STEPP Verification Report

StormTrap TrashTrap® Trash Capture Device (TCD) Tested in Accordance with ASTM 3332

March 2025

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Abbreviations and Definitions

Abbreviation/Term	Definition
COV	Coefficient of variance
MDL	Method detection limit
MQL	Method quantification limit
MTD	Manufactured treatment device
MTFR	Maximum treatment flow rate
PSD	Particle size distribution
QAPP	Quality assurance project plan
RPD	Relative percent difference
SSC	Suspended sediment concentration

[1] Revision Table

Revision Number	Reason for Revision
1	Initial document revision

Approvals

StormTrap LLC (Applicant):

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Director of Water Quality Technology

Date

Independent Observer:

Jason Wiesbrock, P.E., SpaceCo Inc.

Date

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1.0 Description of the Technology

StormTrap TrashTrap® netting systems combine the natural energy of water flow with disposable mesh nets to capture and retain trash, floatables, and solids from stormwater and wastewater. The systems can be adapted to a variety of applications. TrashTraps can be connected in parallel or series to handle a wide range of pipe or channel sizes and flow rates. TrashTraps have three different standard modules, and several net assembly sizes are available for each. Modules are the same in all critical respects. Only the outside structure is different, and independent of the system's performance (Figure 1). The three different modules are:

- The In-Line TrashTrap modules are installed underground and upstream of the outfall. Components are installed in a high-strength precast concrete chamber, and servicing the unit is done at ground level.
- The End-of-Pipe TrashTrap modules are utilized where the end of the collection system enters the water course. Components can be installed into a new headwall or retrofitted to existing outfall structures.
- The Floating TrashTrap modules perform in the same manner as End-of-Pipe systems, but they float on the water. Components are installed in a pontoon structure that floats constantly at water level, and, if equipped, funnel and side curtains direct trash into mesh nets.

Figure 1 – Standard TrashTrap Modules

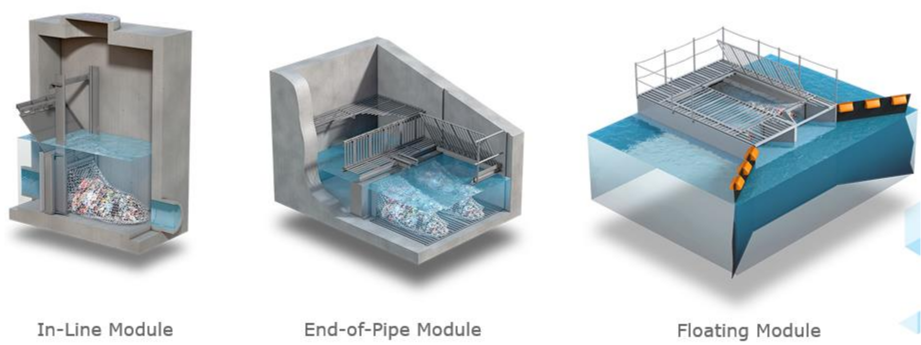
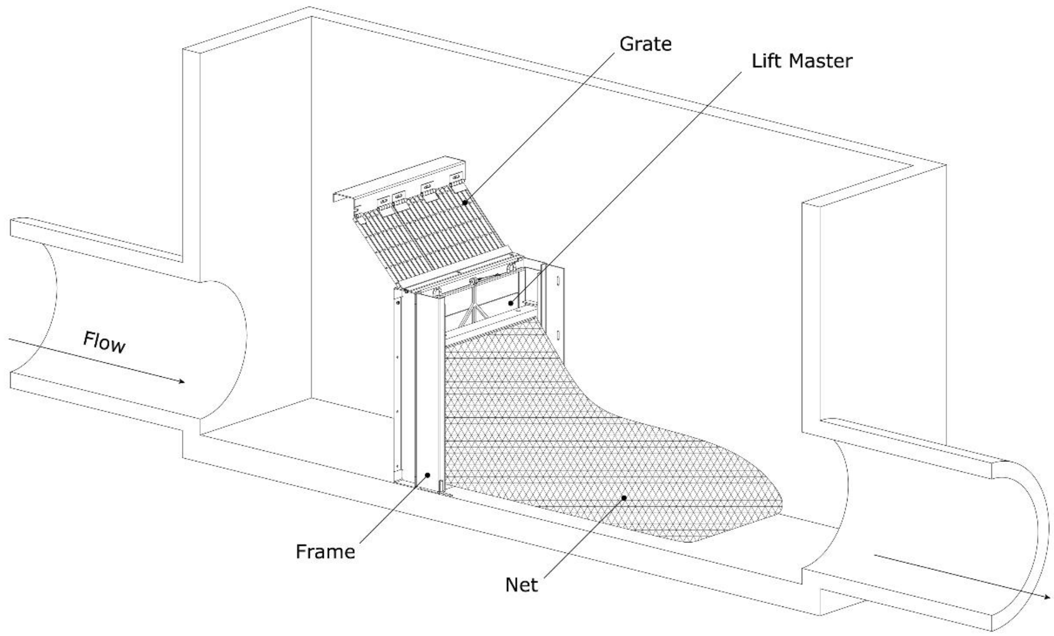


Figure 2 shows a TrashTrap in an in-line configuration. A guiderail is used to secure the TrashTrap to the structure. It contains a groove into which a net assembly can be inserted. Each net assembly is comprised of a net that is attached to a frame at the opening that keeps the mouth of the net open and allows the net to be secured to the guiderail. In some installations a LiftMaster is included in the design. A LiftMaster is a component that encompasses the net assembly and aids in the lowering and raising of the net when performing maintenance activities. For clarity, some of the LiftMaster has been removed from the figure.

The TrashTrap is designed to bypass the very high flows that can occur during large storms. Captured debris is contained in the netting assembly and is unaffected by the water surface elevation within the system. The grate is an optional component that allows for some floatable capture at the netting assembly bypass flows. Captured debris is retained upstream of the grating unless the water surface elevation exceeds the top of grating elevation. If the water surface elevation does not surpass the grating, after the precipitation event subsides, and the water level recedes, captured debris will migrate into the net.

Figure 2 – Schematic of TrashTrap



2.0 Laboratory Testing

Testing was conducted at a temporary laboratory facility located in Morris, Illinois in September and October of 2023. The facility is described in more detail in Section 3. The third-party observer was Jason Wiesbrock, P.E., Vice President of Space Co. Inc. Mr. Wiesbrock is responsible for managing the Morris, Illinois office of SpaceCo.

Mr. Wiesbrock has a BSc in Civil Engineering from the University of Illinois and he is a Professional Engineer in the state of Illinois. He has nearly 30 years experience, including stormwater management projects and regulatory compliance work, and he has been called on as an expert witness on civil engineering projects. His resume and statement of qualification is included in Appendix I.

