WASTE TRANSPORT IN PIPING SYSTEMS

SERVED BY LOW-FLOW WATER CLOSETS

Texas A&M Energy Systems Lab

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Executive Summary

Waste Transport in Piping Systems Served by

Low Flow Water Closets.

(August 2005)

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The amount of water currently used in water closets in the United States is a result of the 1992 Energy Policy Act. This legislation lowered the flush volume from 3.5 gallons (13.2 L) to 1.6 gallons per flush (6 L per flush). The water closets that comply with this legislation are labeled as Low Flow Water Closets. Since their introduction, this class of water closets has received lack luster reviews from both the plumbing industry and the American public. Their apparent shortcomings are attributed to two primary areas: Bowl Clearance and Waste Transport Distance. However, as the United States continues to grow and develop, water is becoming an increasingly important commodity, especially in areas of limited rainfall and natural water sources.

Several studies have ranked water closet performances solely on bowl clearance. However, few have attempted to characterize their ability to transport waste. This report evaluates water closet performance based on waste transport.

The critical areas of the study include:

- In-depth Literature Review regarding the state of low flow water closets and public pressures regarding water closets
- Open and Closed Venting Effects on System Behavior
- Open Channel Flow Carry of Waste
- Development of Synthetic Media
- Waste Loading Sequence Effects
- Flush Discharge Curve Capturing
- Effects of Pipe Material, Size, and Slope on Waste Transport

In order to understand the physics behind the low flow water closets, a flush curve, which depicts the discharge of a load following a flush, was established for each water closet. The shape of the flush curve was determined to be specific to each water closet. When the water closets were connected to a variety of pipes (3” (75mm) diameter cast iron, 3” (75 mm) diameter PVC, 4” (100 mm) diameter cast iron, and 4” (100 mm) diameter PVC) at different slopes (1% and 2%), the ability of the water closet to transport waste was characterized by a dimensionless Flush Performance Number (FPN). This FPN is specific to each water closet technology.

While characterizing the forces associated on the waste during transport, it was determined that waste within the sewer environment continues to obey the conventional laws of physics.

Additional findings include:

- For each water closet, there is a unique discharge curve,
- For each discharge curve, there is a unique transport distance,
- To sooner the media leaves the water closet the further it travels,
- The system behaves as an open channel flow problem, and the basic laws of physics are applicable,
- Pipe slope, size, and material are critical factors in determining transport distance,
- Open and closed venting has no affect when capturing a flush curve (essential no significant system attached),
- Open and closed venting are factors when connected to a large system,
- FPN provides a number used to help make "Apples to Apples Comparison",
- Using FPN value to compare WC there is definitive separation between technology type,
  - Improved Siphon Average FPN = 0.79
  - Standard Siphon Average FPN = 0.57
  - Pressure Assisted Average FPN = 0.49
  - Dual-Cycle Average FPN = 0.45

CHAPTER I

INTRODUCTION

Background

Since the introduction of low flow water closets (LFWCs), use less the 1.6 gallons per flush (gpf) (6 L per flush) to the United States in the early 1990s, they have been criticized for their performance, specifically with respect to bowl clearance (Fallon 2002). Over the last ten years, manufacturers have made greater efforts to improve the bowl clearance ability of their LFWCs, such as, larger tank and bowl discharge throats, pressure assisted flushing, and a variety of other techniques. Several independent studies have been conducted (Henderson 2000; NAHB 2002; Gauley and Kohler 2003) to compare the bowl clearance performance of a variety of manufacturer's water closets. Few studies, however, have evaluated the waste transport abilities of low flow water closets.

Objectives

The objectives of the study include:

- Reviewing of the current literature discussing the state and history of low flow water closets and pressures regarding reducing water requirements for water closets
- Developing of synthetic media to represent waste loading
- Capturing of flush discharge curves for water closets
- Characterizing the effects of waste loading sequences

- Understanding the effects of open and closed venting on system behavior of waste transport
- Profiling the effects of pipe material, size, and slope on waste transport

Basic Plumbing System

The standard plumbing configuration for a typical bowl-tank water closet consists of four components: bowl, vent stack, sanitary drain piping, and make-up water (see Figure 1):

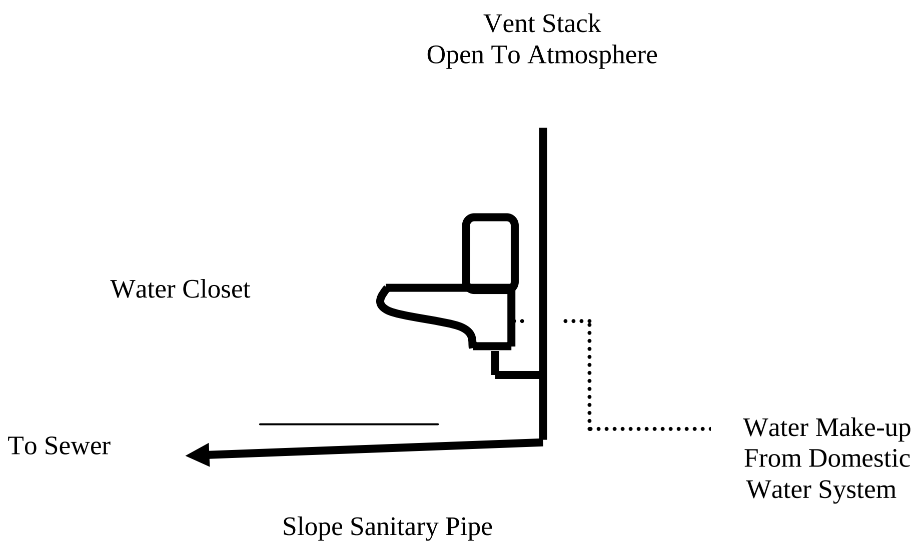


Figure 1: Typical Water Closet System Components

Bowl The bowl is the point of use by an individual. A variety of bowl designs and techniques are employed for maximum bowl clearance (see Figure 2).

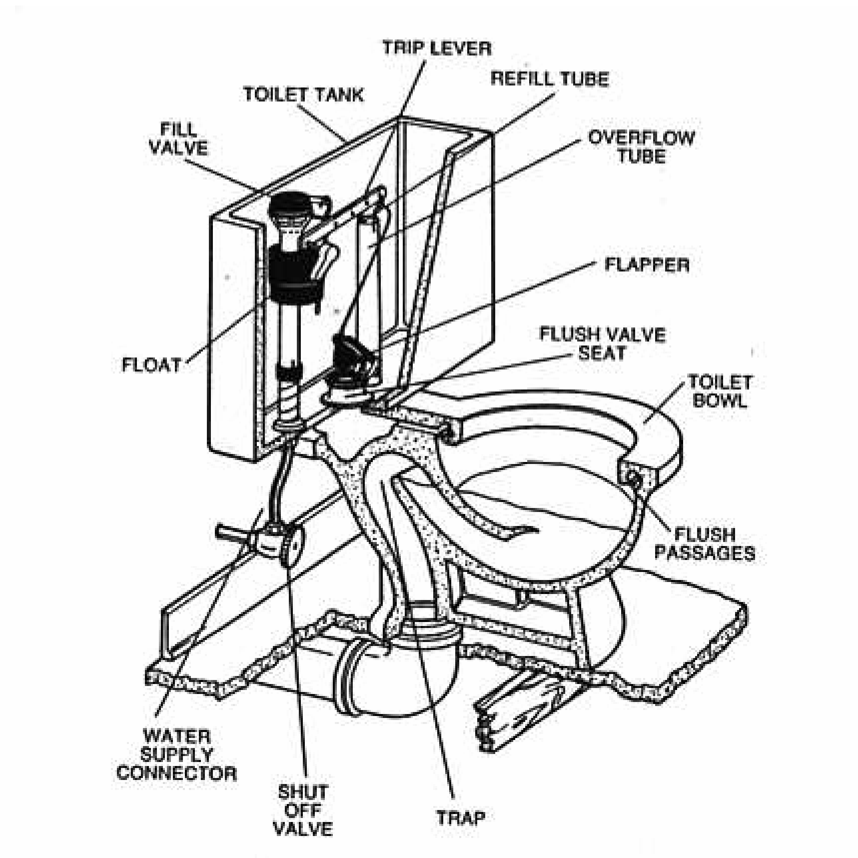


Figure 2: Typical Bowl Type Water Closet

(Source: toiletology.com 2005)

Vent Stack The vent stack was introduced following the invention of the elevator. As buildings began to be built taller, the pressure wave following the flush of a water closet on the upper floors would travel down the sanitary pipes to the lower levels and cause significant problems to the lower level plumbing system, e.g. blown out traps, broken pipes, broken fixture, etc. The vent stack relieves excess pressure of the sanitary system, either following a flush cycle or allowing the connecting sewer to "breathe."

Sanitary Piping

The sanitary piping connects the water closet to a sewer system. It carries the waste away from building to a proper location for disposal. The piping of the sanitary system is sloped downward to aid gravity in transporting the waste. The slope cannot be too flat or the waste will settle out of the flow very quickly following discharge. At the same time, it cannot be so steep that the water slug flows too fast, leaving the heavier waste behind.

Water Make-Up

The water make-up line comes from the city water source. It is not included in this study. However, for a variety of water closets, including, pressure assisted water closets, the line pressure is a factor in the performance of the water closet.

Water Closets Studied

A total of sixteen water closets were studied (see Table 1). The water closets were divided into four technology groups:

Table 1: Water-Closets Studied

Manufacturer	Model	Technology
American Standard	Doral	Siphon
Crane	Athens	Siphon
Kohler (x4)	Wellworth	Siphon
American Standard (x2)	Champion	Improved Siphon
Crane	Atlas	Improved Siphon
Kohler	Cimmeron	Improved Siphon
Toto (x2)	Drake	Improved Siphon
Toto	Drake – Max	Improved Siphon
Water Manager	Power Flush	Pressure Assisted
Kohler	Wellworth – Pressure Lite	Pressure Assisted
Sterling	Karsten	Dual-Cycle

- Siphon: original water closet design, approximately 2” (50 mm) tank throat diameter (see Figure 3).

Figure 3: Tank of Typical “Standard” Siphon Water Closet

- Improved Siphon: modified siphon design, greater than 3” (75 mm) tank throat diameter (see Figures 4a and 4b). The increased tank throat diameter increases the amount of water that initially discharges during flushing, thus increasing the initial forces on the water.

Figure 4a: One Style of an Improved Siphon Water Closet Tank

Figure 4b: Another Style of an Improved Siphon Water Closet

- Pressure Assisted: flushes using a bladder pressurized to the line-pressure of the water make-up (see Figure 5).

Figure 5: Tank of a Pressure Assisted Water Closet

- Dual-Cycle: two-stages of flushing for the two types of waste (solid and liquid). Liquid waste does not require as much water (see Figure 6).

Figure 6: Dual-Cycle Water Closet

The water closets were randomly assigned an alphabetic tag, for example, WC-A, WC-B, etc. For the purpose of this report, the water closets studied will be addressed as WC-A, WC-B, WC-C etc. for the rest of this report. There are a variety of other techniques and modifications, such as vacuum and pressure assisted, which can be applied to water closets to improve their performance. However, this study investigates only siphon, improved siphon, pressure assisted, and dual cycle water closet technologies.

Chapter 2

Background on the Issue

Plumbing systems have been around for over 10,000 years. However, the basic components of the modern system have been in place since the mid 1800s. In the late 1800s, some water closets flushed with volumes of up to 40 liters (over 10.5 gallons per flush). By the 1900s, the volume of 3.5 gallons per flush (gpf) (13.25 liters per flush - lpf) was the standard in the United States. This is where the water closet's capacity remained until the early 1980s in Europe and the early 1990s in the United States, at which time the volume was reduced to 6 liters (1.6 gallons) per flush (Swaffield and Galowin, 1992) in both locations.

The pressure to decrease the water requirement for water closets is from two fronts, spearheaded by necessity. Since 1972, the water consumption rates in the United States have increased on average at a rate of approximately 25% per year. The American Water Works Association reports that 8 million toilets are installed every year in the United States. The reduction of the water requirement per flush from 3.5 to 1.6 gallons (13.25 to 6 liters) has resulted in significant savings of fresh water (Fallon, 2002).

Although this equates to substantial volumetric and monetary savings of water, the initial public response to low flow water closets was less than positive, due to their poor performance upon their introduction into the market place. Their apparent shortcomings are attributed to two primary areas:

- Bowl Clearance
- Waste Transport Distance.

However, over the last ten years, substantial improvements have been made to the water closet's design (larger tank throat size, pressure assistance, etc). A 2000 consumer survey ranked public opinion of low flow water closets at a score of 7.4 on a scale from 1 to 10, with 10 being the highest (Ballanco, 2002). This is an indication that the manufacturer's improvements to their products are working and the issues with bowl clearance being appropriately addressed.

