The Implications of Reduced Flows in Building Drains

PERC Phase 2.0

What is PERC ?

Formed in December of 2008

MoU Signed at EPA HQ

First Project: Drainline Transport

MoU with AS-Flow in 2010

Why Drainline Transport?

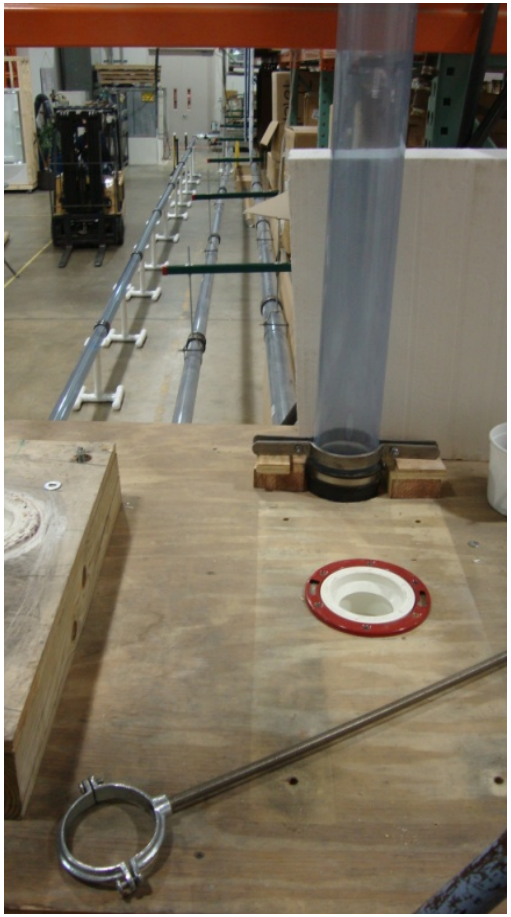
- Toilet consumption reduced 3.5 gpf → 1.6 gpf →1.28 gpf → ?
- Commercial installations
  - Isolated bathrooms
  - Long horizontal run building drains
  - Non-water consuming urinals, ultra low flow faucets (0.5 gpm)
  - Proliferation of other water efficient technologies; medical, food service, industrial and commercial processes
  - Toilets increasingly stressed
- Domestic installations
  - Reduced flow showerheads and appliances
  - Graywater reuse systems – long term potential to eliminate long duration flows

The PERC Approach

- PERC Design of Experiment
  - The "Real World": Too Variable to Duplicate / Characterize
  - Need to Understand What's Really Important
  - Build a Perfect Drainline
- The Test Apparatus
  - 4" Clear PVC, (3" Clear PVC added in Phase 2)
  - 135 feet long (~41 M)
  - Slope Adjustable

The PERC Approach

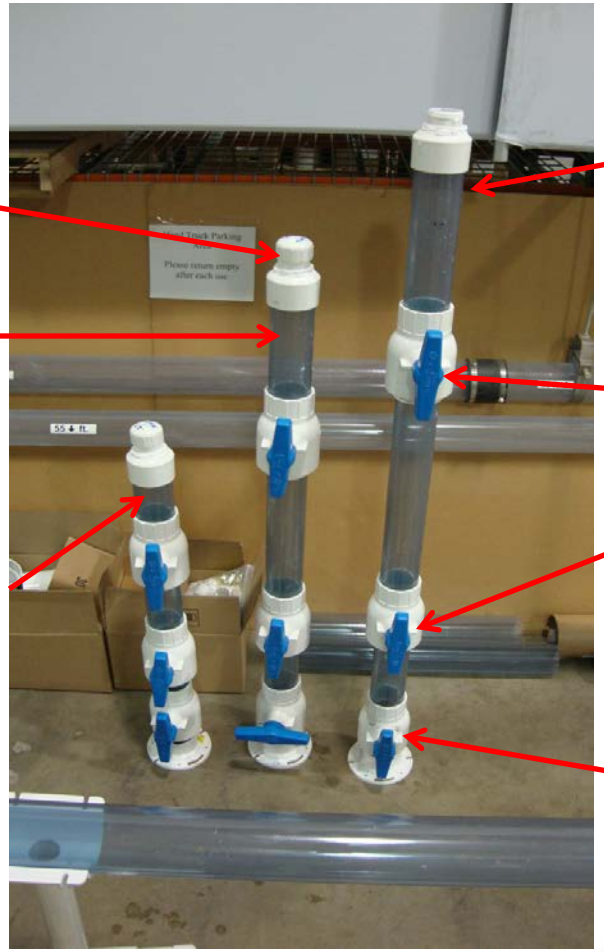
Test Apparatus Viewed from Flush Stand



Two 90° Wide Sweep Bends at Far End

The PERC Approach

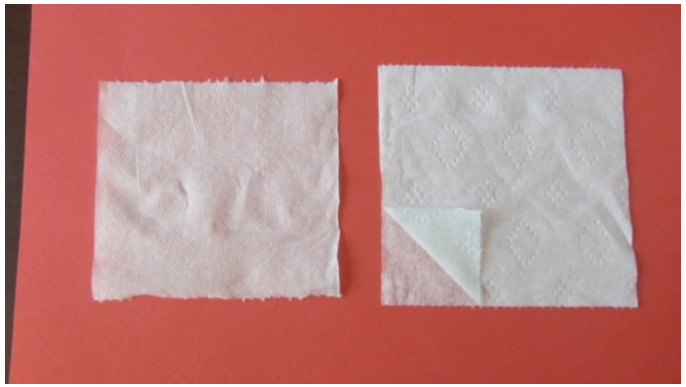
- Surge Injectors
  - More Accurate than Toilets
  - Control Flush Rate (2)
    - Threaded cap orifice
    - 2500 ml/sec
    - 3500 ml/sec
  - Control % Trailing Water (2)
    - 75%
    - 25%
  - Test Volumes (3)
    - 1.6, 1.28, 0.8 gpf
    - (6.0, 4.8, 3.0 Lpf)



