The Drainline Transport of Solid Waste in Buildings

November 2012

Plumbing Efficiency Research Coalition

Alliance for Water Efficiency

ASPE

IAPMO

ICC INTERNATIONAL CODE COUNCIL

PHCC PLUMBING-HEATING-COOLING CONTRACTORS ASSOCIATION

pmi PLUMBING MANUFACTURERS INTERNATIONAL

Recognition of Contributors

Securing adequate funding for this study was a major obstacle that impacted its scope and execution on several levels. PERC's funding struggles resulted in this study being delayed for nearly two years past its original conception.

Of course, PERC's timing for seeking funding was not the best. Executing our foundational Memorandum of Understanding (MoU) in early 2009, our first attempts at garnering interest in this work came as the U.S. economy was entering a recession. We soon realized that securing a funding commitment from U.S. Government agencies would not be forthcoming. As a result, all funding for this study was obtained from the private sector.

Paradoxically, throughout this time, the interest level in the status of the study never wavered. PERC members were frequently asked when the study would begin and be concluded. (We often lamented that if these questions were written on checks, we'd have completed the larger study by now!) The experience with funding sources makes thanking our financial and in-kind contributors all the more gratifying.

Therefore, we are extremely grateful to the following organizations and individuals who made this study possible.

American Standard Brands – Without American Standard Brands' generous contributions, this study would not have taken place in 2012. Their offer to allow the study to be conducted at their Product Development Design Center in Piscataway, NJ and underwrite the expense of expanding their drainline test apparatus to PERC specifications resulted in an over 50 percent reduction in cost. In addition, their financial contribution and assistance in identifying excellent, experienced technical personnel to execute the PERC work plan at a reasonable cost was also critically important to the success of this study.

Funding Partners

The following organizations and individuals made cash contributions to the study:

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Plumbing Manufacturers International
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Waterless Company

The PERC Technical Committee (TC) also wishes to extend thanks to C.J. Lagan, Manager of Compliance Engineering at American Standard Brands. Mr. Lagan worked closely with the TC, contributing considerable personal time, in the development and execution of the designed experiment that facilitated the statistical analysis of the PERC Test Plan data.

Finally, both the PERC Executive Committee and Technical Committee would like to express our thanks to Dr. Steve Cummings of Caroma Dorf, and Mr. Jeff Clark (retired), co-chairs of the Australasian Scientific Review of Reduction of Flows on Plumbing and Drainage Systems (ASFlow) committee for their input and support. PERC looks forward to an ongoing exchange of information with ASFlow in the years to come.

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Peter DeMarco: International Association of Plumbing and Mechanical Officials (IAPMO)
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1. Executive Summary

INTRODUCTION & BACKGROUND

Need - With the enactment of the Energy Policy Act of 1992, all water closets (toilets) manufactured in or imported into the United States were required to flush no more than a maximum average of 1.6 US gallons (6.0 Liters), effective January 1, 1994 for residential models and January 1, 1997 for all other models. Given the fact that this change was made without researching the impact on drainline transport efficacy, many in the plumbing trades and in various professional associations expressed concern. After these new models were introduced into the marketplace, a significant number of consumers reported poor flush performance. This prompted some early reporting and research on the first generation of 1.6 gallons per flush (gpf) (6.0 Liters per flush – Lpf) water closet models. This research focused primarily on flush efficacy, that is, the ability of water closets to reliably clear waste from the bowl. Most studies did not, however, examine the transport of that waste through drainline systems built using common designs and materials.

Since then, water closet manufacturers have made great strides in improving flushing performance in 1.6 gallons per flush (gpf) (6.0 Liters per flush – Lpf) water closets. Flushing technology has also continued to progress. Many water closet manufacturers are now offering models that further reduce flush volumes to 1.0 gpf (3.8 Lpf) and even 0.8 gpf (3.0 Lpf).

These developments have rightfully raised the debate of drainline carry efficacy anew. Many plumbing experts have questioned whether these reduced flush volumes are approaching a "tipping point" where some sanitary waste systems would be unable to function properly. Of particular concern are larger commercial systems that have long horizontal runs to the sewer. Some drainline transport problems in Europe and Australia have been reported, further raising concerns.

Reduced consumption from water closets is only one contributor to the significant decrease in liquids discharged to building drainlines. Instead, this change has been brought about as a result of reduced indoor water use by many water-consuming devices and equipment. Table 1 in Section 2 illustrates the reductions implemented over the past decades that are now leading to concerns over the function of gravity drainlines. Given these changes, and ongoing efforts to further reduce water consumption, the need to better understand the function of drainlines, as currently constructed, becomes clear. Future reductions in discharges to sanitary plumbing system flows should only be made within the context of a better understanding of how these systems perform and which controllable variables truly impact performance.

Formation of PERC - In an effort to meet the critical need for information on this topic, the Plumbing Efficiency Research Coalition (PERC) was formed. On January 5, 2009, at the U.S. EPA offices in Washington DC, a Memorandum of Understanding (MoU) was executed among five prominent plumbing and water efficiency associations constituting PERC:

Alliance for Water Efficiency (AWE)
International Association of Plumbing and Mechanical Officials (IAPMO)
International Code Council (ICC)
Plumbing Heating and Cooling Contractors – National Association (PHCC)
Plumbing Manufacturers International (PMI)
In 2011, the American Society of Plumbing Engineers (ASPE) joined the coalition as its sixth member.

Drainline Testing Priority - The MoU calls for these organizations to collaborate and provide technical expertise towards the development and completion of research programs that foster increased water efficiency in the built environment. The Coalition identified drainline transport of waste in commercial applications as the high-priority, first project to be studied.

PERC then secured the required funding from a wide range of contributors throughout the industry and the country. Additionally, American Standard Brands generously provided both the space and facilities required for the testing program at their Product Development Center located in Piscataway, NJ. Testing commenced on March 12, 2012 and concluded on July 11, 2012.

Past Research on Drainline Transport - Research on the characteristics of waste transport in building drainlines has a history of several decades. The PERC Technical Committee (TC) reviewed a large number of published reports resulting from this earlier research.

In addition, immediately prior to the formation of the PERC in 2009, a "Dry Drains Forum" was convened as part of the ISH trade show in Frankfurt, Germany. At this forum, several prominent researchers and other industry experts provided further information on the causes and effects of 'starving' drainlines of liquid flows. Later, other papers and presentations on the topic were discussed at the 2009 CIB-W062 conference convened in Düsseldorf, Germany. PERC was represented at both venues.

ASFlow Relationship - ASFlow is an Australian coalition of manufacturers and utility stakeholders that have joined forces specifically to investigate the effect of reduced flows in building drains and sewers. In December of 2010, ASFlow and PERC executed a MoU at U.S. EPA headquarters in Washington, DC. The MoU calls for both organizations to work cooperatively in the development of research initiatives pertaining to the impact of reduced flows on drainline transport.

In the recent past, ASFlow conducted several widely acclaimed research projects, including studies on the impacts of non-water consuming urinals on drainlines, the effect of

various horizontal junction fitting designs and associated installation techniques on drainline transport, and the effect of various types of toilet paper on drainline transport. Each of these projects provided needed information on drainline function. Of immediate and significant interest to PERC were the finding related to toilet paper.

Toilet Paper as an Important Variable - In a study by Dr. Steve Cummings, Research and Development Manager, Caroma Dorf, and manufacturer co-chair of the ASFlow committee, the results revealed that selection of toilet paper (and its wet tensile strength) had a profound impact on drainline transport distances. That is, higher strength paper resulted in shorter transport distances. As a result of ASFlow findings, a simple test was developed by the PERC TC to roughly measure the wet tensile strength of toilet paper available in North America. The wet tensile strength test was then used to select a high tensile strength toilet paper for use as a "worst case" selection for the PERC Test Plan.

PERC TEST PLAN

This report details the testing methodologies, analyses and findings resulting from the drainline transport research. The PERC coalition anticipates that these results will improve the understanding of sanitary plumbing system performance, inform future system design and policy decisions, and spur further testing and research into these systems, which are a vital element of infrastructure for human civilization.

Test Apparatus - The research was primarily designed to investigate long building drains in commercial buildings. In considering the appropriate test apparatus for this research, the PERC TC examined numerous alternatives as to configuration, length, materials, fittings, and, very importantly, the ability to modify the installation for slope during the test program. Actual 'real world' building drainlines vary as to materials, age, condition, diameter, slope, geometry, type and number of fittings used and quality of original installation. Any attempt at trying to duplicate or even generally characterize those conditions in a laboratory setting is nearly impossible.

Therefore, the TC concluded that the best way to approach such a study was to construct an 'as near to perfect' test apparatus as possible. This would yield results that would help us to better understand how drainlines function and how the variables we can control (volume of toilet flush discharge, drainline slope, toilet flush discharge characteristics, and type of toilet paper) affect drain line transport of solid wastes under ideal conditions. With this in mind, the test apparatus was constructed employing 4-inch[1] (100mm) polyvinyl chloride (PVC) pipe. The test apparatus was 135 feet (41 meters) in total length and incorporated two wide sweep 90° bends in order to fit within the floor footprint available to PERC at the American Standard Brands facility.

Surge Injectors - The test plan goal was to tightly control as many variables as possible in the Test Apparatus. As such, the same approach was employed when considering how to inject water and solids into that apparatus. From the beginning of this study, PERC made clear to its members and study sponsors that this effort would not be another toilet study. Much work has been completed on studying toilet performance and PERC would not seek to rank specific products or designs against each other in any manner.

It became critical that we rigorously control the flush attributes associated with a specific discharge, i.e., volume, flush rate (velocity) and percent trailing water, in order to ensure that injections into the apparatus consistently embody the precise flush characteristics needed for the analyses.

The TC solved this by designing what became referred to as Surge Injectors. The Surge Injectors were installed onto a typical closet flange on the drainline test apparatus flush stand. They were manually activated by opening the "release valve" at the bottom of the injector. Air flowing into the injector from a drilled orifice allowed water to flow from the injector into the test apparatus at a controlled flush rate.

Simulated Solid Test Media - Early in the development phase of the Test Plan, the PERC TC decided to use uncased MaP[2] test media to simulate solid waste. This test media is widely used by manufacturers and laboratories to test the flush performance of toilets. MaP media is comprised of soybean paste, a food product typically used in Japanese cuisine. The MaP media was extruded into approximately ¾-inch diameter cylinders, each 4 inches in length (20mm and 100mm, respectively) and weighing 50 grams (approximately 12 oz.).

The MaP protocol for testing toilets utilizes four (4) crumpled balls of toilet paper, each consisting of six (6) sheets, for a total of 24 sheets of paper. The PERC TC reviewed this requirement and determined that this amount of toilet paper was to be incorporated into the Test Plan.

Having had the benefit of reviewing Dr. Cummings' test report on the effect of toilet paper on drain line transport distances, the TC intentionally selected a brand of toilet paper that, through testing, was found to have a very high wet tensile strength. Similarly, another brand was selected for the study that was found to have a very low wet tensile strength. It became apparent that a person that would use 24 sheets of high tensile strength toilet paper, which happened to be a 2-ply paper, would use much more of the single-ply low tensile strength paper. Therefore, the TC decided to use double the amount of sheets of single-ply paper to normalize the amount of paper between the high tensile strength brand and the low tensile strength brand.

As a result, each test run incorporating the single-ply low tensile strength paper used eight (8) balls of six (6) sheets each, a total of 48 sheets, as opposed to four (4) balls, 24 total sheets of the 2-ply high tensile strength paper.

1 *All pipe sizes called out in this report are nominal pipe sizes.*

2 *MaP: Maximum Performance; refer to: www.map-testing.com*

TEST PROCEDURE

The test procedure consisted of 40 test runs, each such run consisting of 100 flushes from the Surge Injector. Each test run required the use of a Surge Injector specifically set up to provide the required flush volume (3.0, 4.8, or 6.0 liters – 0.8, 1.28, or 1.6 gallons), flush rate, and percent trailing water.

The test procedure also specified that at the end of each test run, a higher volume clear water discharge would be introduced into the drainline apparatus (simulating a discharge from a pre-programmed flushometer valve) in order to observe the clearing potential of the clear water discharge. Therefore, the procedure incorporated a clearing flush at the end of each 100-cycle test run. The clearing flush would be set and evaluated at 3.0 gallons (11.4 L) and 5.0 gallons (18.9 L) volumes.

Designed Experiment - The PERC Work Plan cited the need to develop a multi-factorial designed experiment to analyze data, rank the test plan variables for significance, and search for possible interactions among those test plan variables. In general terms, a multi-factorial designed experiment, also referred to as Design of Experiments (DOE), is the development of a random testing sequence at predetermined variable factor levels. By analyzing specific factor levels across the bulk of the experimental runs, the experimental efficiency is increased. This method also provides for the interpretation of test variable interactions.

As it pertains to the PERC Test Plan, a DOE was constructed capable of analyzing and ranking the controlled variables. In consultation with Mr. C.J. Lagan of American Standard Brands, the PERC TC determined that a DOE employing Analysis of Variance (ANOVA) as one of the principle tools was required. ANOVA is a statistical tool that separates random variation (noise) from a signal (significance of the variable). ANOVAs are useful for comparing two, three, or more variables, judging significance by a low "p" value (chosen in advance) in consideration of the level of inherent variability contained in the experiment. Generally speaking, the p-value relates very closely to the risk in assuming that the factors are either significant or non-significant. This makes analysis of the data using ANOVA a good fit.

Thus, the PERC Test Plan was constructed, incorporating the variables of slope, volume, percent trailing water, flush rate, and toilet paper selection based on wet tensile strength.

FINDINGS AND CONCLUSIONS

Clearing Flush - A 5 gallon (19L) clearing flush failed to clear the drainline in 7 of 39 test runs. As a result, this potential solution to a drainline blockage proved to be unreliable and cannot be suggested as a building drain clearing solution.

Significant vs. Non-Significant Variables - Toilet hydraulics (percent trailing water and flush rate) were found to be non-significant variables in this study. As such, the effect that toilet fixture designs have on drainline transport in long building drains has been found to be minimal. Instead, flush volume, toilet paper, and pipe slope were found to have a large effect upon drainline transport of solid waste.

FIGURE 1. PRIMARY MAIN EFFECTS PLOT ALL DATA AND RESPONSE TABLE FOR MEANS

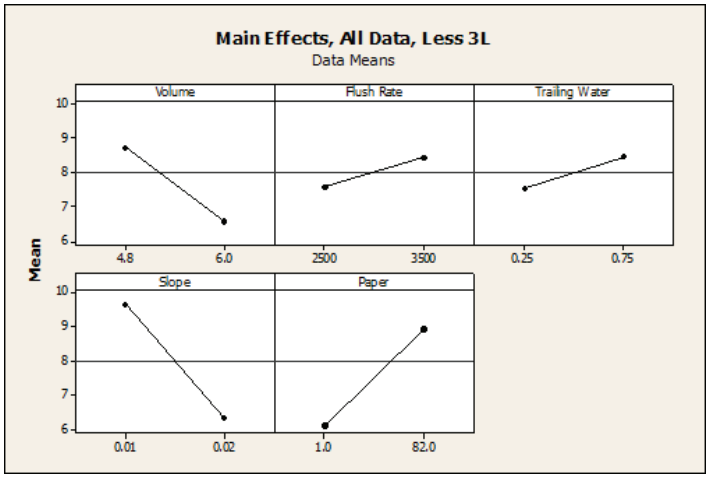


TABLE 1-A. RESPONSE TABLE FOR MEANS

Level	Volume	Flush Rate	%Trailing Water	Slope	Paper
1	8.710	7.567	7.535	9.671	6.104
2	6.554	8.416	8.448	6.311	8.935
Delta	2.156	0.849	0.913	3.360	2.831
Significance Rank	3	5	4	1	2

When considering all except the 0.8 gallon (3.0 L) data (which consists mostly of noise and cannot be used for this purpose), observe the slopes in Figure 1 and note that there are three (3) significant variables and two (2) non-significant variables. Table 1-A applies a numeric value to all of the Test Plan variables, which allows for discrete ranking. Significance of the variables can be ranked by the relative difference in the delta values, which results in the following ranking:

Significant Variables	Non-significant Variables
Slope > Paper > Volume >	% Trailing Water > Flush Rate

Due to the inherent variability with this Test Plan and considering the fact that the Delta values in Table 1-A are tightly grouped within the significant and non-significant test variables, the PERC TC cautions against basing any plumbing system design decisions on the discrete rankings among those factors, pending further study. The major finding of this analysis is that pipe slope, toilet paper, and flush volume are all definitely significant while percent trailing water and flush rate are not.

0.8 gpf / 3.0 Lpf flush volume - Observation of waste movement within the Test Apparatus during the 0.8 gallon (3.0 L) test runs clearly demonstrated a major difference in performance when compared to the other volume levels (1.28 gallons and 1.6 gallons). In five (5) of the sixteen (16) test runs conducted at the 0.8 gpf / 3.0 Lpf volume, the test media in the test apparatus compressed together to form large plugs in the drain line that resulted in full-pipe or near full-pipe conditions. While these plugs eventually cleared themselves prior to any water overflows at the flush stand, the PERC TC still found that this flush volume created a chaotic, unpredictable condition to the extent that the data at the 0.8 gpf / 3.0 Lpf volume was mostly noise and not useable in the statistical analysis.

As a result, the PERC TC recommends further study at this discharge level.

1.28 gpf/4.8 Lpf and 1.6 gpf/6.0 Lpf flush volumes - The 1.28 gallon (4.8 L) and 1.6 gallon (6.0 L) test runs resulted in an orderly and predictable movement in the Test Apparatus. As a result, the PERC TC anticipates no problems with use of 1.28 gpf (4.8 Lpf) toilets (HETs) in new commercial construction. In retrofit applications, it is suggested that drainlines first be inspected for defects, root intrusions, sagging or other physical conditions that could result in clogging with lower flush volumes.

Based on the findings from this study, the PERC TC recommends that the U.S. EPA WaterSense® Program expand their specification on toilets to include commercial flushometer-valve operated HETs.

Percent Trailing Water and Flush Rate – The findings show that, in a long drainline, when toilet paper and a more realistic test media are used (such as that used in this study), and in long duration (100 flush) flush sequences, percent trailing water and flush rate (i.e.: toilet flush discharge characteristics) are non-significant factors in drainline performance.

This finding has implications regarding the necessity for a Drainline Transport Characterization Test within the North American standard for toilets, *ASME A112.19.2 / CSA B45.1, Ceramic Plumbing Fixtures*. In fact, toilet manufacturers are frequently asked by their customers for the results of that test in the standard in the mistaken belief that those results are meaningful. Results from this study indicate they are not. Findings from this study will be forwarded to the ASME / CSA Joint Harmonized Committee of Plumbing Fixtures for their consideration.

Significance of Toilet Paper Selection - As noted earlier, research conducted by Dr. Steve Cummings in Australia illustrated how different brands of toilet paper directly impact drainline transport distances. As a follow-up to that research, the PERC TC performed tests on the Test Apparatus where the resulting transport distances similarly indicated a strong inverse correlation between the wet tensile strength values and the resulting transport distances both with and without the MaP test media. See Table 1-B.

TABLE 1-B
CORRELATION OF WET TENSILE STRENGTH AND DRAINLINE TRANSPORT DISTANCES

Toilet Paper Properties	Low Tensile Strength Paper	High Tensile Strength Paper
Dimensions (1 square)	4.125" x 3.75"	4.25" x 4"
Ply (single or double)	Single	Double
Tensile Strength Value	1	82
DLT Distance with MaP Media and paper	24	11
DLT Distance without MaP Media (paper only)	135	45
Correlation – DLT Distance to Tensile Strength Value with MaP Media and paper	-0.91	
Correlation – DLT Distance to Tensile Strength Value Without MaP Media (paper only)	-88.3	

It should be noted that Table 1-B shows only the inverse correlation results between wet tensile strength and transport distances on the two toilet papers used in the PERC Test Plan. In addition, this test was run on three (3) brands of toilet paper from Australia (the "best", "worst" and "nearest to average" brands, based on transport distances as identified in Dr. Cummings' report) and three (3) popular brands of paper sold in the United States. In each case, an inverse correlation in the high 80's or 90's resulted.

Therefore, a definite correlation exists between the wet tensile strength of toilet paper and transport distances. As such, toilet paper selection has the potential to be very significant in terms of drainline performance. In fact, as noted earlier, the data clearly suggests that the selection of toilet paper is definitely more significant than other toilet flush characteristics (flush rate and trailing water).

However, it is important to keep in mind that the highest and lowest wet tensile strength brands of toilet paper were intentionally selected for this test, so as to measure the potential for toilet paper to affect drainline transport results. Accordingly, there would be less significance among brands of toilet paper that fall *between* these extremes.

Therefore, the PERC TC suggests that the wet tensile strength test described in this report be used where building drainline blockages chronically occur in order to identify a replacement toilet paper with a lower wet tensile strength than whatever paper may currently be used. This possible remedy to chronic drainline blockages may be a first step in a set of best management practices for building drainline systems.

FUTURE STUDY OPPORTUNITIES

There is much yet to be done to bring the ideal of laboratory testing closer to the conditions and materials found in new and remodeled commercial buildings, i.e., the 'real world'. The tasks proposed here by the PERC have not been prioritized. However, our partner, American Standard Brands, has generously offered to continue to provide the facilities used in this first phase for subsequent work undertaken on drainline transport. Following are the critical areas of future study that we believe need to be carried out in the near future:

This testing program used 4-inch (100mm) diameter pipe as the test apparatus. Waste transport is significantly affected by pipe diameter. The study of the impacts of 3-inch (75mm) diameter pipe on waste transport is essential to expand the boundaries of our understanding.

The test apparatus in this testing program was set at one percent and two percent drainline slopes. In actual practice, however, the slope in a building often varies between those two numbers. That recognition of 'real world' installed piping systems calls for testing to be performed at increments between one and two percent. Further, both 3-inch (75mm) and 4-inch (100mm) pipe should be tested using the same testing parameters that were shown to be significant in the completed study.

Toilet paper testing was not a part of the original work plan, having been added mid-way through the study. Toilet paper has been shown to be an important variable in the transport of solid wastes in building drainlines. As such, a more comprehensive testing scope and work plan needs to be developed in order to provide guidance for the owners and managers of commercial buildings.

Testing was accomplished using clear plastic pipe. Other pipe materials are most commonly used. We propose to simulate cast iron installations while maintaining a visual observation of activity in the drainline.

It is well known the surface of cast iron can become much rougher over a period of time, due to the formation of oxides and biofilm activity, as well as congealed grease. It is proposed to duplicate the increasing friction factors caused by years of use, thereby more closely replicating 'real world' conditions.

A meaningful finding of this study was that a clearing flush of five (5) gallons of clear water delivered after the 100th flush injection in each test run did not consistently clear the test apparatus. However, it is proposed that a separate experiment be designed explicitly for the evaluation of clearing flushes at lower intervals and higher volumes. Included would be the investigation of other potential drain clearing technologies such as tipping mechanisms and siphonic devices currently being utilized elsewhere.

One of the more surprising findings of this study was the possible inverse effect of the slope test variable at the 0.8 gallon (3.0 L) test run level. Analysis indicated a possibility that higher slope levels are actually a detriment to drainline performance, albeit at a significance much lower than toilet paper selection, as the ratio of solids to water increased, such as in the 0.8 gallon (3.0 L) test runs. This deserves additional study.

The study results indicated that 0.8gpf (3.0 Lpf) flush volumes may be problematic in commercial installations that have long horizontal drains and little or no additional long duration flows available to assist the toilet in providing drainline transport of solids. Volume levels between 1.28 gallons (4.8 L) and 0.8 gallons (3.0 L) must be evaluated to determine at what levels drainline performance becomes chaotic, leading to an increased potential for clogging failures.

The study strongly indicated that toilet paper selection has the potential to be a very significant variable relating to drainline transport characteristics. Experiments should be designed to determine how other materials, such as moisturized non-woven "wipes", paper toilet seat covers, and other so-called 'flushable' consumer products impact drainline performance.

2. Introduction and Background

With the enactment of the Energy Policy Act of 1992, all water closets (toilets) manufactured in or imported into the United States were required to flush no more than a maximum average of 1.6 US gallons (6.0 Liters), effective January 1, 1994 for residential models and January 1, 1997 for all other models. Given the fact that this change was made without researching the impact on drainline transport efficacy, many in the plumbing trades and in various professional associations expressed concern. After these new models were introduced into the marketplace, a significant number of consumers reported poor flush performance. This prompted some early reporting and research on the first generation of 1.6 gallons per flush (gpf) (6.0 Liters per flush – Lpf) water closet models. This research focused primarily on flush efficacy, that is, the ability of water closets to reliably clear waste from the bowl. Most studies did not, however, examine the transport of that waste through waste piping systems built using common designs and materials.

Since then, water closet manufacturers have made great strides in improving flushing performance in 1.6 gallons per flush (gpf) (6.0 Liters per flush – Lpf) water closets. While there have been intermittent and anecdotal complaints of drain line carry and transport problems, they have been largely attributed to older or faulty sanitary drain lines.

In recent years, technological advances made possible the development of water closets consuming less than 1.6 gpf, while retaining high levels of flush performance. To incentivize further development of these higher efficiency devices, known as High-Efficiency Toilets (HETs), voluntary product performance and labeling programs have been developed. The EPA WaterSense® specification for gravity flush water closets, for example, requires a 20 percent reduction in the flush discharge volume of water closets to receive the WaterSense® label. This brings consumption down to a maximum average of 1.28 gpf (4.8 Lpf) for HETs. The voluntary programs have since been followed by legislation and ordinances in several locations requiring the use of HETs. The State of California passed legislation in 2007 to require all toilets sold or installed in that state to be HET's by the year 2014. There are other provisions in California that significantly accelerate this transition and other areas of the country have enacted similar requirements (Texas, Georgia, New York City).

Flushing technology has also continued to progress. Many water closet manufacturers are now offering models that further reduce flush volumes to 1.0 gpf (3.8 Lpf) and even 0.8 gpf (3.0 Lpf).

These developments have rightfully raised the debate of drainline carry efficacy anew. Many plumbing experts have questioned whether these reduced flush volumes are approaching a "tipping point" where a significant number of sanitary waste systems would be unable to function properly. Of particular concern are larger commercial systems that have long horizontal runs to the sewer. Some drainline transport problems in Europe and Australia have been reported, further raising concerns.

Reduced consumption from water closets is only one contributor to the significant decrease in liquids discharged to building drainlines. Instead, this change has been brought about as a result of reduced indoor water use by many water-consuming devices and equipment. Table 1 illustrates the reductions implemented over the past decades that are now leading to concerns over the function of gravity drainlines. Given these changes, and continued efforts to reduce water consumption, the need to better understand the function of drainlines, as currently constructed, becomes clear. In order to avoid unintended consequences, further reductions in discharges to sanitary plumbing system flows should only be made within the context of a better understanding of how these systems perform and which controllable variables truly impact performance. Yet, until this study, a research project of sufficient scope to be able to determine if significant problems could arise regarding drain line transport in these "water-efficient buildings" had not been conducted.

In an effort to meet the critical need for information on drainlines, the Plumbing Efficiency Research Coalition (PERC) was formed. On January 5, 2009, a Memorandum of Understanding (MoU) was executed at the U.S. EPA offices in Washington DC among the five prominent plumbing and water efficiency associations constituting PERC: the Alliance for Water Efficiency (AWE), the International Association of Plumbing and Mechanical Officials (IAPMO), the International Code Council (ICC), the Plumbing Heating and Cooling Contractors – National Association (PHCC) and the Plumbing Manufacturers International (PMI). In 2011, the American Society of Plumbing Engineers (ASPE) joined the coalition as its sixth member.

The MoU calls for these organizations to collaborate and provide technical expertise towards the development and completion of research programs that foster increased water efficiency in the built environment. The Coalition identified drainline transport of waste in commercial applications as the high-priority, first topic to be studied. Using their collective expertise, the group created a multi–factorial designed experiment to measure the impact of the toilet fixture on drainline transport relative to other plumbing system variables, such as drainline pitch, and flush volume.

