# DRAIN LINE CLOGS WITH A 1.6 GALLON PER FLUSH WATER CLOSET

by

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# Abstract

Typical building sanitary lines are sloped at a minimum of 1/8” to utilize gravity and prevent liquid separation from solid waste. The purpose of this research is to analyze how a lesser amount of water from a 1.6 gallon per flush water closet affects drainage in a four inch diameter pipe at 1/4" slope. Low flow water closet manufacturers ensure that waste clears the bowl, but there is no significant research following the flushed water further down the pipe line. This research utilizes a 1.6 gallon per flush floor-mounted water closet connected to 30 feet of sloped four inch PVC Drain Waste Vent piping.

Data presented from 25 flush trials indicates that further research needs to be conducted at a smaller pipe diameter. Four-inch piping is too large, causing the 1.6 gallons of water to quickly lose the required force over the course of 30 feet, resulting in pipe line clogs. An average of four additional water-only flushes are necessary to completely clear the test media and toilet paper from the pipe.

This research references previously published research and focuses on test results presented by the Plumbing Efficiency Research Coalition. Two case studies of city wide replacements of old water closets are presented to discuss the viability of city wide mandates in relation to water conservation.

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# Acronyms

| | |
|---|---|
| American National Standards Institute | ANSI |
| American Society of Mechanical Engineers | ASME |
| Drain Waste Vent | DWV |
| Gallons Per Capita Per Day | gcpd |
| Gallons Per Flush | gpf |
| Low Flow Fixtures | lff |
| Low Flow Water Closets | lfwc |
| Million Gallons Per Day | mgd |
| The Plumbing Efficiency Research Coalition | PERC |
| Pounds Per Square Inch | psi |

# Acknowledgements

This project would not have been possible without the support of many people. Many thanks to my adviser, Thomas Logan (Tom), who helped make this project possible with his experience and expertise. Also thanks to my committee members, Don Phillippi and Charles Burton (Chuck), who offered guidance and support. And finally, thanks to the Architectural Engineering Department and numerous friends who endured the crazy shenanigans I came up with every couple of months to get this project completed.

# Chapter 1 - Introduction

Sanitary lines are sloped and oversized to assist the flow of solid materials out of the building. Water closets in the past have typically consumed between four to six gallons per flush (gpf) to ensure discharge of waste. The large amount of water expended made water closets the top water consumers in buildings.

With environmental concerns, governments around the world have begun to add laws to restrict water consumption and enforce the use of low flow fixtures. In the United States, the Energy Policy Act of 1992 prohibits manufacturers from producing large water consuming plumbing fixtures in Section 123 “Energy Conservation Requirements for Certain Lamps and Plumbing Projects”. Many towns and cities follow the Uniform Plumbing Code (UPC) or the International Plumbing Code (IPC), both of which address and restrict water usage. Several states are enforcing low flow fixtures (lff) that exceed code standards, shown in Table 1.1, on the following page.

Table 1.1, on the following page, displays the year the states enacted a law concerning water usage and lists the maximum allowable water usage for common plumbing fixtures. More information about individual state statutes and legislation can be found on the National Conference of State Legislatures (NCSL) website.

**Table 1.1 Maximum Allowed Flow Rates for States with Efficiency Standards**

| State | Effective Date | Toilet (gpf) | Urinal (gpf) | Lavatory (gpm) | Kitchen Faucet (gpm) | Shower (gpm) |
|---|---|---|---|---|---|---|
| California | January 1, 2014 | 1.28 | 0.5 | 2.2 | 2.2 | 2.5 |
| Colorado | September 1, 2016 | 1.28 | 0.5 | 1.5 | NA | 2 |
| Conneticut | October 1, 1990 | NA | 1 | 0.5 | 2.5 | 2.5 |
|  | January 1, 1992 | 1.6 | - | - | - | - |
| Iowa | January 1, 1991 | 3 | NA | NA | NA | NA |
| Georgia | July 1, 2012 | 1.28 | 0.5 | 1.5 | 2 | 2.5 |
| Nevada | March 1, 1993 | 1.6 | 1 | 2.5 | 2.5 | 2.5 |
| New York | July 23, 2002 | 1.6 | 1 | 2.5 | 2.5 | 2.5 |
| Texas | January 1, 2014 | 1.28 | 0.5 | 2.2 | 2.2 | 2.5 |
| Washington | July 1, 2993 | 1.6 | 1 | 2.5 | 2.5 | 2.5 |
|  | July 1, 2016 | 1.28 | - | 0.5 | 2.2 | - |
| Massachusetts | September 1, 2015 | 1.6 | 1 | NA | NA | NA |
|  | January 1, 2019 | 1.28 | 0.5 | - | - | - |
| Rhode Island | January 1, 2016 | 1.3 | 0.125 | 1.5 | NA | NA |

*Referenced from the National Conference of State Legislatures (NCSL) Website*

Lff were introduced in the late 1980s and were quickly inundated with complaints. Showerheads and faucets did not produce enough pressure while water closets clogged too often. This forced improvement to comply with water regulations. The market currently offers 0.8, 1.28, and 1.6 gpf water closets that employ different mechanisms to achieve proper discharge with less water.