The net assembly variables affecting performance include frame aperture size, net length, and netting mesh opening size. All commercial net assembly frames are larger than the 12”x12” aperture that was tested. The smaller aperture was chosen to simplify scaling calculations and to limit the flow required. TrashTraps are typically designed for a flow velocity of 5 ft/s so a 1’ x 1’ net is designed for 5 cfs, which was near the limit of our pumping capacity, so a larger aperture was not practical.

Testing was conducted in accordance with ASTM 3332 “Standard Test Method for Determining Trash and/or Debris Capture Performance of Stormwater Control Measures”, except for Sections 9.4 and 9.6. Tests for Trash and Debris, and 5 mm beads were not conducted, and no claims will be made.

It was assumed that performance will scale with net surface area so that the frame aperture (12”x12”) need not be varied. This was confirmed during testing as explained later in this report. Two net lengths and all three commercially available hole opening sizes (5mm, ½”, 1”) were tested.

2.1 Test Setup

The laboratory test set-up was a water flow loop, capable of moving water at a rate of up to 7 CFS. The test loop, illustrated in Figure 3, is comprised of water reservoirs, pumps, valves, test channel, receiving pit, flow meters, level sensors and a thermometer.

The device tested was a commercially available net attached to a square wooden frame with a 1’ by 1’ cross sectional open area, which will be called the aperture throughout this report (Figure 4). The total width and height of the net/frame assembly was 15”. The frame was made from standard 2 x 4s, so the opening (aperture) size was 12” x 12” and the depth of the frame, in the flow direction, was 3.5 inches. The frame was fitted into a metal C channel that was secured at the end of a 15” wide by 41.5” high channel such that when the frame was installed the exposed frame was 13” x 13”. Since the aperture was 12” x 12”, this resulted in an open area equal to 92% of the cross section of the net and frame assembly, which is equal or less than the open area of commercial configurations.

This means the test set up was conservative from a hydraulics perspective. Commercial systems would have an equal or larger aperture compared to the frame assembly and thus would create less headloss.

Figure 3 – Test Equipment Layout

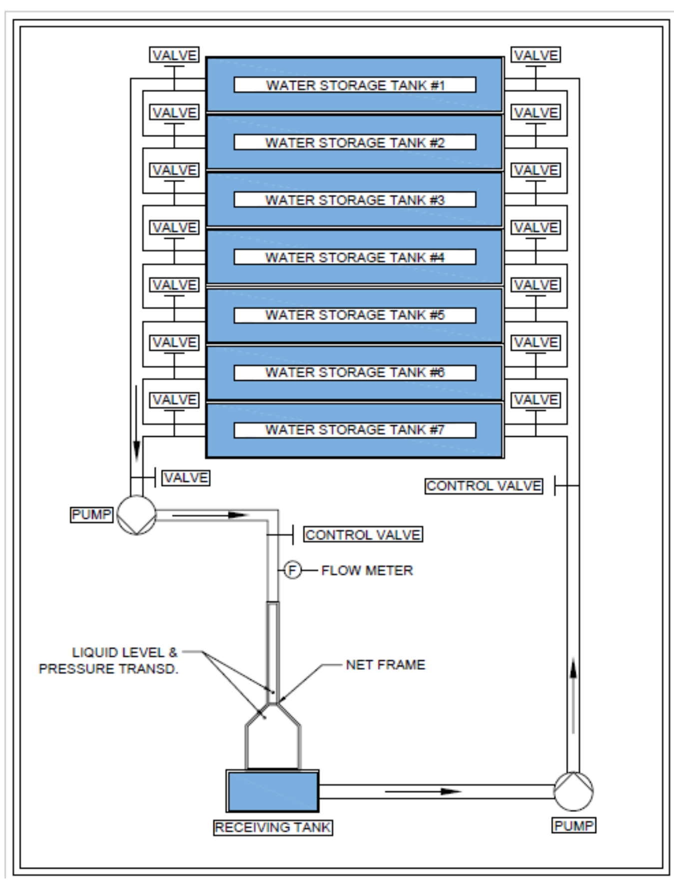
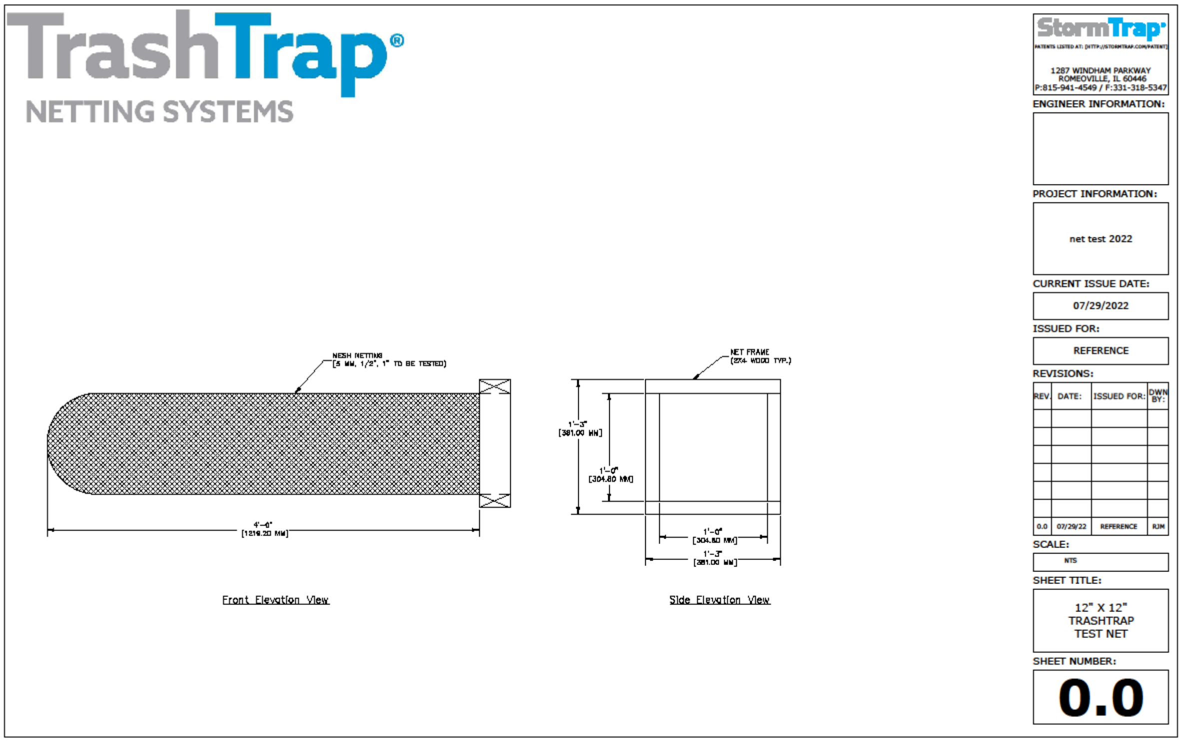


