the problem of the new standard versus the previously standard water closets. They will show whether or not there is indeed a difference in the way that solid media behaves after being flushed through the two classes of water closet. If the findings are as hypothesized then the desire to do further research on the performance of the low-flow water closet performance will be validated. Such research is necessary since there is a debate over how well the new water closets are performing as compared to the old ones. Further research could possibly convince lawmakers to look into revising the law that was passed more than a decade ago. Local authorities may find it necessary to write codes requiring water closets to meet certain transport distance specifications.

## RESULTS: WATER CLOSET COMPARISON

There were a total of six water closets compared during experimentation. Three of them were from the 1.6 gpf (6 liters per flush) class and three from the 3.5 gpf (13 lpf) class. The low-flow water closets used are referred to as WC-A, WC-B, and WC-C throughout the discussion. The high volume flush water closets are referred to as WC-D, WC-E, and WC-F throughout. As mentioned before, the labels 1.6 gpf (6 lpf) and 3.5 gpf (13 lpf) are nominal in nature and do not indicate the actual volume of water that the respective water closets consume but rather refer to the required or industry standard volumes. The actual volume of water consumed per flush is indicated by the flush curve data.

### *Water Closet Characteristics*

From the flush curve data, a few main characteristics can be compared among the water closets. The volume of water consumed is simply a measure of the amount of water expended per flush and can be found from the cumulative amount of water that was weighed during testing (see Figures 8 and 9).

Among the low-flow water closets, WC-A had the highest volume discharged at 1.60 gallons per flush (6.1 lpf). Water closet WC-B discharged 1.48 gpf (5.6 lpf) and WC-C had the lowest discharge at 1.26 gpf (4.8 lpf).

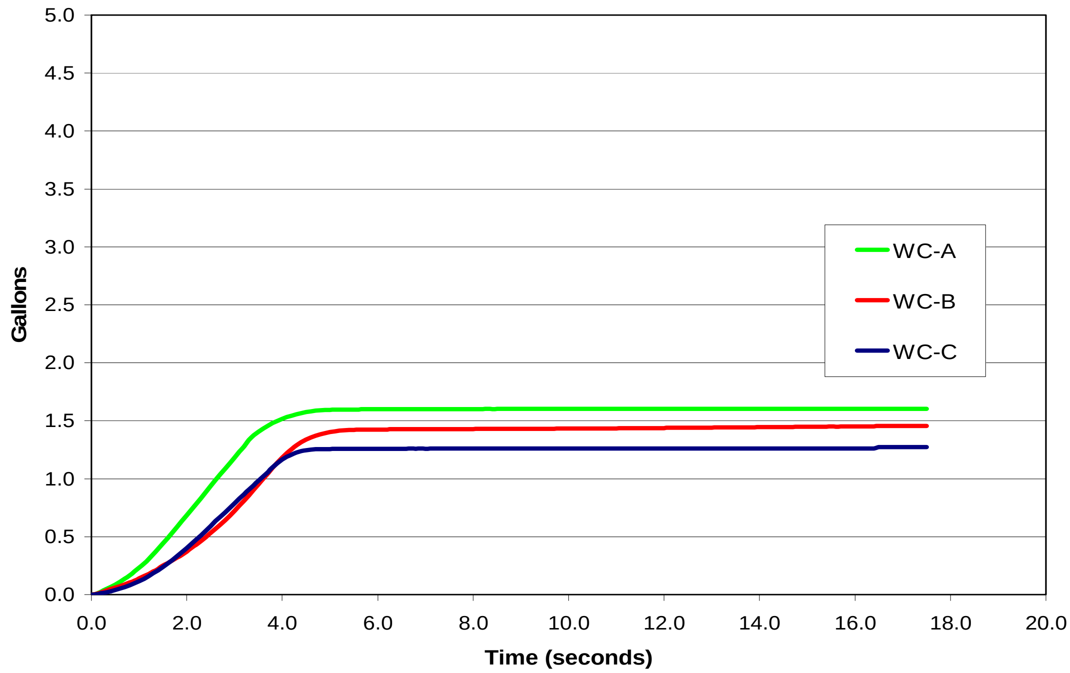



*Figure 8*: Cumulative Gallons of Water Discharged – 1.6 gpf Water Closets

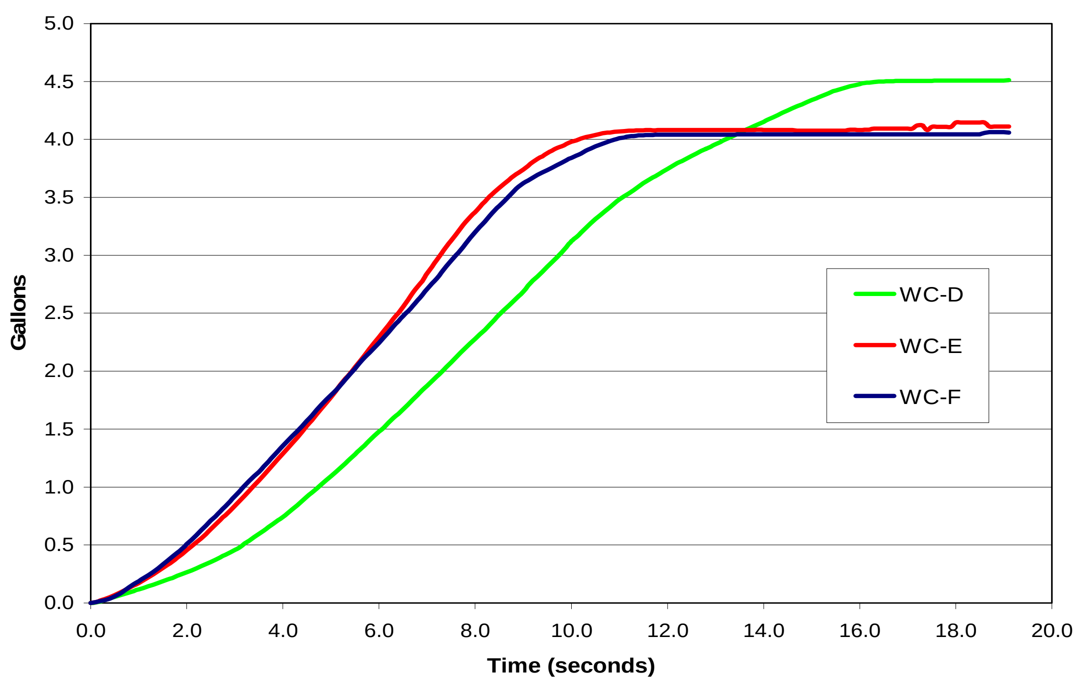



*Figure 9*: Cumulative Gallons of Water Discharged – 3.5 gpf Water Closets

Among the high volume flush water closets, WC-D discharged the most water at 4.51 gallons per flush (17.1 liters per flush). Water closet WC-E discharged 4.11 gpf (15.6 lpf) and WC-F had the lowest discharge at 4.06 gpf (15.4 lpf).

Instantaneous flow rate measurements were also generated from these data by taking the derivative of the curve that plots the cumulative gallons of water versus time which yields gallons per minute versus time (see Figures 10 and 11). These data reveal how quickly water is evacuated from the water closet and it also indicates the flush duration. To smooth the curves the data were plotted as a 10 point moving averages where each point is an average of the previous 10 data points. Points at which the graph drops below zero gallons per minute are due only to measurement error.

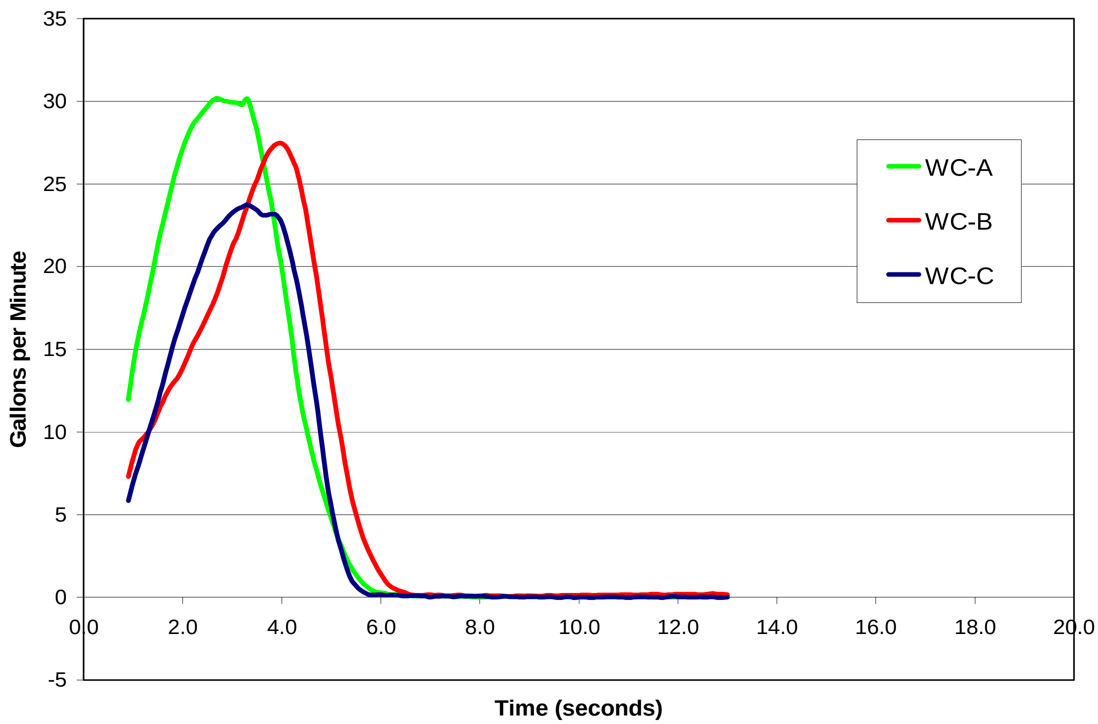



*Figure 10*: Instantaneous Flow Rate – 1.6 gpf Water Closets

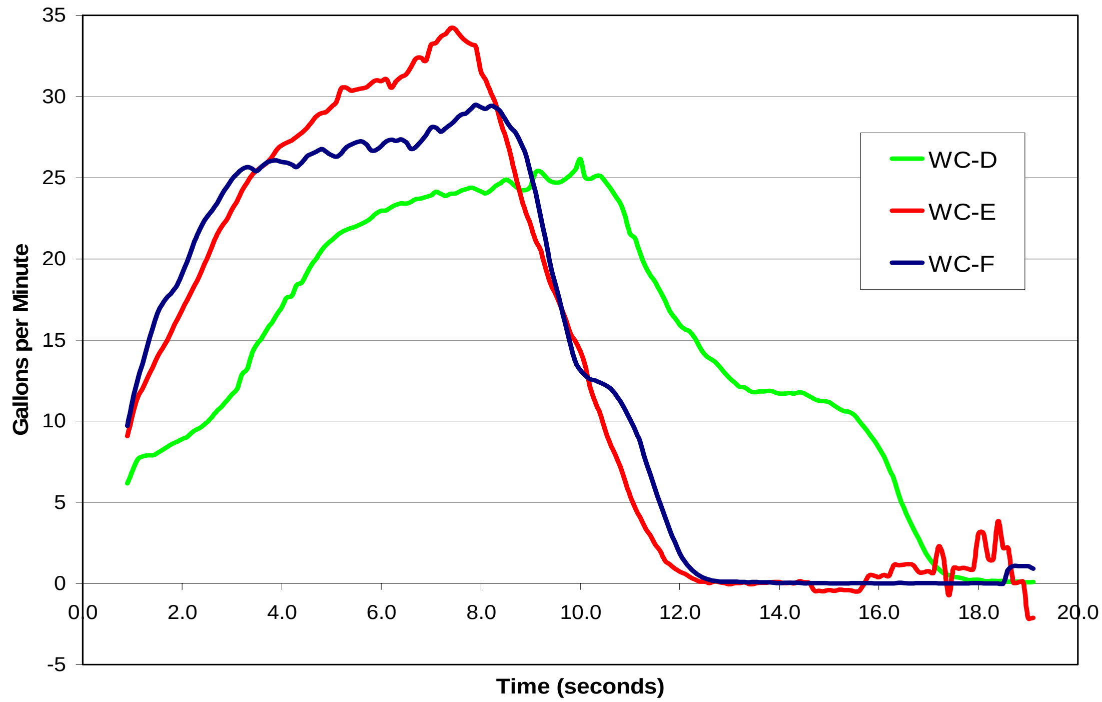



*Figure 11*: Instantaneous Flow Rate – 3.5 gpf Water Closets

Data from the instantaneous flow rates was also compared. Among the low-flow group, WC-A peaked first at around three seconds into the flush. Then at around 3.5 seconds WC-C peaked and is followed by WC-B at four seconds into the flush. The flush durations of WC-A and WC-C were slightly shorter than six seconds and WC-B had a duration of 6.5 seconds. Among the high volume flush group, WC-E peaked first at around 7.5 seconds. It was followed by WC-F at 8.5 seconds and then by WC-D at 10 seconds. The flush duration of WC-E and WC-F was 12.5 seconds while WC-D had a duration of 18 seconds.

There is no apparent correlation between a water closet's total flush volume and flow rate peak nor is there any apparent relationship between volume and flush duration.

The three factors are independent of one another and it is believed that flow rate peak and flush duration are merely functions of the design of the water closet.

*Performance Comparison: First Flush*

Observations recorded as first flush data were grouped by water closet and then by pipe. A separate ANOVA was conducted for each pipe, comparing the sample means for each water closet on that particular pipe. The results for each pipe are as follows (for SPSS descriptive statistics on the water closets' performance see Appendix E and for full SPSS multiple comparison ANOVA output see Appendix G).

*3" Cast Iron*

It was observed that the high volume water closets are the three with the farthest transport distance on the three inch (76 mm) cast iron pipe. The high volume water closets had an average transport distance that was 132% farther than the low-flush water closets. (see Table 1 for overall results and Appendix C for individual flush data tables).

Table 1

*Water Closet Comparison Data: First Flush on 3" CI*

| **Water Closet** | **Class (gpf)** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** | **Mean Transport Distance for Class (ft.)** |
|---|---|---|---|---|---|
| WC-A | 1.6 | 10 | 17 | 3.62 | 19 |
| WC-C | 1.6 | 10 | 17 | 1.61 | |
| WC-B | 1.6 | 10 | 22 | 6.29 | |
| WC-E | 3.5 | 10 | 40 | 8.50 | 44 |
| WC-D | 3.5 | 10 | 45 | 5.11 | |
| WC-F | 3.5 | 10 | 48 | 6.93 | |

*3" PVC*

It was observed that the three high volume water closets had the farthest transport distance and for an average distance of 109% farther than the low-flush group (see Table 2 for overall results and Appendix C for individual flush data tables).