The remainder of this paper is organized into three sections:

Chapter 2 will discuss low flow water closets (lfwc) and problems with drain line blockages. Chapter 3 will present the testing methodology and the effects of a 1.6 gpf water closet on pipe line drainage. Finally, Chapter 4 will present two case studies: the Delaware River Basin and San Simeon, to discuss the efficacy of implementing lfwc in a city. These case studies will impart the feasibility and savings of such a large change.

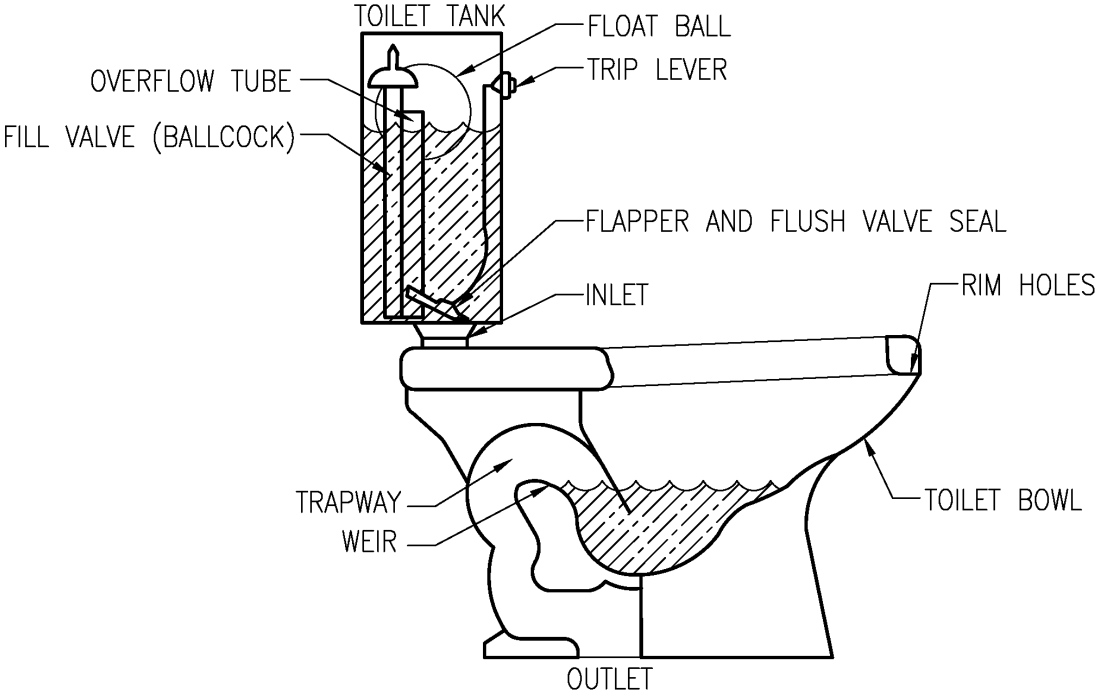
# Chapter 2 - Low Flow Water Closets

Lfwc have been researched and designed by manufacturers to clear waste from the bowl, but there has not been significant research on pipe line clogs – blockages in the line before exiting the building. Water closets follow ASME/ANSI A112.19.2 testing standards for performance. Water closets can also be tested for a "EPA WaterSense" label.

## The Mechanics of a Water Closet

Traditional water closets use gravity to clear the bowl in residential applications. When the handle is operated, the flush valve opens and the water is released. The force from gravity pulls water into the bowl and forces the waste out while the tank refills. Gravity is assisted through siphoning because the bowl is attached to the outlet via an integral trap. The components can be seen in the cross section in Figure 2.1, below.

**Figure 2.1 Gravity and Siphon Tank Water Closet Cross Section**



*Replicated from Renovation Headquarters.*

The weir and the trap way are areas related to the siphoning action and comprises the integral trap. This tank system is inexpensive and replacement parts are simple to install. Lfwc use either A) gravity, as shown in Figure 2.1, or B) compressed air to operate.

A) Gravity is similar to the method discussed above, but is improved upon by increasing the siphoning action. This is assisted by glazing the entire fixture and optimally designing the bowl and integral trap using 3-D modeling and computer testing applications. Different models use various mechanisms to ensure a low gpf while clearing the bowl. Models that utilize gravity have a mechanism that restrict water flow. Some common examples are:
   a. A fitting around the flapper,
   b. An adjustable ball cock that cuts off the flow, or
   c. A bucket device that pulls water from the top of the tank to utilize head pressure.

