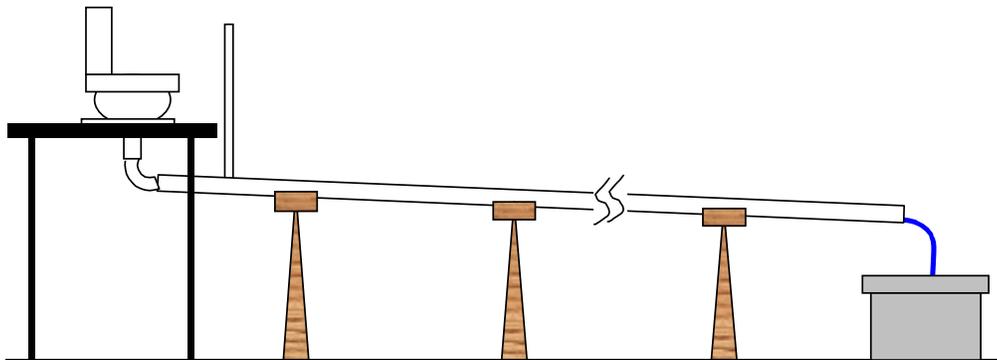


Evaluation of Water-Efficient Toilet Technologies to Carry Waste in Drainlines

A Canada Mortgage and Housing Corporation Project

Final Report

(Revision #1 – April 1, 2005)



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by

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Appendix B: Achieving Slopes of 2% in New Construction

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CONTRIBUTORS

Initiated by municipalities and other interested organizations in Canada, the Drainline Carry Testing program was a cooperative effort between Canada Mortgage and Housing Corporation (CMHC) and several Canadian partners, such as:

- CMHC
- City of Calgary
- City of Toronto
- Region of Durham
- Region of Peel
- Region of Waterloo
- Province of Manitoba
- Ontario Ministry of Municipal Affairs and Housing

We gratefully acknowledge the contributions from these participating agencies and municipalities. We would also like to acknowledge the efforts of all those persons that provided a technical review of this document prior to finalization, especially Dr. Larry Galowin of the National Institute for Standards and Technology, Al Dietemann of Seattle Public Utilities, Dave Bracciano of the Tampa Bay Water Co., Glen Pleasance of the Region of Durham, and Cate Soroczan of CMHC who provided significant input and guidance.

DISCLAIMERS

Every effort was made to ensure the accuracy of the testing program and the presentation of the project results contained in this report. However, because this testing program was conducted under laboratory conditions these results should not necessarily be considered as fully representative of results that may occur under field conditions.

Although this test project utilized a media whose physical properties closely resemble typical human waste, the reader is reminded that there is an enormous variation in human waste from person to person, and from one day to another.

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Readers are reminded that this report represents a 'snap shot' of drainline transport levels achieved by certain toilet models and flushing technologies at a particular time. As such, changes in the performance of specific flushing technologies may have occurred since the testing was completed.

The selection of toilets included as part of this project is in no way intended to represent all of the various makes and models available, nor is it intended to include a comprehensive list of all toilets that might employ each of the flushing technologies tested.

The results obtained during this testing program are not guarantees of performance.

CONVERSIONS

We expect that this document will be read and reviewed by interested parties in both Canada and the U.S.A.; as such, following are some of the measurement conversions used. All references to ‘gallons’ in this document refer to U.S. gallons.

S-I Units	U.S. Units
13.25-litre flush	3.5-gallon flush
6.0-litre flush	1.6-gallon flush
4.0-litre flush	1.1-gallon flush
1 litre	0.264 gallon
3.785 litres	1.0 gallon
1.0 metre	3.28 feet
24.4 metres	80 feet
0.3048 metres	1.0 foot
25.4 mm	1.0 inch
75 mm pipe	3 inch pipe
100 mm pipe	4 inch pipe

DEFINITIONS

Drainline:	horizontal drain pipe
Gpf:	gallons per flush
H-E:	High-Efficiency (as in High-Efficiency Toilet)
HET:	High-Efficiency Toilet: effective flush volume of less than 4.8 litres (1.28 gallons), i.e., equal to less than 80% of flush volume of a 6-litre (1.6-gallon) toilet. Typically achieved via the use of dual-flush or pressure-assisted technologies.
Lpf:	litres per flush
ULF:	Ultra-Low-Flush (i.e., 6-litre / 1.6-gallon)
Water Closet:	toilet

EXECUTIVE SUMMARY

No province in Canada currently prohibits the sale and installation of 13- and 20-litre toilet models¹. As such, Canada is behind most of the developed countries of the world, including the U.S., when it comes to supporting water efficiency. This hesitancy appears to stem from two concerns: the perception that efficient toilets do not perform well², and the perception that efficient toilets do not provide enough water to adequately transport waste through drainlines which may lead to blockages.

In 2003 CMHC supported a toilet flush performance evaluation project, *Maximum Performance (MaP) Testing of Toilets*, that tested the ability of more than seventy models to clear a minimum of 250g of realistic media (a combination of soybean paste and toilet paper) in a single flush. Test results identified a wide range in performance. Appendix A includes the CMHC *MaP Research Highlight* which outlines the results of the 2003 testing, but updated results are periodically posted on the websites of both the *Canada Water and Wastewater Association* (cwwa.ca/home_e.asp) and the *California Urban Water Conservation Council* (cuwcc.org/products_tech.lasso).

With the completion of this project CMHC has now addressed the second concern, i.e., the effect of water-efficient toilets on drainline carry distances.

Project Goal: to examine ability of water-efficient toilets to transport waste through drainlines under laboratory conditions.

The following variables were examined to assess their impact on drainline carry distance:

1. flushing system (e.g. pressure-assist, washdown, siphon jet, etc.),
2. flush volume,
3. drainline slope ,
4. diameter of drainline³,
5. vertical drop height from flange to drainline,
6. mass loading,
7. next flush,
8. venting, and
9. ‘dips and sags’ in drainage piping

Due to the limited depth of 2 x 8” floor joists commonly used in home construction it can be difficult to achieve drainline slopes of 2% in some installations. Limitations are explored briefly in Appendix B.

The use of Water Wigglers (basically small water-filled balloons) as a suitable media for drainline carry testing has been considered by some agencies. A brief comparison of using Water Wigglers vs. soybean paste can be found in Appendix C.

Worse Case Scenario – Flow Conditions

In a typical residential installation, drainlines may receive flow not only from a single toilet but also ancillary flows from showers, clothes washers, dishwashers, etc. In some cases, however, such as in a

¹ Ontario and some municipalities do require the use of water-efficient 6-litre toilets in new installations.

² Although the performance level of several early models of ULF toilets was questionable, the performance of today’s models, in general, meet or exceed customer expectations.

³ Many contractors in Canada continue to use imperial measurements when referring to pipe sizes, e.g. a 3 inch vs. a 75mm pipe. As such, in this report pipe sizes are referred to by their imperial measurement.

seldom used powder room, virtually all the flow in a drainline may be related to toilet flushing. The purpose of this study was to examine drainage conditions under the latter condition, i.e., under the ‘worse case scenario’ with no ancillary flows.

Best Case Scenario – Drainline Installation

Drainlines installed in the field represent a range of ages, lengths, pipe materials, and slopes. There will also be significant variation from site to site in the amount of sediment buildup within the drain or the number of horizontal bends or vertical dips and sags. Although these differences occur in actual field conditions, it is not possible to test every possible permutation of drainline setup as part of a lab testing program. Since the primary purpose of this study was to examine drainline carry associated with the use of water-efficient toilets rather than the effect that different drainline conditions have on carry distances, it was decided that drainline testing would be completed using new clear plastic pipe (to facilitate observations) installed straight and true⁴, and using pipe couplings that do not interfere with internal flow. The drainline setup used in this project, therefore, represents the ‘best case scenario’ of piping installation.

Results

Flushing System

To establish a relative ranking the carry distance of each flushing system was compared to the average carry distance of all models tested⁵. The 6-L pressure-assisted model achieved the highest ranking with carry distances approximately 130% of the average distance, whereas the washdown and vacuum-assisted models had carry distances of less than 80% of the average.

Study results showed a *modest* relationship between flush rate (how quickly waste is evacuated from the bowl) and drainline carry. For example, the 3.8-L pressure-assist model (quick flush rate) flushed with only 63% of the water and carried waste 71% as far as the average non-pressure-assist 6-L model, but the flushing systems that scored second and fourth place overall are both gravity models using traditional 50mm (2 inch) flappers (relatively slow flush rate).

Flush Volume

There is a positive correlation between flush volume and drainline carry distance. Study data suggests that increasing the flush volume will increase carry distances *on average* as follows:

- 3” pipe at 1% slope: 2.7 metre per litre (34 feet per gallon)
- 4” pipe at 1% slope: 2.7 metre per litre (34 feet per gallon)
- 4” pipe at 2% slope: 4.5 metre per litre (56 feet per gallon)

Drainline Slope

There is a positive correlation between slope and drainline carry, *on average* as follows:

- 0% slope, 3” and 4” piping: carry distance ~ 6 m (20 ft)
- 1% slope, 3” piping: carry distance ~ 10 m (33 ft)
- 1% slope, 4” piping: carry distance ~ 8 m (26 ft)
- 2% slope, 3” piping: carry distance ~ 22 m (72 ft)
- 2% slope, 4” piping: carry distance ~ 14 m (46 ft)

⁴ ‘Dips and sags’ were purposely installed in the piping during one portion of the testing.

⁵ The 3.8-L pressure-assist model was not included in the average because it uses a different flush volume.

Study data suggests that the slope vs. carry distance relationship is not linear, i.e., that the effect is more pronounced as drainline slope increases. In any event, decreasing the slope from two percent to one percent will reduce the drainline carry distance by roughly half.

Drainline Diameter

There is an inverse correlation between pipe diameter and drainline carry. Study data indicates that the carry distance in a 3" diameter line is *on average* approximately 50 percent greater than in a 4" line at a 2% slope, and 25 percent greater when the slope is only 1%. These results are supported by data from a Swaffield/Galowin study⁶ that show carry distances will be approximately 25 percent greater in 3" pipes vs. 4" pipes.

Vertical Drop Height

There is only a slight increase in drainline carry with an increase in drop height from floor flange to drainline. This apparent loss in energy may be caused by the deceleration in flow rate and increase in turbulence as the flow direction changes suddenly from vertical to horizontal as it enters the drainline. Carry distance appears to be more affected by the slope and diameter of the drain pipe than the velocity of the waste as it enters the drain.

Mass Loading

There is an inverse correlation between mass loading and drainline carry, i.e., drainline carry decreases as mass loading increases. Drainline carry decreases *on average* by about 1.5 m (5 ft) for every 100g of mass loading.

Next Flush

Test data shows that the next flush following a solids flush transports the waste media some additional distance. Because of time constraints it was not possible to allow test media to completely dry between consecutive flushes – this would have required several days between tests. As such, second flushes occurred only minutes after the initial flush, i.e., while some water was still dammed up behind the 'first flush' test media as it rested in the drainline. Data indicated that under these conditions a second 'water only' flush transported waste approximately 65% further in the drainline, and a second 'solids' flush transported waste material somewhat less.

Venting

There did not appear to be a noticeable correlation between venting and drainline carry under the conditions established for this project, i.e., no noticeable difference in carry distance was identified even when the vent pipe was completely blocked. This result is not meant to imply that similar results would be found under field conditions.

'Dips and Sags' in Drainage Piping

There appears to be a noticeable correlation between the presence of 'dips and sags' in the piping and drainline carry, i.e., carry distance was reduced when 'dips and sags' were introduced in the piping. Although it is not possible to test drainline carry under all possible deviations from a straight run of pipe, it suffices to say that any such deviations may lead to carry distances being somewhat reduced.

⁶ Big Drains, Small Drains, How do your wastes flow?, ASPE 1992 Convention Proceedings Technical Papers, Nov. 14-17, 1992, Washington, DC, pp 45 - 115, by Lawrence S. Galowin & John A. Swaffield

Conclusions

3" Piping installed at 2% slope (typical of residential installation): Under study conditions water-efficient toilets can transport 200g of test media approximately 16m to 27m (52ft to 89ft), depending on type of flushing system, with no supplemental flows from showers, baths, or clothes washers.

4" Piping installed at 1% slope (typical of commercial installation): Under study conditions water-efficient toilets can transport 200g of test media approximately 6m to 10.5m (20ft to 34ft), depending on type of flushing system, with no supplemental flows.

Under conditions examined in this study, namely clean drain pipes, straight runs, and proper slopes, all ULF and H-E toilets tested would be expected to meet or exceed the relatively short waste carry distance requirements typical of household plumbing installations even with no supplemental flows from showers, baths, or clothes washers. Installations with extremely long drainage distances, e.g., shopping malls or industrial sites, however, may require evaluation on a site-by site basis, especially if no supplemental flows are available⁷.

Identification of Areas of Possible Further Testing

Budget and time constraints⁸ naturally resulted in some limitations to project testing. Each of these limitations represents a potential area for further testing:

- different pipe materials were not tested (research by Dr. Larry Galowin indicates that carry distances in cast iron piping are approximately two-thirds of that in plastic pipes)
- no testing was completed using rigid pipe couplings
- no testing was completed on toilets flushing greater than 6 litres (1.6 gallons)
- waste media settling in the drainline was not allowed to dry out completely (simulating weekend or vacation drying) before the next flush
- no testing was completed using sanitary napkins
- no testing was completed using increasing loadings of toilet paper
- no testing was completed on old piping removed from demolished buildings
- no testing was completed to assess the effects of supplemental flows
- no testing was completed on toilet models that repeatedly fail to clear at least 200g
- testing was completed for only two flange-to-drain conditions (minimum and maximum drop heights); a more circuitous route from flange-to-drain may effect carry distances.
- no testing was completed to compare the various test media and methodologies used for drainline testing by different test agencies or nations.

⁷ As well, pipes connecting commercial sites to sewers may be 6" diameter or larger, further reducing carry distances.

⁸ Under 'normal' household conditions the interval between consecutive flushes of a single toilet (especially if it is a rarely used fixture) may be several days or even weeks, thereby allowing any waste material that remains in the drainline to become completely dry prior to the 'second flush'. Similarly long intervals between flushes were not practical to achieve during this project and, as such, waste media was not allowed to dry between flushes.

EVALUATION OF WATER-EFFICIENT TOILET TECHNOLOGIES TO TRANSPORT WASTE IN DRAINLINES

1.0 Study Background

While the sale and installation of 13- and 20-litre toilets has been effectively banned in the U.S.A. since 1995, there is no such standard in Canada. To date, Ontario is the only Canadian province to mandate the installation of Ultra-Low Flush (ULF) Toilets in new construction, though inefficient toilets are still readily available in the provincial marketplace. In the absence of provincial standards a number of individual municipalities, e.g., Victoria and Vancouver in British Columbia, have mandated the use of ULF toilets in new installations. The hesitancy of Canadian provinces to adopt ULF toilet standards appears to stem from two concerns: performance levels of ULF toilets⁹ and their ability to carry waste through drainlines.

With the completion of this study, CMHC has now supported initiatives to address both of these concerns. The *Maximum Performance (MaP) Testing of Popular Water-Efficient Toilets* report¹⁰ documents flush performance results for more than seventy certified 6-litre (1.6-gallon) toilet models, rating each one based on their ability to successfully flush a minimum benchmark level of 250 grams of test media (soybean paste and toilet paper) in a single flush¹¹. Test results identified a wide range in performance. Appendix A includes the CMHC *MaP Research Highlight* outlining results of the 2003 testing, but updated results are periodically posted on the websites of both the *Canada Water and Wastewater Association* (cwwa.ca/home_e.asp) and the *California Urban Water Conservation Council* (cuwcc.org/products_tech.lasso).