Table 2

*Water Closet Comparison Data: First Flush on 3" PVC*

| **Water Closet** | **Class (gpf)** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** | **Mean Transport Distance for Class (ft.)** |
|---|---|---|---|---|---|
| WC-B | 1.6 | 10 | 39 | 10.90 | 45 |
| WC-C | 1.6 | 10 | 46 | 9.57 | |
| WC-A | 1.6 | 10 | 49 | 14.13 | |
| WC-E | 3.5 | 10 | 90 | 14.70 | 94 |
| WC-D | 3.5 | 10 | 93 | 9.41 | |
| WC-F | 3.5 | 10 | 98 | 4.95 | |

*4" Cast Iron*

The transport distances for the four inch (102 mm) cast iron pipe, while shorter than for the other pipes, were farther for the high volume water closets. The high volume water closets had an average 93% longer distance than the low-flush group (see Table 3 for overall results and Appendix C for individual flush data tables).

Table 3

*Water Closet Comparison Data: First Flush on 4" CI*

| **Water Closet** | **Class (gpf)** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** | **Mean Transport Distance for Class (ft.)** |
|---|---|---|---|---|---|
| WC-A | 1.6 | 10 | 13 | 2.79 | 14 |
| WC-C | 1.6 | 10 | 13 | 1.52 | |
| WC-B | 1.6 | 10 | 16 | 3.11 | |
| WC-D | 3.5 | 10 | 24 | 4.70 | 27 |
| WC-E | 3.5 | 10 | 27 | 5.42 | |
| WC-F | 3.5 | 10 | 28 | 2.83 | |

*4” PVC*

It was observed that the transport distances for the four inch (102 mm) pipe, were greater for the high volume water closets.  The average distance for the high volume group was 74% farther than the low-flush group (see Table 4 for overall results and Appendix C for individual flush data tables).

Table 4

*Water Closet Comparison Data: First Flush on 4” PVC*

| **Water Closet** | **Class (gpf)** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** | **Mean Transport Distance for Class (ft.)** |
|---|---|---|---|---|---|
| WC-C | 1.6 | 10 | 16 | 2.63 | 19 |
| WC-A | 1.6 | 10 | 18 | 3.99 | |
| WC-B | 1.6 | 10 | 24 | 2.64 | |
| WC-F | 3.5 | 10 | 32 | 4.41 | 33 |
| WC-E | 3.5 | 10 | 32 | 4.05 | |
| WC-D | 3.5 | 10 | 35 | 4.23 | |

*Performance Comparison: Last Flush*

Observations recorded as last flush data were grouped in the same manner as those recorded as first flush data and the multiple comparison ANOVA analysis was the same. The results for each pipe are as follows (for full SPSS output see Appendix H).

*3" Cast Iron*

It was observed that the high volume water closets were the three with the farthest transport distance on the three inch (76 mm) cast iron pipe. The high volume water closets had an average transport distance that was 168% farther than the low-flush water closets (see Table 5 for overall results and Appendix C for individual flush data tables).

Table 5

*Water Closet Comparison Data: Last Flush on 3" CI*

| **Water Closet** | **Class (gpf)** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** | **Mean Transport Distance for Class (ft.)** |
|---|---|---|---|---|---|
| WC-C | 1.6 | 5 | 27 | 0.93 | 31 |
| WC-A | 1.6 | 5 | 34 | 4.10 | |
| WC-B | 1.6 | 5 | 32 | 6.23 | |
| WC-F | 3.5 | 5 | 79 | 8.49 | 83 |
| WC-D | 3.5 | 5 | 85 | 7.17 | |
| WC-E | 3.5 | 5 | 86 | 8.45 | |

*3" PVC*

It was observed that the three high volume water closets had the farthest transport distance and for an average distance of 89% farther than the low-flush group (see Table 6 for overall results and Appendix C for individual flush data tables).

Table 6

*Water Closet Comparison Data: Last Flush on 3" PVC*

| **Water Closet** | **Class (gpf)** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** | **Mean Transport Distance for Class (ft.)** |
|---|---|---|---|---|---|
| WC-B | 1.6 | 5 | 47 | 15.37 | 53 |
| WC-C | 1.6 | 5 | 52 | 3.15 | |
| WC-A | 1.6 | 5 | 60 | 11.85 | |
| WC-F | 3.5 | 5 | 100 | 0 | 100 |
| WC-D | 3.5 | 5 | 100 | 0 | |
| WC-E | 3.5 | 5 | 100 | 0 | |

*4" Cast Iron*

The transport distances for the four inch (102 mm) cast iron pipe were farther for the high volume water closets. The high volume water closets had an average 145% longer distance than the low-flush group (see Table 7 for overall results and Appendix C for individual flush data tables).

Table 7

*Water Closet Comparison Data: Last Flush on 4" CI*

| **Water Closet** | **Class (gpf)** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** | **Mean Transport Distance for Class (ft.)** |
|---|---|---|---|---|---|
| WC-C | 1.6 | 5 | 21 | 1.25 | 22 |
| WC-B | 1.6 | 5 | 22 | 2.49 | |
| WC-A | 1.6 | 5 | 24 | 1.61 | |
| WC-D | 3.5 | 5 | 51 | 9.13 | 54 |
| WC-F | 3.5 | 5 | 54 | 11.92 | |
| WC-E | 3.5 | 5 | 58 | 15.50 | |

*4” PVC*

It was observed that the transport distances for the four inch (102 mm) pipe, were greater for the high volume water closets. The average distance for the high volume group was 180% farther than the low-flush group (see Table 8 for overall results and Appendix C for individual flush data tables).

Table 8

*Water Closet Comparison Data: Last Flush on 4” PVC*

<table>
<tr><th>Water Closet</th><th>Class (gpf)</th><th>Number of Flushes</th><th>Mean Transport Distance (ft.)</th><th>Standard Deviation</th><th>Mean Transport Distance for Class (ft.)</th></tr>
<tr><td>WC-C</td><td>1.6</td><td>5</td><td>27</td><td>1.12</td><td rowspan="3">30</td></tr>
<tr><td>WC-A</td><td>1.6</td><td>5</td><td>32</td><td>1.49</td></tr>
<tr><td>WC-B</td><td>1.6</td><td>5</td><td>33</td><td>4.07</td></tr>
<tr><td>WC-F</td><td>3.5</td><td>5</td><td>70</td><td>5.11</td><td rowspan="3">84</td></tr>
<tr><td>WC-E</td><td>3.5</td><td>5</td><td>87</td><td>7370</td></tr>
<tr><td>WC-D</td><td>3.5</td><td>5</td><td>94</td><td>6.00</td></tr>
</table>

## RESULTS: PIPE COMPARISONS

There were a total of four pipes compared during experimentation. Two of them were composed of cast iron (CI) and the other two were composed of polyvinylchloride (PVC). One pipe of three inches in diameter (76 mm) and another of three inches (102 mm) in diameter were used for each pipe composition type. Throughout the discussion the pipes are referred to as 3” CI, 3” PVC, 4” CI, and 4” PVC.

As discussed previously, the data that were measured were grouped into two different categories for each pipe. One category is for the 1.6 gpf (6 lpf) water closets and the other is for the 3.5 gpf (13 lpf) water closets. As with the water closet comparison, a comparison of the four pipes against one another is done using both first flush and last flush data (for full SPSS multiple comparison ANOVA output see Appendices K and L).

### *Performance Comparison: First Flush*

#### *1.6 gpf Water Closets*

For the low-flush group of water closets, the three inch (76 mm) PVC pipe had the farthest average transport distance and the four inch (102 mm) cast iron pipe had the shortest. The three inch (76 mm) cast iron and four inch (102 mm) PVC pipes were in the middle and were found to be statistically similar (see Table 9 for overall results and Appendix D for individual flush data tables).

Table 9

*Pipe Comparison Data: First Flush on 1.6 gpf Water Closets*

| Pipe Size(in.) | Pipe Composition | Number of Flushes | Mean Transport Distance (ft.) | Standard Deviation |
|---|---|---|---|---|
| 4 | Cast Iron | 30 | 14 | 2.81 |
| 3 | Cast Iron | 30 | 21 | 5.25 |
| 4 | PVC | 30 | 19 | 4.65 |
| 3 | PVC | 30 | 45 | 12.03 |

*3.5 gpf Water Closets*

For the high volume water closets, all of the pipes were found to be statistically different. The order of the pipes from shortest mean transport distance to farthest was: four inch (102 mm) cast iron, four inch (102 mm) PVC, three inch (76 mm) cast iron, and three inch (76 mm) PVC (see Table 10 for overall results and Appendix D for individual flush data tables).

Table 10

*Pipe Comparison Data: First Flush on 3.5 gpf Water Closets*

| Pipe Size(in.) | Pipe Composition | Number of Flushes | Mean Transport Distance (ft.) | Standard Deviation |
|---|---|---|---|---|
| 4 | Cast Iron | 30 | 27 | 4.68 |
| 4 | PVC | 30 | 33 | 3.99 |
| 3 | Cast Iron | 30 | 46 | 5.79 |
| 3 | PVC | 30 | 94 | 10.72 |

*Performance Comparison: Last Flush*

*1.6 gpf Water Closets*

For the low-flush group of water closets, the three inch (76 mm) PVC pipe had the farthest average transport distance and the four inch (102 mm) cast iron pipe had the shortest. The three inch (76 mm) cast iron and four inch (102 mm) PVC pipes were in the middle and were found to be statistically similar (see Table 11 for overall results and Appendix D for individual flush data tables).

Table 11

*Pipe Comparison Data: Last Flush on 1.6 gpf Water Closets*

| **Pipe Size(in.)** | **Pipe Composition** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** |
|---|---|---|---|---|
| 4 | Cast Iron | 15 | 22 | 2.09 |
| 4 | PVC | 15 | 30 | 3.72 |
| 3 | Cast Iron | 15 | 31 | 4.95 |
| 3 | PVC | 15 | 53.10 | 11.94 |

*3.5 gpf Water Closets*

For the high volume flush group of water closets, the three inch (76 mm) PVC pipe had the farthest mean transport distance and the four inch (102 mm) cast iron pipe had the shortest. The three inch (76 mm) cast iron and four inch (102 mm) PVC pipes were in the middle and were found to be statistically similar transport distances (see Table 12 for overall results and Appendix D for individual flush data tables).

Table 12

*Pipe Comparison Data: Last Flush on 3.5 gpf Water Closets*

| **Pipe Size(in.)** | **Pipe Composition** | **Number of Flushes** | **Mean Transport Distance (ft.)** | **Standard Deviation** |
|---|---|---|---|---|
| 4 | Cast Iron | 15 | 54 | 11.92 |
| 3 | Cast Iron | 15 | 83 | 8.13 |
| 4 | PVC | 15 | 84 | 11.93 |
| 3 | PVC | 15 | 100 | 0 |

## RESULTS ANALYSIS

The results from the statistical analyses clearly showed a difference in the two classes of water closets when the independent variable was the water closet. There was also a difference found in the performance of the different pipes when pipe type was treated as an independent variable.

### *Water Closet Analysis*

The analysis of the water closets was broken down into two separate parts: first flush and last flush. The first flush data give an indication of the water closets' performance after a single usage. The last flush data indicate the water closets' long term waste clearance performance in which the media have been in the pipes for a period of time. If a water closet performs relatively better on one analysis than on the other than this would indicate that some water closet characteristics are more conducive to either instant or long term performance when considering media transport distance. A similarity in relative performance across the two analyses would suggest that the water closet characteristics that lead to a certain level of short term performance also lead to the same level of long term performance in regards to media transport.

#### *First Flush Analysis*

Upon reviewing the SPSS output, the primary observation made was that in no instance were all of the water closets found to have transport distances that were statistically similar. It was also the case that a 1.6 gpf (6 lpf) water closet was never statistically similar to a 3.5 gpf (13 lpf) water closet. This means that in every instance of first flush analysis, each 3.5 gpf (13 lpf) water closet was found to have a mean transport distance statistically greater than each of the 1.6 gpf (6 lpf) water closets. Therefore, the data show that the 3.5 gpf (13 lpf) water closets transport media farther down waste pipes than do the 1.6 gpf (6 lpf) water closets after the initial flush.

*Last Flush Analysis*

The SPSS output for the last flush data revealed similar results as it did for the first flush data. In no instance were a 1.6 gpf (6 lpf) and 3.5 gpf (13 lpf) water found to have statistically similar means. The data, therefore, show that the 3.5 gpf (13 lpf) water closets provide farther transport distance even for media that has been in waste pipes for a period of time.

## *Pipe Analysis*

The analysis of the four different types of pipe is broken down into two categories as was the water closet analysis. The first flush analysis describes about how the media behave in the pipes when they enter the pipe simultaneously with a volume of water. The last flush data indicates the behavior of the media when they are moved from rest by an oncoming volume of water.

*First Flush Analysis*

The statistical output for the first flush data revealed that the mean transport distance for all of the pipes is not the same. The four inch (102 mm) cast iron pipe had the shortest distance for both water closet classes and the three inch (76 mm) PVC had the highest for both. The three inch cast iron and four inch PVC pipes were in the middle both times and three out of four times were found to be statistically similar. These results suggest that when the media enter the pipe along with the water, the best performer is the three inch (76 mm) PVC pipe and the poorest performer is the four inch (102 mm) cast iron pipe regardless of water closet class.

*Last Flush Analysis*

The statistical output for the last flush data produced matching results for both the 1.6 gpf (6 lpf) and 3.5 gpf (13 lpf) water closet groups. The four inch (102 mm) cast iron pipe was the poorest performer and the three inch (76 mm) PVC pipe was the best performer in both groups. In both examples, the three inch cast iron and the four inch (102 mm) PVC pipes were found to have statistically indistinguishable means. These results indicate that media behave similarly in all four pipes relative to one another in instances when the media enters the pipe with the water and when it is moved from rest.

# CONCLUSIONS

## *Water Closet Analysis Conclusions*

It was shown with a high level of significance that the transport distance produced by the 1.6 gpf (6 lpf) and 3.5 gpf (13 lpf) water closets is statistically different on all pipes tested and for both the first flush and last flush data. Hence, it is concluded that the previously standard, high volume flush water closets that consume 3.5 gallons (13 liters) of water per flush or more do indeed transport solid waste media farther down waste pipes than do the new standard low-flow water closets that consume no more than 1.6 gallons (6 liters) per flush.

It is, therefore, a possibility that the anecdotal complaints that water closet owners have lodged about plumbing backups are the result of inferior pipe clearance. Although the bowl clearance properties of water closets may also play a role in backups, the goal of this study was not to make conclusions about the hydraulic clearing properties of water closets.

When comparing water closets with others in the same class it is difficult to draw conclusions as to the role of different flush characteristics in media transport. The water closets of the same class were, for the most part, found to be statistically similar and, therefore, the mean transport distance resulting from different water closets in the same class is indistinguishable. Because the water closets within each class used in this study are indistinguishable from one another, it is not possible to relate transport distance with the water closet's flush characteristics. The effects of flush characteristics cannot be determined by comparing different water closet classes because there is the additional variable of water volume that may be the sole variable that affects media transport. It is concluded then that the water closets' flush characteristics of flush duration and instantaneous flow rate observed in this study had no impact on the resulting media transport distance.

