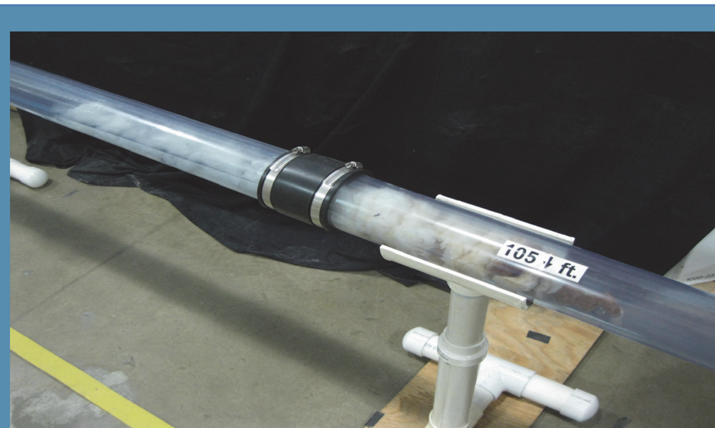
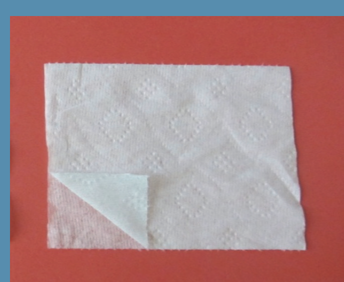
Plumbing
Efficiency
Research
Coalition

The Drainline Transport of Solid Waste in Buildings – Phase 2.0

September 2015


FUNDING PARTNERS

The members of the PERC Executive and Technical Committees would like to express their extreme gratitude to the organizations listed below that made cash or in-kind contributions to the study:

East Bay Municipal Utility District

ASHRAE

Fluidmaster
The IAPMO Group
Kohler Company
Metropolitan Water District of Southern California
Natural Resources Defense Council
Region of Peel, Ontario, Canada
TOTO USA, Inc.
United Association

City of Calgary, Alberta, Canada
Cast Iron Soil Pipe Institute
Delta Faucet Company
Indian Plumbing Association
Plastic Pipe and Fittings Association
San Francisco Public Utilities Commission
Seattle Public Utilities
Southern Nevada Water Authority
World Plumbing Council

Portland Water Bureau

Gauley Associates, Ltd.
VitrA USA, Inc.

IN APPRECIATION

C.J. Lagan, American Standard Brands

American Standard Brands' contributions to this study were again essential to its completion. Their continued partnership with PERC in allowing the study to be conducted at their Design Center in Piscataway, NJ, in providing the materials for the test apparatuses used throughout this study, and in providing for significant labor related savings throughout the study resulted in a well over 50% reduction in cost. Without those cost savings, the PERC studies would not have been possible.

The PERC Technical Committee, especially the technical director of this study, would like to recognize the contributions of Mr. C.J. Lagan, Sr. Manager, Testing and Compliance for American Standard Brands. Mr. Lagan worked tirelessly, assisting in construction the PERC database and the analyzing of data. His strong background in statistics was applied in the development and execution of the designed experiment and was a major asset throughout the program. Mr. Lagan also provided assistance by managing the day-to-day operations of the PERC study, including supervision of the PERC technicians, all in addition to his job related responsibilities.

Robert Schaarschmidt

Mr. Schaarschmidt was the lead technician for both the PERC Phase 1 and PERC Phase 2 studies. An experienced engineering assistant, Mr. Schaarschmidt's commitment to accuracy and detail was critical to the application of the Designed Experiment and the success of both PERC studies.

William Kuru, PhD, Kohler Company

The PERC Technical Committee, especially the technical director of this study, would also like to recognize William Kuru, PhD, Principal Engineer, Applied Technology, Kohler Company. Dr. Kuru provided an independent analysis of the PERC Designed Experiment data and contributed content in this report related to using the standard deviation of test run results as secondary response output (See Additional Findings section).

Peer Review

PERC also wishes to thank the following individuals who participated in the Peer Review of this report. Their time and effort in contributing their insights and expertise is greatly appreciated.

Julius Ballanco, P.E., President, JB Engineering and Code Consulting, P.C.
Dr. Steve Cummings, Research & Development Manager, GWA Group
Bill Gauley, P. Eng., Principal, Gauley Associates Ltd.
Ronald George, President, Plumb-Tech Design & Consulting Services LLC
Kent Sovocool, Senior Conservation Research Analyst, Southern Nevada Water Authority

PERC Executive Committee Representatives

Mary Ann Dickinson, Alliance for Water Efficiency (AWE)
Billy Smith, American Society of Plumbing Engineers (ASPE)
Peter DeMarco, International Association of Plumbing and Mechanical Officials (IAPMO)
Lee Clifton, International Code Council (ICC)
Dr. Gerry Kennedy, Plumbing-Heating-Cooling Contractors National Association (PHCC)
Barbara C. Higgens, Plumbing Manufacturers International (PMI)

PERC Technical Committee Representatives

John Koeller, P.E., AWE
Milt Burgess, P.E., ASPE
Peter DeMarco, Project Technical Director and Lead Author, IAPMO
Lee Clifton, ICC
Charles White, PHCC
Matt Sigler, PMI

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1. EXECUTIVE SUMMARY

Background

Potential blockages in commercial building drain lines have been feared by plumbers and building managers due to increasingly efficient plumbing fixtures. The Plumbing Efficiency Research Coalition (PERC) identified this issue as a critical research need, and undertook an earlier phase of this study to examine the behavior of drain lines under certain conditions. This report is the second part of that study evaluating the characteristics of transport of solid waste in commercial building drains. Since the study is actually in two parts, in order to understand the findings and recommendations contained in this second study installment, it is imperative for readers to first read the PERC Phase 1 final report, *The Drainline Transport of Solid Waste in Buildings*, which was published in November of 2012 and is available for viewing and download at: www.plumbingefficiencyresearchcoalition.org.

The issuance of the PERC Phase 1 report was highly anticipated by a wide spectrum of stakeholders in the Plumbing, Water Utility and Water Efficiency sectors, as it began to provide needed answers to the question of whether or not drain line blockages could regularly occur. The report was presented and well received at numerous industry meetings and conferences. Most notably, the U.S. Environmental Protection Agency (EPA) relied on and cited the PERC report in its Notification of Intent (NOI) to develop a WaterSense specification for commercial toilets and flushometer-valves. The EPA is currently developing that specification.

PERC Phase 2.0 Findings and Conclusions

This section is intended for readers strictly interested in learning only the primary results and implications from this study. The findings and conclusions are presented here in non-technical terms. The body of this report contains a more detailed and technical approach to presenting the data and the findings resulting from this study.

This study had two primary deliverables that were detailed in the PERC Phase 2 Work Plan Proposal used to generate funding. They are characterized below:

Deliverable 1: Assess the Implications of a 4-inch to 3-inch Pipe Diameter Size Reduction on Drainline Transport

Goal: *Evaluate how a pipe size reduction would impact drainline transport performance. Plumbing engineers and other plumbing professionals have been recommending pipe size reductions in the codes as a result of reduced flows for many years. The hypothesis being that a smaller pipe diameter will provide for a higher water flood levels in the pipe, which will better facilitate drainline transport. Phase 2 of the PERC study will show how a commonly suggested pipe size reduction (going from 4-inch diameter pipe to 3-inch pipe) will impact drainline transport.*

The findings from this study's Designed Experiment apply exclusively to a 4-inch to 3-inch Pipe Diameter size reduction and to commercial building drain applications with little or no supplemental water flows to assist the toilet in the drainline transport of solid wastes. No implications should be inferred towards recommendations for Pipe Diameter size reductions, of other diameters, or any other application, such as sewer lines.

Under most of the conditions the PERC Test Plan sought to replicate, reducing Pipe Diameter from 4-inch to 3-inch did not consistently result in improved drainline transport. In addition, an increased potential for chaotic and increasingly variable drainline transport results were noted due to High Tensile Strength Toilet Paper inhibiting airflows in the smaller diameter Test Apparatus. Finally, the excessive use and abuse of toilet paper and other paper products is a serious reality in commercial restrooms. Consequently, PERC finds that a reduction of 4-inch to 3-inch diameter may not reliably improve drainline transport performance in long building drains.

Deliverable 2: Evaluation of a 3.8 Lpf / 1.0 gpf Flush Volume

Goal: *Evaluate a new flush discharge level of 3.8 liters per flush (Lpf) (1.0 gallons per flush (gpf)). The PERC Phase 1 study found that a flush volume of 4.8 Lpf (1.28 gpf) generated good results, similar to that of 6.0 Lpf (1.6 gpf) flush volume results. However, the results at 3.0 Lpf (0.8 gpf) in Phase 1 became chaotic. Conducting tests at the 3.8 liters per flush (Lpf) (1.0 gallons per flush (gpf) flush volume level will provide additional insight into the "tipping point" flush volume level, below which chronic blockage problems are more likely to occur.*

Considering the above two deliverables together, Phase 2 will evaluate how pipe size reduction in a building drain might allow for the successful use of lower consumption toilets in new installations that employ smaller diameter drains. Conversely, it may also provide data that confirms that we are indeed reaching a tipping point where further toilet consumption level reductions are risky in installations that do not provide for significant additional flows into the building drain.

In referring to our primary results as illustrated in the Main Effects and Interval Plot for AFO results and the predictive tools afforded by the software as illustrated in the Surface Plots, a significant decrease in drainline transport performance is noted between the 4.8 Lpf / 1.28 gpf and the 3.8 Lpf / 1.0 gpf Flush Volumes.

Based on these results, PERC does not recommend the use of 3.8 Lpf / 1.0 gpf toilets (or less) in commercial applications that have long horizontal drains and that do not provide additional long duration flows from other sources to assist with the drainline transport of solid waste. This recommendation only applies to the installation conditions noted above and does not apply to residential dwelling unit applications.

Additional Findings

PERC findings as they pertain to the ASME/CSA national standard

The PERC results illustrate that the attributes relating to toilet design and which are manifested in toilet discharge flush curves, do not relate to drainline transport efficacy in long drains (see details in the body of the report). The results from this PERC study will be presented to the ASME/CSA Committees for their consideration regarding the need to retain the existing Drainline Transport Characteristics Test in future versions of the industry standard.

The Importance of Toilet Paper Selection

The PERC Phase 1 and PERC Phase 2.0 reports resoundingly demonstrate that the wet tensile strength of the toilet paper used appears to have profound implications for drainline carry. Indeed in both the PERC reports it was the number one explanatory variable.

PERC thus finds that toilet paper is the most significant test variable in all PERC tests and as such the use high tensile strength paper makes poor transport and clogs more probable in horizontal drains.

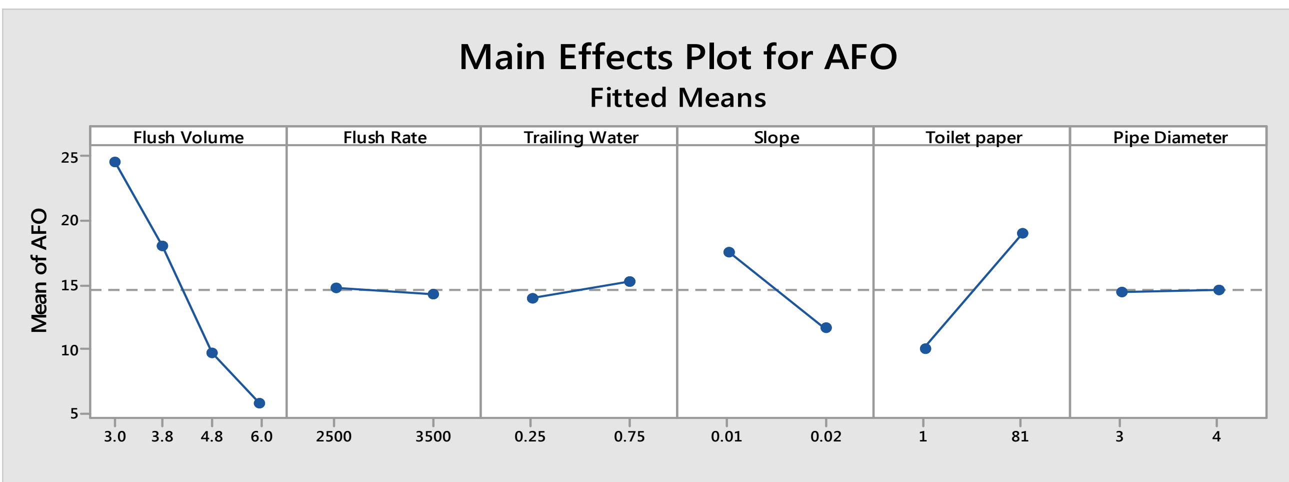
Data Review

This section provides a very basic review of the data used to generate the findings above. The data from both PERC Phase 1 and PERC Phase 2 are combined for the analyses that follow.

Main Effects

The Main Effects Plot shown below in Figure 4-1 is a visual characterization of the results from the PERC Phase 2 Designed Experiment. In reviewing Figure 4-1, the more vertical the line, the more significant the variable. This indicates that while all of the volume reductions are clearly significant, the most significant reduction occurred between the 4.8 Lpf / 1.28 gpf and the 3.8 Lpf / 1.0 gpf levels. In PERC Phase 2.0, Toilet Paper Wet Tensile Strength was the most significant Test Variable at all Flush Volumes.

Figure 4-1, Main Effects Plot, All Data



Surface Plots

A predictive tool that the software utilized throughout this study is able to generate is illustrated by the surface curves shown in Figures 4-6 and 4-7. These surface curves use actual test data to predict Average results at any combination of test variables. With the exception of the test runs conducted at 2 percent slope and employing Low-Tensile Strength Toilet Paper (discussed again later in this section), the surface plots predict significantly worse performance when going from the 4.8 Lpf / 1.28 gpf to the 3.8 Lpf / 1.0 gpf Flush Volumes.

Figure 4-6, Surface Plot for AFO, High Tensile Strength Paper Data Only

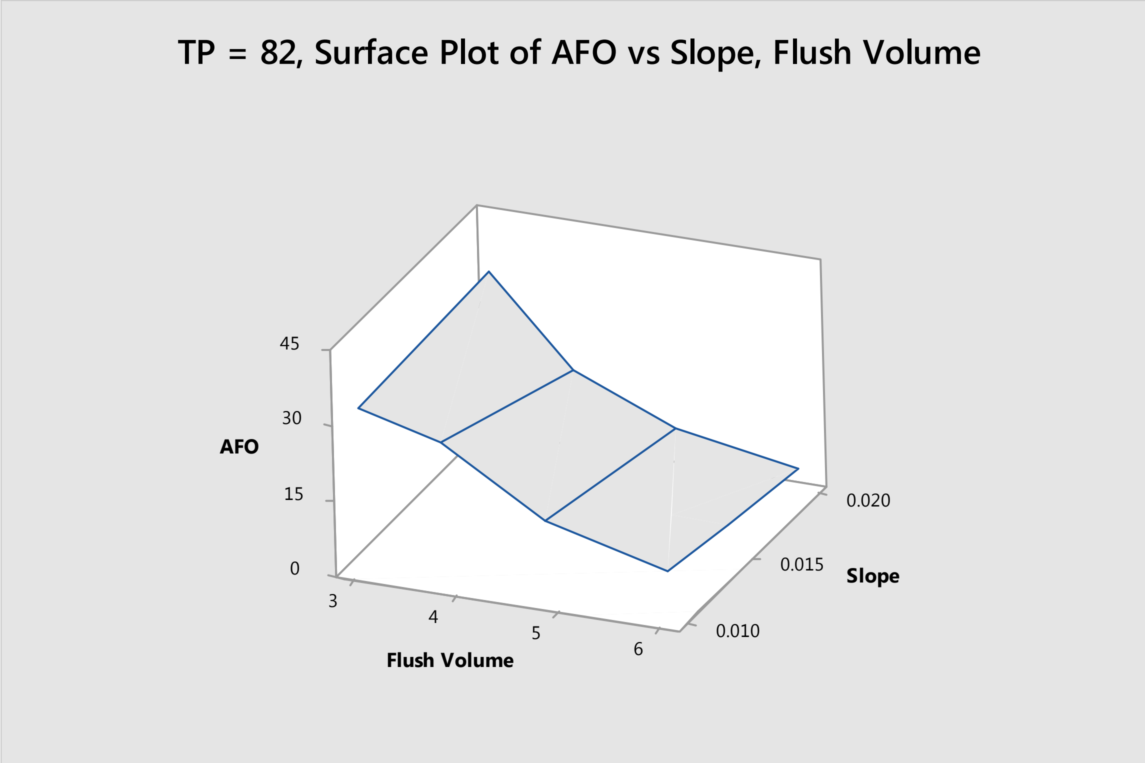
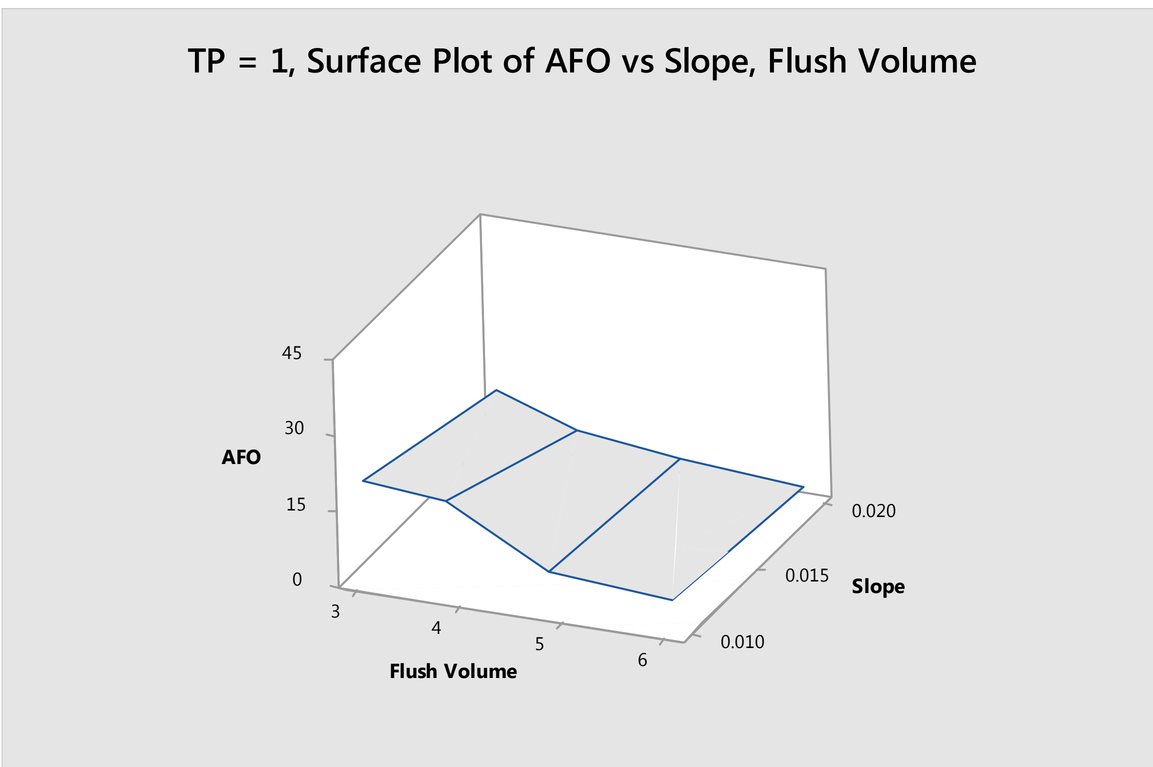


Figure 4-7, Surface Plot for AFO, Low Tensile Strength Paper Data Only



Pipe Diameter

The influence of pipe diameter on drainline transport is perhaps the most important aspect of the PERC Phase 2.0 study. Past research demonstrates the hydraulic advantages of reduced diameter (or reduced cross sectional dimensions in pipes of other than round shape) for improved drainline transport distances.[1] Code change proposals have been submitted to model code agencies in the United States and Canada citing some of these past research efforts and calling for sizing reductions in sanitary building drains in order to improve drainline performance.

Referring back to our Main Effects Plot for all data, shown in Figure 4-1, the Pipe Diameter variable was found to be non-significant with a very high p-value of 0.912. This is discussed in much greater detail in the body of the report.

End of Executive Summary

The PERC Phase 1 and PERC Phase 2.0 reports and all the raw data used to generate the findings and conclusions contained herein are available for download free of charge at: www.plumbingefficiencyresearchcoalition.org.

PERC, of course, expects and welcomes all constructive criticisms.

[1] See Prof. John Swafiled's paper and presentation: "Dry Drains: Myth, Reality or Impediment to Water Conservation" which, while critical of PERC's initial announcement (see PERC 1 Report), this paper provides an excellent recap of key past research efforts including significant findings. 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

2. INTRODUCTION & BACKGROUND

Background

This report is the second part of an extended study on the transport of solid waste in building drains. For a comprehensive understanding of the findings and recommendations contained herein, it is imperative for readers to first read the PERC Phase 1 final report, *The Drainline Transport of Solid Waste in Buildings*, which was published in November of 2012 and is available for viewing and download at www.plumbingefficiencyresearchcoalition.org.

The PERC Phase 1 report contains a thorough discussion on the need for a commercial drainline study, the rationale for and description of the test procedures and data analysis methods that were used, the test apparatus, test equipment, the test media, and the findings and conclusions. Those discussions will not be repeated here.

The PERC Phase 1 study was conducted by developing a multi-factorial designed experiment to analyze drainline transport data, rank the test plan variables for significance, and search for possible interactions among those test plan variables. This method also provided for the interpretation of test variable interactions.

The issuance of the report was highly anticipated by a wide spectrum of stakeholders in the Plumbing, Water Utility and Water Efficiency industries. The report was overwhelmingly well received and, most notably, the U.S. Environmental Protection Agency (EPA) cited the PERC report in its Notification of Intent (NOI) to develop a WaterSense specification for commercial toilets and flushometer-valves. As this report is being written, the EPA is in the final stages of developing that specification.

As to be expected, the PERC Phase 1 report was certainly not without its critics. The report went into great detail about why attempting to replicate "real world" conditions to conduct the testing was problematic, prohibitively expensive, sacrificed accuracy, and would result in findings that would then be limited in application. Still, comments pertaining to the use of PVC pipe rather than Cast Iron and the use of Surge Injectors rather than toilets were the two often most cited criticisms. These issues will be briefly revisited later in this report.