B) Compressing any gas will result in higher pressure and force. This is exploited by having the pressurized air apply force on the water. The sudden release of pressure causes the loud noise associated with many lfwc. These water closets utilize simple mechanisms that are calibrated to clear the bowl with less water while retaining the traditional water closet appearance of a floor mounted tank water closet or a flush valve water closet. These models generally force water out of a “siphoning jet” hole at the base of the rim to directly push water down. Some examples of these systems are:
   a. Compressed air in a vessel in the tank that applies force and refills after use,
   b. The air above the water is compressed to exert more force when flushed, or
   c. Two internal compartments create a vacuum to force water into the bowl.

Tank water closets require 10 pounds per square inch (psi) or less depending on the model and flush valve water closets require 15 psi to operate therefore flush valves are usually directly or indirectly connected to the building water line, resulting in highly pressurized water that easily clears the bowl. Some will employ one of the low flow mechanisms mentioned above and have it hidden in a tank behind the water closet.

## PERC Findings About Low Flow Water Closets

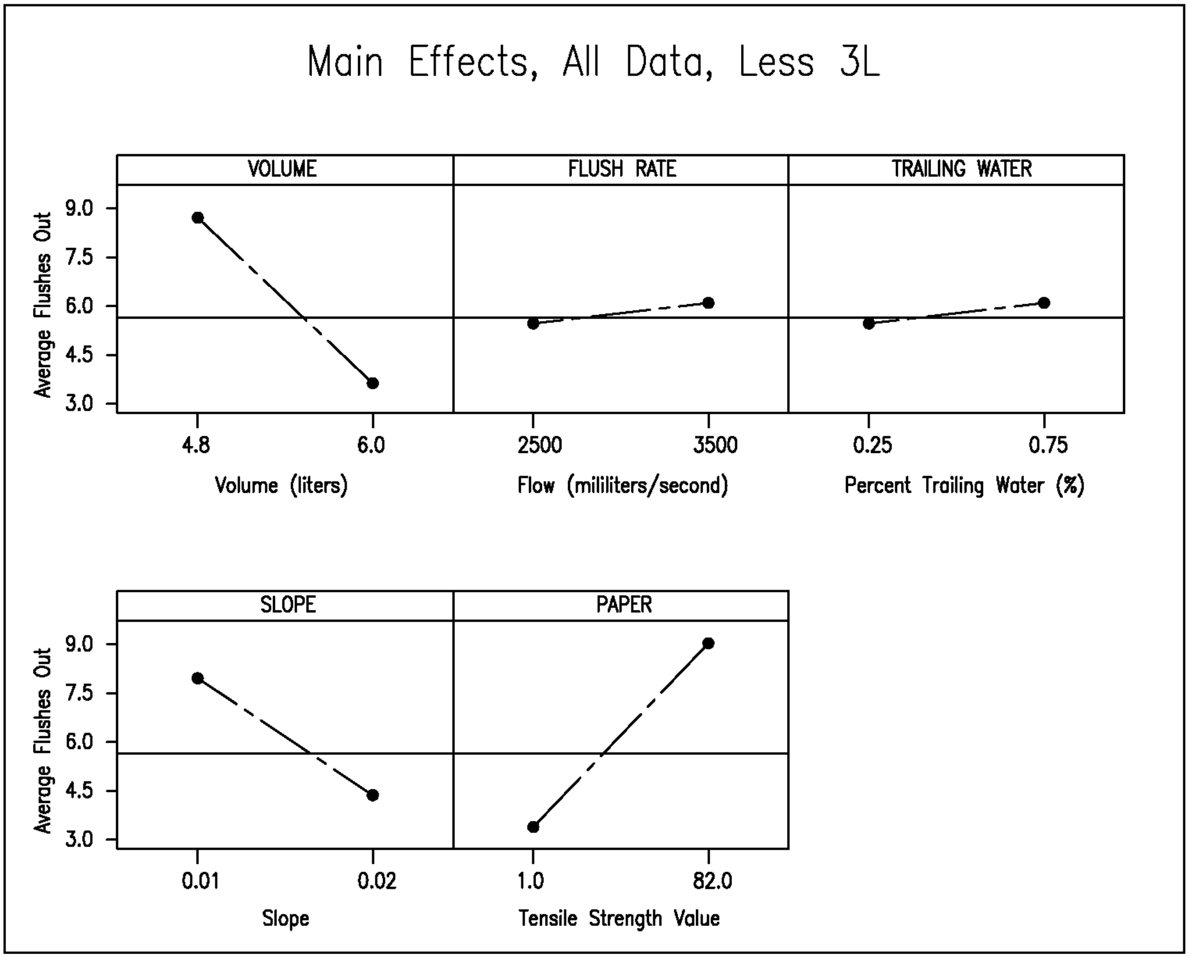
The Plumbing Efficiency Research Coalition (PERC) was organized to research pipe line drainage using lfwc. PERC published their findings in *The Drainline Transport of Solid Waste in Buildings* report in November 2012. The research concluded that the 1.28 and 1.6 gpf fixtures have consistent results are effective in discharging waste, and can be used in new and retrofit projects. However, 0.8 gpf fixtures need further testing before any final statements can be said about their effectiveness due to widely varied results, making 0.8 gpf fixtures unreliable for commercial use.