Test Media

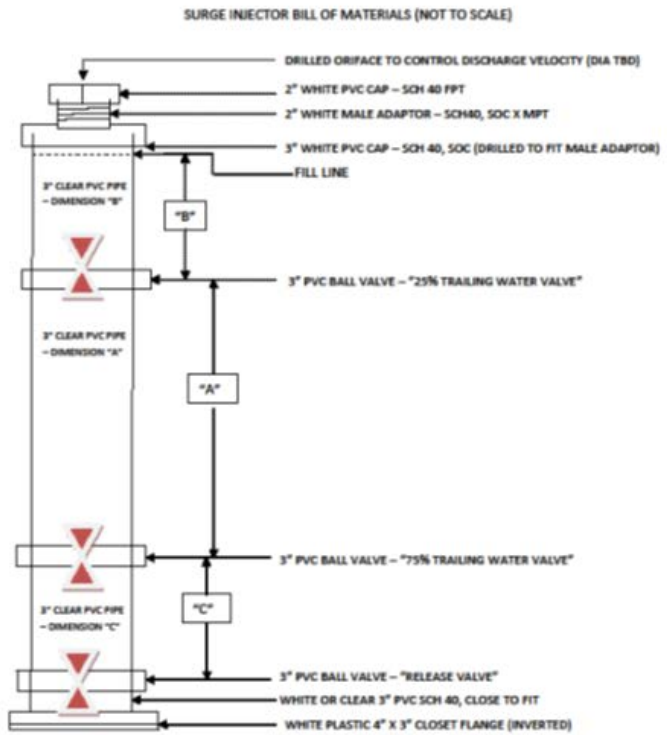
- Uncased "MaP" Test Media
  - Proven "Realistic" in Toilet Testing
  - Deformable, "breaks down"

- Toilet Paper
  - Two common US Brands
    - Low Tensile Strength
    - High Tensile Strength



Test Media – How much to use?

- Assumptions:
  - Commercial Office Building
    - Non-water consuming urinals and 0.5 gpm faucets
  - All males use urinals for liquid waste
  - Males: use toilet 33.3 % of the time for solid waste, urinals 66.7 % of the time.
  - Females: use the toilet 100% of the time, 33.3 percent for solid waste, 66.7 percent of the time for liquid waste and toilet paper only.



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

Illustration: Schematic – Elevation view of Surge Injector

Test Media – How much to use?

- Assumptions (continued):
- 50 percent of the flushes: solid waste and toilet paper
- 50 percent having liquid waste and paper only.
- 100 percent of the flushes contain toilet paper.
- Solid waste loadings vary randomly and evenly @ 300, 200 and 100 grams
- *Note: Amounts of solid waste are consistent with past medical studies*

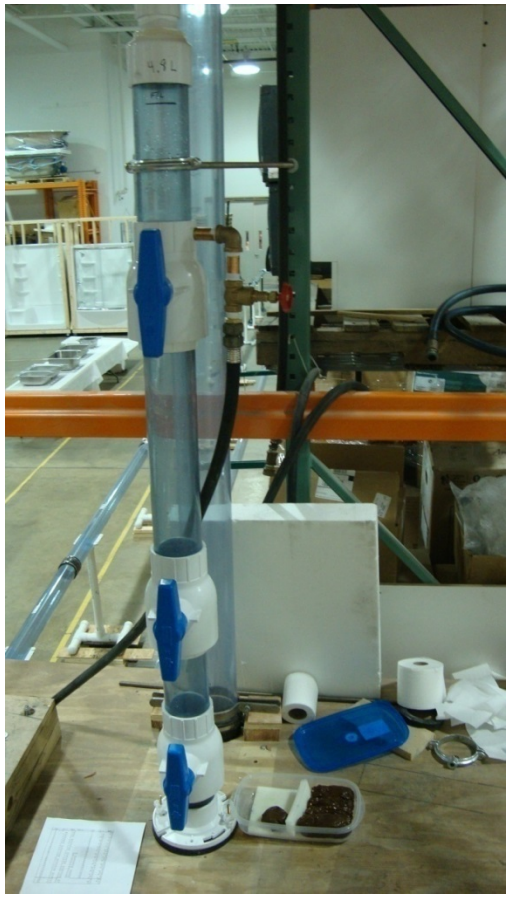


Photo: Surge Injector installed on apparatus flush stand

Test Media – How much to use?

- Toilet Paper Amounts
  - Different tensile strengths – different use amounts
  - Double the amount of low tensile strength paper to normalize

The PERC Phase 1 Test Plan Primary Deliverables

- Identify a flush volume based "**tipping point**" where drain line transport efficacy is compromised due to insufficient water to move solid waste
- Determine and rate the comparative **significance** of real world factors (test variables) in the movement of solid waste in drain lines
- Determine if **toilet design** matters
- Share findings with industry SDOs

The PERC Test Plan

- The Designed Experiment (DOE)
  - What is a designed experiment?
    - Groups test variables
    - Assigns random test sequence
    - Determine the relative significance of the test variables
    - Uses pre-determined statistical model to analyze data
    - Able to differentiate between “signal” (impact of the variables on the system) and “noise” (random occurrences in the system not attributed to the test variables)
  - Analysis of Variance “ANOVA”
    - Statistical model best suited to rank test variables
    - Significance determined by low “P-value”

The PERC Test Plan – Phase 1

The test variables

- ✓ *1 Diameter: 4-inch / ~100* mm
- ✓ *2 Pitches: 1.00%; 2.00%*
- ✓ *3 Flush Volumes: 6.0/1.6; 4.8/1.3; 3.0/0.8 (Lpf / gpf)*
- ✓ *2 Flush Rates: 3500; 2500 (ml/sec –peak flow)*
- ✓ *2 Percent Trailing Water Levels: 75%; 25%*
- ✓ *2 Toilet Paper Tensile Strengths: High; Low*

The PERC Test Plan

- Execution of the DOE
  - Test Sequence
    - 100 cycle ***Test Runs*** that capture the test variables
    - Random test sequence determined by computer
  - How do we measure?
  - ***Flushes to Out (FO)***: *the number of flushes it took for an individual injection of test media to run the 135 foot Test Apparatus course of in a Test Run*
  - ***Average Flushes to Out (AFO):*** *the average Flushes to Out value in a Test Run after 100 flush cycles*
  - **IMPORTANT** - The AFO scores were used to calculate all results

Test Procedure

Example: Injection with 75 percent trailing water

1. Remove threaded cap with drilled orifice at the top of the Surge Injector.
2. Fill Surge Injector with water until water flows past the height of the 75 percent ball valve.
3. Close the 75 percent ball valve and place the required amount of test media and toilet paper into the injector.
4. Fill the surge injector to the marked ‘fill line’.
5. Replace the threaded cap on the Surge Injector
6. Open the 75 percent trailing water valve and immediately open the discharge valve allowing water and test media to flow into the test apparatus.
7. Record (on the data sheet) the distance that the test media travels on the first flush.
8. Repeat steps 1 through 7 as per the Test Plan.
9. Record the distance that the test media travels on each subsequent flush until the test media exits the apparatus.