However, the fact that PERC was able to generate the necessary funds to conduct a considerably larger study using the same methodology is testimony that stakeholders found the PERC Phase 1 report to be informative and worthy of further investment.

Introduction to Phase 2.0

Phase 2.0 of this study employs the same methodology as used in PERC Phase 1 and, in fact, builds on and utilizes the PERC Phase 1 database.

All of the data from the PERC Phase 1 study is included in the PERC Phase 2.0 data presented herein. Phase 2.0 adds new data on the 4-inch diameter apparatus used in PERC Phase 1 by conducting a full set of test runs (32) at 3.8 Lpf / 1.0 gpf (which is a new flush volume level not previously studied), and an additional 16 test runs at the 6.0 Lpf / 1.6 gpf flush volume level. Then, all the PERC Phase 1 test runs previously conducted on the 4-inch diameter apparatus were re-run on the 3-inch pipe diameter test apparatus at both the 1 and 2-percent slope test variable settings.

3. TEST PLAN, TEST EQUIPMENT, MATERIALS, TEST MEDIA & TEST PROCEDURES

The deliverables for Phase 2 of this study are shown below exactly as they were detailed in the Phase 2 Work Plan: *"Phase 2 will focus on only two new parameters. The deliverables associated with conducting this work are extremely important towards realizing the implications of reduced pipe sizing in building drains. In addition, the drainline performance of toilets flushing between 4.8 Lpf (1.28 gpf) and 3.0 Lpf (0.8 gpf) will be investigated.*

*"**Deliverable 1 –** As discussed above, plumbing engineers and other plumbing professionals have been recommending pipe size reductions in the codes as a result of reduced flows for many years. Phase 2 of the PERC study will show how a commonly suggested pipe size reduction (going from 4-inch diameter pipe to 3-inch pipe) will impact drainline transport. Additionally, it will rank the significance of reducing pipe diameter to flush consumption level reductions, slope, toilet paper wet tensile strength, and toilet discharge characteristics of flush rate and percent trailing water. As such, the results from Phase 2 will provide needed data in understanding the implications of these pipe size reduction recommendations.*

*"**Deliverable 2 –** Evaluating a new flush discharge level at 3.8 Lpf (1.0 gpf) will provide for a better understanding of how the drainline performs at the critical consumption level between 4.8 Lpf (1.28 gpf) and 3.0 Lpf (0.8 gpf), where drainline performance in Phase 1 became chaotic. This will provide additional insight into the "tipping point" flush volume level, below which chronic blockage problems are more likely to occur.*

"Considering the above two deliverables together, Phase 2 will evaluate how pipe size reduction in a building drain might allow for the successful use of lower consumption toilets in new installations that employ smaller diameter drains. Conversely, it may also provide data that confirms that we are indeed reaching a tipping point where further toilet consumption level reductions are risky in installations that do not provide for significant additional flows into the building drain."

Clearly, these issues are critical towards a better understanding of the performance limits of gravity building drains and will allow for future studies to be developed with an improved understanding of these performance limits.

A copy of the PERC Phase 2 Work Plan appears in **Appendix B** of this report.

Test Variables

The PERC Phase 1 Test Plan was constructed incorporating the test variables of slope, percent trailing water, flush rate, and toilet paper selection based on wet tensile strength, and flush volumes of 6.0 Liters per flush (Lpf) / 1.6 gallons per flush (gpf), 4.8 Lpf / 1.28 gpf and 3.0 Lpf / 0.8 gpf. For PERC Phase 2.0, two (2) new test variables were added: pipe diameter, to support the work associated with Deliverable 1, and a 3.8 Lpf / 1.0 gpf Flush Volume to support Deliverable 2.

Test Equipment

Test Apparatuses – The PERC Phase 1 report provides photos and a schematic drawing that details the materials used to build the 4-inch diameter test apparatus. Other than the diameter of the clear PVC pipe and couplings, the same Bill of materials was used to construct the 3-inch diameter test apparatus. A photo of the PERC test apparatus is also shown on the cover of this report.

Surge Injectors – The PERC Phase 1 report provides a schematic drawing and details the materials used to build the surge injectors that were used in Phase 1 along with a photo of the actual surge injectors used. For Phase 2.0, one new surge injector using the same Bill of Materials was built to accommodate the new 3.8 Lpf / 1.0 gpf flush volume.

"Real World" Conditions – The reviews of the PERC Phase 1 study were overwhelmingly positive. The most often cited criticisms of the Phase 1 study were that the smooth, clear PVC pipe employed in the Test Apparatus and the use of Surge Injectors rather than actual toilets do not reflect 'real world' conditions.

According to commenters, the use of other pipe materials, preferably used cast iron soil pipe that had been previously installed and exhibited degradation through corrosion, would have provided a more realistic and worst-case condition for this study. Would the results change if other piping material was selected? While initially cast iron soil pipe has a rougher wall, examination of horizontal cast iron installed for a period of time has shown that the inside wall of the pipe has a smoother surface than when first installed. This is created by build-up that smoothens the inside wall. For this reason, there are more accurate results with the use of smooth wall pipe.

In addition, the Average Flushes to Out (AFO) data results, which are used to generate most of this study's findings, would have been considerably higher across the full spectrum of testing under such test conditions. The movement of the test media in the apparatus would have been greatly influenced by the higher and inconsistent coefficient of roughness in the pipe rather than being influenced by the incremental reduction of flush volume, changes in slope, and the wet tensile strength of toilet paper. We believe this would have substantially masked the significance (or non-significance) of all the important test variables.

It is important to recognize that both PERC Phase 1 and PERC Phase 2 are studies of drainline transport. Neither report is a study of water closet performance. Water closet performance and initial drainline transport is something that water closet manufacturers have studied for their various models of water closets. For this reason, Surge Injectors are used to introduce the test media to the drain. This approach resulted in several important advantages, such as accuracy and consistency of flush volumes, flush rates, and percent trailing water to a degree impossible to attain if actual toilets were used.

The PERC approach is unique when compared to other studies and research efforts on drainline transport. The PERC studies do not attempt to be informative on how far a toilet using a given flush volume will transport solid waste in a building drain. Rather, the studies rely on the precise control of variables in an ideal test apparatus and the measured movement of test media in the apparatus such that the influence of those variables on drainline transport can be better understood. Using this approach, the PERC Test Plan provides a scientific approach that seeks to predict an efficacy tipping point for commercial installations with long horizontal building drains relatively free of major design, installation or age related defects.

Test Media

Simulated Solid Waste Test Media – It is essential to employ the same test methods and materials employed in PERC Phase 1; as such, uncased MaP[2] test media was again used to simulate solid waste. MaP media is comprised of soybean paste, a food product typically used in Japanese cuisine, extruded into approximately ¾-inch diameter cylinders, each 4 inches in length (20mm and 100mm, respectively) and weighing 50 grams each (approximately 1.8 oz. each).

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

In addition, four (4) crumpled balls of high tensile strength toilet paper, each consisting of six (6) sheets, for a total of 24 sheets of paper, and eight (8) balls of six (6) sheets each, a total of 48 sheets of low tensile strength paper were used along with the MaP test media. Photos of the test media are appear in the PERC Phase 1 report and are shown on the cover of this report.

Test Procedure

The test procedure and designed experiment detailed in the PERC Phase 1 report were again applied throughout PERC Phase 2.0. Using the 4-inch diameter apparatus employed in PERC Phase 1, a full set of test runs (32) at 3.8 Lpf / 1.0 gpf (the new flush volume level) were conducted and an additional 16 test runs were conducted at the 6.0 Lpf level, employing low tensile strength toilet paper. All of the test runs conducted on the 4-inch diameter apparatus were then re-conducted on the 3-inch pipe diameter test apparatus in randomized test order. All of this work accounts for 128 unique test runs, 64 each on the 4-inch and 3-inch diameter apparatuses, and a total of 12,800 injections that were captured throughout the PERC Phase 1 and PERC Phase 2 studies.

4. DATA REVIEW

The PERC Phase 1 and PERC Phase 2.0 reports and all the raw data used to generate the findings and conclusions contained herein are available for download free of charge at: www.plumbingefficiencyresearchcoalition.org.

As mentioned previously, the data from both Phase 1 and 2 are combined for the analyses that follow.

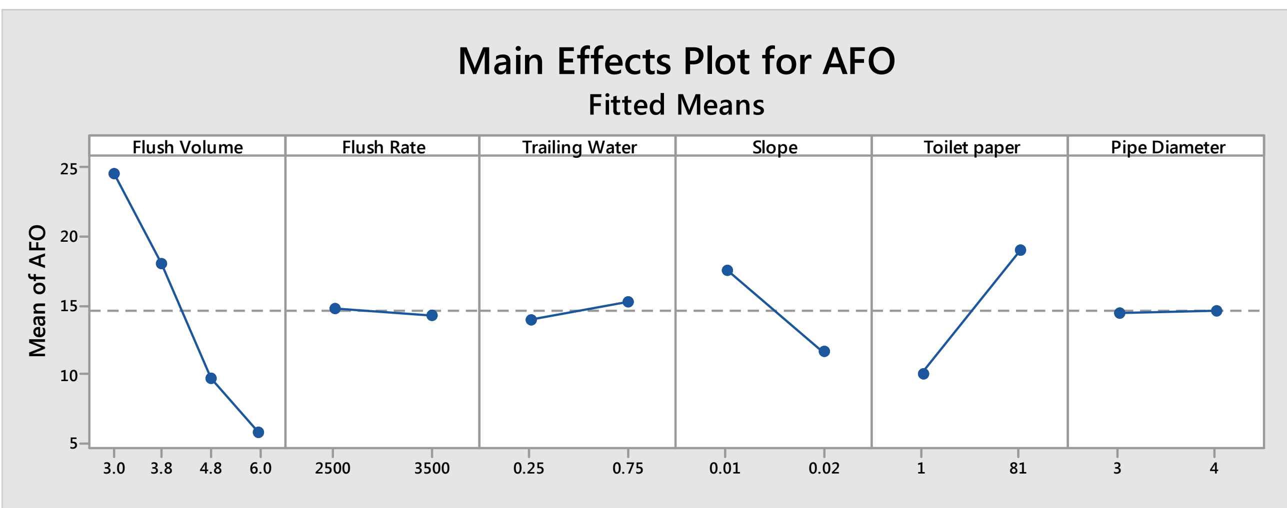
Main Effects

The Main Effects Plot for the entire data set is shown in Figure 4-1. As found in PERC Phase 1, Flush Volume, Slope and Toilet Paper remain clearly significant. Due to the strength of the PERC Phase 1 findings, this was expected.

In reviewing the Main Effects Plots, remember that the more vertical the line, the more significant the variable. Note that the most vertical part of the Flush Volume plot occurs between the 4.8 Lpf / 1.28 gpf and 3.8 Lpf / 1.0 gpf data points. This indicates that while all of the volume reductions are clearly significant, the most significant reduction occurred between the 4.8 Lpf / 1.28 gpf and the 3.8 Lpf / 1.0 gpf levels.

Conversely, note that the slope is least vertical between the 6.0 Lpf / 1.6 gpf and 4.8 Lpf / 1.28 gpf values, indicating that this reduction was the least significant of the Flush Volume reductions in our study. Additional discussion on this issue will follow.

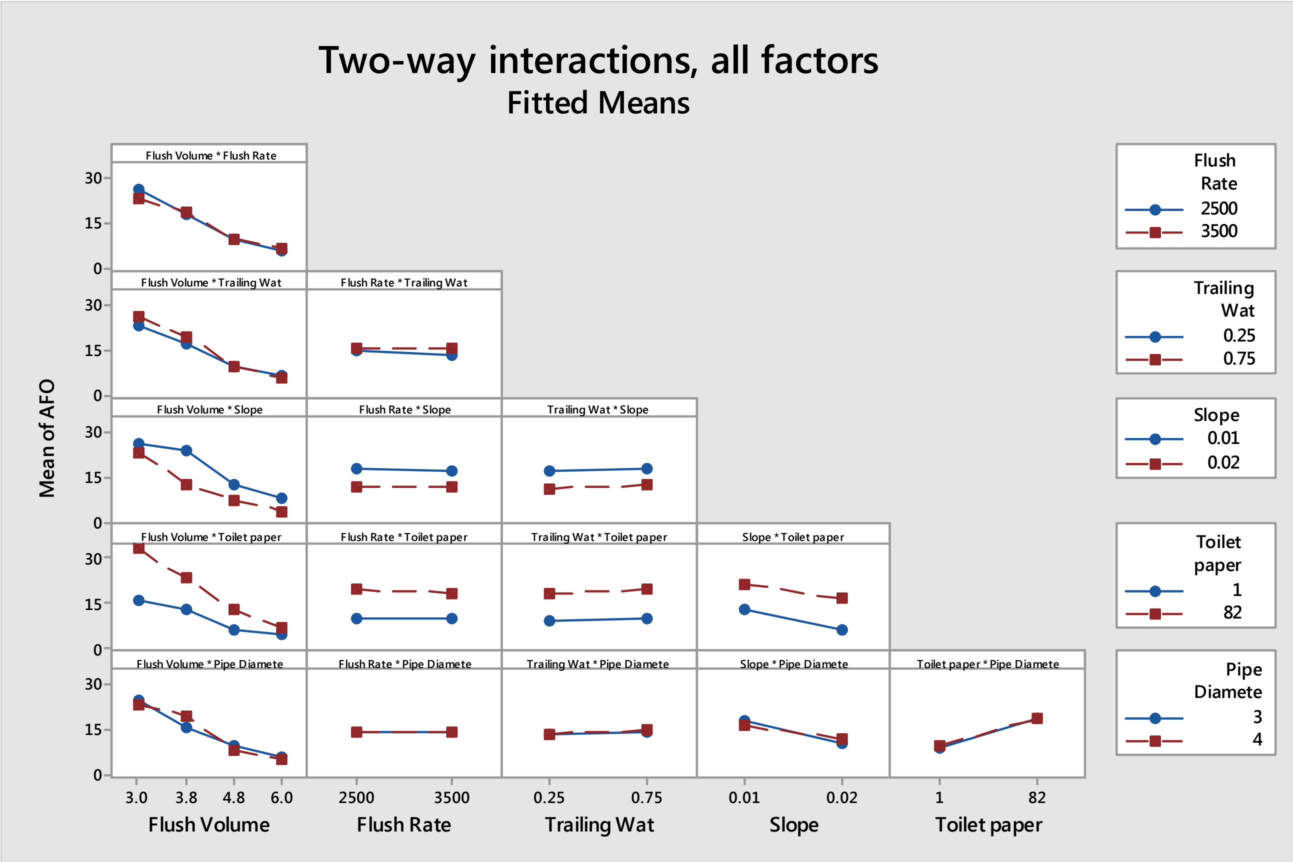
Figure 4-1, Main Effects Plot, All Data



Two-Way Interactions

The interaction plot in Figure 4-2 takes both significant and non-significant factors into account. Note that when all variables and interactions are factored in, regardless of significance, no strong interactions are indicated (by crossing lines) but there are indications of mild interactions between Pipe Diameter and Slope and between Pipe Diameter and Flush Volume, with lines crossing at the 3.8 Lpf / 1.0 flush volume consumption level.

Figure 4-2, Two-way Interactions Plot, All Data



However, when the data is recalculated using a reduced model[3] ANOVA analysis (See Table 4-1) significant interactions between Volume and the factors of Slope, Paper, and Pipe Diameter become apparent, as indicated by low p-values, highlighted in green. Slope and Pipe Diameter interaction also appears significant. These interactions are discussed under "Additional Observations" later in this report. However, it is important to note that Pipe Diameter by itself is clearly non-significant, with a p-value of 0.912 (highlighted in yellow below), far exceeding the threshold for significance of 0.05, shown highlighted in yellow below.

The adjusted R-square value over 85.2 percent indicates that the test plan indeed captured most (85%) of the major factors (test variables) that account for the movement of test media through the apparatus.

[3] "Reduced model" means the results are calculated using only significant factors, the non-significant factors being disregarded. Interaction Plots, such as Figure 4-3, cannot be generated using reduced models.

Table 4-1, General Factorial Regression: AFO versus Flush Volume, Flush Rate, Trailing Water, Slope, Toilet Paper

Factor	Levels	Values
Flush Volume	4	3.0, 3.8, 4.8, 6.0 (Lpf)
Slope	2	0.01, 0.02 (degrees slope)
Toilet paper	2	1, 82 (low and high tensile strength)
Pipe Diameter	2	3, 4 (nominal pipe diameter, inches)

Stepwise Selection of Terms

α to enter = 0.05, α to remove = 0.05

The stepwise procedure added terms during the procedure in order to maintain a hierarchical model at each step.

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Model	16	12214.7	763.42	46.59	0.000
Linear	6	10744.6 1	790.76	109.30	0.000
Flush Volume	3	6964.1	2321.36	141.68	0.000
Slope	1	1097.2	1097.24	66.97	0.000
Toilet paper	1	2682.4	2682.38	163.72	0.000
Pipe Diameter	1	0.9	0.87	0.05	0.912
2-Way Interactions	10	1470.1	147.01	8.97	0.000
Flush Volume*Slope	3	285.8	95.27	5.81	0.001
Flush Volume*Toilet paper	3	917.0	305.68	18.66	0.000
Flush Volume*Pipe Diameter	3	164.4	54.80	3.34	0.016
Slope*Pipe Diameter	1	102.9	102.88	6.28	0.010
Error	111	1818.7 1	6.38		
Total	127	14033.4			

Model Summary

S	R-sq	R-sq (adj)	R-sq (pred)
4.0325	87.09%	85.23%	82.83%

Response Table for Means

Tables 4-2, 4-3 and 4-4, Response Table for Means, show numeric values for each of the Test Plan variables, which allows for discrete ranking of the PERC Phase 2 test variables. This is a calculated grouping of 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 Table 4-2, the second column (Volume), all 3.0 Lpf / 0.8 gpf test runs averaged an AFO score of 24.68, shown as the Level 1 value, and the 3.8 Lpf / 1.0 gpf test runs averaged an AFO score of 18.11, shown as the Level 2 value. This yields a delta of 6.57. Significance of the variables can then be ranked by the relative difference in the delta values in the bottom row.

In PERC Phase 2.0, Toilet Paper Wet Tensile Strength was the most significant Test Variable at all Flush Volumes. Note that in Table 4-4, the Flush Volume variable (showing the difference between the 6.0 Lpf (1.6 gpf) and the 4.8 Lpf (1.28 gpf) Flush Volumes), falls from second in significance to third, behind Slope. This again illustrates that this flush volume reduction is the least significant of the three Flush Volume reductions, implying a lower relative level of risk.

Table 4-2, Response Table for Means
Volume: 3.0 Lpf (0.8 gpf) to 3.8 Lpf (1.0 gpf)

Level	Volume	Flush Rate	%Trailing Water	Slope	Toilet Paper	Pipe Diameter
1 (3.0 Lpf)	24.68	14.77	13.93	17.45	9.94	14.44
2 (3.8 Lpf)	18.11	14.28	15.11	11.59	19.10	14.60
Delta	6.57	0.49	1.18	5.86	9.16	0.16
Significance Rank	**2**	**5**	**4**	**3**	**1**	**6**

Table 4-3, Response Table for Means
Volume: 3.8 Lpf (1.0 gpf) to 4.8 Lpf (1.28 gpf)

Level	Volume	Flush Rate	%Trailing Water	Slope	Toilet Paper	Pipe Diameter
1 (3.8 Lpf)	18.11	14.77	13.93	17.45	9.94	14.44
2 (4.8 Lpf)	9.56	14.28	15.11	11.59	19.10	14.60
Delta	8.55	0.49	1.18	5.86	9.16	0.16
Significance Rank	**2**	**5**	**4**	**3**	**1**	**6**

Table 4-4, Response Table for Means
Volume: 4.8 Lpf (1.28 gpf) to 6.0 Lpf (1.6 gpf)

Level	Volume	Flush Rate	%Trailing Water	Slope	Toilet Paper	Pipe Diameter
1 (4.8 Lpf)	9.56	14.77	13.93	17.45	9.94	14.44
2 (6.0 Lpf)	5.75	14.28	15.11	11.59	19.10	14.60
Delta	3.81	0.49	1.18	5.86	9.16	0.16
Significance Rank	**3**	**5**	**4**	**2**	**1**	**6**

Tables 4-5 and 4-6, the Response Tables for Means from the PERC Phase 1 study follow. Keep in mind the PERC Phase 1 Test Plan included neither the Pipe Diameter test variable nor the 3.8 Lpf (1.0 gpf) Flush Volume test variable. Also, note that the ranking of the Test Plan variables changed considerably from PERC Phase 1 to PERC Phase 2.0 due mostly to inclusion of the 3" Pipe Diameter apparatus and the increased influence of toilet paper in the 3-inch test apparatus (discussed later in this report).

