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

Plumbing Efficiency Research Coalition

Alliance for Water Efficiency

ASPE American Society of Plumbing Engineers

IAPMO

ICC International Code Council

PHCC Plumbing-Heating-Cooling Contractors Association

pmi Plumbing Manufacturers International

Phase 2
Test Plan Proposal to Investigate Drainline Transport in Buildings

<u>Executive Summary</u>

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 <u>all</u> 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 <u>will</u> 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			
Diameter (in)	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**

List of Phase 1 and Phase 2 Test Runs and applicable variables

Phase 1 (black) ***Phase 2 Red***

4" Pipe

Run	Flush Volume	Flush Rate	Trailing Water	Slope	Toilet paper
1	6	Low	0.75	0.01	High Tensile
2	3	Low	0.75	0.01	High Tensile
3	4.8	Low	0.75	0.01	High Tensile
4	6	High	0.25	0.01	High Tensile
5	3	Low	0.25	0.01	High Tensile
6	6	High	0.75	0.01	High Tensile
7	4.8	High	0.25	0.01	High Tensile
8	3	High	0.75	0.01	High Tensile
9	3	High	0.25	0.01	High Tensile
10	4.8	Low	0.25	0.01	High Tensile
11	4.8	High	0.75	0.01	High Tensile
12	6	Low	0.25	0.01	High Tensile
13	3	Low	0.75	0.01	Low Tensile
14	4.8	Low	0.75	0.01	Low Tensile
15	3	Low	0.25	0.01	Low Tensile
16	4.8	High	0.25	0.01	Low Tensile
17	3	High	0.75	0.01	Low Tensile
18	3	High	0.25	0.01	Low Tensile
19	4.8	Low	0.25	0.01	Low Tensile
20	4.8	High	0.75	0.01	Low Tensile
21	*6*	*Low*	*0.75*	*0.01*	*Low Tensile*
22	*6*	*High*	*0.25*	*0.01*	*Low Tensile*
23	*6*	*High*	*0.75*	*0.01*	*Low Tensile*
24	*6*	*Low*	*0.25*	*0.01*	*Low Tensile*
25	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
26	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
27	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
28	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
29	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*
30	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*
31	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*
32	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*

Phase 2

3" Pipe

Run	*Flush Volume*	*Flush Rate*	*Trailing Water*	*Slope*	*Toilet paper*
1	*6*	*Low*	*0.75*	*0.01*	*High Tensile*
2	*3*	*Low*	*0.75*	*0.01*	*High Tensile*
3	*4.8*	*Low*	*0.75*	*0.01*	*High Tensile*
4	*6*	*High*	*0.25*	*0.01*	*High Tensile*
5	*3*	*Low*	*0.25*	*0.01*	*High Tensile*
6	*6*	*High*	*0.75*	*0.01*	*High Tensile*
7	*4.8*	*High*	*0.25*	*0.01*	*High Tensile*
8	*3*	*High*	*0.75*	*0.01*	*High Tensile*
9	*3*	*High*	*0.25*	*0.01*	*High Tensile*
10	*4.8*	*Low*	*0.25*	*0.01*	*High Tensile*
11	*4.8*	*High*	*0.75*	*0.01*	*High Tensile*
12	*6*	*Low*	*0.25*	*0.01*	*High Tensile*
13	*3*	*Low*	*0.75*	*0.01*	*Low Tensile*
14	*4.8*	*Low*	*0.75*	*0.01*	*Low Tensile*
15	*3*	*Low*	*0.25*	*0.01*	*Low Tensile*
16	*4.8*	*High*	*0.25*	*0.01*	*Low Tensile*
17	*3*	*High*	*0.75*	*0.01*	*Low Tensile*
18	*3*	*High*	*0.25*	*0.01*	*Low Tensile*
19	*4.8*	*Low*	*0.25*	*0.01*	*Low Tensile*
20	*4.8*	*High*	*0.75*	*0.01*	*Low Tensile*
21	*6*	*Low*	*0.75*	*0.01*	*Low Tensile*
22	*6*	*High*	*0.25*	*0.01*	*Low Tensile*
23	*6*	*High*	*0.75*	*0.01*	*Low Tensile*
24	*6*	*Low*	*0.25*	*0.01*	*Low Tensile*
25	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
26	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
27	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
28	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*
29	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*
30	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*
31	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*
32	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*