### *Pipe Analysis Conclusions*

The results of the statistical analyses showed that there is indeed a difference in media transport distance depending on what type of pipe is used. It was observed that the three inch (76 mm) PVC pipe consistently yielded the farthest distances and that the four inch (102 mm) cast iron pipe consistently yielded the shortest distances.

It was found that the three inch (76 mm) cast iron and four inch (102 mm) PVC pipes were usually statistically similar and so it is concluded that there is no difference in the effect of the two on media transport distance. The reason for this is that the advantage of the smaller diameter pipe and the advantage of the PVC over cast iron cancel each other out for these two pipes. The PVC is advantageous because it is smoother on the inside and provides much less friction than the cast iron. The smaller pipe is advantageous because, for a given volumetric rate (gallons per flush in this case), the velocity increases as the cross-sectional area decreases. With a higher discharged water velocity the transport distance increases.

The final conclusions in regards to the pipe analyses is that pipe composed of PVC yields farther media transport distances than does pipe composed of cast iron. It is also concluded that pipe that is three inches (76 mm) in diameter yields farther transport distances than pipe that is four inches (102 mm) in diameter.

## RECOMMENDATIONS FOR FURTHER RESEARCH

It is recommended that subsequent research look into the effects of water closet flush characteristics by comparing a sample of low-flow water closet groups with distinct instantaneous flow rate properties. The water closets could be adjusted so that they are all discharging the same volume of water. The variable of total water volume discharged would be eliminated leaving only the flow rate properties to be compared. It could then be determined if there exists a correlation between a water closet's flush characteristics and the resulting media transport distance. The results could provide insight into ways to optimize water closet characteristics to produce ideal transport distance results.

It is also recommended that research be done on the newest generation of the low-flow water closets. Design changes have been made that may affect their performance. Water closets other than the gravity flush style such as flush valve and pressure assisted flush should also be studied.

## REFERENCES


102nd Congress. (1992, October 24). *Energy Policy Act of 1992* (Public Law 102486). Washington, D.C: US Government Printing Office.

Condon, T. (1998, February). Taking the Plunge: An FM's Account of Low Flush Toilets. *Today's Facility Manager*. [WWW document] URL http://www.facilitycity.com/tfm/tfm_98_02_cover1.asp.

Conley, K. D. (1998, February). Low Flush Solutions. *Today's Facility Manager*. [WWW document] URL http://www.facilitycity.com/tfm/tfm_98_02_cover1.asp.

Faloon, K. (2002, July 3). Water Conservation: The Great Toilet Debate. *Plumbing & Mechanical Magazine*. [WWW document] URL http://www.pmmag.com/pm/cda/articleinformation/features/bnp__features__item/0,,80242,00+en-uss_01dbc.html.

George, R. L. (2001, June). The History of Plumbing: Part 4 – modern plumbing enhances the American way of life. *Plumbing Engineer*. [WWW document] URL http://www.plumbingengineer.com/pdf/pe/articles/0601PE48.pdf.

Hunter, R. B. (1940). Methods of Estimating Loads in Plumbing Systems. *Building Materials and Structures BMS65*. National Bureau of Standards, Washington, D.C.

NAHB Research Center. (1999, June). Water Closet Survey: June 1999. [WWW document] URL http://www.nahbrc.org/tertiaryR.asp?TrackID=&DocumentID=3034&CategoryID=16.

Perman, S. (2000, April 3). Psst! Wanna Buy an Illegal Toilet? *Time*, 155, 6.

Sticken, E. (2001, April 11). Knollenberg Resurrects Bill to Amend Federal Low-Flow Toilet Law. *Plumbing & Mechanical Magazine*. [WWW document] URL http://www.pmmag.com/pm/cda/articleinformation/features/bnp__features__item/0,,24910,00+en-uss_01dbc.html.

Tobin, M. (2001, March/April). The Low Flow's False Flush. *E Magazine: The Environmental Magazine*, 12, 15-16.

United States House of Representatives. (1999, February 8). *H.R. 623 The Plumbing Standards Improvement Act*. [WWW document] URL from http://www.house.gov/knollenberg/legresource/plumbing/extremark.htm.

*Supplemental Sources Consulted*

Blake, K. (2000, May). Dateline Washington. *Consumers' Research Magazine*, 83, 6.

Gorman, C. (1996, July 1). Toilet Wars. *Time*, 148, 59.

Heavens, A. (2002, August 8). *Tackling Low Flow Woes.* [WWW document] URL http://realtytimes.com/rtnews/rtcpages/20020808_lowflow.htm

Lieberman, B. (1998, August 8). Low-flow revolt: Congress Looks at Repealing New Toilet Standard. *The Chicago Tribune*, p. 21.

Lieberman, B. (1998, October). Potty politics. *Washington Monthly*. 39, 30-31.

Lieberman, B. (1999, October). Let Consumers Choose Their Own Toilets. *Consumers' Research Magazine*, 82, 17-20.

Meyer. B. D. (1999, September). ASPERF Challenges Water-Closet Testing. *Consulting-Specifying Engineer*, 26, 90.

Rospond, K. M. (1998, October). Low-flow plumbing: all washed up? *Consulting-Specifying Engineer*, 24, 110.

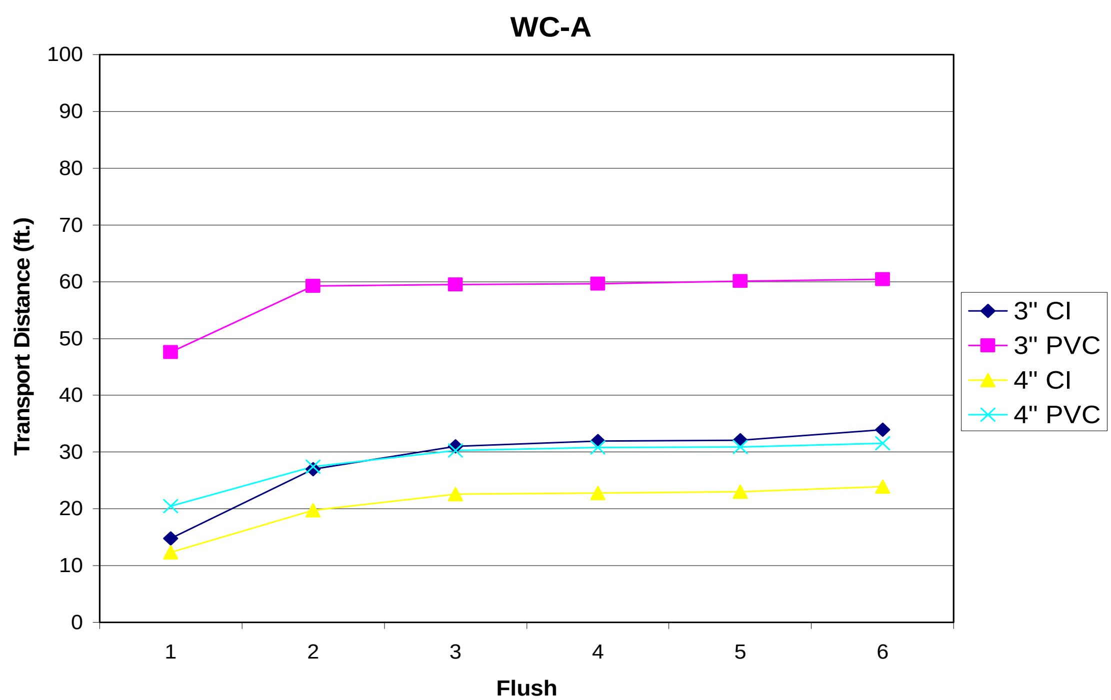
Smith, S. (2000, June 6). Low Opinions of Low Flush. *Plumbing & Mechanical Magazine*. [WWW document] URL http://www.pmmag.com/pm/cda/articleinformation/features/bnp__features__item/0,,3753,00+en-uss_01dbc.html.

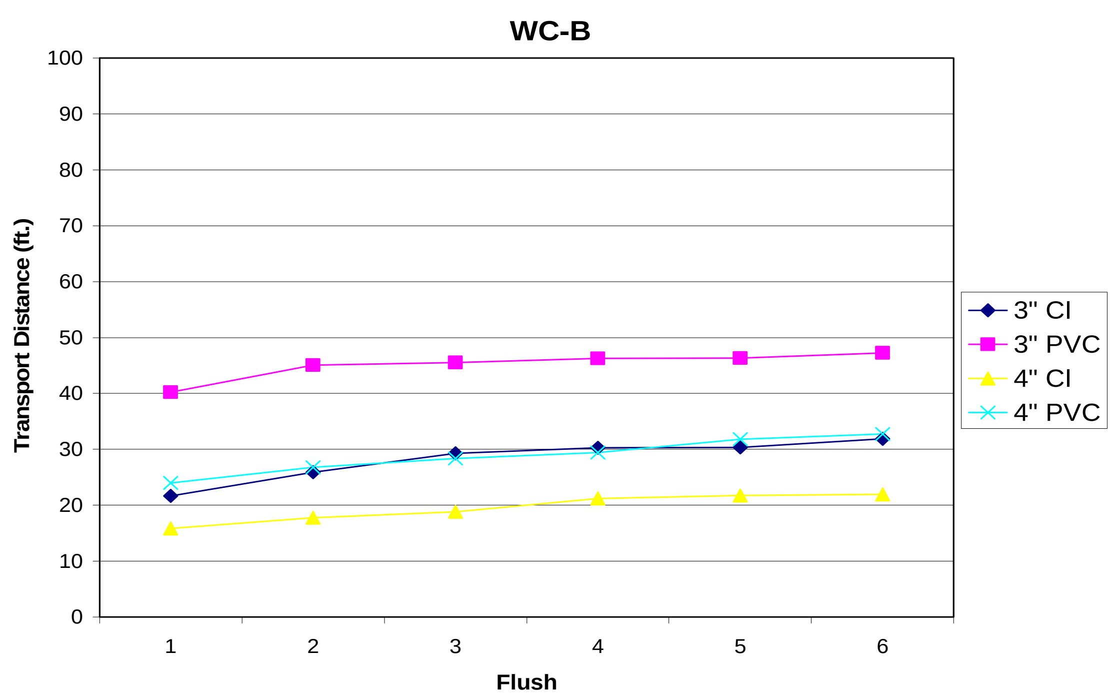
State Farm Insurance. (1999, February 8). *Low Flow Toilets*. [WWW document] URL http://www.statefarm.com/consumer/vhouse/articles/lowflow.htm.

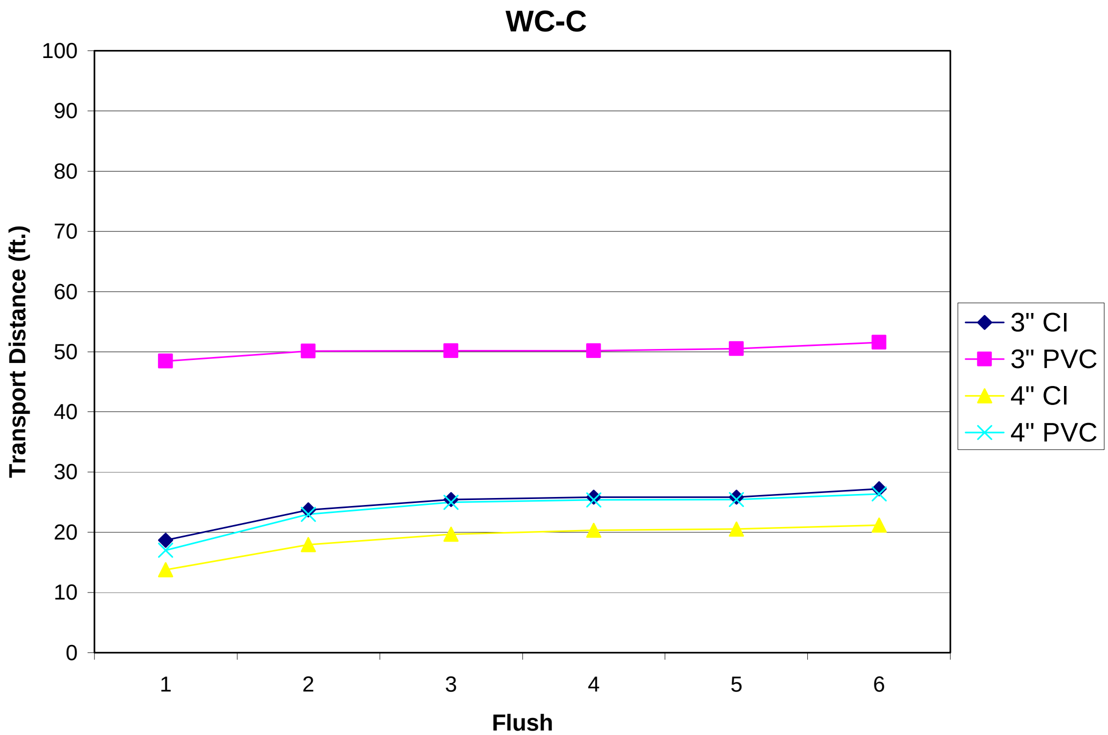
Vickers, A. (1993, August). The Energy Policy Act: Assessing its Impacts on Utilities. *Journal of American Water Works Association*, 85, 56-62.