Yet, how does the utilization of less water per flush affect the waste transport of the mass following a flush? There is not a definitive answer. Some claim that the reduced volume impacts the mass carry. Others claim that with new improvements made to the water closets, they are now out performing the 3.5 gpf (13.25 lpf) (Ballanco, 2000). However at Texas A&M Energy System Lab, it was shown that the previous large capacity water closets significantly out performed the reduced flow water closets with respect to waste transport (Reyes, 2004).

The current national standard used to evaluate water closet performance is ASME A112.19.6-1995 “Hydraulic Performance Requirements for Water Closets and Urinals.” This test calls for several procedures to be conducted:

- Ink Test
- Dye Test
- Water Consumption
- Ball Discharge Test
- Granule Test
- Drain-line Transport Characterization
- And Others

Although the results of these test are not reported in this study, these test were conducted in order to understand the current standards of testing low flow water closets by industry.

Ink Test

Description: The bowl is filled with water and the exposed dry bowl portion is cleaned, dried, and a water- soluble ink line is drawn inside the bowl approximately 1” below the rim (see Figure 7). After flushing, the number of segments and segment lengths are recorded. This test is repeated three times.

Failure Criteria: Maximum length of remaining line segment cannot exceed a specified length.

Figure 7: ASME Ink Line Test

Dye Test

Description: A blue dye is added to the bowl. A sample of this dyed bowl water is collected and added to 1 L of water (control dilution). Following flushing, the bowl water is again collected and compared to the (control dilution). See Figure 8.

Failure Criteria: The final bowl dilution cannot be “bluer” than the original control.

Figure 8: ASME Dye Test

Water Consumption

Description: The water closet is flushed into a calibrated measuring device and the volume is recorded (see Figure 9).

Failure Criteria: Following a flushing cycle and after the trap seal is restored, the volume of water collected cannot exceed 1.6 gallons (6 L), with an allowable error of 0.1 gallons (.4 L).

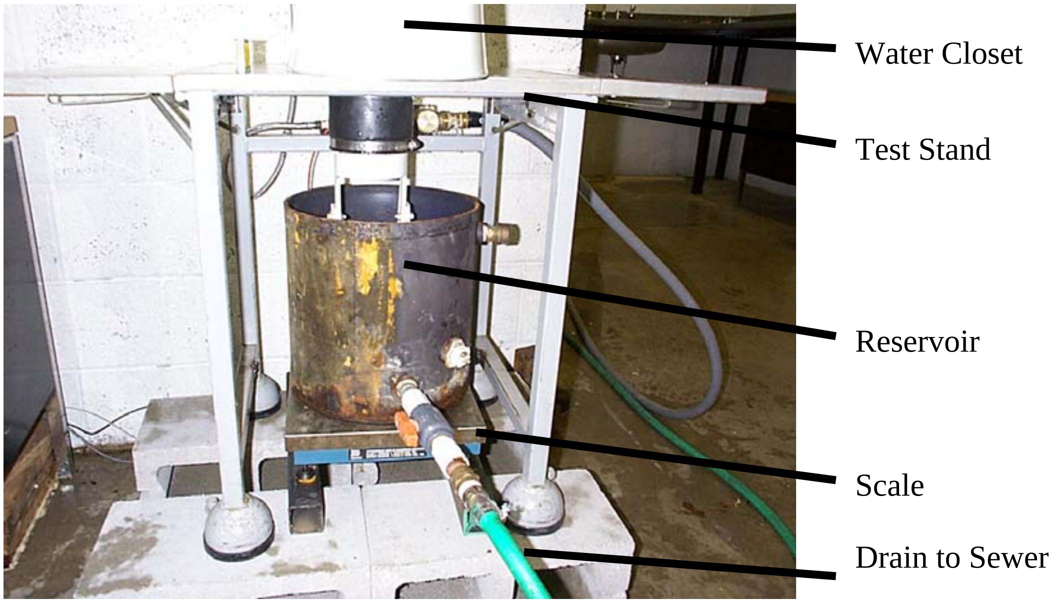


Figure 9: ASME Water Consumption Test Set-up;

Same Set-up for Flush Curve Capturing can be Used

Ball Test

Description: 100, 3/4” (19 mm) diameter polypropylene balls (see Figure 10) are placed into the bowl and then flushed. The balls remaining in the water closet are counted. This test is repeated three times and the average number of balls remaining is reported

Failure Criteria: Water closet must remove 75 balls per flush based on an average of three flushes.

Figure 10: ASME Ball Test

Granule Test

Description: 100 mL of polypropylene granules (see Figure 11) are placed into the bowl and then flushed. The granules remaining in the water closet are then counted. This test is repeated three times and the average number of granules remaining is reported.

Failure Criteria: The average number of granules remaining in water closet following flushing sequence (3 times) cannot exceed 125 granules.

Figure 11: Granule Test

The focus of these tests are directly associated with bowl clearance. ASME only requires one tested associated with waste transport – “Drainline Transport Characterization.” This test requires a pipe run of 60 feet (18.2 m) of 4” (100 mm) diameter clear PVC piping. When connected to a water closet, the flush should carry the 100, 1/2” (12.5 mm) diameter polypropylene balls a total average distance of 40 feet (12.2 m) or greater (ASME, 1995). Use of these polypropylene balls to generate transport distance data is questionable. Since the pipes are installed with a downward slope, the balls could actually roll downhill with no water in the pipe for carry. Additionally, the balls are not representative of typical human waste.

Relatively little is known about the properties of human stool, other than standard characteristic traits, such as:

- Mass (based on European Diet)
    - Average = 120 grams (0.26 lb)
    - Maximum = 250 grams (0.55 lb) (See Figure 12).

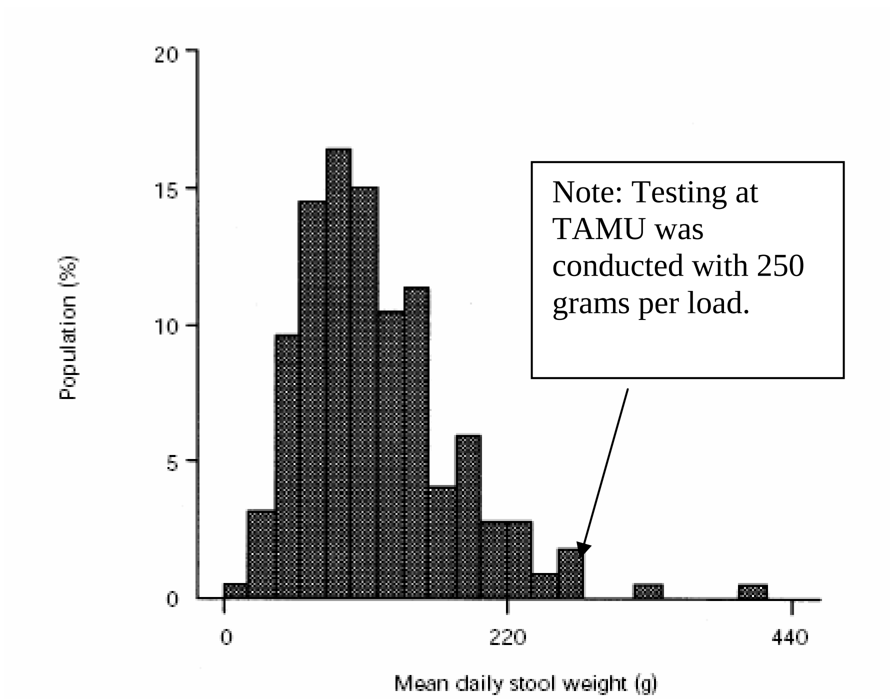


Figure 12: Typical Human Waste Distribution (Danone, 2005)

- Content consists of
    - 75% water
    - Remaining portion
        - 1/3 – Indigestible
        - 1/3 - Living Cells
        - 1/3 – Dead Cells (Fordtran and Sleisenger, 1993).

The mass of stool varies based on diet. Little is known about how the stool behaves following discharge. Important facts, such as:

- Stool discharge size/mass as deposited in and from the water closets
- Smearing along pipe wall
- Decay rate within the sewer environment

are all critical factors in determining how the waste travels through the sanitary piping system. Not only is the quantity of stool important to bowl clearance and transport, but also there are a variety of types of stool that are produced, which greatly affect the performance of water closets. The Bristol Stool Scale characterizes stool by seven types and was developed based on research conducted at the Bristol School of Medicine in 1976 (see Table 2).

Table 2: Bristol Stool Scale (familydoctor.co.uk, 2005)

Type 1		Separate hard lumps, like nuts
Type 2		Sausage-like but lumpy
Type 3		Like a sausage but with cracks in the surface
Type 4		Like a sausage or snake, smooth and soft
Type 5		Soft blobs with clear-cut edges
Type 6		Fluffy pieces with ragged edges, a mushy stool
Type 7		Watery, no solid pieces

Each type of stool would behave differently during discharge. A typical, healthy stool is between a Type 3 and 4.

In addition to solid and/or liquid human waste, the bowl usually also contains paper waste. An unofficial on-line "Paper Use Survey" was conducted through a web site at *Poopreport.com (see Appendix C).* From this generalized survey, the average paper use was found to be 24 squares per use, based on 45 responses. Although this survey was by no means scientific, it does provide an insight into the magnitude of paper being utilized. In contrast to the *Poopreport.com* survey, Charmin^{TM} reports that the average user uses 8.6 squares per trip, but does not specify the type of use as either solid or liquid waste (Toiletpaperworld.com 2004). During discharge, the paper waste emulsifies and breaks up significantly. In order to protect the pipes, no tests at TAMU included any paper during flushing.

CHAPTER 3

TEST SET-UP AND PROCEDURES

In order to characterize the mass transport abilities of the water closets, some materials had to be made and support equipment had to be developed:

- Synthetic Media
- Means to Establish a Flush Curve
- Piping System to Determine Mass Transport Abilities.

Synthetic Media Development

Synthetic media that simulates human waste is required for the study. There are a variety of industry standards that are representative of a typical solid waste load. However, most of these synthetic media are developed for bowl clearance studies and are not suitable for waste transport studies. For instance, soybean based media appears to be very realistic. However, following discharge, the media soaks up water, breaks up, and smears along the pipe walls. These characteristics, although realistic, are not desirable for this study, because of cleanliness and repeatability issues.

The media for this study must be robust enough to survive not only the flush cycle but transport through the piping system as well. If the media breaks apart during the flush cycle, it is essentially impossible to locate all pieces and establish a center of mass for the media transport distance. In addition, the testing must be repeatable.

Smearing along the walls of the piping system would contaminate the pipe runs for any subsequent testing.

A variety of possible synthetic media have been evaluated (see Table 3).

Table 3: Possible Synthetic Media Evaluated

Media	**Description**	**Comments**
Silicon - Unprotected	A variety of silicon pieces of different sizes were provided by ASPE.	The silicon was sticky and would not travel in the piping system.
Silicon - Protected	Silicon products provided by ASPE placed in condoms.	Condom would snag on pipe and degrade over time (typical of media tested in condom).
Play Dough® in Condom	Child's molding clay.	Vary dense, too heavy, stuck in water closet
Nickelodeon Gak in Condom	Child's toy, similar to *Play Dough*®, but not as dense.	Very light - floated on water; clears the piping system
Miso Paste (Soy Based Media) – Unprotected	Soy based media, seems to be very authentic, used by industry.	Breaks up during cycle; contaminates piping system.
Miso Paste (Soy Based Media) – Protected (See App. B)	Miso product in condom.	Same condom problem.
Water Wiggler	A tube filled with water (See Figure 13).	Passes through water closet; provides repeatable data.

In some cases, in order to strengthen the media or protect the system from break-up of the media following discharge, some media alternatives were enclosed in a condom.

This worked very well in the PVC piping systems. However, in the cast iron pipe, the latex would snag on the rough surfaces. Also, over time, the condom would weaken and break apart.

After evaluating the above alternatives, water wigglers were selected as the synthetic media used for this study. Water wigglers come in a variety of sizes. For the study, two medium sized (4" x 1 ½" (100 mm x 40mm) diameter; mass of 125 grams) "water wigglers" were used to represent the media with combined mass of 250 grams (refer to Figure 13).

Figure 13: Two Medium Sized Water Wigglers are Utilized to Simulate a Load; Combined Mass of 250 grams

The density of the water wigglers is roughly 1,100 kg/m^3. This density will insure that the water wigglers do not float during transport (density of water is 1,000 kg/m^3). They drag along the bottom of the pipe to represent a worst case of transport. Although this is a child's toy, it has a comparable density to human stool and it is flexible enough that it will travel through the water closet. See Appendix B for Instructions to Create Water Wigglers.