PERC then secured the required funding from a wide range of contributors throughout the industry and the country. Additionally, American Standard Brands generously provided both the space and facilities required for the testing program at their Product Development Center located in Piscataway, NJ. Testing commenced on March 12, 2012 and concluded on July 11, 2012.

The purpose of this report is to detail the testing methodologies, analyses and findings resulting from the

drainline transport research. It is the hope of PERC that these results will improve the understanding of sanitary plumbing system performance, inform future system design and policy decisions, and spur further testing and research into these systems, which are a vital element of infrastructure for human civilization.

TABLE 2-A. WATER CONSUMPTION BY WATER-USING PLUMBING PRODUCTS AND APPLIANCES – 1980 TO 2012

Water-using Fixture or Appliance	1980s Water Use	1990 Requirement	EPAct 1992 Requirement	2009 Baseline Plumbing Code	2012 'Green Code' Requirement	% Reduction in avg water use since 1980s
Residential Bathroom Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	2.2 gpm	1.5 gpm	57%
Showerhead	3.5+ gpm	3.5 gpm	2.5 gpm	2.5 gpm	2.0 gpm	43%
Toilet – Residential	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.28 gpf	74%
Toilet - Commercial	5.0+ gpf	3.5 gpf	1.6 gpf	1.6 gpf	1.6 gpf[1]	68%
Urinal	1.5 to 3.0+ gpf	1.5 to 3.0 gpf	1.0 gpf	1.0 gpf	0.5 gpf	67%
Commercial Lavatory Faucet	3.5+ gpm	2.5 gpm	2.2 gpm	0.5 gpm	0.5 gpm	86%
Food Service Pre-rinse Spray Valve	5.0+ gpm	No requirement	1.6 gpm (EPAct 2005)	No requirement	1.3 gpm	74%
Residential Clothes Washer	51 gallons/load	No requirement	26 gallons/load (2012 standard)	No requirement	16 gallons/load	67%
Residential Dishwasher	14 gallons/ cycle	No requirement	6.5 gallons/cycle (2012 standard)	No requirement	5.0 gallons/cycle (ASHRAE S191P)	64%

gpm: gallons per minute
gpf: gallons per flush

3. Test Plan

Note: The original PERC Test Plan Proposal appears in Appendix B.

PAST RESEARCH

Research on the characteristics of waste transport in building drainlines has a history of several decades. The PERC Technical Committee (TC) reviewed a large number of published reports resulting from this earlier research. In addition, immediately prior to the formation of the PERC in 2009, a "Dry Drains Forum" was convened as part of the ISH trade show in Frankfurt, Germany. At this forum, several prominent researchers and other industry experts provided presentations, notably the late Professor John Swaffield of Heriot Watt University in Scotland.

We highlight Professor Swaffield's presentation, inasmuch as the thesis of his presentation was that adequate research on the topic of drainline transport had already been conducted (implying, therefore, that further such research was unwarranted). Later, this thesis was repeated in another paper and presentation[3] he provided for the 2009 CIB-W062 conference in Düsseldorf, Germany, in which he specifically referred to the recently announced PERC drainline study effort as unnecessary. His presentation later proved to be extremely useful to the PERC TC as it summarized all of the significant research efforts conducted internationally over the course of the past 30 years.

PERC TC member Pete DeMarco attended the 2009 CIB-W062 conference and was fortunate enough to begin an ongoing dialogue with Professor Swaffield that lasted up to a few days before his sudden passing in 2011.

During those discussions, we clarified to Professor Swaffield that the PERC study would, in fact, be worthwhile, and was unique in the following areas.

We sought to investigate what happens in very long drainlines over a very long test sequence (100 flushes).

We would be able to rigorously control flush discharge parameters such as velocity and percent trailing water more accurately by not using toilets, which are inherently inconsistent in their discharge profile.

We sought to incorporate both a deformable, realistic test media and toilet paper together in the test plan.

We would develop a designed experiment that would allow for ranking of drainline transport variables such as slope, flush volume, etc., per the Test Plan proposal.

We would investigate the efficacy of a clearing flush.

Many of these areas were not fully included in previous research and, as such, the TC believed they were essential to more closely replicating 'real world' conditions found in North American buildings. As a result, Professor Swaffield was kind enough to help guide the PERC TC in the final stages of the development of the Test Plan, and was keen to follow along with our efforts, since the prospect of ranking drainline systems variables was intriguing to him.

ASFLOW

Dr. Steve Cummings, Research and Development Manager, Caroma Dorf, is the manufacturer co-chair of the Australasian Scientific Review of Reduction of Flows on Plumbing and Drainage Systems (ASFlow) committee.

ASFlow is an Australian coalition of manufacturers and utility stakeholders that have joined forces specifically to investigate the effect of reduced flows in building drains and sewers. In December of 2010, ASFlow and PERC executed a Memorandum of Understanding (MoU) at U.S. EPA headquarters in Washington, DC. The MoU calls for both organizations to work cooperatively in the development of research initiatives pertaining to the impact of reduced flows on drainline transport.

ASFlow has conducted several widely acclaimed research projects, including studies on the impacts of non-water consuming urinals on drainlines, the effect of various horizontal junction fitting designs and associated installation techniques on drainline transport, and the effect of various types of toilet paper on drainline transport.

TOILET PAPER

In 2010, Dr. Cummings issued a report[4] detailing the results of his study on the effect of toilet paper selection on drainline transport distances. Dr. Cummings presented these results at the Water Smart Innovations Conference in 2010 in a joint presentation with PERC[5].

In Dr. Cummings' study, 22 brands of toilet paper available in the Australian market were purchased and tested. The results revealed that selection of toilet paper has a profound impact on drainline travel distances. In studying Dr. Cummings' report, it became apparent that there might be relationship between the papers' wet tensile strength and drainline transport distances. A simple test was developed by the PERC TC to roughly measure the wet tensile strength of toilet paper[6]. Subsequent testing conducted on the drainline transport Test Apparatus revealed an inverse

3 *Swaffield, Prof. John, 2009, "Dry Drains: Myth, Reality or Impediment to Water Conservation"*
Paper and presentation downloadable from:
Paper: http://www.map-testing.com/assets/files/Swaffield-CIBW62-2009-paper.pdf
Presentation: http://www.map-testing.com/assets/files/Swaffield-DRY-DRAINS-CIBW62-2009-presentation.pdf

4 *Cummings, Dr. Steve, 2010. "Operational Performance Boundaries in Drainage Systems"; downloadable here:*
http://www.map-testing.com/assets/files/Cummings-2010-drainlineconnections-toiletpaper.pdf

5 *http://www.map-testing.com/assets/files/WaterSmartInnovations-2010-PERC-ASFlow-Presentation.pdf*

6 *See Section 7 of this report, Findings, to review the wet tensile strength test procedure, and refer to Appendix C to review correlation data between toilet paper wet tensile strength values and drainline transport travel distances.*

correlation between the wet tensile strength of toilet paper and drainline transport distances. That is, higher strength paper resulted in shorter transport distances. The wet tensile strength test was then used to select a high tensile strength toilet paper for use as a "worst case" selection for the PERC Test Plan.

While the PERC TC would have chosen to add the selection of toilet paper to the original Test Plan proposal as a controlled test variable by selecting both a high and a low wet tensile strength toilet paper, there were insufficient funds to do so at the outset of testing. However, once testing commenced and the PERC TC realized that the plan would be completed sooner and more efficiently than estimated, and as additional funding was secured, toilet paper selection was added to the list of controllable test variables and a low tensile strength toilet paper was identified and added to the Test Plan for the 1.28 gpf (4.8 Lpf) and 0.8 gpf (3.0 Lpf) volume Test Runs only[7].

TEST APPARATUS

This research was primarily designed to investigate long building drains in commercial buildings. In considering the appropriate test apparatus for this research, the PERC TC examined numerous combinations of configuration, length, materials, fittings, and, very importantly, the ability to modify the installation for slope during the test program. We recognized that actual building drainlines vary immensely and in every way possible. Materials, age, condition, diameter, slope, geometry, type and number of fittings used and quality of original installation are all highly variable in the 'real world', which makes any attempt at trying to duplicate or even generally characterize those conditions nearly impossible.

Therefore, the TC concluded that the best way to approach such a study was to construct an 'as near to perfect' test apparatus as possible. This would yield results that would help us to better understand how drainlines function and how the variables we can control (volume of toilet flush discharge, drainline slope, toilet flush discharge characteristics, and type of toilet paper) affect drain line transport of solid wastes under ideal conditions (see Section 3, PERC Test Plan).

The travel distances achieved using the test apparatus were expected to be very different from actual travel distances that would occur on just about every 'real world' building drain. Hence, we offer no recommendations in this report about how far toilets of various flush volumes or design technologies will transport solid waste, as every drainline is, in fact, unique and will yield dramatically different results. But, by better understanding how the variables we can control universally impact drain line performance, we gain clarity as to which of these variables are most important and which have minimal, if any, impact upon long term performance.

With this in mind, the test apparatus was constructed employing 4-inch[8] (100mm) polyvinyl chloride (PVC) pipe. See Section 4, Test Equipment, Materials and Test Media, for the Test Apparatus component details and photos.

Surge Injectors

Following with the logic that the best way to investigate drain line transport in building drains was to tightly control as many variables as possible in the Test Apparatus, the same approach was employed when considering how to inject water and solids into that apparatus. From the beginning of this study, PERC made clear to its members and study sponsors that this effort would not be another toilet study. Much work has been completed on studying toilet performance and PERC would not seek to rank specific products or designs against each other in any manner.

Additionally, it is widely understood that toilet performance is inherently variable. This is especially true for the siphonic toilets that are overwhelmingly used in North American installations. Therefore, it became critical that we rigorously control the flush attributes associated with a specific discharge, i.e., volume, flush rate (velocity) and percent trailing water, in order to ensure that injections into the apparatus consistently embody the precise flush characteristic called for in the Test Plan.

The TC solved this by designing what became referred to as Surge Injectors. In the simplest terms, a Surge Injector is a 3-inch (75mm) diameter clear pipe, sectioned off by ball valves at the 25 percent and 75 percent volumetric heights and containing a PVC cap with an orifice drilled into the top to control the flow of air into the pipe. The Surge Injectors were installed onto a typical closet flange on the drainline test apparatus flush stand. They were manually activated by opening the "release valve" at the bottom of the injector. Air flowing into the injector from the drilled orifice allowed water to flow from the injector into the test apparatus at a controlled flush rate.

Use of the Surge Injectors allowed the TC to accurately control the flush attributes throughout the duration of the testing as follows:

Flush rate – controlled by varying the diameter of the drilled orifice. Larger diameter orifices allowed air to flow more quickly into the Surge Injector, thus increasing the flush rate. Conversely, smaller orifices restricted the flow of air into the Surge Injector and slowed down the flush rate. Each Surge Injector was tested to determine the drilled orifice diameter required to replicate flush rates consistent with 'slow acting' toilets (such gravity-fed toilets that utilize standard 2–inch (50mm) diameter flapper type flush valves), and 'fast discharge' toilets (such as gravity-fed toilets employing 3–inch (75mm) diameter flapper-type flush valves or pressure-assisted *and flushometer-valve* toilets). The threaded caps were color coded and marked to ensure that the technicians utilized the correct cap for each test run.

7 Lack of funds prohibited incorporating the addition of the toilet paper variable at the 1.6 gpf (6.0 Lpf) volume.

8 All pipe sizes stated in this report are nominal pipe sizes.

Percent Trailing Water – controlled by the selected use of the ball valves on the injectors. (See Section 5, Test Procedures)

Volume - controlled by three different Surge Injectors, one each for the 6 Lpf, 4.8 Lpf and 3.0 Lpf volumes (Lpf = Liters per flush).

See Appendix C, Figure AC-A through AC-D to view the various discharge curves from the Surge Injectors. The procedure for using the Surge Injectors appears in Section 5, Test Procedures.

Refer to Section 4, Test Equipment, Materials and Test Media, for Surge Injector component details and photos.

Test Media

Simulated Solid Test Media

Early in the development phase of the Test Plan, the PERC TC decided to use uncased MaP[9] test media to simulate solid waste. This test media is widely used by manufacturers and laboratories to test the flush performance of toilets.

MaP media is comprised of soybean paste, a food product typically used in Japanese cuisine. It was shipped to the test site in 5 gallon (19L) buckets. For both MaP testing and for this testing, the test media was extruded into approximately ¾-inch diameter cylinders, each 4 inches in length (20mm and 100mm, respectively) and weighing 50 grams (approximately 12 oz.). See Section 4, Test Equipment, Materials and Test Media, for a detailed description of the uncased MaP test media.

Toilet Paper

The MaP protocol for testing toilets utilizes four (4) crumpled balls of toilet paper, each consisting of six (6) sheets, for a total of 24 sheets of paper. The PERC TC reviewed this requirement and while it might certainly be considered by some as a 'worst case' in terms of toilet paper use, it does appear to be appropriate for a drainline study of this type. Therefore, the PERC TC determined that we would employ this amount of toilet paper in the Test Plan.

Having had the benefit of reviewing Dr. Cummings' test report on the effect of toilet paper on drain line transport distances, the TC intentionally selected a brand of toilet paper that, through testing, was found to have a very high wet tensile strength. When the decision was made to add toilet paper to the list of controlled test variables, another brand of toilet paper was identified for the study that was found to have a very low wet tensile strength. It became apparent that a person that would use 24 sheets high tensile strength toilet paper, which happened to be a 2-ply paper, would use much more of the single-ply low tensile strength paper. Therefore, the TC decided to use double the amount of sheets to normalize the amount of paper between the high tensile strength brand and the low tensile strength brand.

9 MaP: Maximum Performance; refer to: www.map-testing.com

It should be noted that, as a result, each test run incorporating the single-ply low tensile strength paper used eight (8) balls of six (6) sheets each, a total of 48 sheets as opposed to four (4) balls, 24 total sheets of the 2-ply high tensile strength paper.

PHOTO 3A

(Left) High Tensile Strength Paper (4 balls / 24 sheets) - (Right) Low Tensile Strength Paper (8 balls / 48 sheets)

As detailed in the PERC Test Plan Proposal and with the goal to replicate a building drain, the following assumptions as to use patterns pertaining to the amount of media to employ during the course of the testing were applied:

- 50 / 50 "male to female" ratio
- All males use urinals for liquid waste
- Non-water consuming urinals and 0.5 gpm commercial bathroom faucets are installed so no long duration flows from other fixtures will assist the movement of solid waste in the drainline.
- Males: use the toilet 33.3 percent of the time for solid waste flushes only and urinals are used 66.7 percent of the time. Thus, only the solid waste flushes from males from toilets would be captured in the Work Plan and the liquid waste flushes from males would not be factored into the Work Plan.
- Females: use the toilet 100 percent of the time, 33.3 percent for solid waste flushes and 66.7 percent of the time for liquid waste and toilet paper only.
- When combined, the above factors equate to 50 percent of the flushes having solid waste and toilet paper and the other 50 percent having liquid waste and paper only. Note that 100 percent of the flushes contain toilet paper.
- The solid waste loadings vary randomly and evenly between 300 grams, 200 grams 100 grams and 0 grams (simulating female liquid waste only flushes)[10].

Therefore, the test variables utilized in the Test Plan were finalized as follows:

10 These amounts of solid waste are consistent with medical studies that detail the amount of fecal matter generated by healthy adults. The same media loading pattern was employed for all 40 Test Runs. In other words, while the amount of soy paste varied among 300, 200, 100 or 0 grams, per a random computer generated sequence, the same random sequence was used for each test run.

TABLE 3-B. STUDY VARIABLES

Diameter (in/mm)	4/100			
Pitch (%)	1.0%		2.0%	
Flush Volume (Lpf/gpf)	6.0/1.6	4.8/1.3	3.0/0.8	
Flush Rate - Peak Flow (ml/sec)	3500		2500	
Percent Trailing water (Percent water after solids)	75		25	
Toilet Paper	High Tensile Strength		Low Tensile Strength	
Loadings (grams soybean paste)	300	200	100	0

CLEARING FLUSH

As stated in the Test Plan Proposal, "At the end of each test run, a higher volume clear water discharge will be introduced into the drainline apparatus (simulating a discharge from a pre-programmed flushometer valve) in order to observe the clearing potential of the clear water discharge."

Prior research (Swaffield, 2009 CIB-W062) cited the potential for siphonic or tipping mechanisms to provide a surge of water that would flush out building drains in the event that water efficiency measure pushed some plumbing system past their tipping point and chronic clogging occurred. The PERC TC, in discussion with several flushometer valve manufacturers, envisioned the possibility that programmable electronic flushometer valves could be set up to deliver a higher volume flush at predetermined intervals that could both provide the clearing surge of water and also be tested and become plumbing code compliant in a reasonable length of time. This approach was considered a viable low cost solution that PERC could evaluate and recommend if proven effective.

Therefore, the Test Plan incorporated a clearing flush at the end of each 100-cycle test run. The clearing flush would be set and evaluated at 3.0 gallons (11.4 L) and 5.0 gallons (18.9 L) volumes.

THE DESIGNED EXPERIMENT

The PERC Work Plan Proposal cited the need to develop a multi-factorial designed experiment to analyze data, rank the test plan variables for significance, and search for possible interactions among those test plan variables. In general terms, a multi-factorial designed experiment, also referred to as Design of Experiments (DOE), is the development of a random testing sequence at predetermined variable factor levels. By analyzing specific factor levels across the bulk of the experimental runs, the experimental efficiency is increased. This method also provides for the interpretation of test variable interactions.

When designed correctly, A DOE can accommodate process or system variations that may exist whether or not they are under the control of the experimenter. In other words, a well-designed DOE is insensitive to random fluctuations of the process. DOEs are increasingly used in industry as control process improvement tools and in new product development programs to assist in determining the effect of various design elements on product performance.

A DOE uses a statistical approach that randomizes test runs of specific system variables. DOEs actively change the incorporation of test sequences that permit changes to more than one test variable at a time, in a specific manner, in order to reduce the amount of testing that would otherwise be required using traditional scientific method techniques. Running experiments in this manner then allows for analyzing the resulting data using commercially available computer software programs that employ various pre-constructed statistical models chosen by the designer specifically for the type of experiment being conducted.

As it pertains to the PERC Test Plan, a DOE would need to be constructed that was capable of analyzing and ranking our controlled Test Plan variables. In consultation with Mr. C.J. Lagan of American Standard Brands, the PERC TC determined that a DOE employing Analysis of Variance (ANOVA) as one of the principle tools was required. ANOVA is a statistical tool that separates random variation (noise) from a signal (significance of the variable). ANOVAs are useful for comparing two, three, or more variables, judging significance by a low "p" value (chosen in advance) in consideration of the level of inherent variability contained in the experiment. Generally speaking, the p-value relates very closely to the risk we are taking in assuming that the factors are either significant or non-significant. This makes analysis of the data using ANOVA a good fit.

Thus, the PERC Test Plan was constructed, incorporating the Test Plan Variables of Slope, Volume, Percent Trailing Water, Flush Rate, and (added later as detailed above) Toilet Paper Selection based on wet tensile strength.

4. Test Equipment, Materials and Test Media

EQUIPMENT AND MATERIALS

Drainline Test Apparatus

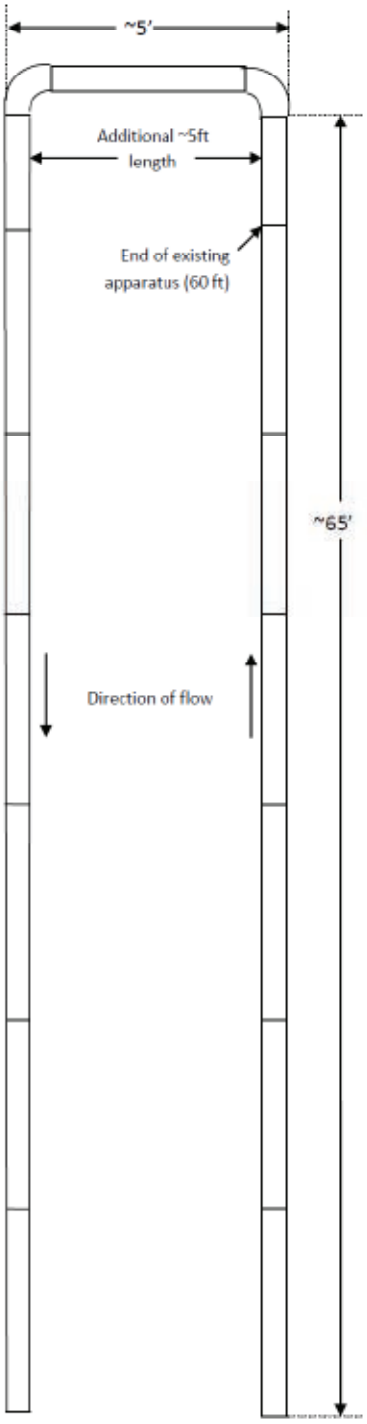
The test apparatus was constructed of 4–inch (100mm) diameter clear polyvinyl chloride (PVC) pipe. Pipe sections were joined by 4–inch (100mm) unshielded rubber couplings. The apparatus was set for both the 1 percent slope test runs and 2 percent slope test runs using a laser level. The slope was checked periodically throughout the test program.

The test apparatus was 135 feet (41 meters) in total length and incorporated two wide sweep 90° bends in order to fit within the floor footprint available to PERC at the American Standard Brands facility.

See Figure 4-A and Photos 4-B through 4-G for further details on the pipe layout and Surge Injectors.

TEST MEDIA

Uncased MaP Test media - As discussed in Section 3, it



Bill of materials

Apparatus (Illustration not to scale)

1. 80 ft - 4" Clear PVC pipe: 60' currently installed on Am Std
   80' additional required
   Cut into 10' lengths
2. 4" Unshielded Rubber Couplings: 8 additional required
3. Sch 40 PVC 4" Wide Sweep 90° Bends: 2 each
4. PVC Support sub-assemblies: 14 (see photo)
5. Shallow vessel for capturing water and media: 1

PVC Support Sub-assembly (14 needed):

1. 2" PVC Sch 40 Pipe: 40 ft
2. 1-1/2" PVC Sch 40 Pipe: 20 ft
3. 2"Tee PVC Sch 40 socket: 42 each
4. 2" Cap PVC Sch 40 socket: 56 each
5. 2" x 1-1/2" reducing bushing, PVC Sch 40 socket: 14 each
6. 6" x 1-1/2" reducing Tee, PVC Sch 40 socket: 14 each

FIGURE 4-A

DRAIN LINE TEST APPARATUS – PLAN VIEW AND BILL OF MATERIALS

PHOTO 4-B
FLOOR LEVEL VIEW

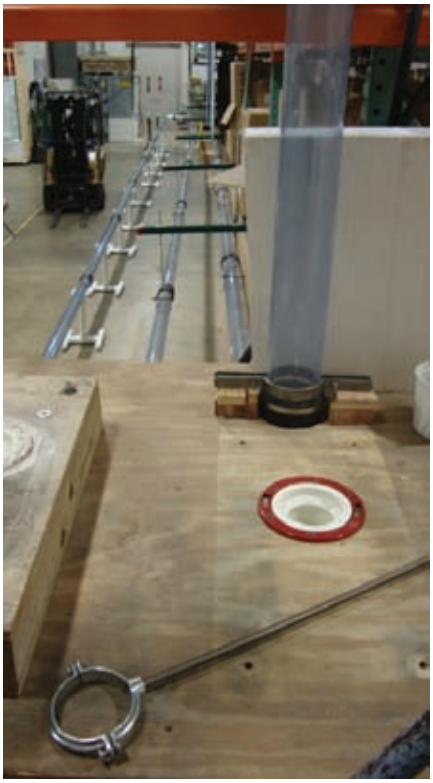
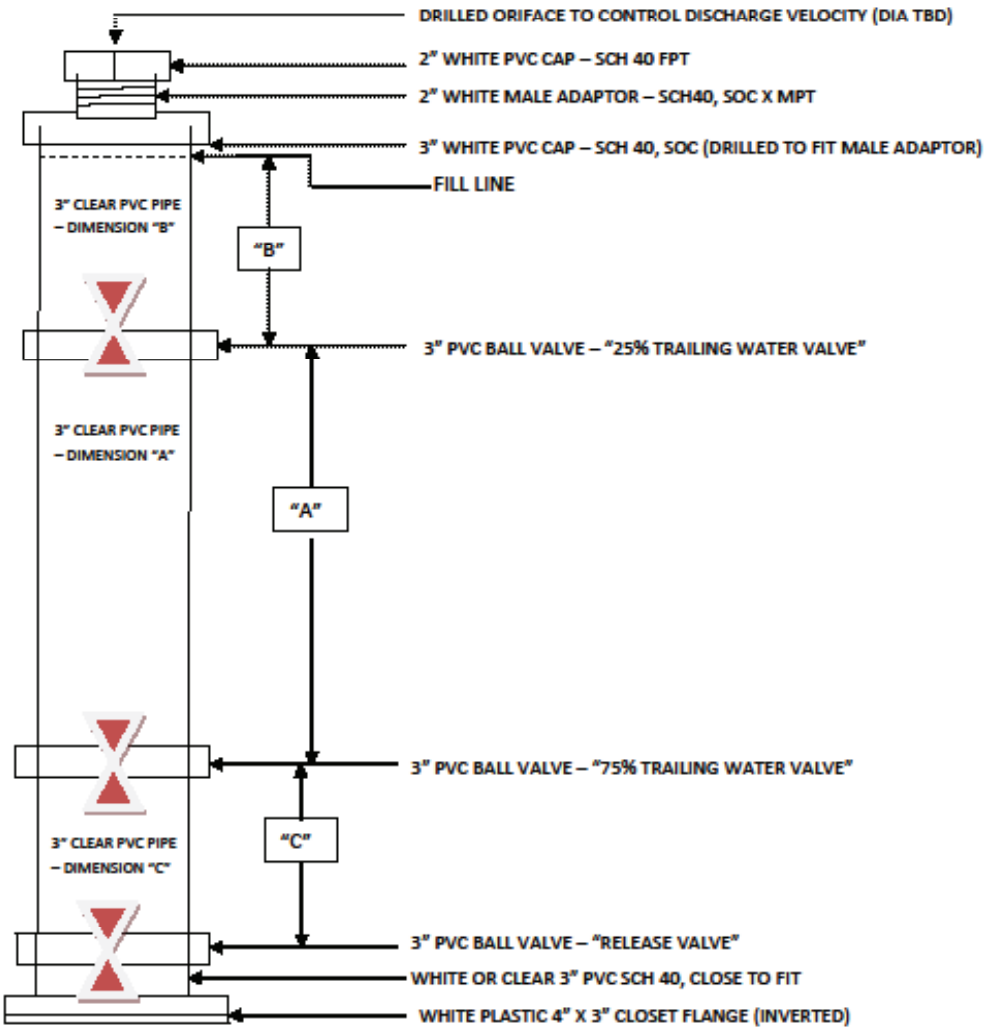


PHOTO 4-C
FLUSH STAND VIEW

PHOTO 4-D
VIEW OF 90° WIDE SWEEP BENDS

PHOTO 4-E
PLUMBING UNDER FLUSH STAND

SURGE INJECTOR BILL OF MATERIALS (NOT TO SCALE)



SURGE INJECTORS (3)	~1.6 GPF / 6.0 LPF	~1.28 GPF / 4.8 LPF	~0.8 GPF / 3.0 LPF
PART "A" (INCHES)	25.2	20.2	12.6
PART "B" (INCHES)	12.6	10.1	6.3
PART "C" (INCHES)	12.6	10.1	6.3

FIGURE 4-F
SURGE INJECTOR
ELEVATION VIEW AND BILL OF MATERIALS

PHOTO 4-G - SURGE INJECTORS

PHOTO 4-H - UNCASED MAP TEST MEDIA

was determined by the TC that the study would employ a "realistic as possible" test media and also include toilet paper. Uncased MaP test media was selected utilized as a representative simulated solid waste[11]. It consists primarily of soybean paste and water with the following nominal specifications: 35.5 percent water, 33.8 percent soybean, 18.5 percent rice, and 12.2 percent salt, and having a density of 1.15 ± 0.10 g/mL (i.e., density greater than water).