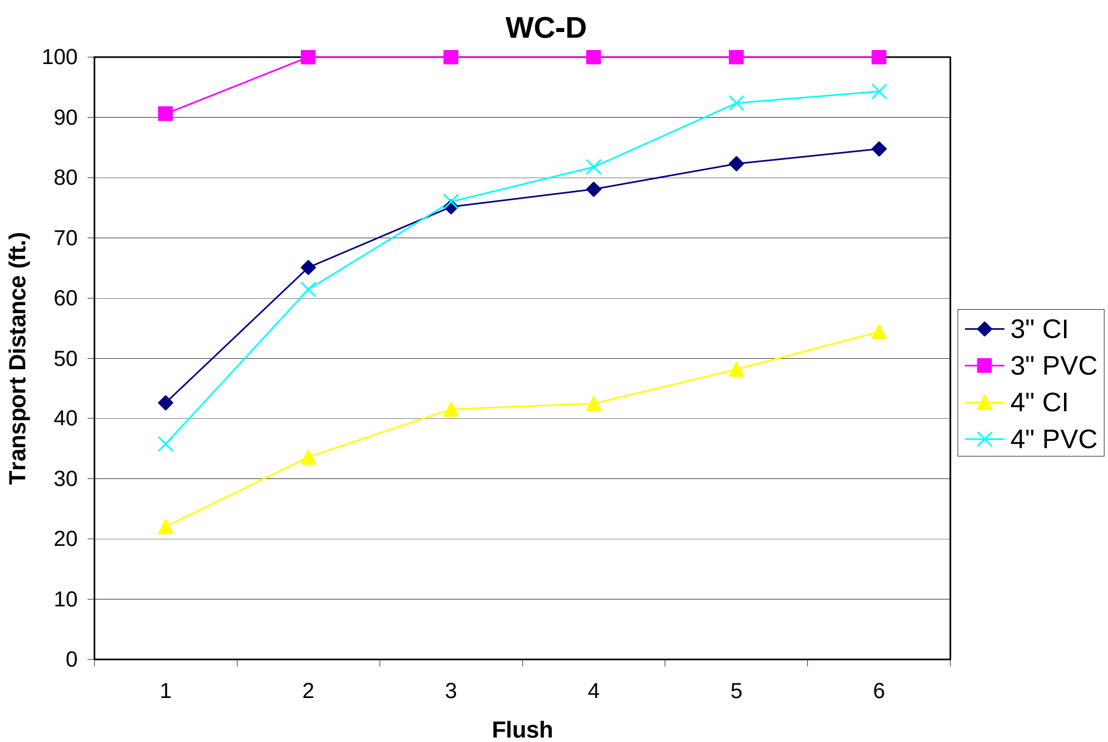
# APPENDIX A

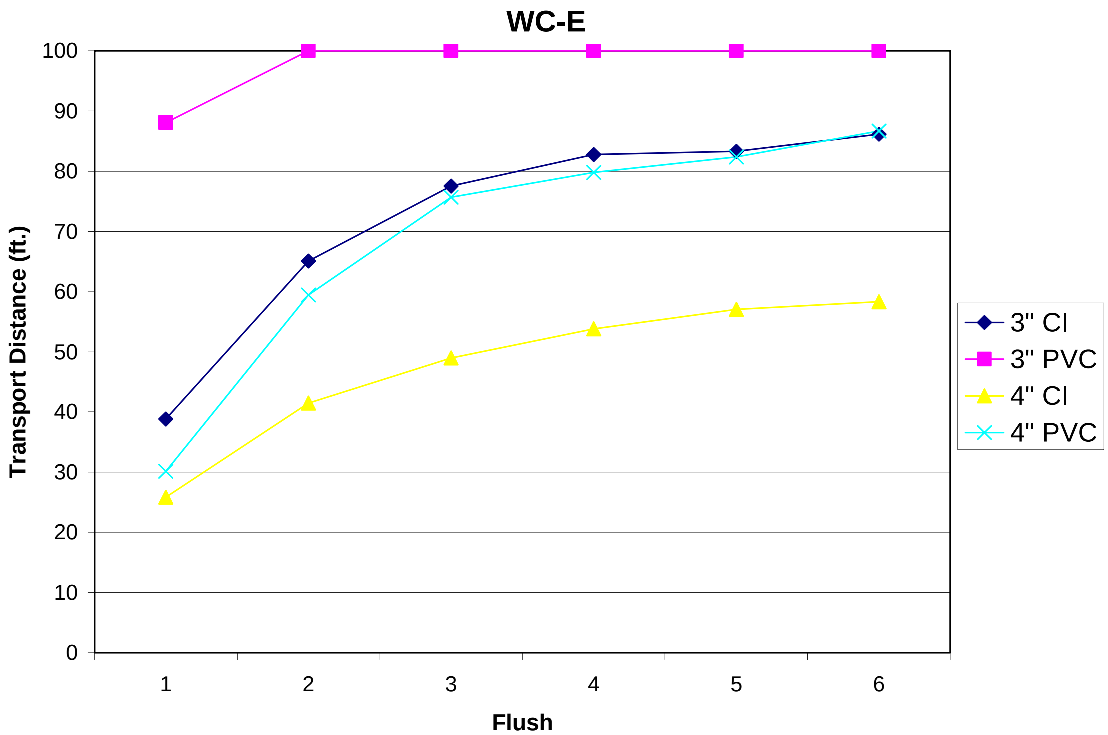
## FIRST LOAD OBSERVATIONS: FLUSH BY FLUSH

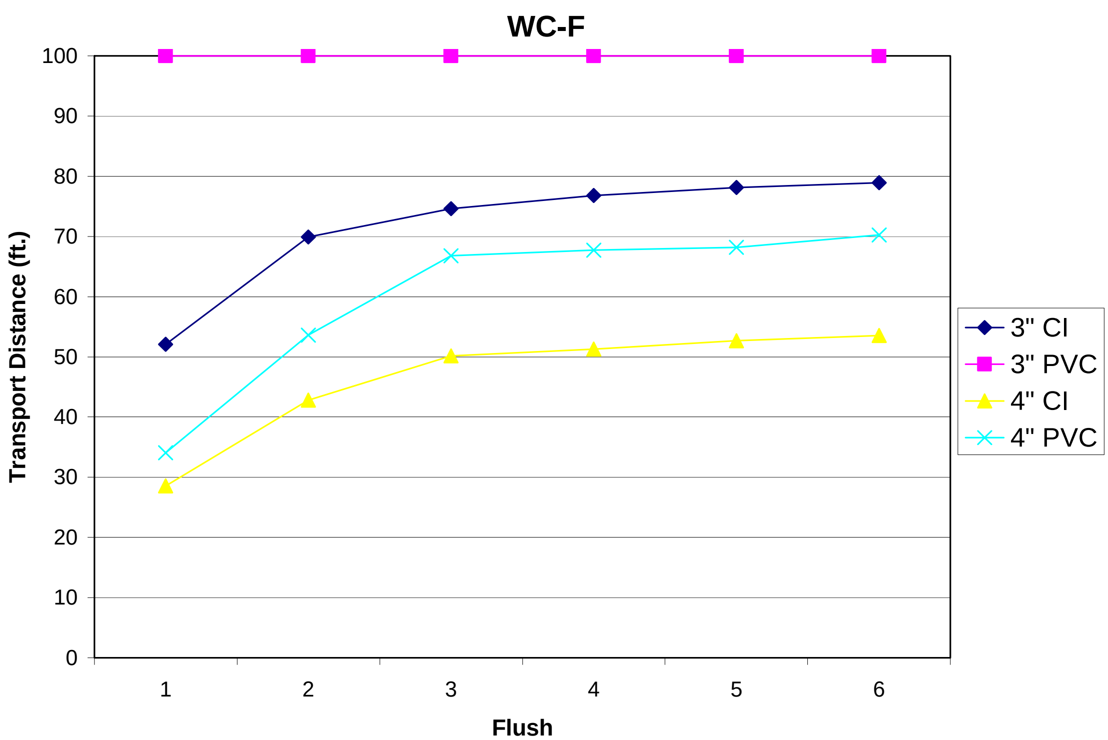



WC-C
Transport Distance (ft.)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
Flush
3" CI
3" PVC
4" CI
4" PVC


WC-D
Transport Distance (ft.)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
Flush
3" CI
3" PVC
4" CI
4" PVC


WC-E
Transport Distance (ft.)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
Flush
3" CI
3" PVC
4" CI
4" PVC


WC-F
Transport Distance (ft.)
100
90
80
70
60
50
40
30
20
10
0
1
2
3
4
5
6
Flush
3" CI
3" PVC
4" CI
4" PVC

# APPENDIX B

## DATA OBSERVATION TABLE

| Flush | | Load 1 | | | Load 2 | |
|---|---|---|---|---|---|---|
| | | | | | | |
| 0 | | x | x | | x | x |
| | | | | | | |
| 1 | | | | | x | x |
| | | | | | | |
| 2 | | | | | x | x |
| | | | | | | |
| 3 | | | | | x | x |
| | | | | | | |
| 4 | | | | | | |
| | | | | | | |
| 5 | | | | | | |
| | | | | | | |
| 6 | | | | | | |

# APPENDIX C

## WATER CLOSET COMPARISONS: OBSERVED DATA

**WC-A**
**First Flush**

| 3" CI | | 3" PVC | | 4" CI | | 4" PVC | |
|---|---|---|---|---|---|---|---|
| **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | |
| 13.98 | 18.82 | 45.11 | 34.11 | 8.70 | 10.51 | 17.10 | 12.68 |
| 10.16 | 18.79 | 30.02 | 34.46 | 15.89 | 11.08 | 21.59 | 15.30 |
| 16.23 | 22.81 | 50.19 | 46.36 | 13.18 | 11.92 | 19.46 | 18.44 |
| 19.50 | 15.30 | 54.10 | 69.80 | 10.63 | 18.23 | 19.40 | 16.57 |
| 13.95 | 18.80 | 58.40 | 69.80 | 13.28 | 11.77 | 24.99 | 11.69 |
| **Average Distance** | | **Average Distance** | | **Average Distance** | | **Average Distance** | |
| 16.83 | | 49.23 | | 12.52 | | 17.72 | |
| **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | |
| 3.62 | | 14.13 | | 2.79 | | 3.99 | |

**WC-A**
**Last Flush**

| 3" CI | 3" PVC | 4" CI | 4" PVC |
|---|---|---|---|
| **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** |
| 34.72 | 51.40 | 22.93 | 30.49 |
| 30.28 | 51.54 | 22.30 | 31.28 |
| 29.97 | 52.53 | 25.62 | 33.67 |
| 40.00 | 74.70 | 25.69 | 29.91 |
| 34.70 | 72.05 | 23.09 | 32.26 |
| **Average Distance** | **Average Distance** | **Average Distance** | **Average Distance** |
| 33.93 | 60.44 | 23.93 | 31.52 |
| **Standard Deviation** | **Standard Deviation** | **Standard Deviation** | **Standard Deviation** |
| 4.10 | 11.85 | 1.61 | 1.49 |

**WC-B**
**First Flush**

| 3" CI | | 3" PVC | | 4" CI | | 4" PVC | |
|---|---|---|---|---|---|---|---|
| **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | |
| 16.30 | 14.65 | 33.22 | 32.48 | 11.53 | 18.97 | 24.48 | 21.76 |
| 15.85 | 12.69 | 25.68 | 33.06 | 17.09 | 15.51 | 23.95 | 23.18 |
| 23.42 | 27.30 | 35.13 | 35.19 | 21.39 | 17.70 | 24.31 | 28.41 |
| 28.35 | 28.73 | 35.38 | 57.20 | 15.73 | 13.14 | 27.77 | 24.05 |
| 24.30 | 26.97 | 49.65 | 56.15 | 13.45 | 19.40 | 19.30 | 25.23 |
| **Average Distance** | | **Average Distance** | | **Average Distance** | | **Average Distance** | |
| 21.85 | | 39.31 | | 16.39 | | 24.24 | |
| **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | |
| 6.29 | | 10.90 | | 3.11 | | 2.64 | |

**WC-B**
**Last Flush**

| 3" CI | 3" PVC | 4" CI | 4" PVC |
|---|---|---|---|
| **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** |
| 24.96 | 33.24 | 22.91 | 36.84 |
| 26.76 | 38.59 | 23.37 | 33.54 |
| 31.49 | 36.99 | 24.61 | 34.56 |
| 39.25 | 66.95 | 18.53 | 32.91 |
| 37.06 | 60.65 | 20.22 | 25.98 |
| **Average Distance** | **Average Distance** | **Average Distance** | **Average Distance** |
| 31.90 | 47.28 | 21.93 | 32.76 |
| **Standard Deviation** | **Standard Deviation** | **Standard Deviation** | **Standard Deviation** |
| 6.23 | 15.37 | 2.49 | 4.07 |

**WC-C**
**First Flush**

| 3" CI | | 3" PVC | | 4" CI | | 4" PVC | |
|---|---|---|---|---|---|---|---|
| **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | |
| 16.18 | 15.73 | 49.82 | 48.98 | 13.51 | 13.02 | 19.53 | 15.54 |
| 20.33 | 18.30 | 47.59 | 41.33 | 14.17 | 13.77 | 15.16 | 10.54 |
| 18.36 | 16.74 | 49.80 | 48.43 | 14.29 | 14.04 | 15.17 | 16.71 |
| 18.50 | 15.90 | 39.40 | 22.60 | 12.57 | 9.30 | 18.87 | 19.20 |
| 17.60 | 15.20 | 55.50 | 54.70 | 13.73 | 14.54 | 16.39 | 15.81 |
| **Average Distance** | | **Average Distance** | | **Average Distance** | | **Average Distance** | |
| 17.28 | | 45.81 | | 13.29 | | 16.29 | |
| **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | |
| 1.61 | | 9.57 | | 1.52 | | 2.63 | |

**WC-C**
**Last Flush**

| 3" CI | 3" PVC | 4" CI | 4" PVC |
|---|---|---|---|
| **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** |
| 27.53 | 49.90 | 19.98 | 25.89 |
| 28.18 | 49.49 | 23.28 | 24.71 |
| 26.62 | 49.80 | 20.70 | 26.77 |
| 28.00 | 51.70 | 21.26 | 27.54 |
| 26.00 | 57.00 | 20.76 | 27.10 |
| **Average Distance** | **Average Distance** | **Average Distance** | **Average Distance** |
| 27.26 | 51.58 | 21.19 | 26.40 |
| **Standard Deviation** | **Standard Deviation** | **Standard Deviation** | **Standard Deviation** |
| 0.93 | 3.15 | 1.25 | 1.12 |

**WC-D**
**First Flush**

| **3" CI** | | **3" PVC** | | **4" CI** | | **4" PVC** | |
|---|---|---|---|---|---|---|---|
| **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | |
| 48.26 | 49.34 | 100.00 | 100.00 | 23.40 | 21.72 | 26.84 | 34.16 |
| 40.77 | 47.23 | 97.51 | 100.00 | 18.57 | 23.42 | 40.58 | 36.22 |
| 39.64 | 43.31 | 82.09 | 100.00 | 24.82 | 21.64 | 38.37 | 35.60 |
| 36.59 | 52.10 | 73.37 | 85.59 | 21.27 | 31.62 | 36.40 | 29.89 |
| 47.81 | 40.03 | 90.59 | 97.12 | 22.16 | 33.40 | 36.61 | 30.35 |
| **Average Distance** | | **Average Distance** | | **Average Distance** | | **Average Distance** | |
| 44.51 | | 92.63 | | 24.20 | | 34.50 | |
| **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | |
| 5.11 | | 9.41 | | 4.70 | | 4.23 | |

**WC-D**
**Last Flush**

| **3" CI** | **3" PVC** | **4" CI** | **4" PVC** |
|---|---|---|---|
| **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** |
| 79.70 | 100.00 | 59.85 | 94.14 |
| 91.85 | 100.00 | 52.28 | 93.07 |
| 79.39 | 100.00 | 59.65 | 85.07 |
| 79.50 | 100.00 | 46.84 | 100.00 |
| 93.31 | 100.00 | 38.27 | 99.28 |
| **Average Distance** | **Average Distance** | **Average Distance** | **Average Distance** |
| 84.75 | 100.00 | 51.38 | 94.31 |
| **Standard Deviation** | **Standard Deviation** | **Standard Deviation** | **Standard Deviation** |
| 7.17 | 0.00 | 9.13 | 6.00 |

**WC-E**
**First Flush**

| 3" CI | | 3" PVC | | 4" CI | | 4" PVC | |
|---|---|---|---|---|---|---|---|
| **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | | **Transport Distance (ft.)** | |
| 45.62 | 36.91 | 78.08 | 65.90 | 22.31 | 33.29 | 32.87 | 31.61 |
| 29.17 | 33.45 | 64.65 | 98.95 | 24.97 | 25.24 | 33.51 | 41.46 |
| 30.85 | 58.47 | 98.51 | 99.47 | 36.69 | 26.12 | 29.32 | 33.84 |
| 43.35 | 40.55 | 99.36 | 99.25 | 32.87 | 23.98 | 27.43 | 33.37 |
| 39.96 | 43.48 | 99.81 | 98.33 | 23.28 | 20.39 | 27.44 | 33.58 |
| **Average Distance** | | **Average Distance** | | **Average Distance** | | **Average Distance** | |
| 40.18 | | 90.23 | | 26.91 | | 32.44 | |
| **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | | **Standard Deviation** | |
| 8.50 | | 14.70 | | 5.42 | | 4.05 | |