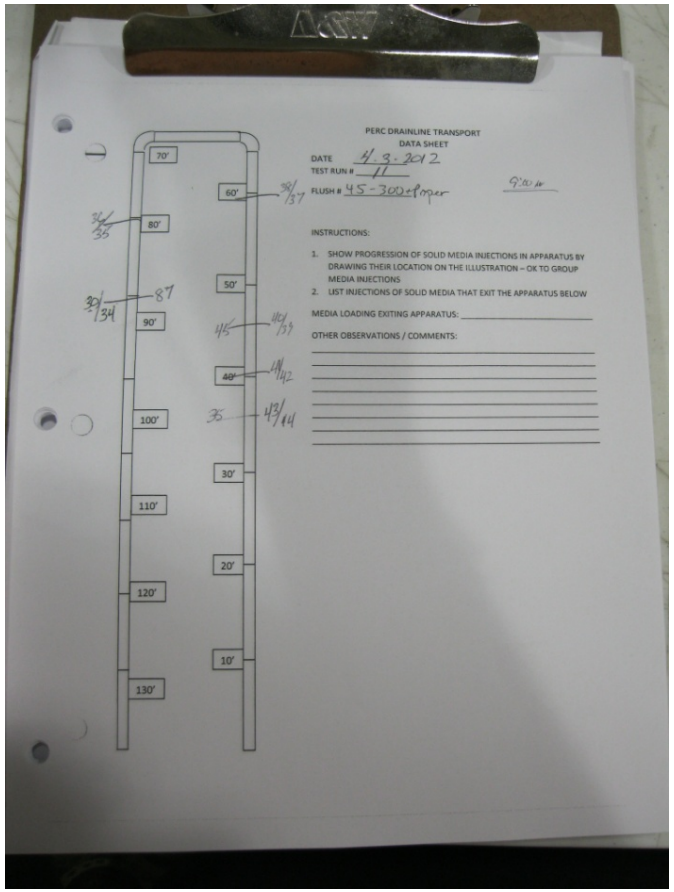
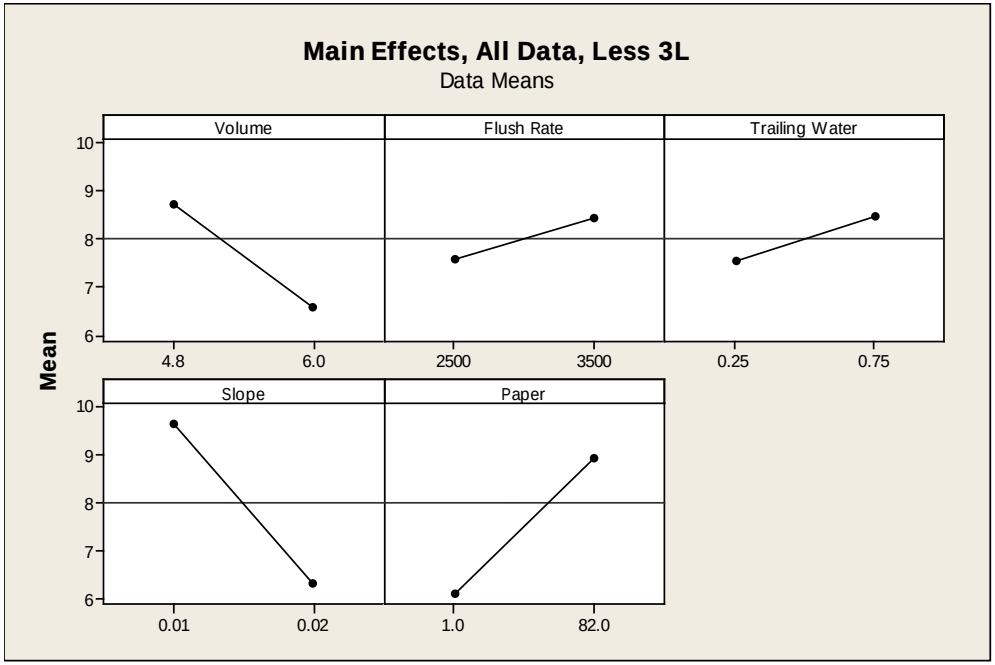


Photo: Completed data sheet

Phase 1 Findings

Variable	P Value
Volume	0.000*
Flush Rate	0.216
Trailing Water	0.185
Slope	0.000*
Paper	0.000*

- P-values below 0.05 indicate significance of the test variable
- R-Sq = 81.61percent



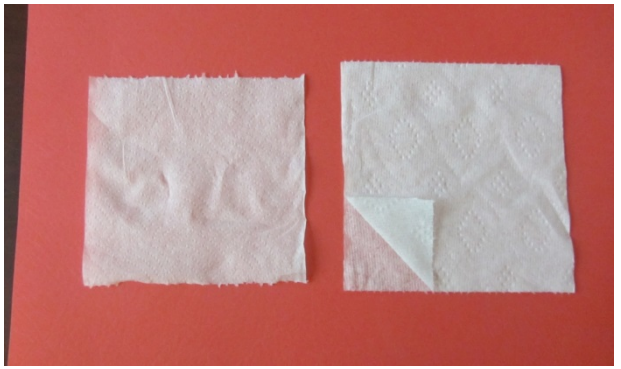
Level	Volume	Flush Rate	%Trailing Water	Slope	Paper
1	8.710	7.567	7.535	9.671	6.104
2	6.554	8.416	8.448	6.311	8.935
Delta	2.156	0.849	0.913	3.360	2.831
Rank	**3**	**5**	**4**	**1**	**2**