Toilet Paper – As discussed in section 3, two types of toilet paper widely available in the U.S. market were selected for this testing and purchased at local supermarkets in New Jersey. One type of toilet paper was selected specifically for its high wet tensile strength, the other selected for its low wet tensile strength.

11 MaP: Maximum Performance; refer to www.map-testing.com. This test media is widely used by manufacturers and laboratories to test the flush performance of toilets and was purchased from Veritec Consulting, Inc. in Mississauga Ontario, Canada.

PHOTO 4-I - TOILET PAPERS

5. Test Procedures

STAFF

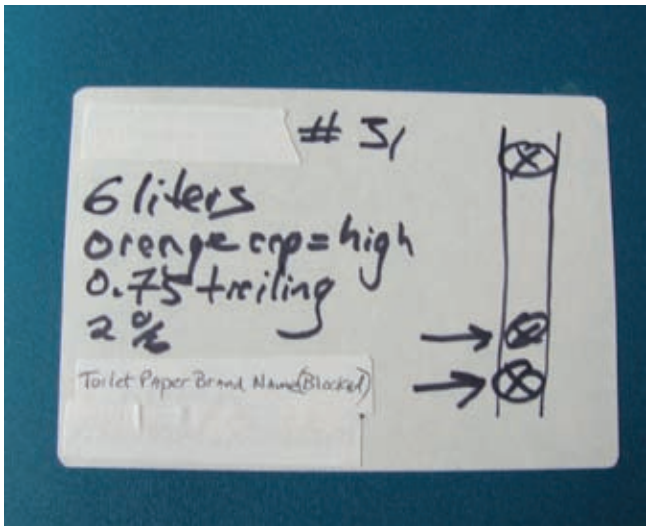
American Standard hired two temporary employees to conduct the PERC Test Plan in the American Standard facility. One of them, Mr. Robert Schaarschmidt, is an ex-American Standard full time employee with extensive background in testing of toilets and also possesses prior experience in drainline transport testing. Mr. Schaarschmidt was the Lead Technician for this effort and was responsible for monitoring the test apparatus and recording all raw data. The other temporary employee operated the Surge Injectors throughout the testing program.

TEST PROCEDURE

As detailed in Section 3, the Test Plan consisted of 40 test runs, each such run consisting of 100 flushes from the Surge Injector. Each test run required the use of a Surge Injector specifically set up to provide the required flush volume (3.0, 4.8, or 6.0 liters), flush rate, and percent trailing water, per the Test Plan. The Lead Technician ensured that the proper Surge Injector was used and was set up to deliver the required flush discharge curve.

At the beginning of each test run, the Lead Technician was provided a binder for that specific test run. The cover of the binder detailed all of the flush characteristics called for in that test run. See Photo 5-A.

PHOTO 5-A
BINDER LABELED WITH TEST RUN VARIABLES

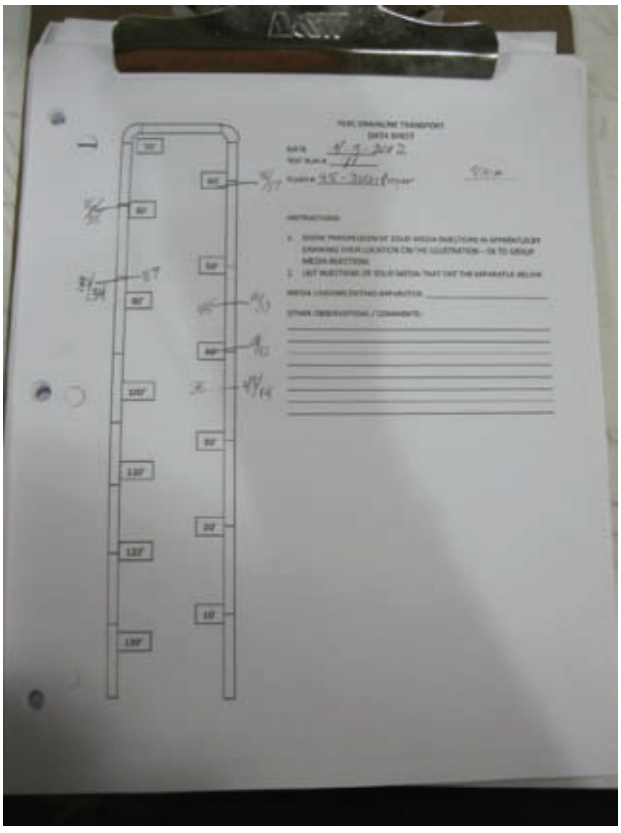


The appropriate Surge Injector was installed on the flush stand at the head of the Test Apparatus by attaching it to a typical closet flange (See Section 4, Test Equipment, Materials and Test Media).

The following procedure was then followed for each flush cycle:

1. Example - Injection with 75 percent trailing water: Remove the threaded cap with drilled orifice at the top of the Surge Injector.
2. Ensure that the release valve at the bottom of the Surge injector is closed.
3. Fill the Surge Injector with water until water flows past the height of the 75 percent ball valve. Close the 75 percent ball valve and place the required amount of test media (as called for in the test binder for each flush injection) and toilet paper into the injector from the top.
4. Fill the Surge Injector to within 1 inch of the marked 'fill line'".
5. Replace the threaded cap on the Surge Injector and hand-tighten to ensure air cannot enter through the threads.
6. Open the 75 percent trailing water valve and immediately open the discharge valve allowing water and test media to flow into the test apparatus.
7. Record (on the data sheet) the distance that the test media travels on the first flush.
8. Repeat steps 1 through 7 as per the Test Plan.
9. Record (on the data sheet) the distance that the test media travels on each subsequent flush until the test media exits the apparatus. (See data sheet, photo 5-B)

PHOTO 5-B
DATA SHEET



IMPORTANT - The number of flushes required for each injection of test media to run the full course of the 135 foot long apparatus and exit was recorded as 'Flushes to Out'. The 'Flushes to Out' values for each injection of test media that exited the apparatus during the 100 cycle Test Run were averaged, yielding the 'Average Flushes to Out' (AFO) data that was used to calculate all results.

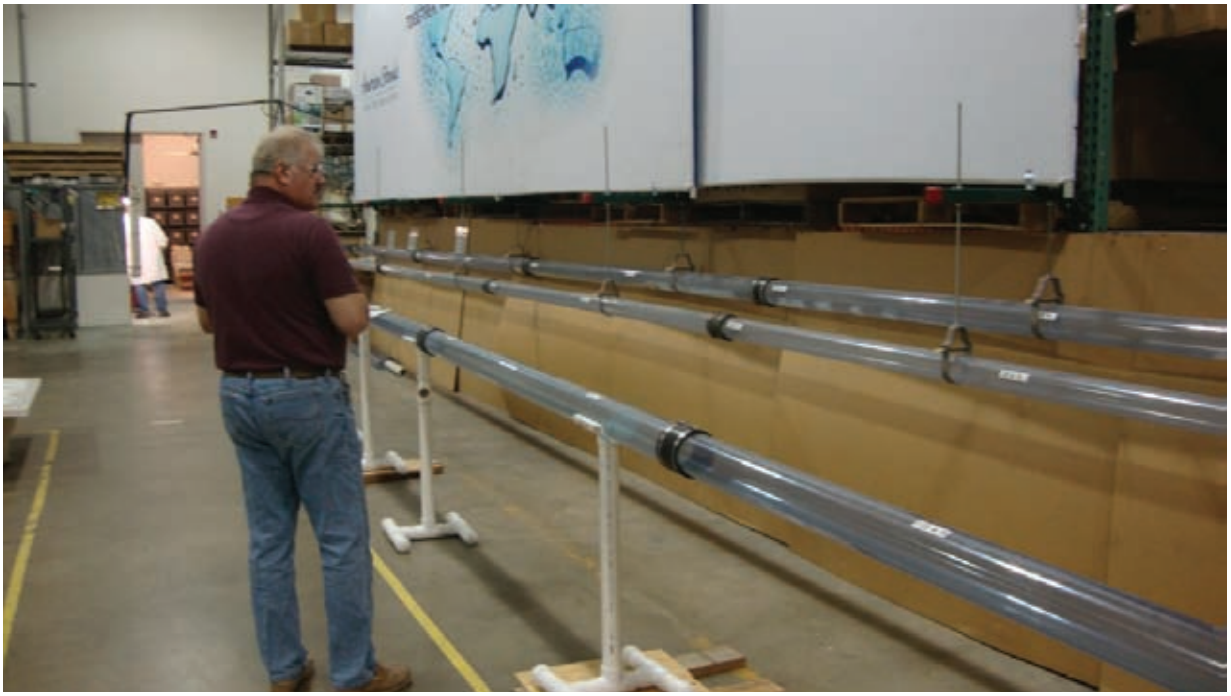


PHOTO 5-C

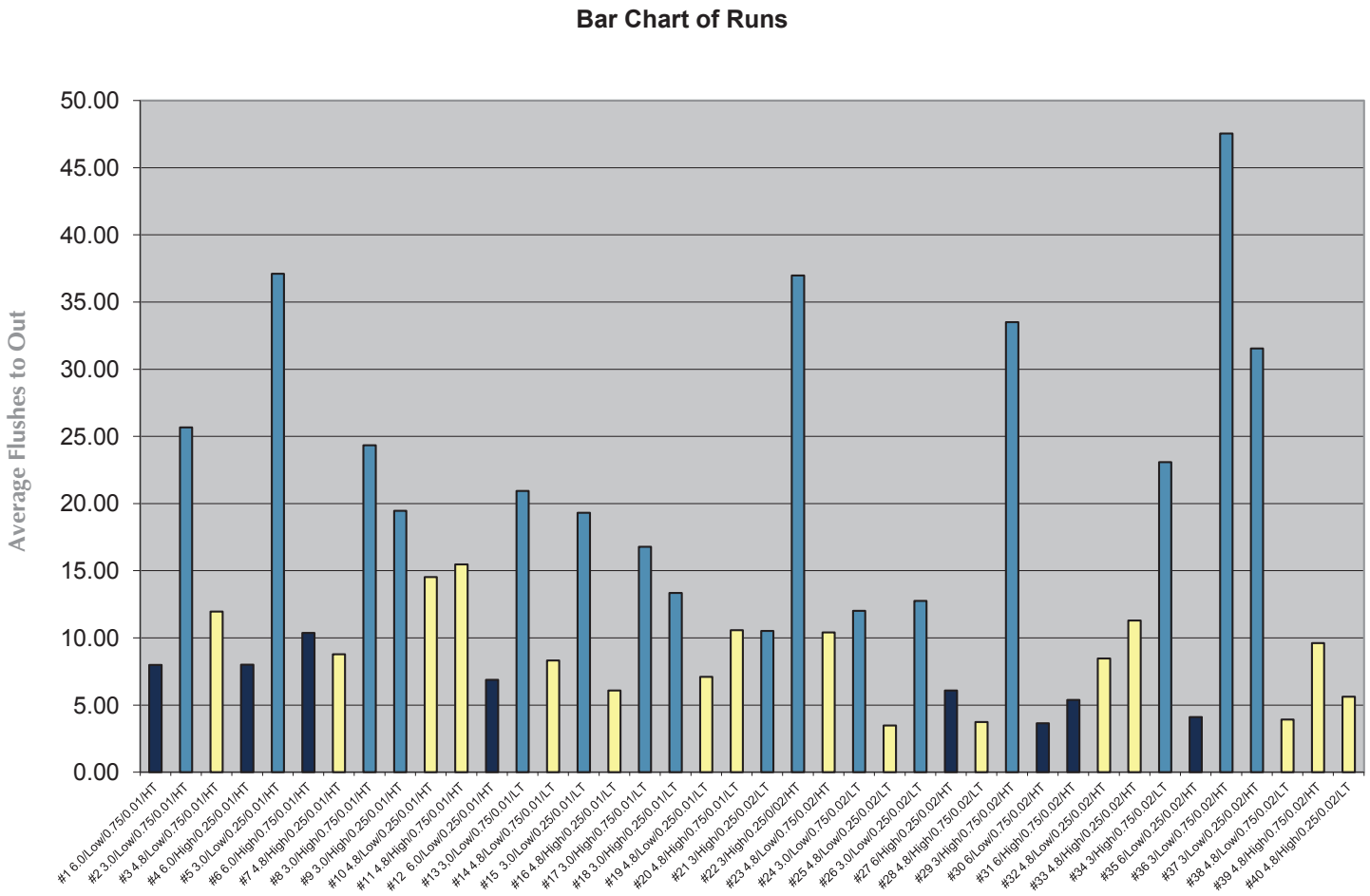
LEAD TECHNICIAN RECORDING TEST MEDIA TRAVEL DISTANCES

6. Data Review

The PERC Test Plan generated a large amount of data that we offer freely to all interested parties. All raw data sheets from the 40 test runs, along with the Excel file used to organize the data and generate the various charts included in this report, are available for review and download at www.plumbingefficiciencyresearchcoalition.org.

The resulting Average Flushes to Out (AFO) values from the test runs are detailed in Figure 6-A.

FIGURE 6-A

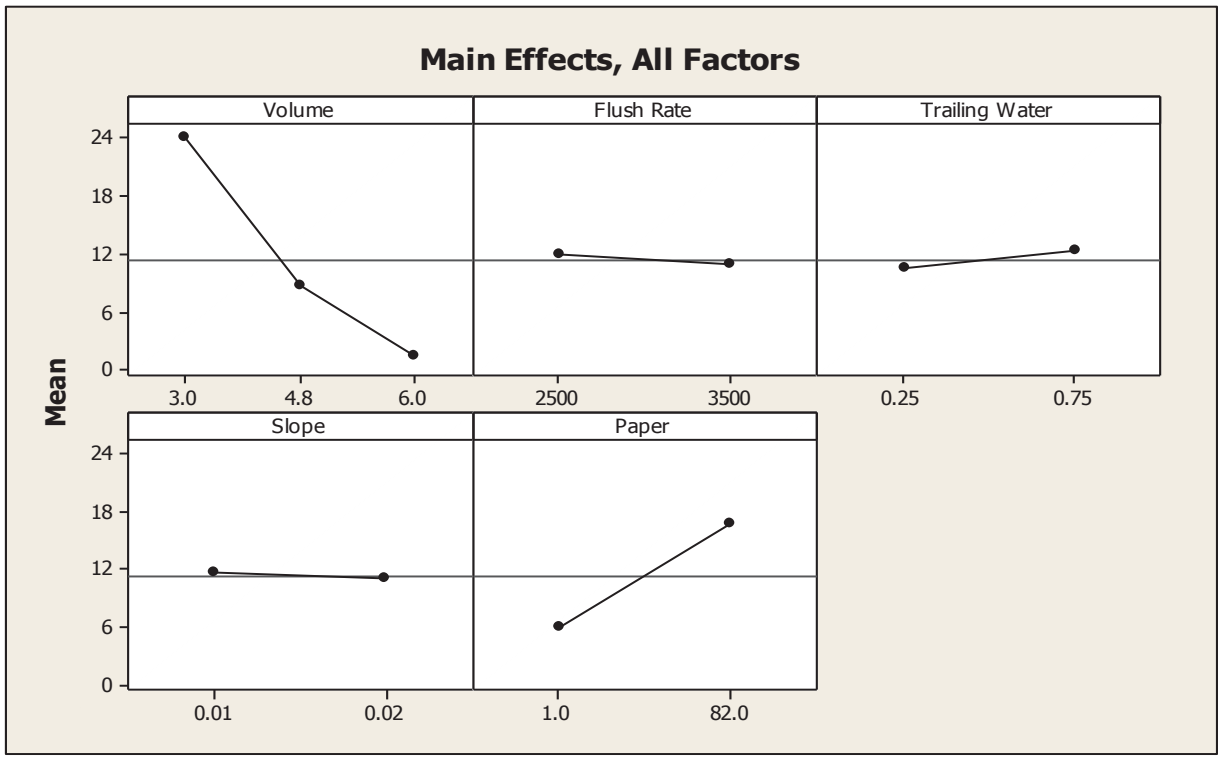


Note: All Test Runs employing 1.6 gallon (6.0 L) injections are shown in dark blue, 1.28 gallon (4.8 L) injection are shown in yellow and 0.8 gallon (3.0 L) injections are shown in light blue.

It came as no surprise that the 1.6 gallon test runs resulted in the lowest AFO scores, followed by the 1.28 gallon test runs. The 0.8 gallon test runs produced, by far, the worst results in the AFO category. Noteworthy in this bar chart is the high variation in the 0.8 gallon results.

Applying the ANOVA Model to these results yields the following:

FIGURE 6-B – MAIN EFFECTS PLOT



Factor	Type	Levels	Values
Volume	fixed	3	3.0,4.8,6.0
Flush Rate	fixed	2	2500, 3500
Trailing Water	fixed	2	0.25, 0.75
Slope	fixed	2	0.01, 0.02
Paper	fixed	2	1, 82

Analysis of Variance for Ave Flushes to Out, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Volume	2	2493.44	3090.34	1545.17	50.36	0.000
Flush Rate	1	8.33	8.33	8.33	0.27	0.606
Trailing Water	1	29.33	29.33	29.33	0.96	0.335
Slope	1	2.37	2.37	2.37	0.08	0.783
Paper	1	888.35	888.35	888.35	28.95	0.000
Error	33	1012.57	1012.57	30.68		
Total	39	4434.40				

S = 5.53932 R-Sq = 77.17percent R-Sq (adj) = 73.01percent

In the Figure 6-B Main Effects Plot above, the weighted significance of a test variable is indicated by the slope of the line in the chart. The more vertical the line, the greater the significance of that test variable. Conversely, a horizontal line is an indication that the test variable is not significant. In other words, in this latter case, changing that variable has little impact on the test results. In this plot, we see only two (2) significant variables, Volume and Paper. All of the other test variables are shown as non-significant.

The numeric values below the Main Effects Plot provide discrete values to the results. A low P-value, in this case, less than 0.05 indicates significance, while values over 0.05 are deemed to be non-significant.

We also note the R-Squared (R-Sq) values in this data. Higher R-Sq values indicate that the test plan data has, in fact, captured what is happening in the system under evaluation, in this case, the Test Apparatus. If we were running this analysis on a series of injection molded parts to measure the deviation of a particular dimension or some other measurable variable, we would expect to see an R-Sq value over 90 or 95. However, we are analyzing the free flow of deformable solids in a drainline and, therefore, we expect highly variable results. In experiments with this degree of inherent variability, an R-Sq value of 80 is considered good.

As noted above, the test results achieved an R-Sq value of 77.17 in this model, slightly below our desired result. We

also noted that, in this model, slope is indicated as non-significant, which was both a surprise and a cause for concern. This raised a red flag to the TC and necessitated a closer look at the data.

We already noted that the 0.8 gallon (3.0 L) test runs yielded highly variable results, much more so than the 1.28 gallon (4.8 L) or the 1.6 gallon (6.0 L) test runs. In addition, and as you will see in Section 7, Findings and Conclusions, several of the 0.8 gallon (3.0 L) test runs resulted in near-full pipe conditions where the Test Apparatus was jammed with test media. In these test runs, it was apparent that a very chaotic condition existed where movement of the solids in the pipe was entirely random. While the Test Apparatus never overflowed during these test runs, this observation, along with the highly variable AFO test run scores, caused the TC to more carefully scrutinize the 0.8 gallon (3.0 L) data.

As a first step, the TC generated Control Charts for the data both with and without the 0.8 gallon (3.0 L) data included. Refer to Figure 6-C.

FIGURE 6-C

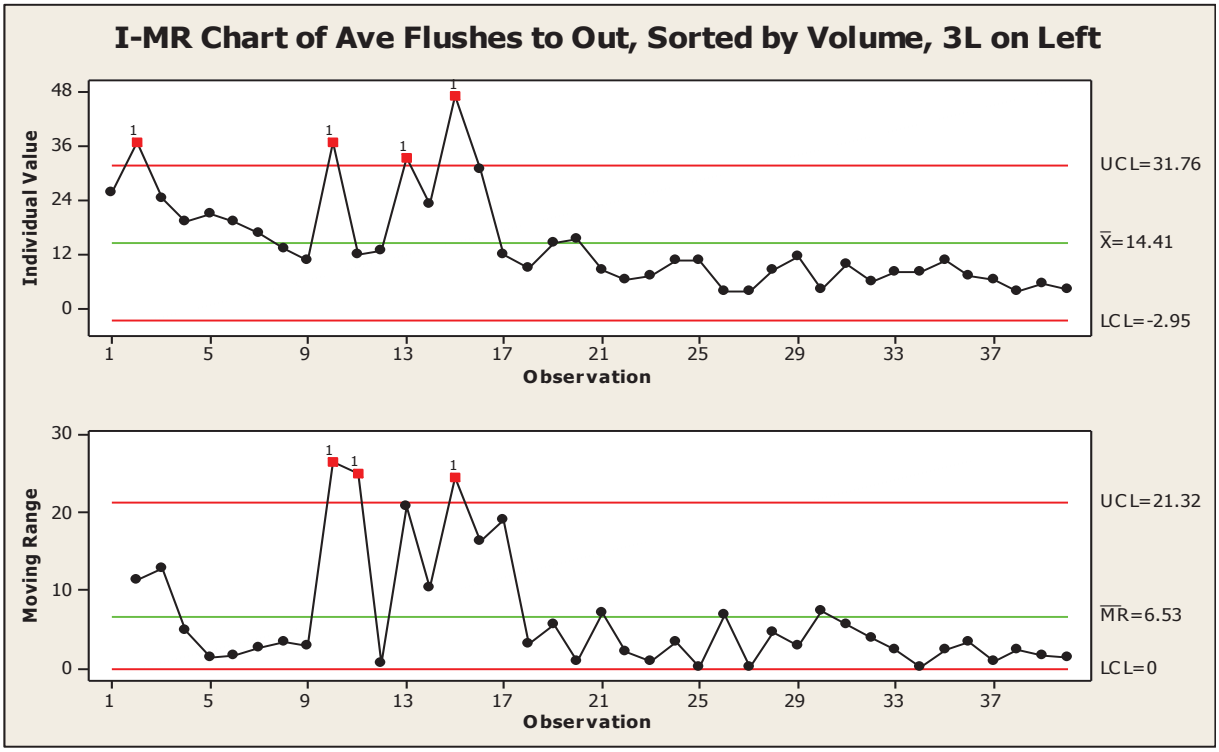
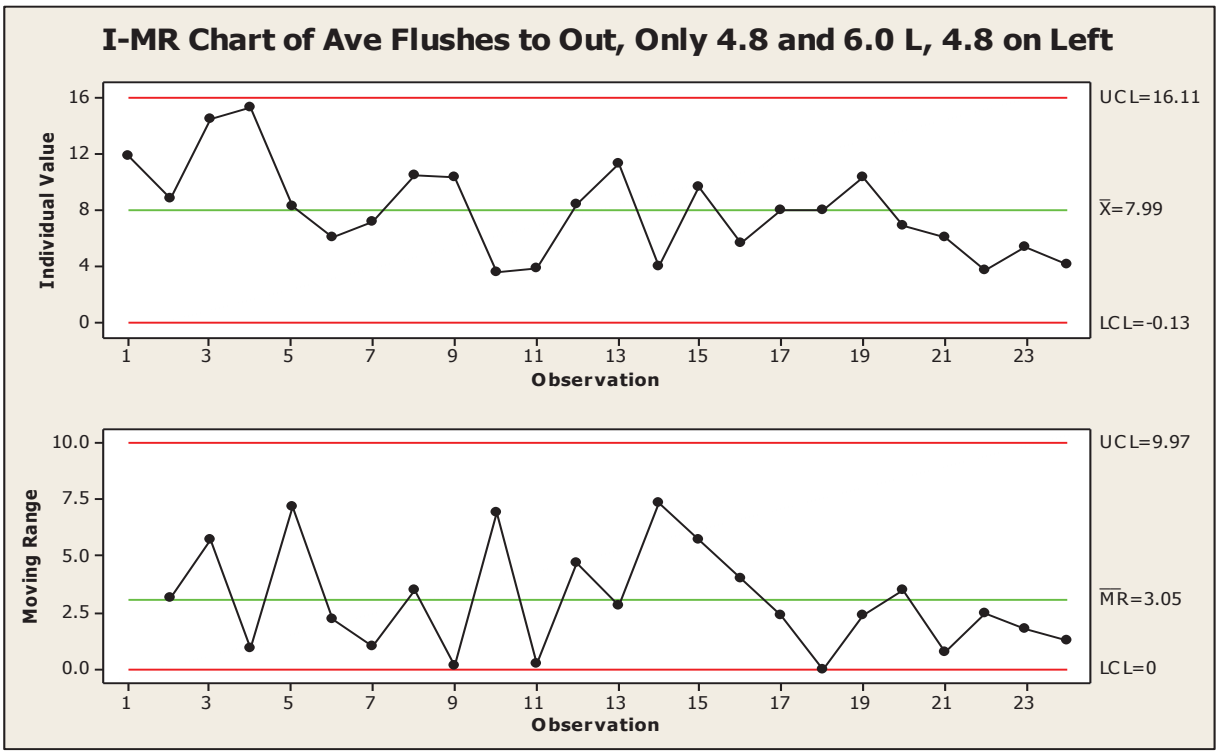


Figure 6-C shows four (4) of the sixteen (16) 0.8 gallon (3.0 L) test runs yielded results that were over the Upper Confidence Limit (UCL) for the data set. This indicates that the results from these tests were random and, accordingly, that the resulting data is being influenced by something other than the test variables. We then ran a Control Chart for the AFO less the data from the 0.8 gallon (3.0 L) Test Runs. The results displayed in Figure 6-D show all data points to be under the UCL.

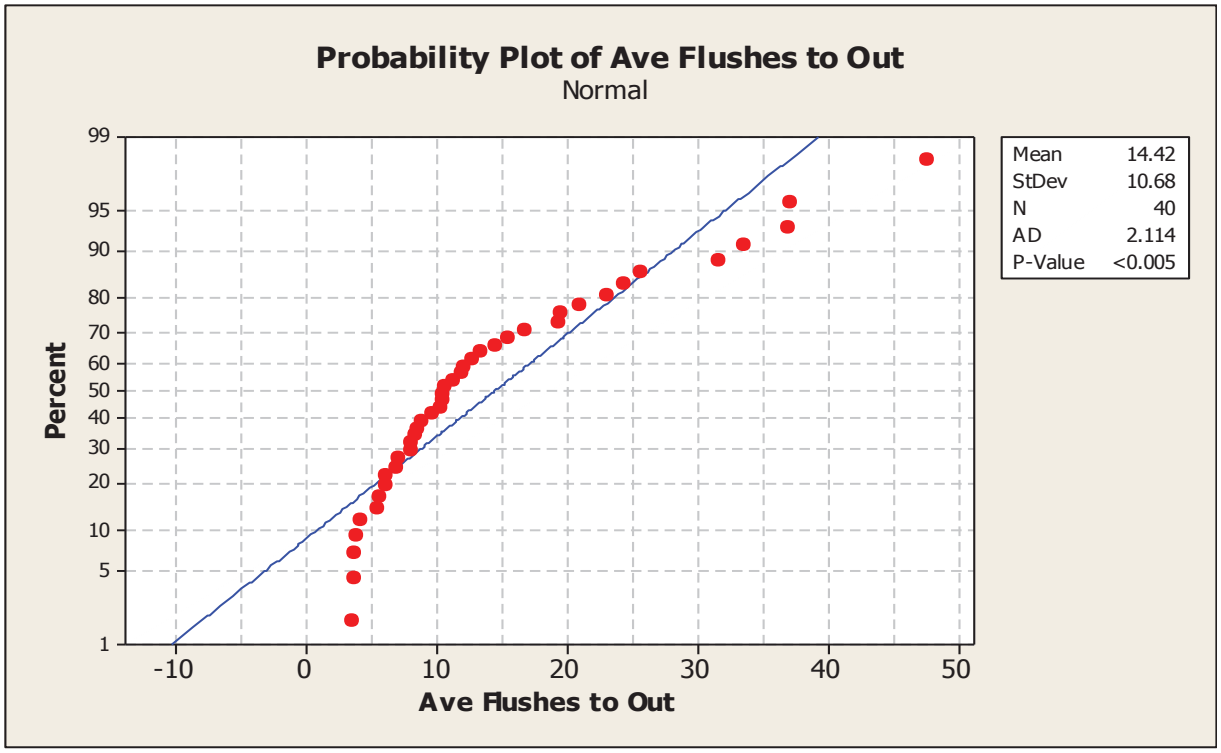
FIGURE 6-D



The TC generated Probability Plots on the data sets, both with and without the 0.8 gallon (3.0L) data. The probability plot is a graphical technique for assessing whether or not a data set follows a given distribution. In these charts, the closer that actual data points fall along the probability line (the line the computer predicts for the test results), the better the fit between the data and the model.