Table 4-5, PERC 1 Response Table for Means
Volume: 4.8 Lpf (1.28 gpf) to 6.0 Lpf (1.6 gpf)

Level	Volume	Flush Rate	%Trailing Water	Slope	Paper
1 (4.8 Lpf)	8.710	7.567	7.535	9.671	6.104
2 (6.0 Lpf)	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**

Table 4-6, PERC 1 Response Table for Means
Volume: 3.0 Lpf (0.8 gpf) to 4.8 Lpf (1.28 gpf)

Level	Volume	Flush Rate	%Trailing Water	Slope	Paper
1 (3.0 Lpf)	24.50	7.567	7.535	9.671	6.104
2 (4.8 Lpf)	8.710	7.567	7.535	9.671	6.104
Delta	15.79	0.849	0.913	3.360	2.831
Significance Rank	**1**	**5**	**4**	**2**	**3**

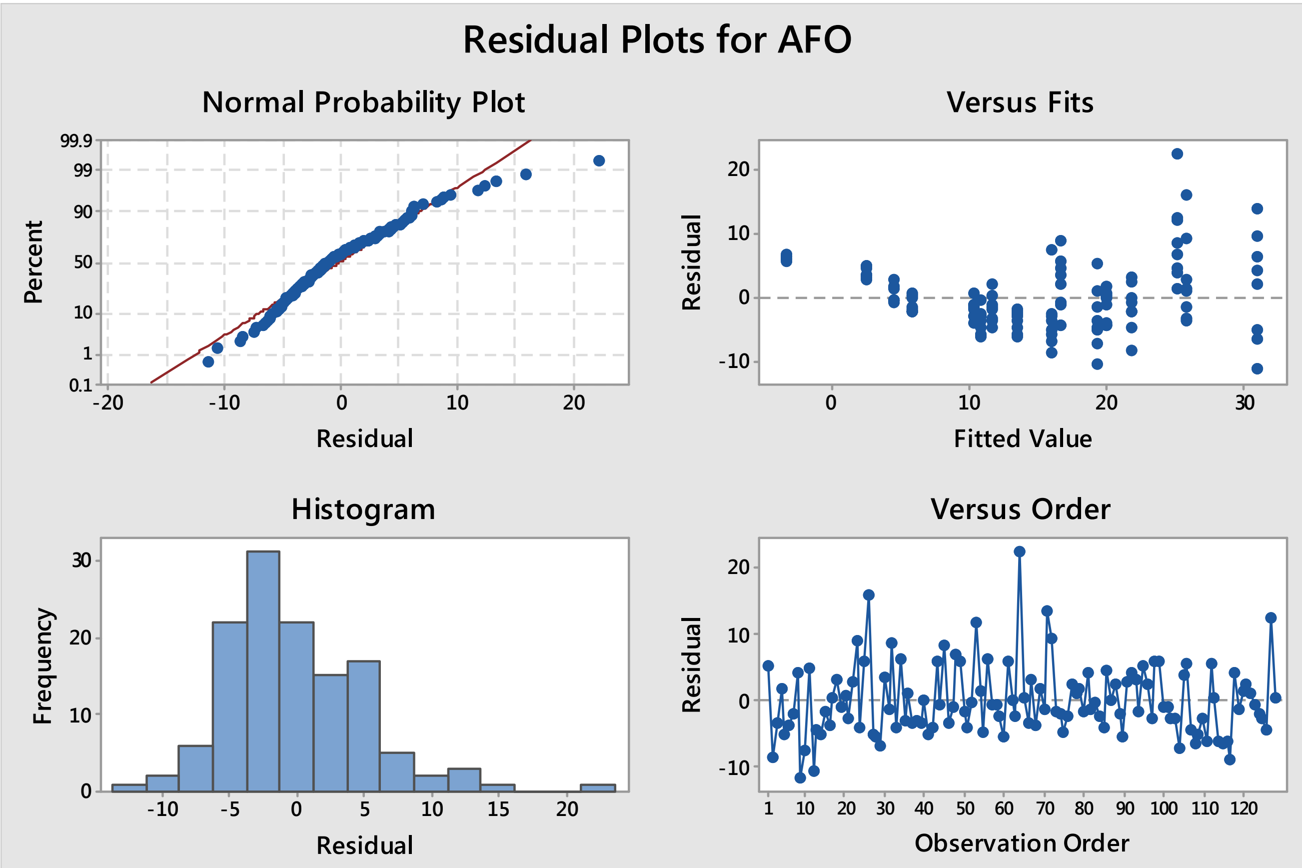
As stated in the PERC Phase 1 report, every real world building drain has its own unique set of conditions, consequently, the PERC Technical Committee cautions against basing any plumbing system design decisions on the discrete rankings of these test variables.

Regression Analysis

One of the software tools available to statistically analyze PERC data is a regression model. A regression model is the equation of the best-fit line through all of our data. Given this equation, the software plugs in different factors to predict an Average Flushes to Out (AFO) score under any combination of significant test variables. The “goodness of fit” tests for regression equations are illustrated in the Residual Plots for AFO shown below. As the name implies, residuals plots are generated using data residuals. A residual is simply the distance a data point is from a best-fit line (see the definition of terms in **Appendix B**). The most telling of the 4 plots below are the Normal Probability Plot and the Histogram of residuals.

On the Residual Plots for AFO shown in Figure 4-4 below, which uses data residuals as the basis of determining fit, the data points do not follow a straight line particularly well, and the histogram does not show good bell curve distribution. This indicates the regression residuals do not appear to be normally distributed, indicating the need for a transformation of the regression model. A transformation is used to develop an equation of a line (regression model) when the data being analyzed is not particularly linear. In other words, there are likely relationships between the variables, such as a square root function or a log function, and the regression model needs to be adjusted to take these into account.

Figure 4-3, Residual Plots for AFO



Note the resulting 73.8% adjusted R-square result using this mathematical model, highlighted in yellow.

Table 4-7 Regression Analysis: AFO versus Flush Volume, Slope, Paper

```
Stepwise Selection of Terms
α to enter = 0.15, α to remove = 0.15
Analysis of Variance

Source           DF  Adj SS   Adj MS  F-Value  P-Value
Regression        3   10443  3480.96   120.22    0.000
  Flush Volume    1    6663  6663.27   230.12    0.000
  Slope           1    1097  1097.24    37.89    0.000
  Toilet paper    1    2682  2682.38    92.64    0.000
Error           124    3590    28.96
Total           127   14033

Model Summary

      S      R-sq          R-sq(adj)  R-sq(pred)
5.38102      74.37%        73.75%     72.62%

Coefficients
Term             Coef  SE Coef  T-Value  P-Value   VIF
Constant        46.90     2.44    19.18    0.000
Flush Volume   -6.428    0.424   -15.17    0.000  1.00
Slope          -585.6     95.1    -6.16    0.000  1.00
Toilet paper   0.1130   0.0117     9.54    0.000  1.00

Regression Equation
AFO = 47.05 - 6.414 Flush Volume - 594.1 Slope + 0.1134 Toilet paper
```

When allowing the software to transform the regression equation using a natural log function, the result is a much better probability fit and a better bell curve distribution on the histogram plot below. Note that the adjusted R-square value increases to 86.6 percent. Thus, due to the strength of the data that was accumulated in the PERC Phase 1 and PERC Phase 2.0 studies, the software can predict, with an acceptable level of accuracy, Average Flushes to Out (AFO) scores for any combination of test variables.

Figure 4-4, Residual Plot for AFO (transformed)

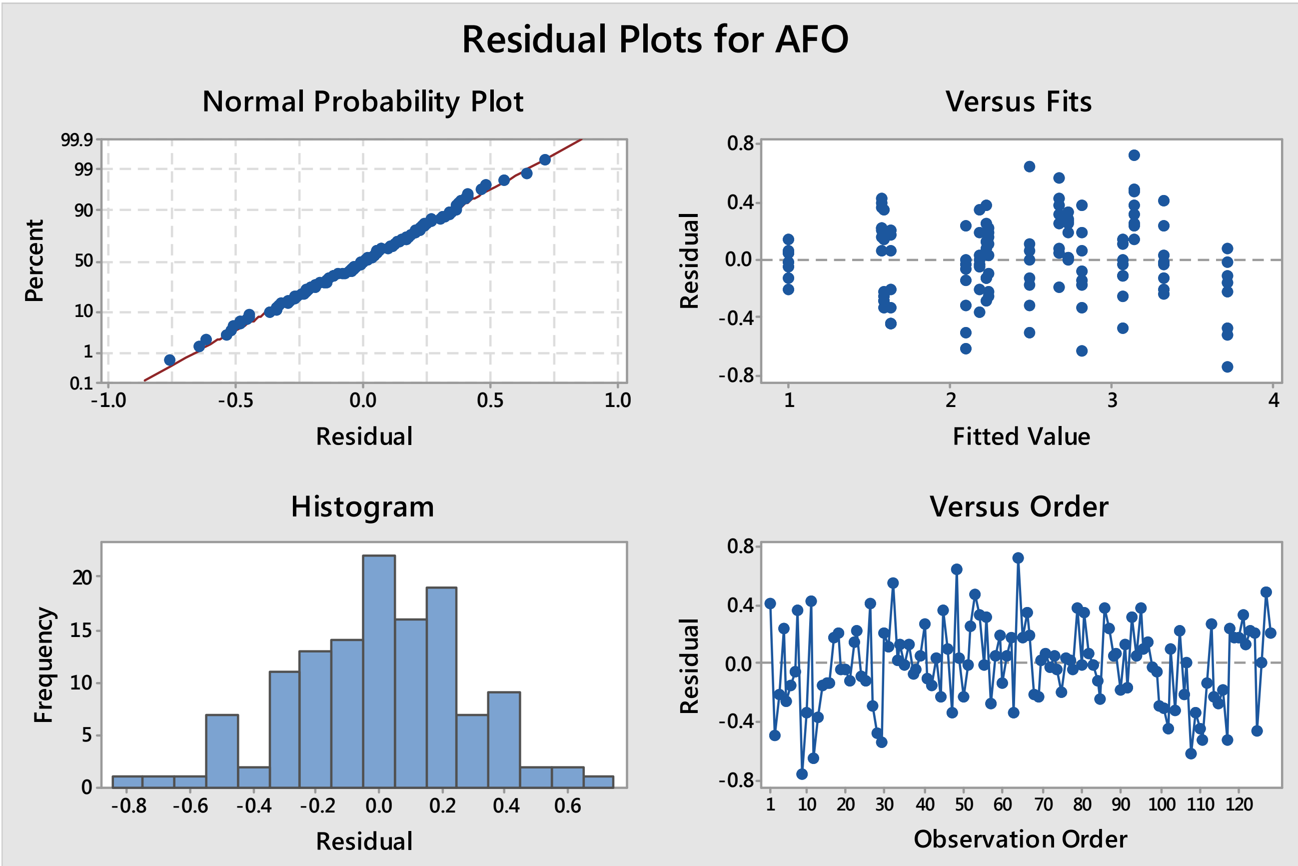


Table 4-8, Regression Analysis: AFO versus Flush Volume, Slope, Toilet Paper…

```
Method

Box-Cox transformation
Rounded λ              0
Estimated λ            0.000356252
95% CI for λ           (-0.135144, 0.137856)

Analysis of Variance for Transformed Response

Source           DF  Adj SS   Adj MS  F-Value  P-Value
Regression        3  65.477  21.8255   274.26    0.000
  Flush Volume    1  40.989  40.9891   515.08    0.000
  Slope           1  10.689  10.6890   134.32    0.000
  Toilet paper    1  13.798  13.7985   173.39    0.000
Error           124   9.868   0.0796
  Lack-of-Fit    12   3.723   0.3102     5.65    0.000
  Pure Error    112   6.145   0.0549
Total           127  75.344

Model Summary for Transformed Response

   S       R-sq     R-sq(adj)  R-sq(pred)
0.282097  86.77%     86.45%      85.89%

Coefficients for Transformed Response
Term              Coef   SE Coef  T-Value  P-Value   VIF
Constant         5.152     0.128    40.20    0.000
Flush Volume   -0.5041    0.0222   -22.70    0.000  1.00
Slope           -57.80      4.99   -11.59    0.000  1.00
Toilet paper  0.008107  0.000616    13.17    0.000  1.00

Regression Equation
ln(AFO) = 5.152 - 0.5041 Flush Volume - 57.80 Slope + 0.008107 Toilet paper
```

Another predictive tool that the ANOVA software is able to generate is illustrated by the surface curves shown in Figures 4-6 and 4-7. These surface curves do not use residuals, but rather use actual test data to predict AFO values at any combination of test variables. Even more interesting is that the curves show predicted AFO scores at test variable values between the actual test variables values that were used in the study. For example, note that the Z-axis predicts AFO values for a 1.5% slope. Two surface plots are shown, one for high tensile strength paper and one for low tensile strength paper.

With the exception of the test runs conducted at 2 percent slope and employing Low-Tensile Strength Toilet Paper (discussed again later in this section), the surface plots predict significantly worse performance when going from the 4.8 Lpf / 1.28 gpf to the 3.8 Lpf / 1.0 gpf Flush Volumes.

Photo 4-1, Paper Accumulation Resulting in Full Pipe Condition, 3.8 Lpf / 1.0 gpf Flush Volume Test Run, 3-inch Diameter Apparatus

Figure 4-5, Surface Plot for AFO, High Tensile Strength Paper Data Only

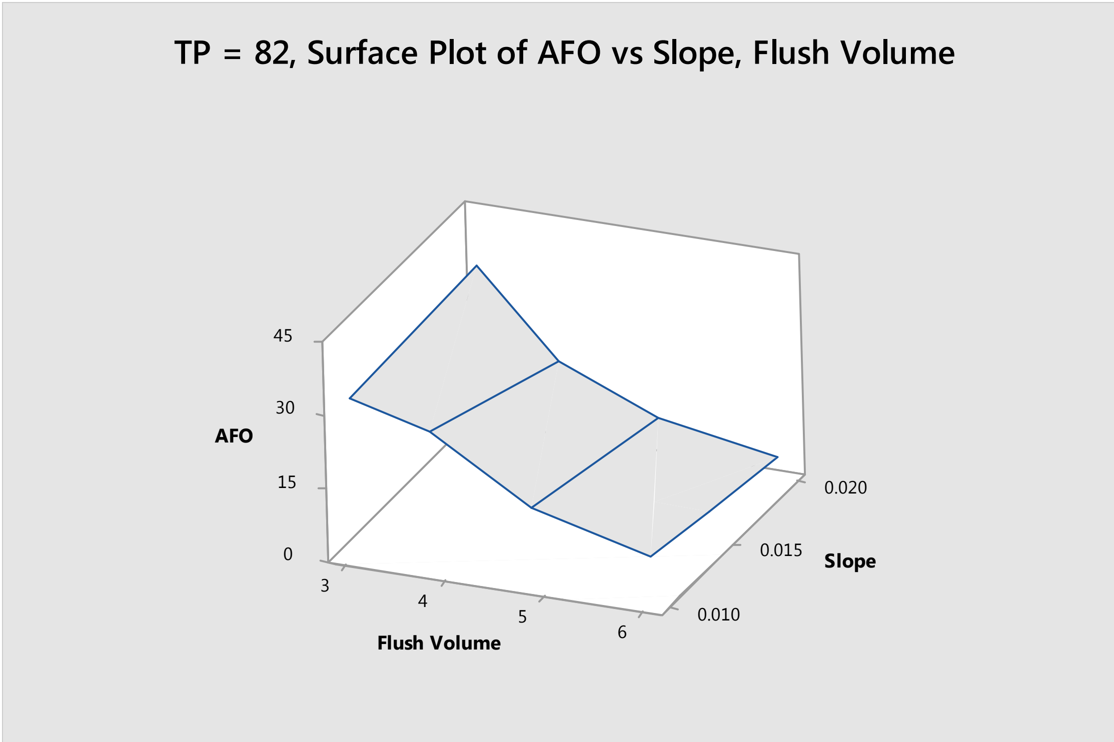
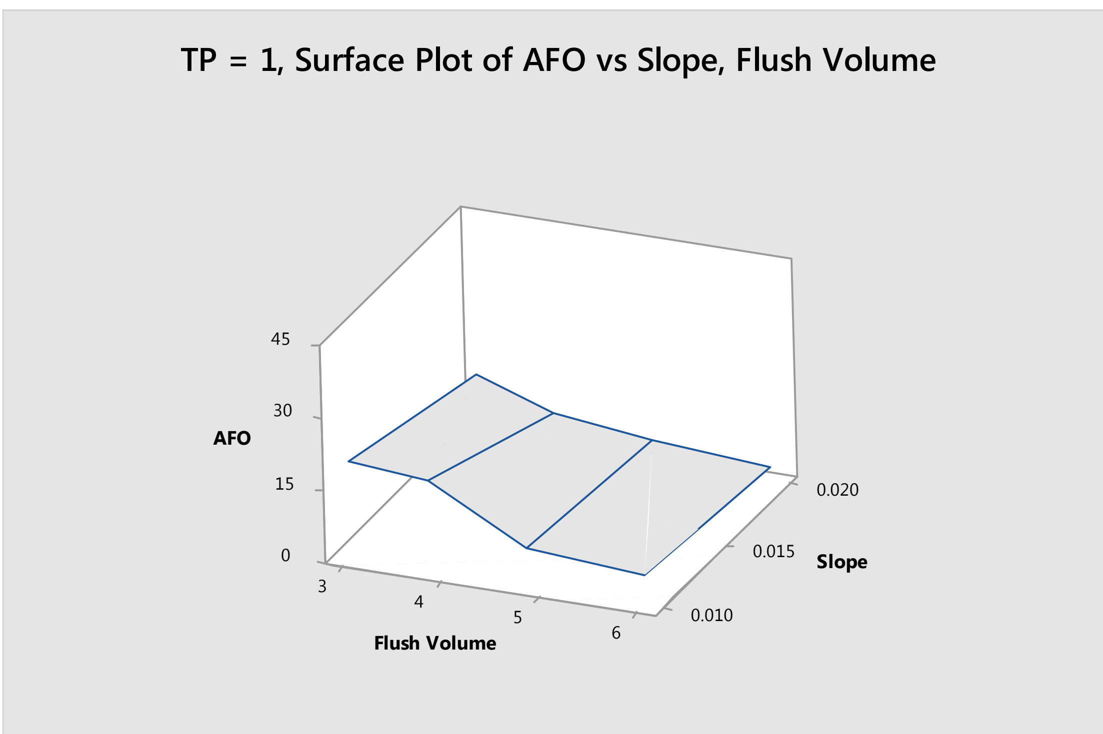


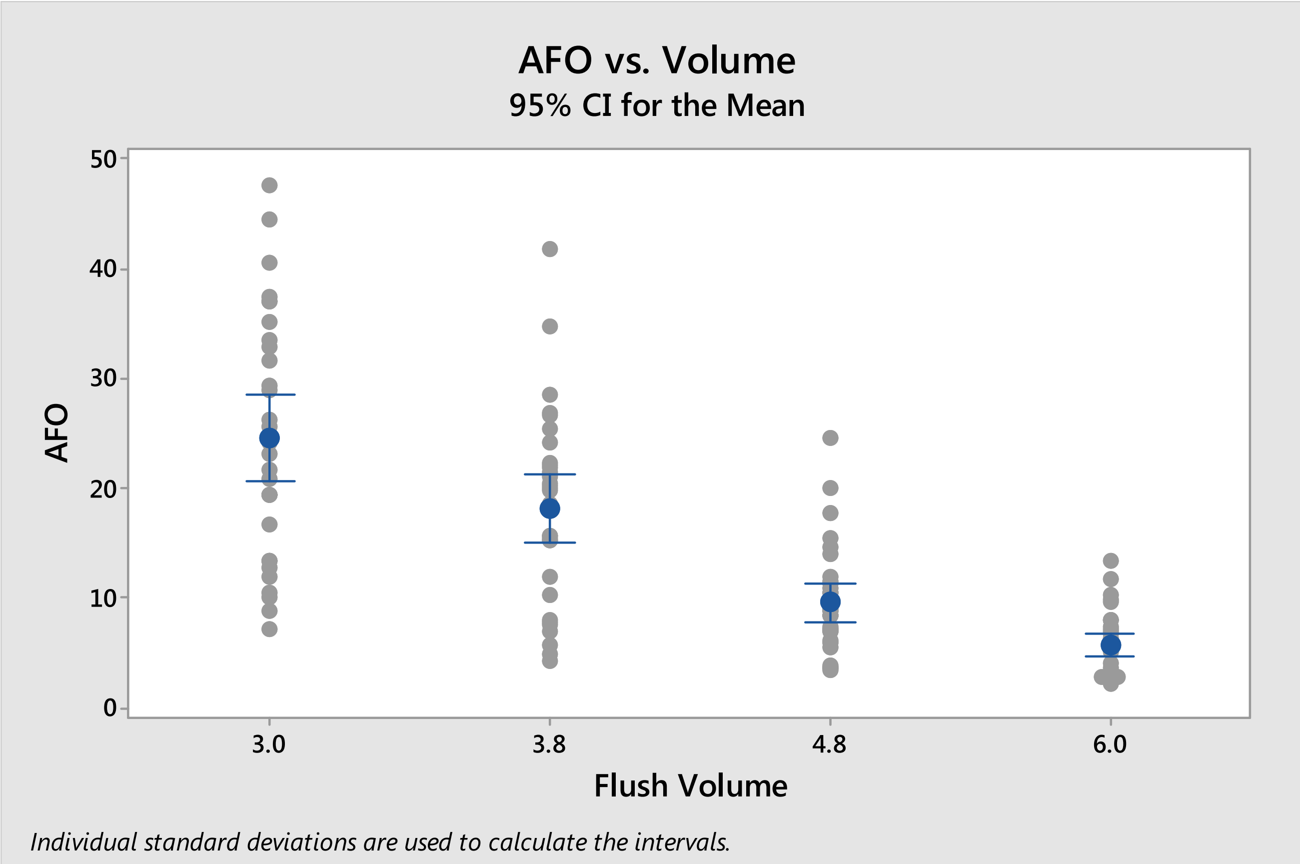
Figure 4-6, Surface Plot for AFO, Low Tensile Strength Paper Data Only



Confidence Intervals

The confidence interval plot in Figure 4-7 offers further evidence of the significant difference between the 4.8 Lpf / 1.28 gpf and the 3.8 Lpf / 1.0 gpf results. Confidence Interval Plots illustrate, in this case with 95% confidence that the average AFO scores at the four (4) different flush volume levels, will fall between the two (2) horizontal blue lines. Note the gap between intervals on the 4.8 Lpf 1.28 gpf and the 3.8 Lpf / 1.0 gpf results and the overlap between the 3.8 Lpf / 1.0 gpf and 3.0 Lpf / 0.8 gpf results. Additional discussion on the significance between the 4.8 Lpf / 1.28 gpf and the 3.8 Lpf / 1.0 gpf results follow later in this section.