To insure repeatability, two water-wigglers were flushed into an empty piping system 100 times. During this repeatability test, three observations were recorded:

- Pass - both water wigglers left the water closet
- Partial Failure – one water wiggler left the water closet
- Failure – neither water wiggler left the water closet.

In addition, the statistical distribution of the waste transport of one water closet was evaluated to determine whether or not the use of water wigglers would result in a normal distribution for transport distance. This distribution is created by flushing two water wigglers in an empty 3" (75 mm) PVC pipe and reporting the average transport distance.

Means to Capture a Flush Curve

A flush curve is a graphical representation of the rate at which the water leaves the water closet during the flush cycle (see Figure 14).

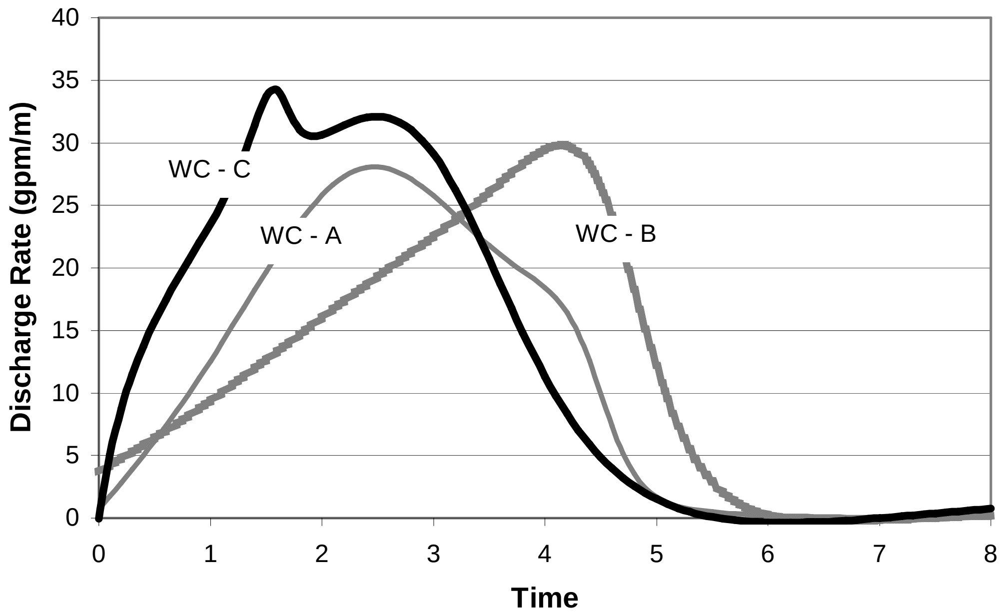


Figure 14: Flush Discharge Curves

A flush curve with a slow gradual discharge corresponds to a bowl that empties slowly (WC-B Curve); a flush curve with a steep, quick peak corresponds with a bowl that empties quickly and then washes the bowl sides prior to refill (WC-C).

Initially, three configurations were used to capture a flush curve (see Figure 15)

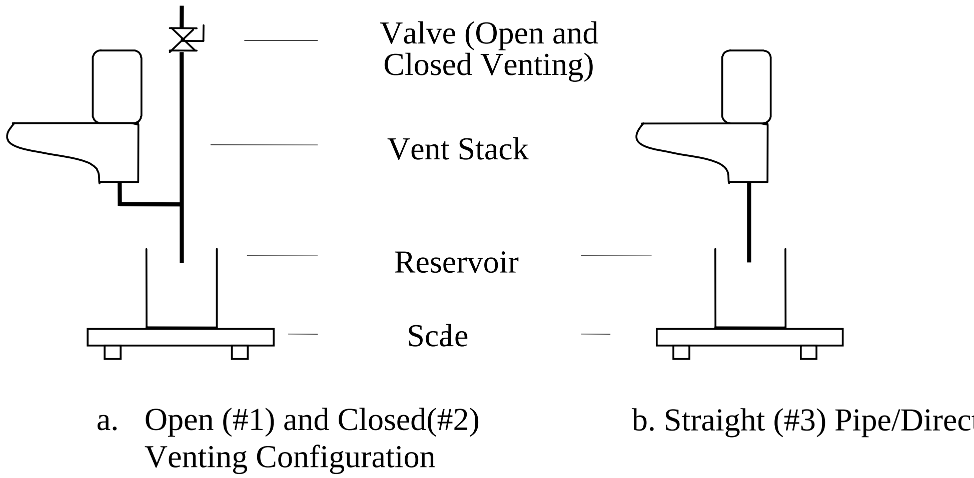


Figure 15: Flush Discharge Curve Test Configuration

An electronic scale collected and recorded the increase of the mass of the water in the reservoir during discharge (Figure 16). This data was then plotted to represent the flush curve. Three flush curves were captured for an initial set of water closets to determine any significant differences between the configurations.

Figure 16: Actual Flush Curve Set-up.

Piping System to Determine Mass Transport Abilities

The waste transport stand (see Figure 17) consists of a raised platform with four pipe runs of one hundred feet (thirty meters), each of a different material and size (3" cast iron (CI), 3" PVC, 4" CI, and 4" PVC) (3" = 75 mm and 4" = 100 mm). Each run was adjustable to allow for a variety of slopes to be tested. This study evaluated slopes of 1% and 2%.

Figure 17: Waste Transport Study Stand and the Four Adjustable Pipe Runs

The 3” (75mm) PVC is clear, which allows for the visual inspection of the waste transport. The remaining pipes (3” (75 mm) CI, 4” (100 mm) PVC, and 4” (100 mm) CI) were modified by cutting away the top third portion of the pipes. The openings were covered with plastic wrap to re-enclose to the piping system.

The platform had four openings to allow for the simultaneous testing of four water closets. The water closets were connected to the one hundred foot (thirty meter), straight piping (see Figure 19) system by the detail provided by ASPE (see Figure 20).

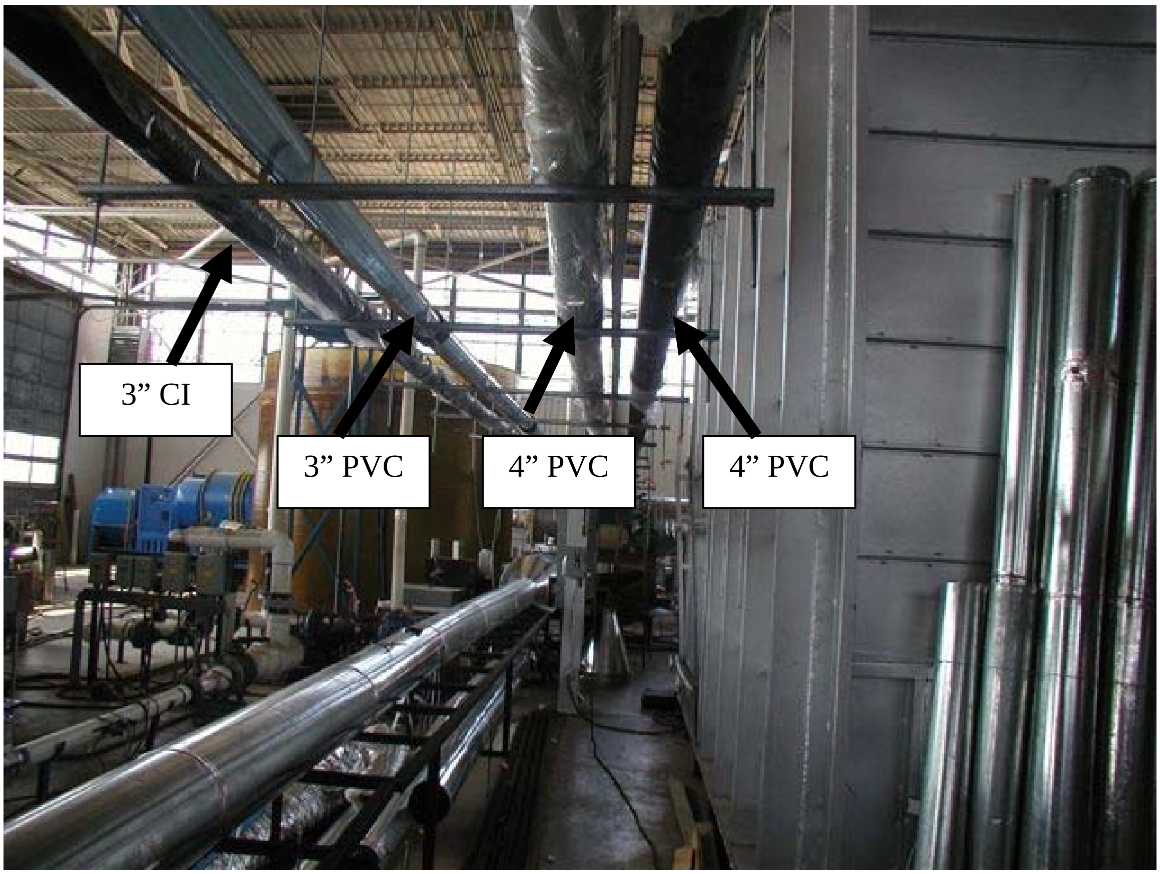


Figure 19: Pipe Runs –

3” Cast Iron, 3” PVC, 4” Cast Iron, and 4” PVC

(3” = 75 mm and 4” = 100 mm)

There are a variety of connection details used by industry. This detail is repeated for each pipe run (see Figure 20).

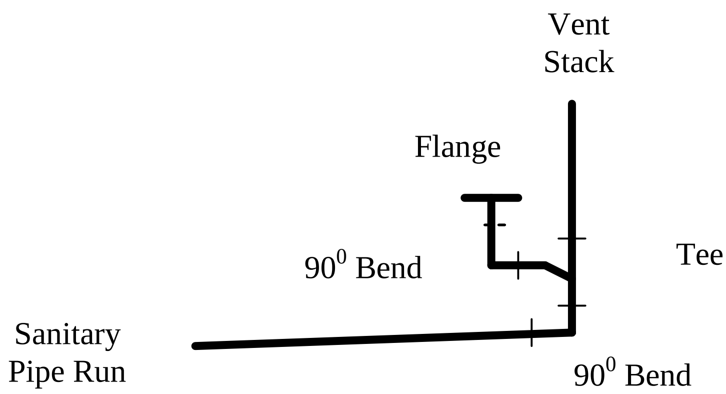


Figure 19: Sanitary Piping Connection of Water Closets for Testing

The entire test system is constructed as a "looped" system (see Figure 20 and 21) in order to avoid wasting of water. At the end of the pipe runs, a trough collects the water and returns the water in a storage tank. The pump then refills the make-up system.

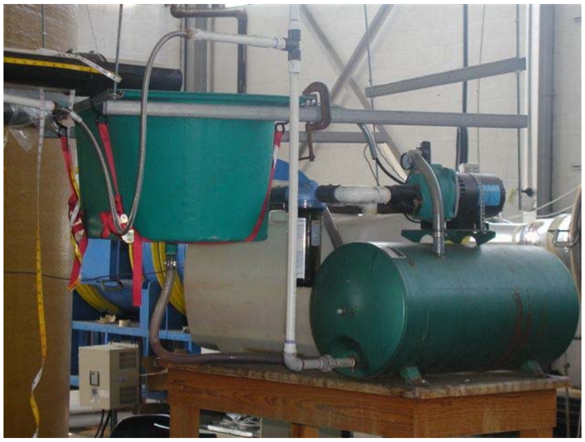


Figure 20: Water Reclamation

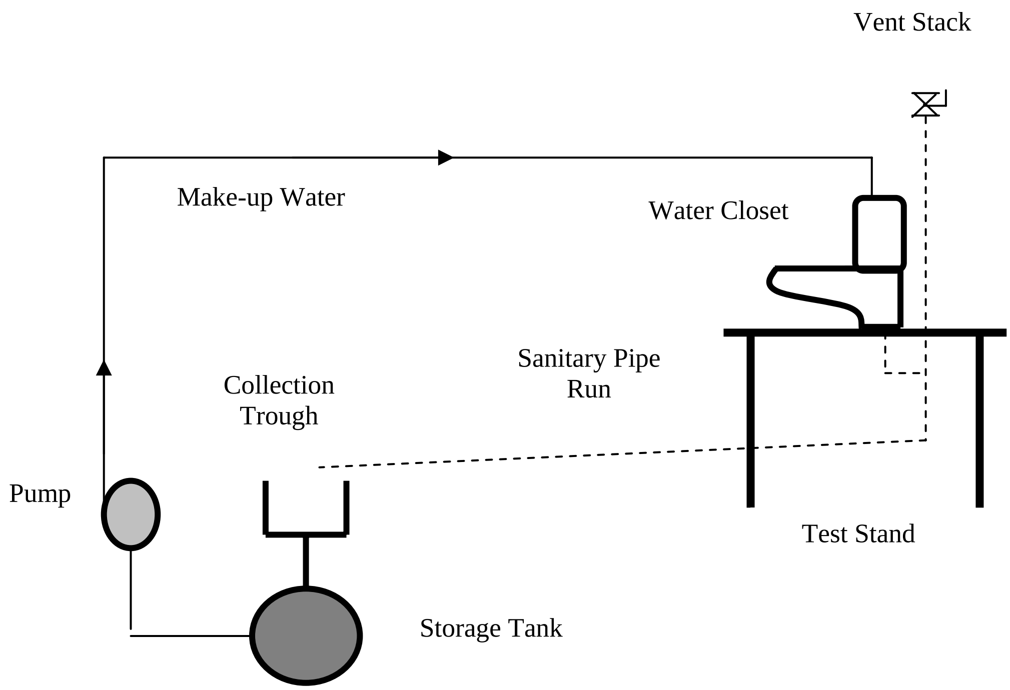


Figure 21: Complete Waste Transport Study Stand Schematic

Procedures

Once the testing equipment was in place, a series of tests were conducted to profile the performance of the water closets.