PERC ran experiments using clear piping and a controlled surge injector rather than a water closet. Different brands of water closets boast different flushing methods, making an ‘ideal’ selection difficult. Water closets and their associated water discharge assembly may skew results if installed incorrectly. Using the surge injector ensures consistent control over the gpf whereas improperly installed water closets may shift during testing or may not drain correctly, affecting the flush rate and volume and ultimately, the results.

The PERC study focused on several factors correlated to pipe line blockage: the amount of toilet paper used, the volume of water, the slope of the pipe, the flush rate of the water closet, and the amount of trailing water.

It seems intuitive to believe that a large volume of water will have a large effect on drainage. Contrasting this, the PERC study discovered that a high volume of water does not always clear drain lines and should not be relied on. The data in Figure 2.2, on the following page, is a compilation of trials for 1.28 and 1.6 gpf runs (0.8 gpf trials were excluded due to unreliable results) from the PERC research. The PERC researchers documented their data using metric units: 3 liters is equivalent to 0.8 gallons in standard units, the slope of 0.01 and 0.02 is equivalent to 1/8” and 1/4" per foot, and the tensile strength value was determined for the toilet paper the researchers used with 1.0 signifying single ply paper and 82.0 for two-ply paper. ‘Trailing water’ is the amount of water following the flush to assist the flow of waste. The research ran several hundred flushes and averaged them to get the vertical axis “Average Flushes Out”. The more horizontal the line, the less significant the variable is in affecting the drainage.

**Figure 2.2 Compiled Data for the 1.28 and 1.6 GPF Trials**



*Replicated from the PERC research (2012).*

According to Figure 2.2, the toilet paper and pipe slope, albeit in conjunction with the volume of water had a larger effect on drainage while the speed of the water in the pipe and the trailing water are not significant.

## Pipe Blockage Problems

The introduction of lff brought doubts about pipe line blockages questioning whether with less water the waste is leaving the building. Waste piping is sloped to help prevent the solids and liquids from separating and the pipe is generally oversized to accommodate the solids and large volumes of water used in the past. Waste poses a health hazard if not properly disposed of or treated – waterborne pathogens are highly dangerous and can spread with leaks.

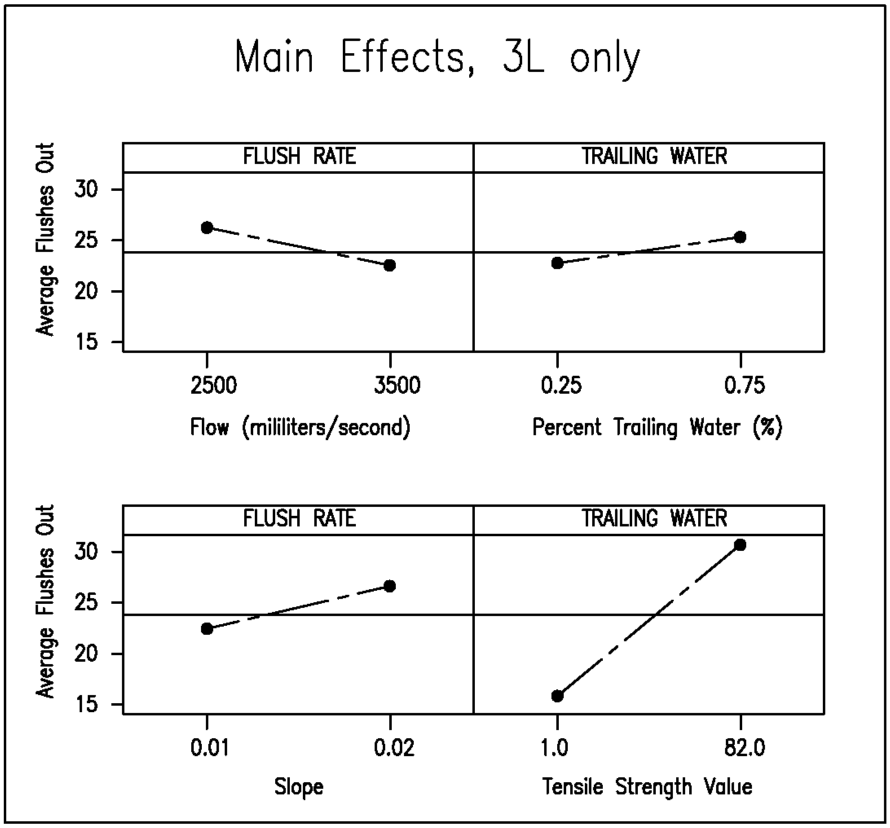
The PERC study concludes that additional flushes of water are not consistent in clearing pipe lines and reinforces the need for further research on pipe line drainage:

"- movement of the solids occurred independently of the subsequent flushes and occurred only when the weight of the water behind the solids overcame the friction of the solids resting on the interior of the pipe wall -" (PERC, 2012).