Figure 4-7, Confidence Interval Plot, All Data



Pipe Diameter

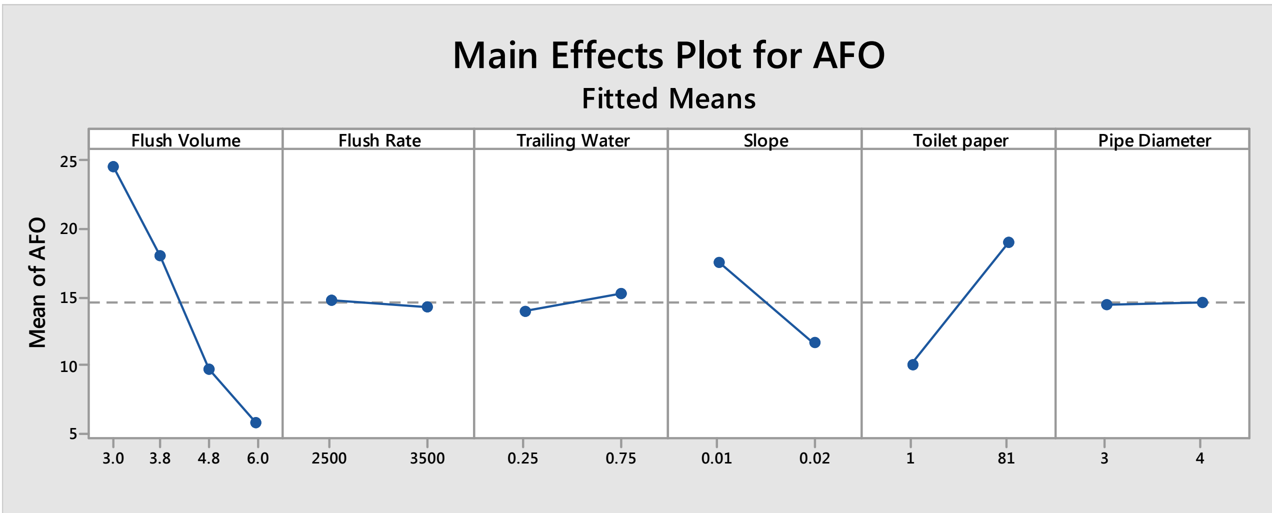
The influence of pipe diameter on drainline transport is perhaps the most important aspect of the PERC Phase 2.0 study. Past research demonstrates the hydraulic advantages of reduced diameter (or reduced cross sectional dimensions in pipes of other than round shape) for improved drainline transport distances.[4] Code change proposals have been submitted to model code agencies in the United States and Canada citing some of these past research efforts and calling for sizing reductions in sanitary building drains in order to improve drainline performance.

This PERC study focuses exclusively on one specific pipe size reduction, going from a 4-inch diameter drainline to a 3-inch diameter drainline. This is consistent with the type of commercial buildings the PERC Test Plans focus on, namely commercial buildings with long horizontal building drains. The loadings into the test apparatus in the PERC test plan are consistent with an office building having one men's bathroom and one women's bathroom with an occupancy of about 30 people, split evenly between male and female users. No supplemental flows other than water closet flushing were modeled.

[4] See Prof. John Swafiled's paper and presentation: "Dry Drains: Myth, Reality or Impediment to Water Conservation" which, while critical of PERC's initial announcement (see PERC 1 Report), this paper provides an excellent recap of key past research efforts including significant findings. 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

Referring back to our Main Effects Plot for all data, shown again in Figure 4-8, the Pipe Diameter variable was found to be non-significant with a very high p-value of 0.912. However, breaking down the data into smaller segments yields additional insights.

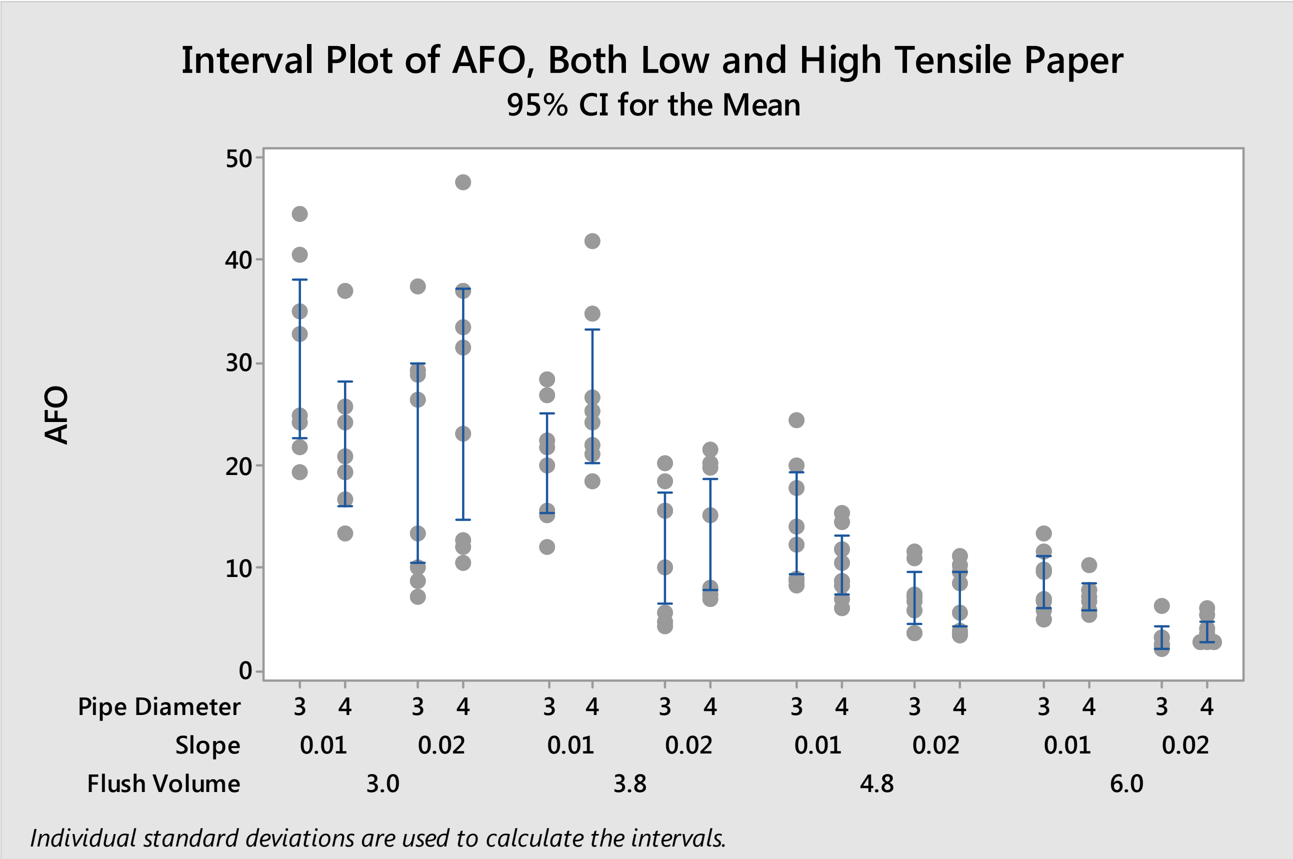
Figure 4-8, Main Effects Plot, All Data



As testing during PERC Phase 2.0 was in progress, full pipe or near full pipe conditions mostly resulting from the use of high tensile strength toilet paper resulted in airflow blockages in the test apparatuses. These conditions inhibited the movement of the test media resulting in high AFO scores on many test runs, especially those conducted on the smaller 3-inch Pipe Diameter Test Apparatus at the lower flush volumes and at the 1 percent slope setting. This often cancelled out the hydraulic benefit provided by the smaller pipe diameter, resulting in higher AFO scores and the ANOVA non-significant result. On test runs where the Flush Volume and Slope were at the lower levels, full pipe conditions and airflow blockages increased in both frequency and severity, occurring on the 4-inch Pipe Diameter test runs as well.

Refer to the Interval Plot for AFO shown in Figure 4-9. This plot breaks down the data first by Flush Volume, and then by Slope, and finally Pipe Diameter, illustrating increases in both AFO scores and in variability as Flush Volumes were reduced, an indication of increasing chaos in the test apparatus.

Figure 4-9, Interval Plot, All Data



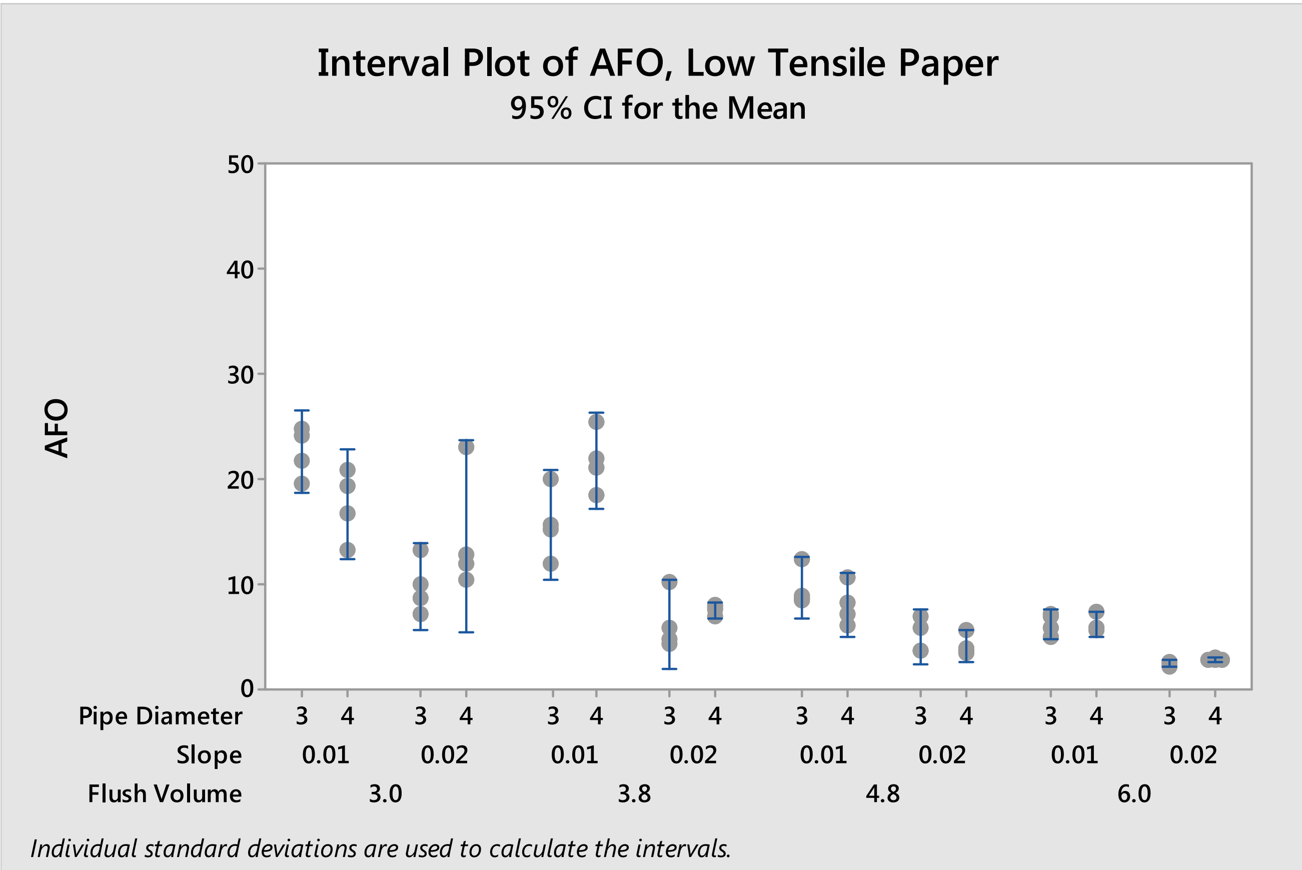
The Interval Plots shown in Figures 4-10 and 4-11 break down the data further, separating the High Tensile Strength Toilet Paper results from the Low Tensile Strength Toilet Paper results. On the Interval Plot for AFO, Low Tensile Strength Paper plot, note that the 6.0 Lpf / 1.6 gpf and the 4.8 Lpf / 1.28 gpf Flush volume results show little difference due to Pipe Diameter, resulting in slightly higher AFO scores on the 3-inch diameter Test Runs. This was somewhat surprising as lower AFO scores were anticipated on the 3-inch diameter Test Apparatus. However, much in the same way that the long length of the Test Apparatuses negated the hydraulic benefit of the Percent Trailing Water and the Flush Rate test variables, as demonstrated in both the PERC Phase 1 and PERC Phase 2.0 results, the affect of the smaller Pipe Diameter was also negated after the first few flushes once media began to build up and cluster in the apparatus. At that point, the other significant test variables were what drove the behavior of the test media in the Test Apparatuses, with the effect of Pipe Diameter diminished to non-significance.

Also on the Interval Plot for AFO, Low Tensile Strength Paper plot, the test runs conducted at the 3.8 Lpf / 1.0 gpf Flush Volume at 2 percent slope resulted in good (low) and relatively consistent AFO scores. However, the behavior of the test media in the Test Apparatuses changed considerably at 1 percent Slope, resulting in poor results comparable to the results at the 3.0 Lpf / 0.8 gpf Flush Volume.

Discounting the highly chaotic 3.0 Lpf / 0.8 gpf and the 3.8 Lpf / 1.0 gpf results at 1 percent Slope, the resulting AFO scores using Low Tensile Strength Toilet Paper were consistently higher on the 3-inch Pipe Diameter Test Apparatus than on the 4-inch Pipe Diameter Test Apparatus.

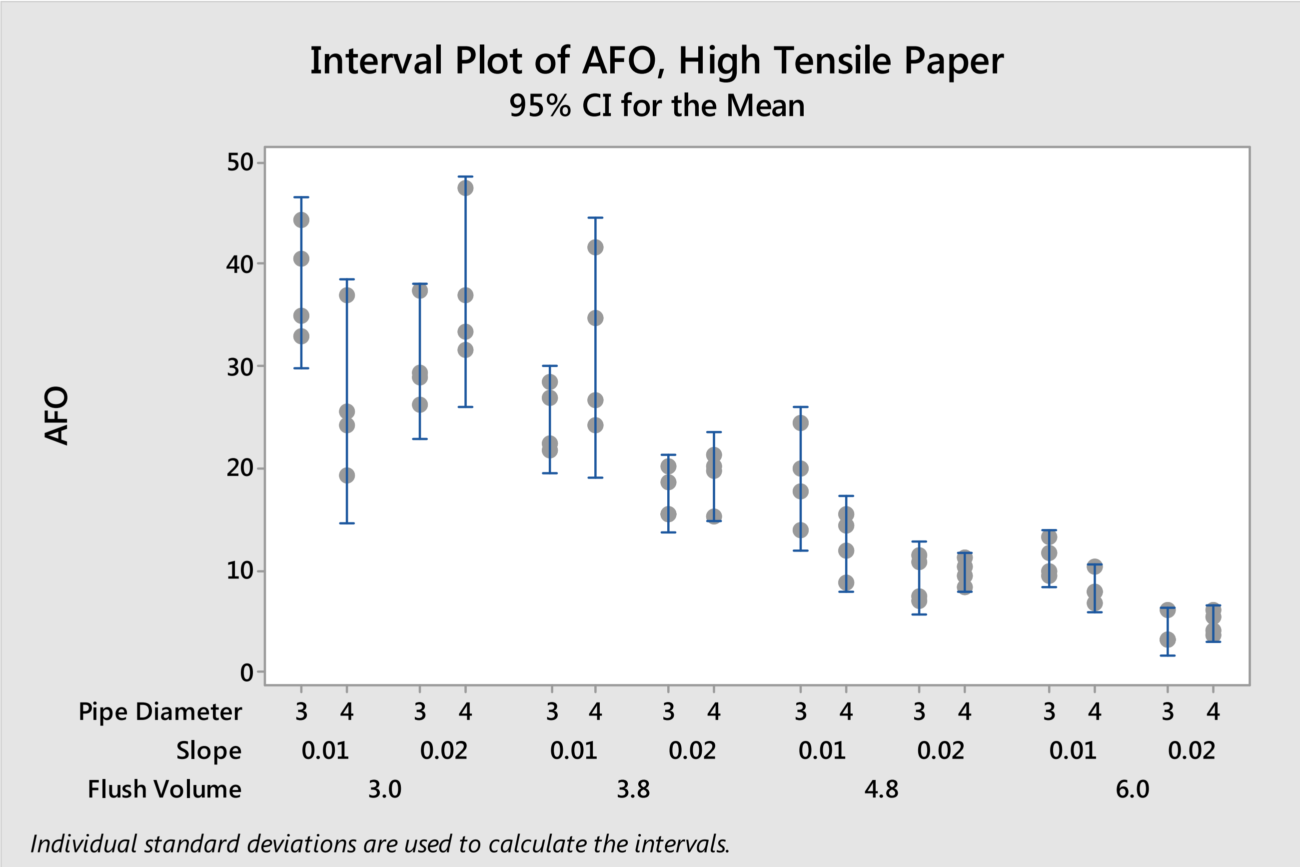
As an aside to this discussion on Pipe Diameter, an increased sensitivity to Slope occurs at the 3.8 Lpf / 1.0 gpf and 3.0 Lpf / 0.8 gpf Flush Volumes. This illustrates yet another concern regarding flush volumes lower than 4.8 Lpf / 1.28 gpf.

Figure 4-10, Interval Plot, Low Tensile Strength Paper Data Only



On the Interval Plot for AFO, High Tensile Strength Paper plot that follows (Figure 4-11), the effect of the High Tensile Strength Toilet Paper on the variability of AFO results are clearly illustrated. The added variability imparted by the High Tensile Strength Toilet Paper, clearly the number 1 significant Test Variable, overwhelms the effect of the other Test Variables. Once again, increased sensitivity to slope is noted as Flush Volumes are reduced and even begin to manifest at the 4.8 Lpf / 1.28 gpf Flush Volumes, especially on the 3-inch Pipe-Diameter Test Apparatus, due to an increased propensity for High Tensile Strength Toilet Paper to create air-flow blockages with the smaller pipe diameter.

Figure 4-11, Interval Plot, High Tensile Strength Paper Data Only



6.0 Lpf / 1.6 gpf Data

Not surprisingly, the 6.0 Lpf / 1.6 gpf results are very similar to those from PERC Phase 1. AFO results were consistently very good, although noticeably worse AFO results occurred on the 3-inch diameter apparatus with high tensile strength paper and at 1% slope. The adjusted R-Square value is good at 80.75. As a result, a significant secondary level interaction between Slope and Pipe Diameter, favoring the 4-inch Pipe Diameter results, is noted on the 6L Interactions Plot and with a p-value of 0.033.

Figure 4-12, Main Effects Plot, 6L Data Only

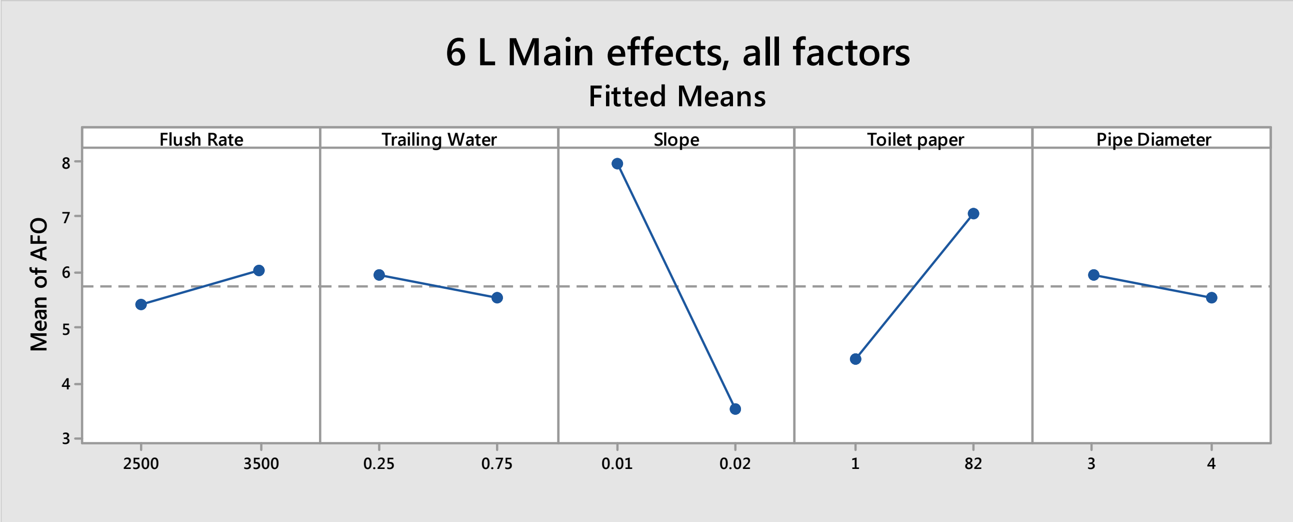


Figure 4-13, Interactions Plot, 6L Data Only

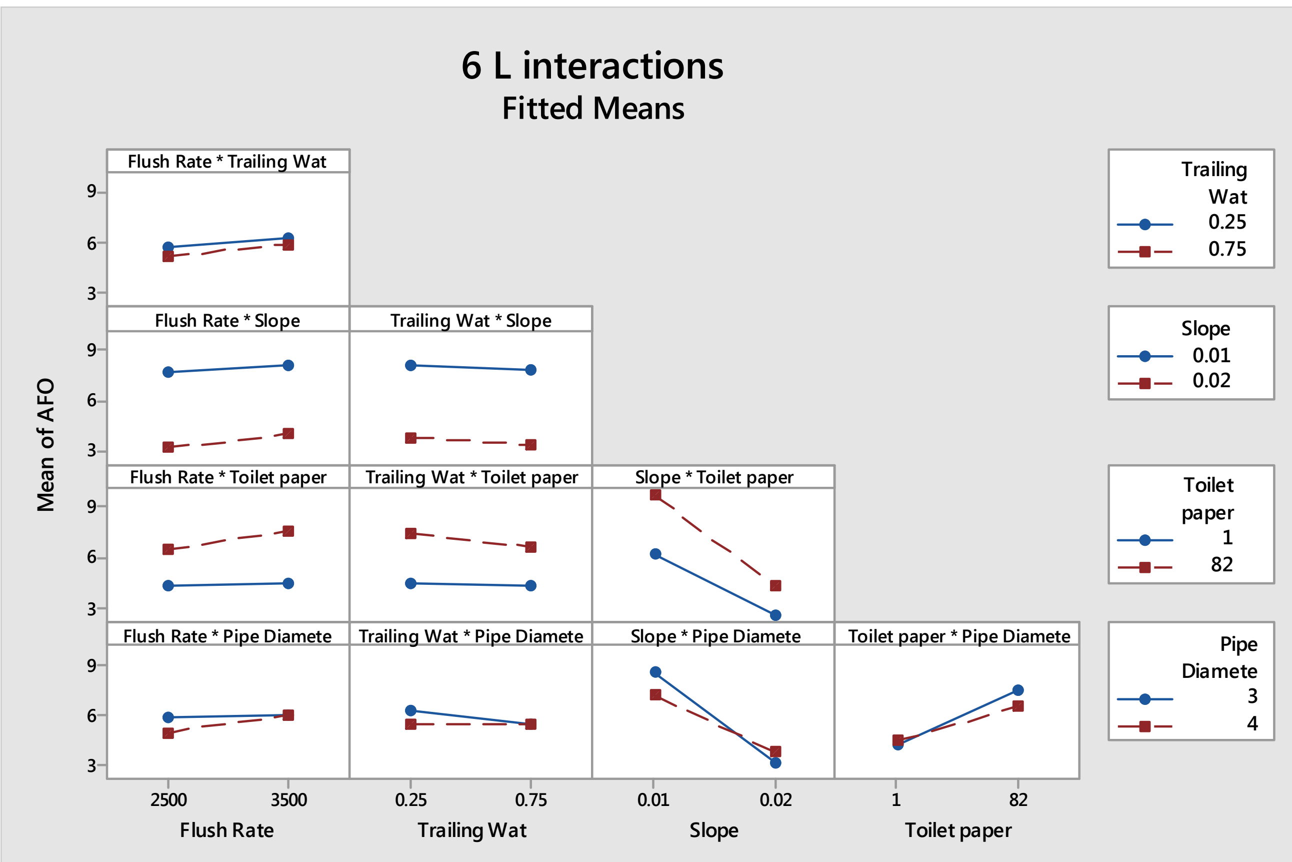


Table 4-9, General Linear Model: AFO versus Flush Rate, Trailing Water, Slope, Toilet paper, Pipe Diameter

```
Factor Information

Factor         Type   Levels  Values
Slope          Fixed       2  0.01, 0.02
Toilet paper   Fixed       2  1, 82
Pipe Diameter  Fixed       2  3, 4

Analysis of Variance

Source                 DF   Adj SS   Adj MS  F-Value  P-Value
  Slope                 1  157.794  157.794    94.73    0.000
  Toilet paper          1   55.716   55.716    33.45    0.000
  Pipe Diameter         1    1.315    1.315     0.79    0.382
  Slope*Pipe Diameter   1    8.417    8.417     5.05    0.033
Error                  27   44.972    1.666
Total                  31  268.214

Model Summary

   S      R-sq     R-sq(adj)  R-sq(pred)
1.29060  83.23%     80.75%       76.45%
```

4.8 Lpf / 1.28 gpf Data

Refer to the Main Effects plot for 4.8 Lpf that follows. The PERC Phase 2.0 results for the 4.8 Lpf / 1.28 gpf Flush Volume show three significant test variables, Slope, Toilet Paper and Pipe Diameter. The Pipe Diameter significant finding again favors the 4-inch Pipe Diameter results with a p-value of 0.03. A significant secondary interaction also resulted between Slope and Pipe Diameter. AFO results were generally good, although significantly worse AFO test run results occurred on the 3-inch Pipe Diameter Test Apparatus with high tensile strength paper, at 1 percent Slope. The adjusted R-Square value is 73.77. The lower R-squared value, the finding of significance for Pipe Diameter at this Flush Volume and the significant secondary interaction between Slope and Pipe Diameter are all attributed to the more chaotic 3-inch, 1 percent Slope results. Said another way, the finding of significance of Pipe Diameter and the secondary interaction involving Pipe Diameter results more from a poor, highly variable result on the 3-inch Pipe Diameter than from a good result on the 4-inch Pipe Diameter.