1.1 Toilet fixtures and drainline carry

Critics suggest ULF toilet technology, which uses only 6 litres (1.6 gallons) of water per flush, is insufficient to draw waste away from the building through existing drainlines whose size, length, and slope were designed when greater flow rates were produced from older 13 and 20 litre toilet flushes. The concern is that low flush volumes will lead to clogging or plugging of the drainline, poor toilet performance, and potentially expensive clean-out costs.

1.2 Plumbing standards based upon past studies

Laboratory studies have been conducted within a variety of environments to provide information on waste carry under different conditions and with a variety of toilet fixtures. These studies were intended to provide information necessary to reduce or eliminate the concerns of plumbing professionals. As a consequence, plumbing standards for toilet fixtures were developed for Canada and the U.S. that reflected engineers' best estimates of what represented actual movement of waste in a drainline when flushing with six litres of water. Those standards mandated a drainline carry averaging no less than 12m (40 feet) when depositing 100 spherical polypropylene balls 19 ± 0.4 mm diameter (0.75 ± 0.015 in)¹² into the bowl of the toilet fixture under test. Consult the appropriate standards for further details on the test procedure and

⁹ Although the performance level of several early models of ULF toilets was questionable, the performance of today's models, in general, meet or exceed customer expectations.

¹⁰ Gauley & Koeller, 2003

¹¹ The 250g benchmark is expected to represent approximately the 95th percentile of 'normal' human loadings.

¹² For further information on the history of the development of a drainline carry test, read the article titled "ANSI's Drainline Carry Test" by R. Bruce Martin, published in *Plumbing Engineer*, March 2004.

performance requirements¹³. There is some question, however, regarding the suitability of using spherical polypropylene balls to assess drainline performance.

1.3 Re-visiting waste carry through two new studies

Within the past 10 years new toilet fixture flushing technologies have been developed, some flushing with less than 6 litres (1.6 gallons) of water, and different test media have been identified that appears to better represent “real world” conditions. As such, the drainline carry issue was re-visited in 2004 through two distinctly different studies. The U.S. Department of Energy (DOE) is funding a study at the Texas A&M University¹⁴ and Canada Mortgage and Housing Corporation (along with other funding partners) sponsored this study completed by Veritec Consulting, Inc., in Mississauga, Ontario.

1.4 Variables to be evaluated

The current debate regarding the ability of a ULF flush to sufficiently carry waste through the drainline tends to focus on the following variables:

1. type of flushing system (e.g., siphonic, washdown, pressure-assist, vacuum-assist, etc.)
2. flush volume
3. slope of the drainline,
4. diameter of the drainline¹⁵,
5. vertical drop heights from flange to drainline
6. mass of solids being flushed,
7. effect of next flush¹⁶,
8. venting, and
9. dips and sags.

1.5 Drainline carry vs. toilet performance

Although the importance of ‘clearing the bowl’ as part of an overall toilet performance evaluation is clearly recognized, as stated earlier, bowl clearing is addressed by MaP testing and is not included as part of this project. Perhaps future testing (if any) may combine bowl clearing and drainline carry requirements into a single project.

Project Goal: to examine ability of water-efficient toilets to transport waste through drainline under laboratory conditions.

¹³ Canadian Standards Association B45, Plumbing Fixtures; American Society of Mechanical Engineers A112.19.2-2003, Vitreous China Plumbing Fixtures and Hydraulic Requirements for Water Closets; these two standards are currently in the process of harmonization into a single standard for both countries.

¹⁴ Promoted by the American Society of Plumbing Engineers Research Foundation (ASPERF), the DOE is funding approximately \$100,000US toward the effort. A description of the work may be found in the March-April 2003 issue of *Plumbing Systems & Design*: <http://www.psdmagazine.org/pdf/index04-03.htm>

¹⁵ Ontario Building Code and Uniform Plumbing Code (USA) both state that 3” horizontal drainage piping can serve up to three toilets, thereupon it must be increased to 4” piping

¹⁶ Refers to next naturally occurring flush, whether a liquid or solids flush, not double-flushing’ to clear the bowl.

2.0 Test/Study Methodology

The test regime for this study involved physically measuring the effectiveness of several different *types* of water-efficient toilets to carry a realistic test media (combination of soybean paste and toilet paper) along both 3" and 4" (75mm and 100mm respectively) drainlines installed at different slopes and under various conditions.

The following photographs show the media and equipment used in this study. Note that the top right photo shows 200g of media (the mass of media used in testing) and four balls of toilet paper, and the bottom right photo shows the two levels of the test rig – the lower level was used to test the minimum drop height and the upper level was used to test the maximum drop height. Figures 1 and 2 on the following page illustrate the overall setup of the test rig/drainlines.



Bulk Media, Toilet Paper, extruded Media



Extruded Media & Toilet Paper



Test Media in Bowl



Test Rig and 3" line

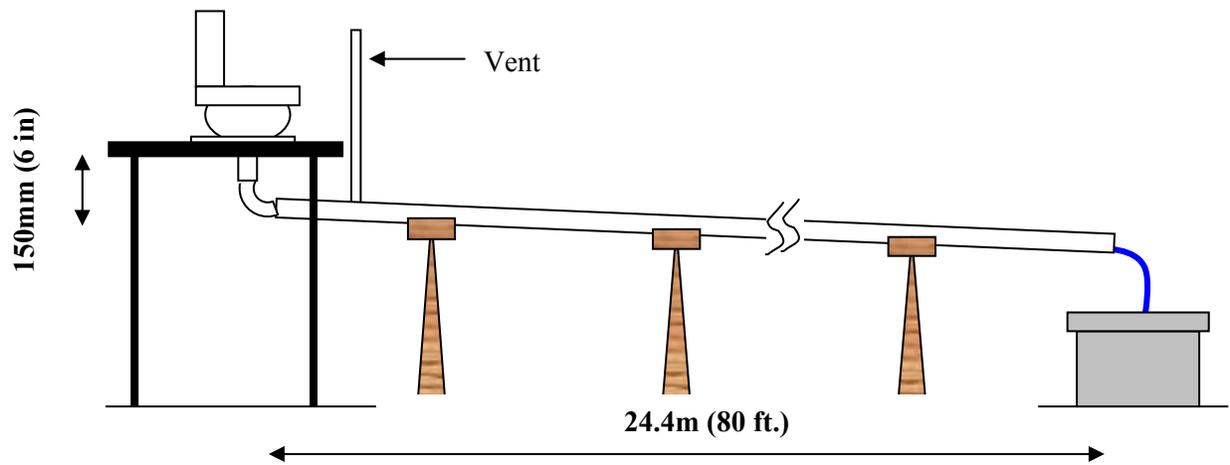


Figure 1: Set-up Minimum Drop Height

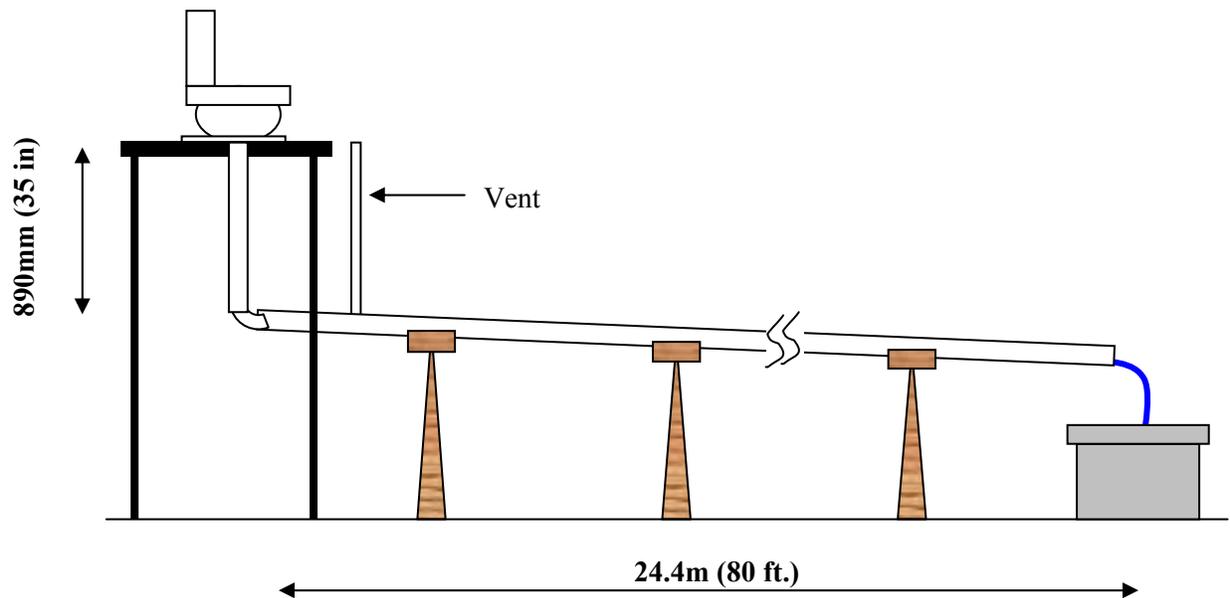


Figure 2: Set-up Maximum Drop Height

Test Variables

The critical variables incorporated and evaluated within the study are as follows:

Flushing Systems

Nine (9) different types of toilet flushing systems were tested in this study to determine their effect on drainline carry distances. Because the intent of this study aspect was to evaluate different flushing systems and not specific toilet models, model names have been purposely omitted from this report. The flushing systems included in this study are *intended* to represent *most* types found in the marketplace, see Table 1.

Table 1: Flushing Systems Tested

1)	Gravity - Washdown (European/Australian)
2)	Gravity – 75mm (3 in) Flush Valve
3)	Gravity – Tipping Bucket
4)	Gravity – Siphon Jet in Trapway
5)	Gravity – Siphon Jet in Sump of Bowl
6)	Gravity – Rim Jet
7)	Gravity – Vacuum-Assist
8)	Pressure-Assist – 6.0-Lpf (1.6-gpf)
9)	Pressure-Assist – 3.8-Lpf (1.0-gpf)

Drainline slopes

Three (3) drainline slopes were evaluated:

- 1) Two percent (2%) as per code¹⁷,
- 2) One percent (1%), and
- 3) Flat (0%)¹⁸

Drainline pipe diameters

Two (2) different pipe sizes were included in the study¹⁹:

- 1) 3 inch²⁰, and
- 2) 4 inch

Vertical drop heights

Two different vertical drop heights from the floor flange to the drainline were tested to reflect both the upper and lower limits set forth by code:

- 1) 150 mm (6 in)²¹
- 2) 900 mm (35 in)²²

¹⁷ 7.4.8.1 (1) 1997 Ontario Building Code, “Every drainage pipe that has a size of 3 in. or less, and every fixture drain shall have a downward slope in the direction of flow of at least 1 in 50.”

¹⁸ Flat slopes were tested only as part of the ‘slope vs. carry distance’ portion of the project.

¹⁹ Many contractors, even in Canada, continue to use imperial measurements when discussing construction elements, e.g. pipes are referred to as 3-inch or 4-inch (vs. 75 mm or 100mm). As such, in this report, pipe sizes are referred to by their imperial measurement.

²⁰ Ontario Building Code and Uniform Plumbing Code (USA) both state that 3” horizontal drainage piping can serve up to three toilets, thereupon it must be increased to 4” piping

²¹ Basically, minimum possible height when attaching a 90-degree elbow to a toilet floor flange.

²² 7.5.5.3 (3) 1997 Ontario Building Code, “No vertical leg of the waste pipe from a water closet or other fixture having an integral siphonic flushing action shall exceed 900 mm (2 ft 11 in).”

Test media

Tests were typically conducted using 200 grams of a media simulating human waste (i.e., soybean paste and toilet paper)²³, though different mass loadings were used to evaluate the effect of ‘mass vs. carry distance’ portion of the project. For a complete background on the media and typical waste demands upon a toilet fixture, consult the Final Report on Maximum Performance (MaP) testing of toilet fixtures²⁴. Four test samples of 50g each (200g total) with toilet paper are shown in photo on right.



Test set-up

A test rig was constructed such that each toilet could be bolted to a typical toilet floor flange. Clear plastic piping was used to facilitate observations and all piping was installed by a licensed plumber to ensure that it was installed correctly and in accordance with code. Flexible rubber-sleeve mechanical couplings (see photographs below) were used to connect the pipe sections²⁵. A laser level was used to establish a benchmark and ensure pipe slopes were properly adjusted. A string-line was used to ensure pipe runs were straight and true.²⁶

Flushing technologies numbers 1 through 7 (listed in Table 1) were adjusted to 6-Lpf (1.6-gpf) where possible. Pressure-assist fixtures (numbers 8 and 9) could not be adjusted²⁷. Static supply line pressure for the test rig was set at 50 pounds per square inch (psi).



Flexible rubber-sleeve mechanical coupling

²³ Average human loading demands are approximately 130g, but can be greater than 250g.

²⁴ Gauley & Koeller, 2003.

²⁵ Originally, rigid ABS couplings were tried they interfered with flow at the pipe junctions, thereby reducing carry distances. As the intent of this study was to evaluate effectiveness of water-efficient toilets to transport waste, rather than interference caused by pipe couplings, rubber-sleeve couplings that do not interfere with flow were used.

²⁶ It should be noted that the piping used during testing was new clear plastic pipe, free from buildup that may occur in older installations. The piping was installed in perfectly straight runs (except when testing the effects of sags), and slopes were accurately determined. Because clear piping was used, it was possible to identify any interference from pipe couplings protruding into the pipe – observations not possible in actual field conditions. A laser level was used to ensure pipe slopes were accurate, whereas this type of leveling would not be expected in the field.

²⁷ Flush volumes of gravity toilets were adjusted during ‘flush volume vs. carry’ testing, whereas the pressure-assisted toilets, which could not be adjusted, were not included in these tests.

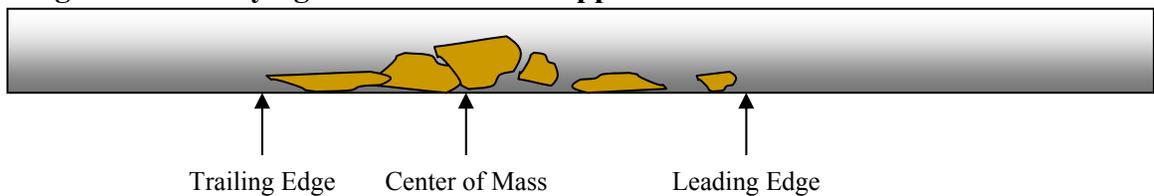
Waste in Drain (Waste Plug)

Flushed waste media either a) carried the entire 24m (80ft) length of drainline and was discharged to a receiving tank, or b) settled (came to rest) at some point in the drainline.

The test media used in this study is a combination of extruded soybean paste and balls of toilet paper. This combination of media is free to break up into smaller pieces and to either spread out as it is carried through the drainline or to ‘clump up’ in a ball, i.e., there is some variation in the size of the waste plug.

Measurements identified in this study are based on the centre of mass of the deposited media, i.e., the technician noted the leading and trailing edge of the waste plug and visually assessed the position of the center of mass. Figure 3 below helps illustrate how the measurements were made within the drainline.

Figure 3: Identifying Centre of Mass Stopped within Drainline



The length of waste plug sizes ranged from 12 cm (5 in) to 3.6 m (11.8 ft) with an *average* size of 63 cm (25 in) and a *median* size of 53 cm (22 in). Figure 4 illustrates the range in plug sizes (data sorted from shortest to longest length). In most cases, the second (water-only) flush tended to shorten or compact the plug length slightly. In a small number of instances it caused the plug to spread out significantly (Figure 5).