The erratic results of the 0.8 gpf trials from the PERC study suggests that there may be a tipping point for water volume in relations to the slope of a pipe. This is shown in Figure 2.3, on the following page.

The data in Figure 2.3, on the following page, is a compilation of the 0.8 gpf trials. This figure was created using the same concept as Figure 2.2, on page seven, and can be compared. In figure 2.3 (the 0.8 gpf trails) the slope of the graphs vary from Figure 2.2. The inverse slope and the angle of the data suggests that a smaller pipe slope is more effective in draining the line while a steeper pipe slope results in early separation. It also suggests that there may be a point where there is not enough water or force to overcome the friction of the solids sitting on the pipe.

**Figure 2.3 Data for 0.8 GPF Trials**



*Replicated from the PERC Research (2012).*

# Chapter 3 - Research

Water closets are tested to clear the bowl, but this testing does not account for what may happen down the line after waste clears the bowl. Typical water closet testing uses synthetic fecal matter made from soybean paste extruded into a plastic casing. The average male discharges around 250 grams of waste and some water closets are tested to flush over 650 grams of replicated waste. This research follows the PERC research by including toilet paper with the replicated waste to simulate realistic situations.

## Testing Plans

A 1.6 gpf floor mounted tank water closet is connected to 30 feet of four inch diameter PVC DWV piping. The water closet outlet is vertically connected to a wye and then connected to 30 feet of piping by another wye, both used as a clean out at the turns. Details of the water closet and transition connection, as well as a plan drawing are shown in Figures 3.1 and 3.2, on the following pages.

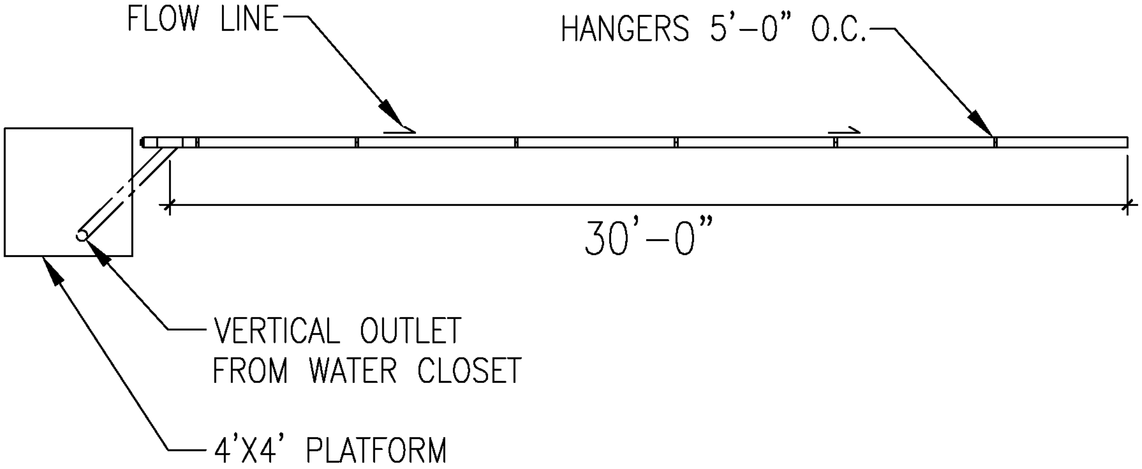
**Figure 3.1 Floor Mounted Water Closet Connections and Transitions**

(a) Floor mounted water closet on platform with water connection

(b) Vertical connection and transition

(c) Connection to the 30-feet run

**Figure 3.2 Experiment Assembly Plan View**



The experiment analyzed the effects of flow at 1/4" per foot slope in lieu of the more common 1/8” per foot slope to observe results when the slope is steeper to assist the flow. 25 flushes were run. Test media and toilet paper must clear 30 feet of PVC drain waste vent (DWV) piping. The amount of additional water-only flushes to clear the line will be recorded.

Four wads of six sheets of two-ply toilet paper were flushed with six 50 gram rolls of test media, made by Maximum Performance, totaling in 300 grams. Maximum Performance’s test media is used by many developers to test water closets and have become an industry standard testing material. This test media is a mixture of soybean paste that has been extruded into plastic casings. The PERC researchers documented the average waste discharged to be around 250 grams and ran their experiments with 300 and 200 gram trials. The test media is shown in Figure 3.3, on the following page.