**WC-E**
**Last Flush**

| 3" CI | 3" PVC | 4" CI | 4" PVC |
|---|---|---|---|
| **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** |
| 78.57 | 100.00 | 31.10 | 82.51 |
| 94.34 | 100.00 | 61.75 | 87.96 |
| 80.16 | 100.00 | 62.48 | 84.96 |
| 81.35 | 100.00 | 67.99 | 99.10 |
| 96.26 | 100.00 | 68.21 | 78.86 |
| **Average Distance** | **Average Distance** | **Average Distance** | **Average Distance** |
| 86.13 | 100.00 | 58.30 | 86.68 |
| **Standard Deviation** | **Standard Deviation** | **Standard Deviation** | **Standard Deviation** |
| 8.45 | 0.00 | 15.50 | 7.70 |

**WC-F**
**First Flush**

**3" CI**

**Transport Distance (ft.)**

| | |
|---|---|
| 51.09 | 32.01 |
| 50.17 | 47.29 |
| 59.47 | 45.19 |
| 50.69 | 51.42 |
| 49.16 | 46.43 |

**Average Distance**
48.29

**Standard Deviation**
6.93

**3" PVC**

**Transport Distance (ft.)**

| | |
|---|---|
| 100.00 | 100.00 |
| 100.00 | 100.00 |
| 100.00 | 84.35 |
| 100.00 | 100.00 |
| 99.86 | 100.00 |

**Average Distance**
98.42

**Standard Deviation**
4.95

**4" CI**

**Transport Distance (ft.)**

| | |
|---|---|
| 31.70 | 27.75 |
| 25.30 | 29.80 |
| 25.69 | 24.41 |
| 31.04 | 27.06 |
| 29.17 | 32.50 |

**Average Distance**
28.44

**Standard Deviation**
2.83

**4" PVC**

**Transport Distance (ft.)**

| | |
|---|---|
| 28.43 | 29.34 |
| 36.04 | 32.26 |
| 36.46 | 27.03 |
| 33.09 | 30.70 |
| 38.28 | 24.72 |

**Average Distance**
31.63

**Standard Deviation**
4.41

**WC-F**
**Last Flush**

| 3" CI | 3" PVC | 4" CI | 4" PVC |
|---|---|---|---|
| **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** | **Transport Distance (ft.)** |
| 80.17 | 100.00 | 63.16 | 70.09 |
| 77.54 | 100.00 | 58.22 | 77.35 |
| 72.14 | 100.00 | 60.89 | 70.98 |
| 92.81 | 100.00 | 33.59 | 62.93 |
| 72.14 | 100.00 | 52.00 | 70.04 |
| **Average Distance** | **Average Distance** | **Average Distance** | **Average Distance** |
| 78.96 | 100.00 | 53.57 | 70.28 |
| **Standard Deviation** | **Standard Deviation** | **Standard Deviation** | **Standard Deviation** |
| 8.49 | 0.00 | 11.92 | 5.11 |

# APPENDIX D

## PIPE COMPARISONS: OBSERVED DATA

**3" CI**
**First Flush**

| 1.6 gpf | | | 3.5 gpf | | |
|---|---|---|---|---|---|
| **Transport Distance (ft.)** | | | **Transport Distance (ft.)** | | |
| 16.18 | 13.98 | 16.30 | 51.09 | 48.26 | 45.62 |
| 15.73 | 18.82 | 14.65 | 32.01 | 49.34 | 36.91 |
| 20.33 | 10.16 | 15.85 | 50.17 | 40.77 | 29.17 |
| 18.30 | 18.79 | 12.69 | 47.29 | 47.23 | 33.45 |
| 18.36 | 16.23 | 23.42 | 59.47 | 39.64 | 30.85 |
| 16.74 | 22.81 | 27.30 | 45.19 | 43.31 | 58.47 |
| 18.50 | 19.50 | 28.35 | 50.69 | 36.59 | 43.35 |
| 15.90 | 15.30 | 28.73 | 51.42 | 52.10 | 40.55 |
| 17.60 | 13.95 | 24.30 | 49.16 | 47.81 | 39.96 |
| 15.20 | 18.80 | 26.97 | 46.43 | 40.03 | 43.48 |
| **Average Distance** | | | **Average Distance** | | |
| 20.66 | | | 45.90 | | |
| **Standard Deviation** | | | **Standard Deviation** | | |
| 5.25 | | | 5.79 | | |

**3" CI**
**Last Flush**

| 1.6 gpf | | | 3.5 gpf | | |
|---|---|---|---|---|---|
| **Transport Distance (ft.)** | | | **Transport Distance (ft.)** | | |
| 27.53 | 34.72 | 24.96 | 80.17 | 79.70 | 78.57 |
| 28.18 | 30.28 | 26.76 | 77.54 | 91.85 | 94.34 |
| 26.62 | 29.97 | 31.49 | 72.14 | 79.39 | 80.16 |
| 28.00 | 40.00 | 39.25 | 92.81 | 79.50 | 81.35 |
| 26.00 | 34.70 | 37.06 | 72.14 | 93.31 | 96.26 |
| **Average Distance** | | | **Average Distance** | | |
| 31.03 | | | 83.28 | | |
| **Standard Deviation** | | | **Standard Deviation** | | |
| 4.95 | | | 8.13 | | |

3” PVC
First Flush

| 1.6 gpf | | |
|---|---|---|
| Transport Distance (ft.) | | |
| 49.82 | 45.11 | 33.22 |
| 48.98 | 34.11 | 32.48 |
| 47.59 | 30.02 | 25.68 |
| 41.33 | 34.46 | 33.06 |
| 49.80 | 50.19 | 35.13 |
| 48.43 | 46.36 | 35.19 |
| 39.40 | 54.10 | 35.38 |
| 22.60 | 69.80 | 57.20 |
| 55.50 | 58.40 | 49.65 |
| 54.70 | 69.80 | 56.15 |
| Average Distance | | |
| 44.79 | | |
| Standard Deviation | | |
| 12.03 | | |

| 3.5 gpf | | |
|---|---|---|
| Transport Distance (ft.) | | |
| 100.00 | 100.00 | 78.08 |
| 100.00 | 100.00 | 65.90 |
| 100.00 | 97.51 | 64.65 |
| 100.00 | 100.00 | 98.95 |
| 100.00 | 82.09 | 98.51 |
| 84.35 | 100.00 | 99.47 |
| 100.00 | 73.37 | 99.36 |
| 100.00 | 85.59 | 99.25 |
| 99.86 | 90.59 | 99.81 |
| 100.00 | 97.12 | 99.83 |
| Average Distance | | |
| 93.81 | | |
| Standard Deviation | | |
| 10.72 | | |

3” PVC
Last Flush

| 1.6 gpf | | |
|---|---|---|
| Transport Distance (ft.) | | |
| 49.90 | 51.40 | 33.24 |
| 49.49 | 51.54 | 38.59 |
| 49.80 | 52.53 | 36.99 |
| 51.70 | 74.70 | 66.95 |
| 57.00 | 72.05 | 60.65 |
| Average Distance | | |
| 53.10 | | |
| Standard Deviation | | |
| 11.94 | | |

| 3.5 gpf | | |
|---|---|---|
| Transport Distance (ft.) | | |
| 100.00 | 100.00 | 100.00 |
| 100.00 | 100.00 | 100.00 |
| 100.00 | 100.00 | 100.00 |
| 100.00 | 100.00 | 100.00 |
| 100.00 | 100.00 | 100.00 |
| Average Distance | | |
| 100.00 | | |
| Standard Deviation | | |
| 0.00 | | |

**4” CI**
**First Flush**

| 1.6 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 13.51 | 8.70 | 11.53 |
| 13.02 | 10.51 | 18.97 |
| 14.17 | 15.89 | 17.09 |
| 13.77 | 11.08 | 15.51 |
| 14.29 | 13.18 | 21.39 |
| 14.04 | 11.92 | 17.70 |
| 12.57 | 10.63 | 15.73 |
| 9.30 | 18.23 | 13.14 |
| 13.73 | 13.28 | 13.45 |
| 14.54 | 11.77 | 19.40 |
| **Average Distance** | | |
| 13.96 | | |
| **Standard Deviation** | | |
| 2.81 | | |

| 3.5 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 31.70 | 23.40 | 22.31 |
| 27.75 | 21.72 | 33.29 |
| 25.30 | 18.57 | 24.97 |
| 29.80 | 23.42 | 25.24 |
| 25.69 | 24.82 | 36.69 |
| 24.41 | 21.64 | 26.12 |
| 31.04 | 21.27 | 32.87 |
| 27.06 | 31.62 | 23.98 |
| 29.17 | 22.16 | 23.28 |
| 32.50 | 33.40 | 20.39 |
| **Average Distance** | | |
| 26.73 | | |
| **Standard Deviation** | | |
| 4.68 | | |

**4” CI**
**Last Flush**

| 1.6 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 19.98 | 22.93 | 22.91 |
| 23.28 | 22.30 | 23.37 |
| 20.70 | 25.62 | 24.61 |
| 21.26 | 25.69 | 18.53 |
| 20.76 | 23.09 | 20.22 |
| **Average Distance** | | |
| 22.35 | | |
| **Standard Deviation** | | |
| 2.09 | | |

| 3.5 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 63.16 | 59.85 | 31.10 |
| 58.22 | 52.28 | 61.75 |
| 60.89 | 59.65 | 62.48 |
| 33.59 | 46.84 | 67.99 |
| 52.00 | 38.27 | 68.21 |
| **Average Distance** | | |
| 54.42 | | |
| **Standard Deviation** | | |
| 11.92 | | |

**4” PVC**
**First Flush**

| 1.6 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 19.53 | 17.10 | 24.48 |
| 15.54 | 12.68 | 21.76 |
| 15.16 | 21.59 | 23.95 |
| 10.54 | 15.30 | 23.18 |
| 15.17 | 19.46 | 24.31 |
| 16.71 | 18.44 | 28.41 |
| 18.87 | 19.40 | 27.77 |
| 19.20 | 16.57 | 24.05 |
| 16.39 | 24.99 | 19.30 |
| 15.81 | 11.69 | 25.23 |
| **Average Distance** | | |
| 19.42 | | |
| **Standard Deviation** | | |
| 4.65 | | |

| 3.5 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 28.43 | 26.84 | 32.87 |
| 29.34 | 34.16 | 31.61 |
| 36.04 | 40.58 | 33.51 |
| 32.26 | 36.22 | 41.46 |
| 36.46 | 38.37 | 29.32 |
| 27.03 | 35.60 | 33.84 |
| 33.09 | 36.40 | 27.43 |
| 30.70 | 29.89 | 33.37 |
| 38.28 | 36.61 | 27.44 |
| 34.72 | 30.35 | 33.58 |
| **Average Distance** | | |
| 33.19 | | |
| **Standard Deviation** | | |
| 3.99 | | |

**4” PVC**
**Last Flush**

| 1.6 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 25.89 | 30.49 | 36.84 |
| 24.71 | 31.28 | 33.54 |
| 26.77 | 33.67 | 34.56 |
| 27.54 | 29.91 | 32.91 |
| 27.10 | 32.26 | 25.98 |
| **Average Distance** | | |
| 30.23 | | |
| **Standard Deviation** | | |
| 3.72 | | |

| 3.5 gpf | | |
|---|---|---|
| **Transport Distance (ft.)** | | |
| 70.09 | 94.14 | 82.51 |
| 77.35 | 93.07 | 87.96 |
| 70.98 | 85.07 | 84.96 |
| 62.93 | 100.00 | 99.10 |
| 70.04 | 99.28 | 78.86 |
| **Average Distance** | | |
| 83.76 | | |
| **Standard Deviation** | | |
| 11.93 | | |

# APPENDIX E

## SPSS OUTPUT

## FIRST FLUSH – WATER CLOSET DESCRIPTIVE STATISTICS

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound | | |
| 3”CI | WC-A | 10 | 16.8340 | 3.62366 | 1.14590 | 14.2418 | 19.4262 | 10.16 | 22.81 |
| | WC-B | 10 | 21.8560 | 6.29388 | 1.99030 | 17.3536 | 26.3584 | 12.69 | 28.73 |
| | WC-C | 10 | 17.2840 | 1.60675 | .50810 | 16.1346 | 18.4334 | 15.20 | 20.33 |
| | WC-D | 10 | 44.5080 | 5.11239 | 1.61668 | 40.8508 | 48.1652 | 36.59 | 52.10 |
| | WC-E | 10 | 40.1810 | 8.49507 | 2.68638 | 34.1040 | 46.2580 | 29.17 | 58.47 |
| | WC-F | 10 | 48.2920 | 6.92651 | 2.19035 | 43.3371 | 53.2469 | 32.01 | 59.47 |
| | Total | 60 | 31.4925 | 14.36908 | 1.85504 | 27.7806 | 35.2044 | 10.16 | 59.47 |
| 3”PVC | WC-A | 10 | 49.2350 | 14.12633 | 4.46714 | 39.1296 | 59.3404 | 30.02 | 69.80 |
| | WC-B | 10 | 39.3140 | 10.89863 | 3.44645 | 31.5176 | 47.1104 | 25.68 | 57.20 |
| | WC-C | 10 | 45.8150 | 9.57353 | 3.02742 | 38.9665 | 52.6635 | 22.60 | 55.50 |
| | WC-D | 10 | 92.6270 | 9.41042 | 2.97584 | 85.8952 | 99.3588 | 73.37 | 100.00 |
| | WC-E | 10 | 90.2310 | 14.70444 | 4.64995 | 79.7121 | 100.7499 | 64.65 | 99.81 |
| | WC-F | 10 | 98.4210 | 4.94424 | 1.56351 | 94.8841 | 101.9579 | 84.35 | 100.00 |
| | Total | 60 | 69.2738 | 27.14956 | 3.50499 | 62.2604 | 76.2873 | 22.60 | 100.00 |
| 4”CI | WC-A | 10 | 12.5190 | 2.79235 | .88302 | 10.5215 | 14.5165 | 8.70 | 18.23 |
| | WC-B | 10 | 16.3910 | 3.10838 | .98296 | 14.1674 | 18.6146 | 11.53 | 21.39 |
| | WC-C | 10 | 13.2940 | 1.52327 | .48170 | 12.2043 | 14.3837 | 9.30 | 14.54 |
| | WC-D | 10 | 24.2020 | 4.69606 | 1.48502 | 20.8426 | 27.5614 | 18.57 | 33.40 |
| | WC-E | 10 | 26.9140 | 5.42098 | 1.71426 | 23.0361 | 30.7919 | 20.39 | 36.69 |
| | WC-F | 10 | 28.4420 | 2.83426 | .89627 | 26.4145 | 30.4695 | 24.41 | 32.50 |
| | Total | 60 | 20.2937 | 7.38182 | .95299 | 18.3867 | 22.2006 | 8.70 | 36.69 |
| 4”PVC | WC-A | 10 | 17.7220 | 3.99338 | 1.26282 | 14.8653 | 20.5787 | 11.69 | 24.99 |
| | WC-B | 10 | 24.2440 | 2.63923 | .83460 | 22.3560 | 26.1320 | 19.30 | 28.41 |
| | WC-C | 10 | 16.2920 | 2.62880 | .83130 | 14.4115 | 18.1725 | 10.54 | 19.53 |
| | WC-D | 10 | 34.5020 | 4.23530 | 1.33932 | 31.4723 | 37.5317 | 26.84 | 40.58 |
| | WC-E | 10 | 32.4430 | 4.04610 | 1.27949 | 29.5486 | 35.3374 | 27.43 | 41.46 |
| | WC-F | 10 | 31.7350 | 4.58227 | 1.44904 | 28.4570 | 35.0130 | 24.72 | 39.28 |
| | Total | 60 | 26.1563 | 8.11997 | 1.04828 | 24.0587 | 28.2539 | 10.54 | 41.46 |