Figure 4: Lengths of Media Plug – Single Flush

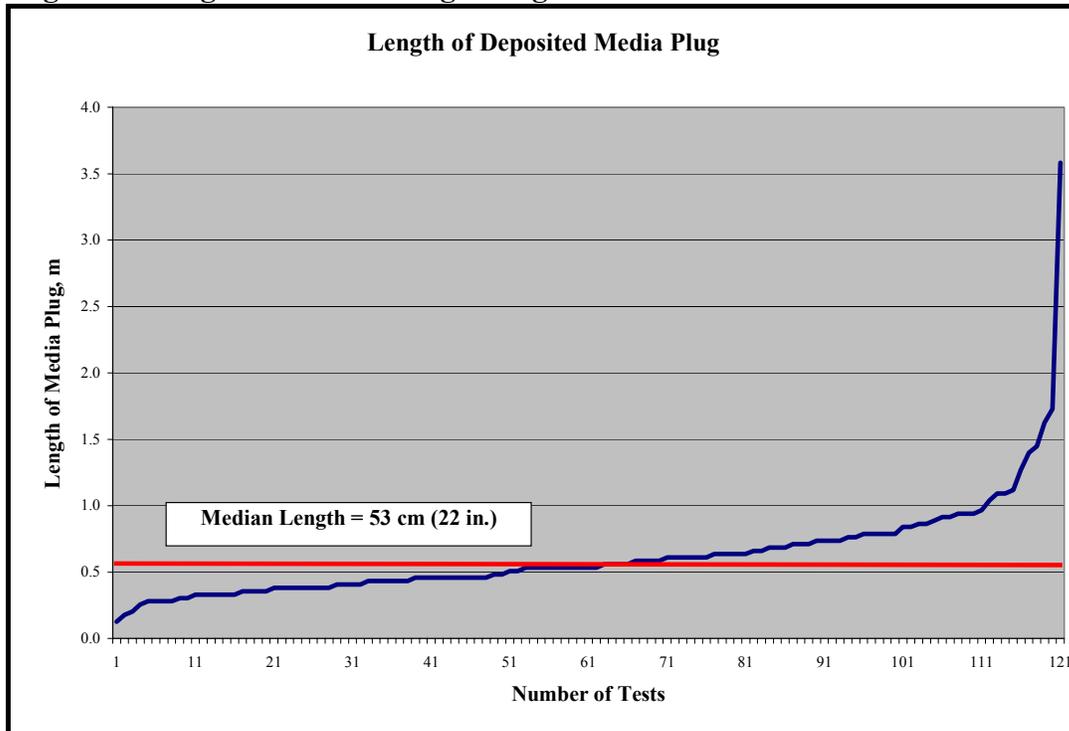
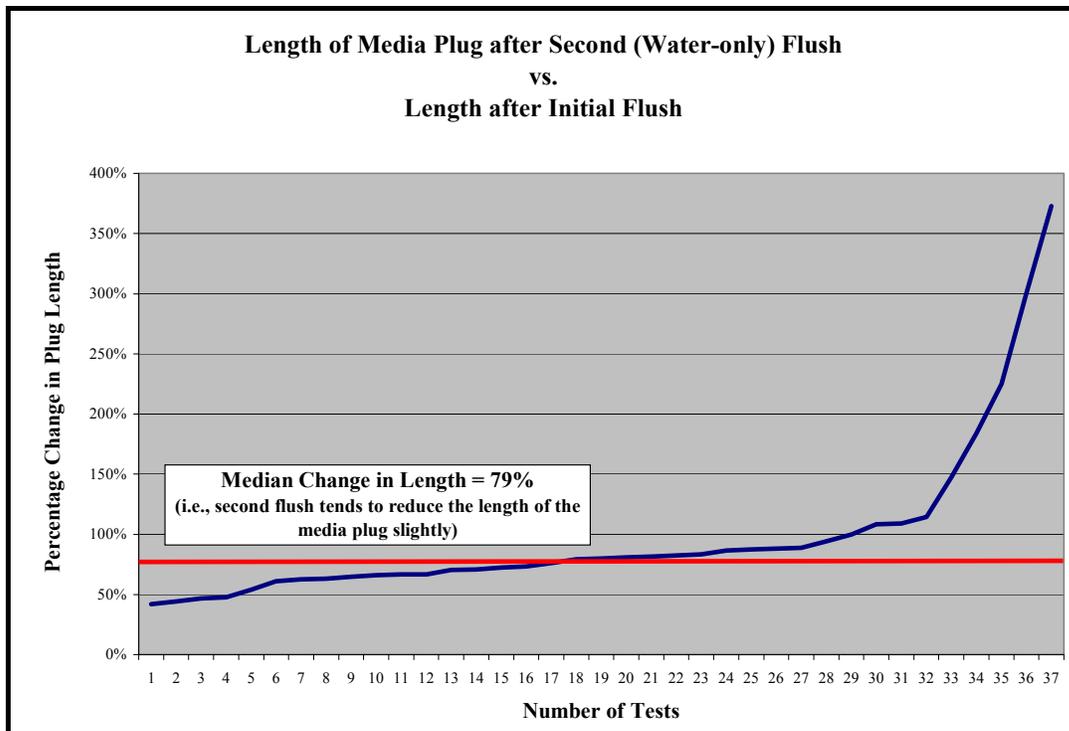


Figure 5: Effect of Second Flush on Length of Media Plug



3.0 Test Results

The results of this study have been divided into the following sections -

1. Effect of different flushing systems
2. Effect of flush volume
3. Effect of drainline slope
4. Effect of drainline diameter
5. Effect of drop height
6. Effect of mass loading
7. Effect of next flush
8. Effect of blocking the vent
9. Effect of dips and sags in the drainline
10. Minimum expected carry distance for ULF models

During discussions with plumbing inspectors at the outset of this project it was identified that it can sometimes be difficult or even impossible to achieve drainline slopes of 2% in household installations due to the limited depth offered by commonly used 2 x 8" floor joists. These limitations are explored briefly in Appendix B.

This study also compared the use of Water Wigglers to the soybean paste used in this study. Water Wigglers are small water-filled balloons intended for use as a child's toy, however, there is some question as to their potential for use as a test media in drainline experiments. Results can be found in Appendix C.

3.1 Effect of different flushing systems

There was a correlation between different flushing systems and drainline carry, i.e., carry distance varied with different flushing systems.

As stated earlier, nine different flushing technologies or systems were evaluated in this study. To assess the effectiveness of each system, the carry distances for each system were compared to average carry distances of all 6-L systems under each testing scenario (pipe diameter, drop height, and slope). As noted earlier, a solids loading of 200 grams of soybean paste plus toilet paper was used in testing.

Testing was completed using the 3" pipe at 0%, 0.5%, 1%, 1.5%, and 2% slopes and using the 4" pipe at 1% and 2% slopes for both minimum and maximum drop heights.

Results indicated very little difference in carry distance between maximum and minimum drop heights (within 1% for the 3" pipe and within 4% for the 4" pipe). As such, data for minimum and maximum drop heights were combined when evaluating different flushing systems.

Test regimes where solids cleared the entire 24 metre length of piping (e.g., the 3" pipe at 2% slope for both drop heights and the 4" pipe at 2% slope for maximum drop height) were not included in the results as it was not possible to identify a final carry distance.

The results illustrated in Tables 2a through 4 compare the average carry distance of each flushing technology to the overall average carry distance of all models under the same testing regime for each of the two pipe diameters.

Table 2a Waste Carry Distances (m)

3" Diameter, Minimum Drop Height, 200g

Flushing Technology/Slope	0%	0.5%	1%	1.5%	2%
Pressure-Assist – 6.0-Lpf (1.6-gpf)	7.5	8.8	13.6	20.1	*
Gravity – Rim Jet	7.3	9.5	11.8	16.3	*
Gravity – 75mm (3 in) Flush Valve	7.5	7.6	10.6	14.9	*
Gravity –Jet in Sump of Bowl	6.5	8.2	11.3	14.8	*
Gravity – Jet in Trapway	6.2	8.3	11.3	14.0	*
Gravity – Tipping Bucket	7.0	7.9	9.1	15.0	*
Gravity - Washdown	4.9	6.1	8.8	10.9	19.4
Gravity – Vacuum-Assist	5.2	5.8	6.8	8.1	12.7
Pressure-Assist – 3.8-Lpf (1.0-gpf)	4.6	5.9	6.8	8.3	12.8
Average (not including 3.8-L model)	6.5	7.8	10.4	14.3	-

* media traveled entire length of drainline

Table 2b Waste Carry Distances (m)

3" Diameter, Maximum Drop Height, 200g

Flushing Technology/Slope	0%	0.5%	1%	1.5%	2%
Pressure-Assist – 6.0-Lpf (1.6-gpf)	6.4	7.8	14.0	19.9	*
Gravity – Rim Jet	8.2	8.7	9.9	17.8	*
Gravity – 75mm (3 in) Flush Valve	7.5	8.2	14.1	17.0	*
Gravity –Jet in Sump of Bowl	6.2	7.5	10.8	12.7	*
Gravity – Jet in Trapway	5.6	8.6	11.2	16.5	*
Gravity – Tipping Bucket	5.0	7.6	10.0	12.8	*
Gravity - Washdown	4.6	6.7	8.4	13.6	*
Gravity – Vacuum-Assist	5.1	5.8	9.1	9.1	15.5
Pressure-Assist – 3.8-Lpf (1.0-gpf)	3.5	5.6	6.6	12.5	16.3
Average (not including 3.8-L model)	6.1	7.6	10.9	14.9	-

* media traveled entire length of drainline

Table 2c Waste Carry Distances (m)

4" Diameter, Minimum Drop Height, 200g

Flushing Technology/Slope	1%	2%
Pressure-Assist – 6.0-Lpf (1.6-gpf)	10.6	19.5
Gravity – Rim Jet	8.8	16.6
Gravity – 75mm (3 in) Flush Valve	9.2	15.7
Gravity –Jet in Sump of Bowl	7.8	16.3
Gravity – Jet in Trapway	8.7	11.8
Gravity – Tipping Bucket	7.3	14.2
Gravity - Washdown	6.4	10.3
Gravity – Vacuum-Assist	7.1	9.8
Pressure-Assist – 3.8-Lpf (1.0-gpf)	6.7	9.2
Average (not including 3.8-L model)	8.2	14.3

**Table 3a Comparative Waste Carry Distances (Percent vs. Avg. Carry)
3" Diameter, Minimum Drop Height, 200g**

Flushing Technology/Slope	0%	0.5%	1%	1.5%	2%
Pressure-Assist – 6.0-Lpf (1.6-gpf)	116%	114%	130%	141%	*
Gravity – Rim Jet	112%	123%	113%	114%	*
Gravity – 75mm (3 in) Flush Valve	115%	98%	102%	105%	*
Gravity –Jet in Sump of Bowl	100%	106%	109%	104%	*
Gravity – Jet in Trapway	96%	106%	109%	98%	*
Gravity – Tipping Bucket	107%	102%	87%	105%	*
Gravity - Washdown	75%	78%	85%	76%	*
Gravity – Vacuum-Assist	79%	75%	65%	57%	*
Pressure-Assist – 3.8-Lpf (1.0-gpf)	71%	76%	65%	58%	*

* media traveled entire length of drainline

**Table 3b Waste Carry Distances (Percent vs. Avg. Carry)
3" Diameter, Maximum Drop Height, 200g**

Flushing Technology/Slope	0%	0.5%	1%	1.5%	2%
Pressure-Assist – 6.0-Lpf (1.6-gpf)	105%	102%	128%	133%	*
Gravity – Rim Jet	135%	115%	91%	119%	*
Gravity – 75mm (3 in) Flush Valve	123%	108%	128%	114%	*
Gravity –Jet in Sump of Bowl	102%	98%	99%	85%	*
Gravity – Jet in Trapway	92%	113%	102%	110%	*
Gravity – Tipping Bucket	83%	99%	92%	86%	*
Gravity - Washdown	75%	88%	77%	91%	*
Gravity – Vacuum-Assist	84%	77%	83%	61%	*
Pressure-Assist – 3.8-Lpf (1.0-gpf)	58%	73%	61%	84%	*

* media traveled entire length of drainline

**Table 3c Waste Carry Distances (Percent vs. Avg. Carry)
4" Diameter, Minimum Drop Height, 200g**

Flushing Technology/Slope	1%	2%
Pressure-Assist – 6.0-Lpf (1.6-gpf)	129%	137%
Gravity – Rim Jet	106%	116%
Gravity – 75mm (3 in) Flush Valve	112%	110%
Gravity –Jet in Sump of Bowl	95%	114%
Gravity – Jet in Trapway	106%	82%
Gravity – Tipping Bucket	88%	100%
Gravity - Washdown	78%	72%
Gravity – Vacuum-Assist	86%	69%
Pressure-Assist – 3.8-Lpf (1.0-gpf)	82%	64%

**Table 3d Waste Carry Distances (Percent vs. Avg. Carry)
Average of All Slopes and Drop Heights, 200g**

Flushing Technology/Slope	3"	4"	Avg.
Pressure-Assist – 6.0-Lpf (1.6-gpf)	121%	133%	127%
Gravity – Rim Jet (2 in. Flush Valve)	115%	111%	113%
Gravity – 75mm (3 in) Flush Valve	112%	111%	111%
Gravity –Jet in Sump of Bowl	100%	105%	102%
Gravity – Jet in Trapway	103%	94%	99%
Gravity – Tipping Bucket	95%	94%	95%
Gravity - Washdown	81%	75%	78%
Gravity – Vacuum-Assist	73%	77%	75%
Pressure-Assist – 3.8-Lpf (1.0-gpf)	68%	73%	71%

It is interesting to note that the first two **gravity** toilets listed in Table 3d (rim jet with a 2” flapper and siphon jet with a 3” flapper) have very similar results (average values within 3% of each other) even though they use what seems to be significantly different flushing systems.

The 6-L pressure-assist model had the best results (Table 3d) with average carry distances more than 20% further than average in the 3” pipe and more than 30% further in the 4” pipe.

The gravity-fed washdown and the gravity-fed vacuum-assist fixtures scored lower average drainline carry distances even though both models scored highly in the MaP testing program.

It is interesting to note that there appears to be only a modest relationship between flush rate (how quickly the waste is evacuated from the bowl) and carry distance. For instance, although the 6-L pressure-assist model (quick flush rate) scored the highest ranking, the washdown model (also quick flush rate) scored the second lowest ranking of the 6-L models. What’s more, the 3.8-L pressure-assist model (quick flush rate) flushed with only 63% of the water and carried waste 71% as far as the average non-pressure-assist 6-L models, but the flushing systems that scored second and fourth place overall are both gravity models using traditional 50mm (2 inch) flappers (relatively slow flush rate).

Although the test results reveal distinct differences in waste carry among the different flushing systems, the results are somewhat surprising. That is, flushing systems that are better at clearing media from the bowl (based on MaP testing) are not necessarily the same systems that carry waste the furthest in the drainline. It appears from Table 4 that there is no strict correlation between flushing solids from the bowl and carrying it down the drainline.