Figure 4 – Prototype Frame and Net



In the test flow loop, potable water was pumped from the storage tanks by a pump from Rain for Rent. The pump was Rain for Rent #610374 Engine: Perkins 2952/2200 serial #PJ38440. Pump: PowerPrime DV200C serial #108197. For the higher flow tests, a second pump was added just downstream of the first pump. It was the Rain for Rent #619036 with a Perkins engine and a PowerPrime DV200C pump, serial #71068N. The outlet pipe from the pump was dropped to the ground and then raised at the entrance to the test channel in order to ensure that the pipe was always full where the flow meter was located. From the test channel, the water flowed into a receiving tank where it was pumped out and back into the storage tanks using another pump from Rain for Rent. This pump was Rain for Rent #611213 Engine: John Deere 6068HF485 serial #PE6068L141598 Pump: PowerPrime DV200C serial #2020DV200C-112.

Flow measurements were made using a Greyline Time of Transit Flow Meter (TTFM) 1.0 (serial #71418, calibrated 14 June 2023), configured to take readings every 30 seconds. The TTFM was installed with at least 20' of straight pipe upstream and downstream, to ensure the location complied with the manufacturer's recommendations. Elevation measurements were taken with 2 point-gage systems adjusted to a known reference, one 2" upstream and one 2" downstream of the guiderail. Both elevation sensors were calibrated by the manufacturer and were verified daily with an engineer's scale ruler. All elevation data was logged on a MadgeTech Titan S8 serial #S49796, configured to record all channels simultaneously at a rate of once every 30 seconds. The thermometer was a MadgeTech MicroTemp serial #Q47774, calibrated 14 June 2023. Temperature was recorded once per minute. Time keeping was done with Traceable stopwatches model 1042, serial #94460-55, calibrated 15 March 2023.

The following are details of the test flow loop:

- From the storage tanks, water flowed through 12” pipes, except at the pump which had a 12” inlet and 8” outlet. The outlet was directly attached to an 8”x12” concentric flange to maintain the use of 12” pipe, to the 14” wide, 41.5” deep, 16’ long test channel.
- At the end of the test channel an outlet channel flared out to 8’ wide and it was 8’ long. The outlet channel terminated with a free-fall thru 0.125” screening material affixed directly above the receiving tank.
- The water was pumped back into the storage tanks to complete the flow loop. There was a 12” gate valve upstream of the return pump.
- There were 12” gate valves upstream and downstream of the inlet pump.
- The water storage tanks had a total capacity of approximately 140,000 gallons, 20,000 gallons each, with the option for freshwater make-up.

Figure 5 is a view of the test channel looking downstream from on top of one of the water storage tanks. Figure 6 is a view looking upstream from the far side of the receiving pit. The concrete blocks surrounding the channel were installed to provide structural support. The backstop on the far (downstream) side of the receiving pit was intended to prevent any water from jetting over the pit. The channel flares after the net opening in order to mimic a typical end of pipe installation. The width of the channel was 8’, so a single sheet of plywood could be used for the flow. The downstream sensor placement was chosen to minimize any possible wall effects, thus rendering the exact channel geometry irrelevant.

Figure 7 shows the two upstream pumps used to deliver the flow. The second pump was added for the scour test. Figure 6 shows the downstream pump, which drew water from the receiving pit and returned it to the tanks. Figure 7 shows the location of the two sensors. Both sensors are float types with a hole in the floor of the channel that allows a plastic tube to fill and raise the float. The upstream opening is in the centerline of the channel where the tube in the middle left of the figure is sticking out. The downstream opening is visible in the lower left of the picture. The tube for the downstream sensor is just out of the frame.

Figure 5 – Test Channel Looking Downstream

Figure 6 – Looking Upstream from the Receiving Pit

Figure 7 – Upstream Pumps

Figure 8 – Downstream Pump

Figure 9 – Sensor Locations

3.0 Performance Claims

The following are the performance claims made by StormTrap LLC. They are based on the independently verified laboratory test results described in more detail in Section 4.

Hydraulics

Based on the analysis of 168 runs we were able to conclude that headloss is not a significant function of net length or hole opening size, so we claim the following relationship for headloss, in inches, as a function of flow velocity, in ft/s, across our product line (Equation 18):

$\Delta h = 0.91176*v + 0.07010$

% Restriction

TrashTrap hydraulics are practically unaffected until a certain amount of netting mesh open area is reached. At this point, bypass occurs. This critical area does not change with net length so % restriction is a function of net length, as shown in Table 1 below.

Table 1 – % Restriction at Bypass, 5 ft/s

Net length (ft)	Critical % Restriction
2	75%
4	88%
6	92%
8	94%

Trash Removal

Removal was 100% up to the point of bypass for all the nets tested. Mass capacity was not found to be a function of hole opening size. The average mass capture was 2.64 lbs/ft^3 of net volume.

Maintenance Capacity

All nets should be emptied when they are ≤ 85% full.

Scour

TrashTrap nets do not scour any previously captured material at an average of 9.77 ft/s. According to ASTM E332, this makes it suitable for off-line installation at flow velocities up to the StormTrap recommended limit of 5 ft/s and for on-line installation for velocities up to 4.89 ft/s.

4.0 Testing Results

Some aspects of E3332 are open to interpretation, and how they get interpreted impacts how results are obtained and subsequently interpreted. This section describes how StormTrap decided to interpret aspects of E3332 and explains why the decisions were made.

4.1 Test Apparatus

The language in ASTM E3332 clearly assumes that there will be pipes immediately upstream and downstream of the test unit, as is typical when testing an HDS or filter. However, piping is not prescribed and since TrashTraps are not typically installed in pipes the decision was made to use a channel upstream and downstream of the device, as shown in Figure 6, Figure 7 and, Figure 9.