**Figure 3.3 Encased Test Media**

## Results

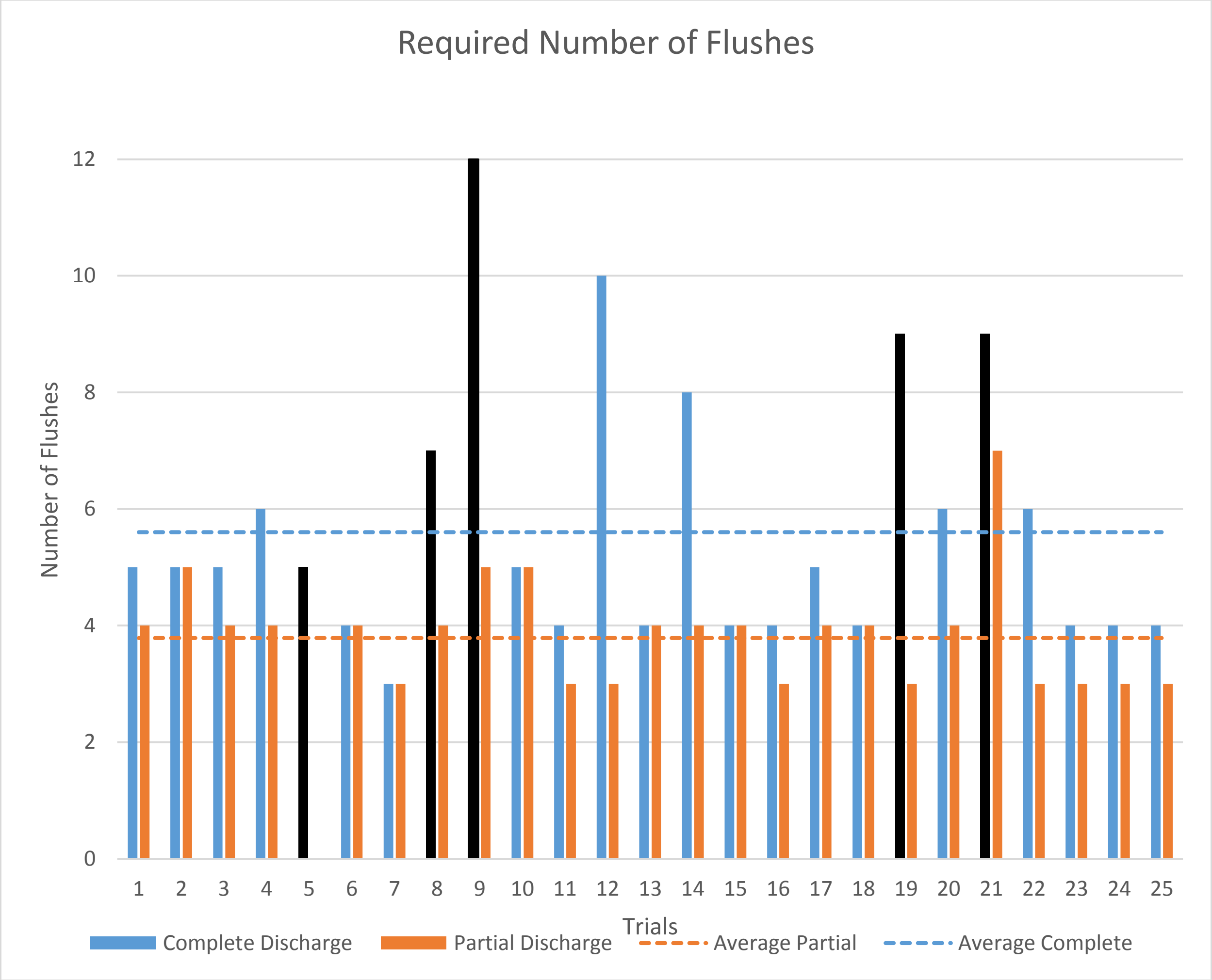
During testing, the test media and toilet paper were flushed and observed to clear the bowl of an 1.6 gallon per flush floor mounted tank water closet. Following this, if the test media and the toilet paper did not completely exit 30 feet of piping sloped at 1/4" per foot, additional water-only flushes were applied to help “push” the test subjects out of the piping. Table 3.1, on the following page, display the amount of flushes needed to clear the line for 25 flushes.

**Table 3.1 Number of Flushes to Clear 30 Feet of Piping**

| | **Number of Flushes for:** | |
|---|---|---|
| **Trial** | **Partial Discharge** | **Complete Discharge** |
| 1 | 4 | 5 |
| 2 | 5 | 5 |
| 3 | 4 | 5 |
| 4 | 4 | 6 |
| 5 | 0 | 5 |
| 6 | 4 | 4 |
| 7 | 3 | 3 |
| 8 | 4 | 7 |
| 9 | 5 | 12 |
| 10 | 5 | 5 |
| 11 | 3 | 4 |
| 12 | 3 | 10 |
| 13 | 4 | 4 |
| 14 | 4 | 8 |
| 15 | 4 | 4 |
| 16 | 3 | 4 |
| 17 | 4 | 5 |
| 18 | 4 | 4 |
| 19 | 3 | 9 |
| 20 | 4 | 6 |
| 21 | 7 | 9 |
| 22 | 3 | 6 |
| 23 | 3 | 4 |
| 24 | 3 | 4 |
| 25 | 3 | 4 |

The ‘Partial Discharge’ column records the number of flushes it took for one or some of the test media to clear the pipe, while the ‘Complete Discharge’ column records the total number of flushes to completely clear the pipe of all test media and toilet paper. This data is compiled into a graph, shown in Figure 3.4, on the following page.