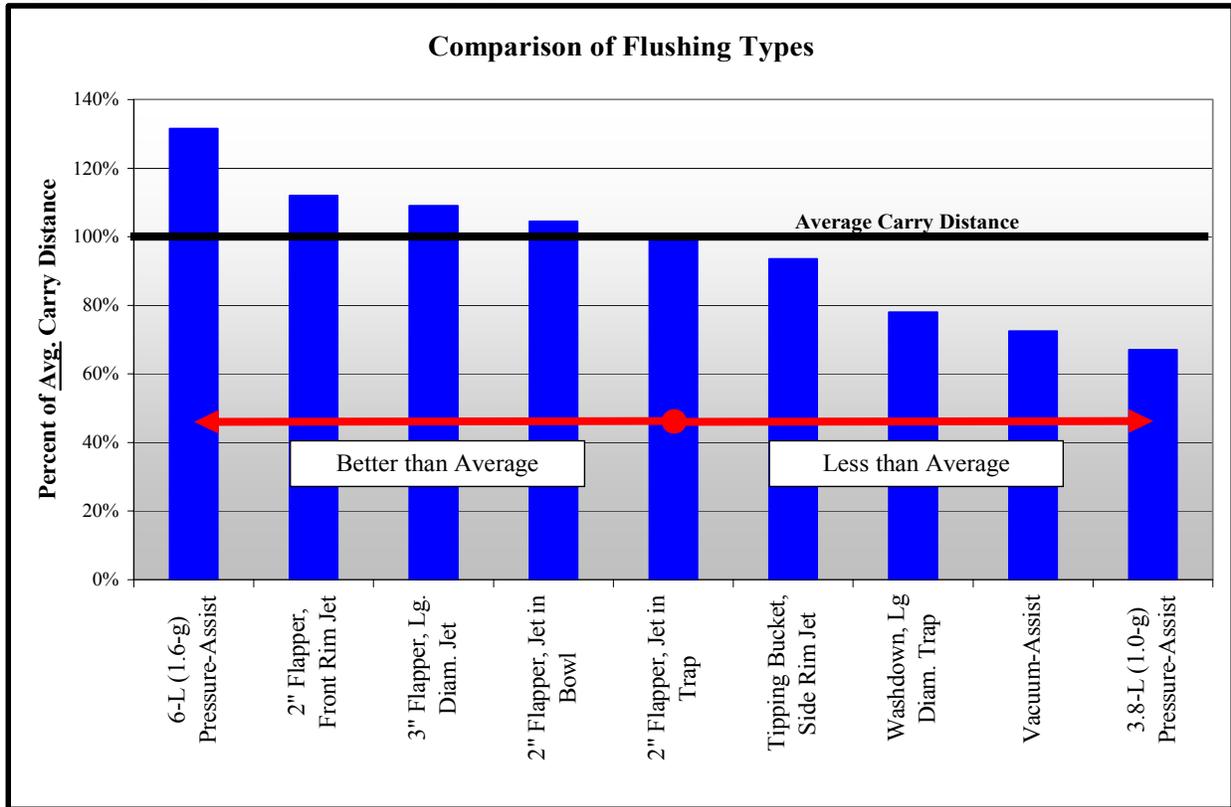
Table 4: Flushing Technologies and Pipe Diameter – Comparison to MaP Testing
3” Diameter, 200g, 1.5% Slope²⁸

Flushing Technology	Average Carry Distance - metres (from Table 2)	MaP Testing Results for Representative Fixture – grams (from MaP reports)
Pressure-Assist – 6.0-Lpf (1.6-gpf)	20.1	900
Gravity – Rim Jet	16.3	550
Gravity – 75mm (3 in) Flush Valve	14.9	900
Gravity – Siphon Jet in Sump of Bowl	14.8	325
Gravity – Siphon Jet in Trapway	14.0	375
Gravity – Tipping Bucket	15.0	725
Gravity - Washdown	10.9	650
Gravity – Vacuum-Assist	8.1	500
Pressure-Assist – 3.8-Lpf (1.0-gpf)	8.3	650

Figure 6 compares the different flushing systems. Each system is compared to the average of all 6-L systems to provide a relative ranking system (data for the 3.8-L pressure-assist model is not included in the average because of the flush volume difference).

²⁸ A 2% slope was not used as carry distance exceeded pipe length for most toilet samples

Figure 6: Comparison of Flushing Systems



3.2 Effect of toilet flush volume

There is a positive correlation between flush volume and drainline carry distance, i.e., higher flush volumes equate to greater carry distances.

Variations in flush volumes were achieved by either holding the flush handle open for an extended period or physically closing the flapper early by pushing on it with a thin wooden dowel. Flush volumes between 3 and 8 litres (0.8 and 2.1 gallons) were evaluated. Larger flush volumes resulted in the media being discharged from the end of the drainline. Pressure-assisted models were not included in this aspect of testing as their flush volumes cannot be adjusted.

The results of the testing have been charted (Figures 7a, 7b, 7c, and 7d). Even with the variations within each data set, possibly due to how the media is aligned in the bowl and drainline, the trendlines for each data set have similar slopes indicating a high level of confidence.

Test results indicate the following relationships between carry distance and flush volume:

- Additional 2.7m per extra litre of flush volume at 1% slope (34 ft. per /gallon),
- Additional 4.7m per extra litre of flush volume at 2% slope (59 ft. per gallon).

Figure 7a: 3" Pipe, 1% Slope, Maximum Drop Height

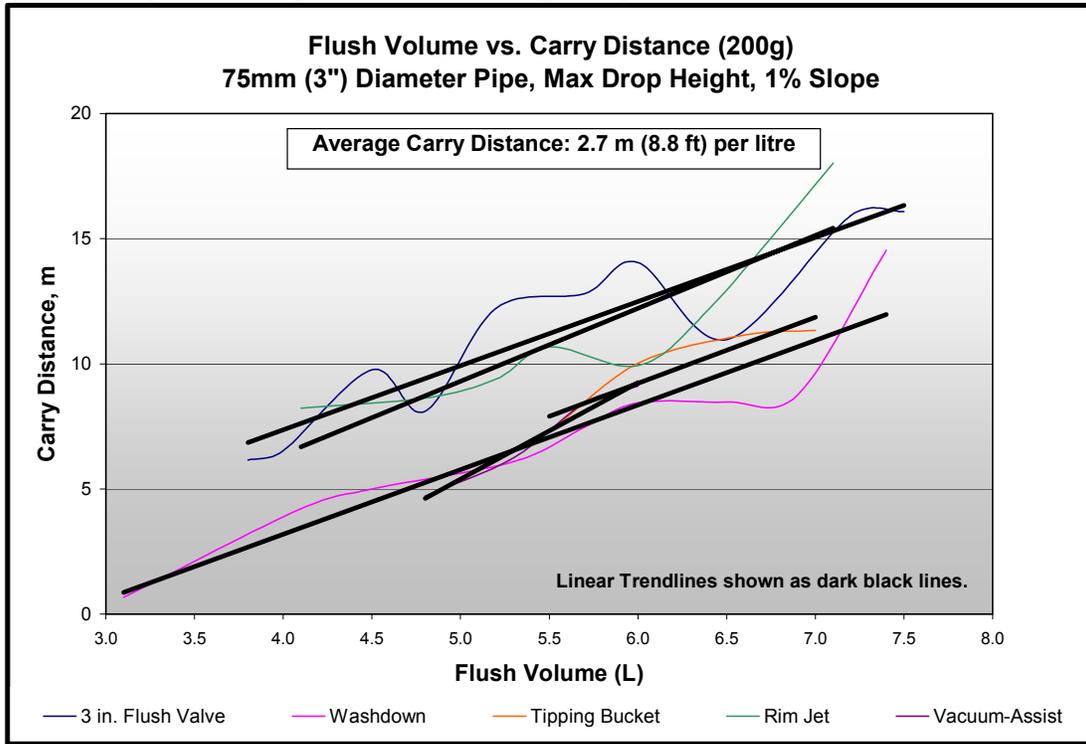


Figure 7b: 3" Pipe, 1% Slope, Minimum Drop Height

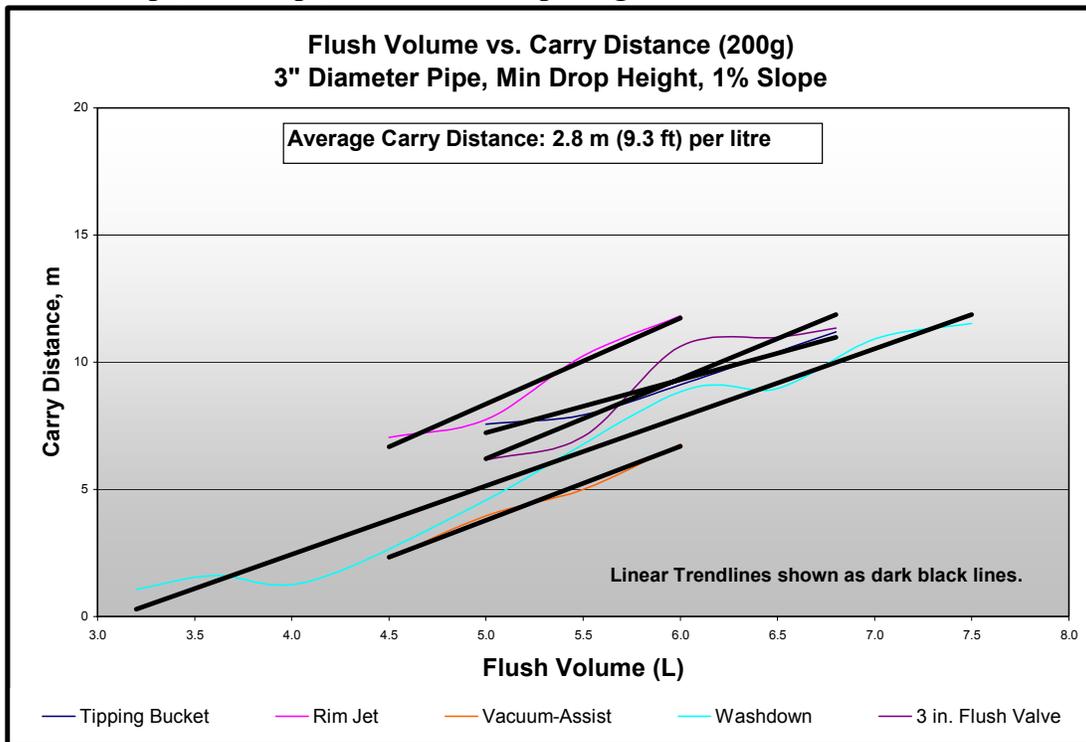


Figure 7c: 4" Pipe, 1% Slope, Minimum Drop Height

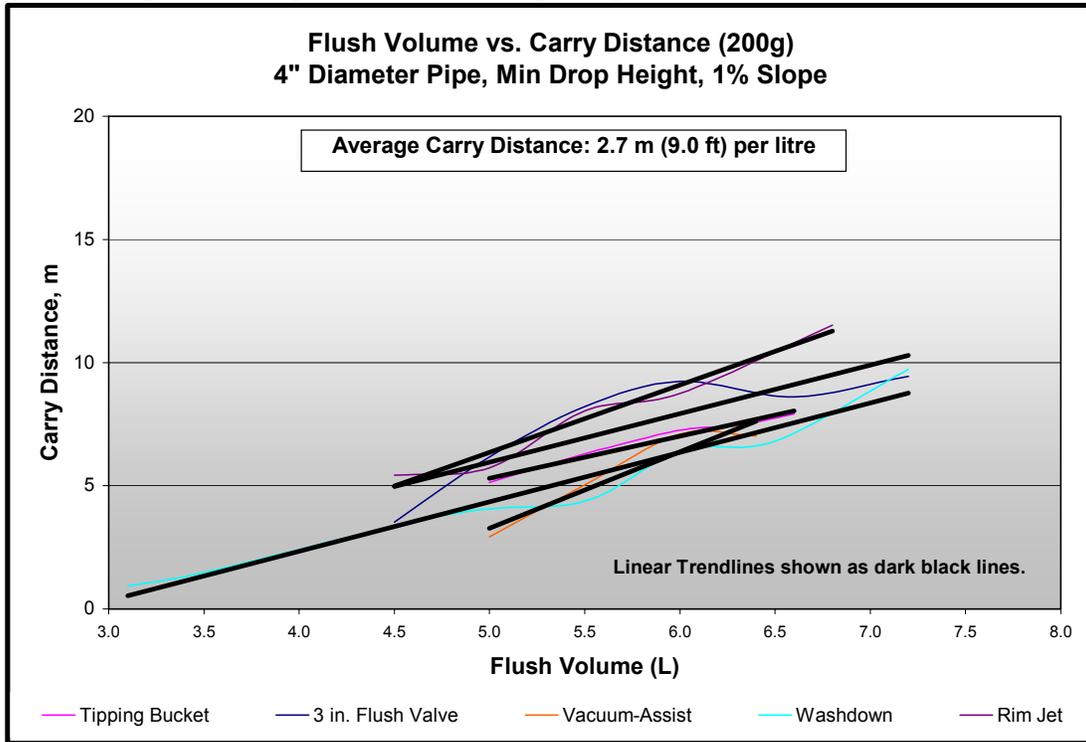
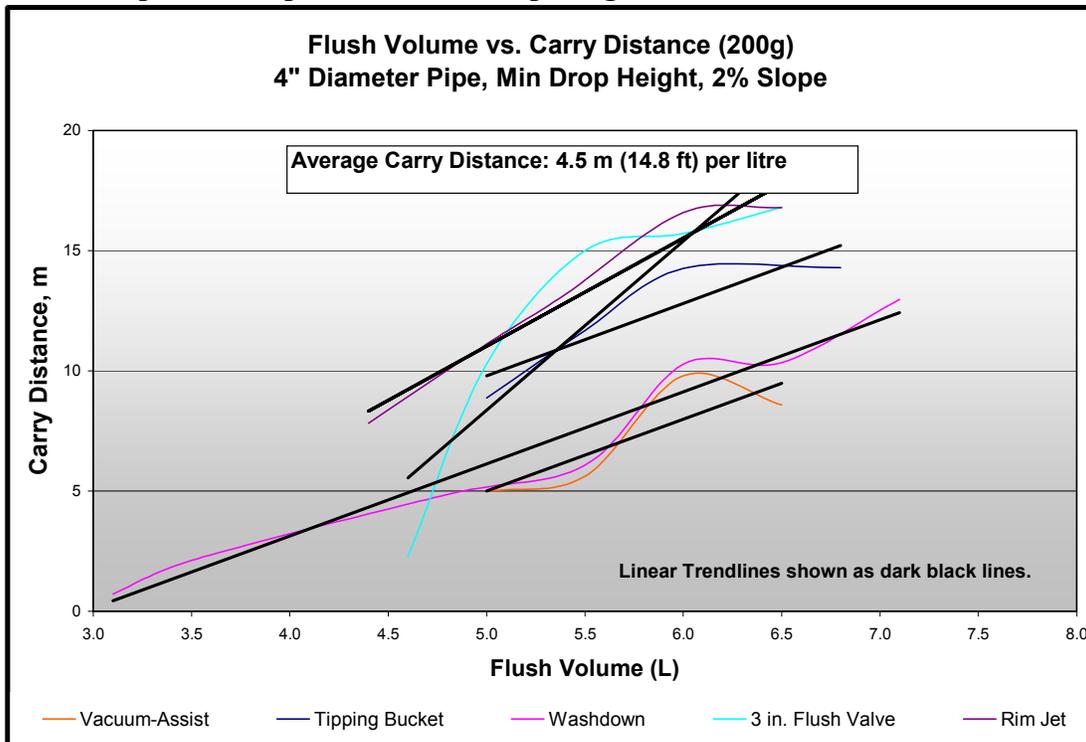


Figure 7d: 4" Pipe, 2% Slope, Minimum Drop Height



3.3 Effect of Drainline Slope

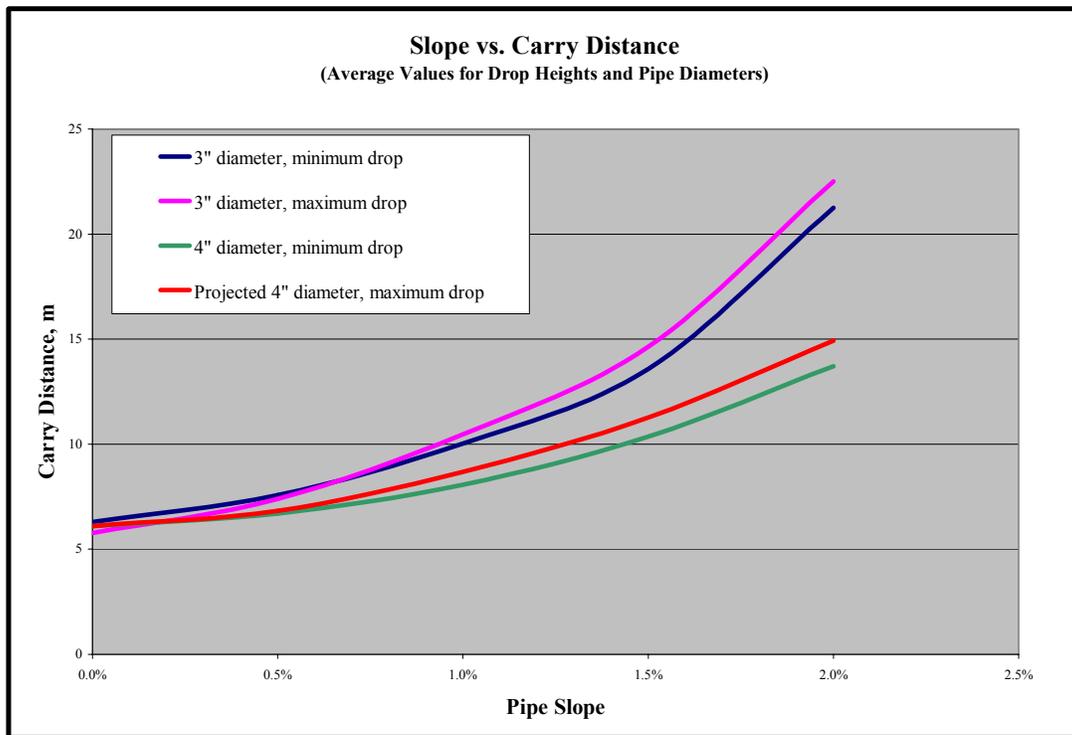
There was a correlation between drainline slope and drainline carry, i.e., the carry distance increases as the pipe slope increases²⁹.