- Effectiveness of Synthetic Media
    - Repeatability of Water Wiggler
        - Flush 100 loads of 2 water wigglers through water closet.
    - Flush 60 loads of 2 water wigglers through water closet in the 3” diameter PVC and report average waste transport distances.

- Effects of Waste Loading on Waste Transport
    - Three loading sequences (Load every flush, Load every other flush, Load every two flushes) were tested and the waste transport distances of the loads following each flush were recorded.
- Effects of Venting on Waste Transport
    - The effects of venting versus non-venting were compared between three water closets. Flushing loads with vent stack open and vent stack closed. The waste transport distances were recorded.
- Effect of Discharge Time on Waste Transport
    - The waste discharge time and transport distance of a water closet was recorded. A stop watch was used to measure the load's discharge time was measured from the time of flush to when the load left the water closet and entered the piping system.
- Effects of Pipe Material, Size, and Slope on Waste Transport
    - Transport distances of all water closets attached to the four systems were tested and recorded. Each test consisted of three runs and the average values of the results are reported, using the flush sequence determined by the results of the "Effects of Waste Loading."

In addition, the flush curve for each water closet is also captured using the set-up shown on Figures 15 and 16.

CHAPTER 4

RESULTS AND DISCUSSION

Once the testing configurations and materials were established, various tests were conducted to determine the water closets' waste transport performance. The specific results (Flush Curves and Waste Transport Data) for each water closet are included Appendix A - Data.

Synthetic Media

Two medium water wigglers, 4" x 1-1/2" (100 mm x 40 mm) diameter with a mass of 125 grams each, were used to simulate a typical load. In order to determine the reliability of the synthetic media, two water wigglers were flushed one hundred times and the results were recorded (see Table 4). An acrylic template with a 2" (50 mm) diameter hole cut 4" (100 mm) from the back edge of the bowl was used to insure consistent placement of the loads within the bowl (see Figure 22).

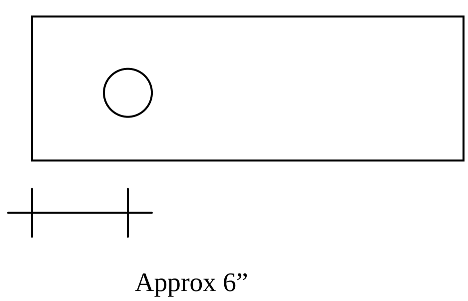


Figure 22: Test Plate

Table 4: Reliability of Water Wigglers		
Pass Both Wigglers Discharged	**Partial Failure** Only One Wiggler Discharged	**Failure** Neither Wiggler Discharged
92	2	6

The results indicate that both water wigglers passed though the bowl 92% of the time. However, with respect to failures, it is more likely that a total failure will occur than a partial failure.

In addition, flushing 60 loads of 2 water wigglers into an empty 3" (0.75 mm) PVC pipe with WC-C showed that the resulting transport distance represents a normal distribution (see Figure 23).

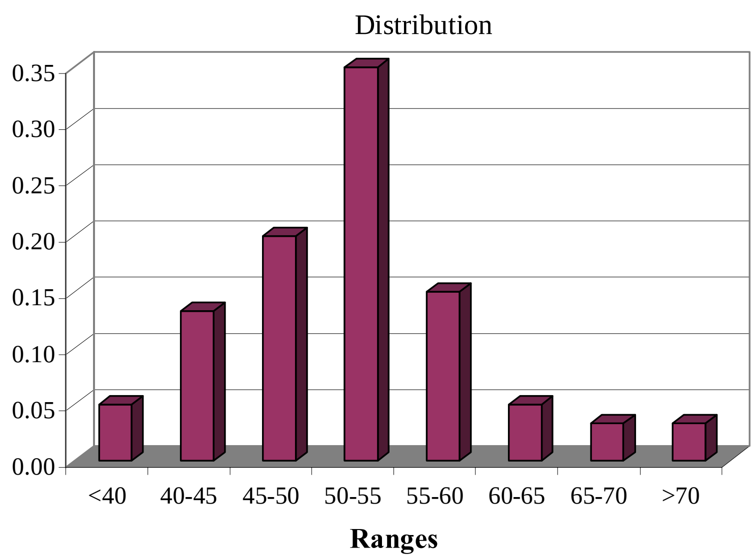


Figure 23: Normal Distribution of Transport distance

Theses results indicate that the water wiggler is both repeatable and follows the basic statistical behaviors.

Capturing of Flush Curves

The discharge curves were captured for the different water closets for three different scenarios (see Figure 24):

- Open Venting
- Closed Venting
- Straight Pipe/Direct Discharge (No Vent Stack – Emptied directly into reservoir)

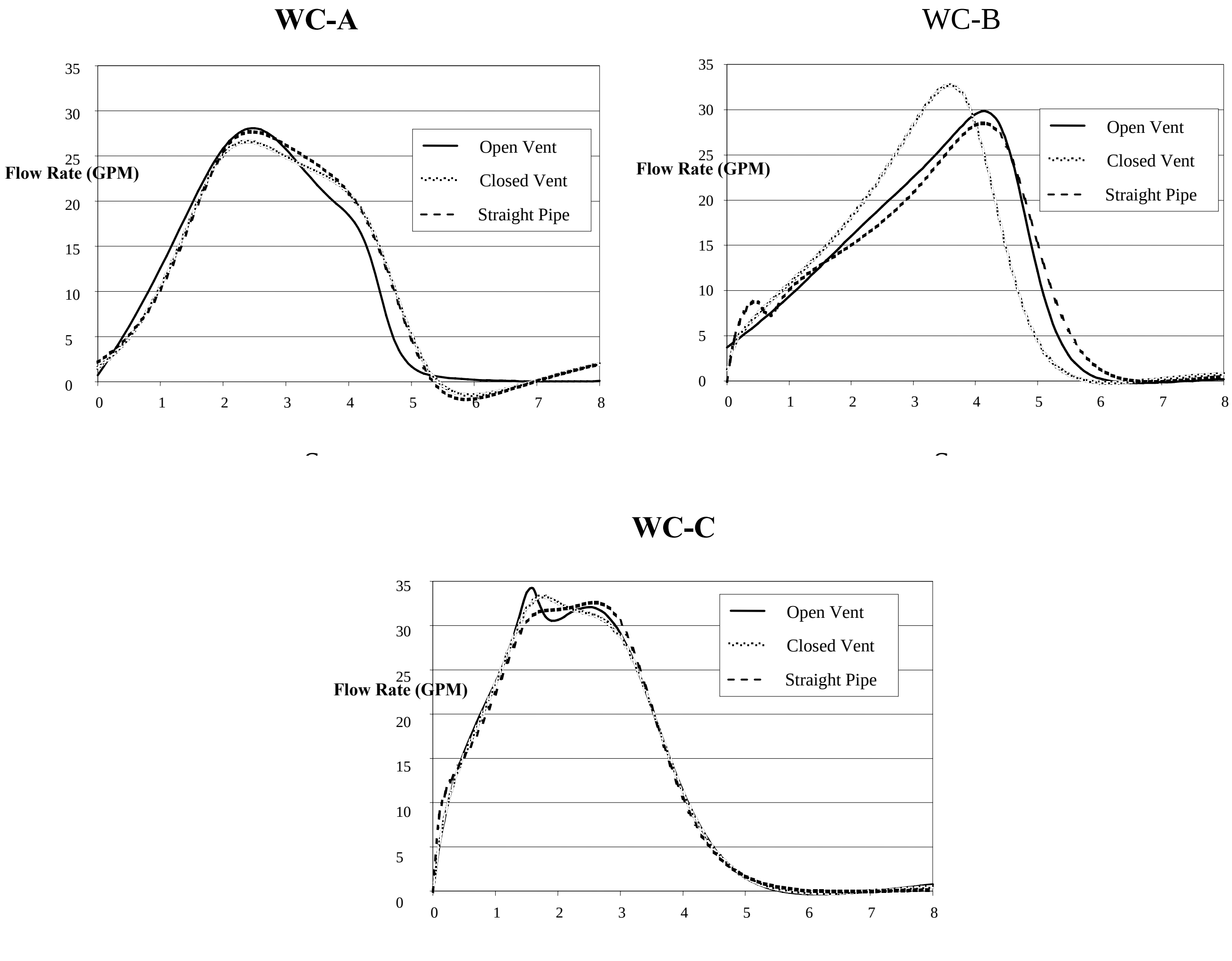


Figure 23: Three Different Water Closet Discharge Curves

Under Open Venting, Closed Venting, and Direct Discharge Conditions

The fact that there is little variation between configurations for the water closets makes sense, since the water slug is not traveling through a piping system; it is being emptied directly into a bucket and the system is open to the environment. Once the water closet is connected to the piping system the affects of open and closed venting are seen.

Effects of Venting on Waste Transport

During initial testing, it was found that there was only a marginal difference between open and closed venting affects for the system. To enclose the system, the pipes were wrapped with a clear plastic tarp (see Figure 24).

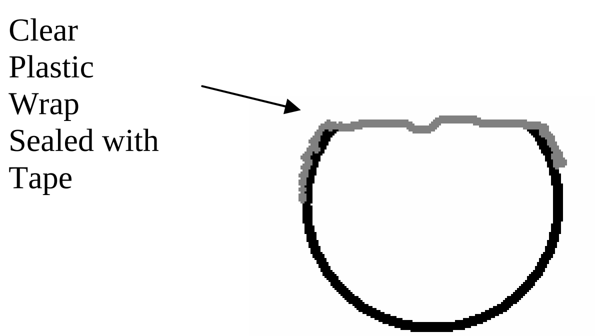


Figure 24: Sketch of Modified Pipe to Allow for Inspection

Once the system was closed to the surrounding atmosphere except through the vent stack and opened discharge end, the affects of open and closed venting became apparent (see Table 5).

Table 5: Open versus Closed Venting			
WC	**Open**	**Closed**	**Closed/Open**
A	49.1	55.1	1.12
B	31.3	35.9	1.15
C	41.8	49.5	1.19
D	64.0	74.7	1.17
E	45.1	52.4	1.16
F	57.8	66.0	1.14
G	48.2	55.6	1.15
H	57.5	66.0	1.15
I	52.2	60.6	1.16
J	35.4	39.5	1.12
K	49.8	58.7	1.18
L	54.9	61.1	1.13
M	42.1	46.8	1.11
N	40.1	47.3	1.18
O	22.7	25.1	1.11
P	28.8	32.5	1.13
		Average	**1.15**
		SD	**0.025**

By closing the vent stack, the pressure wave generated during the flush cycle as the water is discharged into the sewer pipes is not exhausted into the atmosphere. The trapped pressure wave adds additional energy to the transportation of the waste in the sewer pipes. Venting allows for the release of the excess air pressure created when the water displaces the air in the plumbing system. By preventing the release of the excess pressure, the pressure wave is forced to travel along with the waste and in turns helps push the media through the system. The values reported above are the average of three waste transport distances of the load (2 water wigglers) in the 3” (75 mm) PVC. This indicates closed vent flushing increases the waste transport distance by 15% compared to standard open vent flushing.