A rule-of-thumb followed by many statisticians is that if one can place a pencil on the probability line and it covers all or almost all of the data points, then the fit is good. Figure 6-E, which incorporates the 0.8 gallon (3.0 L) data, shows that the data is not a good fit.

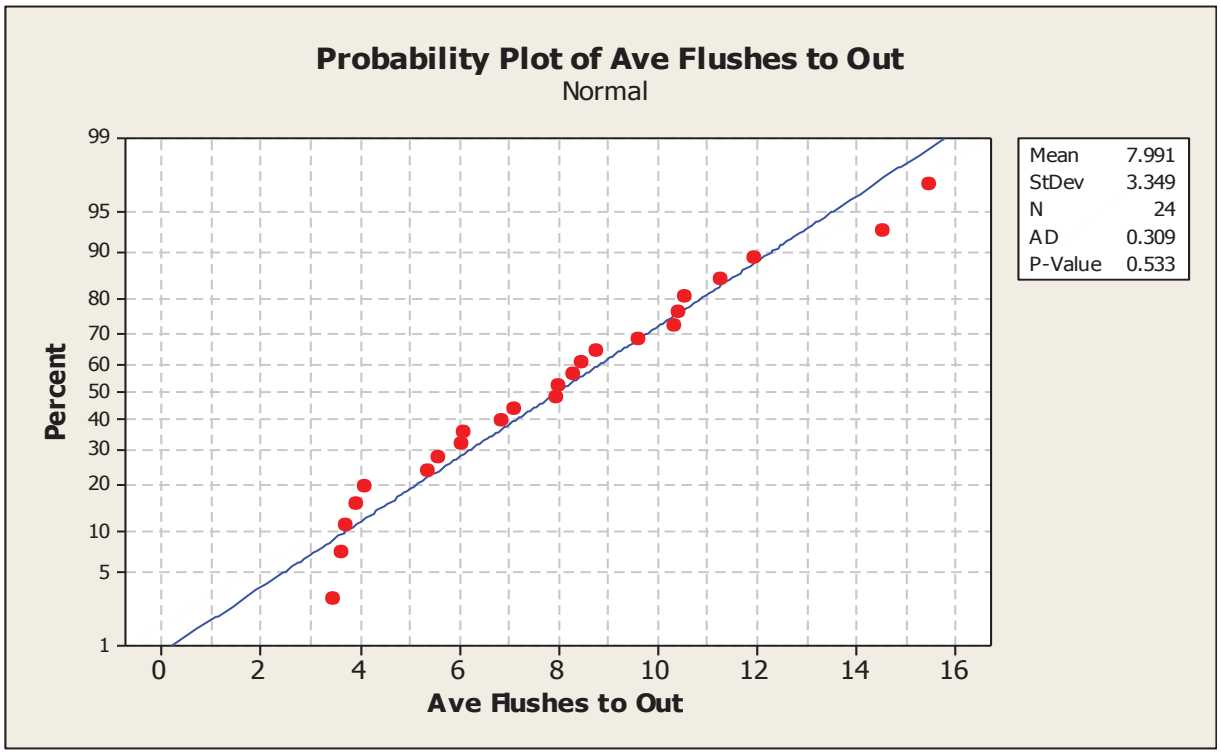
FIGURE 6-E



The same plot, excluding the 0.8 gallon (3.0 L) data, is depicted in Figure 6-F and shows a much improved result:

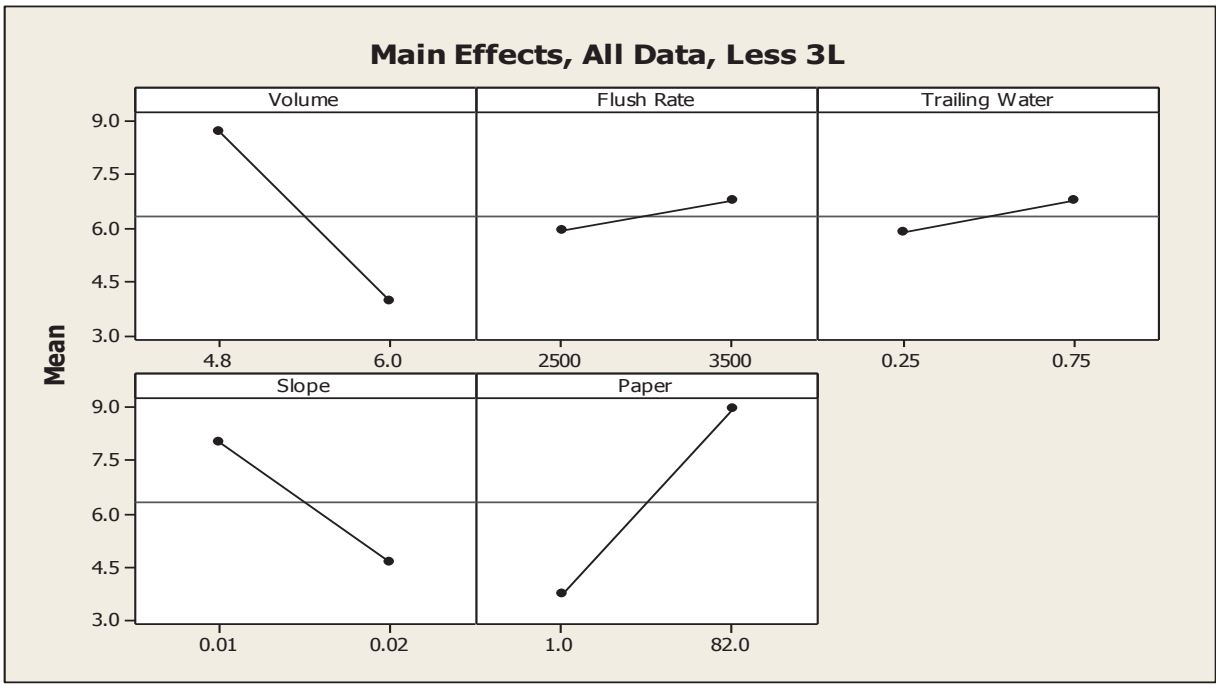
FIGURE 6-F

LESS 0.8 GALLON (3.0 L) DATA



Therefore, the TC excluded the 0.8 gallon (3.0 L) data when determining the Main Effects results, since noise in that data was proven to be skewing results. Re-running the Main Effects Plots on the Test Run data without the 0.8 gallon (3.0 L) data, yielded the results displayed in Figure 6-G that we will heretofore refer to as our **Primary Main Effects Plot**.

FIGURE 6-G - PRIMARY MAIN EFFECTS PLOT



Factor	Type	Levels	Values
Volume	fixed	2	4.8, 6.0
Flush Rate	fixed	2	2500, 3500
Trailing Water	fixed	2	0.25, 0.75
Slope	fixed	2	0.01, 0.02
Paper	fixed	2	1, 82

Analysis of Variance for Ave Flushes to Out, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Volume	1	24.783	90.685	90.685	34.41	0.000
Flush Rate	1	4.326	4.326	4.326	1.64	0.216
Trailing Water	1	4.999	4.999	4.999	1.90	0.185
Slope	1	67.734	67.734	67.734	25.70	0.000
Paper	1	108.641	108.641	108.641	41.22	0.000
Error	18	47.436	47.436	2.635		
Total	23	257.919				

S = 1.62337 R-Sq = 81.61percent R-Sq (adj) = 76.50percent

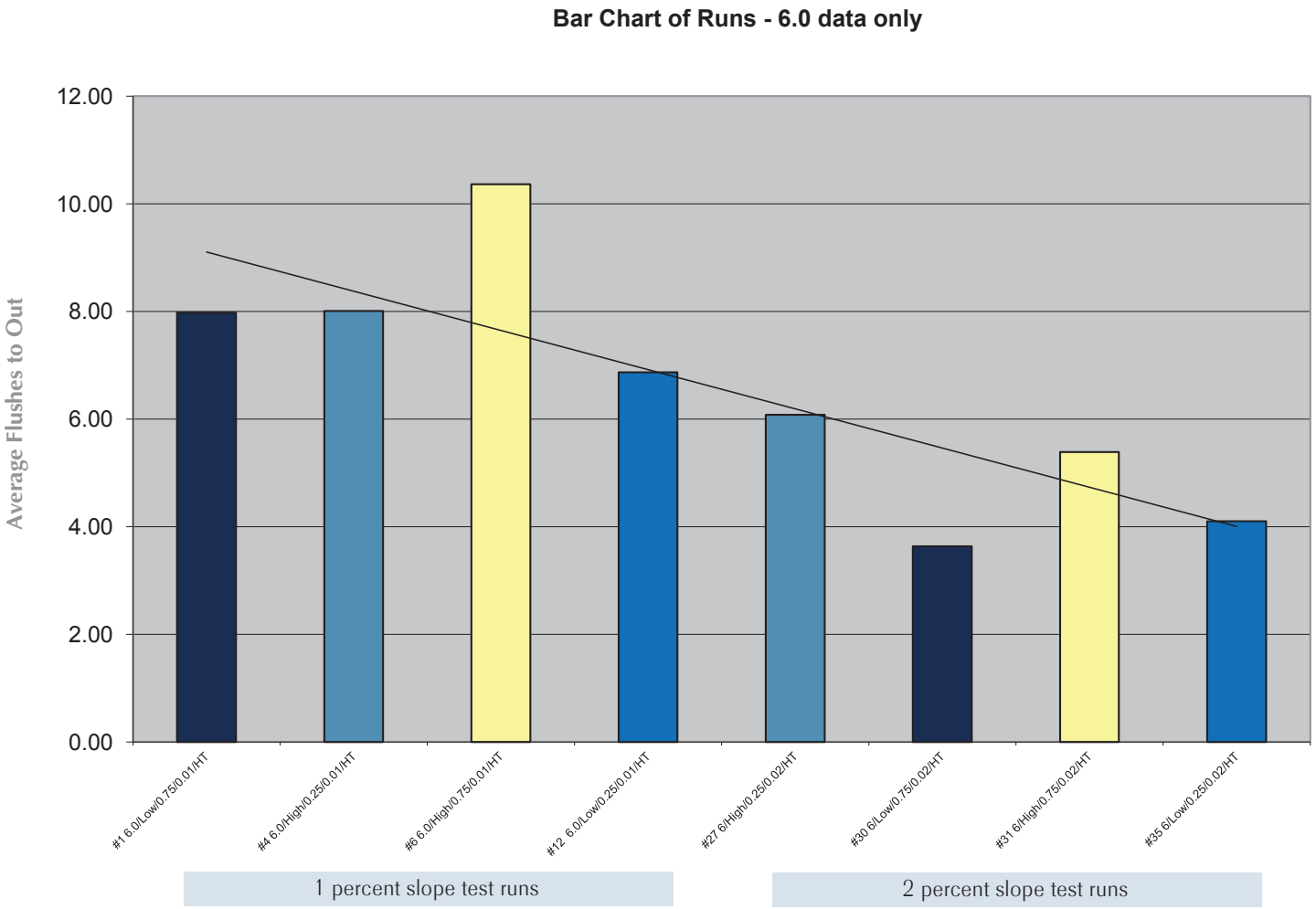
Without the 0.8 gallon (3.0 L) data, the variable "slope" attains a P-value of zero and is considered definitely significant. In addition, the R-Sq value exceeds the 80 percent threshold, at 81.6 percent. This indicates that the test data has captured 81.6 percent of what actually happened in the Test Apparatus.

Thus, the Test Plan indicates three (3) significant variables, volume, slope and paper. The flush discharge characteristics associated with toilet flush characteristics, flush rate, and trailing water, are shown to be non-significant variables.

Drilling down a little further into the data provides additional insight.

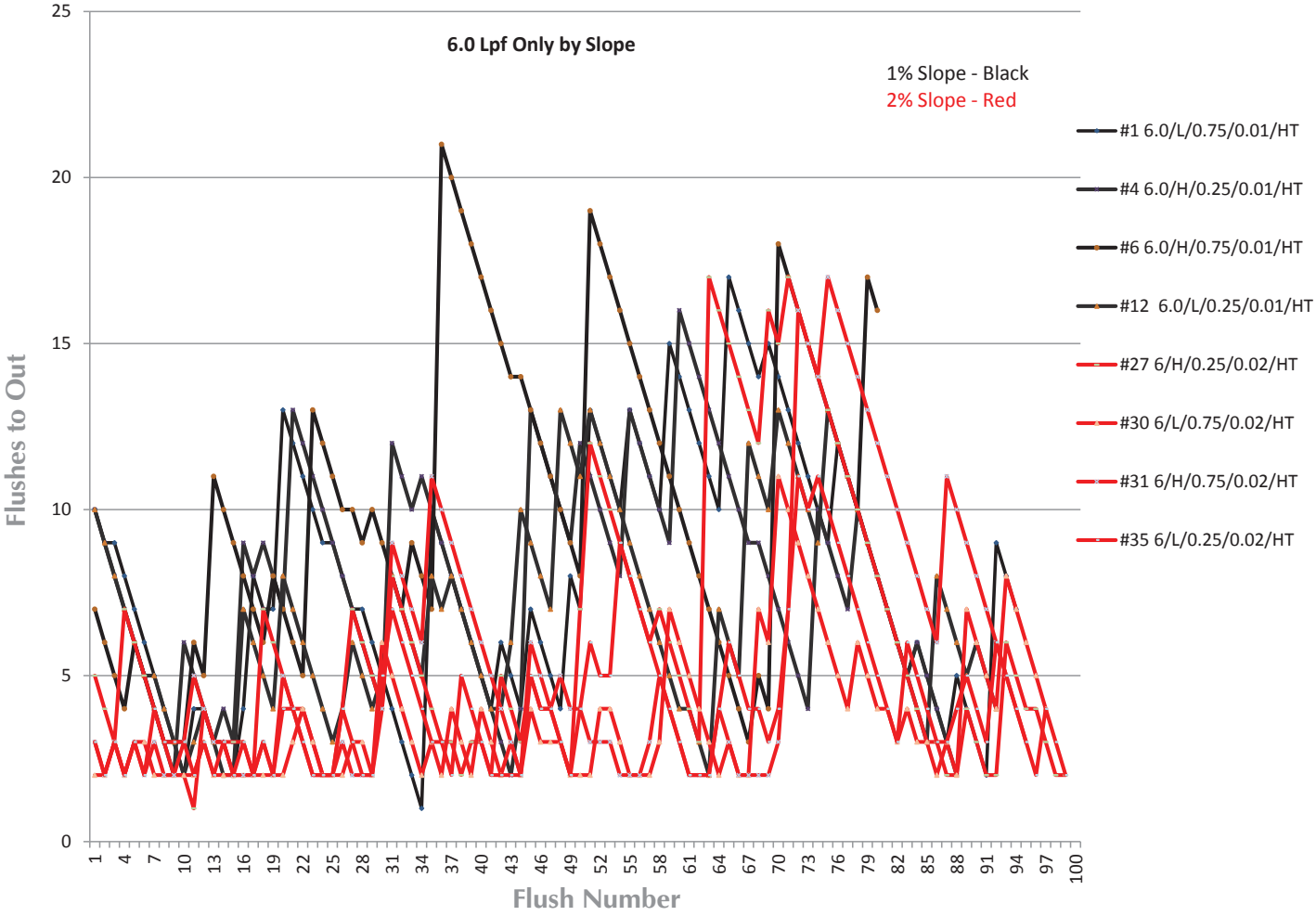
1.6 Gallon / 6.0 Liter Data

FIGURE 6-H



The bar chart in Figure 6-H is color coded so that test runs at the 1 percent slope and 2 percent slope that embody otherwise identical test variables appear in the same color. For example, Test Run #1, shown in navy blue, was conducted at 1.6 gallons (6.0 L), with a "low" flush rate, 75 percent trailing water, and using high tensile strength paper. Test Run #30 was also conducted at 1.6 gallons (6.0 L), with a "low" flush rate, 75 percent trailing water, and using high tensile strength paper, the only difference being slope. The trend line indicates better performance at the 2 percent slope, as expected.

FIGURE 6-I



The line chart in Figure 6-I again breaks down the 1.6 gallon (6.0 L) data by slope. We expect to see better generally results with the 2 percent slope Test Runs, shown in red, so the expectation is to see black over red in the chart as shown.

FIGURE 6-J

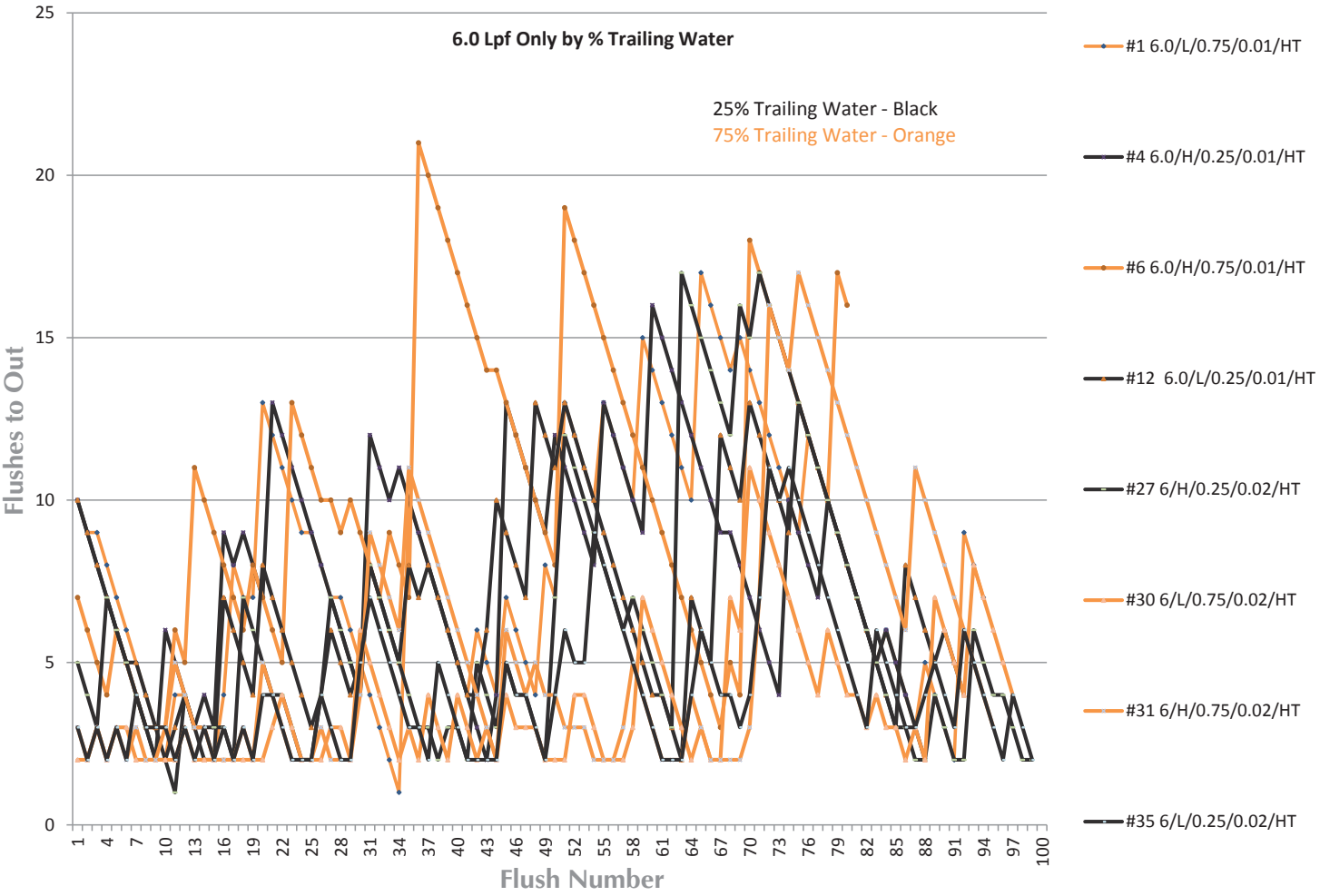


Figure 6-J is a line chart of the same 1.6 gallon (6.0 L) data broken down by percent trailing water. Past research has concluded that percent trailing water is one of the most significant factors in drainline transport; thus, the expectation would be to see black over orange in this chart. However, consistent with the results in our Main Effects Plots, we cannot determine a difference in the results based on trailing water, and percent trailing water again appears to be non-significant.

FIGURE 6-K

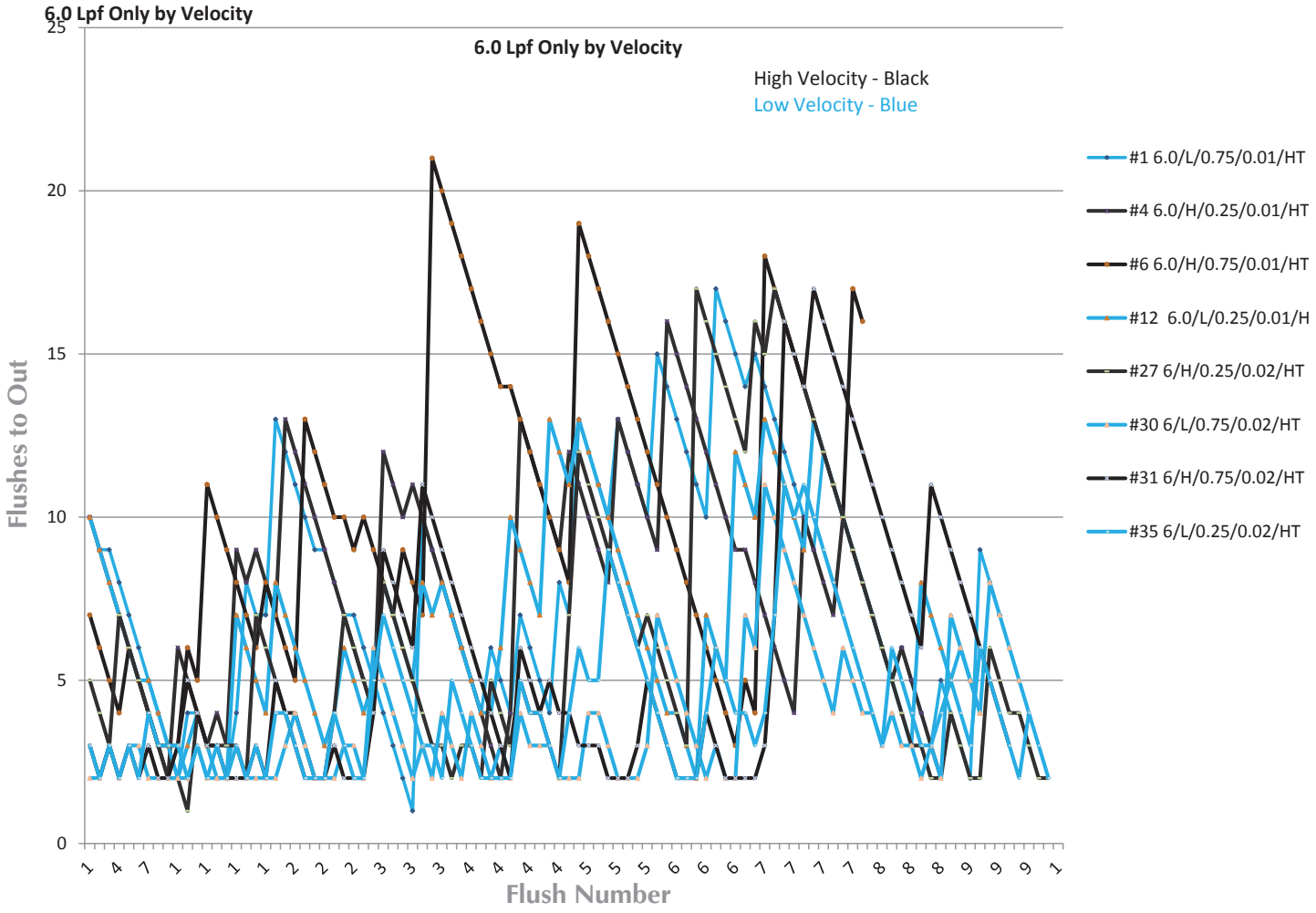
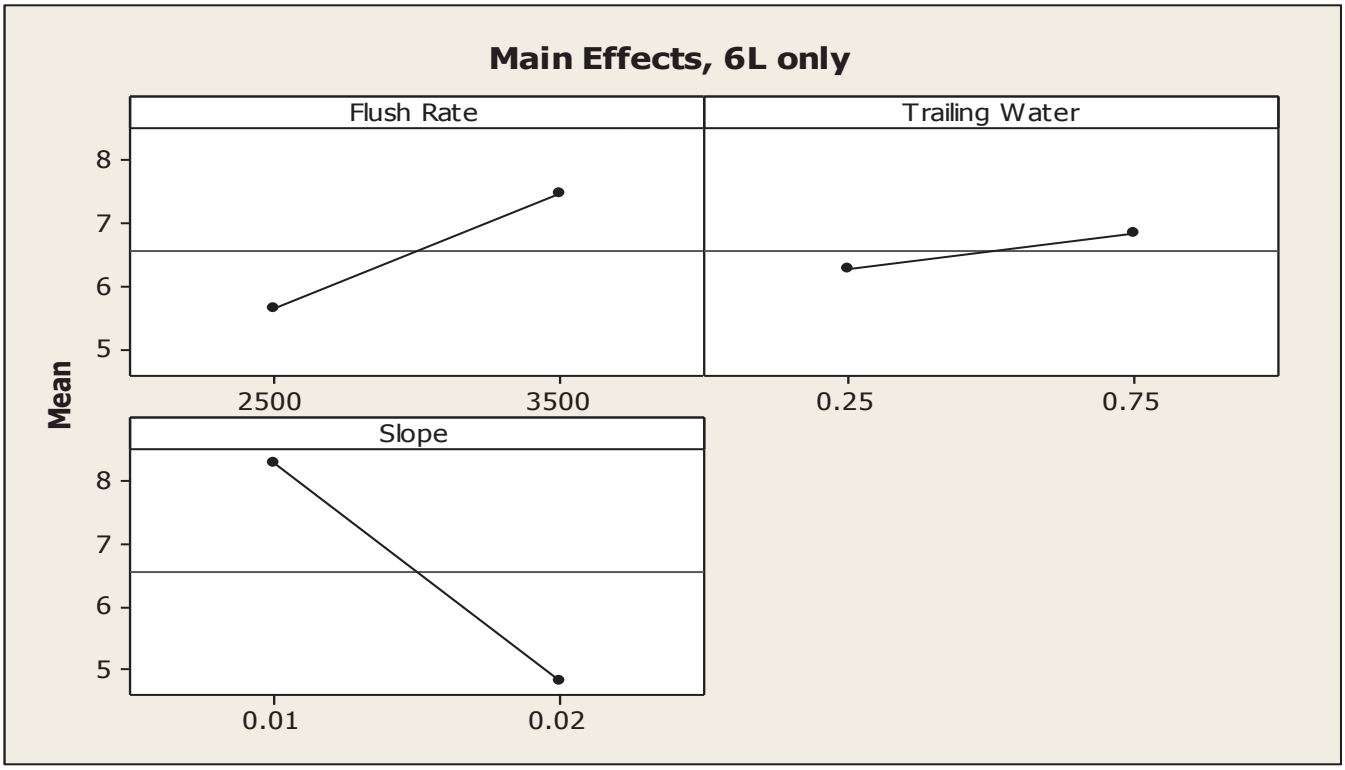


Figure 6-K is a line chart of the same 1.6 gallon (6.0 L) data broken down by flush rate. A higher flush rate would provide for a deeper flood level in the test apparatus but also carries the risk that the water may outrun the solids. The Main Effects Plot for the 1.6 gallon (6.0 L) data indicates marginal significance for Flush Rate, with the lower flush rate (2500 ml/sec peak) showing better performance than the higher flush rate (see next page). Thus, we would expect to see black over blue in this chart.