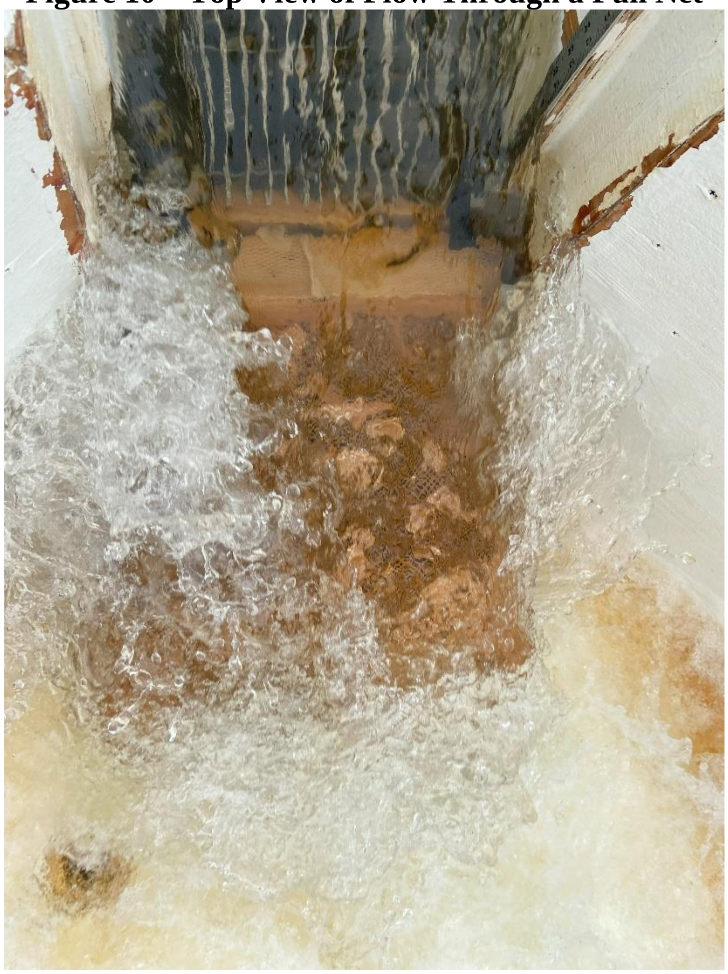
Inlet pipe size is not specified beyond the requirement “that at all test flow rates the pipe is in open channel flow”. StormTrap chose to make the upstream channel equal to the net opening area plus the width of a standard frame since this is the most representative configuration. The only outlet pipe size specification is that it “must be able to accommodate a net or screen at the end of the outlet pipe, or at the tank outlet, to allow for capture of any trash in the effluent flow. The net or screen shall not cause water back up into the outlet pipe”. StormTrap chose to make the outlet channel flare out immediately after the frame to a width large enough that it did not impact the downstream flow.

4.1.1 Downstream Sensor Location

Section 6.5 of E3332 states that the location of the elevation sensors "shall be 1-2 pipe diameters upstream and downstream of the unit". It is assumed, though not stated, that the sensor will be along the centerline. In addition, the standard requires that the location remain fixed for all tests.

StormTrap interpreted this to mean 1-2 channel widths upstream and along the centerline for the upstream sensor. For the downstream sensor a location along the centerline would not work because the net was greater than 2 channel widths long so it would cover the sensor (Figure 10). As the net filled, this would block off any downstream readings. In order to have a location that was logical and reproducible, and which would not be affected by the downstream channel geometry, a point in line with the frame 2 channel widths downstream was chosen (Figure 9).

Figure 10 – Top View of Flow Through a Full Net



4.2 Statistical Analysis

ASTM E3332 provides little guidance on how to analyze all the data that is generated. As with the test apparatus, this required interpretation of the requirements to provide a reasonable analysis of the results.

For example, Section 9.1.4 requires that, for the three runs that generate elevation versus flow data, the elevations at a given flow be within 10% of each other. However, 6.4.1 allows the flow to vary ±10% around the target. The result is that, even if the system has identical elevation versus flow behaviour all three times, the elevation data could be out of spec due to in spec variation in flow. The result would be a false negative, rejecting data that should be accepted. This is particularly a problem at low flows, which are challenging to reproduce, and which yield small elevations that are difficult to measure accurately.

In addition, a point-by-point comparison between runs ignores the fact that the points within a run should fall on a curve. Rigorous analysis requires that the data be compared within runs as well as between runs. There is a statistical method that can be used to determine if multiple curves, not just points, are the same. This method, analysis of covariance (ANCOVA), accounts for the fact that flow is not always exactly on target and therefore provides a more realistic analysis. ANCOVA does not provide a ±10% result but it is more rigour and useful, so it was chosen for this report.

It is possible to perform ANCOVA with the Regression function in Excel, which is part of the Data Analysis Add-On. This add-on is free. Appendix II provides a brief summary of how ANCOVA is used.

This report uses ANCOVA where comparison of curves is required, such as in headloss testing. Where multiple runs generate a single point each, such as the mass capacity testing, only a mean and percent difference is reported. Three total data points is not sufficient data for a meaningful 95% confidence interval.

4.3 Headloss Testing

Hydraulic testing was conducted in accordance with section 9.1 of ASTM E3332. Water surface elevations were recorded at 10, 25, 50, 75, 100, and 125 % of MTFR, then at 25 % increments up to 200%. The pumps maxed out at 175% MTFR so each curve has 8 points. Since nets are commercially available with three mesh opening sizes, 5 mm, 0.5” and 1”, and with variable length, six different net configurations were tested, along with a control. This resulted in 7 x 8 x 3 = 168 data points.

The naming convention used for the different net configurations is “LENGTH MESH SIZE”. For example, a 4’ net with 1” holes is 4FT 1IN and a 2” net with 5 mm holes is 2FT 5MM. Any baseline runs with no net are labelled CONTROL and HI denotes 0.5”.

Figures 10-12 show the upstream elevation for each of the three series of runs. Section 12.7.1 requires reporting velocity head vs. flow rate. Velocity head is given by Equation 1.

Equation 1 $$\boldsymbol{h_v = \frac{v^2}{2g}}$$

h_v = head (ft)
v^2 = velocity (ft/s)
g = gravitational constant (ft/s^2)
Given that the baseline elevation is set at 0, the total elevation is effectively velocity head so Figure 11 through Figure 13 meet the requirement of 12.7.1.