Phase 1 Additional Findings

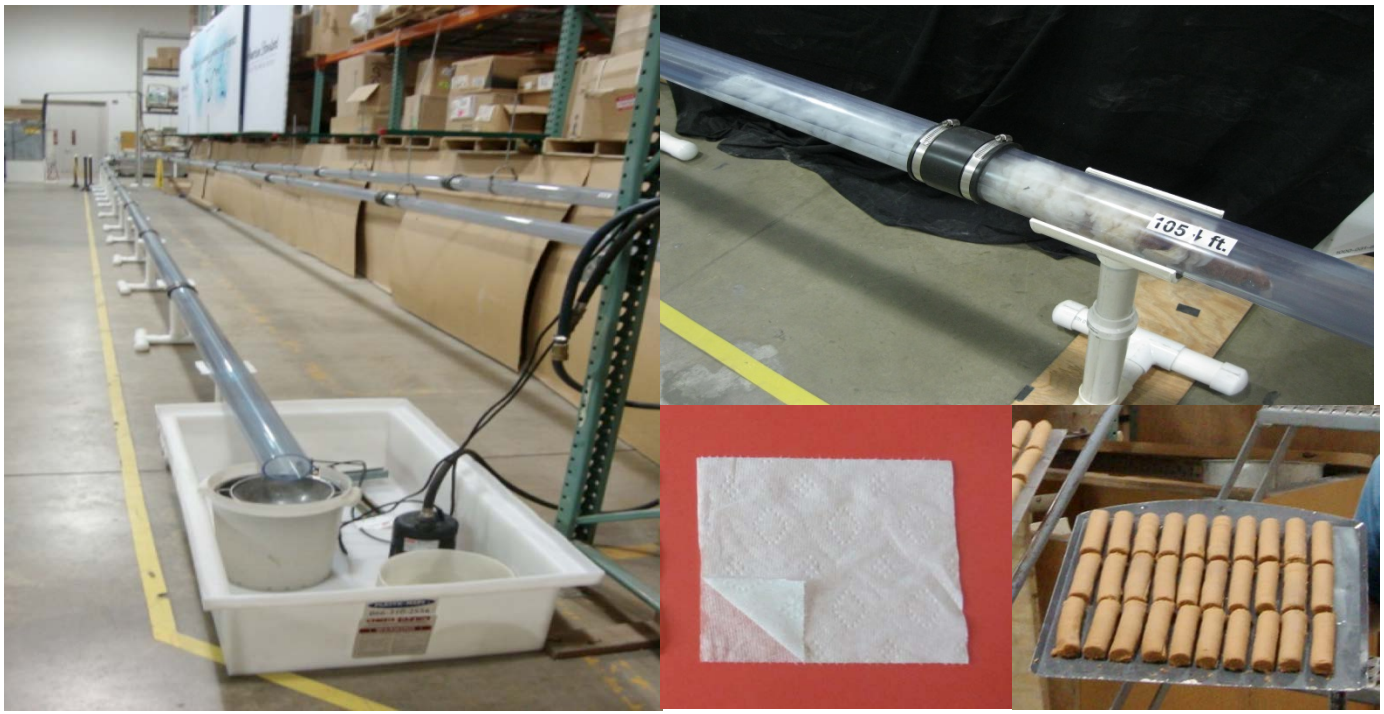
- 0.8 gpf / 3.0 Lpf Toilets: Chaotic conditions resulted in the test apparatus at this discharge volume. Further study needed on commercial installations w/ long horizontal runs to sewer and little or no additional long duration flows.
- 1.28 gpf / 4.8 Lpf HET's: The behavior of the Test Apparatus at this volume level indicates satisfactory performance at this discharge volume.
- Impact of Toilet Flush Characteristics: *Not significant factors in drain line performance in this study* **(further study required)**.

Phase 1 Additional Findings

- Significance of Toilet Paper: *Toilet paper characteristics have the potential to drastically impact DLT distances*
  - Strong inverse correlation between wet tensile strength and DLT distances
  - Caution: Potential demonstrated in the PERC DOE characterizes the extremes of toilet paper influence
  - Easy test to determine relative wet tensile strength developed
  - Possible low-cost solution to mitigate DLT related blockages



PERC Phase 2.0



Primary PERC
Phase 2 Focus Areas

- **Pipe Size Reduction** – Topic of debate at code hearings:
  - Will reduced pipe size improve drainline transport distances?
  - 3-inch test apparatus used in addition to the 4-inch diameter apparatus employed in Phase 1 to determine impact
- **Additional Flush Volume Level –**
  - Phase 1: behavioral shift and a chaotic drainline performance condition at 3.0 Lpf / 0.8 gpf consumption level.
  - Phase 2: investigate drainline transport performance at the 3.8 Lpf (1.0 gpf) volume level.
  - Many U.S. manufacturers already producing toilets that flush at this consumption level for both commercial and residential applications.

PERC Phase 2 - Deliverables

- **Deliverable 1 – Pipe Size Reduction**
  - Show how a commonly suggested pipe size reduction (going from 4-inch diameter pipe to 3-inch pipe) will impact drain line transport in a long horizontal run.
  - 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.
  - Provide needed data on implications of pipe size reductions
  - Advise future code considerations of pipe sizing requirements

PERC Phase 2 - Deliverables

- **Deliverable 2 – Added 1.0 gpf discharge level**
  - Provide 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)
  - Provide insight into the "tipping point" flush volume level, below which chronic blockage problems are more likely to occur.
- **General** - Share findings with industry SDOs

PERC Phase 2.0

- Same test apparatus, same surge injector design, same test media, same test methods, same data collection, same data analysis
  - Added:
    - 3” Pipe Diameter
    - 3.8 Lpf / 1.0 gpf surge injector
  - Phase 1 = 40 test runs
  - Phase 2 = 88 test runs
  - Total = 128 test runs, 12,800 individual “flushes”

Additional PERC Phase 2 Focus Areas

- **Toilet Paper Characteristics**
  - Phase 1 indicated a very strong significance for the wet tensile strength of toilet paper to impact drainline transport performance
  - We cannot assume the results achieved related to toilet paper when using the 3-inch diameter pipe.
- **Toilet Flush Characteristics**
  - Phase 1 results indicated non-significance of the toilet flush characteristics Percent Trailing Water and Flush Rate
  - Before these characteristics can be dismissed, results must be confirmed in Phase 2