FIGURE 6-L – MAIN EFFECTS PLOT – 1.6 GALLONS (6.0 L)



Factor	Type	Levels	Values
Flush Rate	fixed	2	2500, 3500
Trailing Water	fixed	2	0.25, 0.75
Slope	fixed	2	0.01, 0.02

Analysis of Variance for Ave Flushes to Out, using Adjusted SS for Tests

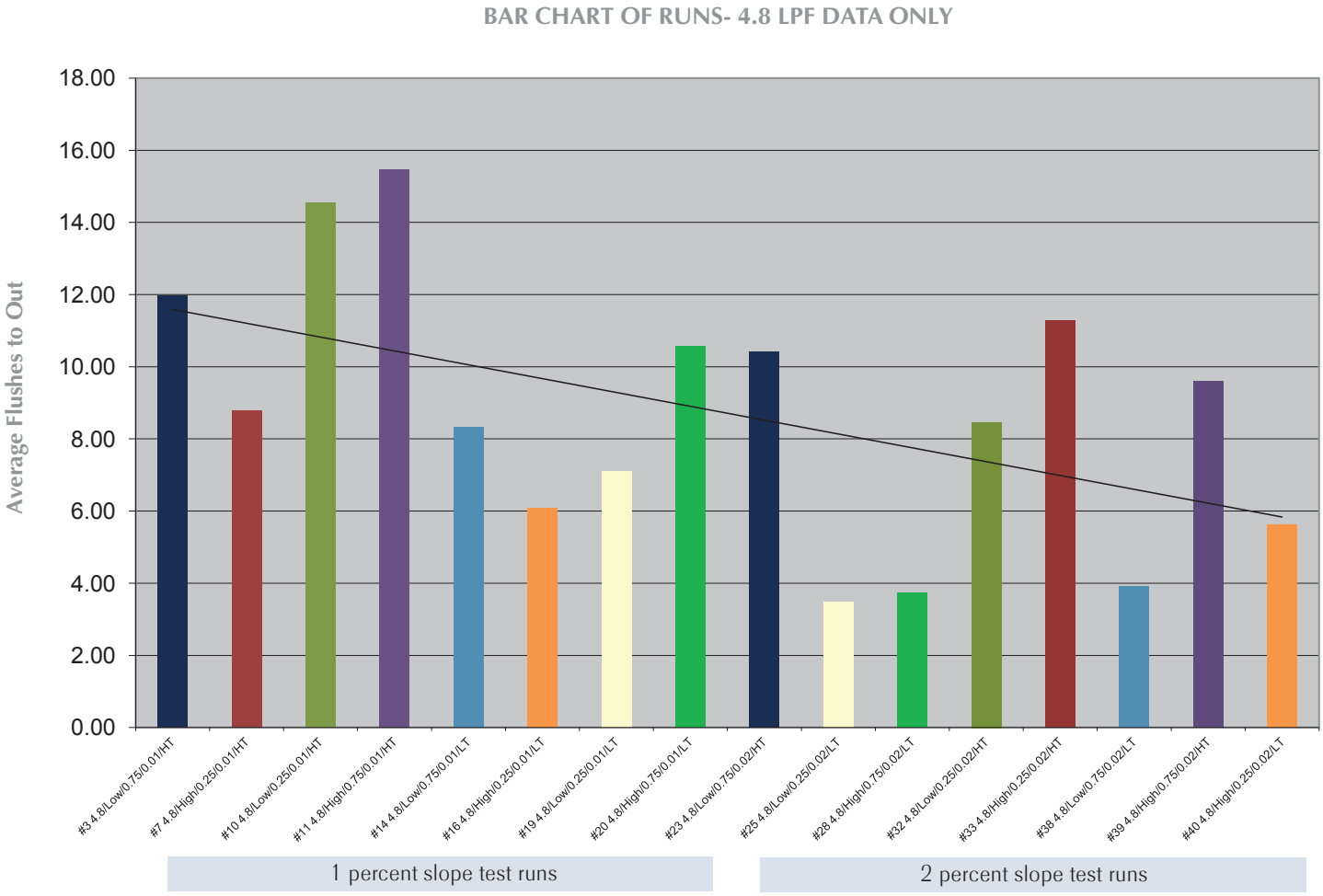
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Flush Rate	1	6.581	6.581	6.581	8.59	0.043
Trailing Water	1	0.665	0.665	0.665	0.87	0.404
Slope	1	24.541	24.541	24.541	32.03	0.005
Error	4	3.065	3.065	0.766		
Total	7	34.851				

S = 0.875290 R-Sq = 91.21percent R-Sq (adj) = 84.61percent

Figure 6-L is a Main Effects plot for the 1.6 gallon (6.0 L) data only. Examining volume level by itself, the data shows definite significance for slope and, to a lesser extent, marginal significance for flush rate (0.05 is the threshold level for significance). It is important to note that the high and low tensile strength toilet paper variable was not run on the 1.6 gallon (6.0 L) volume level due to cost constraints. Hence, this is a relatively small data set that does not include the paper variable that tested out significantly at the 1.28 gallon (4.8 L) and the 0.8 gallon (3.0 L) levels. Hence, we hesitate to draw conclusions regarding the actual significance of flush rate, especially when that variable did not show up as significant on the larger data set Primary Main Effects plot that also includes the 1.28 gallon (4.8 L) volume level (see Figure 6-G).

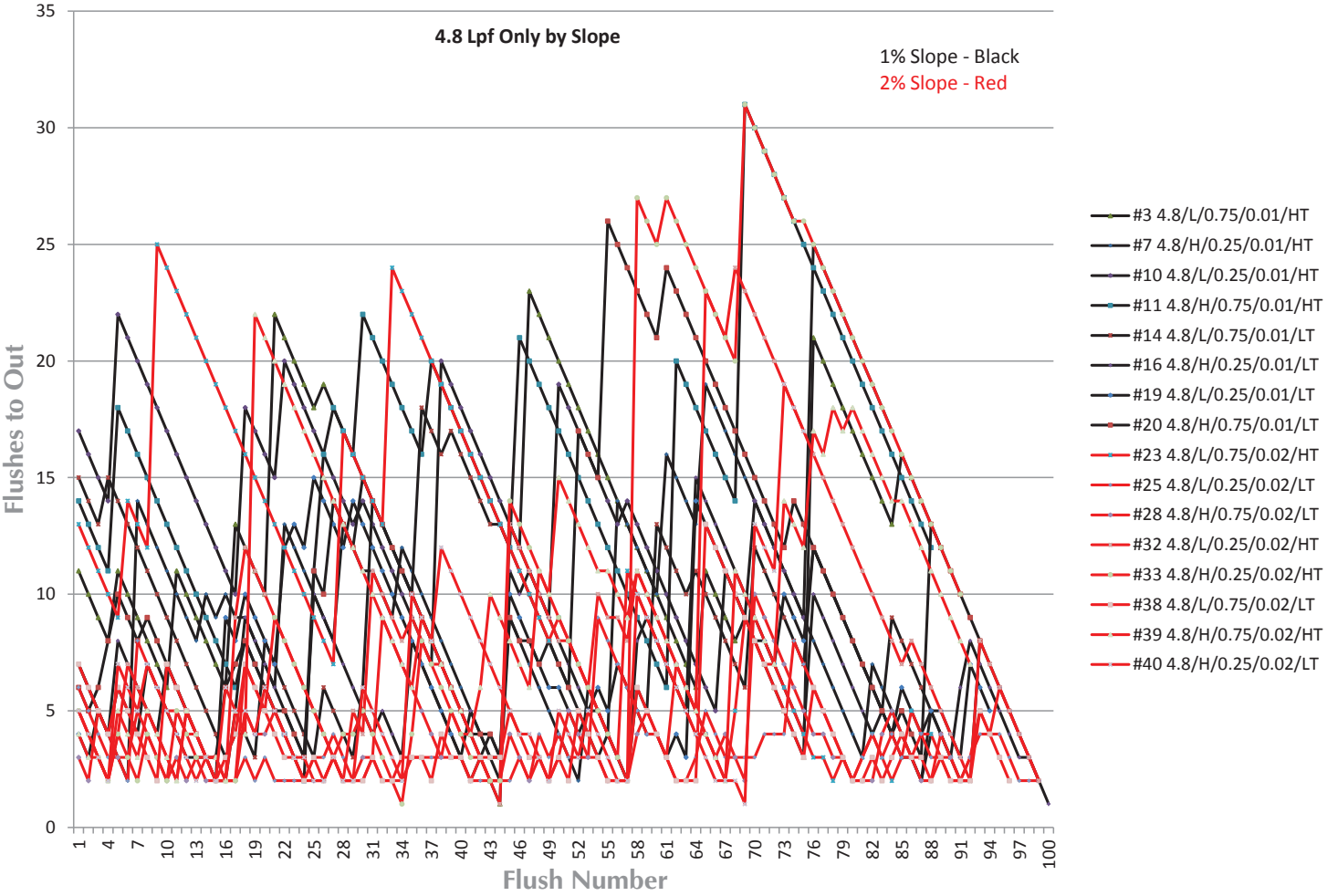
1.28 Gallon / 4.8 Liter Data

FIGURE 6-M



As with the 1.6 gallon (1.6 L) bar chart data, the 1.28 gallon (4.8 L) bar chart in Figure 6-M is also color coded so that test runs at the 1 percent slope and 2 percent slope that embody otherwise identical test variables appear in the same color. Again, the trend line indicates better performance at the 2 percent slope, as expected.

FIGURE 6-N



The line chart in Figure 6-N shows the 1.28 gallon (4.8 L) data broken down by slope. We expect to see generally better waste transport results (i.e., lower AFO) with the 2 percent slope Test Runs, shown in red, so the expectation is to see black over red in the chart.

FIGURE 6-O

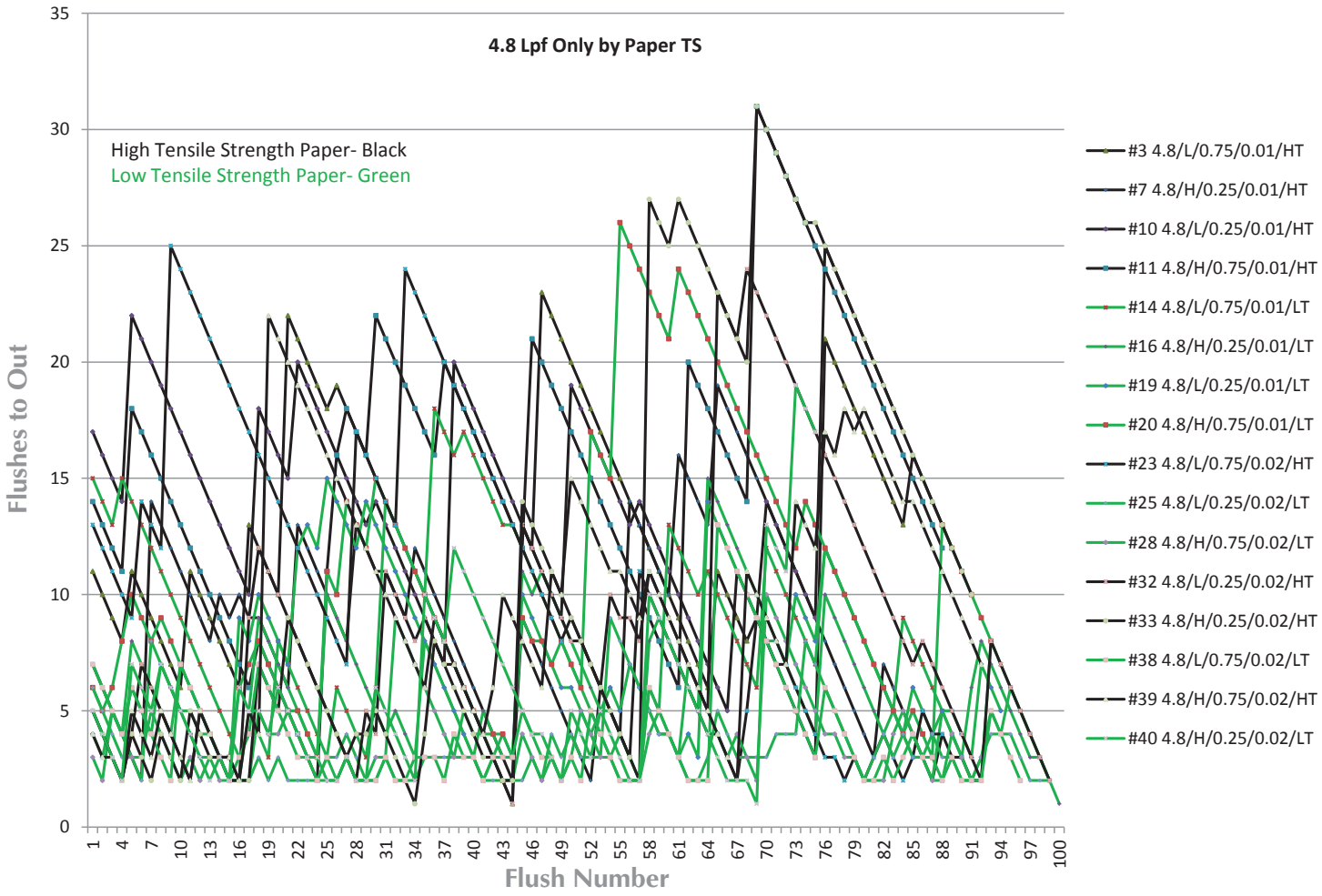


Figure 6-O is a line chart of the same 1.28 gallon (4.8 L) data broken down by toilet paper tensile strength. Past research conducted by ASFlow concluded that selection of toilet paper significantly impacts drainline transport results; thus, the expectation would be to see black over green in this chart, which is clearly evident.

FIGURE 6-P

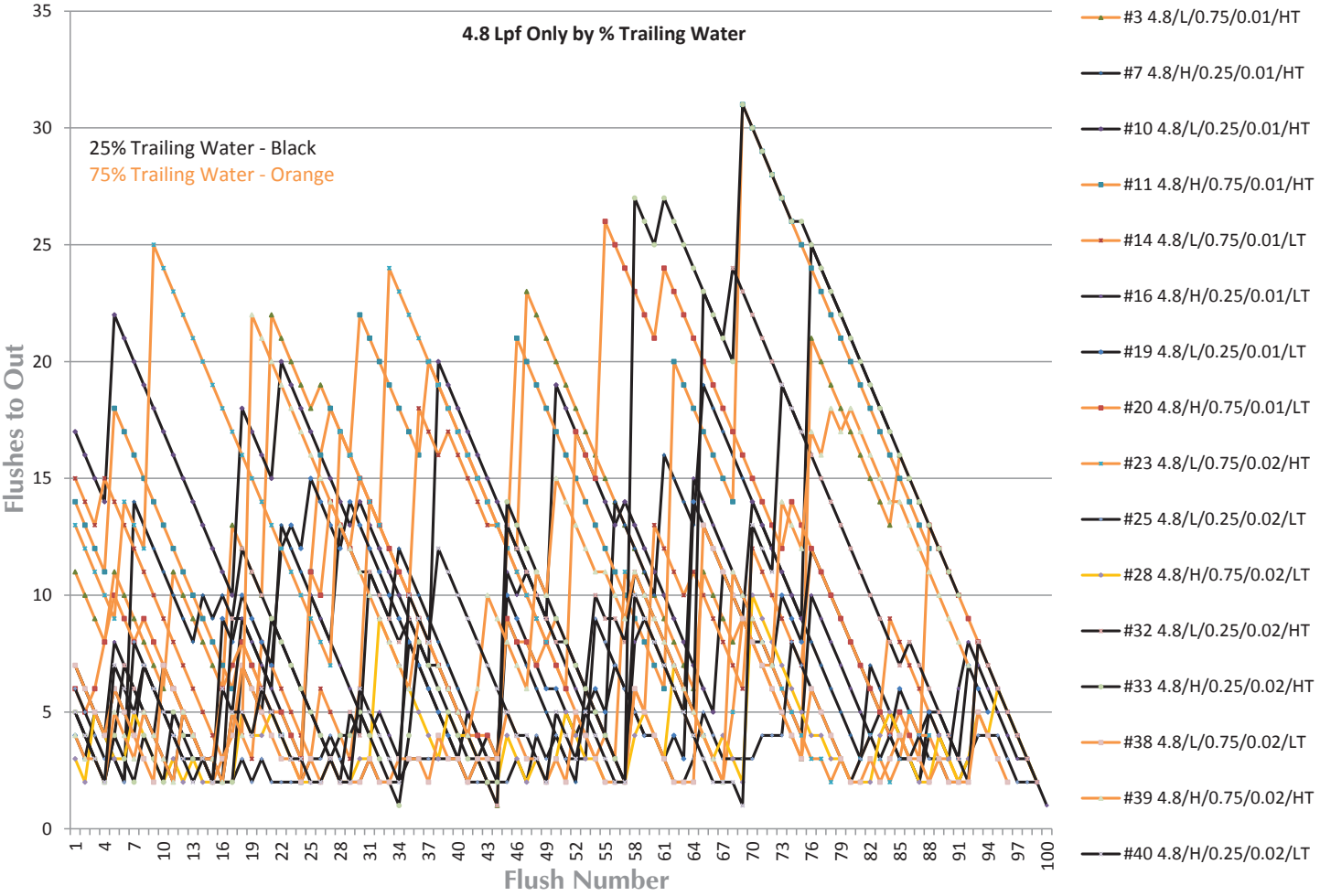


Figure 6-P shows the 1.28 gallon (4.8 L) data broken down by percent trailing water. Once again, based on past research that concluded percent trailing water is one of the most significant factors in drainline transport, the expectation would be to see black over orange in this chart. However, consistent with the results in our Main Effects Plots, we cannot determine a difference in the results based on trailing water, and percent trailing water again appears to be non-significant as a variable influencing drainline transport of wastes.

FIGURE 6-Q

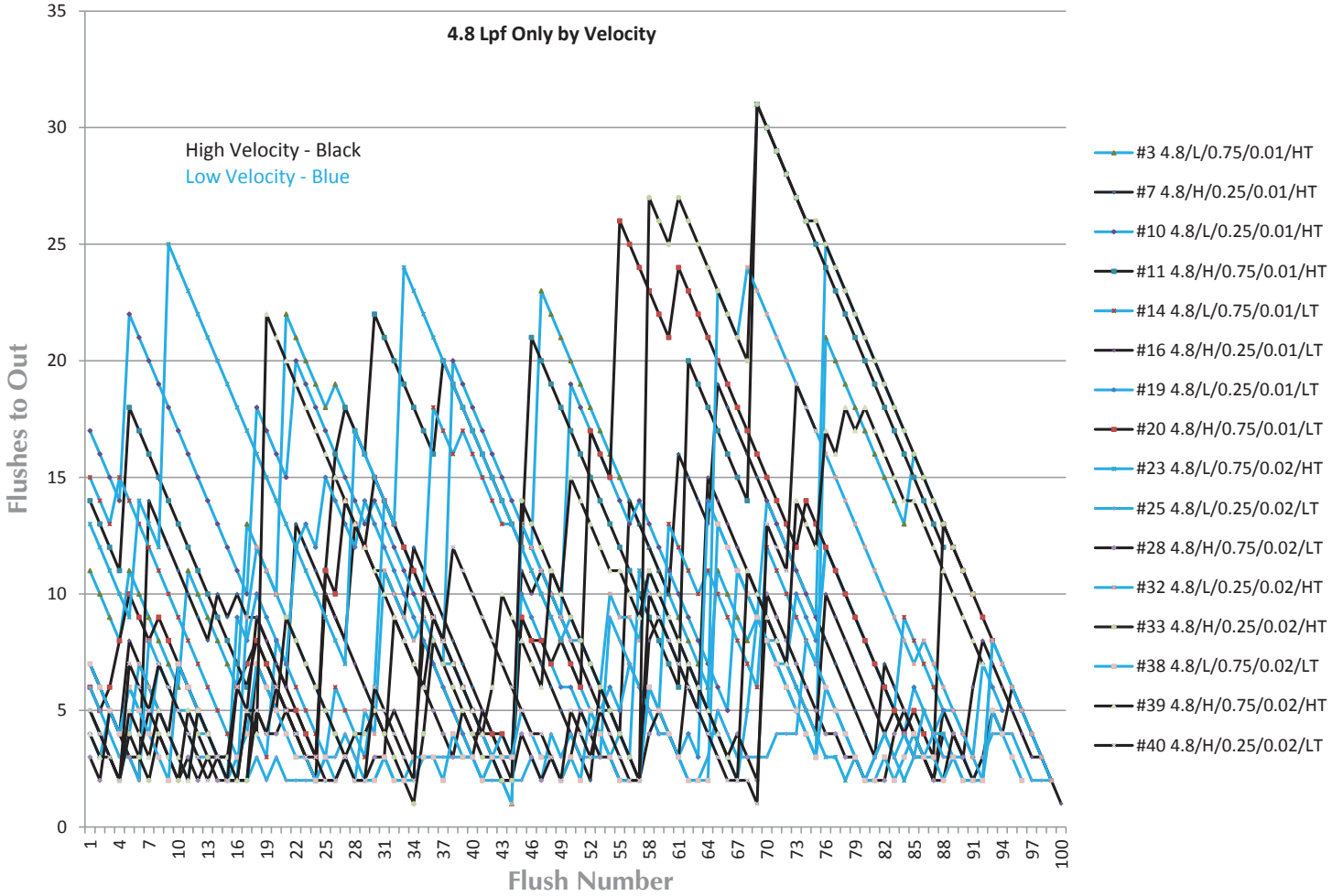
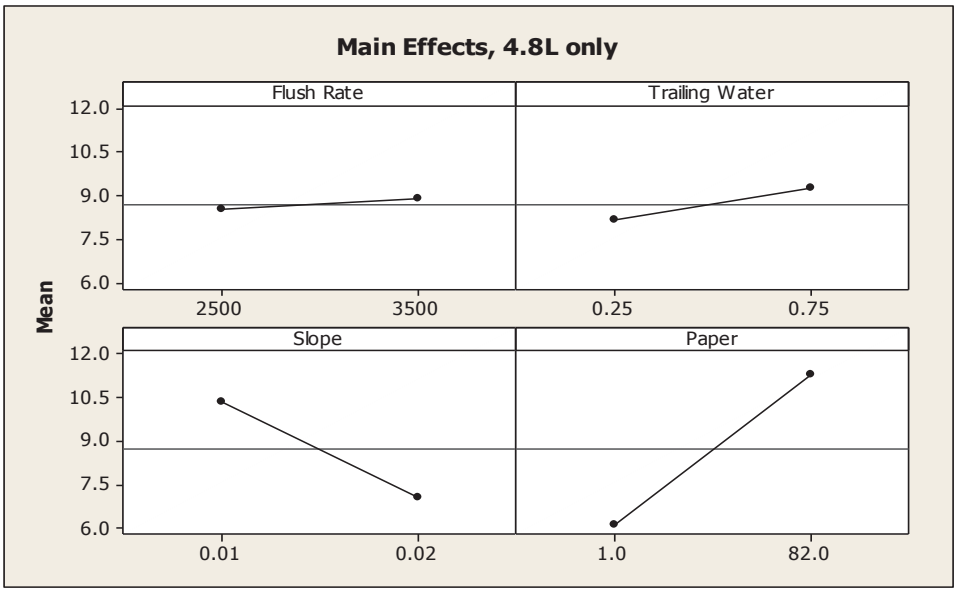


Figure 6-Q shows the 1.28 gallon (4.8 L) data broken down by flush rate. A higher flush rate would provide for a deeper flood level in the test apparatus, but carries the risk that the water might "outrun" the solids. Consistent with the results in our Main Effects Plots, we cannot determine a difference in the results based on flush rate and, as such, it appears to be a non-significant variable.

FIGURE 6-R – MAIN EFFECTS PLOT – 1.28 GALLON (4.8 L)



Factor	Type	Levels	Values
Flush Rate	fixed	2	2500, 3500
Trailing Water	fixed	2	0.25, 0.75
Slope	fixed	2	0.01, 0.02
Paper	fixed	2	1, 82

Analysis of Variance for Ave Flushes to Out, using Adjusted SS for Tests

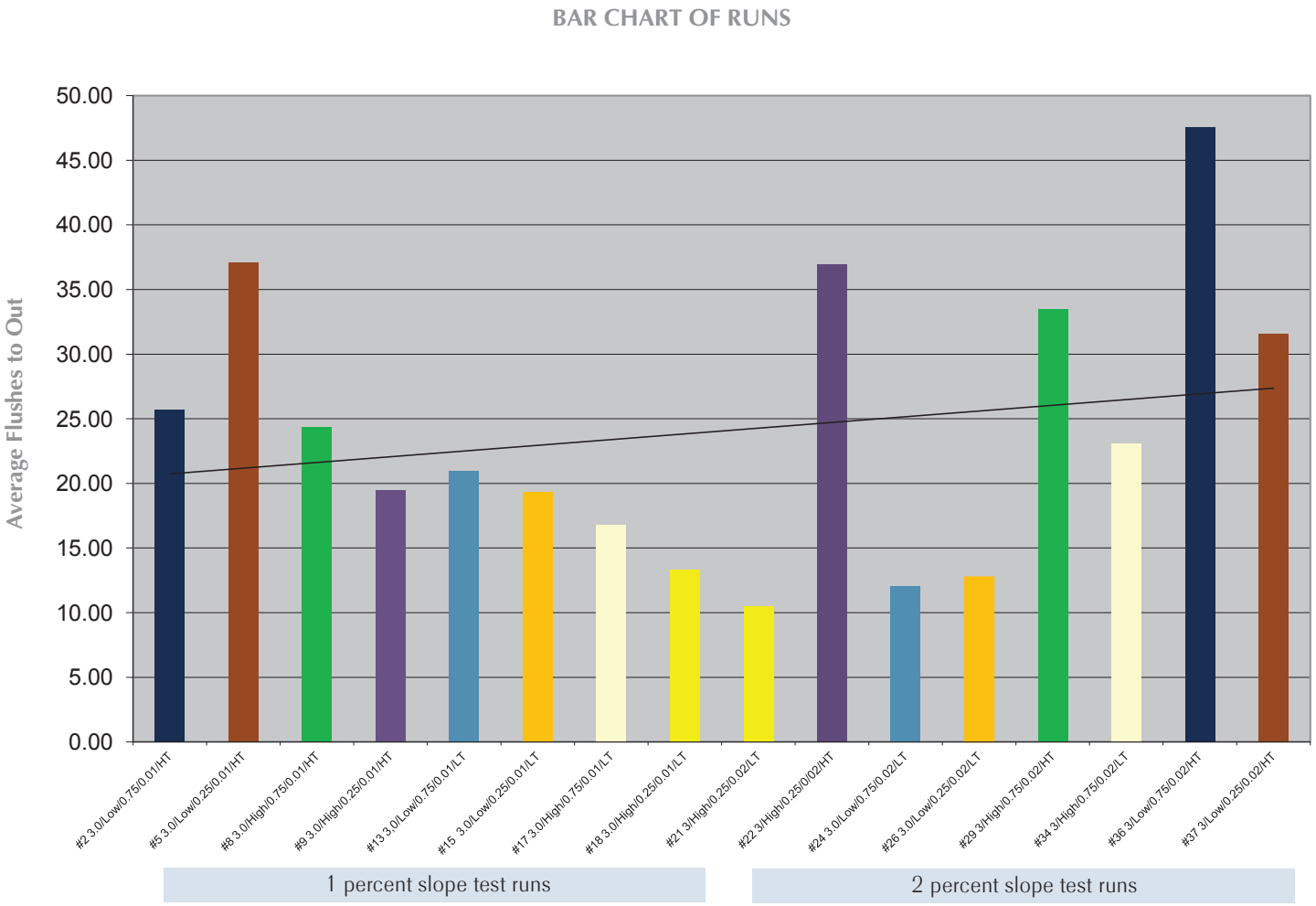
Source	DF	Seq SS	Adj SS	Adj MS	F	P
Flush Rate	1	0.538	0.538	0.538	0.14	0.712
Trailing Water	1	4.672	4.672	4.672	1.25	0.288
Slope	1	43.254	43.254	43.254	11.55	0.006
Paper	1	108.641	108.641	108.641	29.02	0.000
Error	11	41.179	41.179	3.744		
Total	15	198.285				

S = 1.93482 R-Sq = 79.23percent R-Sq(adj) = 71.68percent

Figure 6-R is a Main Effects Plot for the 1.28 gallon (4.8 L) data only. The data shows definite significance for slope and paper. This mirrors the results of the Primary Main Effects plot (See Figure 6-G).