Effects of Loading on Waste Transport

During normal human use, there is not a standard sequence of operation for water closets. However, there is a sense of loading sequences and in order to understand the effects of various loading patterns on waste transport, three sequences were evaluated through one water closet for a cycle of eight flushes:

- Sequence 1: Mass waste load every flush
- Sequence 2: Mass waste load every other flush
- Sequence 3: Mass waste load every third flush

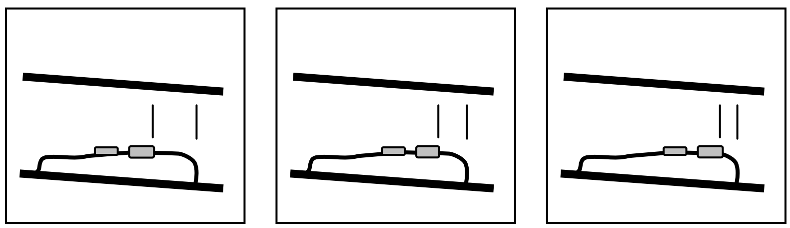
One water wiggler, mass of 120 gram, in the 3” (75 mm) clear PVC pipe run was used to represent a mass loading. The average carry distance was recorded. Each sequence was repeated four times. Five minutes were allowed between each flush to allow for complete drainage of pipe system and each sequence began with a wetting flush. See Table 6 for results of testing.

Table 6: Average Transport Distance Based on Loading Sequence Water Closet C												
	Sequence 1				**Sequence 2**				**Sequence 3**			
Load	**#1**	**#2**	**#3**	**#4**	**#1**	**#2**	**#3**	**#4**	**#1**	**#2**	**#3**	**#4**
Wetting Flush	-	-	-	-	-	-	-	-	-	-	-	-
Flush 1	49.2	-	-	-	25.2	-	-	-	49.8	-	-	-
Flush 2	53.9	53.1	-	-	42.9	-	-	-	52.0	-	-	-
Flush 3	53.9	53.1	38.8	-	49.7	49.3	-	-	53.1	-	-	-
Flush 4	53.9	53.1	47.3	46.9	50.7	50.1	-	-	53.2	48.0	-	-
Flush 5	53.9	53.1	52.7	52.3	52.3	51.7	51.3	-	53.2	52.8	-	-
Flush 6	53.9	53.1	52.7	52.3	52.3	51.7	51.3	-	53.2	52.8	52.4	-
Flush 7	53.9	53.1	52.7	52.3	52.4	52.0	51.5	50.3	53.2	52.8	52.4	-
Flush 8	53.9	53.1	52.7	52.3	52.4	52.0	51.5	51.1	53.2	52.8	52.4	-
Flush 9	53.9	53.1	52.7	52.3	52.4	52.0	51.5	51.1	53.2	52.8	52.4	51.9
Average Final Transport	53.00 feet				51.75 feet				52.58 feet			
Mean					52.44 feet							
Standard Deviation					0.636 feet							

Although the intermediate transport distance for the flush cycles differ, the final resting point of the media is unaffected by the loading sequence. Since there is not a significant difference between the final resting of the loads, Sequence 2 will be used for the continuation of this study when profiling the water closets' overall performance.

Effect of Discharge Time on Waste Transport

In the 3” (75 mm) clear PVC piping, the position of the waste is easily seen in the water slug immediately following discharge from the water closet. Where the waste “rides” that water slug greatly affects its travel distance. The nearer the waste is to the front of the water slug the greater the transport distance (see Figure 25). The positioning of the media occurs during the flush cycle.



WC-A	**WC-B**	**WC-C**
3.5 Second Time Lag Between Load #1 Behind Front of Water Slug	3.25 Second Time Lag Between Load #1 Behind Front of Water Slug	2.5 Second Time Lag Between Load #1 Behind Front of Water Slug

Figure 25: Position of Water Wiggler on Water Slug at 10 Feet (3.0 m) Travel Distance in 3” (75 mm) PVC Pipe following Waste Discharge for WC-A, WC-B, and WC-C

The discharge profile associated with each water closet positions the media in the water slug and is specific to that water closet.

In addition, the discharge time (time waste exits water closet following flush) for the waste leaving the water closet is variable for individual water closets. However, as shown in Table 7 and Figure 26, the sooner the waste exits the water closet, the further it will travel.

Table 7: Discharge Time versus Actual Transport Distance in WC-C in 3" (0.75 mm) PVC		
Run	**Time [sec]**	**Actual [ft]**
1	c	41.2 (12.6 m)
2	4.35	71.7 (21.9m)
3	4.66	57.7 (17.6 m)
4	4.94	51.1 (15.6 m)
5	4.56	61.2 (18.7 m)
6	4.53	61.1 (18.6 m)
7	5.10	34.5 (10.5 m)
8	4.63	52.2 (15.9 m)
9	4.86	53.3 (16.2 m)
10	4.81	55.2 (16.8 m)

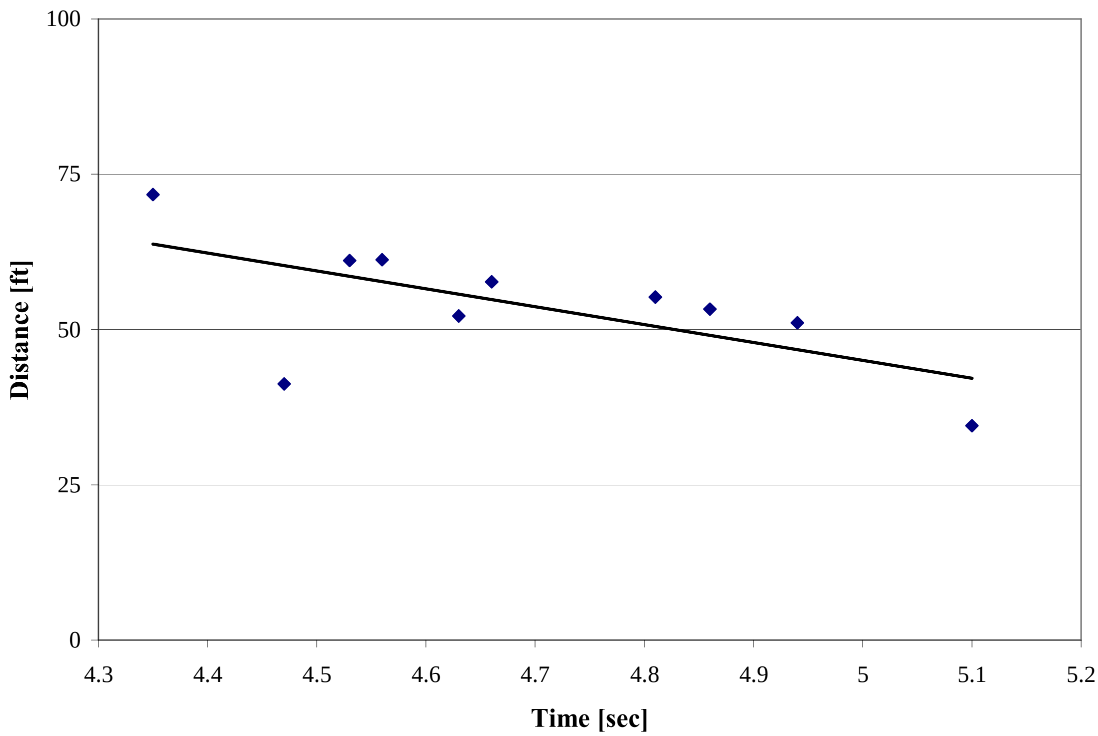


Figure 26: Waste Transport versus Discharge Time

Effects of Pipe Size, Material, and Slope on Waste Transport

When the media travels through the system, there are several forces acting on it:

- Gravity
- Friction of the Pipe
- Momentum of Water
- Buoyancy

These forces are defined by the following relationships:

<u>Conservation of Linear Momentum:</u>

$$F_{WATER} = \rho \times V \times A$$

where

ρ - density of water

V – velocity of flow

A – cross sectional area

Note: V x A = Q (volumetric flow); derived from flush curve

Assumption: assume flow is inviscid. No boundary layer.

Force Due to Gravity:

$$F_g = m \ x \ g$$

where

m – mass of object

g – acceleration due to gravity

Force Due to Friction:

$$F_{friction} = mass \times g \times \cos\Theta x \mu_k$$

where

θ - angle of slope

μ_k – coefficient of friction

Force Due to Buoyance

$$F_{friction} = \rho \times g \times V_{Displaces}$$

where

ρ - Density of the Mass

g – acceleration due to gravity

$V_{Displaced}$ = Volume of the liquid displaced

The system parameters do not create a unique problem, nor is it a special case that violates the basic laws of linear momentum and continuity. The media stops within the system once the force of friction overcomes the momentum of the waste (see Figure 27).

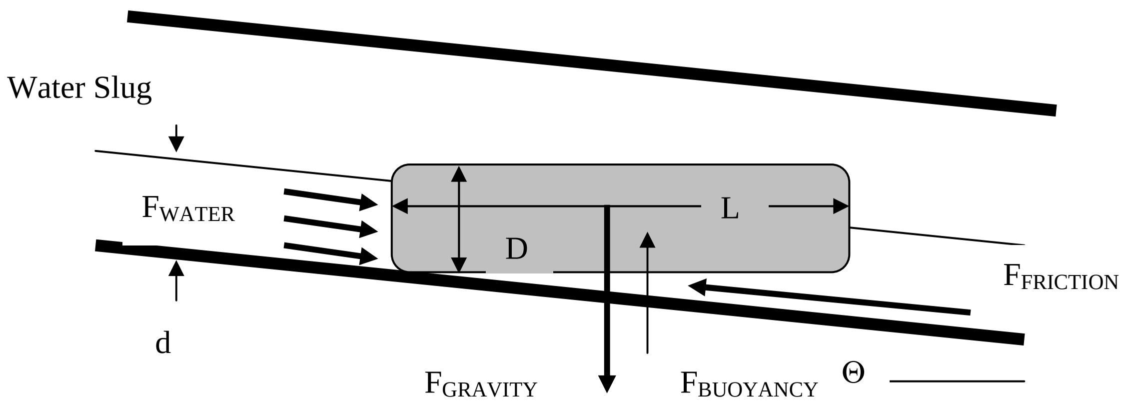


Figure 27: Forces Acting n Mass in System during Transport

The pipe size, material, and slope are all critical factors that affect the transportation of the mass.

- Pipe Size: The smaller the pipe diameter the greater the depth of the water slug. The increased depth will increase the force pushing the water wiggler through the piping system. Applying this concept to the Conservation of Momentum Equation gives:

$$\text{As } \mathbf{d} \text{ Increase} \Rightarrow \mathbf{A} \text{ Increases} \Rightarrow F_{Water} \text{ Increases}$$

Therefore, the 3” (75 mm) diameter pipes should carry further than the 4” (100 mm) diameter pipes if the piping material was the same.

- Material: The wall roughness of the pipe (see Table 8) is critical to the transport distance of the media. The rougher the pipe wall, the greater the coefficient of friction (ASHRAE Fundamental 1995).

Table 8: Effective Roughness (ε) of Conduit Surface	
PVC	0.00005 ft
Cast Iron	0.00085 ft

Applying these values to the Friction Equation then:

$$\text{As } \boldsymbol{\varepsilon} \text{ Increase} \Rightarrow \boldsymbol{\mu} \text{ Increases} \Rightarrow F_{Friction} \text{ Increases}$$

Therefore, the smooth pipe should carry the mass further than the rough pipe if pipe size and slope remained constant.

- Slope: The pipe slope will affect the flow of the water as the slug travels through the pipe. The greater the slope, the faster the slug will travel. However, if the slug travels too fast it runs the risk of out pacing the mass and leaving the waste behind. Thus, the greater the slope, the greater the transport distance.

Calculated Flush Performance Number (Initial and Critical) for Slope of 1/8" per Foot

There several factors that affect the waste transport distance of the load through the water closets, in order to help simplify the understanding of how these factors contribute to waste transport, a dimensionless Flush Performance Number (FPN) based on each water closet's comparative performance was calculated for each water closet. The FPN is based on the:

- Average transport of WC for each pipe (3" (75 mm) CI, 3" (75 mm) PVC, 4" CI (100 mm), and 4" (100 mm) PVC), based on three flushes per pipe for each water closet.
- FPN. This dimensionless number is based on the fact that not all water closets actually discharge 1.6 (6 L) gallons and not all water closets transport the waste the same distance. The FPN makes it easier establish "apple to apples" comparison.

$$FPN = \frac{Transport}{40} \times \frac{1.6\ gpf}{Actual\ gpf}$$

where

- Transport – actual waste transport distance following discharge
- 40 ft - selected based on minimum required transport distance specified by ASME.
- 1.6 gallons – specified discharge requirement.
- Actual Discharge – actual discharge capacity of WC.
- Note: Ratios were set up such that if transport was greater than 40 ft then the WC was “rewarded”, if WC uses more than 1.6 gal then the WC was “penalized.” A toilet that meets ASME standards (1.6 gpf and average transport distance of 40 feet) will score a 1.