The PERC Test Plan – Phase 1

The test variables

- ✓ *1 Diameter: 4-inch / ~100* mm
- ✓ *2 Pitches: 1.00%; 2.00%*
- ✓ *3 Flush Volumes: 6.0/1.6; 4.8/1.3; 3.0/0.8 (Lpf / gpf)*
- ✓ *2 Flush Rates: 3500; 2500 (ml/sec –peak flow)*
- ✓ *2 Percent Trailing Water Levels: 75%; 25%*
- ✓ *2 Toilet Paper Tensile Strengths: High; Low*

The PERC Test Plan – Phase 2

The test variables

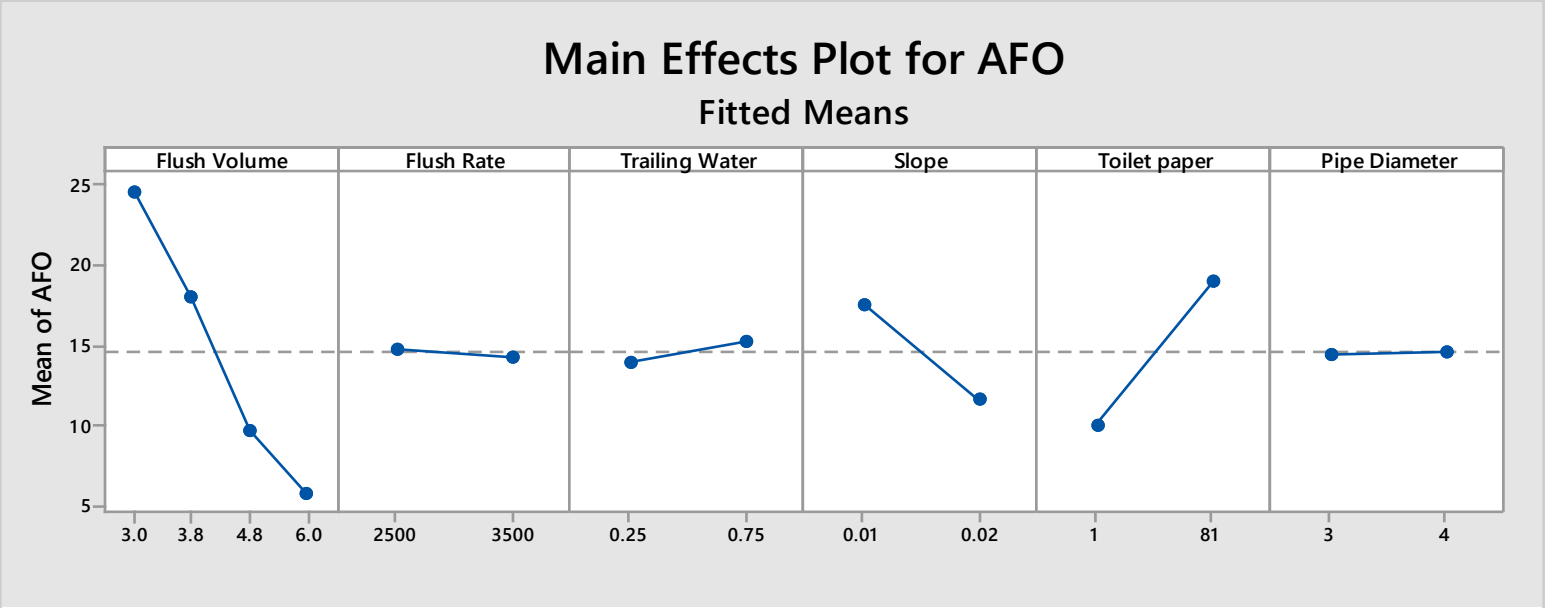
- ✓ *1 Diameter: 4-inch / ~100* mm; **3-inch / ~75 mm**
- ✓ *2 Pitches: 1.00%; 2.00%*
- ✓ *3 Flush Volumes: 6.0/1.6; 4.8/1.3;* **3.8 / 1.0**; *3.0/0.8 (Lpf / gpf)*
- ✓ *2 Flush Rates: 3500; 2500 (ml/sec –peak flow)*
- ✓ *2 Percent Trailing Water Levels: 75%; 25%*
- ✓ *2 Toilet Paper Tensile Strengths: High; Low*

Phase 2 Findings

Variable	P Value
Volume	0.000*
Flush Rate	0.472
Trailing Water	0.182
Slope	0.000*
Paper	0.000*
Pipe Diameter	0.533

P-values below 0.05 indicate significance

R-Sq = 84.6 percent



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	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**

Response Table for Means

Volume: 3.8 Lpf (1.0 gpf) to 4.8 Lpf (1.28 gpf)