Run	Flush Volume	Flush Rate	Trailing Water	Slope	Toilet paper	*Run*	*Flush Volume*	*Flush Rate*	*Trailing Water*	*Slope*	*Toilet paper*
33	3	High	0.25	0.02	Low Tensile	*21*	*3*	*High*	*0.25*	*0.02*	*Low Tensile*
34	3	High	0.25	0.02	High Tensile	*22*	*3*	*High*	*0.25*	*0.02*	*High Tensile*
35	4.8	Low	0.75	0.02	High Tensile	*23*	*4.8*	*Low*	*0.75*	*0.02*	*High Tensile*
36	3	Low	0.75	0.02	Low Tensile	*24*	*3*	*Low*	*0.75*	*0.02*	*Low Tensile*
37	4.8	Low	0.25	0.02	Low Tensile	*25*	*4.8*	*Low*	*0.25*	*0.02*	*Low Tensile*
38	3	Low	0.25	0.02	Low Tensile	*26*	*3*	*Low*	*0.25*	*0.02*	*Low Tensile*
39	6	High	0.25	0.02	High Tensile	*27*	*6*	*High*	*0.25*	*0.02*	*High Tensile*
40	4.8	High	0.75	0.02	Low Tensile	*28*	*4.8*	*High*	*0.75*	*0.02*	*Low Tensile*
41	3	High	0.75	0.02	High Tensile	*29*	*3*	*High*	*0.75*	*0.02*	*High Tensile*
42	6	Low	0.75	0.02	High Tensile	*30*	*6*	*Low*	*0.75*	*0.02*	*High Tensile*
43	6	High	0.75	0.02	High Tensile	*31*	*6*	*High*	*0.75*	*0.02*	*High Tensile*
44	4.8	Low	0.25	0.02	High Tensile	*32*	*4.8*	*Low*	*0.25*	*0.02*	*High Tensile*
45	4.8	High	0.25	0.02	High Tensile	*33*	*4.8*	*High*	*0.25*	*0.02*	*High Tensile*
46	3	High	0.75	0.02	Low Tensile	*34*	*3*	*High*	*0.75*	*0.02*	*Low Tensile*
47	6	Low	0.25	0.02	High Tensile	*35*	*6*	*Low*	*0.25*	*0.02*	*High Tensile*
48	3	Low	0.75	0.02	High Tensile	*36*	*3*	*Low*	*0.75*	*0.02*	*High Tensile*
49	3	Low	0.25	0.02	High Tensile	*37*	*3*	*Low*	*0.25*	*0.02*	*High Tensile*
50	4.8	Low	0.75	0.02	Low Tensile	*38*	*4.8*	*Low*	*0.75*	*0.02*	*Low Tensile*
51	4.8	High	0.75	0.02	High Tensile	*39*	*4.8*	*High*	*0.75*	*0.02*	*High Tensile*
52	4.8	High	0.25	0.02	Low Tensile	*40*	*4.8*	*High*	*0.25*	*0.02*	*Low Tensile*
53	*6*	*Low*	*0.75*	*0.01*	*Low Tensile*	53	6	Low	0.75	0.01	Low Tensile
54	*6*	*High*	*0.25*	*0.01*	*Low Tensile*	54	6	High	0.25	0.01	Low Tensile
55	*6*	*High*	*0.75*	*0.01*	*Low Tensile*	55	6	High	0.75	0.01	Low Tensile
56	*6*	*Low*	*0.25*	*0.01*	*Low Tensile*	56	6	Low	0.25	0.01	Low Tensile
57	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*	57	3.8	High	0.75	0.01	Low Tensile
58	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*	58	3.8	High	0.75	0.01	Low Tensile
59	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*	59	3.8	High	0.75	0.01	Low Tensile
60	*3.8*	*High*	*0.75*	*0.01*	*Low Tensile*	60	3.8	High	0.75	0.01	Low Tensile
61	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*	61	3.8	Low	0.25	0.01	High Tensile
62	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*	62	3.8	Low	0.25	0.01	High Tensile
63	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*	63	3.8	Low	0.25	0.01	High Tensile
64	*3.8*	*Low*	*0.25*	*0.01*	*High Tensile*	64	3.8	Low	0.25	0.01	High Tensile