A weak secondary level interaction is indicated by crossing lines on the Interaction Plot between Flush Rate and % Trailing Water, but because both of those variables are clearly non-significant on their own, this weak (note that both lines are almost flat) secondary result is essentially meaningless.

Figure 4-14, Main Effects Plot, 4.8 L Data Only

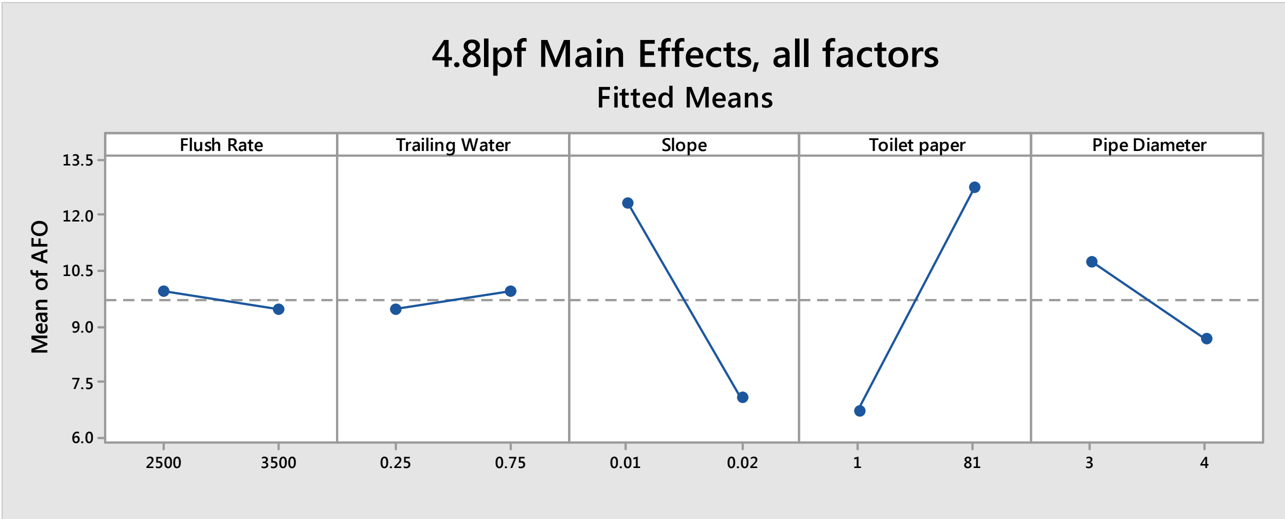


Figure 4-14, Interactions Plot, 4.8 L Data Only

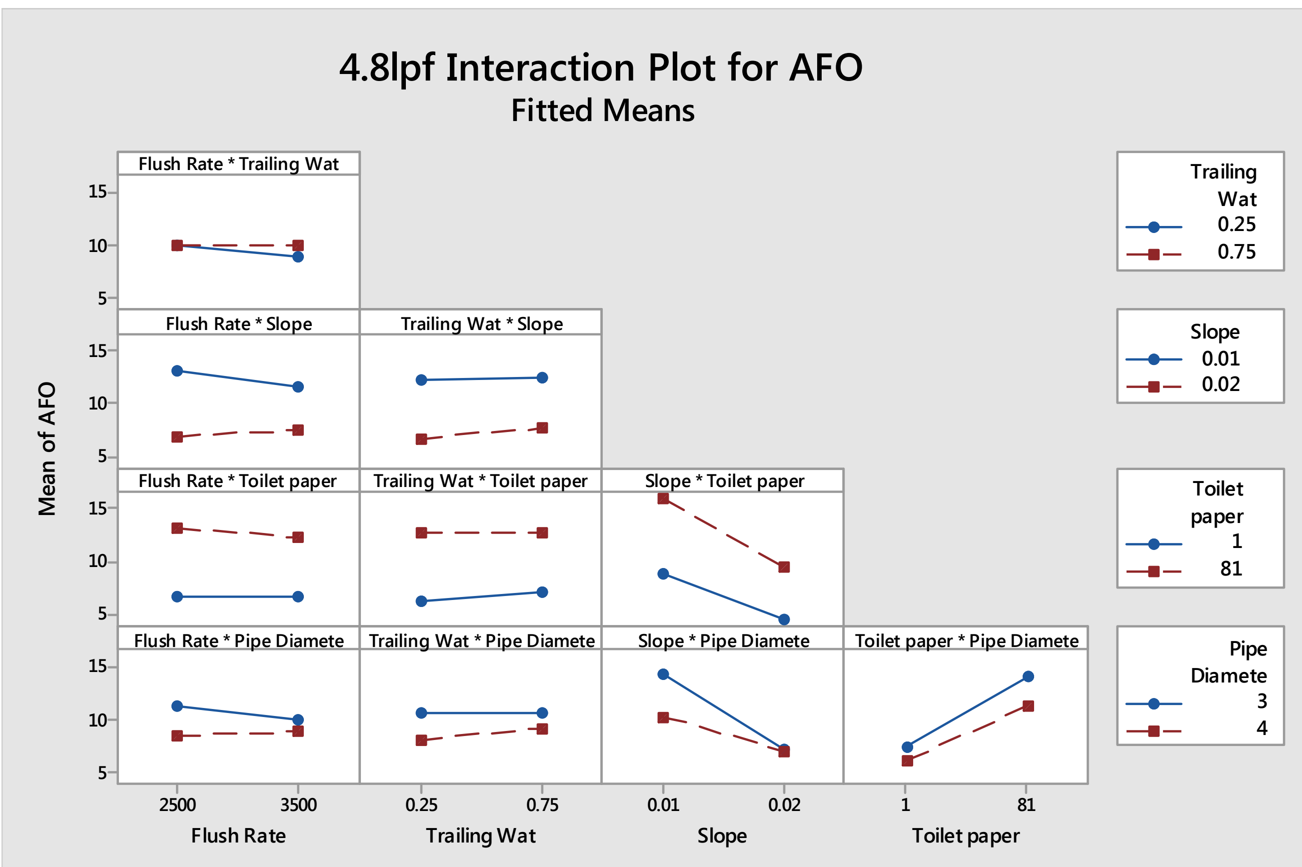


Table 4-10, General Linear Model: AFO versus Flush Rate, Trailing Water, Slope, Toilet paper, Pipe Diameter

Model	4	576.43	144.107	22.80	0.000
Linear	3	545.56	181.852	28.77	0.000
Slope	1	220.73	220.733	34.92	0.000
Toilet paper	1	291.45	291.445	46.10	0.000
Pipe Diameter	1	33.38	33.379	5.28	0.030
2-Way Interactions	1	30.87	30.870	4.88	0.036
Slope*Pipe Diameter	1	30.87	30.870	4.88	0.036
Error	27	170.69	6.322		
Total	31	747.11			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
2.51430	77.15%	73.77%	67.91%

3.8 Lpf / 1.0 gpf Data

As discussed previously, overall results become more chaotic the 3.8 Lpf / 1.0 gpf flush volume level. The test runs at 3.8 Lpf / 1.0 gpf on the 4-inch Pipe Diameter Test Apparatus at 1% slope were worse than at the 3.0 gpf / 0.8 gpf test runs at the same settings. The high AFO scores on the 4-inch Test Apparatus accounted for the only finding of significance for the Pipe Diameter test variable that favors the 3-inch Pipe Diameter results, with a p-value of 0.006.

The finding of significance for Pipe Diameter occurred, once again, not because of good results on the 3-inch Pipe Diameter Test Apparatus, but rather due to the exceptionally poor results on the 4-inch Pipe Diameter Test Apparatus. On the 2% slope test runs, the results were essentially the same.

Figure 4-15, Main Effects Plot, 3.8 L Data Only

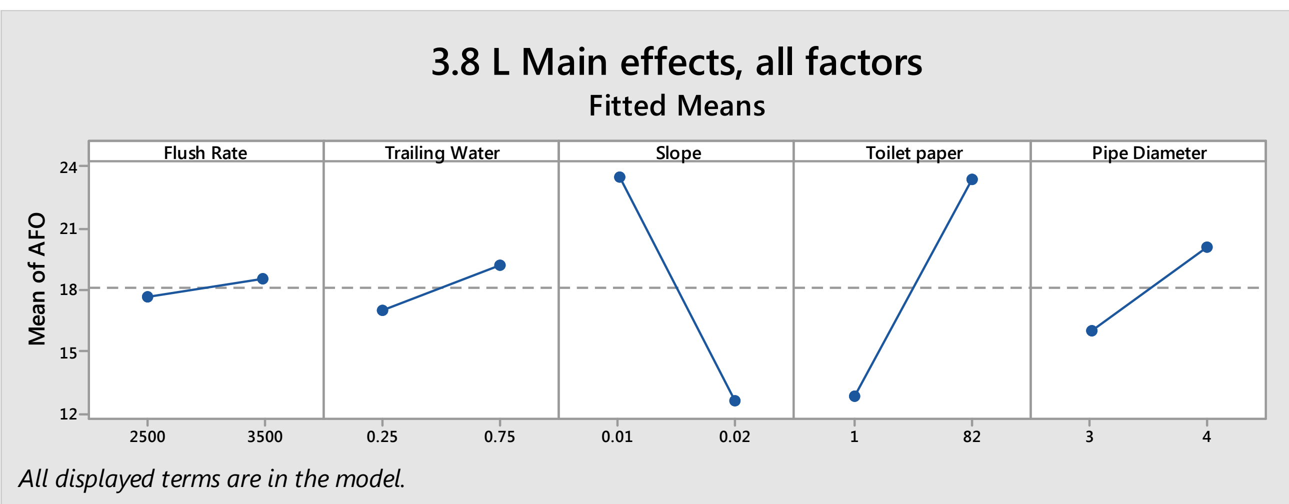


Figure 4-16, Interactions Plot, 3.8 L Data Only

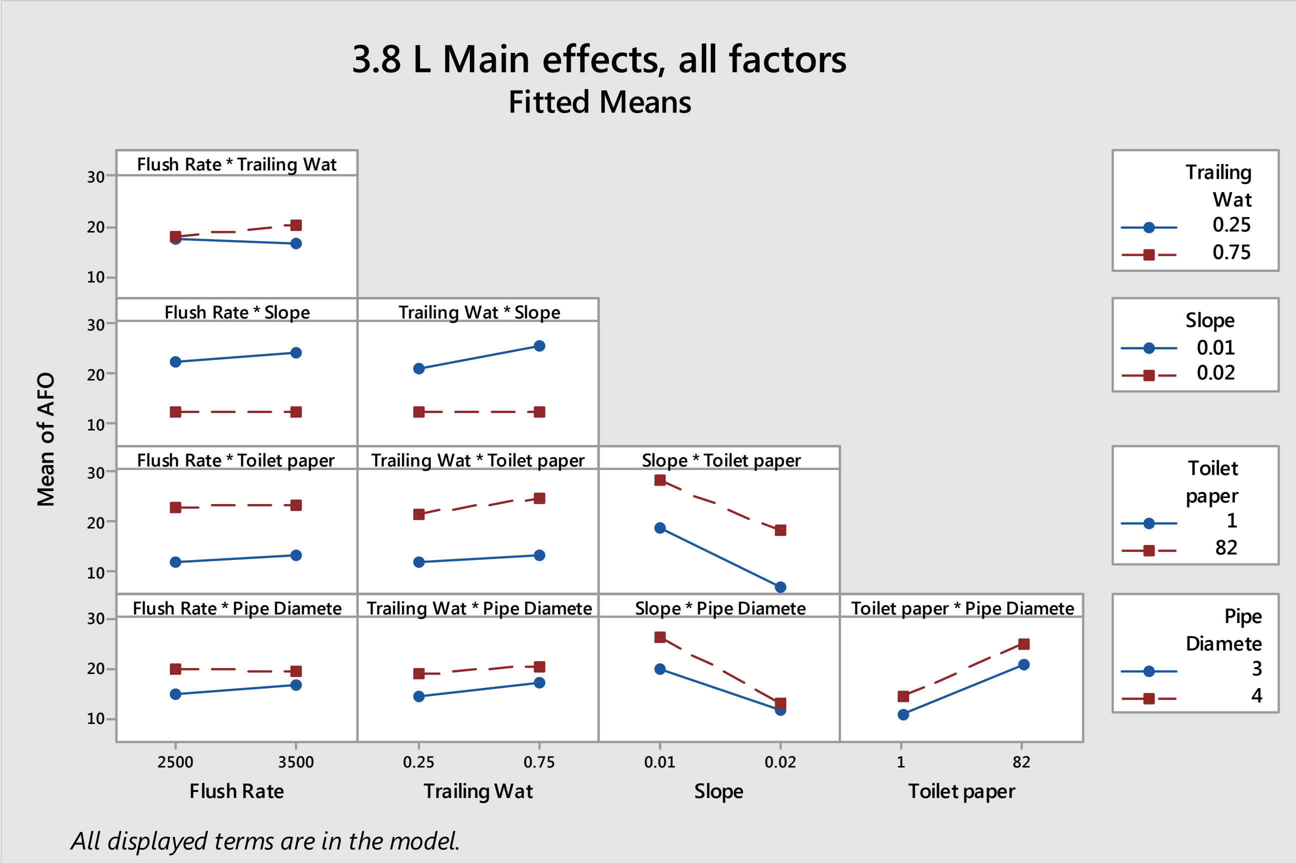


Table 4-11, General Linear Model: AFO versus Flush Rate, Trailing Water, Slope, Toilet Paper, Pipe Diameter

Factor Information

Factor	Type	Levels	Values
Slope	Fixed	2	0.01, 0.02
Toilet paper	Fixed	2	1, 82
Pipe Diameter	Fixed	2	3, 4

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Slope	1	952.5	952.51	66.74	0.000
Toilet paper	1	889.1	889.10	62.29	0.000
Pipe Diameter	1	128.5	128.47	9.00	0.006
Error	28	399.6	14.27		
Total	31	2369.7			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
3.77791	83.14%	81.33%	77.97%

3.0 Lpf / 0.8 gpf Data

The 3.0 Lpf / 0.8 gpf test volume test runs again resulted in very high AFO scores due to increasingly random test media movement in the Test Apparatuses as Flush Volume gets this low. The Main Effects findings yield only 1 significant variable at this level, Toilet Paper. Even the influence of Slope is negated by the increasingly chaotic results. On the interactions plot, secondary level interactions between 2 non-significant variables, Slope and Pipe Diameter, and an additional secondary level interaction between Slope and Toilet Paper are noted. Because the Slope and Pipe Diameter interaction occurs between non-significant test variables, the interaction itself has little significance.

The R-square value of 77.62 is quite good at this flush volume, considering the wildly variable AFO scores. By comparison, a R-square value of 67.32 resulted from the 3.0 Lpf data in Phase 1.

Figure 4-17, Main Effects Plot, 3.0 L Data Only

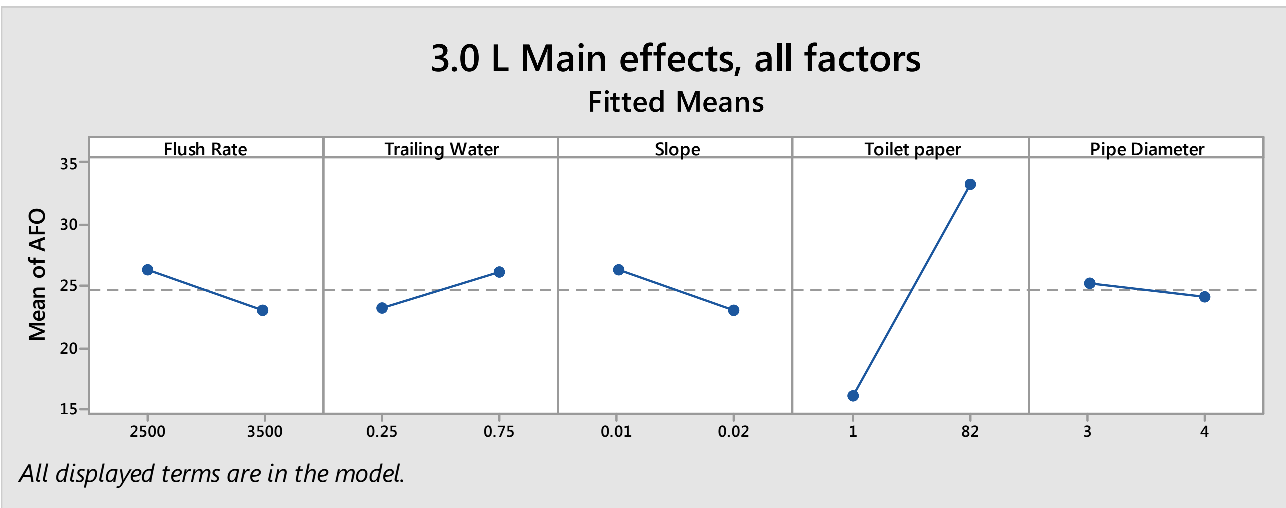


Figure 4-14, Interactions Plot, 3.0 L Data Only

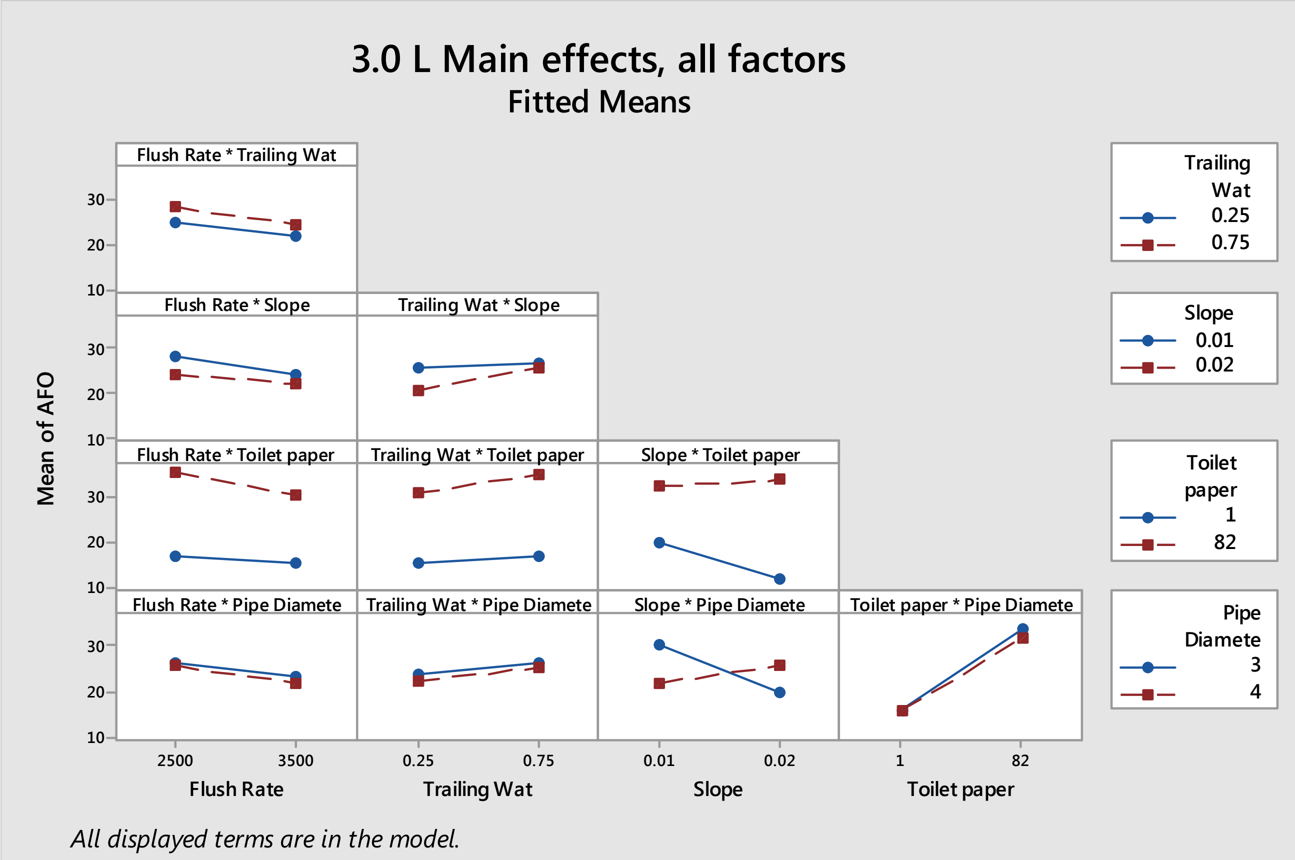


Table 4-12, General Linear Model: AFO versus Flush Rate, Trailing Water, Slope, Toilet paper, Pipe Diameter

Factor Information

Factor	Type	Levels	Values
Slope	Fixed	2	0.01, 0.02
Toilet paper	Fixed	2	1, 82
Pipe Diameter	Fixed	2	3, 4

Analysis of Variance

Source	DF	Adj SS	Adj MS	F-Value	P-Value
Slope	1	79.85	79.85	3.00	0.095
Toilet paper	1	2329.17	2329.17	87.57	0.000
Pipe Diameter	1	12.37	12.37	0.46	0.501
Slope*Toilet paper	1	175.42	175.42	6.60	0.016
Slope*Pipe Diameter	1	396.40	396.40	14.90	0.001
Error	26	691.50	26.60		
Total	31	3684.71			

Model Summary

S	R-sq	R-sq(adj)	R-sq(pred)
5.15716	81.23%	77.62%	71.57%

A closer review of the 3.0 Lpf / 0.8 gpf data may be called for when considering the secondary level interaction between Slope, which was found to be non-significant at 3.0 Lpf / 0.8 gpf, and Toilet Paper, which was the only significant test variable.