The FPNs for each water closet were compared to each other to determine each water closet’s relative performance. Two FPNs were calculated and compared for each water closet:

- FPN_{Intial}: The position of Load #1 traveling into an empty pipe following five minutes after a wetting flush
- $FPN_{Critical}$: The position of Load #2 following flush cycle of sequence 2 (will be established later). Load #2 is considered the critical load, because it is the more realistic load of this testing procedure, in an actual sewer environment, there will always be a load in the sewer pipe and load coming down the pipes.

Using the test stand and the pipes adjusted at a 1% slope, the FPN values were calculated for Load #1 – Initial Position, Load #2 – Final Position, and Critical Load (See Tables 9, 10, and 11 and Figures 28, 29, 30, and 31)

Table 9
Initial Load Location After First Flush

Tag	Description	Type	GPF	Peak Time sec	Peak gpm	Transport Distances 3" CI	3" PVC	4" CI	4" PVC	FPN 3" CI	3" PVC	4" CI	4" PVC	FPN AVG
WC-A	[redacted]	I	1.43	2.5	28.0	18.3	49.1	14.0	16.6	0.512	1.373	0.391	0.465	0.685
WC-B	[redacted]	I	1.54	4.1	29.8	18.5	31.3	16.7	24.2	0.481	0.814	0.433	0.630	0.589
WC-C	[redacted]	I	1.70	2.5	32.1	13.5	41.8	12.6	19.4	0.317	0.983	0.296	0.456	0.513
WC-D	[redacted]	II	1.61	0.8	115.0	24.5	64.0	21.3	35.2	0.609	1.589	0.530	0.874	0.900
WC-E	[redacted]	I	1.79	2.5	30.1	12.9	45.1	12.6	18.6	0.289	1.008	0.283	0.416	0.499
WC-F	[redacted]	I	1.83	2.3	31.0	13.9	57.8	15.7	30.7	0.304	1.263	0.343	0.670	0.645
WC-G	[redacted]	II	1.64	0.7	108.7	26.3	48.2	17.0	33.5	0.640	1.176	0.414	0.818	0.762
WC-H	[redacted]	II	1.56	0.5	57.8	25.4	57.5	17.3	35.0	0.652	1.474	0.444	0.897	0.867
WC-I	[redacted]	II	1.43	1.0	57.4	20.5	52.2	11.8	30.1	0.572	1.461	0.331	0.841	0.802
WC-J	[redacted]	III	1.41	0.4	49.6	14.7	35.4	9.9	25.4	0.417	1.003	0.282	0.722	0.606
WC-K	[redacted]	II	1.61	0.7	75.0	21.8	49.8	11.4	27.8	0.542	1.237	0.283	0.690	0.688
WC-L	[redacted]	II	1.51	0.6	61.0	20.4	53.9	18.9	31.8	0.540	1.427	0.500	0.842	0.827
WC-M	[redacted]	II	1.58	0.5	63.0	17.6	42.1	14.4	33.5	0.446	1.067	0.364	0.847	0.681
WC-N	[redacted]	I	1.83	2.7	31.5	14.1	40.1	12.0	20.3	0.309	0.879	0.263	0.445	0.474
WC-O	[redacted]	III	1.58	0.4	60.4	13.2	22.7	12.0	11.0	0.333	0.574	0.303	0.279	0.372
WC-P	[redacted]	IV	1.42	0.8	22.1	11.0	28.8	8.7	15.7	0.311	0.811	0.245	0.443	0.452
					Aver	17.9	45.0	14.1	25.6					
						4.9	11.4	3.4	7.7					

* First Flush Transport distance of Load #1 into clean pipe

FPN=1.6/gpf x Travel/40

I	Standard Siphon
II	Improved Siphon
III	Pressure Assisted
IV	Dual Cycle

Table 10

Initial Load After Flush Sequence #2

Tag	Description	Type	GPF	Peak Time sec	Peak gpm	Transport Distances 3" CI	3" PVC	4" CI	4" PVC	FPN 3" CI	3" PVC	4" CI	4" PVC	FPN AVG
WC-A	[redacted]	I	1.43	2.5	28.0	27.4	49.7	21.3	25.8	0.768	1.391	0.596	0.721	0.869
WC-B	[redacted]	I	1.54	4.1	29.8	27.7	36.3	23.6	35.0	0.720	0.942	0.613	0.908	0.796
WC-C	[redacted]	I	1.70	2.5	32.1	31.7	51.8	23.6	31.8	0.745	1.219	0.556	0.748	0.817
WC-D	[redacted]	II	1.61	0.8	115.0	38.6	78.8	31.9	41.5	0.959	1.959	0.793	1.031	1.185
WC-E	[redacted]	I	1.79	2.5	30.1	32.9	56.9	22.8	31.6	0.736	1.274	0.510	0.707	0.807
WC-F	[redacted]	I	1.83	2.3	31.0	29.7	77.1	23.0	35.8	0.649	1.685	0.503	0.782	0.905
WC-G	[redacted]	II	1.64	0.7	108.7	33.9	65.4	26.9	41.5	0.826	1.595	0.656	1.012	1.022
WC-H	[redacted]	II	1.56	0.5	57.8	37.0	67.1	25.7	37.2	0.949	1.720	0.659	0.955	1.071
WC-I	[redacted]	II	1.43	1.0	57.4	30.5	61.5	22.1	31.8	0.853	1.720	0.618	0.890	1.020
WC-J	[redacted]	III	1.41	0.4	49.6	26.7	56.4	16.2	32.3	0.757	1.600	0.459	0.916	0.933
WC-K	[redacted]	II	1.61	0.7	75.0	33.1	57.1	20.7	29.8	0.822	1.419	0.515	0.739	0.874
WC-L	[redacted]	II	1.51	0.6	61.0	29.8	59.5	25.3	36.1	0.789	1.576	0.669	0.956	0.998
WC-M	[redacted]	II	1.58	0.5	63.0	30.6	52.4	24.7	35.8	0.774	1.327	0.624	0.906	0.908
WC-N	[redacted]	I	1.83	2.7	31.5	30.6	82.9	23.3	32.8	0.669	1.816	0.510	0.719	0.929
WC-O	[redacted]	III	1.58	0.4	60.4	21.3	44.3	18.3	17.5	0.538	1.122	0.464	0.442	0.642
WC-P	[redacted]	IV	1.42	0.8	22.1	22.1	45.1	16.7	23.9	0.622	1.269	0.470	0.673	0.758

* First Flush Transport distance of Load #1 into clean pipe

COP=1.6/gpf x Travel/40

Type

I	Standard Siphon
II	Improved Siphon
III	Pressure Assisted
IV	Dual Cycle

Table 11

Critical Load After Flush Sequence #2

Tag	Description	Type	GPF	Peak Time sec	Peak gpm	Transport Distances 3" CI	3" PVC	4" CI	4" PVC	FPN 3" CI	3" PVC	4" CI	4" PVC	FPN AVG
WC-A	[redacted]	I	1.43	2.5	28.0	26.7	48.8	20.1	23.7	0.746	1.366	0.562	0.663	0.834
WC-B	[redacted]	I	1.54	4.1	29.8	26.3	33.9	22.1	32.9	0.682	0.881	0.575	0.855	0.748
WC-C	[redacted]	I	1.70	2.5	32.1	30.9	51.1	23.1	28.2	0.727	1.201	0.543	0.663	0.784
WC-D	[redacted]	II	1.61	0.8	115.0	36.8	67.5	29.6	37.1	0.914	1.677	0.735	0.922	1.062
WC-E	[redacted]	I	1.79	2.5	30.1	32.8	51.7	25.1	26.8	0.733	1.156	0.560	0.598	0.762
WC-F	[redacted]	I	1.83	2.3	31.0	28.6	64.1	21.6	33.2	0.624	1.402	0.472	0.725	0.806
WC-G	[redacted]	II	1.64	0.7	108.7	32.8	64.4	22.3	40.0	0.801	1.571	0.543	0.974	0.972
WC-H	[redacted]	II	1.56	0.5	57.8	33.5	64.2	24.7	36.5	0.858	1.646	0.633	0.936	1.018
WC-I	[redacted]	II	1.43	1.0	57.4	29.7	58.9	20.4	34.4	0.831	1.647	0.572	0.963	1.003
WC-J	[redacted]	III	1.41	0.4	49.6	24.7	51.1	23.1	28.2	0.700	1.448	0.655	0.800	0.901
WC-K	[redacted]	II	1.61	0.7	75.0	29.1	58.7	22.5	33.3	0.723	1.460	0.558	0.828	0.892
WC-L	[redacted]	II	1.51	0.6	61.0	24.7	51.1	23.1	28.2	0.653	1.352	0.611	0.747	0.841
WC-M	[redacted]	II	1.58	0.5	63.0	24.7	51.1	23.1	28.2	0.624	1.292	0.584	0.714	0.804
WC-N	[redacted]	I	1.83	2.7	31.5	31.0	65.4	23.2	35.4	0.678	1.433	0.507	0.776	0.848
WC-O	[redacted]	III	1.58	0.4	60.4	24.7	51.1	23.1	28.2	0.624	1.292	0.584	0.714	0.804
WC-P	[redacted]	IV	1.42	0.8	22.1	25.3	44.2	26.3	23.9	0.713	1.246	0.742	0.673	0.843
						35.5	67.5	28.7	38.3					
* First Flush Transport distance of Load #1 into clean pipe						**Type**				1.238	2.351	1.000	1.335	
						I	Standard Siphon			0.52667	1	0.42544	0.56785	
COP=1.6/gpf x Travel/40						II	Improved Siphon							
						III	Pressure Assisted							
						IV	Dual Cycle							