Figure 11 – Upstream Elevation for 1st Series of Runs

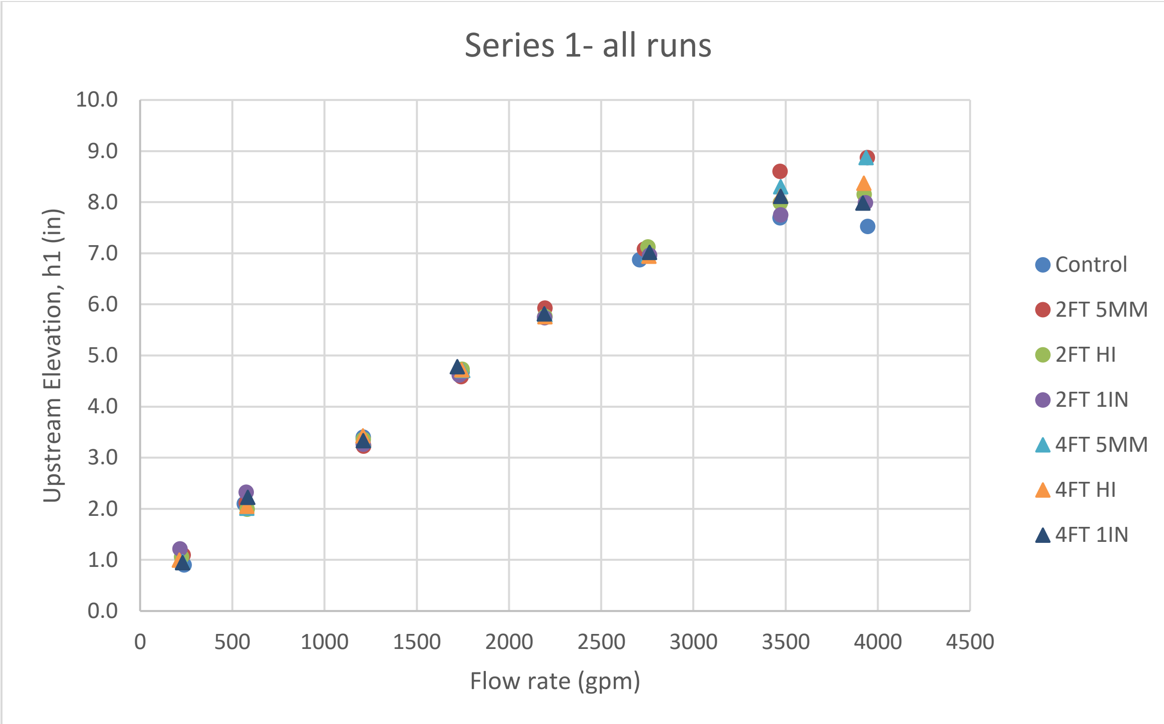


Figure 12 – Upstream Elevations for 2nd Series of Runs

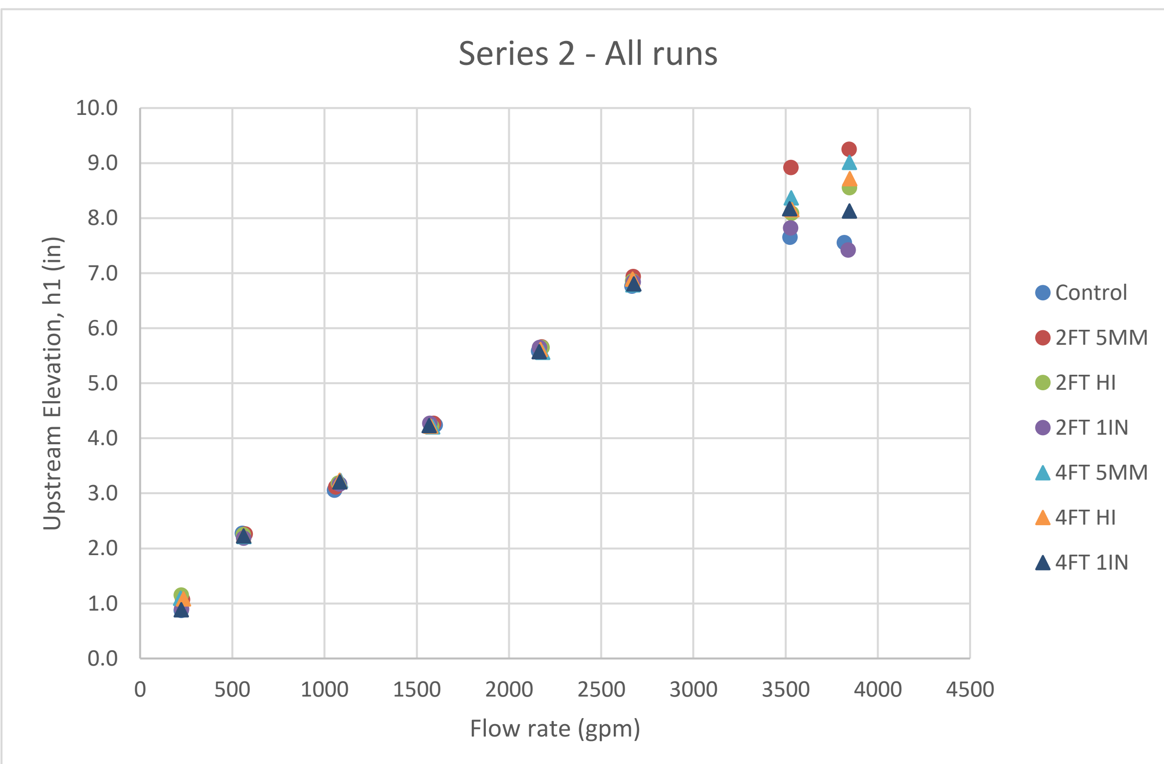
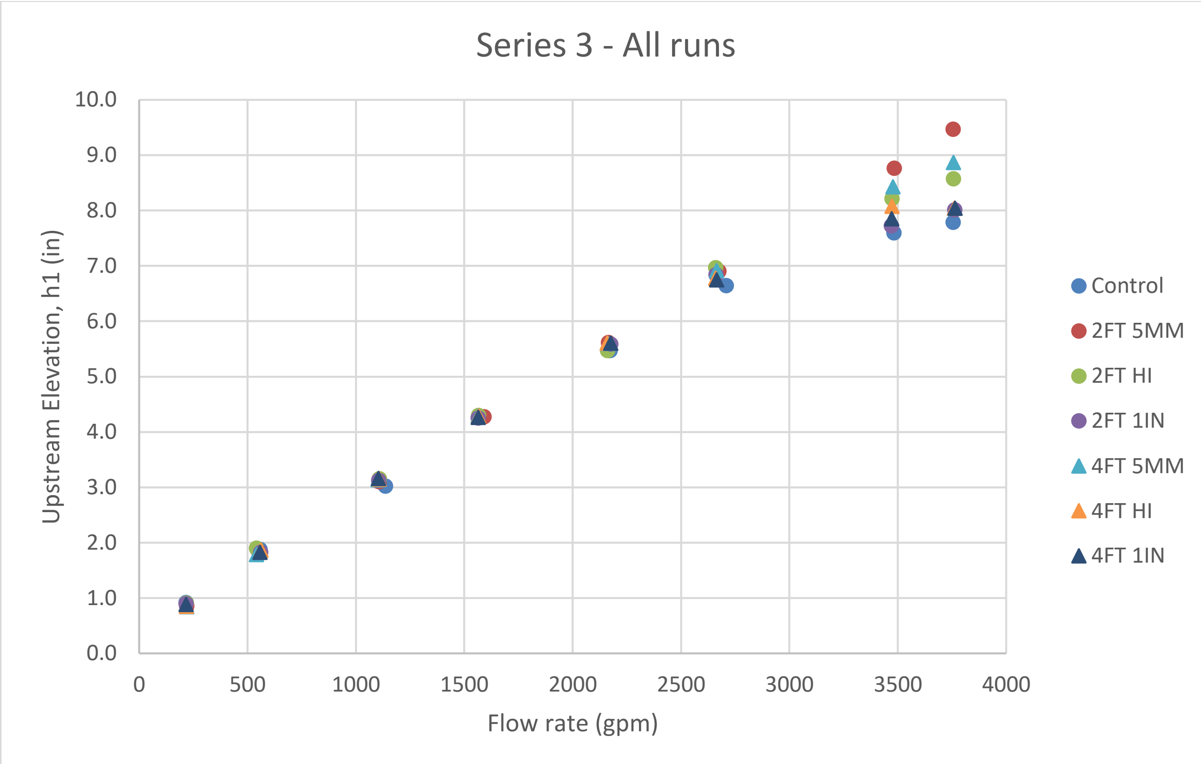