Refer to the Interval Plot for AFO shown in Figure 4-15, Both Low and High Tensile Strength Toilet Paper shown again below. The highly variable results are indicative of the very low Flush Volume. In addition, the results pertaining to Pipe Diameter favor the 3-inch Test Apparatus at 2 percent Slope and favor the 4-inch Test Apparatus at 1 percent Slope. Only when the data is combined do the results from the 2 different pipe diameters cancel out.

Figure 4-15, Interval Plot for AFO, Low Tensile Strength Paper Data Only

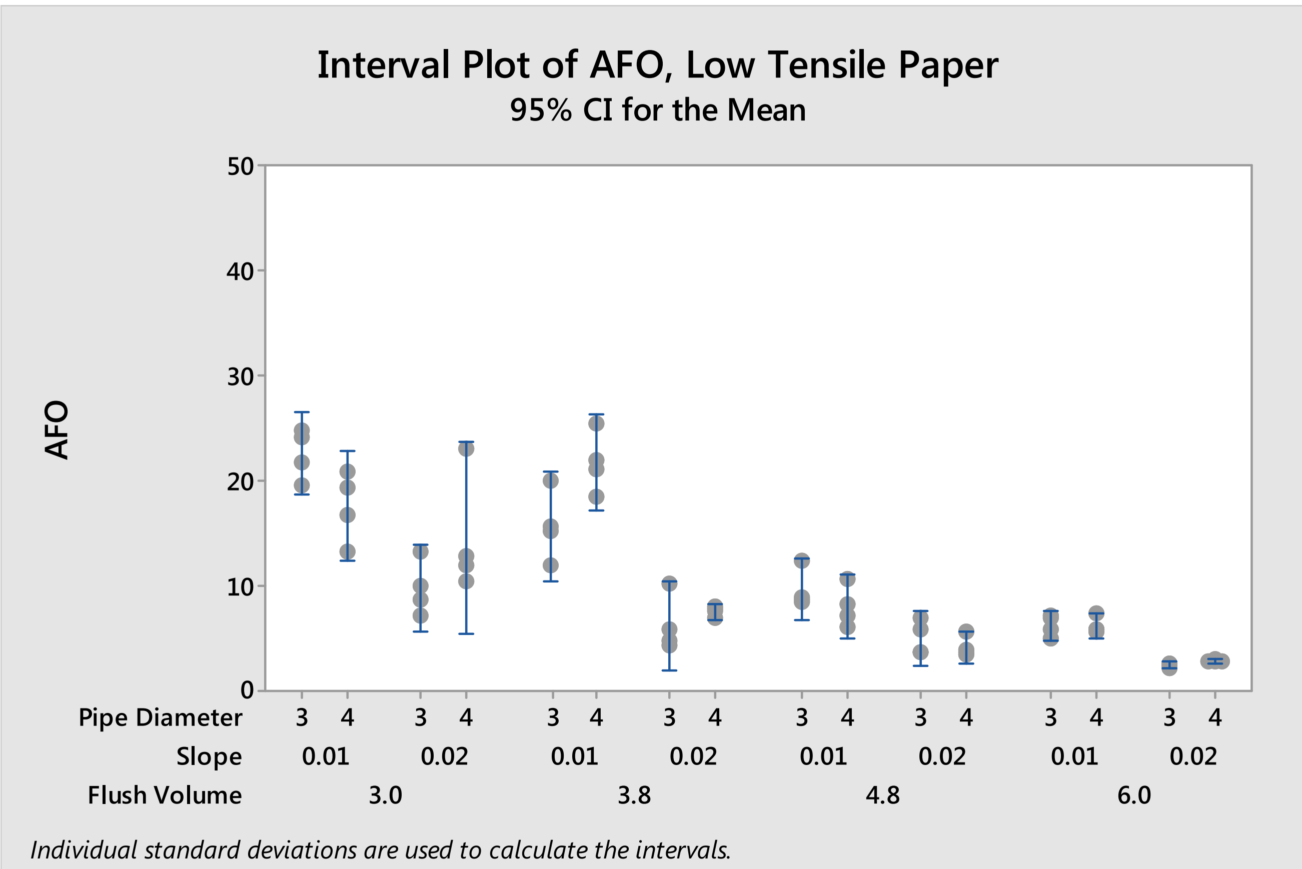
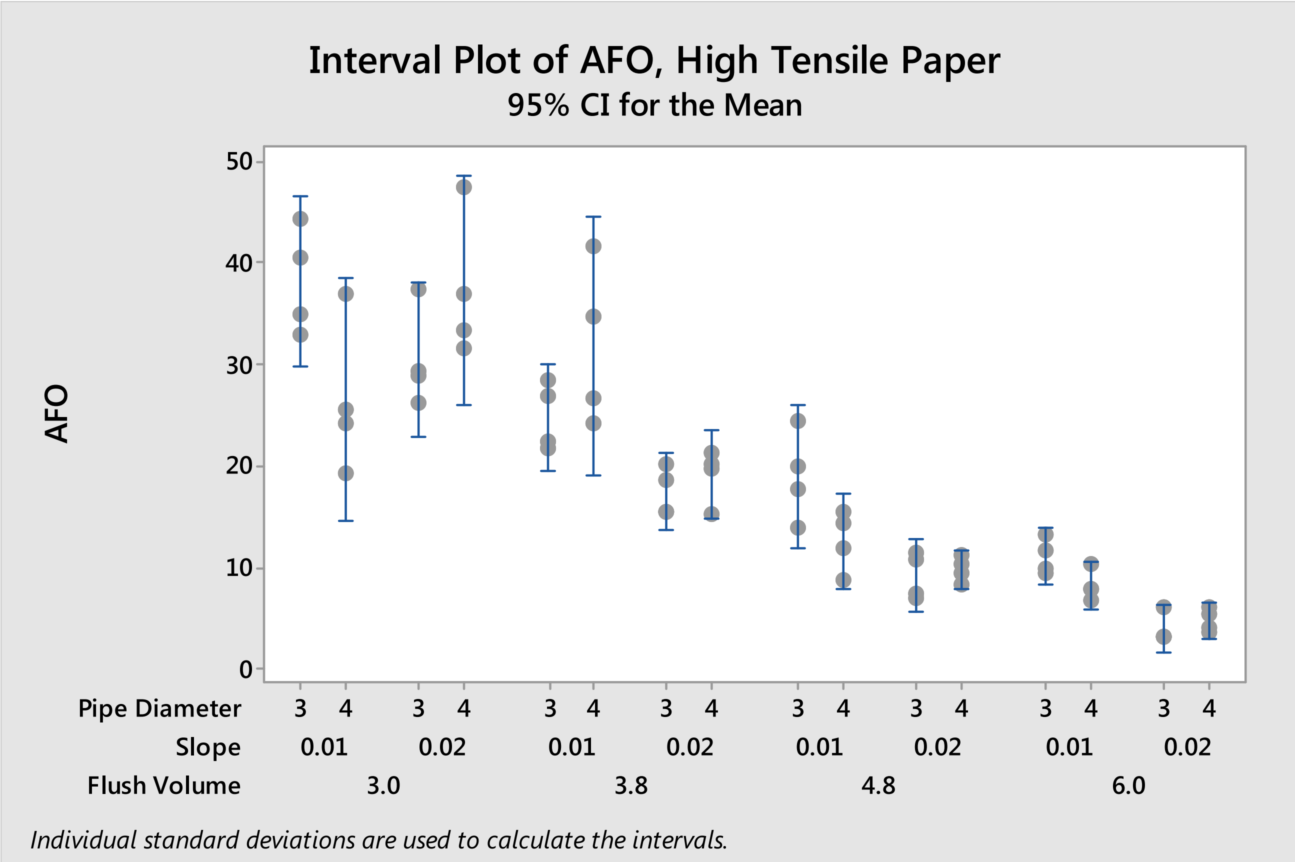


Figure 4-16, Interval Plot for AFO, High Tensile Strength Paper Data Only



5. PERC PHASE 2.0 FINDINGS AND CONCLUSIONS

Deliverable 1: The Implications of a 4-inch to 3-inch Pipe Diameter Size Reduction on Drainline Transport

As a preamble to this discussion, the PERC TC wishes to make clear that the findings from this study's Designed Experiment apply exclusively to a 4-inch to 3-inch Pipe Diameter size reduction and to commercial building drain applications with little or no supplemental water flows to assist the toilet in the drainline transport of solid wastes. No implications should be inferred towards recommendations for Pipe Diameter size reductions of other diameters, or any other application, such as sewer lines.

PERC agrees with the findings of prior research studies that clearly illustrate the hydraulic benefits associated with Pipe Diameter size reductions. Much like how a higher percentage of Trailing Water from a water closet flush does indeed improve initial drainline transport distances, the 3-inch Pipe Diameter Test Apparatus also provided for longer initial transport distances. Further, PERC notes that overall best AFO score achieved over the course of the 128 test runs conducted occurred on the 3-inch Pipe Diameter Test Apparatus (employing 6.0 Lpf / 1.6 gpf Flush Volume, 2% Slope and, of course, Low Tensile Strength Toilet Paper).

However, under most of the conditions that the PERC Test Plan sought to replicate, reducing Pipe Diameter from 4-inch to 3-inch did not consistently result in improved drainline transport. In addition, an increased potential for chaotic and increasingly variable drainline transport results were noted due to High Tensile Strength Toilet Paper inhibiting airflows in the smaller diameter Test Apparatus. Finally, the excessive use and abuse of toilet paper and other paper products is a serious reality in commercial restrooms; as a result, PERC finds that a reduction of 4-inch to 3-inch diameter may not reliably improve drainline transport performance in long building drains.

Deliverable 2: 3.8 Lpf / 1.0 gpf Flush Volume

In referring to our primary results as illustrated in the Main Effects and Interval Plot for AFO results and the predictive tools afforded by the software as illustrated in the Surface Plots, a significant decrease in drainline transport performance is noted between the 4.8 Lpf / 1.28 gpf and the 3.8 Lpf / 1.0 gpf Flush Volumes.

Based on PERC Phase 2.0 results, PERC does not recommend the use of 3.8 Lpf / 1.0 gpf (or less) toilets in commercial applications that have long horizontal drains and that do not provide additional long duration flows from other sources to assist with the drainline transport of solid waste. This recommendation only applies to the installation conditions noted above and does not apply to residential applications.[5]

PERC makes the above findings and conclusions in recognition that several plumbing fixture manufacturers are currently offering commercial (flushometer-valve and pressure assist) toilet models that flush at volumes of 3.8 Lpf / 1.0 gpf and 4.14 Lpf / 1.1 gpf for the North American market. In addition, many models that flush at 4.14 Lpf / 1.1 gpf and as low as 3.0 Lpf / 0.8 gpf are available for residential applications. For a listing of available residential toilet models that flush at these low flush volumes, please visit http://www.map-testing.com/content/info/menu/map-

[5] This study was specifically intended and designed to investigate drainline performance in commercial buildings that have long building drains. Residential building drains are typically much shorter and residential uses of water provide for significant long duration flows, such as from clothes washers and showers, which are available to assist the toilet with the transport of solid wastes in drainlines.

premium.html. These models should perform well in their intended applications assuming additional long duration flows from other water consuming appliances, plumbing fixtures, and other devices are available to assist with the drainline transport of solid wastes. It is noted that residential toilet models that consume as little as 3.0 Lpf / 0.8 gpf are already installed in significant numbers in North America and there have been no confirmed reports of drainline blockages or other problems with those fixtures. It will be interesting to follow the reported performance of these fixtures as they become more prevalent in the built environment.

Additional Findings

The Importance of Toilet Paper Selection

The PERC Phase 1 and PERC Phase 2.0 reports resoundingly demonstrate that, consistent with Dr. Steve Cummings work, the wet tensile strength of the toilet paper used appears to have profound implications for drainline carry. Indeed in both the PERC reports it was the number one explanatory variable. Based on the continued prominence of this in PERC Phase 2.0, at this time some additional formal conclusions can be made with respect to the strength of toilet paper flushed. PERC thus finds that toilet paper is the most significant test variable in all PERC tests and as such the use high tensile strength paper makes poor transport and clogs more probable in horizontal drains. It may be that the prevalence of high tensile paper and some other flushable wipe products formulated today fundamentally runs counter to the practical reductions in flush volume that could otherwise be obtained if low tensile products were used. As noted in **Appendix C**, there is some reasons to believe this may be changing, but there is nothing conclusive in regards to this at this time.

Non-significant test variables

The non-significance of the percent trailing water and flush rate test variables in both the PERC Phase 1 and PERC Phase 2.0 studies has implications for both future research efforts on drainline transport and for the North American industry standard for toilets. As noted in the Findings and Conclusions section of the PERC Phase 1 report, it is important that future research efforts on drainline transport focus only on variables that are important. The incorporation of the percent trailing water and flush rate variables added considerable expense to the PERC studies only to discover and confirm that they were non-significant.

In fact, if PERC did not have to include percent trailing water and flush rate in our designed experiment, both PERC Phase 1 and PERC Phase 2.0 could have been conducted in only 32 test runs (as opposed to 128 test runs) and for about the same cost as was required for Phase 1 only. Obviously, however, the incorporation of both the percent trailing water and flush rate test variables was necessary to prove the ultimate finding of non-significance, a major finding of the studies. As a result, they can be safely eliminated from future research efforts pertaining to long horizontal drainlines.

PERC findings as they pertain to the ASME/CSA national standard

The ASME A112.19.2 / CSA B45.1 Ceramic Plumbing Fixtures standard contains a Drainline Transport Characteristics Test which, briefly explained, is conducted by flushing 100 3/4-inch plastic balls from a toilet into a 4-inch diameter drainline apparatus that is open to atmosphere. The distance that the balls travel in the apparatus is measured and the center of mass is calculated as the average transport distance. In order to pass this test, the 3/4-inch balls must travel a minimum of 40 feet in order to pass the test and meet the standard.

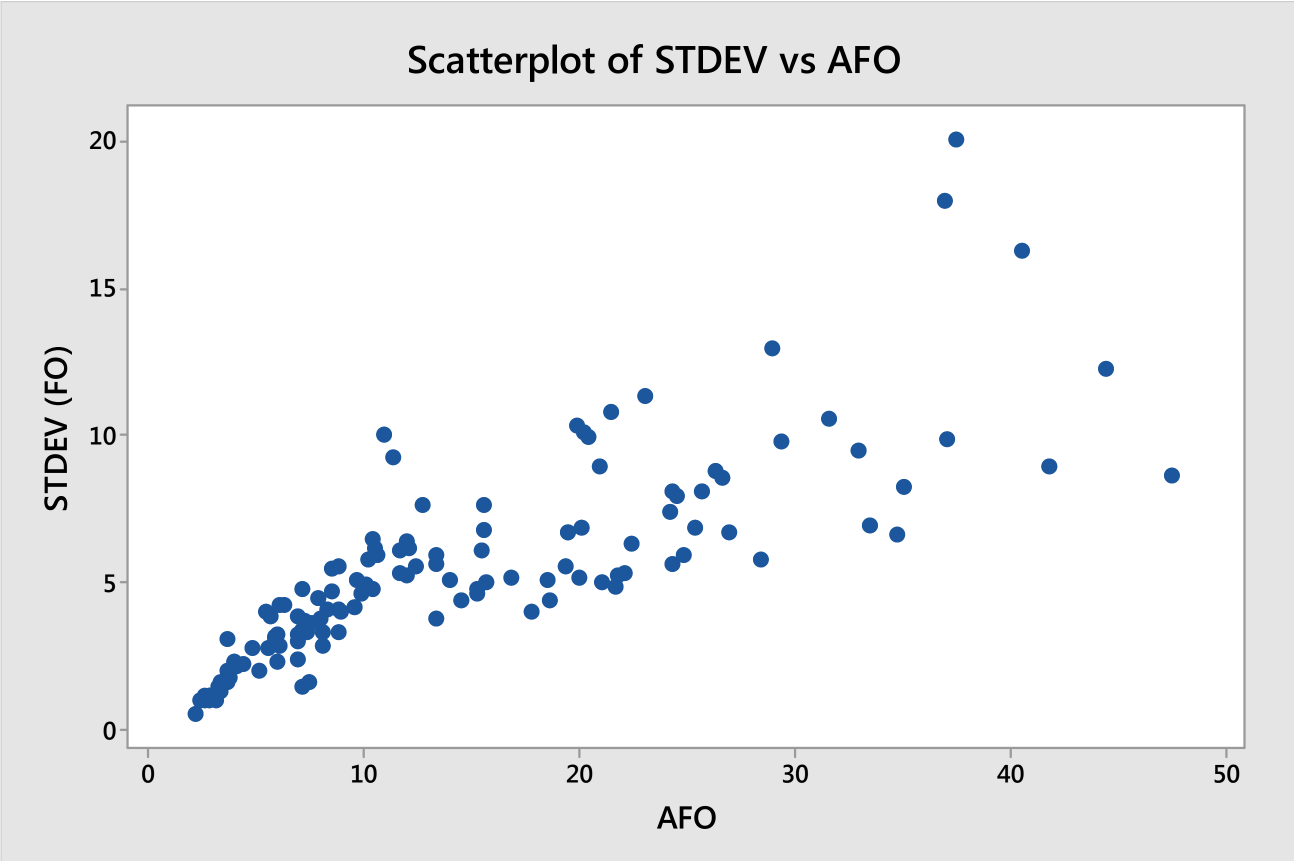
The PERC results illustrate that the attributes relating to toilet design, which are manifested in toilet discharge flush curves, do not relate to drainline transport efficacy in long drains. Further, the fact that the test in the standard is run using completely unrealistic test media and without toilet paper suggests that it lacks scientific merit. The results from this PERC study will be presented to the ASME / CSA Committees for their consideration regarding the need to retain the existing Drainline Transport Characteristics Test in future versions of the industry standard.

Using Standard Deviation for Flushes to Out (STDDEV (FO)) as a Response Output

While developing the Designed Experiment around the movement of test media in the test apparatus early in the PERC Phase 1 program, the PERC TC considered a number of response outputs from which the results could be analyzed. One of the response outputs considered was the standard deviation within the Flushes to Out (STDDEV (FO)) data sets to determine if the results could be better understood by comparing and analyzing the variation within the individual test runs.

While standard deviation generally increased with AFO scores, it often did not. This is illustrated in Figure 5-1, shown below. In some test runs with good to fair AFO scores, between ten (10) and twenty (20) for example, the variation within the data set yielded standard deviation results between five (5) and ten (10). In other test runs that resulted in higher AFO scores, in many cases much higher than twenty (20), the results were uniformly bad but also resulted in a standard deviation between five (5) and ten (10). Thus, if STDDEV (FO) were used as a primary response output, the software would consider that all of the test runs yielding a standard deviation between five (5) and ten (10) were essentially the same, when in fact the high AFO score test runs were much worse. As a result, and after considering other primary response outputs as well, the TC ultimately decided to use Average Flushes to Out as the as the primary response output for analyzing results for the PERC studies.

Figure 5-1, Standard Deviation for Flushes to Out (STDDEV (FO)) versus AFO



However, considering STDDEV (FO) as a secondary output signal does provide additional insights that further support the primary the findings of the PERC studies. Refer to Figure 5-2 below, which illustrates how standard deviation increases as flush volumes are reduced. It further illustrates the influence of pipe diameter is negligible at the 6.0 Lpf / 1.6 gpf and the 4.8 Lpf / 1.28 gpf flush volumes, and become conflicting at the more chaotic, lower flush volumes.