**Figure 3.4 Required Number of Flushes to Clear 30 Feet of Piping**



The data resulted in an average of 3.7 flushes for partial discharge and 5.8 flushes for complete discharge, illustrated by the dashed lines in Figure 3.4, above. The black data (five out of the 25 trials) highlights pipe clogs that did not clear regardless of the number of additional water-only flushes. The difference in the amount of flushes for the clogged trails was dependent on when the solids stopped moving in the pipe. The test media and toilet paper could be seen in the pipe, but did not budge with the oncoming rush of water, shown in Figure 3.5, on the following page.

**Figure 3.5 Pipe Clog Example**

The situation shown in Figure 3.5, above, is for trial 14 before final discharge, but is typical for the seven clog situations – the test media could be seen but every additional flush only moved the test media and toilet paper approximately half an inch at most, if at all. The test media and toilet paper were then retrieved from the pipe rather than flushed out due to low to no movement Figure 3.5 shows toilet paper is blocking the flow of water and causing the water to creep up the sides of the pipe to flow around the blockage.

## Discussion

Building sanitary lines are commonly sloped at 1/8” per foot, but this system was sloped at 1/4" per foot to analyze outcomes when the slope is steeper to assist the flow. It can be observed that there is no complete discharge with one flush in Figure 3.4. Applied to actual building applications, this is a point of concern. Larger pipes disperse water over a larger area and result in less flow while bends cause turbulence in the flow, resulting in a higher chance of a clog at that location. Many building sanitary lines are 4” or larger in diameter and if one flush cannot clear 30 feet of piping, how many flushes does it take when pipe lines are larger and longer with more bends in buildings?

In residential situations, flushes that do not contain solids occur more frequently with all plumbing fixtures connecting into a single main building sanitary line, which may assist the flow of solids out of the building. However, in commercial applications this will vary depending on the building application and occupancy, such as a gym with or without showers or an office building with or without a cafeteria. Horizontally long buildings may be a concern due to the amount of bends that may occur or the length of the run all waste must discharge into before connecting to the city mains. Vertically tall buildings stack to utilize gravity to help with the flow of waste. Existing masses in pipes can also cause blockage and stop water flow. This investigation utilized pipes which were clear of debris and solid objects for every trial, but this ideal situation may not be true for all building lines, especially in older existing buildings.

The data informs that renovation projects should pay extra attention to the type of lff that is being installed and if old piping is being replaced. There is no documentation of pipe line blockage complaints and it will likely take some time before people begin to document or report the problems. Currently, the complaints go unnoticed due to the pipe diameter shrinking overtime caused by the buildup of materials in old piping, and allowing less water to push waste further or out of the building. This research concludes that 1.6 gpf water closets need assistance to clear the pipe line when toilet paper is used, however it is effective if there is another water source upstream to prevent the need for additional flushes.

# Chapter 4 - Citywide Applications of Low Flow Fixtures

The introduction of lff was well-received globally. The United States was hesitant to mandate a nationwide switch, but with growing populations and water conservation problems, it is hard to ignore plumbing fixtures that use less water. This section will discuss the water conservation results from citywide changes to lfwc.

## The Delaware River Basin Area

The Delaware River Basin area was growing and anticipating expansions to existing water and waste treatment facilities in 1988, as well as increasing water withdrawal from the basin that needed to be conserved. The Delaware River Basin is an area with water that feeds into Pennsylvania, New York, New Jersey, and Delaware. The governors of these states formed a commission that compiled statistical data to estimate potential savings, which can be found in Jeffrey Featherstone's policy analysis report *Economic and Social Benefits of Low-Consumption Toilets in the Delaware River Basin.*

Proposed new water treatment facilities would cost around $2 million and new waste treatment facilities would cost around $4 million. With water conservation problems, the Delaware River Basin commission decided to mandate lff in new and renovated projects to help conserve water and prevent the need for new facilities. The mandate estimated savings of 40 million gallons a day (mgd) by the year 2020. Table 4.1, on the following page, lists the water consumption estimates with the new mandate.

**Table 4.1 The Delaware River Basin Estimated Water Savings**

| Peak Daily Residential Water Usage in MGD | | | | |
|---|---|---|---|---|
| **"Water-Saver"  Scenario** | | **1980** | **1990** | **2020** |
| 1980 Population not complying | | 7,012,200 | 5,609,760 | 1,402,440 |
| Water Use @ 112 gpcd* | | 785.4 | 628.3 | 157.1 |
| 1980 Population complying | | 0 | 1,402,440 | 5,609,760 |
| Water Use @ 94 gpcd | | 0 | 131.8 | 527.3 |
| Population Increase | | 0 | 364,400 | 1,424,700 |
| Water Use @ 94 gpcd | | 0 | 34.3 | 133.9 |
| **TOTAL RESIDENTAL WATER USE** | | **785.4** | **794.4** | **818.3** |

*Replicated from Featherstone, 1991.*
** gpcd is the acronym for gallons per capita per day*

Table 4.1 shows that the population was consuming around 785 mgd in 1980 and is estimated to consume around 818 mgd in 2020 with the lff mandate. With the prospects of a population growth of 1.5 million people using 94 gpcd, a 33 mgd water usage increase is small in comparison to the current 785 mgd with a population of 7 million, keeping in mind the 785 mgd is a result of old fixtures that consume large amounts of water.