Figure 13 – Upstream Elevations for 3rd Series of Runs



The data was then analyzed using ANCOVA to test three basic hypotheses:

1. H0: There is no significant difference between the 3 runs for each configuration
2. H0: There is no significant difference between the 2 net lengths
3. H0: There is no significant difference between the 3 mesh opening sizes

These hypotheses were chosen based on the overall physical hypothesis that the headloss coefficient, k_L, only increases when the mesh open area of the net, i.e. the sum of the area of all the holes, is less than the aperture area, i.e. the mouth of the net. The rationale for this is that if the opening area is greater than the aperture area then the net does not provide any extra restriction of the flow and thus should not increase headloss.

Each analysis is discussed in separate sections below. Given the large amount of raw data, it is not included here but can be found in Appendix III and Appendix IV.

4.3.1 H_0: There is no significant difference between the 3 runs for each configuration

The TrashTrap is commercially available in multiple combinations of net length and opening size. For this report, 6 net configurations were tested, consisting of two different net lengths and three opening sizes. A control run with no net was also completed, for a total of 7 configurations. The ASTM standard requires each configuration to be tested at 7 flows on three separate occasions. We chose to do 8 because we hate ourselves. This resulted in 24 data points for each configuration, for a total of 168 data points.

The first null hypothesis to be tested is H_0: each run for a given configuration is the same. In other words, the test apparatus produces repeatable results. This will allow the three separate datasets for each configuration to be collapsed into one dataset for further analysis.

For this analysis the method looks at the dependent (y) variable = headloss, as a function of the dependent variable (x) = series of runs (1, 2 or 3) with flow rate (Q) as the covariate. Table 2 shows the results of ANCOVA for the three sets of data for each configuration shown in Appendix III.

The p value in the table indicates the probability that the variable is significant. If $p < 0.05$ the variable is significantly different than the reference and the null hypothesis, H_0 is rejected. If $p > 0.05$ H_0 is accepted and the variable is not significant. In the following Table 2, the reference for Intercept and Flow is 0 while the reference for Series 1 & 2 is Series 3.

Significant results are indicated in **bold**. This means that the null hypothesis is rejected and any bold values for Intercept indicate a no-zero intercept, any bold values for Series 1 or 2 means that Series is not the same as Series 3 and any bold values for Flow means it is a significant factor in explaining the hydraulics curve. Table 2 shows that the only factor significantly affecting headloss (Δh) was flow rate, independent of what series was analyzed.

Table 2 – Hydraulics Test ANCOVA Results

Configuration	p for Intercept	p for series 1	p for series 2	p for Q
CONTROL	**0.00**	0.60	0.88	**0.00**
2FT 5MM	0.58	0.41	0.53	**0.00**
2FT HI	0.098	0.98	0.91	**0.00**
2FT 1IN	0.43	0.72	0.40	**0.00**
4FT 5MM	0.21	0.54	0.63	**0.00**
4FT HI	**0.0061**	0.56	0.95	**0.00**
4FT 1IN	0.091	0.70	0.95	**0.00**

For every configuration H_0 is accepted, the three hydraulics runs were statistically the same. Two of the intercepts were not 0, the control and the 4FT HI, which is unexpected since headloss at zero flow should be zero inches. The equations below will show that all the intercepts are close to zero. The fact they are not exactly zero is an artifact of regression analysis. They could be forced to zero and the R^2 values would still be very good, where ≥ 0.9 is generally accepted as very good for pilot scale testing, but they were left as is in this report.

This analysis meets the intent of ASTM E3332. It also allows the data sets to be combined to form a single equation for headloss versus flow for each configuration, thus reducing 21 equations to 7 equations. These equations are:

Equation 2 CONTROL: $\Delta h = 0.00155*Q + 0.684$, $R^2 = 0.98$

Equation 3 2FT 5MM: $\Delta h = 0.00222*Q – 0.175$, $R^2 = 0.99$

Equation 4 2FT HI: $\Delta h = 0.00173*Q + 0.266$, $R^2 = 0.98$

Equation 5 2FT 1IN $\Delta h = 0.00217*Q + 0.247$, $R^2 = 0.97$

Equation 6 4FT 5MM: $\Delta h = 0.00164*Q + 0.302$, $R^2 = 0.91$

Equation 7 4FT HI: $\Delta h = 0.00130*Q + 0.875$, $R^2 = 0.88$

Equation 8 4FT 1IN $\Delta h = 0.00150*Q + 0.631$, $R^2 = 0.90$

In every case the fit is very good or good, with the fit for the control and the 2FT net being slightly better than for the 4FT net.

It should be noted that linear equations are consistent with the physics of flow. From Manning's equation for open channel flow, $v = f(Q^{1/2})$ and from Bernoulli $h = f(v^2)$ so $h = f(Q)$ and a linear relationship is expected. To be thorough, the data was also fit to a second order equation. R^2 did increase in some cases but since R^2 was already > 0.9 the improvement was not significant. As a rule, the lowest order polynomial with acceptable fit is preferred. This is supported by the fact that some of the equations had $\Delta h = f(-flow^2)$, which does not make physical sense. Headloss should not go down at higher flow. For these reasons the second order equations were discarded in favour of first order equations.