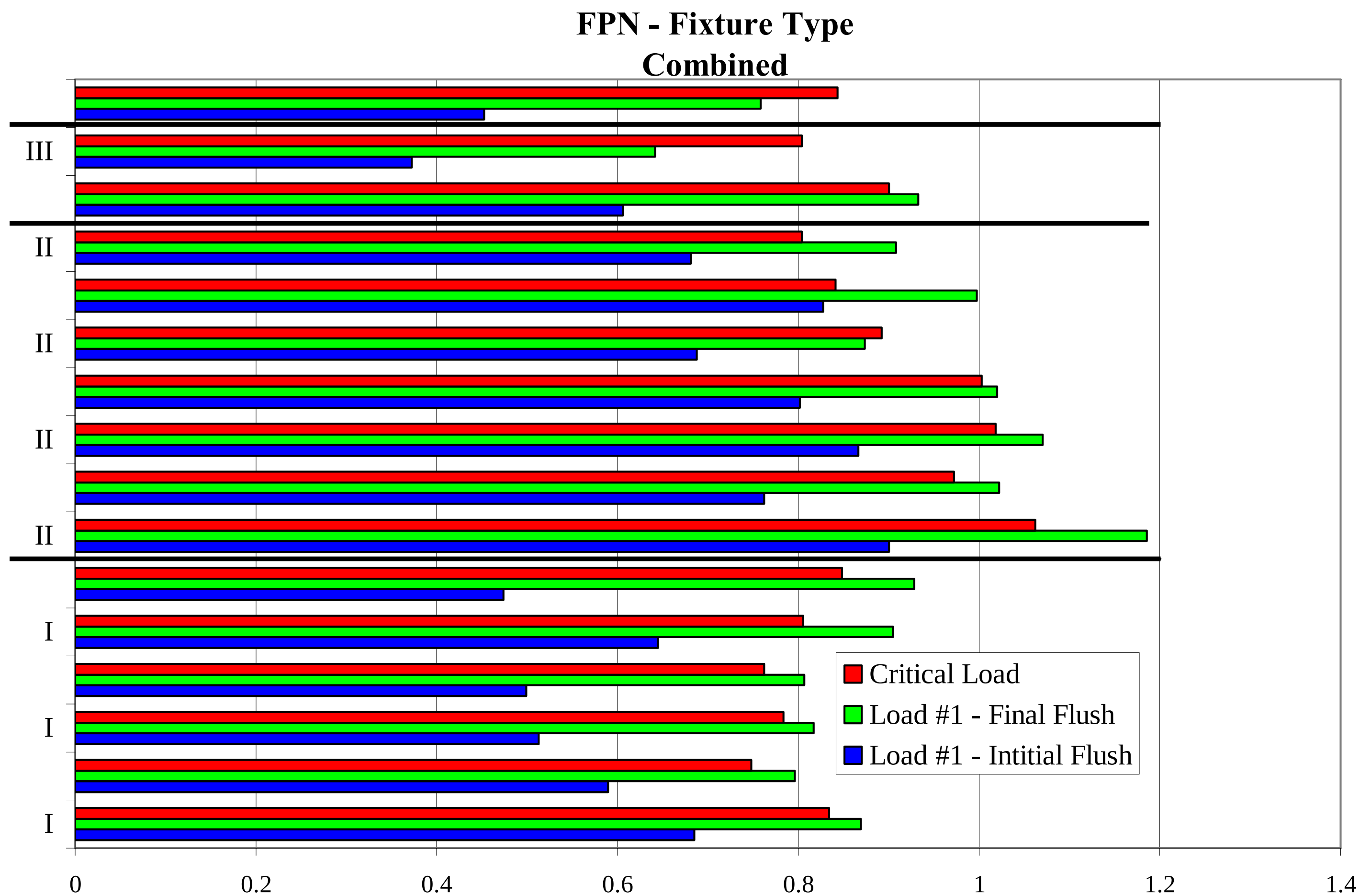


Figure 28: FPNs Values of Load #1 - Initial, Load #1 - Final, and Critical Load

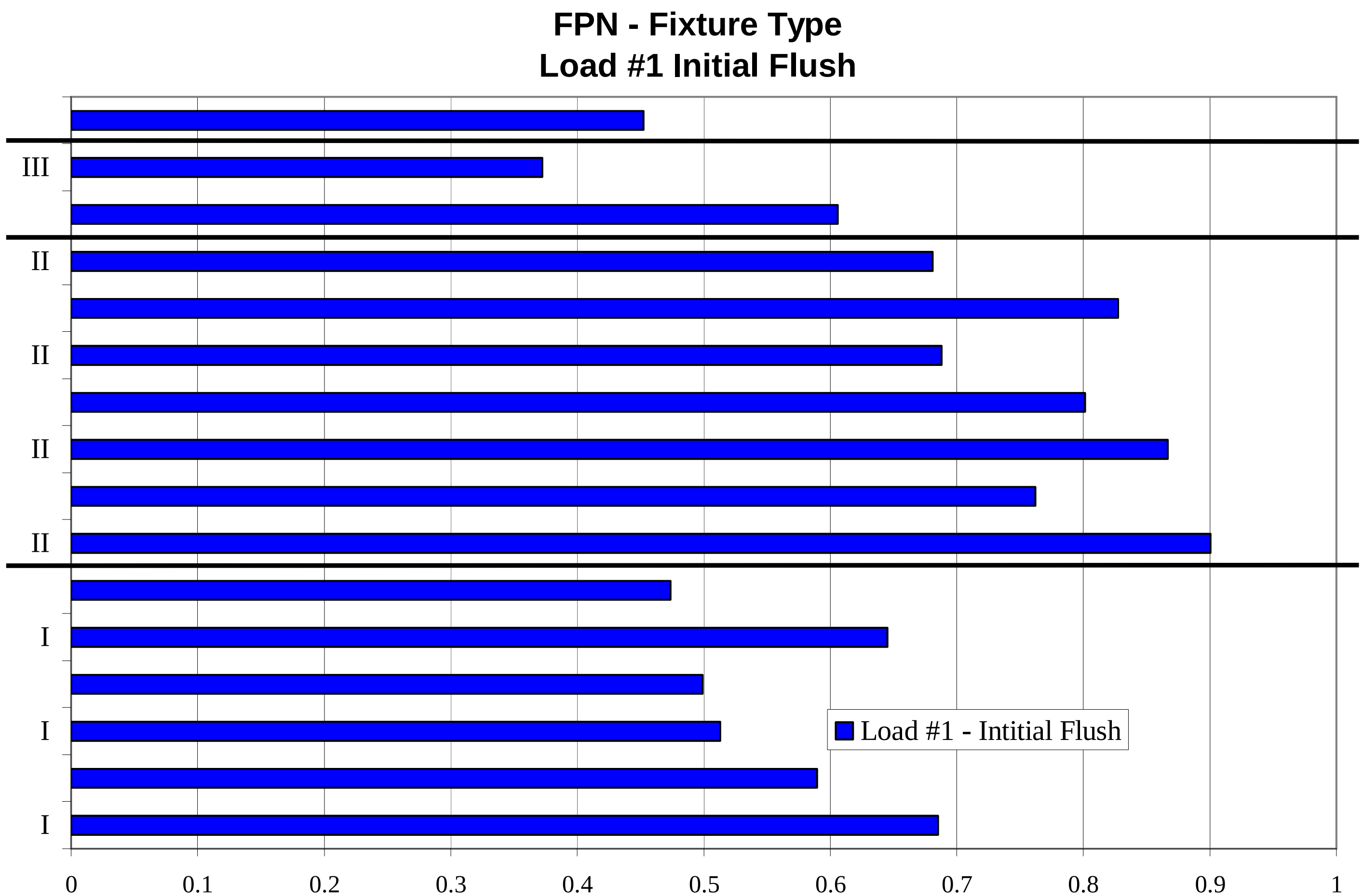


Figure 29: FPNs Values of Load #1 – Initial Flush

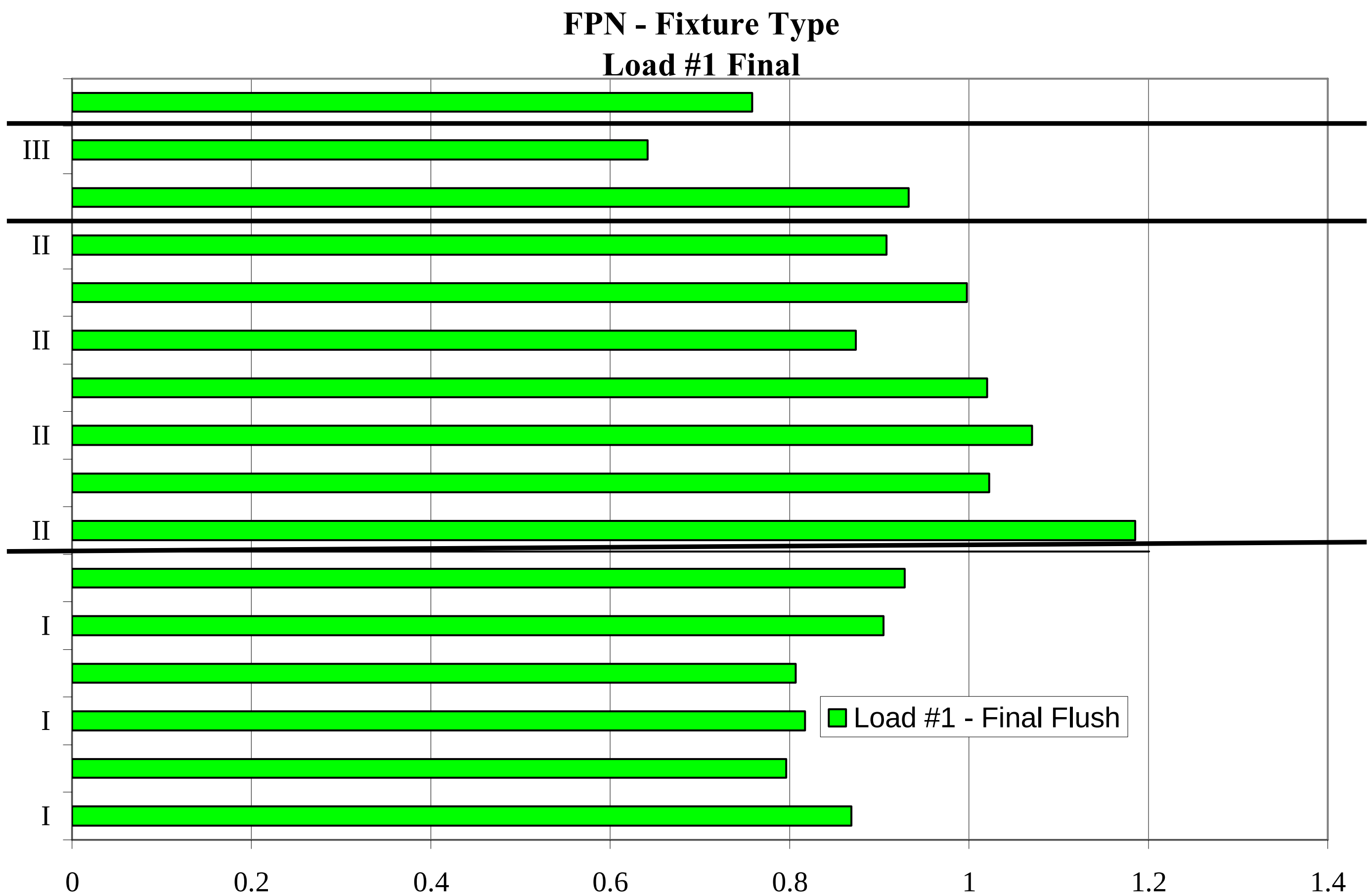


Figure 30: FPNs Values of Load #1 – Final Flush

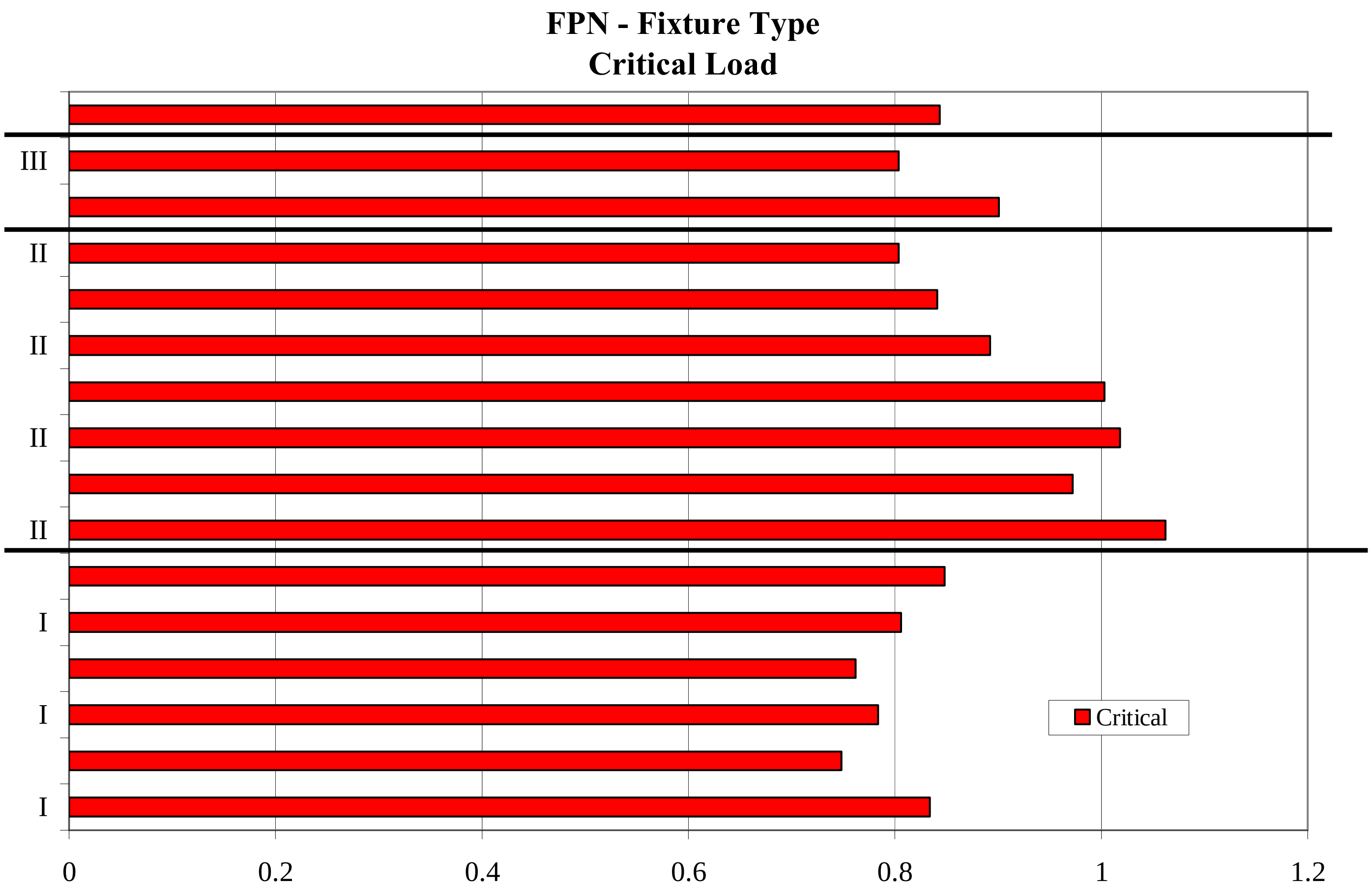


Figure 31: FPNs Values of Critical Load

By comparing the relative rankings between Load #1 – Initial, Load #1 – Final, and Critical Load it indicates the relative performance between these three different FPN values is relatively consistent (see Table 12).