## SPSS OUTPUT

## LAST FLUSH – WATER CLOSET DESCRIPTIVE STATISTICS

| | | N | Mean | Std. Deviation | Std. Error | 95% Confidence Interval for Mean | | Min. | Max. |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound | | |
| 3”CI | WC-A | 5 | 33.9340 | 4.09469 | 1.83120 | 28.8498 | 39.0182 | 29.97 | 40.00 |
| | WC-B | 5 | 31.9040 | 6.23296 | 2.78747 | 24.1648 | 39.6432 | 24.96 | 39.25 |
| | WC-C | 5 | 27.2660 | .93058 | .41617 | 26.1105 | 28.4215 | 26.00 | 28.18 |
| | WC-D | 5 | 84.7500 | 7.16726 | 3.20529 | 75.8507 | 93.6493 | 79.39 | 93.31 |
| | WC-E | 5 | 86.1360 | 8.45079 | 3.77931 | 75.6430 | 96.6290 | 78.57 | 96.26 |
| | WC-F | 5 | 78.9600 | 8.49011 | 3.79689 | 68.4181 | 89.5019 | 72.14 | 92.81 |
| | Total | 30 | 57.1583 | 27.38015 | 4.99891 | 46.9344 | 67.3822 | 24.96 | 96.26 |
| 3”PVC | WC-A | 5 | 60.4440 | 11.84947 | 5.29924 | 45.7309 | 75.1571 | 51.40 | 74.70 |
| | WC-B | 5 | 47.2840 | 15.36382 | 6.87091 | 28.2073 | 66.3607 | 33.24 | 66.95 |
| | WC-C | 5 | 51.5780 | 3.15237 | 1.40978 | 47.6638 | 55.4922 | 49.49 | 57.00 |
| | WC-D | 5 | 100.0000 | .00000 | .00000 | 100.0000 | 100.0000 | 100.00 | 100.00 |
| | WC-E | 5 | 100.0000 | .00000 | .00000 | 100.0000 | 100.0000 | 100.00 | 100.00 |
| | WC-F | 5 | 100.0000 | .00000 | .00000 | 100.0000 | 100.0000 | 100.00 | 100.00 |
| | Total | 30 | 76.5510 | 25.25158 | 4.61029 | 67.1219 | 85.9801 | 33.24 | 100.00 |
| 4”CI | WC-A | 5 | 23.9260 | 1.60594 | .71820 | 21.9320 | 25.9200 | 22.30 | 25.69 |
| | WC-B | 5 | 21.9280 | 2.48498 | 1.11132 | 18.8425 | 25.0135 | 18.53 | 24.61 |
| | WC-C | 5 | 21.1980 | 1.25133 | .55961 | 19.6443 | 22.7517 | 19.98 | 23.28 |
| | WC-D | 5 | 54.3780 | 5.48150 | 2.45140 | 47.5718 | 61.1842 | 46.84 | 59.85 |
| | WC-E | 5 | 58.3060 | 15.50257 | 6.93296 | 39.0570 | 77.5550 | 31.10 | 68.21 |
| | WC-F | 5 | 53.5720 | 11.92517 | 5.33310 | 38.7650 | 68.3790 | 33.59 | 63.16 |
| | Total | 30 | 38.8847 | 18.54809 | 3.38640 | 31.9587 | 45.8106 | 18.53 | 68.21 |
| 4”PVC | WC-A | 5 | 31.5220 | 1.49002 | .66636 | 29.6719 | 33.3721 | 29.91 | 33.67 |
| | WC-B | 5 | 32.7660 | 4.07693 | 1.82326 | 27.7038 | 37.8282 | 25.98 | 36.84 |
| | WC-C | 5 | 26.4020 | 1.12280 | .50213 | 25.0079 | 27.7961 | 24.71 | 27.54 |
| | WC-D | 5 | 94.3120 | 6.00044 | 2.68348 | 86.8615 | 101.7625 | 85.07 | 100.00 |
| | WC-E | 5 | 86.6780 | 7.70381 | 3.44525 | 77.1125 | 96.2435 | 78.86 | 99.10 |
| | WC-F | 5 | 70.2780 | 5.11349 | 2.28682 | 63.9288 | 76.6272 | 62.93 | 77.35 |
| | Total | 30 | 56.9930 | 28.57299 | 5.21669 | 46.3237 | 67.6623 | 24.71 | 100.00 |

# APPENDIX F

## SPSS OUTPUT

### FIRST FLUSH – WATER CLOSET ANOVA

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 3”CI | Between Groups | 10367.317 | 5 | 2073.463 | 61.709 | .000 |
| | Within Groups | 1814.444 | 54 | 33.601 | | |
| | Total | 12181.761 | 59 | | | |
| 3”PVC | Between Groups | 36835.939 | 5 | 7367.188 | 59.798 | .000 |
| | Within Groups | 6652.873 | 54 | 123.201 | | |
| | Total | 43488.812 | 59 | | | |
| 4”CI | Between Groups | 2501.708 | 5 | 500.342 | 37.880 | .000 |
| | Within Groups | 713.273 | 54 | 13.209 | | |
| | Total | 3214.981 | 59 | | | |
| 4”PVC | Between Groups | 3123.939 | 5 | 624.788 | 44.036 | .000 |
| | Within Groups | 766.162 | 54 | 14.188 | | |
| | Total | 3890.101 | 59 | | | |

### LAST FLUSH – WATER CLOSET ANOVA

| | | Sum of Squares | df | Mean Square | F | Sig. |
|---|---|---|---|---|---|---|
| 3”CI | Between Groups | 20735.103 | 5 | 4147.021 | 98.994 | .000 |
| | Within Groups | 1005.399 | 24 | 41.892 | | |
| | Total | 21740.501 | 29 | | | |
| 3”PVC | Between Groups | 16946.051 | 5 | 3389.210 | 52.628 | .000 |
| | Within Groups | 1545.577 | 24 | 64.399 | | |
| | Total | 18491.628 | 29 | | | |
| 4”CI | Between Groups | 8285.289 | 5 | 1657.058 | 23.510 | .000 |
| | Within Groups | 1691.625 | 24 | 70.484 | | |
| | Total | 9976.913 | 29 | | | |
| 4”PVC | Between Groups | 23109.634 | 5 | 4621.927 | 195.839 | .000 |
| | Within Groups | 566.416 | 24 | 23.601 | | |
| | Total | 23676.050 | 29 | | | |

# APPENDIX G

## SPSS OUTPUT

## FIRST FLUSH – MULTIPLE WATER CLOSET COMPARISONS

### Tukey HSD: Dependent Variable – 3" CI

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| WC-A | WC-B | -5.0220 | 2.59233 | .391 | -12.6810 | 2.6370 |
| | WC-C | -.4500 | 2.59233 | 1.000 | -8.1090 | 7.2090 |
| | WC-D | -27.6740* | 2.59233 | .000 | -35.3330 | -20.0150 |
| | WC-E | -23.3470* | 2.59233 | .000 | -31.0060 | -15.6880 |
| | WC-F | -31.4580* | 2.59233 | .000 | -39.1170 | -23.7990 |
| WC-B | WC-A | 5.0220 | 2.59233 | .391 | -2.6370 | 12.6810 |
| | WC-C | 4.5720 | 2.59233 | .497 | -3.0870 | 12.2310 |
| | WC-D | -22.6520* | 2.59233 | .000 | -30.3110 | -14.9930 |
| | WC-E | -18.3250* | 2.59233 | .000 | -25.9840 | -10.6660 |
| | WC-F | -26.4360* | 2.59233 | .000 | -34.0950 | -18.7770 |
| WC-C | WC-A | .4500 | 2.59233 | 1.000 | -7.2090 | 8.1090 |
| | WC-B | -4.5720 | 2.59233 | .497 | -12.2310 | 3.0870 |
| | WC-D | -27.2240* | 2.59233 | .000 | -34.8830 | -19.5650 |
| | WC-E | -22.8970* | 2.59233 | .000 | -30.5560 | -15.2380 |
| | WC-F | -31.0080* | 2.59233 | .000 | -38.6670 | -23.3490 |
| WC-D | WC-A | 27.6740* | 2.59233 | .000 | 20.0150 | 35.3330 |
| | WC-B | 22.6520* | 2.59233 | .000 | 14.9930 | 30.3110 |
| | WC-C | 27.2240* | 2.59233 | .000 | 19.5650 | 34.8830 |
| | WC-E | 4.3270 | 2.59233 | .558 | -3.3320 | 11.9860 |
| | WC-F | -3.7840 | 2.59233 | .691 | -11.4430 | 3.8750 |
| WC-E | WC-A | 23.3470* | 2.59233 | .000 | 15.6880 | 31.0060 |
| | WC-B | 18.3250* | 2.59233 | .000 | 10.6660 | 25.9840 |
| | WC-C | 22.8970* | 2.59233 | .000 | 15.2380 | 30.5560 |
| | WC-D | -4.3270 | 2.59233 | .558 | -11.9860 | 3.3320 |
| | WC-F | -8.1110* | 2.59233 | .032 | -15.7700 | -.4520 |
| WC-F | WC-A | 31.4580* | 2.59233 | .000 | 23.7990 | 39.1170 |
| | WC-B | 26.4360* | 2.59233 | .000 | 18.7770 | 34.0950 |
| | WC-C | 31.0080* | 2.59233 | .000 | 23.3490 | 38.6670 |
| | WC-D | 3.7840 | 2.59233 | .691 | -3.8750 | 11.4430 |
| | WC-E | 8.1110* | 2.59233 | .032 | .4520 | 15.7700 |

* The mean difference is significant at the .05 level.

**Tukey HSD: Dependent Variable – 3" PVC**

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|
| WC-A | WC-B | 9.9210 | 4.96390 | .357 | -4.7447 | 24.5867 |
| | WC-C | 3.4200 | 4.96390 | .982 | -11.2457 | 18.0857 |
| | WC-D | -43.3920* | 4.96390 | .000 | -58.0577 | -28.7263 |
| | WC-E | -40.9960* | 4.96390 | .000 | -55.6617 | -26.3303 |
| | WC-F | -49.1860* | 4.96390 | .000 | -63.8517 | -34.5203 |
| WC-B | WC-A | -9.9210 | 4.96390 | .357 | -24.5867 | 4.7447 |
| | WC-C | -6.5010 | 4.96390 | .778 | -21.1667 | 8.1647 |
| | WC-F | -53.3130* | 4.96390 | .000 | -67.9787 | -38.6473 |
| | WC-E | -50.9170* | 4.96390 | .000 | -65.5827 | -36.2513 |
| | WC-F | -59.1070* | 4.96390 | .000 | -73.7727 | -44.4413 |
| WC-C | WC-A | -3.4200 | 4.96390 | .982 | -18.0857 | 11.2457 |
| | WC-B | 6.5010 | 4.96390 | .778 | -8.1647 | 21.1667 |
| | WC-D | -46.8120* | 4.96390 | .000 | -61.4777 | -32.1463 |
| | WC-E | -44.4160* | 4.96390 | .000 | -59.0817 | -29.7503 |
| | WC-F | -52.6060* | 4.96390 | .000 | -67.2717 | -37.9403 |
| WC-D | WC-A | 43.3920* | 4.96390 | .000 | 28.7263 | 58.0577 |
| | WC-B | 53.3130* | 4.96390 | .000 | 38.6473 | 67.9787 |
| | WC-C | 46.8120* | 4.96390 | .000 | 32.1463 | 61.4777 |
| | WC-E | 2.3960 | 4.96390 | .997 | -12.2697 | 17.0617 |
| | WC-F | -5.7940 | 4.96390 | .850 | -20.4597 | 8.8717 |
| WC-E | WC-A | 40.9960* | 4.96390 | .000 | 26.3303 | 55.6617 |
| | WC-B | 50.9170* | 4.96390 | .000 | 36.2513 | 65.5827 |
| | WC-C | 44.4160* | 4.96390 | .000 | 29.7503 | 59.0817 |
| | WC-D | -2.3960 | 4.96390 | .997 | -17.0617 | 12.2697 |
| | WC-F | -8.1900 | 4.96390 | .570 | -22.8557 | 6.4757 |
| WC-F | WC-A | 49.1860* | 4.96390 | .000 | 34.5203 | 63.8517 |
| | WC-B | 59.1070* | 4.96390 | .000 | 44.4413 | 73.7727 |
| | WC-C | 52.6060* | 4.96390 | .000 | 37.9403 | 67.2717 |
| | WC-D | 5.7940 | 4.96390 | .850 | -8.8717 | 20.4597 |
| | WC-E | 8.1900 | 4.96390 | .570 | -6.4757 | 22.8557 |

* The mean difference is significant at the .05 level.