The conclusion to be drawn from this analysis is that each of the three runs for a given configuration gave the same result. This will allow for the collapse of some data. It also indicates that the test setup and instrumentation are reliable.

4.3.2 H_0: There is no significant difference between the 2 net lengths

Having demonstrated in the previous section that each of the three runs for a given configuration is the same, it was possible to collapse the 21 datasets into seven datasets, one for each configuration, for further analysis. The next most important effect is that of net length. If the null hypothesis is accepted the seven equations from the previous section can be reduced to four (control plus each netting mesh size).

The null hypothesis to be tested is H_0: for a given net mesh size, headloss is not a function of net length

For this analysis the method looks at the dependent (y) variable = headloss, as a function of the dependent variable (x) = net length with flow as the covariate. There is reason to believe that opening size will be a factor so the different opening sizes will not be combined for this analysis. As a result, there will be three ANCOVA results in this section. These are shown in Table 3.

As with Table 2, the p value in the table indicates the probability that the variable is significant. If $p < 0.05$ the variable is significantly different from 0, otherwise it is not. Note that significant results are, again, indicated in **bold**. Table 3 shows that, as expected, flow is a factor in headloss for all three opening sizes. The fact that length is a factor in two cases is surprising, particularly since it is a factor for the largest and smallest opening but not the intermediate ones. Given the large total mesh open area of all the nets, compared to the aperture area, length would not be expected to be a factor. If there was a difference it would be expected to show up at one extreme of opening size, not in the middle.

Table 3 – ANCOVA Results – Δh vs. Opening Size

Configuration	p for Intercept	p for length	p for Flow
5MM	0.18	**0.00**	**0.00**
HI	**0.01**	0.14	**0.00**
1IN	0.94	**0.00**	**0.00**

In this case H_0 is rejected 6 out of 9 times, which suggests an issue with the data. Based on observations, it is likely that the issue was with the downstream sensor. It was in a fixed location, but the flow pattern changed from the 2FT net to the 4FT net. The end of the 2FT net is near the sensor location creating a wave that raises the elevation in that location. This is discussed in more detail in Section 4.1.

An ANCOVA test was conducted using just upstream elevation, to determine if the downstream elevation data is the problem or not. Table 4 shows the ANCOVA results using upstream elevation instead of headloss.

Table 4 – ANCOVA Results – h1 vs. Length

Configuration	p for Intercept	p for length	p for Flow
5MM	**0.00**	0.11	**0.00**
HI	**0.00**	0.83	**0.00**
1IN	**0.00**	0.40	**0.00**

This data matches expectations, flow rate is a significant factor in upstream elevation, but net length is not. The fact that removing the downstream data eliminated the effect of length supports the hypothesis that the downstream sensor location is creating false significance and that hydraulics is in fact independent of length, despite the results in Table 3.

This allows the length data to be combined to create 1 equation for each opening size that replaces the equations in section 3.2.2.1.

The new headloss equations are:

Equation 9 5MM: $\Delta h = 0.00193 * flow + 0.0637$, $R^2 = 0.92$

Equation 10 HI: $\Delta h = 0.00151 * flow + 0.570$, $R^2 = 0.92$

Equation 11 1IN: $\Delta h = 0.00182 * flow + 0.485$, $R^2 = 0.87$

The R^2 values are slightly lower than for the corresponding separate equations (Equation 3 &Equation 6, Equation 4 & Equation 7, Equation 5 & Equation 8) but they are still relatively good. Despite the fact that the downstream elevation was re-introduced, and it is known from Table 3 that this data contains significant sensor error, the goodness of fit suggests that Equation 9-Equation 11 are usable. It is desirable to have the equations in terms of headloss because it is a useful number in hydraulic system design.

To double check the downstream sensor error hypothesis, regression was performed on the combined upstream elevation data, once again removing the effect of the downstream elevation error. The resulting equations are:

Equation 12 5MM: h1 = 0.00224*flow + 0.693, $R^2 = 0.99$

Equation 13 HI: h1 = 0.00208*flow + 0.890, $R^2 = 0.98$

Equation 14 1IN: h1 = 0.00201*flow + 1.02, $R^2 = 0.96$

It can be seen that the fit is better when looking at upstream elevations only, so the downstream data is introducing error, but the error is small. One way to quantify the error in the downstream elevation data is to note that the difference in slope between the two sets of lines is less than 0.001 in/gpm and the intercepts, which should be 0, are within 0.75" of each other. These differences will not have a practical impact in a real installation. This further supports the decision to use Equation 9-Equation 11 instead of Equation 12Equation 14.

4.3.3 H_0: There is no significant difference between the 3 mesh opening sizes

For this analysis, the three different mesh sizes are compared at each length. This results in a 3 factor ANCOVA, similar to the hydraulics analysis, and not a 2 factor ANCOVA, similar to net length. In this three factor ANCOVA, the reference series is the 1 IN mesh data. The expectation, based on physical reality, is that H_0 will be accepted, the difference in mesh sizes is not great enough to have an effect. The results of the analysis are shown in Table 5.

Table 5 – ANCOVA Results Δh vs. Mesh Opening Size

Configuration	p for Intercept	p for 5MM	p for HI	p for Flow
2FT	**0.00**	**0.016**	**0.00**	**0.00**
4FT	**0.00**	0.76	0.42	**0.00**

In this case the results are, again, unexpected. H_0 is rejected 6 out of 8 times, The expectation was that mesh size would not be significant, based on the large total mesh open area for all sizes, and that this would be true for both lengths, based on the conclusion from the previous section that length is not a factor. The analysis shows that mesh opening size is significant for the 2FT nets but not for the 4FT nets.

The analysis in the previous section provides one possible explanation: that the downstream data is inconsistent due to the static position of the sensor. Once again, this effect was examined by looking at only the upstream elevation data.

Table 6 – ANCOVA Results h1 vs. Mesh Opening Size

Configuration	p for Intercept	p for 5MM	p for HI	p for Flow
2FT	**0.00**	**0.00**	0.23	**0.00**
4FT	**0.00**	0.13	0.55	**0.00**

Eliminating the ‘noise’ from the downstream elevation data results in only 1 configuration being significant, the 2FT 5MM net. This might be explained by the fact that, of all the configurations, the 2FT 5MM net has the smallest total mesh opening area. This hypothesis is examined in more detail in the following section.

4.3.4 Net Area Calculations

The physical explanation for the hypotheses in 4.3.2 and 4.3.3 is that, as long as the mesh open area, the sum of all the hole opening areas, is greater than the aperture area then it should not matter how much greater. In other words, increasing net length above a certain minimum and increasing mesh open area above a certain minimum should not have an impact on headloss. The following calculations provide the numbers needed to evaluate this explanation.