0.8 Gallon / 3.0 Liter Data

FIGURE 6-S

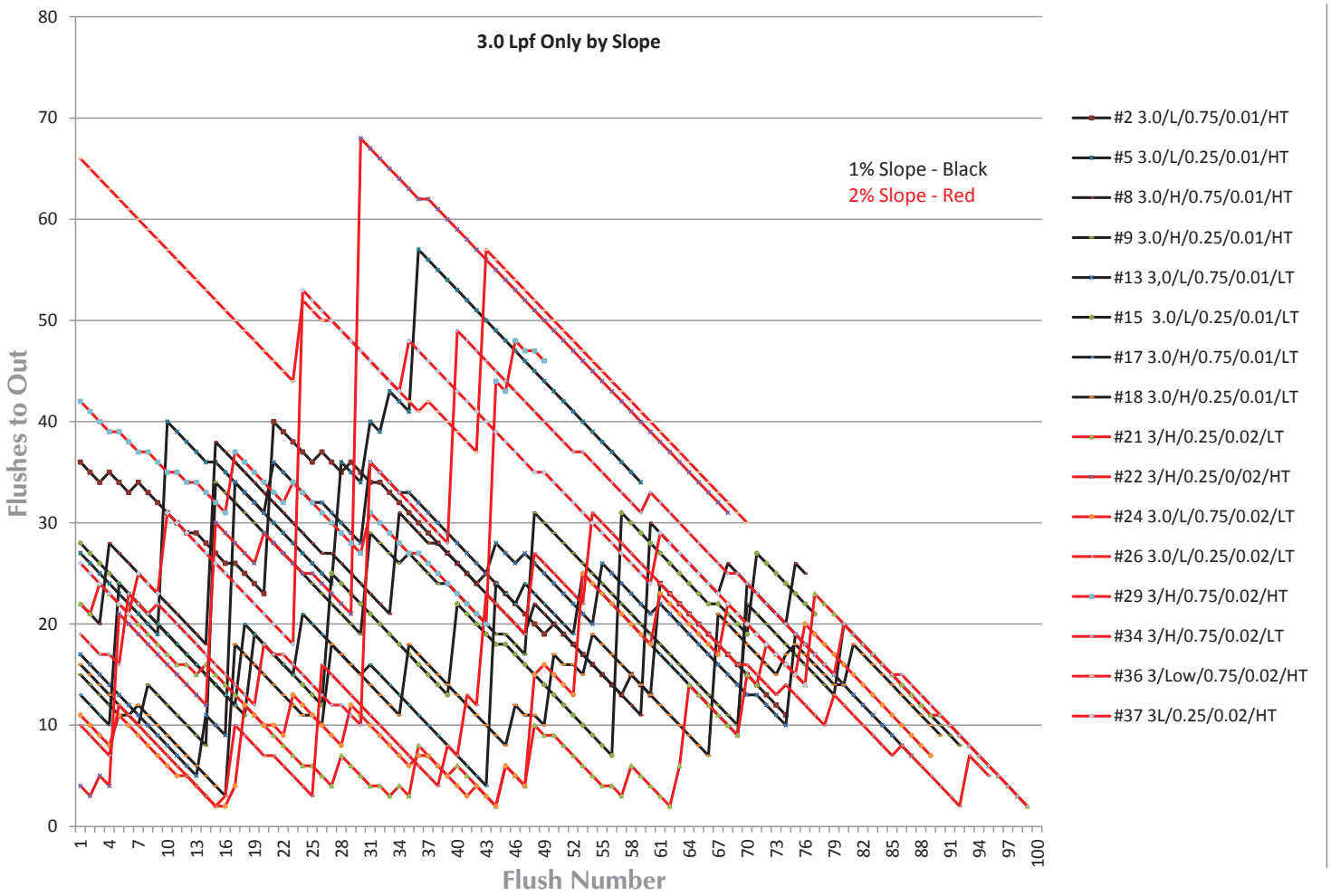


While the 0.8 gallon (3.0 L) data resulted in a chaotic condition in the Test Apparatus, which made the resulting data unusable for incorporation in to our Primary Main Effect findings, there is still a great deal to be learned from this data set. In addition, review of this data also raises some interesting questions.

As with the previous bar charts for the 1.6 gallon (6.0 L) and 1.28 gallon (4.8 L) data, Figure 6-S is also color coded so that test runs at the 1 percent slope and 2 percent slope that embody otherwise identical test variables appear in the same color. In this chart, however, the trend line indicates better performance at the 1percent slope, which is certainly counter-intuitive and surprising.

As seen in the Main Effects Plot for the 0.8 gallon (3.0 L) data (Figure 6-X), the bar chart indicates an inverse relationship between slope and drainline performance, yet slope did not calculate as a significant variable. Therefore, it is difficult to ascertain if this result is merely the outcome of a noisy and chaotic drainline condition (essentially a random result to be ignored) or, if indeed, higher slope levels become marginally detrimental to drainline performance as the ratio of solids to water in a drainline increases.

FIGURE 6-T



The line chart in Figure 6-T breaks down the 0.8 gallon (3.0 L) data by slope. We would normally expect to see better results (lower AFO) with the 2 percent slope Test Runs, shown in red. The expectation would be to see black over red in the chart. However, consistent with the results shown in Figure 6-S, and per our Main Effects plot on the 0.8 gallon (3.0 L) data (Figure 6-X), we cannot conclude a performance advantage due to slope from this chart.

FIGURE 6-U

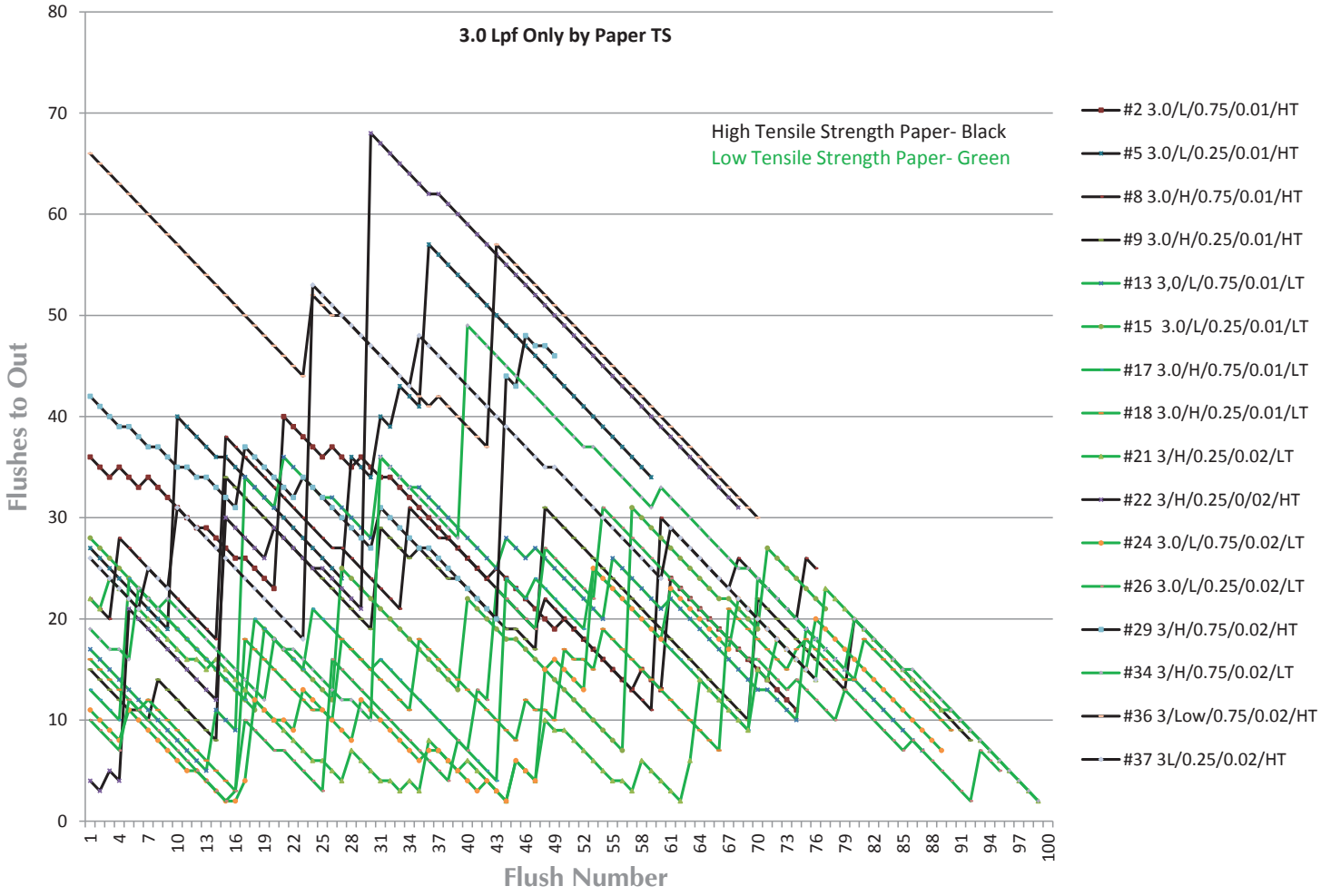


Figure 6-U is a line chart of the 0.8 gallon (3.0 L) data broken down by toilet paper tensile strength. Again, past research conducted by ASFlow concluded that the selection of toilet paper significantly impacts drainline results; thus, the expectation would be to see black over green in this chart, which is clearly evident, even in the chaotic 0.8 gallon (3.0 L) test runs. This result reinforces the importance of paper tensile strength as a significant factor in drainline transport performance.

FIGURE 6-V

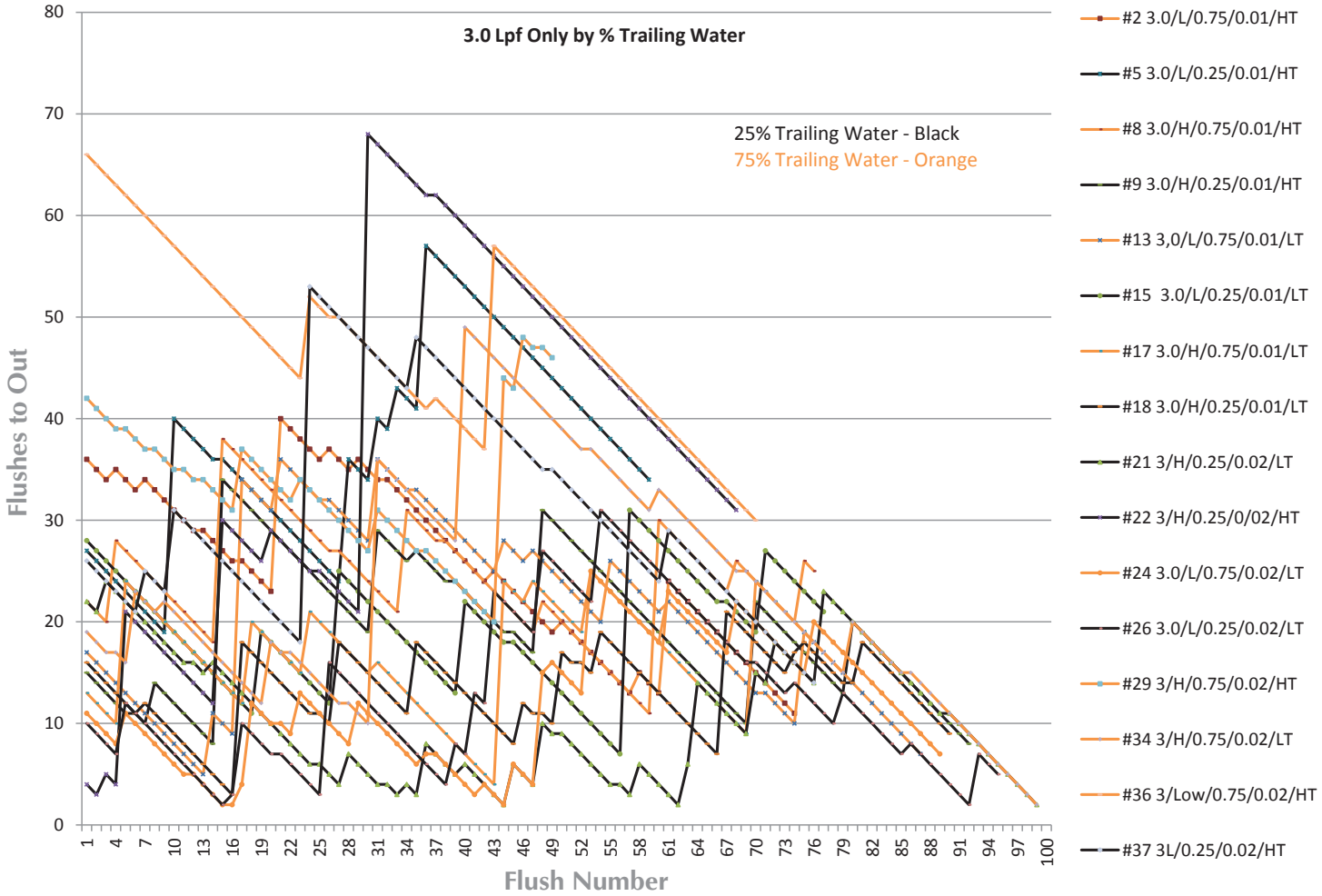


Figure 6-V shows the 0.8 gallon (3.0 L) data broken down by percent trailing water. Once again, based on past research elsewhere that concluded percent trailing water is one of the most significant factors in drainline transport, the expectation would be to see black over orange in this chart. However, consistent with the results in our Main Effects Plots, we cannot determine a difference in the results based on trailing water, and percent trailing water again appears to be non-significant.

FIGURE 6-W

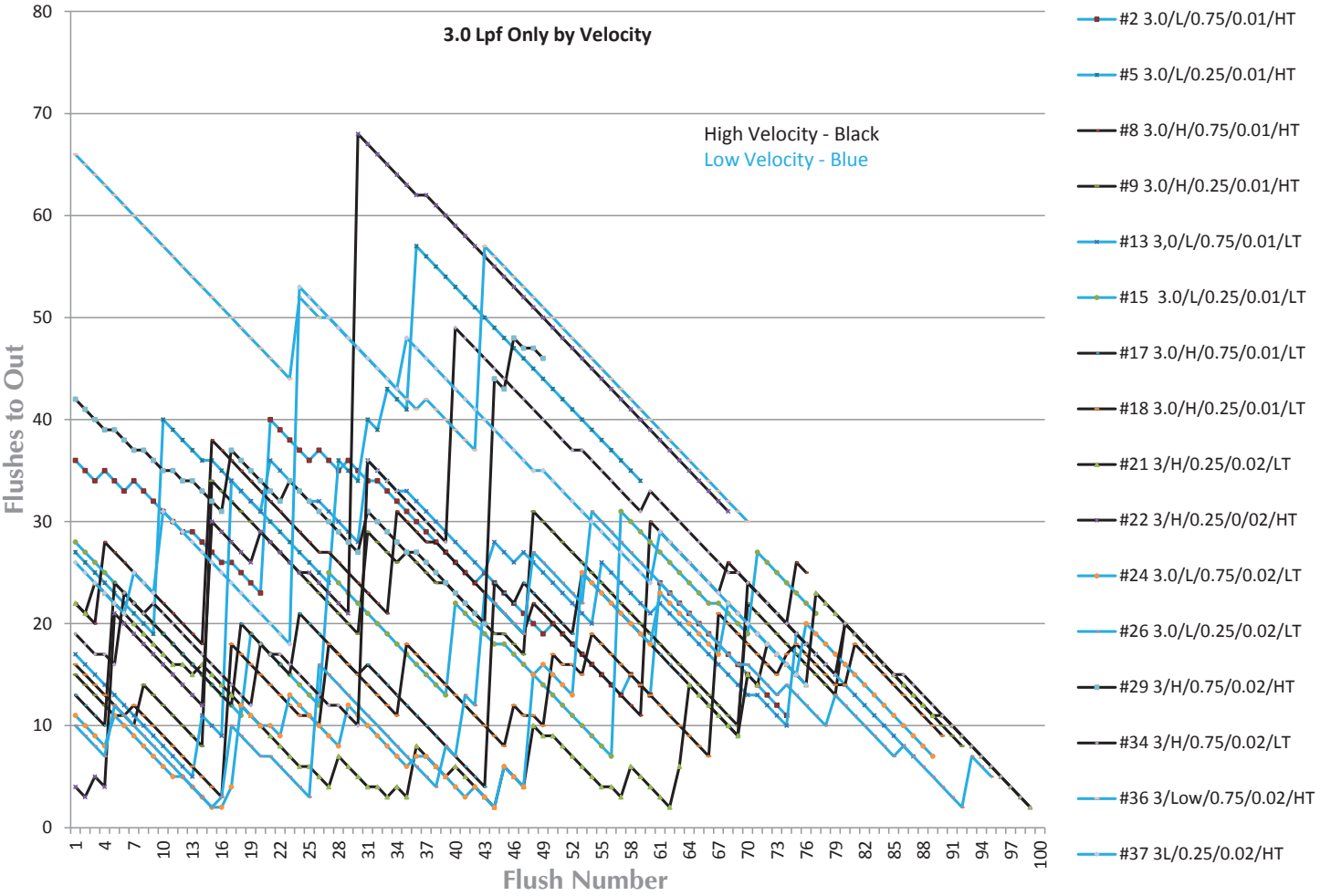
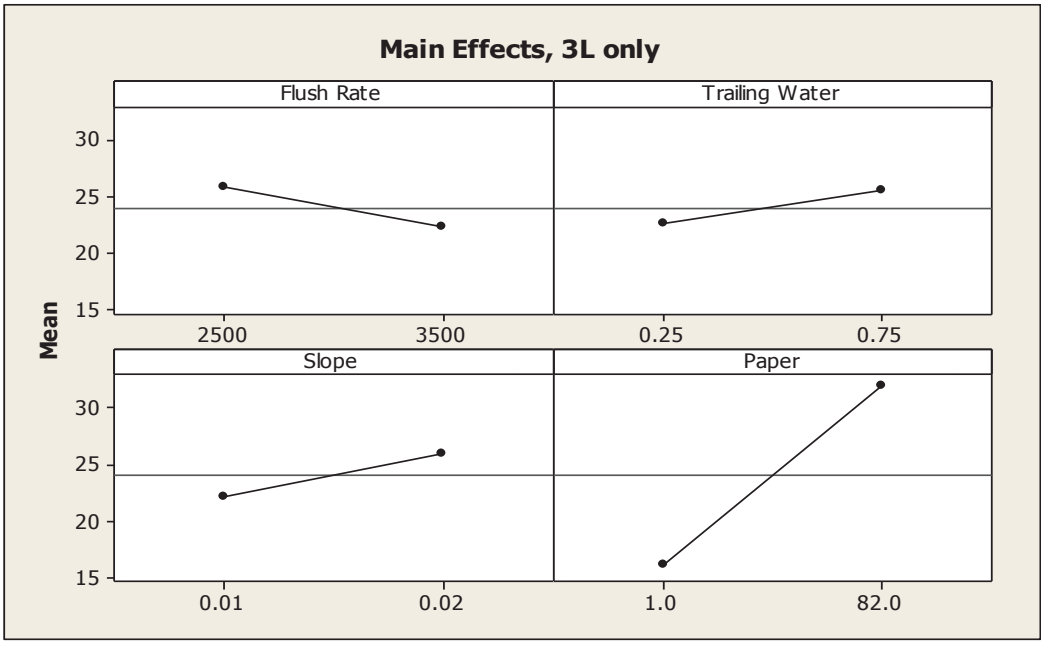


Figure 6-W shows the 0.8 gallon (3.0 L) data broken down by flush rate. A higher flush rate would provide for a deeper flood level in the test apparatus, but carries the risk that the water might "outrun" the solids. Consistent with the results in our Main Effects Plots, we cannot determine a difference in the results based on flush rate, and flush rate again appears to be non-significant.

FIGURE 6-X – MAIN EFFECTS PLOT – 0.8 GALLONS (3.0 L)



Factor	Type	Levels	Values
Flush Rate	fixed	2	2500, 3500
Trailing Water	fixed	2	0.25, 0.75
Slope	fixed	2	0.01, 0.02
Paper	fixed	2	1, 82

Analysis of Variance for Ave Flushes to Out, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Flush Rate	1	50.58	50.58	50.58	1.00	0.340
Trailing Water	1	33.93	33.93	33.93	0.67	0.431
Slope	1	58.47	58.47	58.47	1.15	0.306
Paper	1	1006.66	1006.66	1006.66	19.84	0.001
Error	11	558.19	558.19	50.74		
Total	15	1707.82				

S = 7.12352 R-Sq = 67.32percent R-Sq(adj) = 55.43percent

Figure 6-X is a Main Effects plot for the 0.8 gallon (3.0 L) data only. Looking at this volume level by itself, the data shows definite significance for paper only. Note that the inverse slope result shown on the bar and line charts for the 0.8 gallon (3.0 L) data does show up on the Main Effect Plot, with the trend line favoring the 1 percent slope data. However, the P-value is much too high for this to be considered a significant result. In addition, the R-Sq value of 67.3 is well below our 80 percent desired threshold. In consideration of the chaotic performance of the test apparatus at the 0.8 gallon (3.0 L) level, the low R-Sq value is not at all surprising, and is further evidence that this data is not appropriate for incorporation into our Primary Main Effects Findings.

7. Findings and Conclusions

FINDINGS

The PERC Technical Committee (TC), in review and consideration of the data generated in this study, provides the following findings:

Deliverable 1 *(from the PERC Test Plan proposal): Prior international studies and some field failures reported recently in Australia, indicate that flush volumes consistent with High Efficiency toilets may result in systemic drainline transport related failures in building drains or sewer lines. This study will evaluate the viability of a low-cost building drain clearing solution: Determine if we can clear over 200 ft (61m) of 4–inch (100mm) diameter plastic pipe with a flushometer valve or other device set to deliver higher volume discharges at intermittent intervals (1 percent or 2 percent of total flushes).*

Finding: A 5 gallon (19L) clearing flush failed to clear the drainline in 7 of 39 test runs (the line coincidently cleared after the 100th flush in one test run, so the clearing flush test could not be performed). Due to the inability of a 5 gallon flush to clear the line in Test Run #1, no further consideration was given to testing a 3 gallon clearing flush. As a result, the potential low cost solution proved to be unreliable and unfortunately cannot be suggested as a possible cost-effective building drain clearing solution, at least at the 1 percent or 2 percent frequency levels considered in this work plan[12].

Discussion: When observing the behavior of waste in the test apparatus, it quickly became apparent that once the effect of the initial flush surge diminishes, 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 (as in a sewer). Therefore, there was no advantage in attempting the clearing flush at the 2 percent interval (after the 50th flush injection and again at after the 100th flush injection). This was because the mass of the media in the Test Apparatus at any given point in a given test run varied widely depending upon the random movement of media at any given time during that test run. Accordingly, the clearing flush was not evaluated at a 2 percent interval.

Table 7-A details the results of the clearing flush for the 40 Test Runs.

12 See Section 8, Future Study Opportunities, for additional discussion regarding a clearing flush.

TABLE 7-A CLEARING FLUSH RESULTS

1% SLOPE TEST RUNS – FAILURES HIGHLIGHTED

Test Run #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Test Volume (L)	6	3	4.8	6	3	6	4.8	3	3	4.8	4.8	6	3	4.8	3	4.8	3	3	4.8	4.8
Pass/Fail	F	F	P	P	F	P	P	P	P	P	P	P	P	N/A	F	P	P	P	P	P

2% SLOPE TEST RUNS – FAILURES HIGHLIGHTED

Test Run #	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40
Test Volume (L)	3	3	4.8	3	4.8	3	6	4.8	3	6	6	4.8	4.8	3	6	3	3	4.8	4.8	4.8
Pass/Fail	P	P	P	P	P	P	P	F	P	P	P	P	F	P	P	F	P	P	P	P

Note that failures to clear the Test Apparatus occurred at both 1 percent and 2 percent slope and at all three (3) flush injection volumes.

Deliverable 2*: Prior studies have concluded that toilet flush characteristics (percent trailing water and flush rate) are a significant factor in drainline transport, specifically pointing to the amount of trailing water as a key factor. This study will determine the role that toilet discharge curves play in drainline transport efficacy in a multi flush sequence and will rank the hydraulic characteristics (percent trailing water and flush rate) of the toilet relative to other variables beyond the control of the toilet design (flush volume, toilet paper and drainline slope).*

Finding: Toilet hydraulics (percent trailing water and flush rate) were found to be non-significant variables. As such, the effect that toilet fixture designs have on drain line transport in long building drains has been found to be minimal. These results will be forwarded to the ASME / CSA Joint Committee on Vitreous China Fixtures for their consideration relative to the need for a drain line carry test in the harmonized U.S and Canadian national standard. The PERC TC also looks forward to discussing these findings with other researchers.