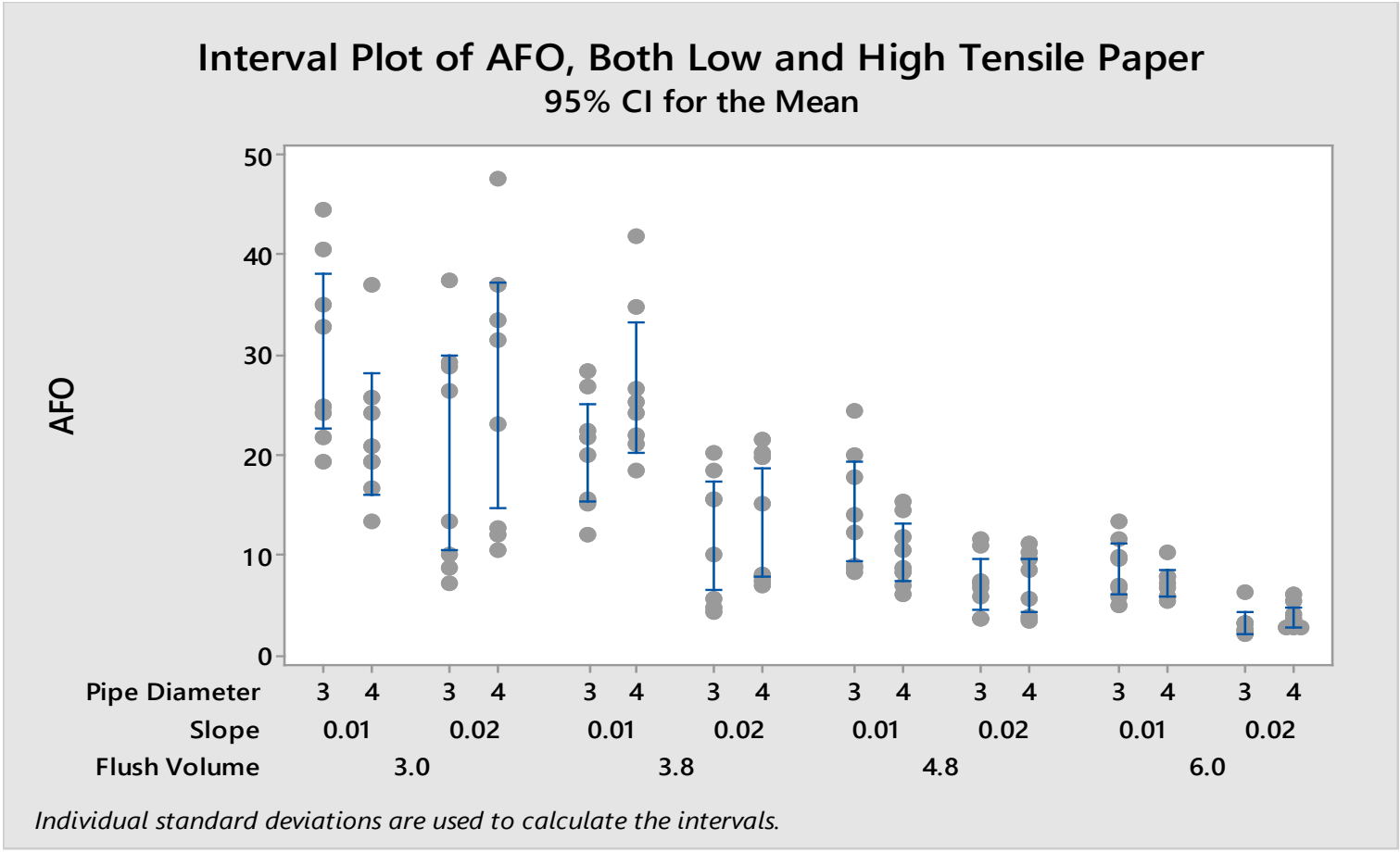
Level	Volume	Flush Rate	%Trailing Water	Slope	Paper	Pipe Diameter
1 (3.8 Lpf)	18.11	14.77	13.93	17.45	9.94	14.44
2 (4.8 Lpf)	9.56	14.28	15.11	11.59	19.10	14.60
Delta	8.55	0.49	1.18	5.86	9.16	0.16
Significance Rank	**2**	**5**	**4**	**3**	**1**	**6**

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	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**

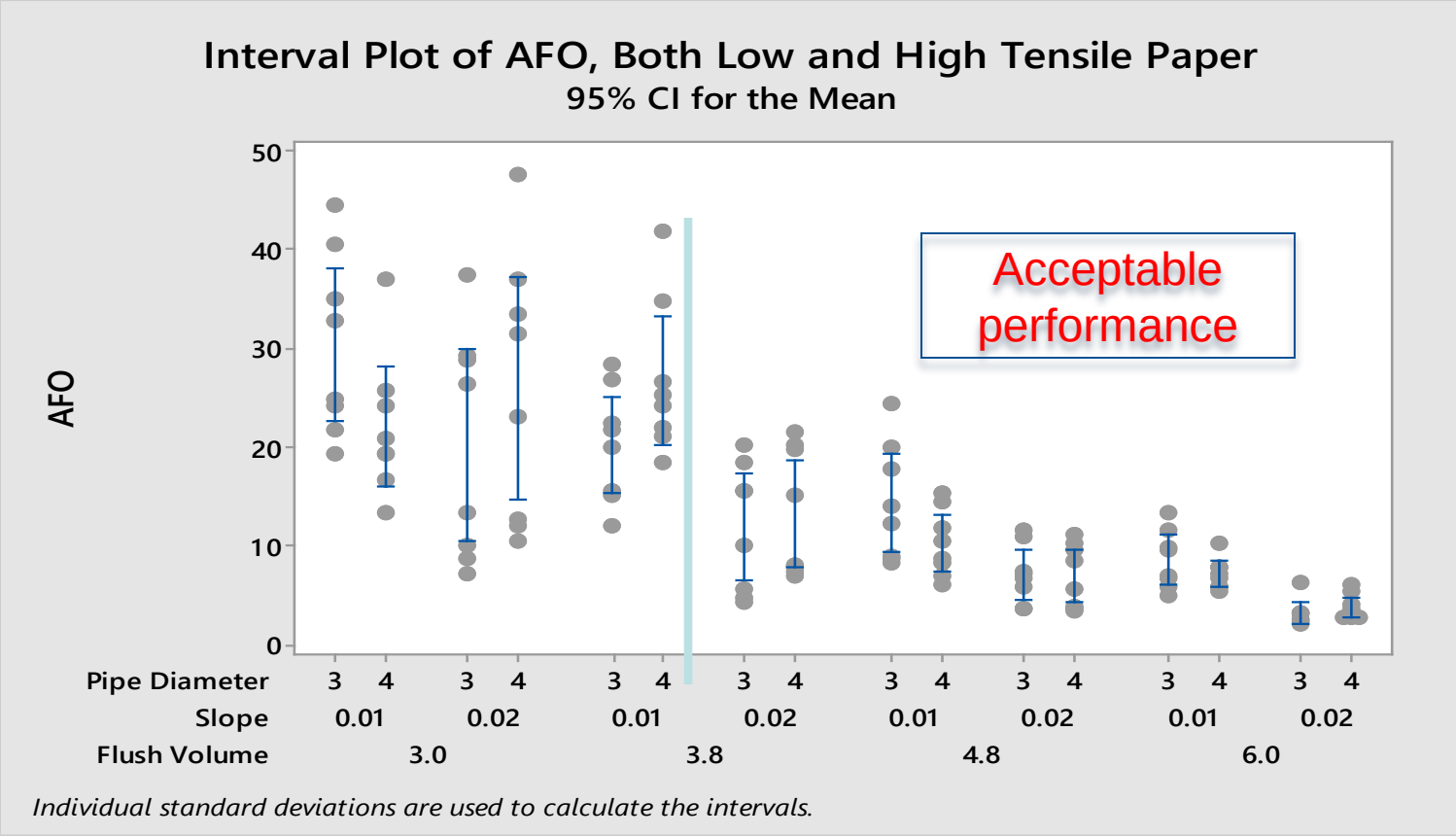
PERC 2 Finding: Pipe Diameter – Deliverable 1



Individual standard deviations are used to calculate the intervals.