Based on test results a set of curves for pipe slope vs. carry distance was developed (Figure 8) for mass loadings of 200g mass³⁰. These curves illustrate the relationship between slope and carry distance for the different system variables. Numerically, the values are as follows:

- 0% slope, 3" and 4" piping: carry distance ~ 6 m (20 ft)
- 1% slope, 3" piping: carry distance ~ 10 m (33 ft)
- 1% slope, 4" piping: carry distance ~ 8 m (26 ft)
- 2% slope, 3" piping: carry distance ~ 22 m (72 ft)
- 2% slope, 4" piping: carry distance ~ 14 m (46 ft)

Figure 8a combines minimum and maximum drop height data for 3" pipes and illustrates approximate range in carry distances depending upon type of flush system employed. Figure 8b combines minimum and maximum drop height data for 4" pipes and illustrates approximate range in carry distances depending upon type of flush system employed.

Figure 8: Slope vs. Carry Distance



²⁹ Some claim that pipe slopes of greater than 2% will cause the water to ‘out race’ the waste. Study results indicate that if such a phenomenon were to occur it would likely require slopes of *considerably greater* than 2% (this observation is supported by the Danish requirement of a 4% pipe slope).

³⁰ A auto laser level was used when adjusting pipe slopes to ensure that they were true. When setting up the 4" pipe with maximum drop height the level apparently became damaged (cause unknown) and was later found to be out of calibration and, as a result, it is not known at what slope these series of tests were completed. The erroneous data was discarded and the laser was replaced.

Figure 8a: Range of Carry Distance in 3" Pipe

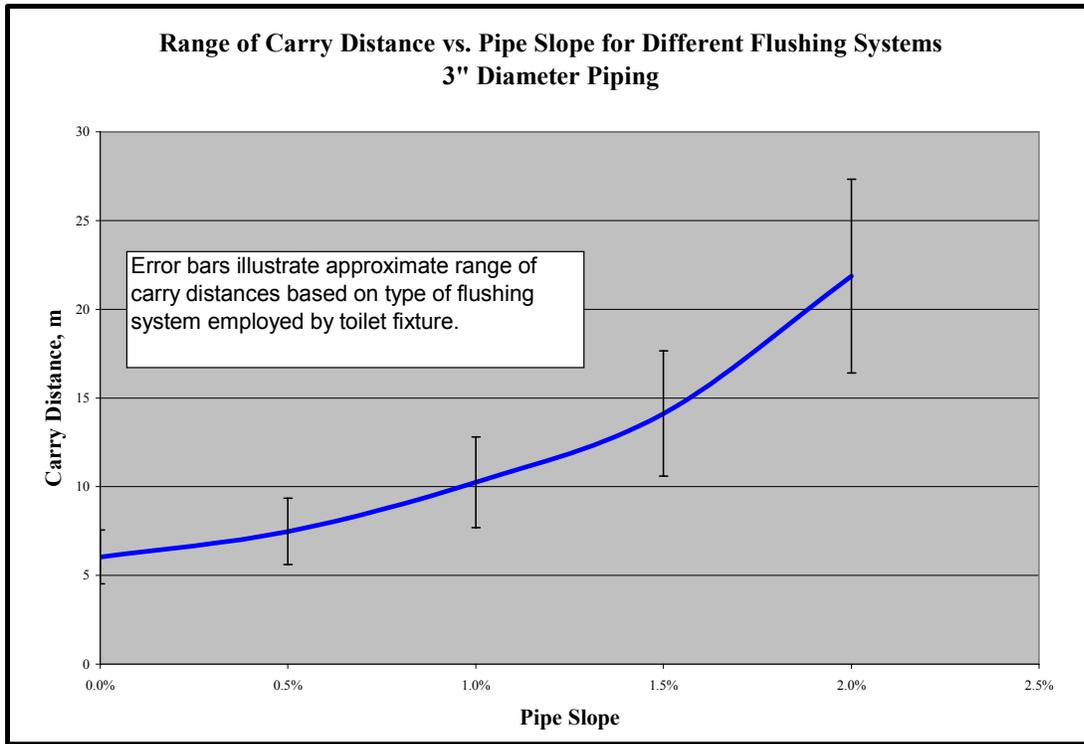
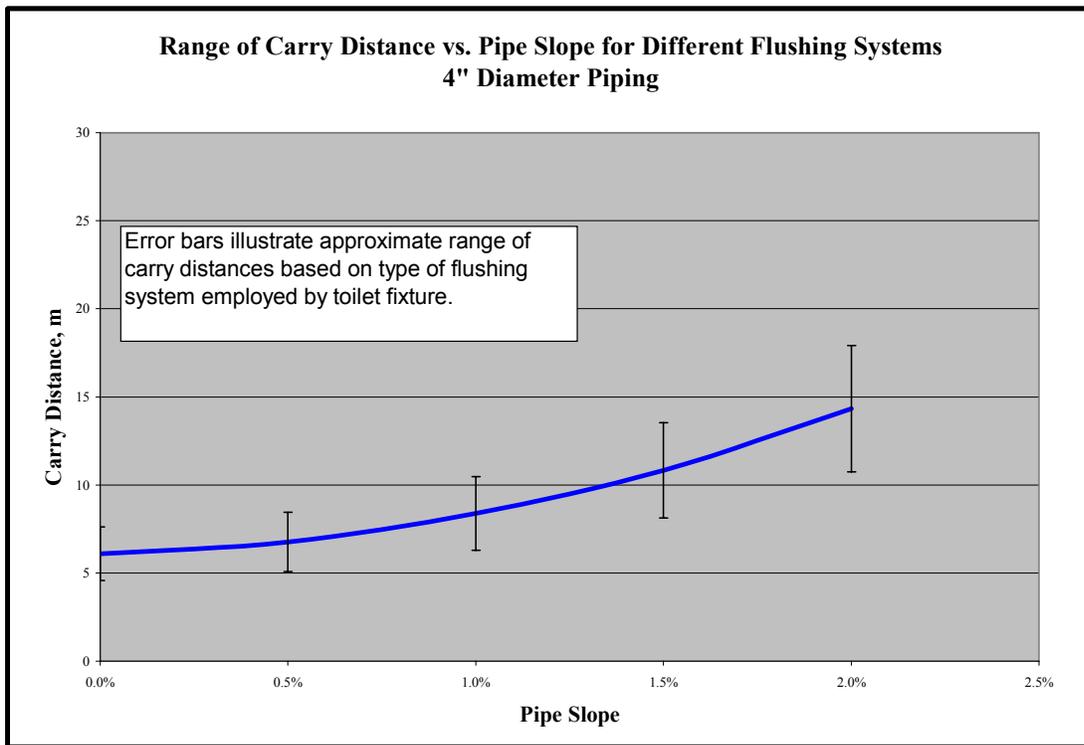


Figure 8b: Range of Carry Distance in 4" Pipe



3.4 Effect of drainline diameter

There was an inverse correlation between drainline diameter and drainline carry, i.e., carry distance decreases as pipe diameter increases (compare Tables 2a and 2c).

Study data indicates that carry distance in 3" diameter drainlines is *on average* approximately 50% greater than that in 4" pipes installed with a 2% slope, and 25% greater when the slope is 1%. These results are supported by data from a Swaffield and Galowin study³¹ that indicates carry distances are approximately 22 – 30% greater in 3" vs. 4" pipes, and approximately 40% greater in 4" vs. 6" pipes.

3.5 Effect of drop height

There did not appear to be a strong correlation between drop height and drainline carry, i.e., the maximum drop height provided only *slightly* greater carry distances (compare Tables 2a and 2c).

Carry distances for the two drop heights were within 1% for the 3" diameter pipe and within 4% for the 4" pipe. As such, values for minimum and maximum drop heights were similar enough to be combined for data analysis.

3.6 Effect of mass loading

There was an inverse correlation between mass loading and drainline carry, i.e., the carry distance decreases as the mass loading increases.

As might be expected, increasing the mass of waste discharged into the drainline reduced the carry distance. As can be seen in Figures 9a and 9b, a pipe sloped at 1% loses *on average* about 1.37m (4.5 ft) of carry distance for every additional 100g of loading, whereas a pipe sloped at 2% loses 1.64m (5.4 ft) of carry distance for every additional 100g of loading.

The curves appear to be somewhat linear, especially within the narrow range of normal solids loading of a toilet fixture (approximately 100 – 300g).

³¹ Big Drains, Small Drains, How do your wastes flow?, ASPE 1992 Convention Proceedings Technical Papers, Nov. 14-17, 1992, Washington, DC, pp 45 - 115, by Lawrence S. Galowin & John A. Swaffield

Figure 9a: Mass vs. Carry Distance, 1% Slope

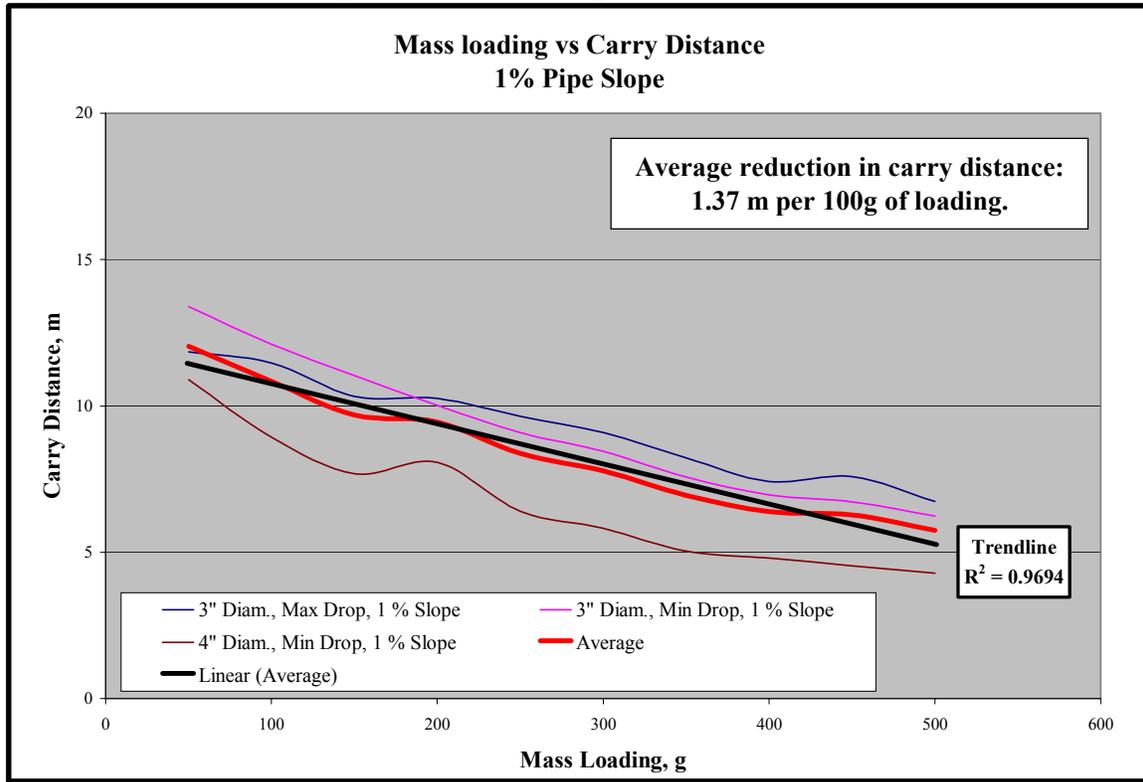
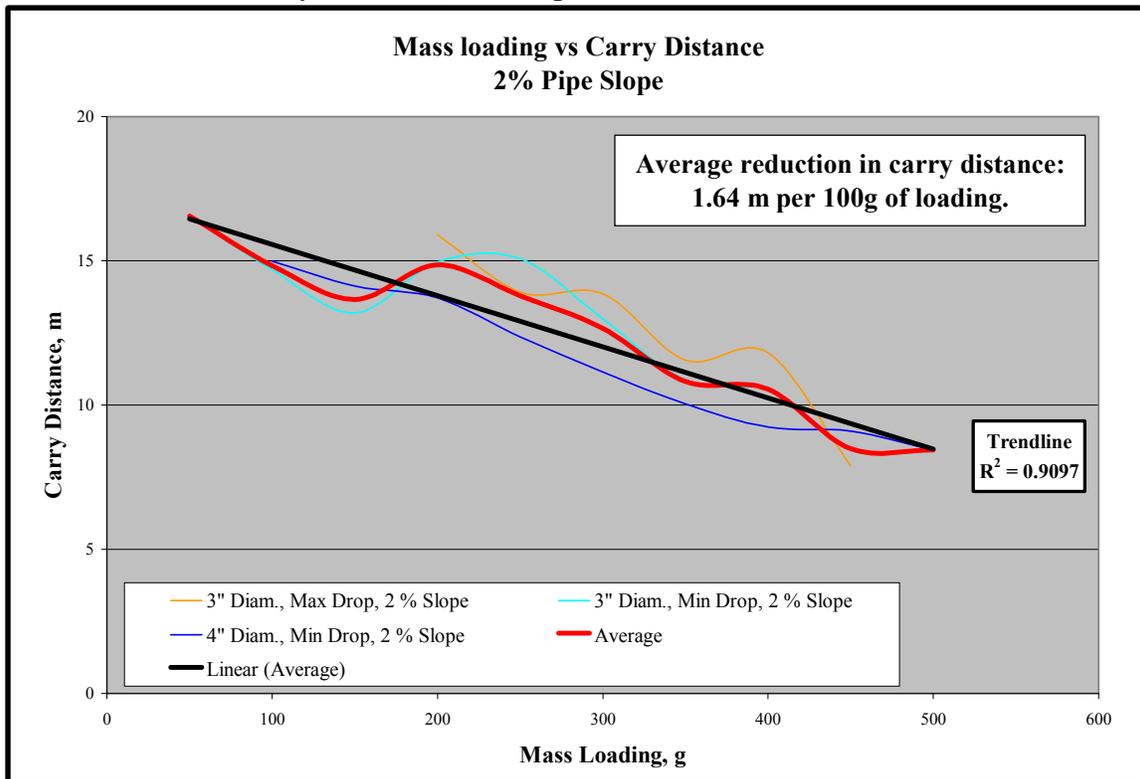


Figure 9b: Mass vs. Carry Distance, 2% Slope



3.7 Effect of next flush

The toilet paper included as part of the test media acted to hold the solids in a group or to create a ‘plug’ as it traveled down the pipe. The velocity of the ‘plug’ typically slows down as it travels in the drain until it settles in the pipe, wherein the trailing water often became dammed up behind the plug (see Figure 10). Unlike some simulated media that allows water to easily pass through, the soybean paste/toilet paper combination often forms a dam that, although not impenetrable, is capable of retaining the trailing water for several minutes.