**Tukey HSD: Dependent Variable – 4" CI**

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| WC-A | WC-B | -3.8720 | 1.62535 | .181 | -8.6741 | .9301 |
| | WC-C | -.7750 | 1.62535 | .997 | -5.5771 | 4.0271 |
| | WC-D | -11.6830* | 1.62535 | .000 | -16.4851 | -6.8809 |
| | WC-E | -14.3950* | 1.62535 | .000 | -19.1971 | -9.5929 |
| | WC-F | -15.9230* | 1.62535 | .000 | -20.7251 | -11.1209 |
| WC-B | WC-A | 3.8720 | 1.62535 | .181 | -.9301 | 8.6741 |
| | WC-C | 3.0970 | 1.62535 | .410 | -1.7051 | 7.8991 |
| | WC-D | -7.8110* | 1.62535 | .000 | -12.6131 | -3.0089 |
| | WC-E | -10.5230* | 1.62535 | .000 | -15.3251 | -5.7209 |
| | WC-F | -12.0510* | 1.62535 | .000 | -16.8531 | -7.2489 |
| WC-C | WC-A | .7750 | 1.62535 | .997 | -4.0271 | 5.5771 |
| | WC-B | -3.0970 | 1.62535 | .410 | -7.8991 | 1.7051 |
| | WC-D | -10.9080* | 1.62535 | .000 | -15.7101 | -6.1059 |
| | WC-E | -13.6200* | 1.62535 | .000 | -18.4221 | -8.8179 |
| | WC-F | -15.1480* | 1.62535 | .000 | -19.9501 | -10.3459 |
| WC-D | WC-A | 11.6830* | 1.62535 | .000 | 6.8809 | 16.4851 |
| | WC-B | 7.8110* | 1.62535 | .000 | 3.0089 | 12.6131 |
| | WC-C | 10.9080* | 1.62535 | .000 | 6.1059 | 15.7101 |
| | WC-E | -2.7120 | 1.62535 | .558 | -7.5141 | 2.0901 |
| | WC-F | -4.2400 | 1.62535 | .113 | -9.0421 | .5621 |
| WC-E | WC-A | 14.3950* | 1.62535 | .000 | 9.5929 | 19.1971 |
| | WC-B | 10.5230* | 1.62535 | .000 | 5.7209 | 15.3251 |
| | WC-C | 13.6200* | 1.62535 | .000 | 8.8179 | 18.4221 |
| | WC-D | 2.7120 | 1.62535 | .558 | -2.0901 | 7.5141 |
| | WC-F | -1.5280 | 1.62535 | .934 | -6.3301 | 3.2741 |
| WC-F | WC-A | 15.9230* | 1.62535 | .000 | 11.1209 | 20.7251 |
| | WC-B | 12.0510* | 1.62535 | .000 | 7.2489 | 16.8531 |
| | WC-C | 15.1480* | 1.62535 | .000 | 10.3459 | 19.9501 |
| | WC-D | 4.2400 | 1.62535 | .113 | -.5621 | 9.0421 |
| | WC-E | 1.5280 | 1.62535 | .934 | -3.2741 | 6.3301 |

* The mean difference is significant at the .05 level.

**Tukey HSD: Dependent Variable – 4” PVC**

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| WC-A | WC-B | -6.5220* | 1.68453 | .004 | -11.4989 | -1.5451 |
| | WC-C | 1.4300 | 1.68453 | .957 | -3.5469 | 6.4069 |
| | WC-D | -16.7800* | 1.68453 | .000 | -21.7569 | -11.8031 |
| | WC-E | -14.7210* | 1.68453 | .000 | -19.6979 | -9.7441 |
| | WC-F | -14.0130* | 1.68453 | .000 | -18.9899 | -9.0361 |
| WC-B | WC-A | 6.5220* | 1.68453 | .004 | 1.5451 | 11.4989 |
| | WC-C | 7.9520* | 1.68453 | .000 | 2.9751 | 12.9289 |
| | WC-D | -10.2580* | 1.68453 | .000 | -15.2349 | -5.2811 |
| | WC-E | -8.1990* | 1.68453 | .000 | -13.1759 | -3.2221 |
| | WC-F | -7.4910* | 1.68453 | .001 | -12.4679 | -2.5141 |
| WC-C | WC-A | -1.4300 | 1.68453 | .957 | -6.4069 | 3.5469 |
| | WC-B | -7.9520* | 1.68453 | .000 | -12.9289 | -2.9751 |
| | WC-D | -18.2100* | 1.68453 | .000 | -23.1869 | -13.2331 |
| | WC-E | -16.1510* | 1.68453 | .000 | -21.1279 | -11.1741 |
| | WC-F | -15.4430* | 1.68453 | .000 | -20.4199 | -10.4661 |
| WC-D | WC-A | 16.7800* | 1.68453 | .000 | 11.8031 | 21.7569 |
| | WC-B | 10.2580* | 1.68453 | .000 | 5.2811 | 15.2349 |
| | WC-C | 18.2100* | 1.68453 | .000 | 13.2331 | 23.1869 |
| | WC-E | 2.0590 | 1.68453 | .824 | -2.9179 | 7.0359 |
| | WC-F | 2.7670 | 1.68453 | .575 | -2.2099 | 7.7439 |
| WC-E | WC-A | 14.7210* | 1.68453 | .000 | 9.7441 | 19.6979 |
| | WC-B | 8.1990* | 1.68453 | .000 | 3.2221 | 13.1759 |
| | WC-C | 16.1510* | 1.68453 | .000 | 11.1741 | 21.1279 |
| | WC-D | -2.0590 | 1.68453 | .824 | -7.0359 | 2.9179 |
| | WC-F | .7080 | 1.68453 | .998 | -4.2689 | 5.6849 |
| WC-F | WC-A | 14.0130* | 1.68453 | .000 | 9.0361 | 18.9899 |
| | WC-B | 7.4910* | 1.68453 | .001 | 2.5141 | 12.4679 |
| | WC-C | 15.4430* | 1.68453 | .000 | 10.4661 | 20.4199 |
| | WC-D | -2.7670 | 1.68453 | .575 | -7.7439 | 2.2099 |
| | WC-E | -.7080 | 1.68453 | .998 | -5.6849 | 4.2689 |

* The mean difference is significant at the .05 level.

# APPENDIX H

## SPSS OUTPUT

## LAST FLUSH – MULTIPLE WATER CLOSET COMPARISONS

### Tukey HSD: Dependent Variable – 3" CI

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| WC-A | WC-B | 2.0300 | 4.09349 | .996 | -10.6268 | 14.6868 |
| | WC-C | 6.6680 | 4.09349 | .589 | -5.9888 | 19.3248 |
| | WC-D | -50.8160* | 4.09349 | .000 | -63.4728 | -38.1592 |
| | WC-E | -52.2020* | 4.09349 | .000 | -64.8588 | -39.5452 |
| | WC-F | -45.0260* | 4.09349 | .000 | -57.6828 | -32.3692 |
| WC-B | WC-A | -2.0300 | 4.09349 | .996 | -14.6868 | 10.6268 |
| | WC-C | 4.6380 | 4.09349 | .863 | -8.0188 | 17.2948 |
| | WC-D | -52.8460* | 4.09349 | .000 | -65.5028 | -40.1892 |
| | WC-E | -54.2320* | 4.09349 | .000 | -66.8888 | -41.5752 |
| | WC-F | -47.0560* | 4.09349 | .000 | -59.7128 | -34.3992 |
| WC-C | WC-A | -6.6680 | 4.09349 | .589 | -19.3248 | 5.9888 |
| | WC-B | -4.6380 | 4.09349 | .863 | -17.2948 | 8.0188 |
| | WC-D | -57.4840* | 4.09349 | .000 | -70.1408 | -44.8272 |
| | WC-E | -58.8700* | 4.09349 | .000 | -71.5268 | -46.2132 |
| | WC-F | -51.6940* | 4.09349 | .000 | -64.3508 | -39.0372 |
| WC-D | WC-A | 50.8160* | 4.09349 | .000 | 38.1592 | 63.4728 |
| | WC-B | 52.8460* | 4.09349 | .000 | 40.1892 | 65.5028 |
| | WC-C | 57.4840* | 4.09349 | .000 | 44.8272 | 70.1408 |
| | WC-E | -1.3860 | 4.09349 | .999 | -14.0428 | 11.2708 |
| | WC-F | 5.7900 | 4.09349 | .718 | -6.8668 | 18.4468 |
| WC-E | WC-A | 52.2020* | 4.09349 | .000 | 39.5452 | 64.8588 |
| | WC-B | 54.2320* | 4.09349 | .000 | 41.5752 | 66.8888 |
| | WC-C | 58.8700* | 4.09349 | .000 | 46.2132 | 71.5268 |
| | WC-D | 1.3860 | 4.09349 | .999 | -11.2708 | 14.0428 |
| | WC-F | 7.1760 | 4.09349 | .513 | -5.4808 | 19.8328 |
| WC-F | WC-A | 45.0260* | 4.09349 | .000 | 32.3692 | 57.6828 |
| | WC-B | 47.0560* | 4.09349 | .000 | 34.3992 | 59.7128 |
| | WC-C | 51.6940* | 4.09349 | .000 | 39.0372 | 64.3508 |
| | WC-D | -5.7900 | 4.09349 | .718 | -18.4468 | 6.8668 |
| | WC-E | -7.1760 | 4.09349 | .513 | -19.8328 | 5.4808 |

* The mean difference is significant at the .05 level.

**Tukey HSD: Dependent Variable – 3” PVC**

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval Lower Bound | Upper Bound |
|---|---|---|---|---|---|---|
| WC-A | WC-B | 13.1600 | 5.07539 | .138 | -2.5328 | 28.8528 |
| | WC-C | 8.8660 | 5.07539 | .516 | -6.8268 | 24.5588 |
| | WC-D | -39.5560* | 5.07539 | .000 | -55.2488 | -23.8632 |
| | WC-E | -39.5560* | 5.07539 | .000 | -55.2488 | -23.8632 |
| | WC-F | -39.5560* | 5.07539 | .000 | -55.2488 | -23.8632 |
| WC-B | WC-A | -13.1600 | 5.07539 | .138 | -28.8528 | 2.5328 |
| | WC-C | -4.2940 | 5.07539 | .955 | -19.9868 | 11.3988 |
| | WC-D | -52.7160* | 5.07539 | .000 | -68.4088 | -37.0232 |
| | WC-E | -52.7160* | 5.07539 | .000 | -68.4088 | -37.0232 |
| | WC-F | -52.7160* | 5.07539 | .000 | -68.4088 | -37.0232 |
| WC-C | WC-A | -8.8660 | 5.07539 | .516 | -24.5588 | 6.8268 |
| | WC-B | 4.2940 | 5.07539 | .955 | -11.3988 | 19.9868 |
| | WC-D | -48.4220* | 5.07539 | .000 | -64.1148 | -32.7292 |
| | WC-E | -48.4220* | 5.07539 | .000 | -64.1148 | -32.7292 |
| | WC-F | -48.4220* | 5.07539 | .000 | -64.1148 | -32.7292 |
| WC-D | WC-A | 39.5560* | 5.07539 | .000 | 23.8632 | 55.2488 |
| | WC-B | 52.7160* | 5.07539 | .000 | 37.0232 | 68.4088 |
| | WC-C | 48.4220* | 5.07539 | .000 | 32.7292 | 64.1148 |
| | WC-E | .0000 | 5.07539 | 1.000 | -15.6928 | 15.6928 |
| | WC-F | .0000 | 5.07539 | 1.000 | -15.6928 | 15.6928 |
| WC-E | WC-A | 39.5560* | 5.07539 | .000 | 23.8632 | 55.2488 |
| | WC-B | 52.7160* | 5.07539 | .000 | 37.0232 | 68.4088 |
| | WC-C | 48.4220* | 5.07539 | .000 | 32.7292 | 64.1148 |
| | WC-D | .0000 | 5.07539 | 1.000 | -15.6928 | 15.6928 |
| | WC-F | .0000 | 5.07539 | 1.000 | -15.6928 | 15.6928 |
| WC-F | WC-A | 39.5560* | 5.07539 | .000 | 23.8632 | 55.2488 |
| | WC-B | 52.7160* | 5.07539 | .000 | 37.0232 | 68.4088 |
| | WC-C | 48.4220* | 5.07539 | .000 | 32.7292 | 64.1148 |
| | WC-D | .0000 | 5.07539 | 1.000 | -15.6928 | 15.6928 |
| | WC-E | .0000 | 5.07539 | 1.000 | -15.6928 | 15.6928 |

* The mean difference is significant at the .05 level.

**Tukey HSD: Dependent Variable – 4” CI**

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| WC-A | WC-B | 1.9980 | 5.30978 | .999 | -14.4195 | 18.4155 |
| | WC-C | 2.7280 | 5.30978 | .995 | -13.6895 | 19.1455 |
| | WC-D | -30.4520* | 5.30978 | .000 | -46.8695 | -14.0345 |
| | WC-E | -34.3800* | 5.30978 | .000 | -50.7975 | -17.9625 |
| | WC-F | -29.6460* | 5.30978 | .000 | -46.0635 | -13.2285 |
| WC-B | WC-A | -1.9980 | 5.30978 | .999 | -18.4155 | 14.4195 |
| | WC-C | .7300 | 5.30978 | 1.000 | -15.6875 | 17.1475 |
| | WC-D | -32.4500* | 5.30978 | .000 | -48.8675 | -16.0325 |
| | WC-E | -36.3780* | 5.30978 | .000 | -52.7955 | -19.9605 |
| | WC-F | -31.6440* | 5.30978 | .000 | -48.0615 | -15.2265 |
| WC-C | WC-A | -2.7280 | 5.30978 | .995 | -19.1455 | 13.6895 |
| | WC-B | -.7300 | 5.30978 | 1.000 | -17.1475 | 15.6875 |
| | WC-D | -33.1800* | 5.30978 | .000 | -49.5975 | -16.7625 |
| | WC-E | -37.1080* | 5.30978 | .000 | -53.5255 | -20.6905 |
| | WC-F | -32.3740* | 5.30978 | .000 | -48.7915 | -15.9565 |
| WC-D | WC-A | 30.4520* | 5.30978 | .000 | 14.0345 | 46.8695 |
| | WC-B | 32.4500* | 5.30978 | .000 | 16.0325 | 48.8675 |
| | WC-C | 33.1800* | 5.30978 | .000 | 16.7625 | 49.5975 |
| | WC-E | -3.9280 | 5.30978 | .975 | -20.3455 | 12.4895 |
| | WC-F | .8060 | 5.30978 | 1.000 | -15.6115 | 17.2235 |
| WC-E | WC-A | 34.3800* | 5.30978 | .000 | 17.9625 | 50.7975 |
| | WC-B | 36.3780* | 5.30978 | .000 | 19.9605 | 52.7955 |
| | WC-C | 37.1080* | 5.30978 | .000 | 20.6905 | 53.5255 |
| | WC-D | 3.9280 | 5.30978 | .975 | -12.4895 | 20.3455 |
| | WC-F | 4.7340 | 5.30978 | .945 | -11.6835 | 21.1515 |
| WC-F | WC-A | 29.6460* | 5.30978 | .000 | 13.2285 | 46.0635 |
| | WC-B | 31.6440* | 5.30978 | .000 | 15.2265 | 48.0615 |
| | WC-C | 32.3740* | 5.30978 | .000 | 15.9565 | 48.7915 |
| | WC-D | -.8060 | 5.30978 | 1.000 | -17.2235 | 15.6115 |
| | WC-E | -4.7340 | 5.30978 | .945 | -21.1515 | 11.6835 |

* The mean difference is significant at the .05 level.