Table 12: Relative Performance Based on Ranking					
Load #1				Load #2 - Critical Flush	
Initial Flush	**Rank**	**Final Flusl**	**Rank**		**Rank**
0.69	**7**	0.87	**11.00**	0.83	**10**
0.59	**11**	0.80	**14.00**	0.75	**16**
0.51	**12**	0.82	**12.00**	0.78	**14**
0.90	**1**	1.19	**1.00**	1.06	**1**
0.50	**13**	0.81	**13.00**	0.76	**15**
0.65	**9**	0.90	**9.00**	0.81	**11**
0.76	**5**	1.02	**3.00**	0.97	**4**
0.87	**2**	1.07	**2.00**	1.02	**2**
0.80	**4**	1.02	**4.00**	1.00	**3**
0.61	**10**	0.93	**6.00**	0.90	**5**
0.69	**6**	0.87	**10.00**	0.89	**6**
0.83	**3**	1.00	**5.00**	0.84	**9**
0.68	**8**	0.91	**8.00**	0.80	**13**
0.47	**14**	0.93	**7.00**	0.85	**7**
0.37	**16**	0.64	**16.00**	0.80	**12**
0.45	**15**	0.76	**15.00**	0.84	**8**

This indicates in establishing a relative performance between water closets Load #1 – Initial Flush is sufficient in establishing the water closet's performance. Therefore, following the adjustment to a 2% slope, only Load #1 – Initial Flush will be recorded.

The FPN values and relative rankings for the 2% slope were calculated similarly (see Table 13 and Table 14).

Tab1e 13:

Initial Load Location After First Flush at 2% Slope

				Time	Peak gpm	Transport Distances				FPN			
Tag	Description	Type	GPF	sec		3" CI	3" PVC	4" CI	4" PVC	3" CI	3" PVC	4" CI	4" PVC
WC-A	[redacted]	I	1.43	2.5	28.0	20.69	54.79	16.40	18.56	0.579	1.533	0.459	0.519
WC-B	[redacted]	I	1.54	4.1	29.8	21.32	36.10	18.96	28.18	0.554	0.938	0.492	0.732
WC-C	[redacted]	I	1.70	2.5	32.1	15.33	47.57	14.46	22.29	0.361	1.119	0.340	0.524
WC-D	[redacted]	II	1.61	0.8	115.0	28.74	70.57	24.12	41.04	0.714	1.753	0.599	1.020
WC-E	[redacted]	I	1.79	2.5	30.1	15.03	50.81	14.22	21.79	0.336	1.136	0.318	0.487
WC-F	[redacted]	I	1.83	2.3	31.0	15.88	68.77	17.42	34.77	0.347	1.503	0.381	0.760
WC-G	[redacted]	II	1.64	0.7	108.7	31.46	54.19	19.08	39.24	0.767	1.322	0.465	0.957
WC-H	[redacted]	II	1.56	0.5	57.8	29.03	63.77	19.80	41.20	0.744	1.635	0.508	1.056
WC-I	[redacted]	II	1.43	1.0	57.4	23.27	61.56	13.52	34.45	0.651	1.722	0.378	0.964
WC-J	[redacted]	III	1.41	0.4	49.6	17.04	41.40	11.47	28.95	0.483	1.175	0.325	0.821
WC-K	[redacted]	II	1.61	0.7	75.0	24.19	58.48	12.91	30.85	0.601	1.453	0.321	0.766
WC-L	[redacted]	II	1.51	0.6	61.0	22.94	61.96	21.50	37.38	0.608	1.641	0.569	0.990
WC-M	[redacted]	II	1.58	0.5	63.0	21.01	48.78	16.83	39.02	0.532	1.235	0.426	0.988
WC-N	[redacted]	I	1.83	2.7	31.5	16.90	47.43	13.21	22.70	0.370	1.039	0.289	0.497
WC-O	[redacted]	III	1.58	0.4	60.4	14.88	25.62	14.27	12.20	0.377	0.649	0.361	0.309
WC-P	[redacted]	IV	1.42	0.8	22.1	12.30	32.78	10.24	18.76	0.346	0.923	0.288	0.529
					Average	20.62	**51.54**	**16.15**	**29.46**				
					SD	5.72	**12.88**	**3.80**	**9.19**				

* First Flush Transport distance of Load #1 into clean pipe

FPN=1.6/gpf x Travel/40

I	Standard Siphon
II	Improved Siphon
III	Pressure Assisted
IV	Dual Cycle

Table 14: Overall Relative Performance

		1%			2%		
		Load #1		Critical	Load #1	Average Ranking [ft]	SD [ft]
		Initial	Final				
WC-A	I	7	11	10	8	9.0	1.8
WC-B	I	11	14	16	11	13.0	2.4
WC-C	I	12	12	14	12	12.5	1.0
WC-D	II	1	1	1	1	1.0	0.0
WC-E	I	13	13	15	13	13.5	1.0
WC-F	I	9	9	11	9	9.5	1.0
WC-G	II	5	3	4	5	4.3	1.0
WC-H	II	2	2	2	2	2.0	0.0
WC-I	II	4	4	3	4	3.8	0.5
WC-J	III	10	6	5	10	7.8	2.6
WC-K	II	6	10	6	7	7.3	1.9
WC-L	II	3	5	9	3	5.0	2.8
WC-M	II	8	8	13	6	8.8	3.0
WC-N	I	14	7	7	14	10.5	4.0
WC-O	III	16	16	12	16	15.0	2.0
WC-P	IV	15	15	8	15	13.3	3.5

The FPN values clearly indicate a division between technology types (see Table 15).

Table 15: Average FPN Value for Technology Types

Technology	Type	Average FPN (Initial Flush) (ft)	SD (ft)
Siphon	I	0.568	0.086
Improved Siphon	II	0.790	0.084
Pressure Assisted	III	0.489	0.17
Dual Cycle	IV	0.452	-

Using the data obtained during testing, a relative pipe performance between pipe material and size can be established (see Table 16).

Table 16: Pipe Type and Size Relative Performance

		Translated			
		3" CI	3" PVC	4" CI	4" PVC
Reference	3" CI	-	2.51	0.79	1.43
	3" PVC	0.40	-	0.31	0.57
	4" CI	1.27	3.23	-	1.82
	4" PVC	0.70	1.76	0.55	-

Chapter 5

Findings

1) **Water Wigglers do provide a suitable test media in order to create a relative comparison between water closets with respect to waste transport though low flow water closets.**

   - They are reliable with a failure rate of 8% of the time. In the event of failure, the failure is typical a compete failure (both wigglers do not leave bowl following flush
   - They are also repeatable. Checking the normality of their distribution, the wigglers follow a typical normal distribution. This indicates that they follow the basic laws of statistics.

2) Flush Curves provide a finger- print of the water closet's performance. Each flush curve is unique and specific to their water closet (see Figure 32).

- The flush curve provides a profile that corresponds to the flush characteristic of the water closet.

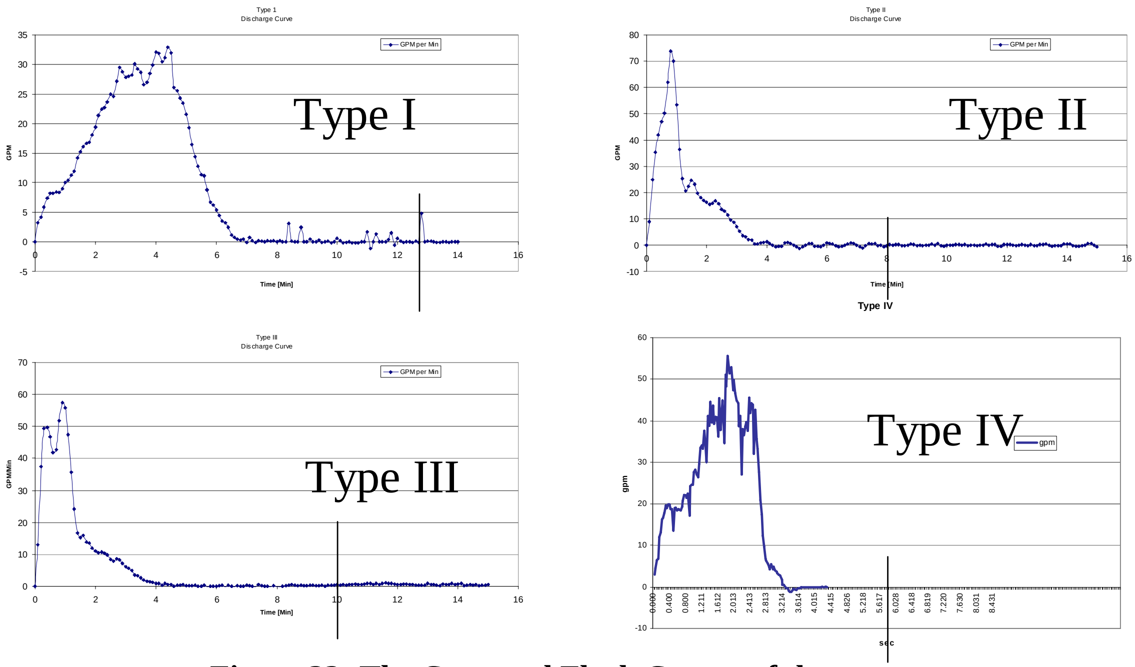


Figure 32: The Captured Flush Curves of the 4 Different Water Closet Technology Types (See Appendix A for Each Water Closet's Flush Curve)

- When capturing a flush curve, the configuration (opened vent stack, closed vent stack, or straight pipe discharge is insignificant. This is due to the relative shortness of the system. When connected to a larger system (100 feet of pipe). The affects of open and closed venting are then considerable.

3) **Whether the vent stack is open or closed significantly impacts the waste transport of the water closet.**

   - The air above the slug of water needs to be accounted for when applying the Law of Conservation of Momentum. The air can provide an additional push to increase the transport distance of the mass by 15%

4) **The intermediate measurement during a flush cycle may vary, but the eventual the wiggler will settle out near the same location.**

   - Various sequences were used (previously discussed Sequence 1, Sequence 2, and Sequence 3). Although these sequences are different, the final resting spot of the wiggler is the same. This is because the wigglers are of the same size and shape. The wigglers will settle out of the flow of water when the momentum forces and buoyancy forces are over come by the gravity and friction forces.

5) **The discharge time (time the waste leaves the water closet) is critical to the waste transport distance. The sooner the waste leave, the further it travels.**

   - This is due to the fact that as the mass and water travels the pipe, the fluid travels faster than the mass. The further upon on the slug of water the mass sits, the more contract time there is between the mass and water slug.

6) **Pipe slope, size, and material are all critical factors involved with waste transport .**

- The systems served by low flow water closets behave as an open channel flow and the basic laws of physics are applicable.
- **Note:** Relative Performance Based on All Water Closets
    - The greater the slope, the greater the waste transport distance
    - The smaller the pipe, the greater the waste transport distance
    - The smoother the pipe, the great the waste transport distance.

7) The FPN creates divisions between the different water closet technologies.

- Using FPN values to compare water closets, there is a definitive separation between technology types. The results indicate that Improved Siphons out perform the Standard Siphon which out perform the Dual Cycle

    1. Improved Siphon   Avg FPN = 0.79
    2. Siphon   Avg FPN = 0.57
    3. Pressure Assist   Avg FPN = 0.49
    4. Dual Cycle   Avg FPN = 0.45

- The FPN provides a relative performance number, which indicates the overall performance of the water closet. The higher the FPN, the better the water closet with respect to waste transport and water conservation.
- By comparing the ranking of the water closets by their $FPN_{Initial}$ to their rankings by their $FPN_{Critical}$, the overall ranking of the water closets remains the same. This indicates that long flushing sequences are unnecessary and that a single flush into an empty pipe several times can provide a good indication of the water closet's performance (see Table 14).

Suggestions for Continued Studies

1) Obtain more water closets. The collection of sixteen water closets provided valuable information, but a larger sample set would provide additional data.
2) Check the affect of variable vent stack openings (25% open, 50% open, etc). Record the airflow through the vent stack for each condition.
3) Measure the actual waste discharge time for each water closet and compare those values to waste transport distance.
4) Begin developing a model in order to alleviate the repeated flushing.

With water conservation becoming a bigger issue every day and the fact that the water closet is the highest use of residential water and in small commercial facilities, it is essential, that new methods be explored to reduce the water requirements per flush. Reducing the water requirements from 3.5 gallons (13.25 L) to 1.6 gallons (6L) per flush has made significant improvement, yet on the national level the rates of domestic water continues to increase at significant rates. If and when the water requirement for the water closet is reduced, the key factors of the system must be considered, both the water closet and the transport piping.