Regarding the relative rankings of the controlled variables contained in the Test Plan, we arrive at the following results:

FIGURE 7-B

PRIMARY MAIN EFFECTS PLOT – ALL DATA AND RESPONSE TABLE FOR MEANS

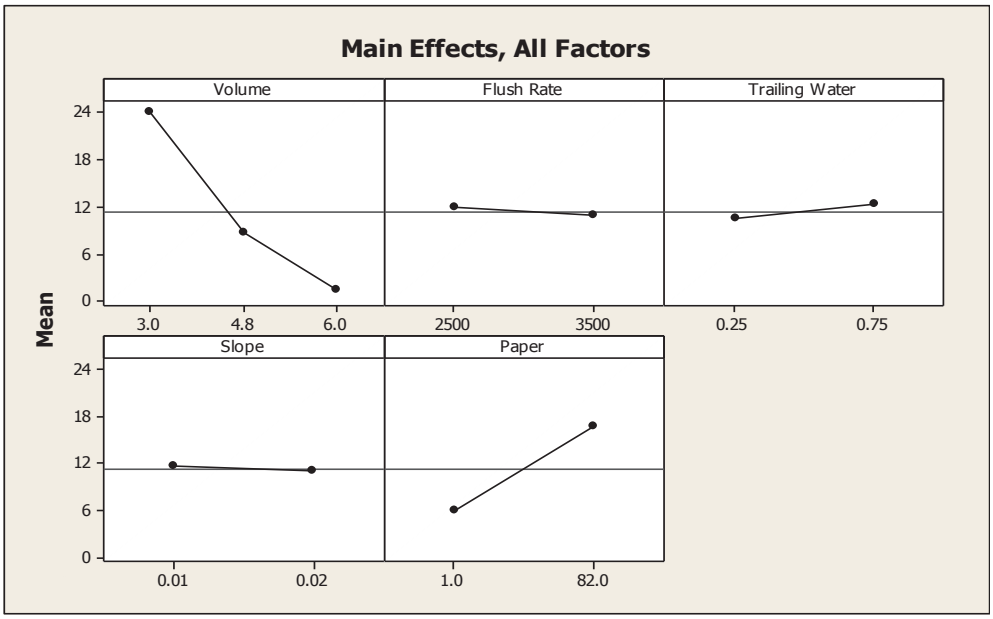


TABLE 7-C - RESPONSE TABLE FOR MEANS

Level	Volume	Flush Rate	%Trailing Water	Slope	Paper
1	8.710	7.567	7.535	9.671	6.104
2	6.554	8.416	8.448	6.311	8.935
Delta	2.156	0.849	0.913	3.360	2.831
Significance Rank	3	5	4	1	2

When considering all except the 0.8 gallon (3.0 L) data (which consists mostly of noise and cannot be used for this purpose), we can readily see from the slopes in Figure 7-B, Primary Main Effect Plot that there are three (3) significant variables and two (2) non-significant variables. Table 7-C, Response Table for Means, applies a numeric value to all of the Test Plan variables, which allows for discrete ranking. This is calculated grouping the test runs by variable type, averaging the Average Flushes-to-Out (AFO) scores and subtracting one set of averaged AFO scores from the other. For example, in the second column (Volume), all 1.6 gallon (6.0 L) test runs averaged an AVO score of 8.710, shown as the Level 1 value, and the 1.28 gallon (4.8 L) test runs averaged an AVO score of 6.554, shown as the Level 2 value. This yields a delta of 2.156. Significance of the variables can then be ranked by the relative difference in the delta values. This results in the following ranking:

Significant Variables	Non-significant Variables
Slope > Paper > Volume >	% Trailing Water > Flush Rate

Due to the inherent variability with this Test Plan and considering the fact that the Delta values in Table 7-C are tightly grouped within the significant and non-significant test variables, the PERC TC urges caution against basing any plumbing system design decisions on the discrete rankings among those factors, pending further study. Under this test scenario, the major finding is that Slope, Paper and Volume are all definitely significant and Percent Trailing Water and Flush Rate are not.

Additional findings resulting from the Work Plan were as follows:

0.8 gpf / 3.0 Lpf flush volume: Observation of waste movement within the Test Apparatus during the 0.8 gallon (3.0 L) test runs clearly demonstrated a major difference in performance when compared to the other volume levels (1.28 gallons and 1.6 gallons). In five (5) of the sixteen (16) test runs conducted at the 0.8 gpf / 3.0 Lpf volume, the test media in the test apparatus compressed together to form large plugs in the drain line that resulted in full-pipe or near full-pipe conditions (see Photo 7-D). While these plugs eventually cleared themselves prior to any water overflows at the flush stand, the PERC TC still found that this flush volume created a chaotic, unpredictable condition in 4-inch pipe to the extent that the data at the 0.8 gpf / 3.0 Lpf volume was mostly noise and not useable in the statistical analysis.

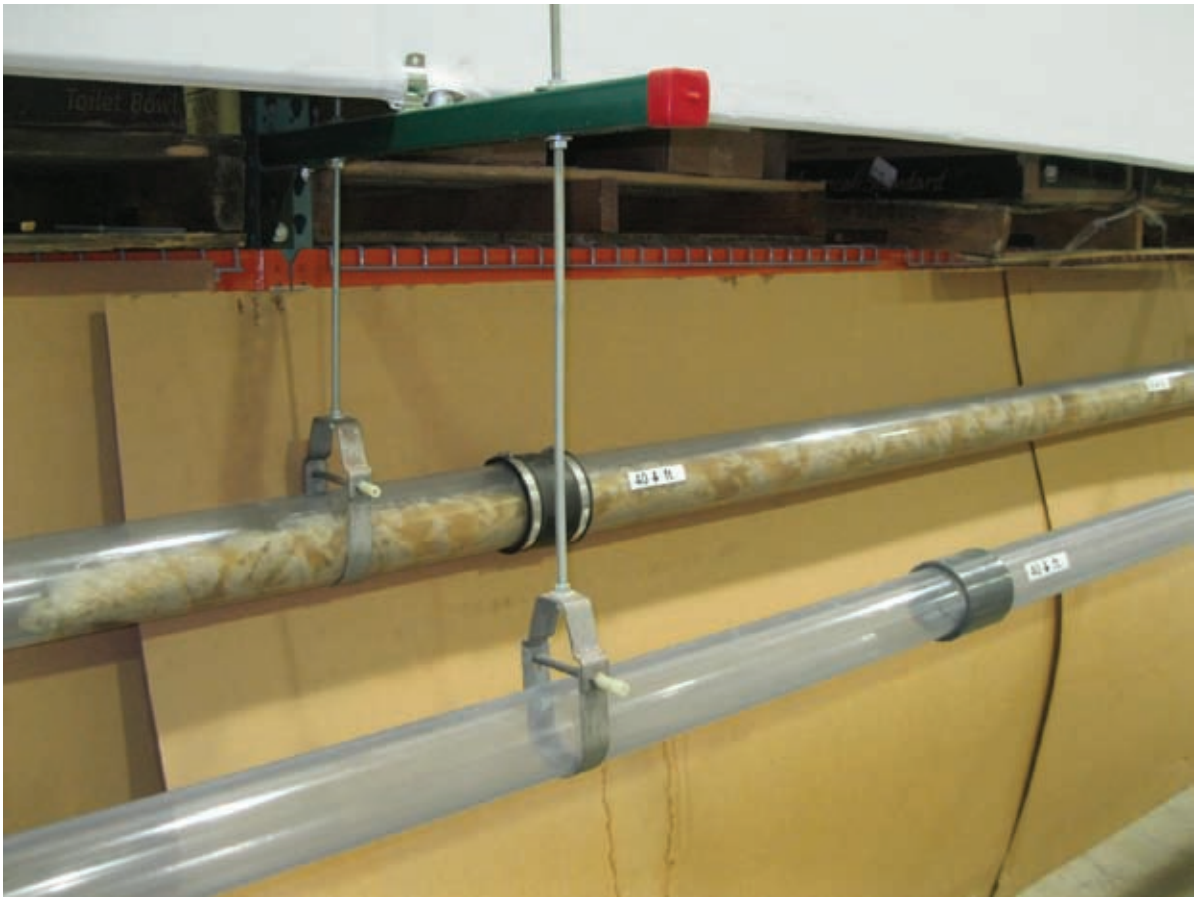


PHOTO 7-D

NEAR FULL-PIPE CONDITION IN TEST RUN #5, @ 0.8 GALLON (3.0 L) VOLUME, 1% SLOPE

As a result, the PERC TC recommends further study at this discharge level.

1.28 gpf/4.8 Lpf and 1.6 gpf/6.0 Lpf flush volumes - The 1.28 gallon (4.8 L) and 1.6 gallon (6.0 L) volumes resulted in an orderly and predictable movement in the Test Apparatus (see Photo 7-E and 7-F). In retrofit applications, it is suggested that drainlines first be inspected for defects, root intrusions, sagging or other physical conditions that could result in clogging with lower flush volumes.

PHOTO 7-E

ORDERLY FLOW OF SOLIDS IN TEST RUN #3 @ 1.28 GALLON (4.8 L) VOLUME, 1% SLOPE

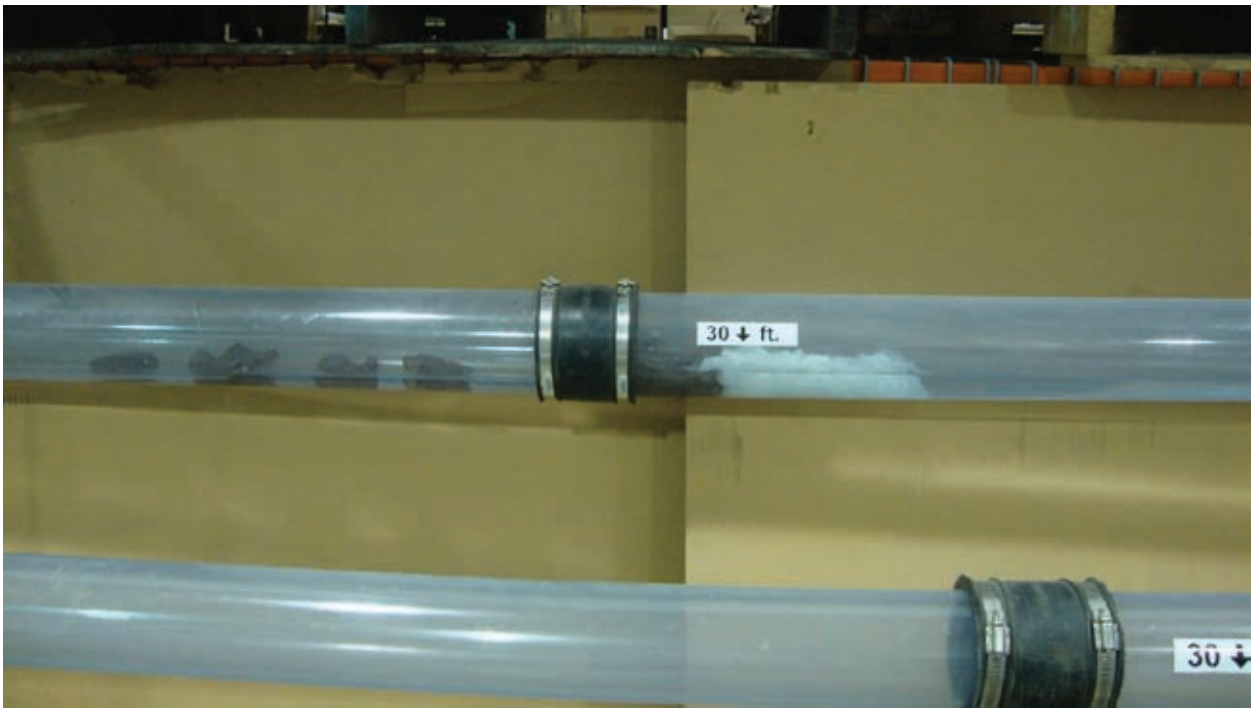


PHOTO 7-F

ORDERLY FLOW OF SOLIDS IN TEST RUN #1 @ 1.6 GALLON (6.0 L) VOLUME, 1% SLOPE

Based on this study, the PERC TC recommends that the U.S. EPA WaterSense® Program expand their specification on toilets to include commercial flushometer-valve operated HETs.

Percent Trailing Water and Flush Rate – The data shows that, in a long drainline, when toilet paper and a more realistic test media are used (such as that used in this study), and in long duration (100 flush) flush sequences, Percent Trailing Water and Flush Rate (i.e.: toilet flush discharge characteristics) were non-significant factors in this study.

This finding has implications regarding the necessity for having a Drainline Transport Characterization Test in the North American standard for toilets, *ASME A112.19.2 / CSA B45.1, Ceramic Plumbing Fixtures*. These findings will be forwarded to the ASME / CSA Joint Harmonized Committee of Plumbing Fixtures for their consideration.

A great deal of effort was built into the PERC work plan to investigate the true significance of the toilet in drainline performance. As noted in Section 8, Future Study Opportunities, ongoing research needs are formidable. Hence, it is critical that future studies focus on system variables that are scientifically proven to be important.

Today, toilet manufacturers are frequently asked by their customers for the results of the ASME / CSA Drainline Transport Characteristics test (in *ASME A112.19.2 / CSA B45.1)* in the mistaken belief that those results are meaningful. For the conditions studied, the results from this study indicate they are not.

This is actually a bit of good news regarding future research needs. If toilet discharge characteristics were found to be significant, it would necessitate that future studies include accommodations for those variables, which would considerably increase the complexity and cost of future studies and future testing.

The Significance of Toilet Paper Selection: Research conducted by Dr. Steve Cummings in Australia illustrated how different brands of toilet paper directly impact drainline transport distances. The PERC TC took this information and expanded upon this work in two key areas.

First, the PERC TC developed an easy test to apply a numeric value for the wet tensile strength of any conventional toilet paper, as detailed below. See Photo 7-G.

PHOTOS 7-G - TOILET PAPER WET TENSILE STRENGTH TEST

Wet tensile strength test procedure:

1. Carefully separate one (1) sheet of paper from a roll of toilet paper to be tested.
2. Being careful not to tear the toilet paper, spread the toilet paper over the open top of the cup and secure the edges with a rubber band around the perimeter of the cup as shown in the top left photo.
3. Soak the toilet paper in room temperature water by inverting the cup into a container of water and allow the paper to soak for 60 seconds, +/- 2 seconds as shown in the top right photo.
4. Remove the cup from the water and place right side up on a flat and reasonably level surface.
5. Using small washers (1/4 inch lock washers were used in this example) or any other light flat, smooth object of like shape and weight, immediately begin carefully placing one washer at a time in the center of the saturated paper, pausing 4 seconds between the addition of the washers as shown in the lower left photo. It is fine for the washers to stack up on each other, forming a small mound as washers are added.
6. Add washers until the paper ruptures as shown in the lower right photo.
7. Count the number of washers (or other objects).

Secondly, the PERC TC performed tests on the Test Apparatus where the resulting transport distances indicate a strong inverse correlation between the wet tensile strength values and the resulting transport distances both with and without the MaP test media. See Table 7-H.

TABLE 7-H
CORRELATION OF WET TENSILE STRENGTH AND DRAINLINE TRANSPORT DISTANCES

Toilet Paper Properties	Low Tensile Strength Paper	High Tensile Strength Paper
Dimensions (1 square)	4.125" x 3.75"	4.25" x 4"
Ply (single or double)	Single	Double
Tensile Strength Value	1	82
DLT Distance with MaP Media and paper	24	11
DLT Distance without MaP Media (paper only)	135	45
Correlation – DLT Distance to Tensile Strength Value with MaP Media and paper	-0.91	
Correlation – DLT Distance to Tensile Strength Value Without MaP Media (paper only)	-88.3	

It should be noted that Table 7-H shows only the inverse correlation results between wet tensile strength and transport distances on the two toilet papers used in the PERC Test Plan. In addition, this test was run on three (3) brands of toilet paper from Australia (the "best", "worst" and "nearest to average" brands, based on transport distances as identified in Dr. Cummings' report) and three (3) popular brands of paper sold in the United States. In each case, an inverse correlation in the high 80's or 90's resulted[13].

Therefore, there is a definite correlation between the wet tensile strength of toilet paper and DLT distances. As such, toilet paper selection has the potential to be very significant in terms of drainline performance. In fact, the data clearly suggests that the selection of toilet paper is definitely more significant than other toilet flush characteristics (flush rate and trailing water).

However, it is important to keep in mind that the highest and lowest wet tensile strength brands of toilet paper were intentionally selected for this test, so as to measure the potential for toilet paper to affect drainline transport results. As an example, the toilet paper chosen for the low tensile strength paper failed after only one (1) washer was placed on the saturated paper using the test protocol detailed above. The high tensile strength paper supported eighty-two (82) washers before failing. Accordingly, there would be less significance among brands of toilet paper that fall between these extremes.

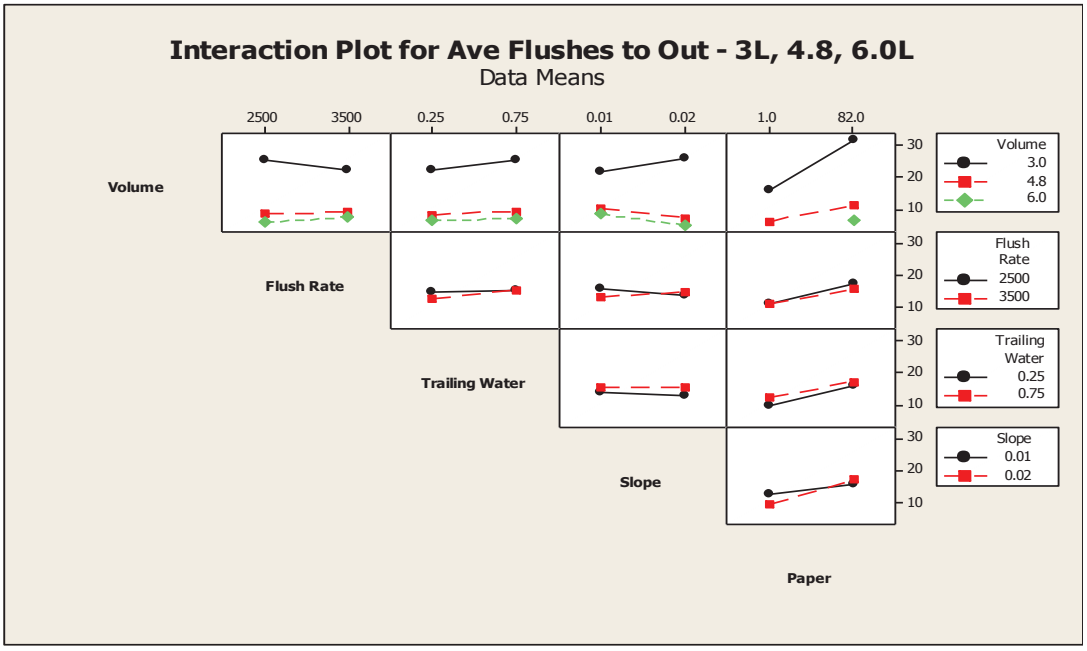
Nonetheless, this test is easy to run. Therefore, the PERC TC suggests that the wet tensile strength test be used where building drainline blockages chronically occur in order to identify a replacement toilet paper with a lower wet tensile strength than whatever paper may be currently used. This possible remedy to chronic drainline blockages may be a first step in a set of best management practices for building drainline systems.

» Interactions – As part of the data analysis, the PERC TC investigated if any significant interactions were occurring between the controlled test variables. This type of analysis checks to determine if two test variables are working in tandem to move the performance result. Figure 7-I is an interaction plot. It shows where interactions exist between the test variables indicated by intersecting columns and rows on the plots. Strong interactions are illustrated by crossed lines in the form of an "X", indicating a significant interaction and would also be indicated by a P-value under 0.05.

13 Correlation data for all toilet paper tests appears in Appendix C – Supporting Materials.

As shown in Figure7-I, while some minor interactions were identified, none is significant. The strongest interaction appears to be between Slope and Paper.

FIGURE 7-I – VARIABLES INTERACTION PLOT



Factor	Type	Levels	Values
Volume	fixed	3	3.0, 4.8, 6.0
Flush Rate	fixed	2	2500, 3500
Trailing Water	fixed	2	0.25, 0.75
Slope	fixed	2	0.01, 0.02
Paper	fixed	2	1, 82

Analysis of Variance for Ave Flushes to Out, using Adjusted SS for Tests

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Slope*Paper	1	57.15	57.15	57.15	1.87	0.181
Flush Rate*Slope	1	30.59	30.59	30.59	1.00	0.325
Flush Rate*Trailing Water	1	9.12	9.12	9.12	0.30	0.589
Error	30	915.72	915.72	30.52		
Total	39	4434.40				

S = 5.52484 R-Sq = 79.35% R-Sq(adj) = 73.15%

8. Future Study Opportunities

The PERC has completed its Phase 1 Work Plan on drainline transport, building upon studies previously conducted by others. This was accomplished within severe funding limits. There is much yet to be done to bring the ideal of laboratory testing closer to the conditions and materials found in the 'real world' of new and remodeled commercial buildings. The following tasks are proposed here with the clear understanding there is a price tag connected with each one. No attempt has been made below to prioritize this list. However, it is likely that available funds will be the driver as we proceed into future drainline testing phases.

As PERC defines future study opportunities, our partner, American Standard Brands, has generously offered to continue to provide the facilities used in this first phase. Following are the critical areas of future study that we believe need to be undertaken in the near future:

1. All of the PERC testing to date has used 4-inch (100mm) diameter pipe. The body of knowledge surrounding flow in partially filled pipes says that waste transport is significantly affected by pipe diameter due to resulting higher flood levels inside the smaller diameter pipe. With that understanding, the study of the impacts of 3-inch (75mm) nominal diameter pipe on waste transport is essential to expand the boundaries of our understanding, using all of the same data points as were developed with 4-inch (100mm) pipe.
2. This testing program was conducted at one percent and two percent drainline slopes. In actual practice, however, the slope in a building often varies between those two numbers. That recognition of 'real world' installed piping systems calls for testing to be performed at increments between one and two percent. Further, both 3-inch (75mm) and 4-inch (100mm) pipe should be tested using the same testing parameters that were shown to be significant in this current study.
3. Toilet paper testing was not a part of the original work plan, having been added mid-way through the study (due largely to ASFlow study findings on the impact of toilet paper). The paper addition has been shown in the preceding pages to be an important variable in the transport of solid wastes in building drainlines. Because of this, a more comprehensive testing scope and work plan needs to be developed in order to provide guidance for the owners and managers of commercial buildings. There is no intention here to regulate the paper manufacturers or the paper products themselves, but rather to provide a sound basis for communicating with individuals responsible for building operations.
4. Testing was accomplished using clear plastic pipe. Commercial buildings are not plumbed with clear plastic pipe, but rather with cast iron or other materials.[14] To that end, we propose to simulate cast iron installations while maintaining a visual observation of activity in the drainline. Needless to say, the specific physical details of this unusual configuration will have to be designed, especially at the interface between the plastic and cast iron to assure that the physics of moving water, waste, and paper are not affected by the joining technique.
5. It is well known the surface of cast iron can become much rougher over a period of time, due to the formation of oxides and biofilm activity, as well as congealed grease. Using the configuration detailed in work item 4 above, through research and analysis it may be possible to duplicate the increasing friction factors caused by years of use. While we know it is virtually impossible to duplicate actual 'real world' installations in the laboratory, we can approach those conditions using the same testing procedures, variables, and data points we have used in this first phase of our drainline research.
6. A meaningful finding of this study was that a clearing flush of five (5) gallons of clear water delivered after the 100th flush injection in each test run did not consistently clear the test apparatus. In order to more comprehensively evaluate the potential for clearing flushes to be considered as an effective drain clearing solution, a separate experiment should be designed explicitly for this purpose. Included would be the evaluation of clearing flushes at lower intervals and higher volumes and would accommodate investigation of other potential drain clearing technologies such as tipping mechanisms and siphonic devices currently being utilized elsewhere.
7. One of the more surprising findings of this study was the possible inverse effect of the slope test variable at the 0.8 gpf (3.0 Lpf) test run level. For the conditions studied in this research, analysis of that data indicates a possibility that higher slope levels are actually a detriment to drainline performance, albeit at a significance much lower than toilet paper selection, as the ratio of solids to water increased, such as in the 0.8 gpf (3.0 Lpf) test runs. This deserves additional study.
8. Results from this study indicate that 0.8 gpf (3.0 Lpf) toilets may be problematic in commercial installations that have long horizontal drains and little or no additional long duration flows available to assist the toilet in providing drainline transport of solids. Volume levels between 1.28 gpf (4.8 Lpf) and 0.8 gpf (3.0 Lpf) must be evaluated to determine at what levels drainline performance becomes chaotic, leading to an increased potential for clogging failures.
9. Results from this study clearly indicate that toilet paper selection has the potential to be a very significant variable relating to drainline transport characteristics. Experiments should be designed to determine how <u>other</u> materials, such as moisturized non-woven "wipes", paper toilet seat covers, and other so-called 'flushable' consumer products impact drainline performance.

The absence of areas of study not listed above does not mean they are not important or not being considered. The work reported here, while providing significant findings, simply scratches the surface and, as with most research programs, the findings carry with them a whole new list of issues that require further investigation. Our goal remains to increase the understanding of how building drains

14 Some jurisdictions permit ABS and PVC where the authority having jurisdiction allows it.

perform. It is important that data-driven results (rather than anecdotal incidents) are employed to better determine how sanitary plumbing systems can continue to perform safely while, at the same time, essential water efficiency measures reduce the amount of water in building drainlines and drive the technology of plumbing.

It is the intent of the PERC TC that this study initiates an increased level of discussion and activism among plumbing industry stakeholders on the impact of water efficiency measures on the performance our plumbing systems, regarding both sanitary and water supply systems. If that occurs, it will certainly be the most significant outcome of this study. We look forward to an ongoing dialogue with all interested parties.

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APPENDICES

APPENDIX A - EXPLANATION OF TERMS

Note: The following explanation of the terms used in the report are intended to provide the reader with a more thorough understanding of how they are used in the context of this report only.

Analysis of Variance (ANOVA) – A statistical model in which the observed result(s) are partitioned into components. These components are random variation (noise) and the signal (significance of the factor). ANOVAs are useful for comparing two, three, or more variables, judging significance by a low "p" value.

Average Flushes to Out (AFO) – In the Test Apparatus, each injection of test media was tracked on data sheets as it made its way around the 135 foot test apparatus. AFO is the average number of flushes it took for an individual injection of test media to run the course in a Test Run. Higher AVO numbers indicates difficulty in moving the solids through the apparatus. Conversely, lower AVO scores indicate that the media in the test apparatus is moving more reliably and orderly.

Designed Experiment (also referred to as Design of Experiment - DOE) - The development of a random testing sequence employing a means to analyze the significance of the test variables incorporated into this study. By analyzing the test variables in a specific sequence and structure, the experimental efficiency is increased. This method also provides for the interpretation of test variable interactions.

Flush Rate – (can also be called "Velocity", "Discharge Rate" or "Discharge Profile"). The Surge Injectors employed in the PERC Test Plan were designed to deliver two velocities of water into the Test Apparatus. These flush rates were selected to replicate slow acting and fact acting toilets on the market today. The "high" flush rate, set at approximately 3500 ml/sec peak flow rate, is typical of a pressure assist toilet or a gravity toilet with a 3-inch diameter flush valve flapper. The "low" flush rate is set at 2500 ml/sec, typical of a gravity siphonic toilet using a 2-inch diameter flush valve flapper.

Flushes to Out – Number of flushes for each media injection to clear the 135-foot long apparatus

Main Effects Plots – The various Main Effects Plots shown in this report graphically detail the results of the Designed Experiment by illustrating which variables are significant and which are not. By review of this data, each of the test variables can be ranked by significance to the performance of the drainline Test Apparatus. These plots constitute the main findings of this PERC study.

Percent Trailing Water – This refers to the percentage of water that trails the solid waste out of a toilet during the flush cycle. Some additional explanation is required here. Different toilet design approaches will impact "how" a toilet flushes and subsequently how much water will trail the solid waste out of the bowl. European and Australian toilets, also known as "Wash Out" or "Wash Down" toilets, work on a non-siphonic design platform. Basically, water cascades down from the tank when the toilet is flushed and the force of the water pushes the waste over the weir of the trapway. Pressure assist toilets (pressure-tank and flushometer-valve) employ pressure from the water supply line instead of gravity and are also non-siphonic. Because these toilets push the waste over the weir of the trapway early in the flush cycle, they typically have a higher percentage of training water from the flush that follows the solid waste out of the bowl to assist with the initial drain line transport of the solid waste down the building drain.

Conversely, siphonic toilets, the overwhelming favorite of the US consumer, use a good deal of the flush water to generate a siphon in the down leg of the toilet before the waste even leaves the bowl. Therefore, while wash out and pressure assist toilets work on a "push" flush action, siphonic toilets work on a "pull" flush action. As a result, there is a much lower percent trailing water on the siphonic models. The Surge Injectors used in this study were set up to deliver extremely consistent levels of percent trailing water as this is controlled by the ball valves on the Surge Injectors. Hence, they were able to simulate a toilet with 75 percent trailing water, like a wash out or pressure assist model, or a siphonic model with only 25 percent trailing water with precision levels exceeding that of using actual toilets.

Test Apparatus – This refers to the 135 foot long drainline transport test rig employed in this study.

Test Run – The PERC work plan consists of a total of 40 segmented injection sequences, each consisting of 100 "flushes" from a Surge Injector set to deliver a precise volume of water at a consistent velocity and percent trailing water. Each such sequence is referred to as a Test Run.