Figure 5-2, STDDEV (FO) versus Flush Volume and Pipe Diameter

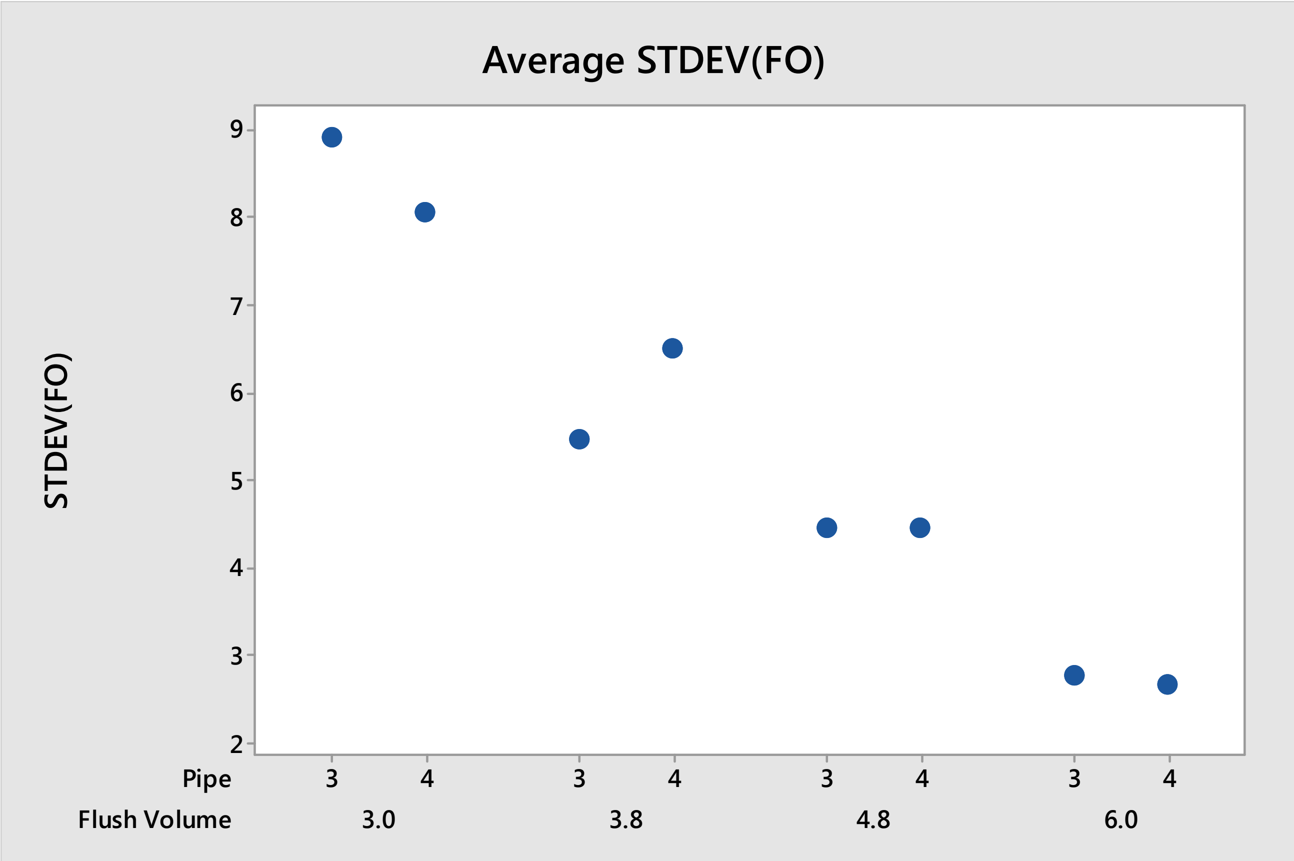
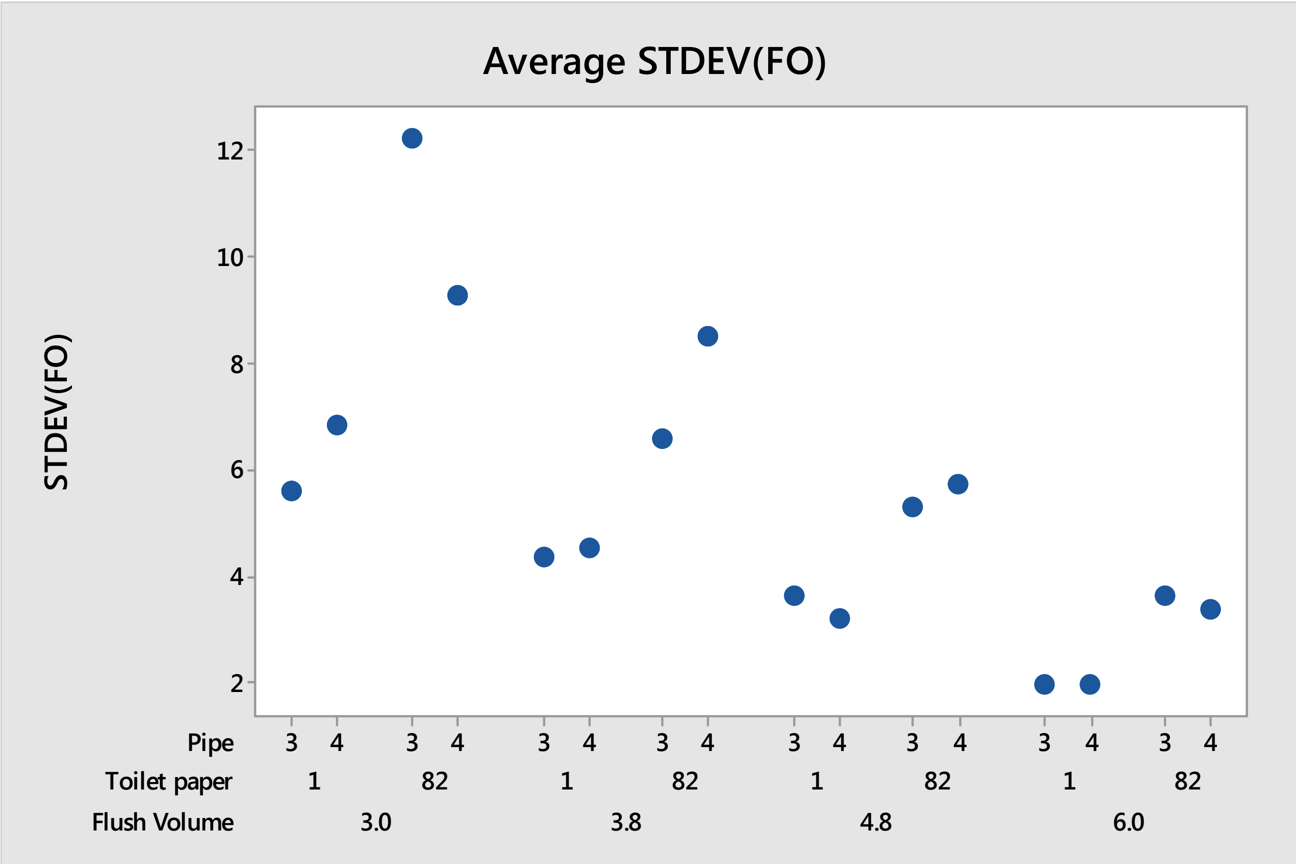


Figure 5-3 below breaks these results down even further by illustrating the influence of toilet paper on STDDEV (FO) results. At every flush volume, variability increases significantly as a result of using high tensile strength toilet paper.

Figure 5-3, STDDEV (FO) versus Flush Volume, Toilet Paper and Pipe Diameter



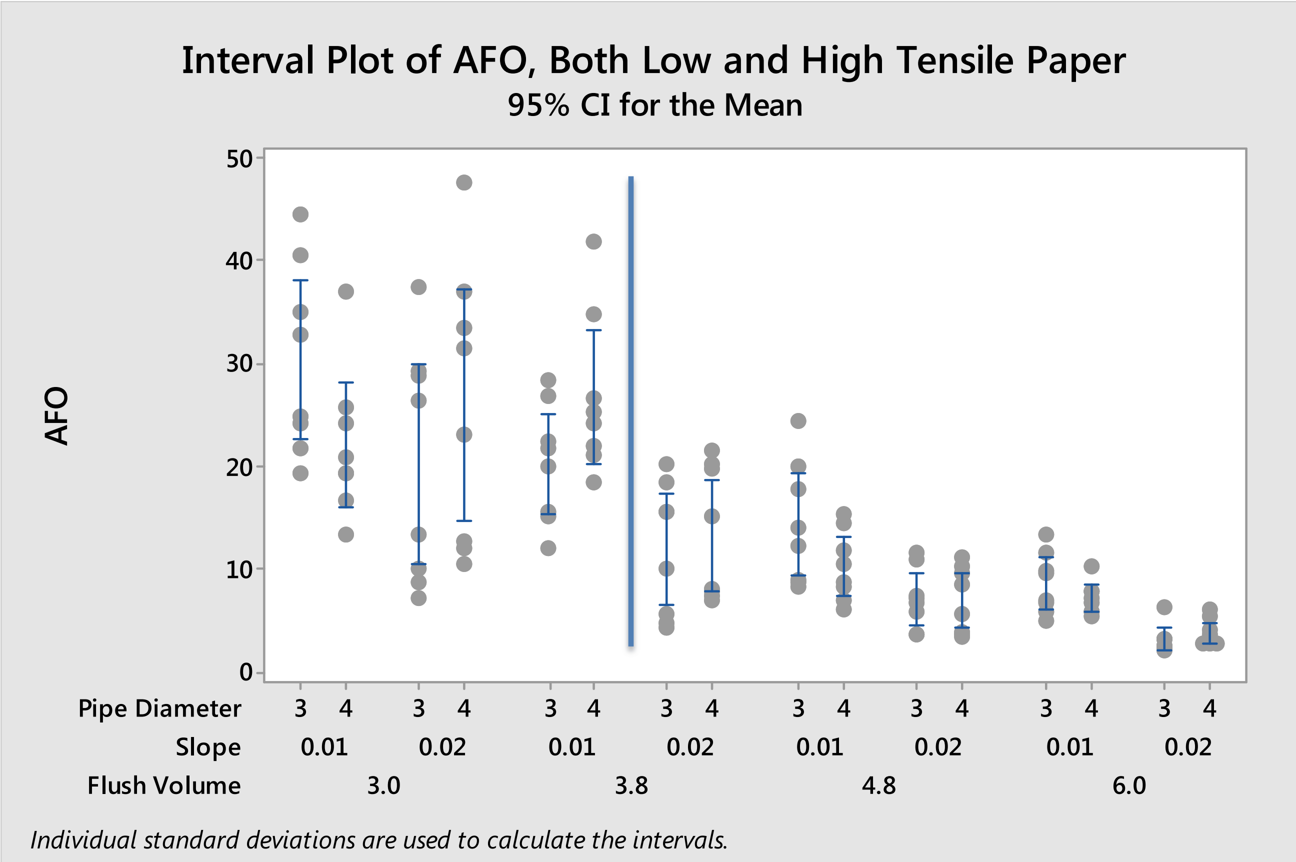
The Efficacy Tipping Point

The data resulting from the PERC Phase 1 and PERC Phase 2.0 studies suggests that a natural tipping point for efficacy occurs <u>within</u> the 3.8 Lpf / 1.0 gpf flush volume level. AFO scores conducted at 2 percent slope on both the 3-inch and 4-inch test apparatuses were consistently and markedly lower at the 2-percent slope setting. The blue line in Figure 5-4 below indicates this tipping point. However, PERC does <u>not</u> suggest that the 3.8 Lpf / 1.0 gpf flush volume toilets will provide satisfactory drainline transport performance when installed on sanitary systems designed to provide 2-percent slope and does not recommend their use on <u>any</u> long, horizontal commercial building drain.

As opposed to the perfectly sloped and junction free test apparatus used in the PERC Phase 1 and PERC Phase 2.0 studies, actual horizontal building drains very often have deviations in slope. These slope deviations are known to increase with time, especially in drains employing PVC pipe. In addition, horizontal junctions and other fittings increase the potential for mechanical blockages due to toilet paper hanging up at the junctions. These realities are not taken into account with the PERC study.

The PERC studies on drainline transport were designed to indicate the flush volume at which chronic blockages are likely to occur. PERC does not suggest that toilets flushing at 3.8 Lpf / 1.0 gpf or less are recommended in some applications and not on others based on the designed slope of the building drain.

Figure 5-4, Interval Plot, All Data, Showing Natural Efficacy Tipping Point



6. FUTURE RESEARCH OPPORTUNITIES FOR PERC

Astute readers of this report have likely noticed that the extended PERC study pertinent to this report is referred to as “Phase 2.0”. This notation would imply that there is more yet to come in PERC Phase 2 and that implication is intentional. Due primarily to labor-related cost savings provided by American Standard, the testing associated with the PERC Phase 2 Test Plan was completed well under budget. It became clear about halfway through the PERC Phase 2 Test Plan there would be sufficient funds remaining to conduct meaningful additional testing.

The PERC TC was convened to discuss what should be done with the remaining funds. It was noted that neither PERC Phase 1 nor PERC Phase 2 evaluated dual-flush toilet discharge profiles. Both PERC Phase 1 and PERC Phase 2.0 illustrate that once the surge of water from a toilet flush attenuates in a long building drain that the movement of solid wastes is not significantly affected by the flush discharge characteristics % Trailing Water and Flush Rate. Yet, Flush Volume remains, of course, significant.

There is a perception among some engineers, plumbers and others in the marketplace that dual-flush toilets, because they flush on full flush volume to flush solid waste, provide equal drainline transport performance as single-flush models at the same (full) flush volume. In other words, a dual-flush toilet flushing at 6.0 / 4.1 Lpf (1.6 / 1.1 gpf) would provide the same drainline transport performance as a single-flush 6.0 Lpf / 1.6 gpf toilet while providing additional water efficiencies. The results from PERC Phase 1 and PERC Phase 2.0 call that perception into question.

The PERC TC determined that an abbreviated Test Plan, PERC Phase 2.1, be developed to compare the drainline transport performance of dual-flush discharge patterns against single-flush discharge patterns. A total of sixteen (16) test runs will be conducted employing surge injectors that are set to deliver dual-flush-like discharges at both the 6.0 – 4.1 Lpf / 1.6 – 1.1 gpf and 4.8 - 3.0 Lpf / 1.28 – 0.8 gpf Flush Volume levels. Testing will be conducted employing a ratio of (1) full volume flush to two (2) reduced volume flushes, which is consistent with the solid to liquid waste ratio used in the PERC studies.[6] Toilet paper will be included in the reduced-flush mode flushes for this testing. The results from those test runs will be compared to the results from identical “single flush” test runs (same test variables). This will provide insights regarding the impact of dual flush discharges on drainline transport.

In addition, PERC Phase 2.1 will also investigate the impact of deviation in Slope on Drainline Transport. The hypothesis for this aspect of work is that any deviation in the slope of a drainline will manifest itself more severely as Flush Volumes are reduced. Eight (8) test runs will be conducted on both the 3-inch Pipe Diameter and 4-inch Pipe Diameter Test Apparatuses with one section of the clear PVC pipe set flat (0 percent slope). We will then compare the impact of the slope deviation on drainline transport performance against the identical test runs (same test variables) conducted on the perfectly sloped Test Apparatuses.

It should be noted that, for the reasons noted above in the Additional Findings section, neither the % Trailing Water nor Flush Rate test variables will be included in the PERC Phase 2.1 study. PERC Phase 2.1 will be published as an addendum to this report in early 2016.

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[6] PERC understands that this ratio is currently under scrutiny as it pertains to actual installed use patterns in the ‘real world’. However, for the purpose of this Test Plan, the 1:2 ratio represents a more ‘conservative’ ratio than the 1:1 ratio assumed by other organizations.

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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 AFO numbers indicates difficulty in moving the solids through the apparatus. Conversely, lower AFO 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

Long Horizontal Building Drain – A building drain that is over 60 linear feet in length.

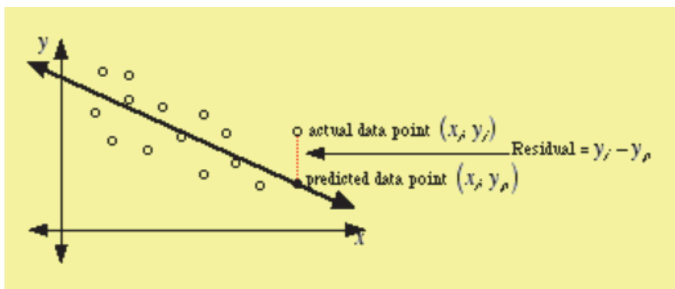
Long Duration Flows – Flows from clothes washers, showers or other water consuming plumbing fixtures, appliances or equipment that are available to assist a toilet in transporting solid waste through a building drain.

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.

Residuals – the difference between an observed value and the estimated value of a data point.



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

AFO – Average Flushes to Out

ASPE – American Society of Plumbing Engineers

AWE – Alliance for Water Efficiency

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

DLT – Drainline transport

DOE – Design of Experiment

gpf – gallons per flush

HET – High Efficiency Toilet

IAPMO – International Association of Plumbing and Mechanical Officials

ICC – International Code Council

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

L – liters

Lpf – Liters per flush

MaP – Maximum performance

Ml/sec – milliliters per second

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

TC – Technical Committee

Phase 2: Test Plan Proposal to Investigate Drainline Transport in Buildings

Plumbing Efficiency Research Coalition

Phase 2
Test Plan Proposal to Investigate Drainline Transport in Buildings

Executive Summary

Completed Study:

The Plumbing Efficiency Research Coalition (PERC) issued its first research report, *The Drainline Transport of Solid Waste in Buildings (Phase 1 Report)*, in November of 2012. PERC is pleased to report that the US EPA WaterSense program has determined, based extensively on our report, to go forward with the development of a specification for commercial high-efficiency toilets.

The *Phase 1 Report* yielded valuable information, not only regarding the efficacy of high efficiency toilets, but more importantly, regarding how drainlines *behave* as long duration flows are reduced. The PERC test program was able to illustrate a statistically significant behavioral change in drainline performance in tests that simulated toilets flushing at 3.0 liters per flush (Lpf) / 0.8 gallons per flush (gpf).

Other important and useful findings include the significant impact that toilet paper has on drainline transport results and the non-significant impact of toilet design. .

Phase 2 Study Plan:

As with all research programs, as questions are answered, many more are uncovered. The PERC research is certainly no exception in this regard. Therefore, The PERC Technical Committee (TC) is pleased to provide the following Test Plan Proposal for Phase 2 of this critically important work. The Phase 2 study will be focused on the following research areas:

Pipe Size Reduction – A 3-inch test apparatus will be used in addition to the 4-inch diameter apparatus employed in Phase 1 to determine impact of reducing the pipe size.

Additional Flush Volume Level – Phase 1 results indicated a behavioral shift and a chaotic drainline performance condition resulted at the 3.0 Lpf / 0.8 gpf consumption level. This suggests a need to investigate drainline transport performance at the 3.8 Lpf (1.0 gpf) volume level as many U.S. manufacturers are already producing toilets that flush at this consumption level for both commercial and residential applications.

Toilet Discharge and Toilet Paper Characteristics – We cannot assume the results achieved related to toilet paper using the 4-inch diameter pipe will be the same when using the 3-inch diameter pipe. Thus, it is critical to study these variables at the 3-inch diameter pipe size.

There are additional areas of study that will be accommodated in Phase 2, as well as limitations regarding the Phase 2 deliverables. We encourage a careful review of the full Test Plan Proposal that follows.

Funding:

Phase 2 of this research study will cost approximately $160,000.00, a significant increase over the approximately $70,000.00 used to complete Phase 1. The reasons for this increase are detailed in the full Work Plan Proposal. Thus, PERC seeks ongoing support from all stakeholders; water utilities, manufacturers, contractors, plumbing engineers, and other NGO's, especially those entities that are helping to incentivize further reductions in toilet consumption levels.

"Why should we help fund PERC?" This is a valid question and should certainly be considered from the perspective of the contributing organization.

Water Utility or Environmental NGO – Water utilities have made huge investments in providing incentives to remove water-guzzling older toilets with low-consumption and high-efficiency models. A single miscalculation in efforts to become more water efficient, especially one that would result in something as newsworthy as chronic drainline blockages, would severely damage the credibility of all water efficiency efforts.

Contractors and Plumbing Engineers – More than any other stakeholder, contractors and plumbing engineers are on the front line when it comes to feeling the financial consequences when plumbing efficacy fails. Even when these problems are clearly not the fault of the contractor or engineer, they are the ones who must pay for the call-backs and make the changes necessary to get the installation working properly.

Manufacturers – The marketplace continues to provide incentives to design toilets that flush at lower and lower consumption levels. In doing so, the marketplace is leaving the responsibility regarding the efficacy of these products to others. Today, a great deal of time and effort is consumed in trying to answer the question; "How low can we go?" When it comes to toilet consumption levels and drainline transport, one thing is clear; somewhere between current high efficiency toilet consumption levels and zero gpf, chronic blockages will occur.

Thus, it is critical for all stakeholders to support a scientific investigation that can help determine the consumption levels where significant blockages are more likely to occur. Help invest in keeping our plumbing systems working!

Phase 2 Work Plan Proposal
Moving Forward

Background:

Thank you for your interest in reviewing the Plumbing Efficiency Research Coalition's (PERC) test proposal for phase 2 of our study on drainline transport in buildings. If you have not already done so, we recommend that you review PERC's report on Phase 1 of this study, which was published in November of 2012, in order to more fully understand the test methodologies and deliverables associated with this Test Plan Proposal. The full report, along with supporting data and other materials can be downloaded free of charge at www.plumbingefficiencyresearchcoalition.org.

A summary of the PERC Phase 1 report is contained in the Appendix of this proposal.

Proposal:

In Phase 2, the PERC Technical Committee (TC) proposes that we continue to investigate how controllable system variables affect drainline transport with focus on the following areas of study:

Pipe Size Reduction – In Phase 1, there were insufficient funds to include pipe diameter as a variable in the study. Today, at virtually every code hearing in the United States, the debate increases regarding needed revisions to the pipe sizing requirements contained in the codes due to reduced flows. Many plumbing engineers recommend reducing pipe diameters in certain installation types to allow for higher flood levels in order to transport waste further in the sanitary drain. The TC agrees that this is an aspect of study that needs to be prioritized.

The TC proposes building a 3-inch diameter 135 foot-long test apparatus to mirror the 4-inch diameter apparatus employed in Phase 1, again using clear plastic piping. By conducting the same Designed Experiment employed in Phase 1, we will be able to measure the significance of a pipe size reduction in relation to the other systems variables under identical conditions.