The amount of water usage and savings was projected into monetary terms in the report. The Delaware River Basin commission estimated an annual 12,000 gallons per household savings and will result in a net savings of $1470 over a typical 25 year water closet life span. As a whole, this will result in capital savings of $250 million.

This case study presents the savings associated with lfwc in new and renovated projects that prevented the expansion of existing facilities. Updated information on this area's water usage in relations to this mandate was unobtainable.

## San Simeon, California

San Simeon, California is a small tourist town along the Pacific coast. California has an extensive history of drought and with an increasing tourist population, San Simeon was consuming more fresh water than the region could supply. Ocean salt water was intruding into fresh water wells and tourist numbers in the summer were exceeding the town’s waste water treatment capacity.

San Simeon decided to replace all toilets with 1.6 gpf or less fixtures. This is significant because San Simeon was the first community to require replacement of existing water closets; other communities were mandating lff for new construction. Following this mandate, San Simeon recorded the performance of the water closets, the water consumption, and the waste treatment facility operation over a two year period (further data was unobtainable).

The San Simeon project information and data are presented in Thomas Konen, Srinivasan Pongavanam, and Bruce Martin’s report *Low Flush Plumbing Fixtures and Wastewater Systems*, published in 1993, four years after the project was completed. The report documents the water closet brands, types, as well as the method of attaining data.

San Simeon estimated an overall 20% water consumption reduction with the installation of lff to assist the well water levels and the waste treatment facility. The actual savings are presented in Table 4.1, on the following page.

**Table 4.2 San Simeon Twelve Month Water Usage Data**

| Water Usage in Cubic Meters | | | |
|---|---|---|---|
| **Segment** | **Before Retrofit** | **After Retrofit** | **Savings (%)** |
| | | | |
| Residential | 30.7 | 19.8 | 36 |
| Commercial | 3.5 | 0.6 | 83 |
| Restaurant | 14.5 | 12.5 | 14 |
| Lodging | 100.7 | 60.2 | 40 |
| Irrigation | 3.1 | 0 | 100 |
| **Total** | **152.5** | **93.1** | **39** |

*Replicated from Konen, 1993.*

The water closet update was completed in December of 1989 and resulted in a total of 39% savings, almost double the estimated 20%. Water usage in Table 4.2, above, is broken down into major industries in town. It is easy to see why the lodging industry is the largest water consumer - all hotel rooms contain an individual restroom that is heavily used in the mornings and evenings, and is compounded by the amount of hotel rooms and the number of hotels in town.

San Simeon’s case is unique in that the city replaced all existing water closets to lfwc, but did not enforce other lff – showerheads and faucets. This example demonstrates that water closets are a large water consumer in the public and private sector and introducing lfwc can result in large savings. The large water savings preempts the need for new water and waste treatment facilities that would cost millions to build and maintain, while conserving and maintaining the water levels in the region.

# Chapter 5 - Conclusion

Lff have been researched and studied throughout the 1990s and have continued to improve. Water and waste treatment facilities are expected to keep up with demands from growing populations which may result in building new facilities. With only 1% of water on Earth designated as potable, it is necessary to study the leading water consumer in buildings – the water closet.

The community case studies presented in Chapter 4 prove that the use of lff result in large water and monetary savings. The case studies are dated, but are readily accessible and reliable. More recent case studies are not readily available or do not have reliable sources and documentation, therefore are not presented in this report. It can be assumed that there are larger water and monetary savings today due to better technology, more education, and cheaper manufacturing processes. Data presented in Chapter 3 strongly argues against using 1.6 gpf water closets in renovation projects due to the unknown nature of existing pipes. In new construction projects, the system can be designed to prevent clogs by decreasing the amount of bends and long runs.

The information in Chapter 3 highlight that further research about pipe line clogs should be conducted before enforcing water closets that use less than 1.6 gpf. Manufacturers have ensured that waste will clear the bowl, but there is data to suggest the amount of water from a 1.6 gpf water closet cannot clear 30 feet of four inch PVC DWV piping at 1/4" per foot slope, and that a minimum of four additional flushes are necessary to clear the pipe line.

Further research on pipe line clogs should consider the use of 3”, 2-1/2”, and 2” diameter piping to observe how solid waste, toilet paper, and less water behave in a smaller pipe. 1.28 gpf water closets also need to be researched to conclude if there are any similarities between the 1.6 and 1.28 gpf results.

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