A second flush serves to carry the waste media some additional distance. In real-world conditions the timing of a second flush would be somewhat variable, i.e., it may occur soon after an initial solids flushing or not for a day or more. In this study, however, it was not practical to wait for long periods of time between flushes. As such, the second flushes in this study followed the first flushes (the solids flushes) by only two or three minutes, i.e., after most, but not necessarily all, of the water trailing the media had dissipated. The results of the second flush testing portion of this study should be taken in context and not considered to necessarily represent the effects of second flushes under different scenarios.

3.7.1 Water-Only Second Flushes

The second water-only flush was typically activated while some of the water from the original solids flush was dammed up behind the media plug (remaining water). A wave is created as the second flush moves through the remaining water. When the wave front hits the plug it lifts and moves the plug further downstream. Of course, repeated flushing of water-only flushes eventually provides enough water to discharge the media from the end of the test pipe.

Figure 11 illustrates the effects of a second water-only flush on the media plug. The effect of the second flush appears to be slightly more pronounced in the 3” pipe where it pushes the waste to 170% of the original carry distance, whereas in the 4” pipe the second flush moves the waste to 159% of the original distance.

Figure 10: Media Dam and Second Flush Wave

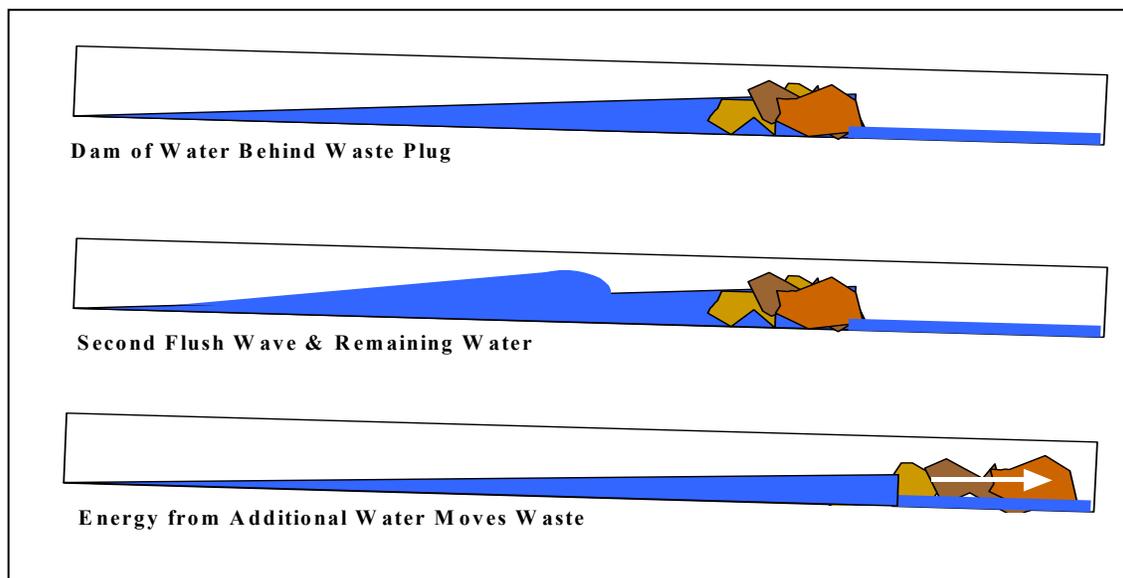
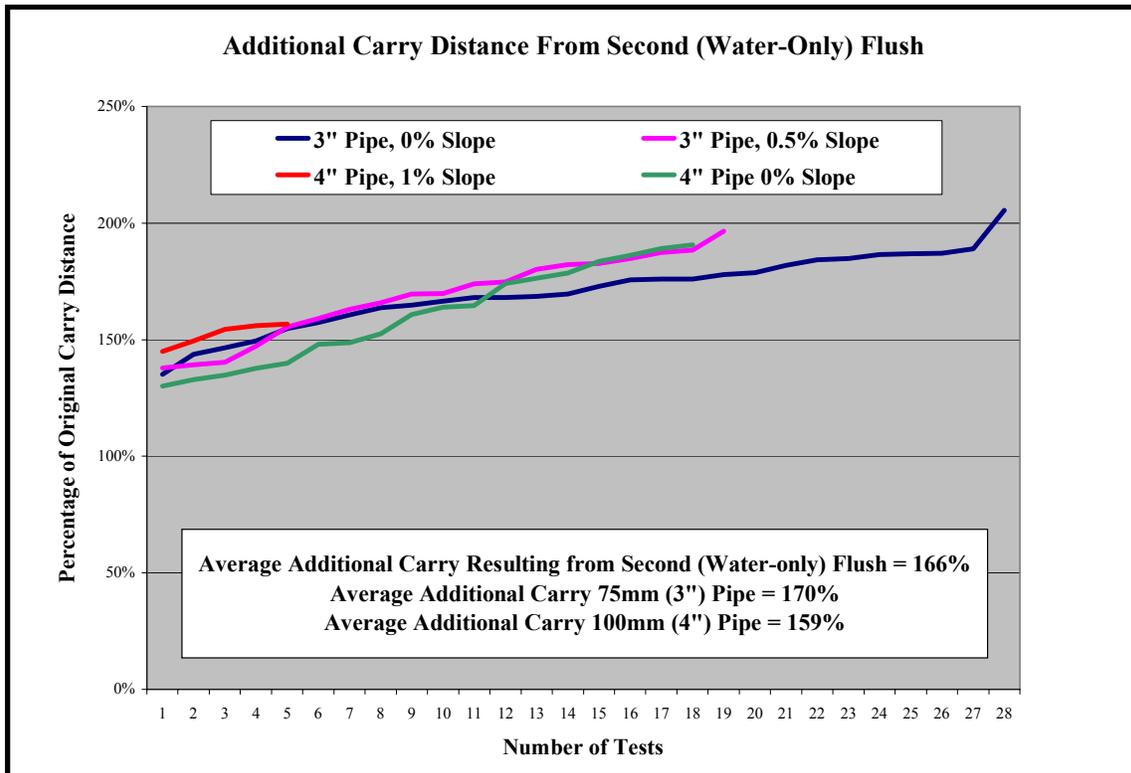


Figure 11: Additional Carry from Second Flush



3.7.2 Solids Second Flushes

Although only a limited amount of testing was completed involving second solids flushes (i.e., two consecutive solids flushes), in most cases the second (solids) flush moved the centre of mass of the test media only *slightly* further along in the pipe. In some cases media from the second flush combined with that of the first flush and formed an even larger *plug*.

The *second flush* results of this study agree with data contained in a Swaffield/Galowin study³² which shows a second *liquid* flush will move the centre of mass of the test media to 150% of the original carry distance, whereas a second *solids* flush will increase the carry to 125% of the original carry distance. The Swaffield/Galowin data also indicates that the centre of mass of repeated alternate solids-liquids flushing will eventually stabilize at approximately 200% of the initial carry distance.

In residential applications, solids flushes are generally followed by one or more liquid-only flushes, and often by supplemental flows. This may not be the case in commercial applications, especially in Mens washrooms where urinals are present (i.e., where toilets are used almost exclusively for solids flushing). There is, therefore, a much greater potential of waste remaining in the drainline, even after several flushes, in commercial installations – especially if drainline runs are very long.

³² Big Drains, Small Drains, How do your wastes flow?, ASPE 1992 Convention Proceedings Technical Papers, Nov. 14-17, 1992, Washington, DC, pp 45 - 115, by Lawrence S. Galowin & John A. Swaffield

3.8 Effect of blocking the vent

There did not appear to be a strong correlation between blocking the vent and drainline carry, at least under the test conditions used in this study, the carry distance did not appear to be affected by either partially or completely blocking the vent stack.

Approximately ten consecutive tests were completed measuring waste carry distances by alternately blocking and opening the vent to the drainage system. Further testing was not completed as no difference in drainline carry was observed under these two different conditions.

In this study, the piping discharged to atmosphere vs. the normal condition of discharging into a sewer. Venting may also be more of a problem if larger flows are introduced (e.g., via a clothes washer) or if significant dips or sags are present in the pipe that may prevent the flow of air.

3.9 Effect of dips and sags in the drainline

There was a correlation between the presence of dips or sags in the pipe and drainline carry, i.e., the carry distance decreases as the drainline becomes less straight and true.

Although this aspect of the testing program was not exhaustive (there is an unlimited number of possible variables to evaluate dips, sags, bends, bumps, buildup within the pipe, rough pipe walls, etc.), it was intended to verify that installing piping that is not straight and true can lead to reductions in carry distances.

The methodology used involved beginning with a straight and true length of 3" drainline at 2% slope and then imparting a sag to the line by lowering a support at one of the pipe joints. An example of the methodology used is illustrated in Figure 14 below. The amount of the sag was increased in 12mm (0.5") stages from zero to 36mm (1.5") and the effect on carry distance was recorded. Two sag locations were tested for the 6-L rim-jet toilet (Figure 15a) at 3 and 6m (10 and 20 ft) and a single sag location was tested for the 3.8-L pressure-assist toilet (Figure 15b) at 3m (10 ft).

Figure 14: Illustration of Imparting a Sag to Drainline

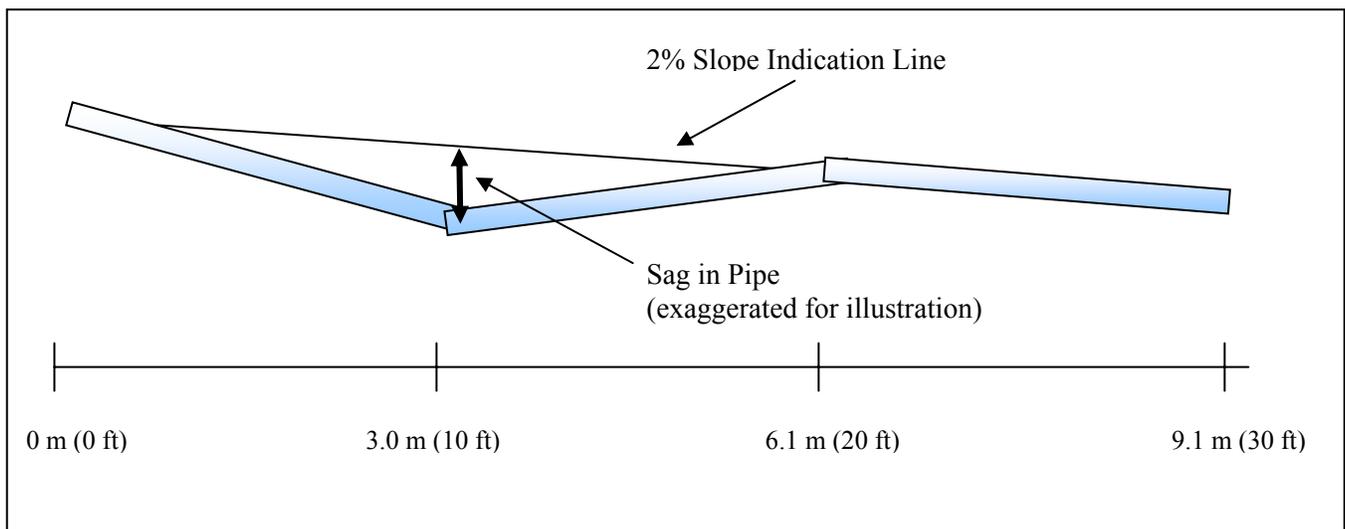


Figure 15a: Effects of Sag in Pipe Slope

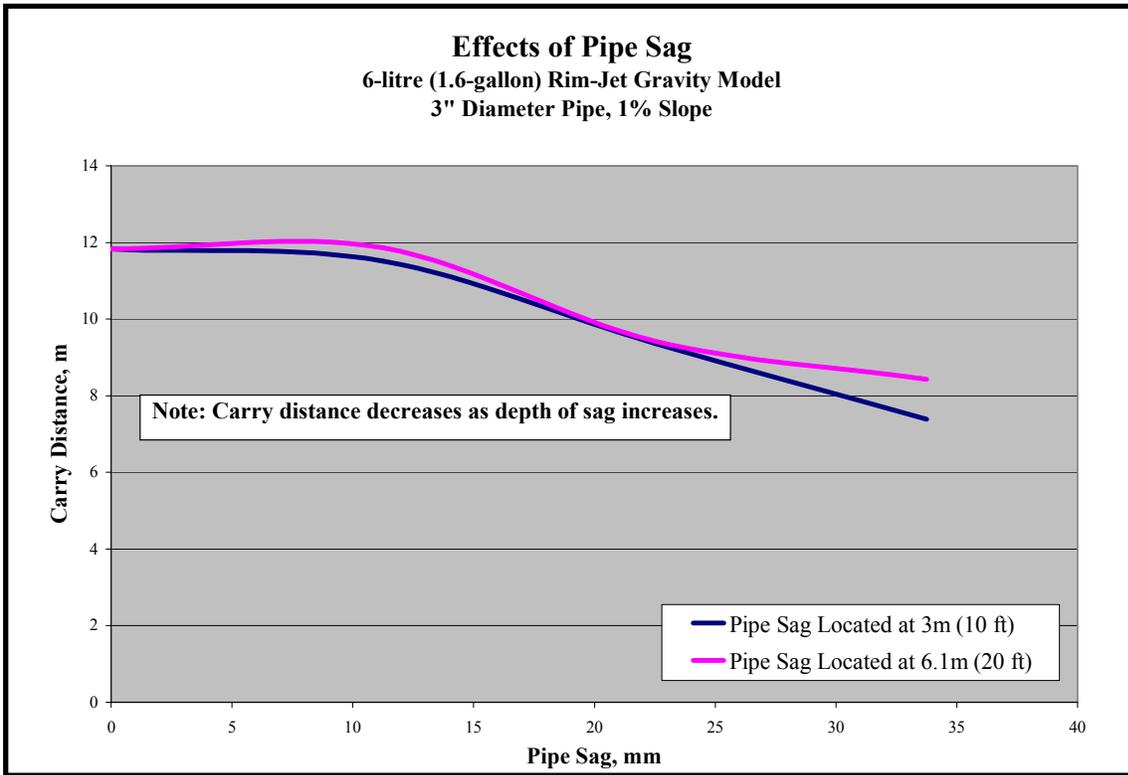
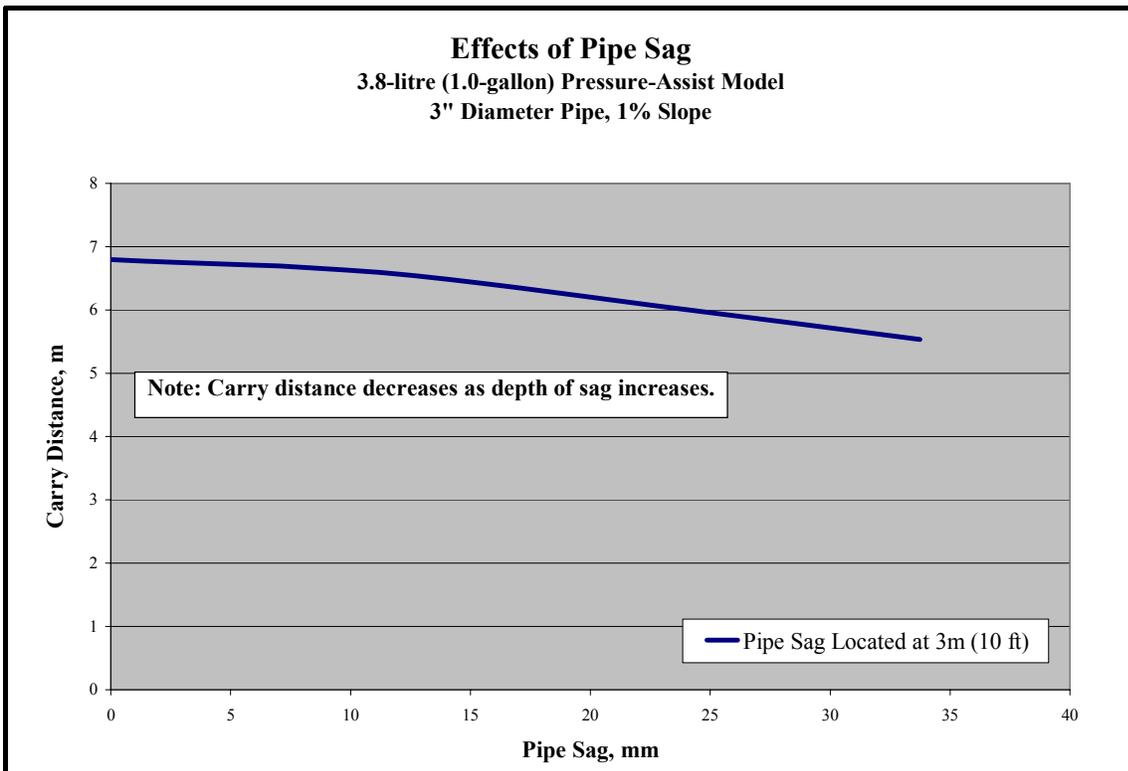