Additional Flush Volume Level – Phase 1 results indicated a chaotic drainline performance condition resulted at the 3.0 Lpf (0.8 gpf) consumption level. This chaotic performance at both 1% and 2% test apparatus slope settings indicated that installing 3.0 Lpf (0.8gpf) toilets in commercial settings might not be viable under some circumstances. Also noteworthy was that the 2% slope results showed worse performance than the 1% slope results at the 3.0 Lpf (0.8 gpf) consumption level. This interesting result may indicate that we have reached a “tipping point” that signals chronic performance problems and could lead to excessive blockages when the water to solid waste ratio in a building drain is reduced to that extent.

This result also confirms the need for additional study at very low toilet discharge levels. As mentioned in the Phase 1 report, three discharge levels were chosen for the Phase 1 study because they replicated three of four consumption levels being utilized by U.S. manufacturers. Those three are 6.0 Lpf (1.6 gpf), 4.8 Lpf (1.28 gpf) and 3.0 Lpf (0.8 gpf). (The fourth threshold commonly produced is the 3.8 Lpf (1.0 gpf) flush volume.) The results indicated satisfactory performance at 6.0 and 4.8 Lpf levels, but also revealed chaotic performance at the 3.0 Lpf (0.8 gpf) level, where test media formed large plugs in the drainline and movement of the solids in the drainline became increasingly independent of the flush injections into the test apparatus.

This suggests a need to investigate the drainline transport performance at the approximate half-way point between the lower two values by conduct testing at the 3.8 Lpf (1.0 gpf) volume level in order to better characterize the difference in performance observed. As noted above, many U.S. manufacturers are already producing toilets that flush at the 3.8 Lpf (1.0 gpf) consumption level for both commercial and residential applications, providing further need to better understand the implications of performance at that level.

Additional Work Needed on 4-inch Test Apparatus – Because the 3.8 Lpf (1.0 gpf) discharge level was not utilized on the 4-inch apparatus in Phase 1, PERC will need to run this volume level on that apparatus before it is dismantled. Additionally, while not a new area of study, also missing from Phase 1 were the test run trials at the 6.0 Lpf (1.6 gpf) consumption level using low-tensile strength toilet paper. Completing this work will allow for direct comparison to the designed experiment proposed for Phase 2, and is therefore required in order to draw meaningful conclusions.

While PERC would certainly wish to recommend additional areas of study to undertake at Phase 2, the budget associated with just investigating the two new parameters above carries with it a significant price tag. Hence, due to cost constraints, we recommend that Phase 2 be limited to the above two new focus areas.

Toilet Discharge Characteristics – In Phase 1, the test variables associated with toilet discharge characteristics, flush rate and percent trailing water, were shown to be non-significant at both the 1% slope and 2% test apparatus slope settings. However, we cannot assume the same result when pipe diameter is changed. Thus, it is critical to study these variables at the 3-inch diameter pipe size. If these characteristics are again shown to be non-significant in Phase 2, it will allow for their elimination from future studies, greatly reducing costs. However, if the flush characteristics are shown to be significant variables at smaller pipe diameter sizes, this will be extremely important to understand.

Clearing Flush – PERC will not formally investigate clearing flush technology efficacy in Phase 2. As mentioned in the Phase 1 report, this aspect of study requires a separate methodology. Because Phase 2 will employ the same designed experiment employed in Phase 1, it will not be well suited for the evaluation of a clearing flush. However, recognizing that conducting the clearing flush trials that were conducted in Phase 1 are without extra cost, PERC will run the clearing flush trials again in Phase 2 and we will record and report on the results, but this aspect of work will <u>not</u> be a formal deliverable in Phase 2.

Phase 2 Deliverables

Phase 2 will focus on only two new parameters. The deliverables associated with conducting this work are extremely important towards realizing the implications of reduced pipe sizing in building drains. In addition, the drainline performance of toilets flushing between 4.8 Lpf (1.28 gpf) and 3.0 Lpf (0.8 gpf) will be investigated.

Deliverable 1 – As discussed above, plumbing engineers and other plumbing professionals have been recommending pipe size reductions in the codes as a result of reduced flows for many years. Phase 2 of the PERC study will show how a commonly suggested pipe size reduction (going from 4-inch diameter pipe to 3-inch pipe) will impact drainline transport. Additionally, it will rank the significance of reducing pipe diameter to flush consumption level reductions, slope, toilet paper wet tensile strength, and toilet discharge characteristics of flush rate and percent trailing water. As such, the results from Phase 2 will provide needed data in understanding the implications of these pipe size reduction recommendations.

Deliverable 2 – Evaluating a new flush discharge level at 3.8 Lpf (1.0 gpf) will provide for a better understanding of how the drainline performs at the critical consumption level between 4.8 Lpf (1.28 gpf) and 3.0 Lpf (0.8 gpf), where drainline performance in Phase 1 became chaotic. This will provide additional insight into the "tipping point" flush volume level, below which chronic blockage problems are more likely to occur.

Considering the above two deliverables together, Phase 2 will evaluate how pipe size reduction in a building drain might allow for the successful use of lower consumption toilets in new installations that employ smaller diameter drains. Conversely, it may also provide data that confirms that we are indeed reaching a tipping point where further toilet consumption level reductions are risky in installations that do not provide for significant additional flows into the building drain.

Clearly, these issues are critical towards a better understanding of the performance limits of gravity building drains and will allow for future studies to be developed with an improved understanding of these performance limits.

Phase 2 Study Variables

Description of variables:	No. of variables:	Variables			
Pipe Diameter (in, nominal)	2	3"		4"	
Pitch (%)	2	1.0%		2.0%	
Flush Volume (Lpf/gpf)*	4	6.0/1.6	4.8/1.3	3.8/1.0	3.0/0.8
Velocity - Peak Flow (ml/sec)	2	3500		2000	
Trailing water (% water after solids)	2	70%		20%	
Toilet Paper Tensile Strength	2	High (81)		Low (1)	

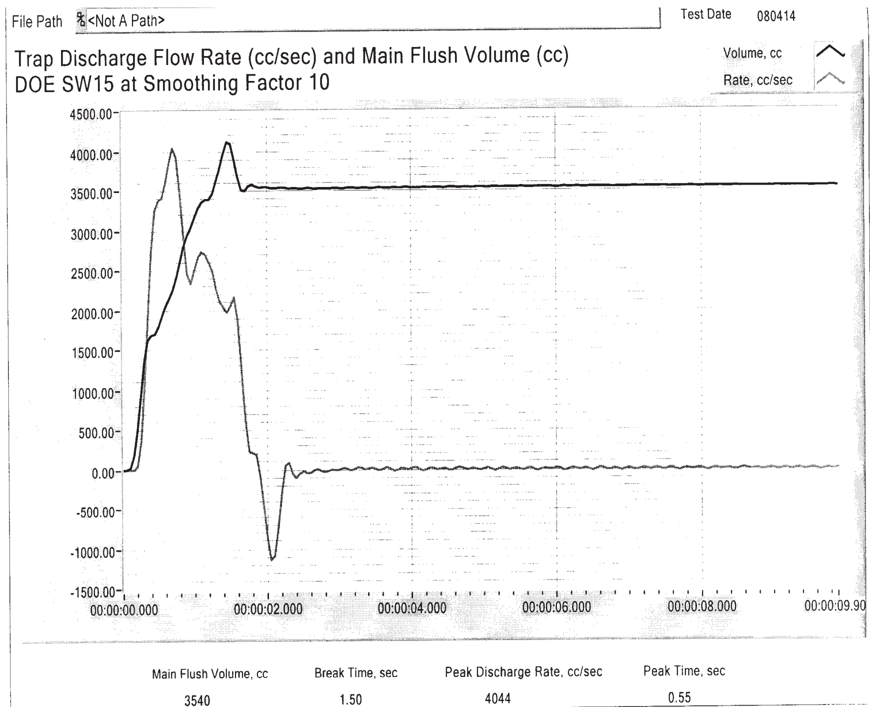
Phase 2 Work Plan Budget

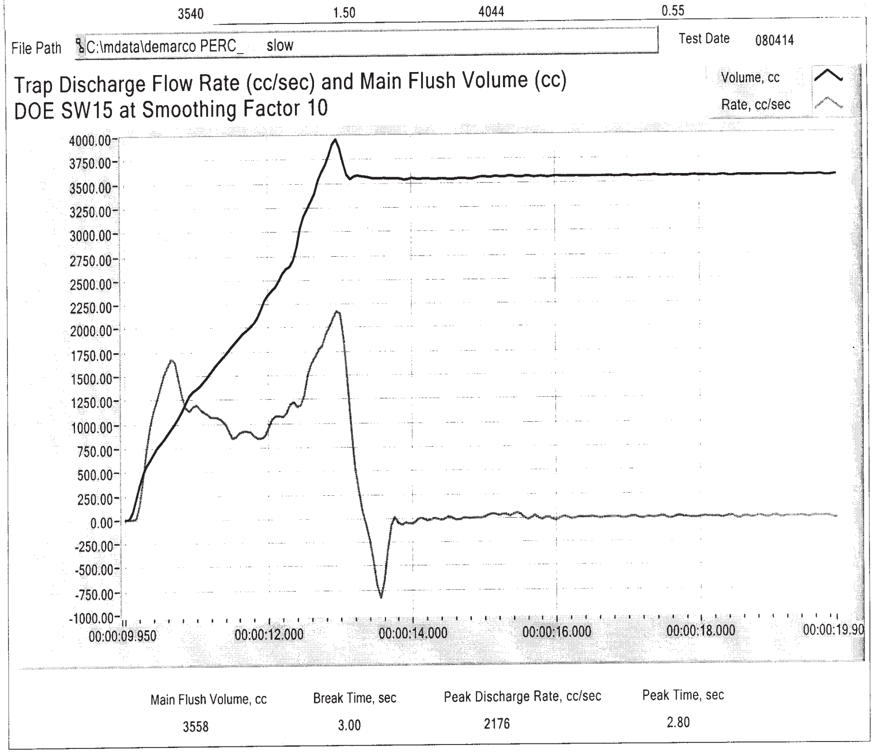
ITEM	PRICE/UNIT		COST
Surge Injector @ 1.0 gpf		**$**	**536.80**
ITEM	**PRICE/UNIT**		**COST**
MISO PASTE (AKA / RED MISO) 10200 grams / test run	$200 each / 20kg	$	9,000.00
TOILET PAPER	$20 / case	$	2,000.00
Shipping / tax (est)	$40 / 20 kg	$	1,800.00
	TOTAL	**$**	**12,800.00**
Labor	**35 weeks**	**$**	**140,000.00**
Total @ 2.5 test runs/week		**$**	**153,336.80**
5% contingency		$	7,666.84
Grand Total		**$**	**161,003.64**

APPENDIX C – ADDITIONAL SUPPORTING MATERIALS

3.8 Lpf / 1.0 gpf Surge Injector Discharge Curves

The discharge curves from the 3.8 Lpf / 1.0 gpf Surge Injector, which were used exclusively in PERC Phase 2.0, are shown below.



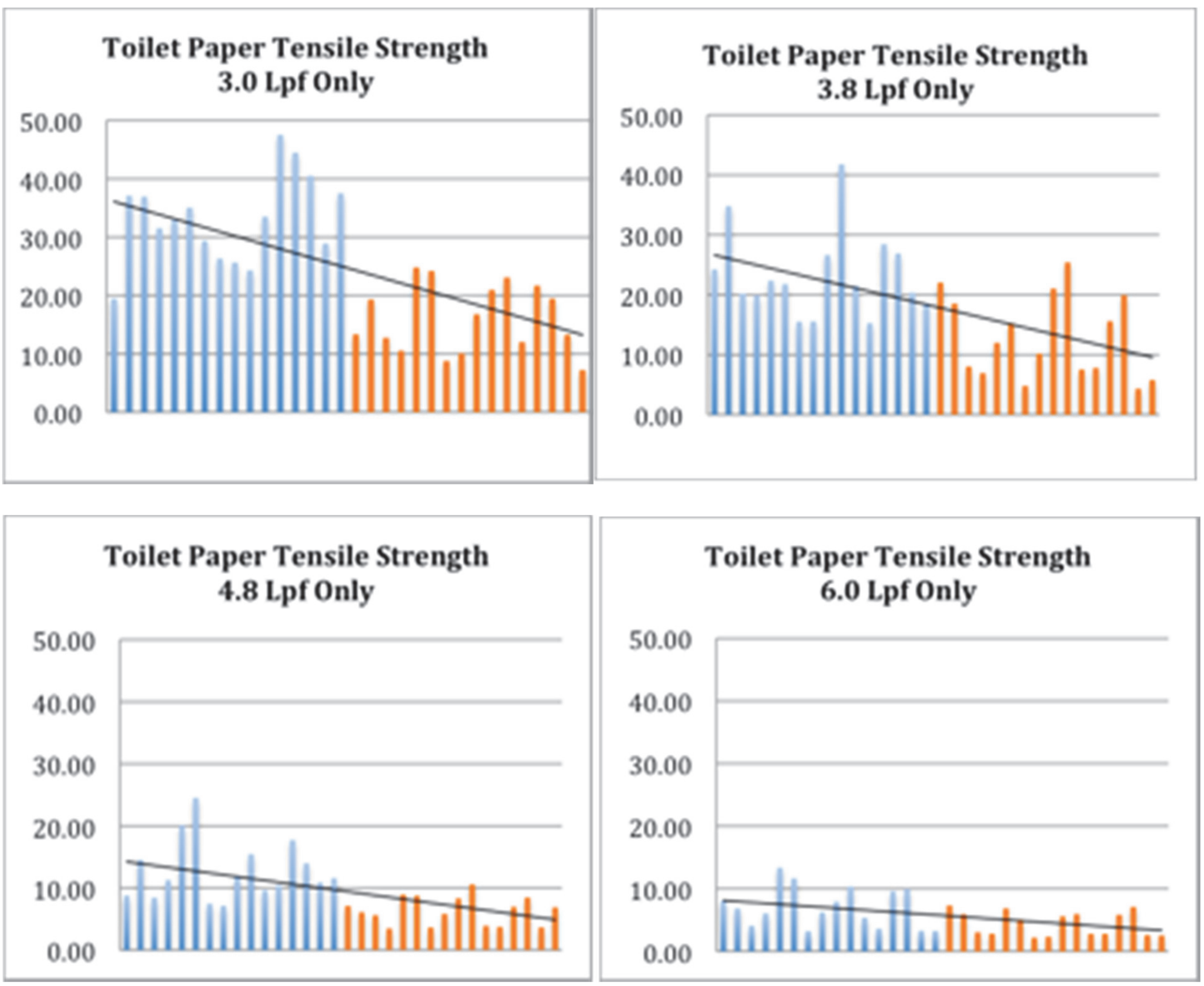


The Significance of Toilet Paper and Other Consumer “Flushables” in Drainline Transport

The Evolving Toilet Paper Roll

Among the most important findings from both the PERC Phase 1 and 2 studies was the strong significance of toilet paper selection in impacting drainline transport results. Many readers of this report, especially those in the plumbing trades and drainline clearing service industry will not be surprised by this finding as anecdotal reports from those sectors have repeatedly cited toilet paper and other paper items as the primary cause of blockages when clearing drains. Yet, this study demonstrated that paper, specifically the wet tensile strength of toilet papers currently available in the North American market, can be, at their high and low extremes, more significant than even a 1-degree reduction in drainline Slope or an incremental decrease in Flush Volume. See Charts C-1 through C-4, which detail the AFO scores from PERC Phases 1 and 2 at the four different Flush Volumes examined. Test runs conducted with High Tensile Strength Toilet Paper are shown in blue and test runs conducted with Low Tensile Strength Toilet Paper are shown in orange.

Charts C1 – C-4
AFO Scores Vs. Wet Tensile Strength



As detailed in the PERC 1 report, our close working relationship with AS-Flow in Australia was instrumental in PERC focusing on the issue of toilet paper. Specifically, Dr. Steve Cummings’ report, “Operational Performance Boundaries in Drainage Systems”, was key in PERC’s decision to include the Wet Tensile Strength of Toilet Paper as a test variable. That report detailed differences in the physical properties in toilet papers available in the Australian market. It also identified specific field drainline blockages where toilet paper, typically getting hung up at a horizontal Y-junctions and being too strong to fall apart, was clearly the reason for the blockages. PERC's contribution to this area of study was discovering and measuring the inverse correlation between wet tensile strength and drainline transport results, as discussed in the PERC Phase 1 report.

Since the PERC Phase 1 report was published, PERC has been tracking changes in the various toilet paper brands that were tested and included as part of that study. Much has changed in the interim. For example, the media has reported about the reduction in toilet paper "sheet size". A simple Google search on "toilet paper size reduction" will result in scores of articles on how toilet paper rolls are getting smaller. However, a closer look at the evolution of toilet paper reveals that sheet size and the amount of paper per roll isn't the only thing changing.

For the PERC Phase 1 study, several brands of toilet paper were purchased in late 2011 at a local grocery store in New Jersey in order to measure and test for various physical attributes. The two brands with the highest and lowest tensile strength were identified and used in the Phase 1 work. When preparing for PERC Phase 2, the same two brands of toilet paper were again purchased. However, it became quickly apparent that the high-tensile strength paper used in Phase 1 had been reformulated and its properties had changed considerably. The individual sheet size was smaller and the wet tensile strength was less than half of the previous version of the same paper. The packaging graphics and the marketing of the paper had not changed; it was still marketed as "Strong". Yet, due to the greatly diminished wet tensile strength, this same brand of paper could no longer be used for PERC Phase 2. Another high-tensile strength paper with a wet tensile strength as close as possible to the toilet paper used in Phase 1 was required. (Such is the assumed risk of using proprietary test media for research or long term testing purposes!)

One of the brands purchased for comparison testing to the high-tensile strength paper used in Phase 1 was a supermarket store brand. On the product packaging it had a graphic advising the consumer to compare it to the brand that was used in Phase 1. As it turned out, and fortunately for purposes of the PERC Phase 2 study, the store brand was identical in every measurable way to high-tensile strength paper used in Phase 1. Indeed, from all appearances, the exact same paper used in Phase 1 was now being sold as a store brand.

It was decided to again purchase all of the brands tested in Phase 1, along with a few new brands, to determine how widespread such changes in size and physical properties were in the marketplace. Refer to Table C-1. This table details the changes that occurred between late-2011 and mid-2014. The results show that in addition to reducing the amount of paper per roll, at least four (4) manufacturers also changed their paper formulations, resulting in very significant reductions in wet-tensile strength. PERC has no idea if this was intentional as a means to reduce drainline blockages, but nonetheless we are pleased to note this trend.

Table C-1
Evolution of Toilet Paper Properties 2011 to 2014

Phase 1								
Brand	Brand A	Brand B	Brand C	Brand D (low tensile Phase 1 and 2)	Brand E (high tensile Phase 1)	Brand F		
Marketed as	Soft	Gentle	Soft and Strong	$ saving	Strong	Eco		
dimensions	4.25" x 4"	4.125" x 4"	4.125" x 4"	4.125" x 3.75"	4.25" x 4"	4.125" x 4"		
ply	double	single	double	single	double	single		
Tensile Strength (# washers)	42	23	20	1	81	1		
Absorption Time (sec)	4	5	4	3	4	4		
Phase 2								
Brand	Brand A	Brand B	Brand C	Brand D	Brand E	Brand F	Brand G (new)	Brand K (hi tensile Phase 2)
Marketed as	Soft	Gentle	Soft and Strong	$ saving	Strong	Eco	Plush	Premium
dimensions	4" x 3.92"	4" x 3.86	4" x 4"	4.125" x 3.75"	4" x 3.92	4.125" x 4"	4" x 4"	double
ply	double	single	double	single	double	single	triple	4.25" x 4"
Tensile Strength (# washers)	32	11	15	1	39	1	48	79
Absorption Time (sec)	1.3	2	1.1	2	3.1	4	1.6	3.6

“Flushables”

While toilet paper is clearly a major factor where drainline blockages occur, there is new and potentially larger threat emerging, the use of (so-called) “flushable” personal wipes. Again, a great deal of information pertaining the issue of blockage problems associated with the use of wipes is widely available on the Internet. Most of the problems that have been associated with the use of wipes have occurred in sewers, including the infamous West-London “Fatburg”.[7] There have also been widespread reports of wipes causing havoc with equipment at wastewater treatment facilities. However, there have also been blockage problems associated with wipes in building drains as well, with at least one resulting in litigation against wipe manufacturers.

Consumers are also part of the problem. There are many types of wipes on the market. The ones typically sold as “personal wipes” are intended by the manufacturer to be used instead of or in addition to toilet paper and disposed of by flushing down a toilet. These are labeled as “flushable”.

[7] Article, *Britain's biggest 'fatberg' removed from London sewer*, BBC Newsbeat, August 6, 2013
http://www.bbc.co.uk/newsbeat/article/23586290/britains-biggest-fatberg-removed-from-london-sewer

However, there are also “baby wipes” and “on the go wipes” that are not intended to be flushed. Yet, due to the lower cost associated with the non-flushable types of wipes, they are also being used as personal wipes and are frequently flushed through the toilet. In addition, the higher fat content in the modern First World consumer diet[8] is contributing to this problem as fats, oils and greases combine with the wipes in sewers and building drains, as evidenced by the “Fatburg”, and lead to more blockage problems.

Just as this problem is multifaceted, so are the pending solutions. The International Organization for Standardization (ISO) is currently developing a consensus based standard (ISO TC224 WG10 – Flushable Products) for products intended to be marketed as “flushable”. The stated purpose of the standard is “to establish the essential qualities, characteristics and performance of products intended for personal use that are declared, advertised and distributed or sold as being a flushable product - i.e., a product suitable for disposal in a toilet.” At least 10 countries are now directly engaged in this ISO process, with completion of a committee draft standard programmed for release no later than 2017. It is unknown how effective this standard will be once published without corresponding regulations to mandate its use.

At the same time, manufacturers of wipes report they are researching formulation changes that reduce the potential for the wipes to cause blockage problems. Manufacturers of equipment for wastewater treatment facilities are redesigning various components to deal with the increased use of wipes. And utilities are launching marketing campaigns to educate consumers about the consequences of what they flush down the toilet. Clearly, this is an issue in flux, which makes it very difficult to conduct research on drainline performance, as so many aspects of the blockage problem and the solutions are rapidly evolving.

PERC will continue to monitor this issue closely.

[8] Study, World Health Organization, *Global and regional food consumption patterns and trends* http://www.who.int/nutrition/topics/3_foodconsumption/en/index2.html