Surge Injector – Replaces the use of a toilet in the PERC work plan. It is designed to control the flush characteristic variables related to a toilet, specifically, volume, flush rate and percent trailing water. There were three Surge Injectors used in this study, one each for the 1.6 gallon (6 L), 1.28 gallon (4.8 L) and 0.8 gallon (3.0 L) volumes incorporated into the Work Plan.

Volume – The 1.6 gallon (6 L), 1.28 gallon (4.8 L) and 0.8 gallon (3.0 L) volumes incorporated into the Work Plan are consistent with toilet discharge levels of product sold in the marketplace today.

ACRONYMS

Adj MS – Adjusted mean square compensates for the covariates to see what the affect of the results would be if there were no differences between the variables

Adj SS – Adjusted sum of the squares measures the reduction in the residual sums of squares provided by each term relative to a model containing all the other terms

ASFlow – Australasian Scientific Review of Reduction of Flows on Plumbing and Drainage Systems

ASHRAE – American Society of Heating Refrigeration and Air-conditioning Engineers

ASPE – American Society of Plumbing Engineers

ASME – American Society of Mechanical Engineers

ASSE – American Society of Sanitary Engineers

AVO – Average Volume to Out

AWE – Alliance for Water Efficiency

CIB – International Council for Research and Innovation in Building and Construction

CSA – Canadian Standards Association

DLT – Drainline transport

DOE – Design of Experiment

EPA – Environmental Protection Agency

EPAct – Energy Policy Act

FPT – female pipe thread

g/ml – grams per milliliter

gpf – gallons per flush

gpm – gallons per minute

HET – High Efficiency Toilet

HEU - High Efficiency Urinal

IAPMO – International Association of Plumbing and Mechanical Officials

ICC – International Code Council

ISH - International Trade Fair for Heating, Ventilation and Air-Conditioning

L - liters

LCL – Lower confidence level

Lpf – Liters per flush

MaP – Maximum performance

Ml/sec – milliliters per second

MOU – Memorandum of Understanding

MPT – male pipe thread

PERC – Plumbing Efficiency Research Coalition

PHCC – Plumbing Heating Cooling Contractors National Association

PMI – Plumbing Manufacturers International

PVC – Polyvinyl Chloride

R-Sq – R-squared is the coefficient of determination and is used in the context of statistical models whose main purpose is the prediction of future outcomes on the basis of other related information.

Sch 40 – schedule 40 type pipe

Seq SS – Sequential sum of the squares measures the reduction in the residual sums of squares provided by each additional term in the model.

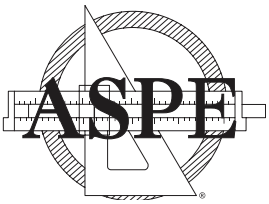
SOC – Socket end connector

SS – Sum of the squares

TC – Technical Committee

UCL – Upper confidence level

Plumbing Efficiency Research Coalition



Test Plan Proposal to Investigate Drainline Transport in Buildings

Test Plan Proposal to Investigate Drainline Transport in Buildings

BACKGROUND:

With the enactment of the Energy Policy Act of 1992, all water closets (toilets) manufactured in or imported into the United States were required to flush no more than a maximum average of 1.6 US gallons, effective January 1, 1994 for residential models and January 1, 1997 for all models. At that time, concern for drainline transport efficacy was voiced by many in the plumbing trade and those in various professional associations. However, early reporting and research on 1.6 gallon per flush (gpf) water closet models focused primarily on the flush efficacy of the various water closet models on the market in response to significant consumer complaints about poor flush performance. Since then, water closet manufacturers have made great strides in improving flushing performance. Intermittent and anecdotal complaints of drainline carry transport problems were not thoroughly researched and largely attributed to older or faulty sanitary drainlines.

Recently, the need to find additional efficiencies on water-consuming plumbing fixtures has resulted in the creation of voluntary specifications that eliminate another 20 percent from the flush discharge volume of water closets, bringing consumption down to a maximum average of 1.28 gpf. These toilets are known as High Efficiency Toilets (HETs). The States of California and Texas have passed legislation to require all toilets sold in those states to be HET's by the year 2014. There are other provisions in California that will significantly accelerate this transition and it is anticipated that other areas of the country will soon enact similar requirements. Some water closet manufacturers are now voluntarily offering models that flush at 1.0 gpf. One manufacturer is actively marketing a model that flushes at 0.8 gpf. This activity has rightfully raised the debate of drainline carry efficacy anew. Many plumbing experts are concerned that we are at or approaching a "tipping point" where a significant number of sanitary waste systems will be adversely affected by drainline transport problems, especially in larger commercial systems that have long horizontal runs to the sewer. Recently, drainline transport problems in Europe and Australia have been reported, further raising concerns here in North America.

Looking forward, newer technologies, such as non-water consuming and High Efficiency urinals (HEUs), lower flow rate faucets and increasingly efficient water consuming appliances will further reduce the amount of water discharged into sanitary waste systems. Equally significant are Graywater Reuse Systems that collect discharged water from lavatory basins, clothes washers, bathtubs and shower fixtures in a residence for reuse, usually for irrigation purposes. This is another emerging technology that significantly reduces waste water in residential sanitary drainage systems. On the commercial side, the emphasis upon water and energy use reduction has resulted in a proliferation of products in the medical and food service sectors that substantially reduce flows to the drain. Yet, to date, an extensive research project of sufficient scope has yet to be conducted that would to determine if significant problems could arise regarding drainline transport in these "efficient buildings".

THE NEED FOR RESEARCH:

The Plumbing Efficiency Research Coalition seeks funding to conduct scientific research to determine the effect of reduced flows into our domestic and commercial plumbing systems. Due to the complexity associated with the number of variables in "real world" plumbing systems, we believe that a multi–factorial designed experiment is required to properly measure the impact of the toilet fixture toward drainline transport relative to other plumbing system variables, such as pitch, and flush volume.

EMERGING TECHNOLOGIES WITH POTENTIAL TO MITIGATE DRAINLINE BLOCKAGES

Based on the casual observations of previous drainline transport research efforts, it is known that intermittent injections of clear water surges of sufficient volumes can transport solids in the drainline great distances and, theoretically, clear a building drain out to the connection to the sewer. For commercial installations, flushometer-valves that employ hands-free electronic activation can now be programmed to flush at pre-designated times and at user-selected volumes.

For example, consider a commercial office building with restrooms employing a bank of High Efficiency flushometer-valve toilets that flush at 1.28 gpf (4.8 Lpf). For example, at pre-determined intervals, the toilets furthest upstream (on the drainline) can be programmed to flush once or twice per day with a higher flush volume that clears the building drain of all solids and transports the solids to the sewer.

These new programmable features have the potential to offer a very low-cost solution for many commercial installations. As such, PERC is recommending that this potential solution be worked into the test plan.

LABORATORY TESTING

The focus of this effort will be to verify the feasibility of using programmable flushometer valves or other sources of clear water to clear long drainlines of deposited solids and to measure the relative importance of other systemic variables. This work would best be conducted on an apparatus employing 4" diameter pipe set at both minimum slope (1 percent) and standard code-compliant slope (2 percent). The study would involve investigating various flush volumes so as to intentionally deposit test media along the length of the test apparatus. The data from the resulting transport distances will allow for determining the relative importance of the test variables. At the end of each test run, a higher volume clear water discharge will be introduced into the drainline apparatus (simulating a discharge from a pre-programmed flushometer-valve) in order to observe the clearing potential of the clear water discharge.

A 200 foot long (~60 meters) test apparatus is

recommended to conduct this test. This will allow for adequate distance to show resolution in drainline transport at the various test flush volumes. In addition, the long distance simulates worst case commercial building drain installations and will allow us to determine if the high volume clearing has potential to clear very long commercial building drains.

To minimize costs, PERC will seek to conduct this test program on a suitable existing test apparatus. PERC is currently in the process of executing a MoU with the AS-Flow committee in Australia. Once the MoU is executed, PERC plans to review this test proposal with the AS-Flow Committee to determine the most cost effective location to conduct this work.

TEST PLAN DETAILS

The PERC Technical Committee has developed a proposed test plan to accomplish this work.

Below are the variables that need to be considered for the test plan. (Also see the associated Excel file that details the designed experiment test plan.)

- Flush volume: Discharge levels of 1.6 gpf (6.0 Lpf), 1.28 gpf (4.8 Lpf) and 0.8 gpf (3.0 Lpf) will be evaluated
- Pipe Diameter and Material: 4" (100mm) diameter clear PVC only. It would be preferable to also evaluate 3" and 6" diameter pipe, but to minimize costs; only 4" (100mm) diameter will be used for this initial work.
- Toilet Discharge Flow Rate / Velocity: Needed to simulate fast acting and slow acting toilets. The PERC Committee will use a "surge generator" type device to simulate those flow rates (rather than actual toilet fixtures). This device (see photo) will allow for more consistent discharge and will maintain the test plan variable pertaining to the discharge more accurately than can be achieved by using actual toilets.
- Trailing water: The surge generator will be constructed to allow injection of the solids at various points that result in a high volume of trailing water (70 percent), typical of fast acting toilets, and a lower volume trailing water (20 percent) typical of slower acting toilets.
- Test Media: Soy bean paste (miso paste) will be used to simulate solid human waste. This test media has been used extensively to test toilets to various flush performance tests, including the current US EPA WaterSense® specification for gravity flush toilets in the United States and has achieved good acceptance in the industry as an appropriate test media. Two-ply toilet paper will also be used.
- The following assumptions pertaining to flush discharges into the test apparatus will be applied:
  - A 2:1 ratio for solid and liquid waste flushes
  - 50 / 50 "male to female" ratio
  - All males use urinals, not toilets for liquid waste.*
  - No other long duration flows are available to assist the toilet. Urinals do not provide any transport assist (waterless or .125 gpf).
  - Males: 33.3 percent solid waste flushes using miso and toilet paper (4 balls @ six sheets each), 0 percent liquid flushes.
  - Females 33.3 percent solid waste flushes using miso and toilet paper and 66.7 percent liquid waste using toilet paper only (4 balls at 6 sheets).*
  - Essentially, this equates to 50 percent of the flushes having miso and paper and the other 50 percent having a lesser amount of paper only.
  - The miso loadings will randomly vary between 300 grams, 200 grams and 100 grams for all solid flushes for each round of testing.
  - Frequency and volume of clearing flush: The test plan will start using a 1 percent frequency for the clearing flush set a 3 gallons (11.4 Liters). If successful at clearing the 300 foot (90 Meter) test apparatus at these levels no additional testing will be required. If not, evaluation at 2 percent frequency or at higher flush volume may be required. It will be up to the test engineer to determine if those values need to be revised once we begin testing, based on observation.

*The above assumptions are not provided to simulate reality in all cases, but rather to provide an assumed worst case scenario.

STUDY VARIABLES:

Diameter (in)	4"			
Pitch (%)	1.0%	2.0%		
Flush Volume (Lpf/gpf)*	6.0/1.6	4.8/1.3	3.0/0.8	
Velocity - Peak Flow (ml/sec)	3500	2000		
Trailing water (% water after solids)	70%	20%		
Flush Contents	Miso/Paper	Paper		
Loadings (grams miso)	300	200	100	0
Clearing Flush Volume (Lpf/gpf)	11.4/3.0	15.1/4.0*	18.9/5.0*	
Frequency of clearing flush	1%	2%*		

*only if necessary

Deliverables from test plan:

1. Prior international studies and some field failures reported recently in Australia, indicate that flush volumes consistent with High Efficiency toilets may result in systemic drainline transport related failures in building drains or sewer lines. This study will evaluate the viability of a low-cost building drain clearing solution: Determine if we can clear over 200 ft of 4" diameter plastic pipe with a flushometer valve or other device set to deliver higher volume discharges at intermittent intervals (1 or 2 percent of flushes).
2. Prior international studies have concluded that toilet hydraulics are a significant factor in drainline transport, specifically pointing to the amount of trailing water as a key factor. This study will determine the role that toilet discharge curves play in drainline transport efficacy in a multi flush sequence and will rank the hydraulic characteristics (percent trailing water and flow rate) of the toilet relative to other variables beyond the control of the toilet design (flush volume and drainline slope).

Lacking from this plan:

1. The impact of various plumbing system geometries. While we may be able to incorporate elbows, junctions, etc. into the test apparatus, this test plan will ultimately only evaluate one simulated system.
2. The impact of systems imperfections (bellies, varying slopes)
3. Some usage and abuse factors, such as paper seat covers and paper towels
4. A determination of where the use of intermittent high volume flush valve would be recommended. This test plan will investigate the viability of the clearing flush solution, but will not provide insight as to specific systems where such a solution may need to be deployed.

Specifically, this effort will allow PERC to issue design recommendations to the construction community regarding the transport potential of single event, high volume clear water surges, thus allowing the use of high efficiency fixtures in long drainline commercial installations and realizing overall water conserving efficiencies. In addition, this work will determine the significance of toilet design as it pertains to multi-flush, real world drainline transport potential. It will do this by evaluating the interactions between the toilet and other system variables and measuring the relative impact of these variables.

Cost: PERC estimates a cost of $170,000 US to conduct this work, as detailed below:

UPDATE: Due to an offer extended to PERC by American Standard Brands, the estimated cost of conducting the above scope of work has been reduced to $73,700.00.

APPARATUS / EQUIPMENT

Labor to build apparatus supports and platform		$	-	Supplied by American Standard Brands
Labor to install piping	135' 4" PVC	$	-	Supplied by American Standard Brands
Material costs (PVC pipe, adjustable support fixtures to allow for slope adjustment)		$	-	Supplied by American Standard Brands
Electronic scale (1) for water discharge		$	-	Supplied by American Standard Brands
Electronic balance (1) for media		$	-	Supplied by American Standard Brands
Shipping costs - equipment and test media		0		
Surge Injectors (3)	$400 each	$	1,200.00	
Misc. (tools, supplies, clean up costs)		$	-	Supplied by American Standard Brands
Disassembly (labor)		$	-	n/a

TEST MEDIA

Miso (12 each 20 Kg buckets)	240 @ $20/kg	$	4,800.00	
Toilet paper	10 @ $100/ case	$	1,000.00	http://www.globalindustrial.com/p/janitorial/bathroom/paper-cleaning-supply/scott-embossed-premium-bathroom-tissue-605-sheets-roll
Misc. (extruder, disp. gloves, hoses, rags)		$	-	

TEST PERSONNEL COSTS

2 Test Engineer (75 days)	600 hr @$50/hr per technician	$	60,000.00	Note: Includes 10 days for assembly and disassembly of apparatus, test runs, etc.; 60 full days total, of which 50 days (8 weeks) for actually running the tests
Per Diem expenses (travel, meals, lodging, etc.)		n/a		
Document search - review		$	-	24 hrs at $150
Report development and preparation		$	3,000.00	Final report & publication/distribution: 20 hrs @ $150
Sub Total		$	70,200.00	
Contingency costs (~5%)		$	3,500.00	
Grand Total		$	73,700.00	

Appendix C – Supporting Materials

(1) SURGE INJECTOR DISCHARGE CURVES

The benefit of using the Surge Injectors over using real toilets was two-fold. Most importantly, the Surge Injectors are more accurate than actual toilets in controlling the flush rate and percent trailing water flush characteristics that were being analyzed in the study. Secondly, the Surge Injectors cannot clog or experience a "short flush", where an incomplete activation of the toilet trip lever results in a partial discharge of water but leaves the solids in the fixture. Such an event would have caused an inconsistency in the test run, risking skewing the results.

The flush curves below detail the discharge characteristics of the Surge Injectors. It should be noted that the flush discharge curves from the Surge Injectors were checked periodically throughout the study to ensure that they remained consistent.

FIGURE AC-A
1.6 GALLON (6.0 L) DISCHARGES
(SLOW FLUSH RATE ON TOP, FAST FLUSH RATE ON BOTTOM)

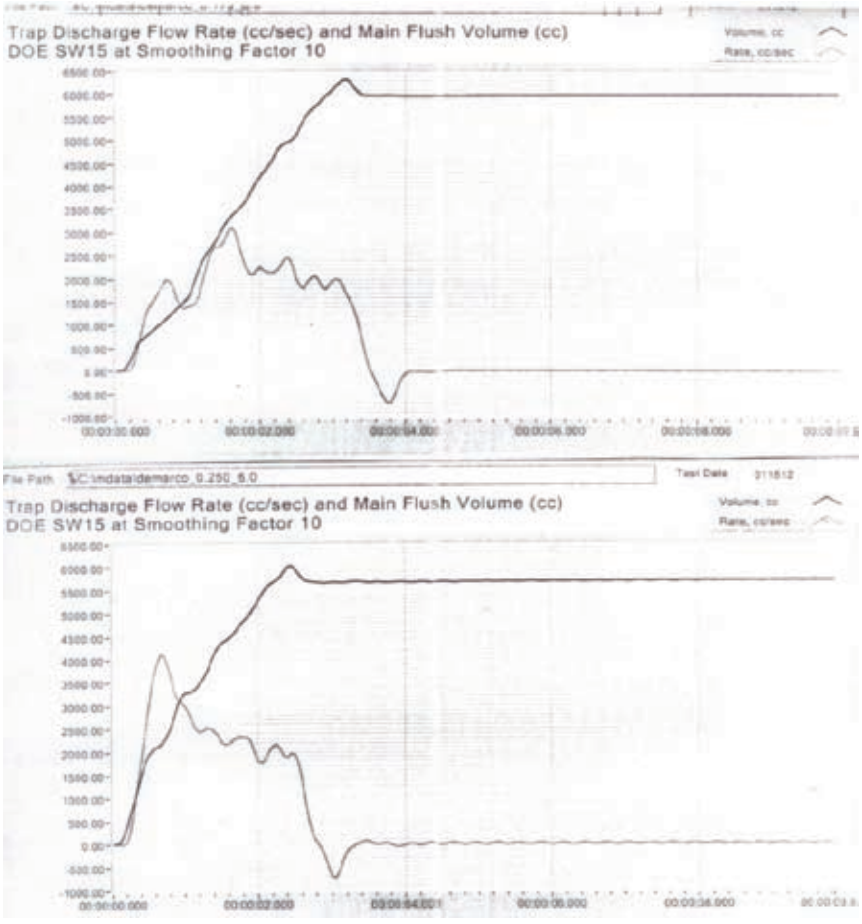


FIGURE AC-B

1.28 GALLON (4.8 L) SURGE INJECTOR DISCHARGES

(SLOW FLUSH RATE ON TOP, FAST FLUSH RATE ON BOTTOM)

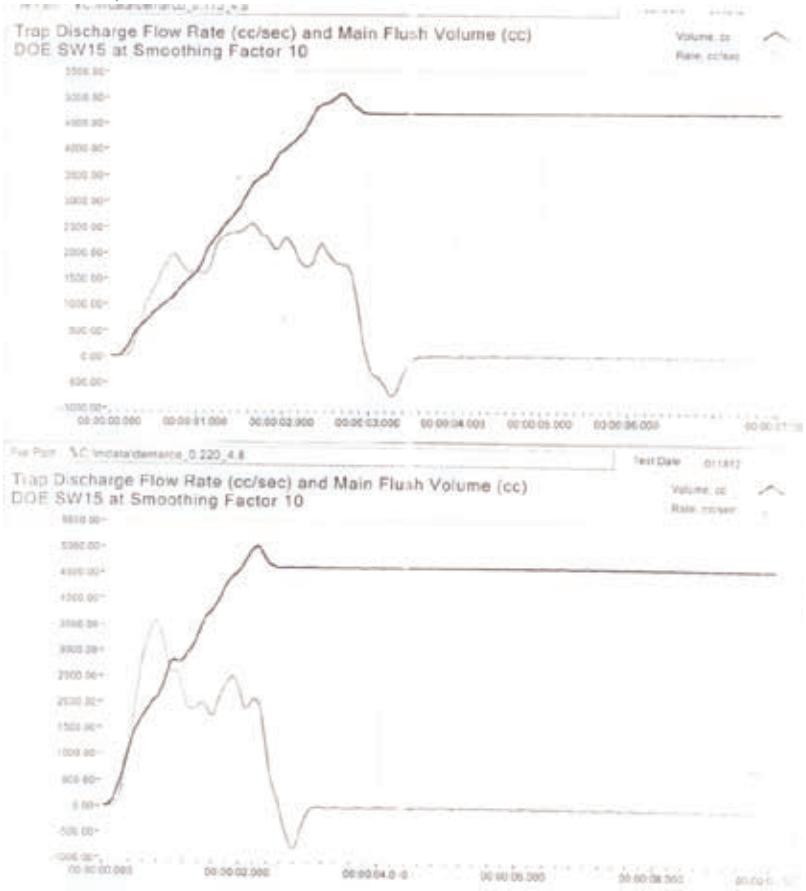


FIGURE AC-C

1.28 GALLON (4.8 L) ACTUAL TOILET DISCHARGE CURVE

(GRAVITY TOILET WITH 3" DIAMETER FLAPPER VALVE (FAST ACTING))

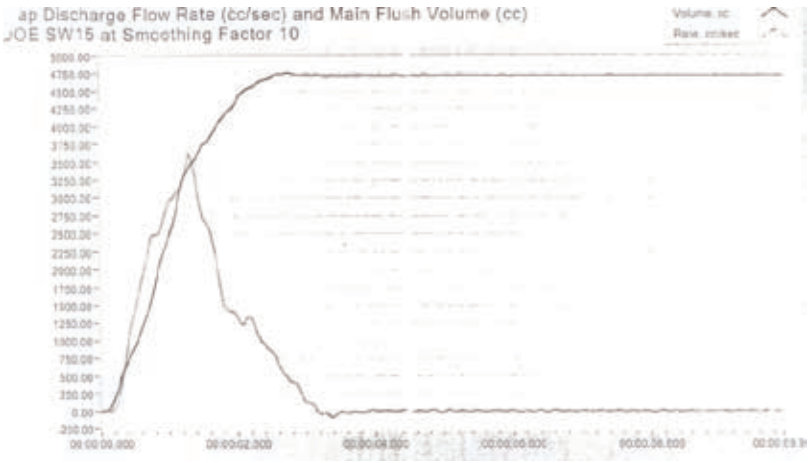
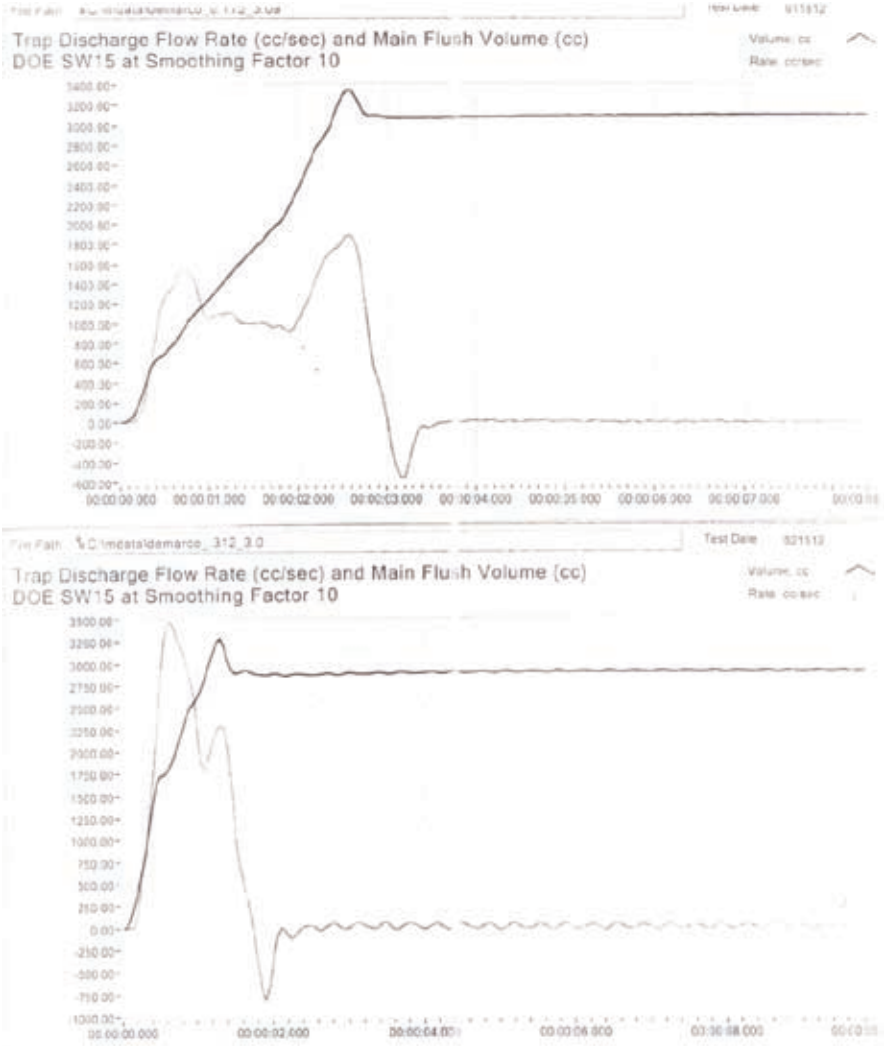


Figure AC-C, above, was generated from an actual 1.28 gpf (4.8 Lpf) toilet. Note that the duration of the flush and the peak flow rate is very similar to the Fast Flush Rate Curve on the bottom of Figure AC-B.

FIGURE AC-D

0.8 GALLON (3.0 L) SURGE INJECTOR DISCHARGES

(SLOW FLUSH RATE ON TOP, FAST FLUSH RATE ON BOTTOM)



(2) CORRELATION OF TOILET PAPER WET TENSILE STRENGTH TO DRAINLINE CARRY DISTANCES

As discussed in the Test Plan section of this report, the PERC TC determined to include specially selected toilet paper into the Test Plan after reviewing a presentation from Dr. Steve Cummings. Table AC-E details the drainline transport distances as reported by Dr. Cummings and the wet tensile strength values determined by the PERC wet tensile strength test.

TABLE AC-E
CORRELATION OF WET TENSILE STRENGTH TO DRAINLINE TRANSPORT DISTANCES IN AUSTRALIAN TOILET PAPERS

Australian Toilet Papers Toilet Paper Properties	Sample #5 (best drainline result)	Sample # 8 (worst drainline result)	Sample # 12 (nearest the average)
Dimensions (1 square)	4" x 4.25"	4" x 4.25"	4" x 4.5"
Ply (single or double)	double	single	double
Tensile Strength Value	9	39	22
DLT Distance with MaP Media (m)	27	11	16
DLT Distance without MaP Media (just paper) (m)[1]	60	38	52
Correlation – DLT Distance to Tensile Strength Value with MaP Media	-0.96		
Correlation – DLT Distance to Tensile Strength Value Without MaP Media	-0.99		

Table AC-F details the correlation between wet tensile strength and drainline transport distances in three (3) U.S. brands of toilet paper, including the two that were selected for the Test Plan.

TABLE AC-F
CORRELATION OF WET TENSILE STRENGTH TO DRAINLINE TRANSPORT DISTANCES IN U.S. TOILET PAPERS

U.S. Toilet Papers Toilet Paper Properties	Brand A	Brand B[2]	Brand C[3]
Dimensions (1 square)	4.125" x 4"	4.125" x 3.75"	4.25" x 4"
Ply (single or double)	double	single	double
Tensile Strength Value	20	1	82
DLT Distance with MaP Media (m)	16	24	11
DLT Distance without MaP Media (just paper) (m)	75	135	45
Correlation – DLT Distance to Tensile Strength Value with MaP Media	-0.91		
Correlation – DLT Distance to Tensile Strength Value Without MaP Media	-0.88		

(FOOTNOTES)

1 *Transport test distances as conducted and reported in a presentation by Dr. Steve Cummings - Operational Performance Boundaries in Drainage Systems, available for download http://www.map-testing.com/assets/files/Cummings-2010-drainlineconnections-toiletpaper.pdf*

2 *Brand B was selected as the low-tensile strength paper for the Test Plan*

3 *Brand C was selected as the high tensile strength paper for the Test Plan*