Pipe diameter reduction does <u>not</u> reliably improve drain line transport in long building drains.

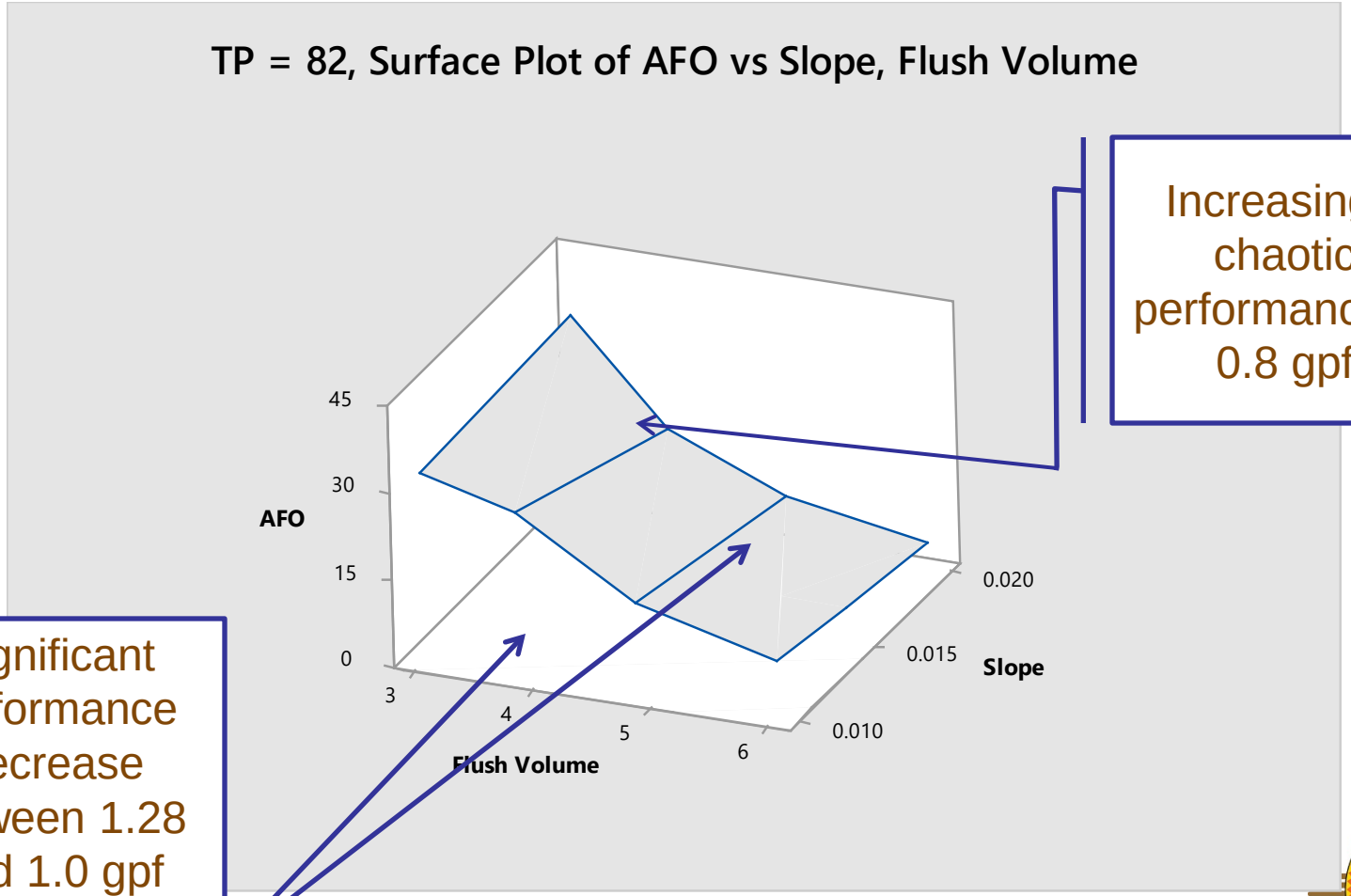
PERC 2 Finding: The "Tipping Point" – Deliverable #2



The tipping point lies <u>within</u> the 1.0 gpf data set.
PERC does not recommend 1.0 gpf in long drains.