Figure 15b: Effects of Sag in Pipe Slope



3.10 Minimum expected carry distance ULF Toilets

Most concerns expressed by the public involve the ability of water-efficient toilets to carry solid waste to the sewer in residential installations. These concerns may be somewhat misplaced as a toilet flush would only be expected to transport waste to the building drain where the flow would be augmented with various supplemental flows from showers, baths, clothes washing, etc. Rarely would a toilet flush alone be expected to transport waste to the municipal sewer or a septic tank. Under the conditions described for this study, average ULF toilets were able to transport test media approximately 20m (84ft) in a 3” drainline installed at 2% slope *without any supplemental flows*. Only in very rare instances is it likely that residential drainline carry requirements would exceed this distance.

Commercial installations, however, are far more likely to have long drainage requirements and little supplemental flows. Based on the results of this study and the Swaffield/Galowin study, there appears to be a potential for waste remaining in, and potentially blocking, 4” drainlines installed at a 1% slope if they exceed approximately 15m (50ft) in commercial installations if no supplemental flows are present³³.

Table 5 summarizes the average distance achieved by the nine test fixtures. These values reflect the installation conditions outlined in this report.

Table 5: Waste Carry Distances (at 200g load)³⁴

Fixture Type	Drainline Installation Characteristics			
	75mm (3-in) drainline		100mm (4-in) drainline	
	1% slope	2% slope	1% slope	2% slope
Pressure-Assist – 6.0-Lpf (1.6-gpf)	13.6m (45 ft)	> 24.4m (> 80 ft)	10.6m (33 ft)	19.5 m (64 ft)
Gravity – Rim Jet	11.8 (39 ft)	> 24.4m (> 80 ft)	8.8 m (29 ft)	16.6 m (54 ft)
Gravity – 75mm (3 in) Flush Valve	10.6 (35 ft)	> 24.4m (> 80 ft)	9.2 m (30 ft)	15.7 m (52 ft)
Gravity –Jet in Sump of Bowl	11.3 (37 ft)	> 24.4m (> 80 ft)	7.8 m (26 ft)	16.3 m (53 ft)
Gravity – Jet in Trapway	11.3 (37 ft)	> 24.4m (> 80 ft)	8.7 m (29 ft)	11.8 m (39 ft)
Gravity – Tipping Bucket	9.1 m (30 ft)	> 24.4m (> 80 ft)	7.3 m (24 ft)	14.2 m (47 ft)
Gravity - Washdown	8.8 m (29 ft)	19.4 m (64 ft)	6.4 m (21 ft)	10.3 m (34 ft)
Gravity – Vacuum-Assist	11.3 (37 ft)	12.7 m (42 ft)	7.1 m (23 ft)	9.8 m (32 ft)
Pressure-Assist – 3.8-Lpf (1.0-gpf)	11.3 (37 ft)	12.8 m (42 ft)	6.7 m (22 ft)	9.2 m (30 ft)

Figures 12 and 13 on the next page can be used to estimated approximate carry distances under various scenarios for both 3” and 4” piping. For example, the carry distance for a toilet flushing 500g of mass loading with a flush volume of 6.5 litres in a 3” pipe would be approximately 19m (62 ft). A rectangle indicator on the charts identifies the expected performance range for an average ULF toilet and a drainline of 2% slope³⁵.

³³ Repeated flushing will eventually move the centre of mass of the waste to about 200% of original carry distance.

³⁴ Total length of test piping was 24.4 m (80 ft).

³⁵ Use data from Table 3d to adjust carry distance based on type of flushing system employed.

Figure 12: Drainline Carry in 3" Diameter Pipe

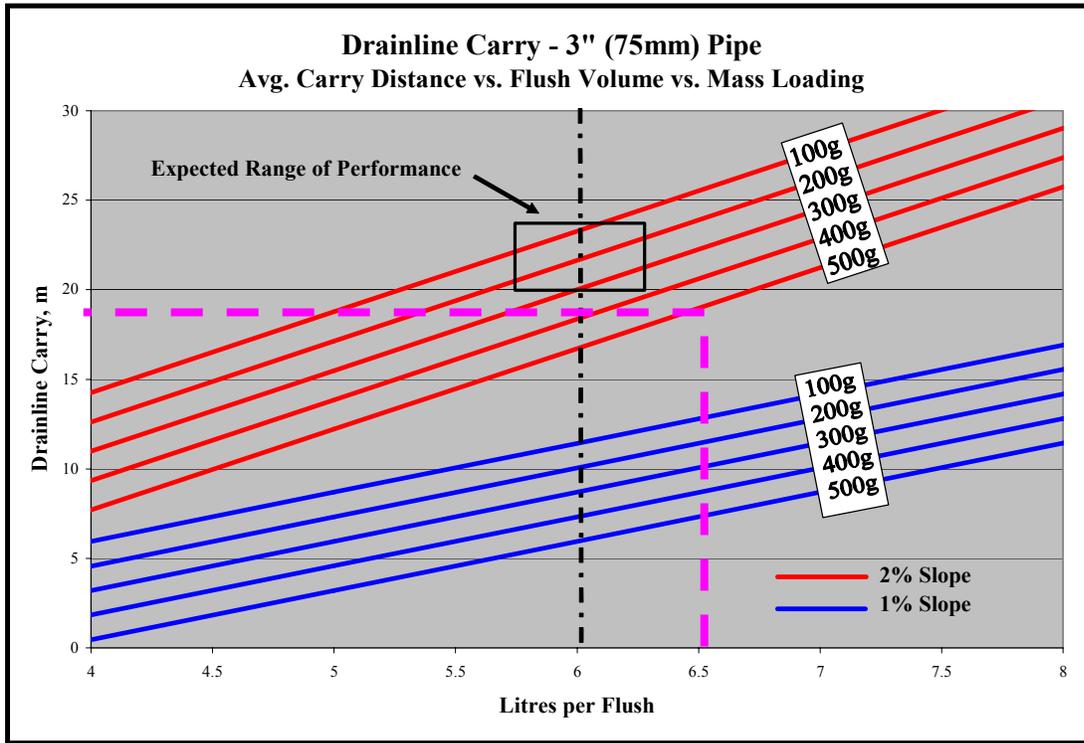
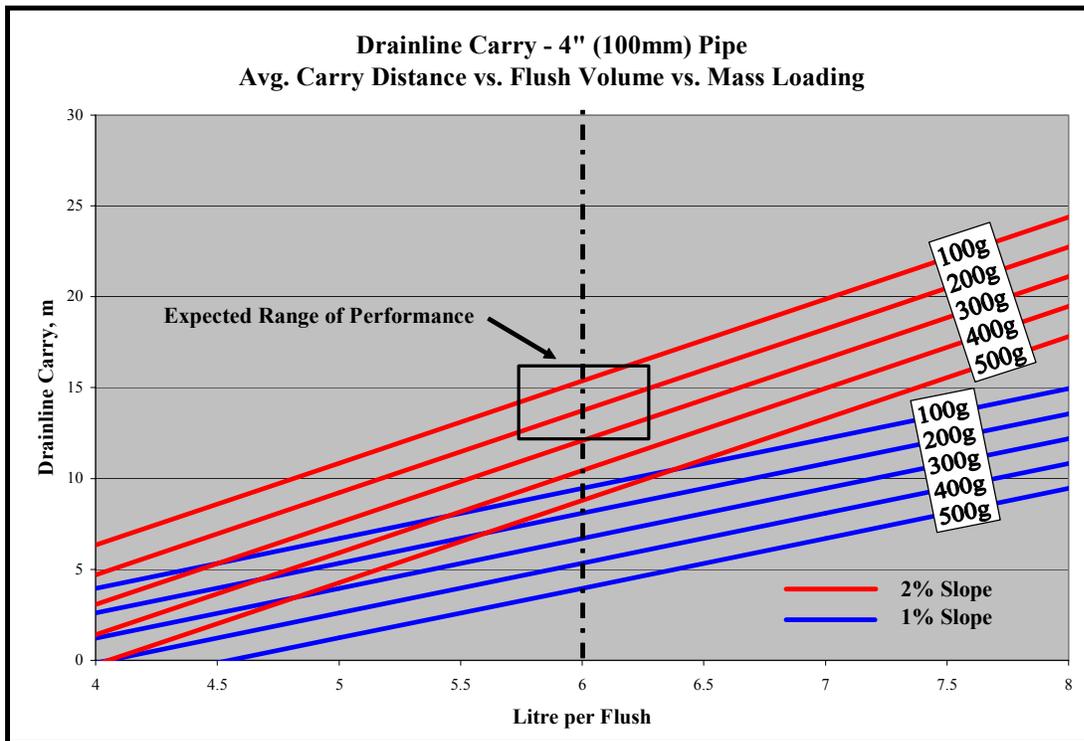


Figure 13: Drainline Carry in 4" Diameter Pipe



4.0 Conclusions

3" Piping installed at 2% slope (typical of residential installation): Under study conditions water-efficient toilets can transport 200g of test media approximately 16m to 27m (52ft to 89ft), depending on type of flushing system, with no supplemental flows from showers, baths, or clothes washers.

4" Piping installed at 1% slope (typical of commercial installation): Under study conditions water-efficient toilets can transport 200g of test media approximately 6m to 10.5m (20ft to 34ft), depending on type of flushing system, with no supplemental flows.

Under conditions examined in this study, namely clean drain pipes, straight runs, and proper slopes, all ULF and H-E toilets tested would be expected to meet or exceed the relatively short waste carry distance requirements typical of household plumbing installations even with no supplemental flows from showers, baths, or clothes washers. Installations with extremely long drainage distances, e.g., shopping malls or industrial sites, however, may require evaluation on a site-by-site basis, especially if no supplemental flows are available³⁶.

5.0 Identification of Areas of Further Testing

Budget and time constraints³⁷ naturally resulted in some limitations to project testing. Each of these limitations represents a potential area for further testing:

- different pipe materials were not tested (research by Dr. Larry Galowin indicates that carry distances in cast iron piping are approximately two-thirds of that in plastic pipes)
- no testing was completed using rigid pipe couplings
- no testing was completed on toilets flushing greater than 6 litres (1.6 gallons)
- waste media settling in the drainline was not allowed to dry out completely (simulating weekend or vacation drying) before the next flush
- no testing was completed using sanitary napkins
- no testing was completed using increasing loadings of toilet paper
- no testing was completed on old piping removed from demolished buildings
- no testing was completed to assess the effects of supplemental flows
- no testing was completed on toilet models that repeatedly fail to clear at least 200g
- testing was completed for only two flange-to-drain conditions (minimum and maximum drop heights); a more circuitous route from flange-to-drain may effect carry distances.
- no testing was completed to compare the various test media and methodologies used for drainline testing by different test agencies or nations.

³⁶ Pipes connecting commercial sites to sewers may be 6" diameter or larger, further reducing carry distances.

³⁷ Under 'normal' household conditions the interval between consecutive flushes of a single toilet (especially if it is a rarely used fixture) may be several days or even weeks, thereby allowing any waste material that remains in the drainline to become completely dry prior to the 'second flush'. Similarly long intervals between flushes were not practical to achieve during this project and, as such, waste media was not allowed to dry between flushes.

APPENDIX A

CMHC RESEARCH HIGHLIGHT

MAXIMUM PERFORMANCE (MAP) TESTING OF POPULAR WATER-EFFICIENT TOILET MODELS

MAXIMUM PERFORMANCE TESTING OF POPULAR WATER-EFFICIENT TOILET MODELS

INTRODUCTION

Approximately one third of all indoor household water is used for toilet flushing when conventional 13-litre toilets are used. A desire to conserve water is leading many consumers to choose water efficient 6-litre toilet models when building or remodeling their homes. Many municipalities across Canada now offer financial rebates for 6-litre toilet retrofits while the province of Ontario and the city of Vancouver, mandate 6-litre toilets in all new construction.

Most 6-litre toilet models exceed customer performance expectations. However, recent research in Canada and the U.S. conclude that there are also certified and commercially available models that do not flush effectively, resulting in customer complaints and the need for double-flushing.

Currently, there is no convenient way for the customer to distinguish between good and marginal performers. In addition, this lack of information on toilet performance levels has served to create a negative perception regarding 6-litre technology in general, as opposed to identifying only the poor performers.

Another issue is the effect of flapper replacement on toilet flush performance. Flappers wear out and need to be replaced approximately every five years. The concern lies in the type of flapper used for replacement. Toilets using adjustable flappers may lose water savings if replaced with a standard flapper—the type typically found at most home supply stores.

RESEARCH PROGRAM

In 2003, CMHC organized a consortium of 22 water agencies from across Canada and the U.S. to test the effectiveness of low-flush toilets. The Maximum Performance Testing of Popular Toilet Models (MaP) program was led by the Canadian Water and Wastewater Association (CWWA) and sought to rank the toilet makes and models based on tested flush performance.

This work built on an earlier report, *Water Closet Performance Testing*, a National Association of Homebuilders Research Centre (NAHBRC) study undertaken in the U.S. but changed in three ways:

- a more realistic testing material was selected (soybean paste and toilet paper)
- each model was adjusted to flush with the required 6 litres¹
- a minimum performance threshold was established (250 grams of solid waste)

¹ During testing it was found that about a third of the models used more than 6 litres when adjusted to manufacturer's instructions. This correlates to an earlier CMHC field-study that found 6-litre toilet flush volumes ranging from 2.5 to 14 litres.