Appendix

For readers who have read PERC's report on Phase 1 of this study, the following will serve as a brief review of the deliverables and additional findings that resulted from Phase 1 and selected items from the section on Future Study Opportunities that pertain to our proposed Phase 2 body of work.

Excerpts from the Phase 1 Report:

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

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

Discussion: When observing the behavior of waste in the test apparatus, it quickly became apparent that once the effect of the initial flush surge diminishes, movement of the solids occurred independently of the subsequent flushes and occurred only when the weight of the water behind the solids overcame the friction of the solids resting on the interior of the pipe wall (as in a sewer). Therefore, there was no advantage in attempting the clearing flush at the 2 percent interval (after the 50^{th} flush injection and again at after the 100^{th} flush injection). This was because the mass of the media in the Test Apparatus at any given point in a given test run varied widely depending upon the random movement of media at any given time during that test run. Accordingly, the clearing flush was not evaluated at a 2 percent interval.

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

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

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

[1] *See Section 8, Future Study Opportunities, for additional discussion regarding a clearing flush.*

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

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

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

Additional findings resulting from the Work Plan were as follows:

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

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

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

- Percent Trailing Water and Flush Rate – The data shows that, in a long drainline, when toilet paper and a more realistic test media are used (such as that used in this study), and in long duration (100 flush) flush sequences, Percent Trailing Water and Flush Rate (i.e.: toilet flush discharge characteristics) were non-significant factors in this study. This finding has implications regarding the necessity for having a Drainline Transport Characterization Test in the North American standard for toilets, *ASME A112.19.2 / CSA B45.1, Ceramic Plumbing Fixtures*. These findings will be forwarded to the ASME / CSA Joint Harmonized Committee of Plumbing Fixtures for their consideration.

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

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

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

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

- It should be noted that Table 7-H shows only the inverse correlation results between wet tensile strength and transport distances on the two toilet papers used in the PERC Test Plan. In addition, this test was run on three (3) brands of toilet paper from Australia (the "best", "worst" and "nearest to average" brands, based on transport distances as identified in Dr. Cummings' report) and three (3) popular brands of paper sold in the United States. In each case, an inverse correlation in the high 80's or 90's resulted[2].

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

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

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

FUTURE STUDY OPPORTUNITIES

The PERC has completed its Phase 1 Work Plan on drainline transport, building upon studies previously conducted by others. This was accomplished within severe funding limits. There is much yet to be done to bring the ideal of laboratory testing closer to the conditions and materials found in the 'real world' of new and remodeled commercial buildings. The following tasks are proposed here with the clear understanding there is a price tag connected with each

[2] *Correlation data for all toilet paper tests appears in Appendix C – Supporting Materials.*

one. No attempt has been made below to prioritize this list. However, it is likely that available funds will be the driver as we proceed into future drainline testing phases.

As PERC defines future study opportunities, our partner, American Standard Brands, has generously offered to continue to provide the facilities used in this first phase. Following are the critical areas of future study that we believe need to be undertaken in the near future*. (Note: Only the future study opportunities that are addressed in the Phase 2 Test Plan Proposal are detailed below.)*

- All of the PERC testing to date has used 4-inch (100mm) diameter pipe. The body of knowledge surrounding multi-phase flow in partially filled pipes says that waste transport is significantly affected by pipe diameter due to resulting higher flood levels inside the smaller diameter pipe. With that understanding, the study of the impacts of 3-inch (75mm) nominal diameter pipe on waste transport is essential to expand the boundaries of our understanding, using all of the same data points as were developed with 4-inch (100mm) pipe.

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