**Tukey HSD: Dependent Variable – 4” PVC**

| (I) WC | (J) WC | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|
| | | | | | Lower Bound | Upper Bound |
| WC-A | WC-B | -1.2440 | 3.07250 | .998 | -10.7440 | 8.2560 |
| | WC-C | 5.1200 | 3.07250 | .565 | -4.3800 | 14.6200 |
| | WC-D | -62.7900* | 3.07250 | .000 | -72.2900 | -53.2900 |
| | WC-E | -55.1560* | 3.07250 | .000 | -64.6560 | -45.6560 |
| | WC-F | -38.7560* | 3.07250 | .000 | -48.2560 | -29.2560 |
| WC-B | WC-A | 1.2440 | 3.07250 | .998 | -8.2560 | 10.7440 |
| | WC-C | 6.3640 | 3.07250 | .335 | -3.1360 | 15.8640 |
| | WC-D | -61.5460* | 3.07250 | .000 | -71.0460 | -52.0460 |
| | WC-E | -53.9120* | 3.07250 | .000 | -63.4120 | -44.4120 |
| | WC-F | -37.5120* | 3.07250 | .000 | -47.0120 | -28.0120 |
| WC-C | WC-A | -5.1200 | 3.07250 | .565 | -14.6200 | 4.3800 |
| | WC-B | -6.3640 | 3.07250 | .335 | -15.8640 | 3.1360 |
| | WC-D | -67.9100* | 3.07250 | .000 | -77.4100 | -58.4100 |
| | WC-E | -60.2760* | 3.07250 | .000 | -69.7760 | -50.7760 |
| | WC-F | -43.8760* | 3.07250 | .000 | -53.3760 | -34.3760 |
| WC-D | WC-A | 62.7900* | 3.07250 | .000 | 53.2900 | 72.2900 |
| | WC-B | 61.5460* | 3.07250 | .000 | 52.0460 | 71.0460 |
| | WC-C | 67.9100* | 3.07250 | .000 | 58.4100 | 77.4100 |
| | WC-E | 7.6340 | 3.07250 | .168 | -1.8660 | 17.1340 |
| | WC-F | 24.0340* | 3.07250 | .000 | 14.5340 | 33.5340 |
| WC-E | WC-A | 55.1560* | 3.07250 | .000 | 45.6560 | 64.6560 |
| | WC-B | 53.9120* | 3.07250 | .000 | 44.4120 | 63.4120 |
| | WC-C | 60.2760* | 3.07250 | .000 | 50.7760 | 69.7760 |
| | WC-D | -7.6340 | 3.07250 | .168 | -17.1340 | 1.8660 |
| | WC-F | 16.4000* | 3.07250 | .000 | 6.9000 | 25.9000 |
| WC-F | WC-A | 38.7560* | 3.07250 | .000 | 29.2560 | 48.2560 |
| | WC-B | 37.5120* | 3.07250 | .000 | 28.0120 | 47.0120 |
| | WC-C | 43.8760* | 3.07250 | .000 | 34.3760 | 53.3760 |
| | WC-D | -24.0340* | 3.07250 | .000 | -33.5340 | -14.5340 |
| | WC-E | -16.4000* | 3.07250 | .000 | -25.9000 | -6.9000 |

* The mean difference is significant at the .05 level.

# APPENDIX I

## SPSS OUTPUT

## FIRST FLUSH -WATER CLOSET HOMOGENEOUS SUBSETS

**Tukey HSD: 3”CI**

| WC | N | Subset for alpha = .05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| WC-A | 10 | 16.8340 | | |
| WC-C | 10 | 17.2840 | | |
| WC-B | 10 | 21.8560 | | |
| WC-E | 10 | | 40.1810 | |
| WC-D | 10 | | 44.5080 | 44.5080 |
| WC-F | 10 | | | 48.2920 |
| Sig. | | .391 | .558 | .691 |

Means for groups in homogeneous subsets are displayed.

**Tukey HSD: 3”PVC**

| WC | N | Subset for alpha = .05 | |
|---|---|---|---|
| | | 1 | 2 |
| WC-B | 10 | 39.3140 | |
| WC-C | 10 | 45.8150 | |
| WC-A | 10 | 49.2350 | |
| WC-E | 10 | | 90.2310 |
| WC-D | 10 | | 92.6270 |
| WC-F | 10 | | 98.4210 |
| Sig. | | .357 | .570 |

Means for groups in homogeneous subsets are displayed.

**Tukey HSD: 4”CI**

| WC | N | Subset for alpha = .05 | |
|---|---|---|---|
| | | 1 | 2 |
| WC-A | 10 | 12.5190 | |
| WC-C | 10 | 13.2940 | |
| WC-B | 10 | 16.3910 | |
| WC-D | 10 | | 24.2020 |
| WC-E | 10 | | 26.9140 |
| WC-F | 10 | | 28.4420 |
| Sig. | | .181 | .113 |

Means for groups in homogeneous subsets are displayed.

**Tukey HSD: 4”PVC**

| WC | N | Subset for alpha = .05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| WC-C | 10 | 16.2920 | | |
| WC-A | 10 | 17.7220 | | |
| WC-B | 10 | | 24.2440 | |
| WC-F | 10 | | | 31.7350 |
| WC-E | 10 | | | 32.4430 |
| WC-D | 10 | | | 34.5020 |
| Sig. | | .957 | 1.000 | .575 |

Means for groups in homogeneous subsets are displayed.

# APPENDIX J

## SPSS OUTPUT

## LAST FLUSH -WATER CLOSET HOMOGENEOUS SUBSETS

**Tukey HSD: 3”CI**

| WC | N | Subset for alpha = .05 | |
|---|---|---|---|
| | | 1 | 2 |
| WC-C | 5 | 27.2660 | |
| WC-B | 5 | 31.9040 | |
| WC-A | 5 | 33.9340 | |
| WC-F | 5 | | 78.9600 |
| WC-D | 5 | | 84.7500 |
| WC-E | 5 | | 86.1360 |
| Sig. | | .589 | .513 |

Means for groups in homogeneous subsets are displayed.

**Tukey HSD: 3” PVC**

| WC | N | Subset for alpha = .05 | |
|---|---|---|---|
| | | 1 | 2 |
| WC-B | 5 | 47.2840 | |
| WC-C | 5 | 51.5780 | |
| WC-A | 5 | 60.4440 | |
| WC-D | 5 | | 100.0000 |
| WC-E | 5 | | 100.0000 |
| WC-F | 5 | | 100.0000 |
| Sig. | | .138 | 1.000 |

Means for groups in homogeneous subsets are displayed.

**Tukey HSD: 4” CI**

| WC | N | Subset for alpha = .05 | |
|---|---|---|---|
| | | 1 | 2 |
| WC-C | 5 | 21.1980 | |
| WC-B | 5 | 21.9280 | |
| WC-A | 5 | 23.9260 | |
| WC-F | 5 | | 53.5720 |
| WC-D | 5 | | 54.3780 |
| WC-E | 5 | | 58.3060 |
| Sig. | | .995 | .945 |

Means for groups in homogeneous subsets are displayed.

**Tukey HSD: 4” PVC**

| WC | N | Subset for alpha = .05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| WC-C | 5 | 26.4020 | | |
| WC-A | 5 | 31.5220 | | |
| WC-B | 5 | 32.7660 | | |
| WC-F | 5 | | 70.2780 | |
| WC-E | 5 | | | 86.6780 |
| WC-D | 5 | | | 94.3120 |
| Sig. | | .335 | 1.000 | .168 |

Means for groups in homogeneous subsets are displayed.

# APPENDIX K

## FIRST FLUSH - MULTIPLE PIPE COMPARISONS

**Tukey HSD**

| Dependent Variable | (I) PIPE | (J) PIPE | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| Pipe - 1.6 | 4"CI | 4"PVC | -5.3513* | 1.81626 | .020 | -10.0857 | -.6169 |
| | | 3"CI | -4.5900 | 1.81626 | .061 | -9.3244 | .1444 |
| | | 3"PVC | -30.7200* | 1.81626 | .000 | -35.4544 | -25.9856 |
| | 4"PVC | 4"CI | 5.3513* | 1.81626 | .020 | .6169 | 10.0857 |
| | | 3"CI | .7613 | 1.81626 | .975 | -3.9731 | 5.4957 |
| | | 3"PVC | -25.3687* | 1.81626 | .000 | -30.1031 | -20.6343 |
| | 3"CI | 4"CI | 4.5900 | 1.81626 | .061 | -.1444 | 9.3244 |
| | | 4"PVC | -.7613 | 1.81626 | .975 | -5.4957 | 3.9731 |
| | | 3"PVC | -26.1300* | 1.81626 | .000 | -30.8644 | -21.3956 |
| | 3"PVC | 4"CI | 30.7200* | 1.81626 | .000 | 25.9856 | 35.4544 |
| | | 4"PVC | 25.3687* | 1.81626 | .000 | 20.6343 | 30.1031 |
| | | 3"CI | 26.1300* | 1.81626 | .000 | 21.3956 | 30.8644 |
| Pipe - 3.5 | 4"CI | 4"PVC | -6.6740* | 1.86746 | .003 | -11.5418 | -1.8062 |
| | | 3"CI | -17.8077* | 1.86746 | .000 | -22.6755 | -12.9398 |
| | | 3"PVC | -67.2903* | 1.86746 | .000 | -72.1582 | -62.4225 |
| | 4"PVC | 4"CI | 6.6740* | 1.86746 | .003 | 1.8062 | 11.5418 |
| | | 3"CI | -11.1337* | 1.86746 | .000 | -16.0015 | -6.2658 |
| | | 3"PVC | -60.6163* | 1.86746 | .000 | -65.4842 | -55.7485 |
| | 3"CI | 4"CI | 17.8077* | 1.86746 | .000 | 12.9398 | 22.6755 |
| | | 4"PVC | 11.1337* | 1.86746 | .000 | 6.2658 | 16.0015 |
| | | 3"PVC | -49.4827* | 1.86746 | .000 | -54.3505 | -44.6148 |
| | 3"PVC | 4"CI | 67.2903* | 1.86746 | .000 | 62.4225 | 72.1582 |
| | | 4"PVC | 60.6163* | 1.86746 | .000 | 55.7485 | 65.4842 |
| | | 3"CI | 49.4827* | 1.86746 | .000 | 44.6148 | 54.3505 |

* The mean difference is significant at the .05 level.

# APPENDIX L

## LAST FLUSH - MULTIPLE PIPE COMPARISONS

### Tukey HSD

| Dependent Variable | (I) PIPE | (J) PIPE | Mean Difference (I-J) | Std. Error | Sig. | 95% Confidence Interval | |
|---|---|---|---|---|---|---|---|
| | | | | | | Lower Bound | Upper Bound |
| Pipe - 1.6 | 4”CI | 4”PVC | -7.8800(*) | 2.48526 | .013 | -14.4607 | -1.2993 |
| | | 3”CI | -8.6847(*) | 2.48526 | .005 | -15.2654 | -2.1040 |
| | | 3”PVC | -30.7520(*) | 2.48526 | .000 | -37.3327 | -24.1713 |
| | 4”PVC | 4”CI | 7.8800(*) | 2.48526 | .013 | 1.2993 | 14.4607 |
| | | 3”CI | -.8047 | 2.48526 | .988 | -7.3854 | 5.7760 |
| | | 3”PVC | -22.8720(*) | 2.48526 | .000 | -29.4527 | -16.2913 |
| | 3”CI | 4”CI | 8.6847(*) | 2.48526 | .005 | 2.1040 | 15.2654 |
| | | 4”PVC | .8047 | 2.48526 | .988 | -5.7760 | 7.3854 |
| | | 3”PVC | -22.0673(*) | 2.48526 | .000 | -28.6480 | -15.4866 |
| | 3”PVC | 4”CI | 30.7520(*) | 2.48526 | .000 | 24.1713 | 37.3327 |
| | | 4”PVC | 22.8720(*) | 2.48526 | .000 | 16.2913 | 29.4527 |
| | | 3”CI | 22.0673(*) | 2.48526 | .000 | 15.4866 | 28.6480 |
| Pipe - 3.5 | 4”CI | 4”PVC | -29.3373(*) | 3.41825 | .000 | -38.3885 | -20.2862 |
| | | 3”CI | -28.8633(*) | 3.41825 | .000 | -37.9145 | -19.8122 |
| | | 3”PVC | -45.5813(*) | 3.41825 | .000 | -54.6325 | -36.5302 |
| | 4”PVC | 4”CI | 29.3373(*) | 3.41825 | .000 | 20.2862 | 38.3885 |
| | | 3”CI | .4740 | 3.41825 | .999 | -8.5771 | 9.5251 |
| | | 3”PVC | -16.2440(*) | 3.41825 | .000 | -25.2951 | -7.1929 |
| | 3”CI | 4”CI | 28.8633(*) | 3.41825 | .000 | 19.8122 | 37.9145 |
| | | 4”PVC | -.4740 | 3.41825 | .999 | -9.5251 | 8.5771 |
| | | 3”PVC | -16.7180(*) | 3.41825 | .000 | -25.7691 | -7.6669 |
| | 3”PVC | 4”CI | 45.5813(*) | 3.41825 | .000 | 36.5302 | 54.6325 |
| | | 4”PVC | 16.2440(*) | 3.41825 | .000 | 7.1929 | 25.2951 |
| | | 3”CI | 16.7180(*) | 3.41825 | .000 | 7.6669 | 25.7691 |

* The mean difference is significant at the .05 level.

# APPENDIX M

## FIRST FLUSH - PIPE HOMOGENEOUS SUBSETS

### Tukey HSD: 1.6 gpf Water Closet Group

| Pipe | N | Subset for alpha = .05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 4”CI | 30 | 14.0680 | | |
| 3”CI | 30 | 18.6580 | 18.6580 | |
| 4”PVC | 30 | | 19.4193 | |
| 3”PVC | 30 | | | 44.7880 |
| Sig. | | .061 | .975 | 1.000 |

Means for groups in homogeneous subsets are displayed.

### Tukey HSD: 3.5 gpf Water Closet Group

| Pipe | N | Subset for alpha = .05 | | | |
|---|---|---|---|---|---|
| | | 1 | 2 | 3 | 4 |
| 4”CI | 30 | 26.5193 | | | |
| 4”PVC | 30 | | 33.1933 | | |
| 3”CI | 30 | | | 44.3270 | |
| 3”PVC | 30 | | | | 93.8097 |
| Sig. | | 1.000 | 1.000 | 1.000 | 1.000 |

Means for groups in homogeneous subsets are displayed.

# APPENDIX N

## LAST FLUSH - PIPE HOMOGENEOUS SUBSETS

### Tukey HSD: 1.6 gpf Water Closet Group

| PIPE | N | Subset for alpha = .05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 4”CI | 15 | 22.3500 | | |
| 4”PVC | 15 | | 30.2300 | |
| 3”CI | 15 | | 31.0347 | |
| 3”PVC | 15 | | | 53.1020 |
| Sig. | | 1.000 | .988 | 1.000 |

Means for groups in homogeneous subsets are displayed.

### Tukey HSD: 3.5 gpf Water Closet Group

| PIPE | N | Subset for alpha = .05 | | |
|---|---|---|---|---|
| | | 1 | 2 | 3 |
| 4”CI | 15 | 54.4187 | | |
| 3”CI | 15 | | 83.2820 | |
| 4”PVC | 15 | | 83.7560 | |
| 3”PVC | 15 | | | 100.0000 |
| Sig. | | 1.000 | .999 | 1.000 |

Means for groups in homogeneous subsets are displayed.

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