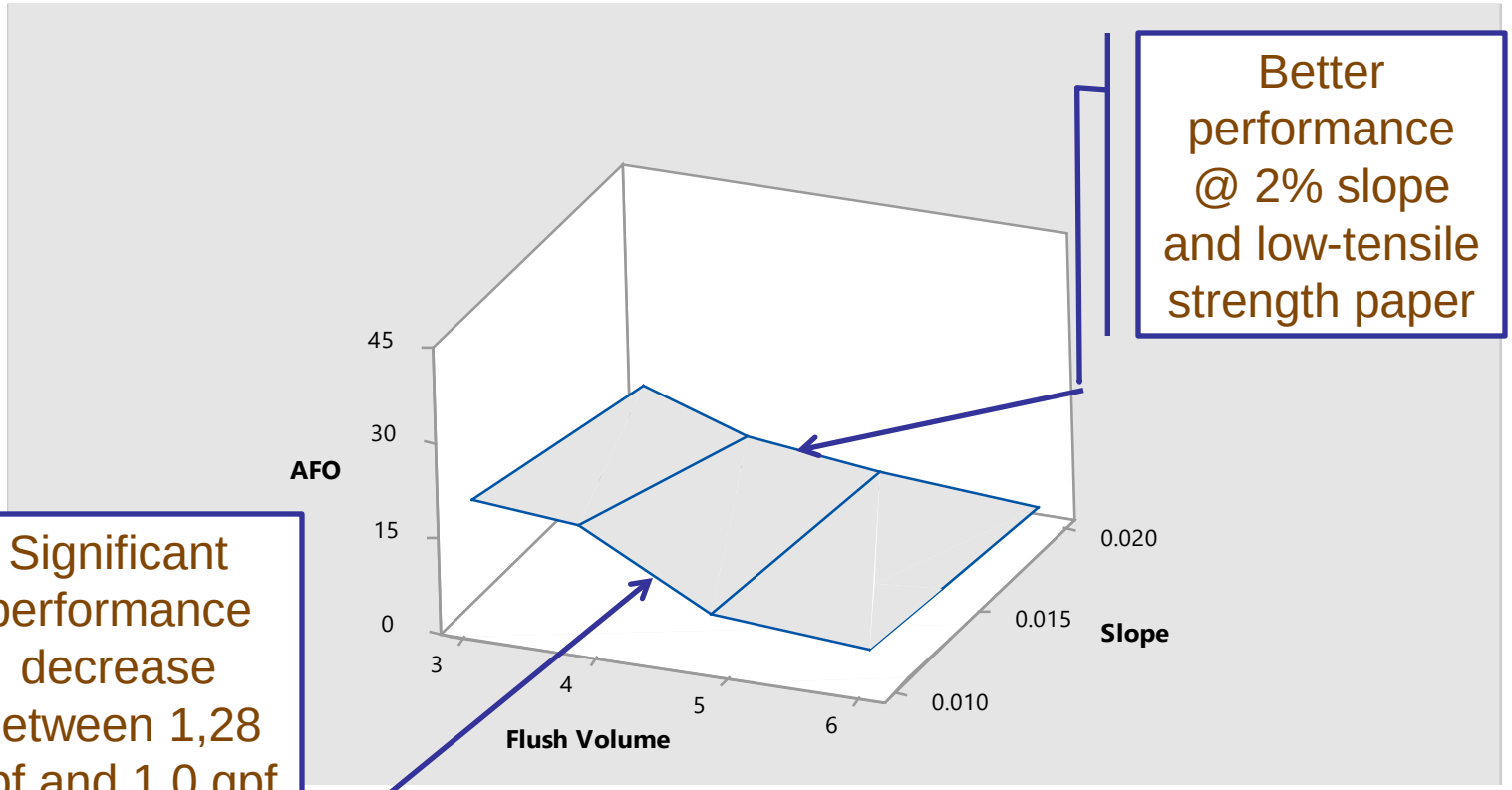
Surface Plot for AFO

High Tensile Strength Paper Data Only



Surface Plot for AFO

Low Tensile Strength Paper Data Only



Phase 2 Additional Findings

- Confirmed: Significance of Toilet Paper: *Toilet paper characteristics have the potential to drastically impact DLT distances*
  - Toilet paper wet-tensile strength was the #1 significant variable in the combined PERC 1 and PERC 2 studies
- Confirmed: Satisfactory performance of 4.8 Lpf / 1.28 gpf HETs
- Confirmed: The non-significance of toilet attributes in long drainlines

Supplemental Testing (PERC 2.1)

- PERC 2.1 – additional testing using Phase 2 funds
- 2 Deliverables
  1. Impact of dual flush discharge patterns on DLT
     - Does a dual flush toilet really provide the same DLT as a single flush toilet?
  2. Impact of slope deviations on DLT
     - Do slope deviations manifest more severely as flush volumes are reduced?

Supplemental Testing (PERC 2.1) Results

- Deliverable 1: Impact of Dual Flush discharges on DLT vs. Single Flush
- Comparing Single Flush to "Full" Dual Flush Value
  - **78.8%** reduction in DLT performance when comparing 1.6 / 1.0 gpf dual flush to 1.6 gpf single flush
  - **59.4%** reduction in DLT performance when comparing 1.28 / 0.8 gpf dual flush to 1.28 gpf single flush
  - Result: Reductions in Flush Volume, even when there is no solid waste other than toilet paper included with the reduced Flush Volume discharge, negatively impacts drain line performance.

Supplemental Testing (PERC 2.1) Results

- Deliverable 1: Impact of Dual Flush discharges on DLT vs. Single Flush
- Comparing Single Flush to the "Effective Dual Flush" Value
  - **5.5%** reduction in DLT performance when comparing 1.6 / 1.0 gpf dual flush to 1.28 gpf single flush
  - **18.7%** improvement in DLT performance when comparing 1.28 / 0.8 gpf dual flush to 1.0 gpf single flush
  - Result: Designers and specifiers should consider the Effective Dual Flush Value when considering the DLT capabilities of a toilet, not the Full Flush Value

Supplemental Testing (PERC 2.1) Results

- Deliverable 2: Impact of slope deviations on DLT
  - Test apparatus modified to make 1 pipe section perfectly flat (no slope)
  - Overall, DTL performance was reduced by 41.7% with the worst results occurring at the lower Flush Volumes
  - Interestingly, the biggest reduction in performance occurred between the 1.28 gpf and 1.0 gpf Flush Volumes, providing additional confirmation of the tipping point identified in Phase 2.0
- Both PERC Reports and supporting data are available for download at: www.plumbingefficiencyresearchcoalition.org

Recognition of Contributors

American Standard

- Without American Standard Brands contributions, this study would not have been possible
  - Allowing PERC to conduct study at Product Development Center in NJ
  - Allowing access by PERC Personnel
  - Expanding their DLT Test Apparatus to PERC specifications
  - In-kind Contributions, $ saving labor
- Mr. C.J. Lagan – Senior Manager of Testing and Compliance - Many hours of work
  - Assistance in obtaining experienced technicians
  - Assistance with the DOE development and data analysis
  - Day to day supervision of PERC Technicians

Recognition of Contributors

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.
The United Association

Recognition of Contributors

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Delta Faucet Company

Indian Plumbing Association

Southern Nevada Water Authority

World Plumbing Council

Portland Water Bureau

Gauley Associates, Ltd.

Vitra, USA

THANKS FOR YOUR KIND ATTENTION

QUESTIONS?

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