METHODOLOGY

Flush performance:

A total of 80 different toilet model fixtures were tested. Of these 80 models, 44 toilet models were considered to meet all the requirements for the study. These were selected to include the top-selling models in the regions represented by the participating organizations. Two examples of each model were tested, purchased where possible “off-the-shelf” in a retail outlet. The remaining 36 toilet models tested were either prototypes (not currently available in the marketplace) provided directly by the manufacturer or single prototypes. The results from these models can be found within the report. All models tested used a variety of different flushing mechanisms and included both gravity-fed and pressure-assist models.

All toilets were initially set according to manufacturer’s instructions and evaluated on actual flush volume. Where necessary toilets were recalibrated to flush with the required 6 litres.

Flush performance was assessed in two ways:

1. *Ability to flush solid material:* Sausage-shaped samples made of soybean paste were flushed with toilet paper to provide a realistic simulation demand on the toilet. The maximum weight of the test media that each model could completely flush, without double flushing, was recorded. The model was judged to be effective if it cleared a minimum of 250 grams of media².
2. *Ability to completely replace water in the bowl as part of a liquid-only flush:* A brine mixture was added to the bowl and the percentage of liquid exchanged was calculated by measuring the conductivity of the liquid in the bowl before and after the flush.

Flapper Replacement:

To test the effect of changing the flapper on flush volume, the original flapper was replaced, first with a standard flapper and then with each of the three most common models of “universal” (adjustable) flappers. In the case of the adjustable flappers, the testers attempted to adjust the flapper to achieve a flush volume of the required 6 litres.

For various reasons, replacement flappers could not be installed in every toilet model. For example, some toilets use proprietary flappers, such as the 3-inch (75 mm) flappers used in the Toto Drake, Ultramax, and Ultimate, the 2-inch (50 mm) disks used in the Mansfield Alto, and the proprietary flush valve seal in the American Standard Champion.

Other models excluded from the test were pressure-assisted toilets, and toilets where the proper operation of the replacement flapper was prevented by interference from existing trim components.

RESULTS

Flush Volume “Out of the Box”

Approximately 30% of the models tested flushed with greater than 6 litres when removed from their factory carton, assembled on the test rig and adjusted in accordance with manufacturer’s instructions. Only 13% flushed with 7 litres or more.

Solids Flushing Performance

Flush performance varied greatly, clearing from 100 to 900 + grams of solids. Of the 44 toilet models, 20 models flushed clearing less than 250 grams; 13 models flushed clearing between 250 grams and 500 grams; and 11 models flushed clearing in excess of 500 grams.

Impact of flapper replacement:

When the original flapper was replaced with a standard, non-adjustable buoyant flapper, 70% of the toilet models used more than the required maximum flush volume.

Liquid Flushing Performance

When the percentage of water exchanged on an all-liquid flush was measured, it was found that virtually all the models exchanged at least 98% of the water in the bowl on a single flush. Since those models that did not adequately clear solid material did well on this test, water exchange on a liquid-only flush does not appear to be a reliable indicator of the effectiveness of a toilet. Problems with water exchange are perhaps more likely to arise with a flush combining liquid and solids.

Even when adjustable flappers could be installed, it was not always possible to adjust them to flush with 6 litres/1.6 gallons. The Niagara® flapper could be adjusted to achieve the correct flush volume on the largest number of toilet models (79%). The Fluidmaster® flapper could be properly adjusted for 55% of toilet models, and the Frugal Flush® flapper for only 17% of toilet models tested.

² J.B. Wyman, K.W. Heaton, A.P. Manning, and A.C.B. Wicks of the University Department of Medicine, Bristol Royal Infirmary, *Variability of colonic function in healthy subjects*, 1978.)

Implications for Consumers and Water Providers

These results provide only a “snapshot” of the effectiveness of low-flush toilet models currently available:

1. The models selected do not represent all models currently on the market.
2. Since only two examples of each model were tested, the results may not represent performance of that model overall.
3. Models may have been modified since the testing was completed.

However, the study offers two clear conclusions:

Firstly, the results show that many low-flush toilets certified by standards bodies in Canada and the U.S. do not flush adequately when adjusted to the required 6-litre/1.6-gallon flush volume. For consumers to feel confident that it is worth investing in a low-flush toilet, they should be able to rely on certification as an indication that the model performs adequately at the required flush volume. Since the liquid exchange test does not appear to accurately indicate how well a toilet performs, it should not be relied on as an important part of the certification process. In contrast, the solid waste test developed for this study has been accepted as a good indicator of toilet performance and may offer a reliable testing method to be included as part of certification requirements. Following the methodology used in this study, soybean paste would be used to represent solid waste, and 250 grams would be adopted as a minimum threshold for adequate performance.

Secondly, the study confirmed that:

1. Many low-flush toilets use more water than indicated when set up according to the manufacturer’s directions.
2. Replacing the flapper is likely to affect the flush volume. Consumers should be encouraged to purchase models that can be easily set up to flush the appropriate volume. They should also consider models that are designed with a standard so that the flapper can be replaced with an equivalent model from a renovation centre. If choosing a model with a proprietary flapper, consumers should ensure that the proper replacement flapper is readily available. If consumers install an adjustable flapper, it may be difficult for them to identify the proper setting to maintain water savings and flush performance.

The desired water savings are more likely to be realized in water utility low-flush toilet rebate programs when toilets:

- can be easily set up to the correct volume
- are equipped with a standard, or proprietary flapper, and not an adjustable flapper
- perform adequately at the correct flush volume

The results from the MaP study have had a fairly significant impact on the 6-litre toilet industry. To date at least 5 Canadian municipalities, along with several water agencies in California now require that toilets must be chosen from those passing the MaP protocol in order to be considered for their toilet rebate programs. A number of toilet manufacturers have proactively opted to have their new designs tested with this protocol to ensure performance quality. While CMHC was a key contributor to the initial MaP study, costs associated with ongoing testing are borne by the manufacturers and result updates to the toilet list are posted quarterly on the websites of the *Canada Water and Wastewater Association* (cwwa.ca/home_e.asp) and the *California Urban Water Conservation Council* (cuwcc.org/products_tech.lasso). The original study and results can be found within the CMHC report, *Maximum Performance Testing of Popular Water-Efficient Toilet Models*.

PROJECT PARTNERS

Canada

- Canadian Water and Wastewater Association (CWWA) – LEAD AGENCY
- B.C. Capital Regional District, Victoria, British Columbia
- B.C. Buildings Corporation, Victoria, British Columbia
- Canada Mortgage and Housing Corporation
- Calgary, Alberta
- Edmonton, Alberta
- Greater Vancouver Regional District, British Columbia
- Halifax, Nova Scotia
- Hamilton, Ontario
- Montréal, Quebec
- Ottawa, Ontario
- Region of Durham, Ontario
- Region of Halton, Ontario
- Region of Peel, Ontario
- Region of Waterloo, Ontario
- Toronto, Ontario
- Winnipeg, Manitoba

U.S.A.

- California Urban Water Conservation Council, Sacramento, California
- East Bay Municipal Utility District, Oakland, California
- Los Angeles Department of Water and Power, Los Angeles, California
- Seattle Public Utilities, Seattle, Washington
- Tampa Bay Water, Clearwater, Florida

Research Report: Maximum Performance Testing of Popular Water-Efficient Toilet Models
Consultant: Veritec Consulting Inc.
Project Manager: Cate Soroczan

Housing Research at CMHC

Under Part IX of the *National Housing Act*, the Government of Canada provides funds to CMHC to conduct research into the social, economic and technical aspects of housing and related fields, and to undertake the publishing and distribution of the results of this research.

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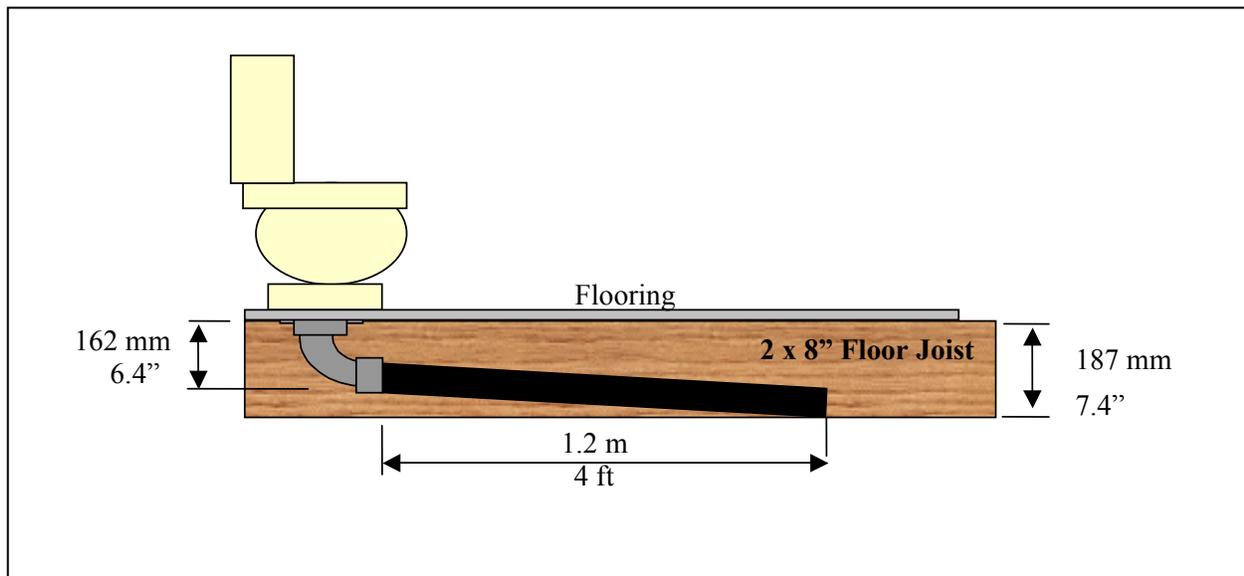
APPENDIX B

ACHIEVING SLOPES OF 2% IN NEW CONSTRUCTION

During an interview with a plumbing inspector, it was learned that although the plumbing code calls for slopes of 2% (often stated as a quarter of an inch per foot), this is sometimes not practical given the limited depth available in typical floor construction. That is, 2 x 8 inch lumber is commonly used as floor joists and, when dressed, this lumber typically has a depth of only 187mm (7 ⅜ in).

The inspector stated that, because it is often not possible to achieve a 2% pipe slope without protruding below the bottom of the floor joists he (and he suspects most other inspectors) permit slopes of less than 2%, even though they do not meet code requirements, without issuing violation notices.

The illustration below helps to define this situation.



A 75mm (3 in) drainline used with a typical floor flange and 90 degree elbow has a total depth to the bottom of the pipe of approximately 162mm (6-3/8 in). Therefore, only about 25 mm (1 in) of space is available before running out of depth. At a 2% slope, this limited dimension permits a run of only about 1.2m (4 ft) before the drain pipe would drop below the bottom of the joist. Even at 1% slope, the maximum distance would be only 2.4m (about 8 feet).

Based on this assessment, it is likely that drainline slopes in many residential dwellings may be less than 2%. The results of this study indicate that slopes of 1% (and even less) may be sufficient to carry waste materials the short distances normally required in household applications.

APPENDIX C

COMPARISON OF SOYBEAN PASTE/TOILET PAPER TO ‘WATER WIGGLERS’

Because they are re-usable and are promoted as representative of human waste in a plumbing system, ‘Water Wigglers’ are being used by manufacturers and other testing laboratories as one of several test media. The purpose of the analysis in this study was to compare the carry distances of the soybean paste and toilet paper used in this test regime with ‘Water Wigglers’ when all other variables are held constant. Two different wigglers were used as test specimens: the green sample was approximately 12cm (4.75 in) long and 4.0cm (1.6 in) in diameter with a mass of about 160g and the red specimen was approximately 12cm (4.75 in) long and 3.5cm (1.4 in) in diameter with a mass of about 132g (see photo).

Although not exact, the green specimen (160g) was compared to a media mass loading of 150g, and both the green and red specimens combined (292g) was compared to a media mass loading of 300g. Testing was completed on three different toilet types: rim-jet gravity model, 4-L pressure-assist model, and washdown model. Test results are illustrated in Figures C1 and C2.

In general, it was more difficult to flush the ‘Water Wigglers’ from the toilet than the test media, i.e., they often became stuck in the toilet trap, causing clogs. When the Wigglers flushed from the toilet they would float in the pipe even with very little water to buoy them. As such, they traveled a significant distance further than the simulated soybean paste media used in this testing. As noted in Figures C1 and C2, the ‘Water Wigglers’ exhibited very different drainline carry characteristics than the simulated waste (soybean paste and toilet paper).



Though, as stated earlier, the comparison testing between the realistic test media used in this study and ‘Water Wigglers’ as a test media was not extensive, the results show ‘Water Wigglers’ were carried an average of 159% of the distance of the soybean media in a 3” pipe at 1% slope. Based on these limited results it does not appear that ‘Water Wigglers’ constitute a suitable test media for toilet drainline carry studies.

Figure C1: Comparison of Soybean Test Media and Water Wigglers

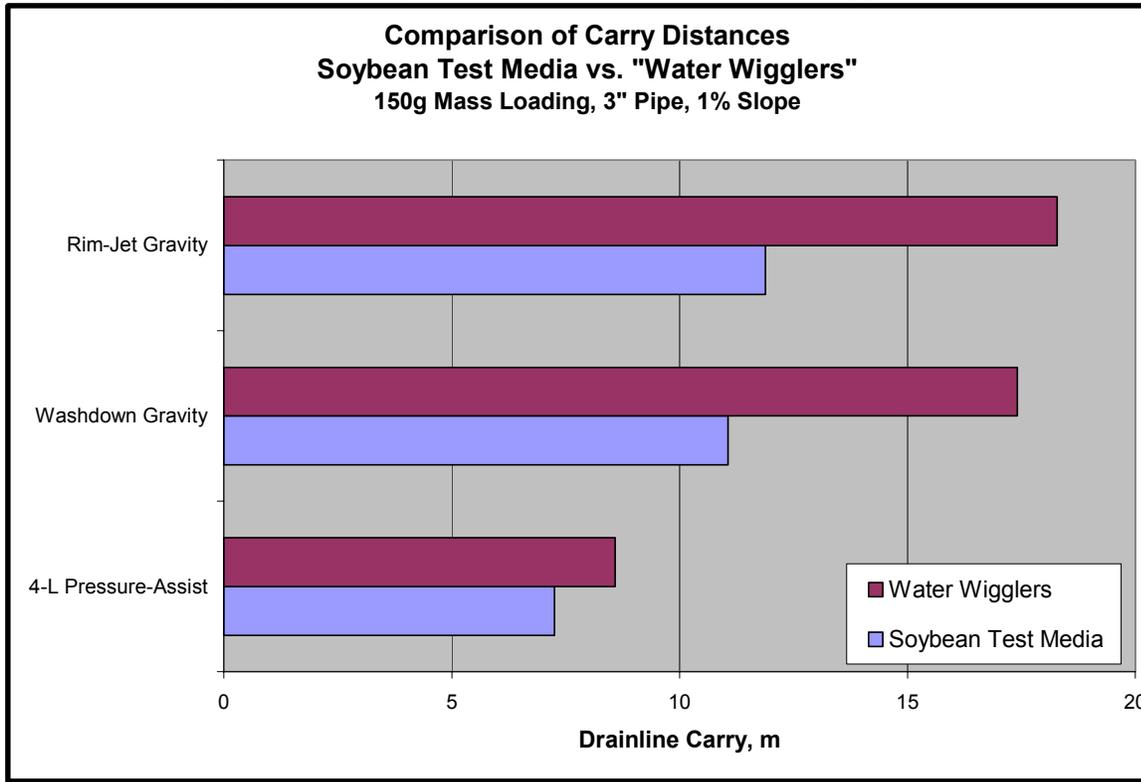


Figure C2: Comparison of Soybean Test Media and Water Wigglers