Due to the method of attachment to the frame, the 2FT nets have an available open length of 20”, while the 4FT nets have an available open length of 44”. For the purpose of calculating net area, the net is assumed to be a cylinder with the same cross section area as the frame opening, 1 ft^2 = 144 in^2. This results in a cylinder diameter of 13.54 in. Since the net actually stretches and narrows this area is slightly overestimated. The fibers comprising the netting are 1/16” thick. This means that the open area is calculated as:

Equation 15 % open area = 100*opening size^2/(opening size + 0.125)^2

The standard equations for area of a cylinder, and equation 15 above, were used to calculate the values in Table 7.

Table 7 – Net Open Area

Configuration	Surface Area (in^2)	% open	Open area (in^2)
2FT 5MM	851	37	315
2FT HI	851	64	545
2FT 1IN	851	79	672
4FT 5MM	1702	37	678
4FT HI	1702	64	1173
4FT 1IN	1702	79	1448

Table 7 confirms that even the smallest open area, 315 in^2, is more than double the aperture area, 144 in^2, so the hydraulics would be expected to be the same for every configuration. Table 4 supports the conclusion that length is not a factor. Table 5 suggests that hole opening size is a significant factor but when the downstream sensor issue is accounted for, only one configuration does not fully fit our physical explanation.

It is noteworthy that the one significant result was for the shortest net with the smallest hole openings. If any configuration would be significant, our physical explanation would say it is that one. That said, the mesh open area is more than double the aperture open, which should be enough that there is no difference, so the balance of probabilities suggests that the physical explanation is correct, and the significant result is an artifact of the data.

4.3.5 Discussion of Hydraulic Results & Analysis

Three curves depicting headloss versus flow rate were generated, each with 8 data points, for each of 6 net configurations plus a frame only control. Analysis of the 3 curves for each of the 7 configurations showed that they were statistically the same so the apparatus generates reproducible results, and the data can be collapsed from 21 sets to 7.

Based on the fact that all of the net open areas were greater than the aperture area, it was expected that net length and hole opening size would not be significant and the remaining 7 equations could be collapsed into 1. There were some instances where curves were significantly different but there were no trends or indications that the expectation was unreasonable. The significant results could be attributed to some anomalies in the downstream elevation data, that created anomalies in the headloss data. These can be attributed to the downstream sensor placement as discussed in Section 3.1.1.

After all the analysis, only 1 curve, for the 2FT 5 MM, net was found to be statistically significantly different. Given that it is only 1 of 21 curves, and the frame aperture area should be enough, the decision was made to treat it as if it was not significant and analyze all the data together. When this was done, Equation 9-Equation 11 could be further collapsed into a single equation, derived from all 168 data points.

Equation 16 $\Delta h = 0.0017 * Q + 0.4039$ $R^2 = 0.90$

Where m = slope

b = intercept

Q = flow (gpm)

Δh = headloss across the system (in)

Figure 14 – Headloss vs Flow, All Data

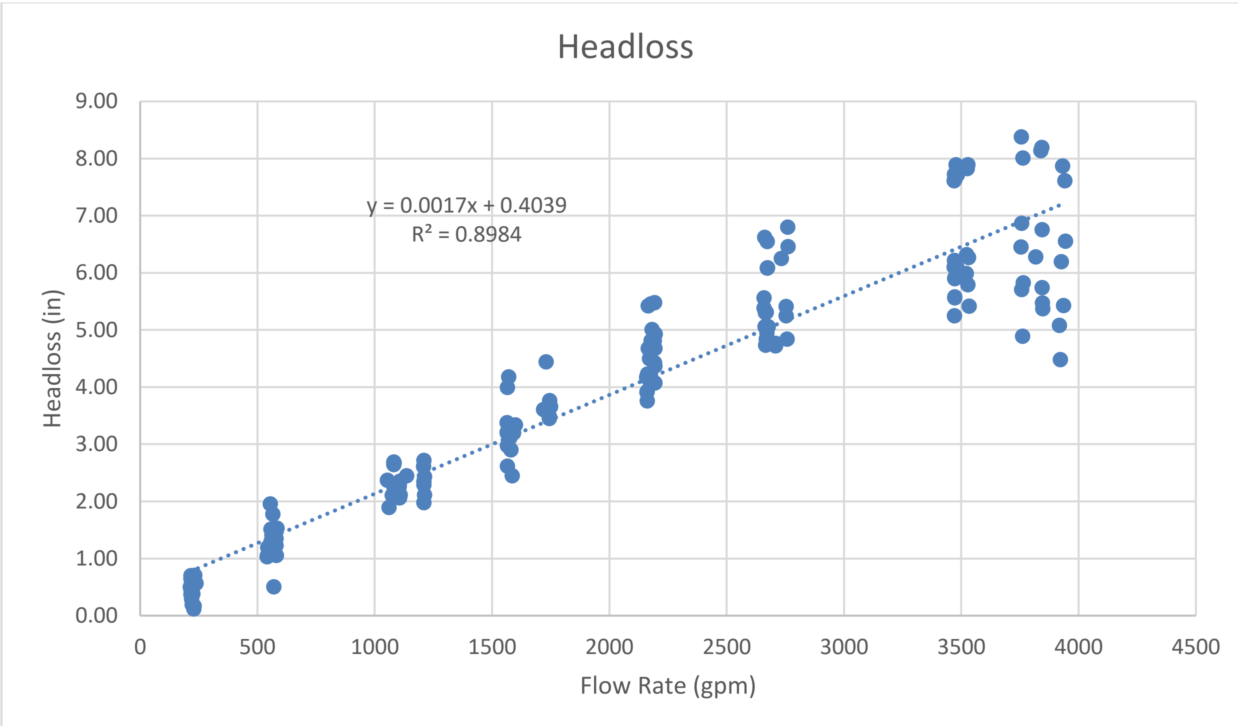


Figure 14 shows the curve fit for the headloss data that was used to develop Equation 16. Visual inspection indicates that the less reliable data at higher flow rates is decreasing the slope. A more conservative approach would be to base the headloss equation on the data over the design range of the system, which is 0 – 5 cfs or 0 – 2244 gpm. Dropping the data for flows above 3000 gpm, well in excess of the design flow, results in Equation 17:

Equation 17 $\Delta h = 0.00203*Q + 0.07010$ $R^2 = 0.95$

Where Q = flow rate in gpm.

The 95% confidence interval for the regression parameters are:

m = 0.00195 – 0.00212

b = – 0.0719 – 0.212

This is a better fit and a slightly more conservative equation so it will be the one claimed. The data for Equation 17 is displayed graphically in Figure 15.

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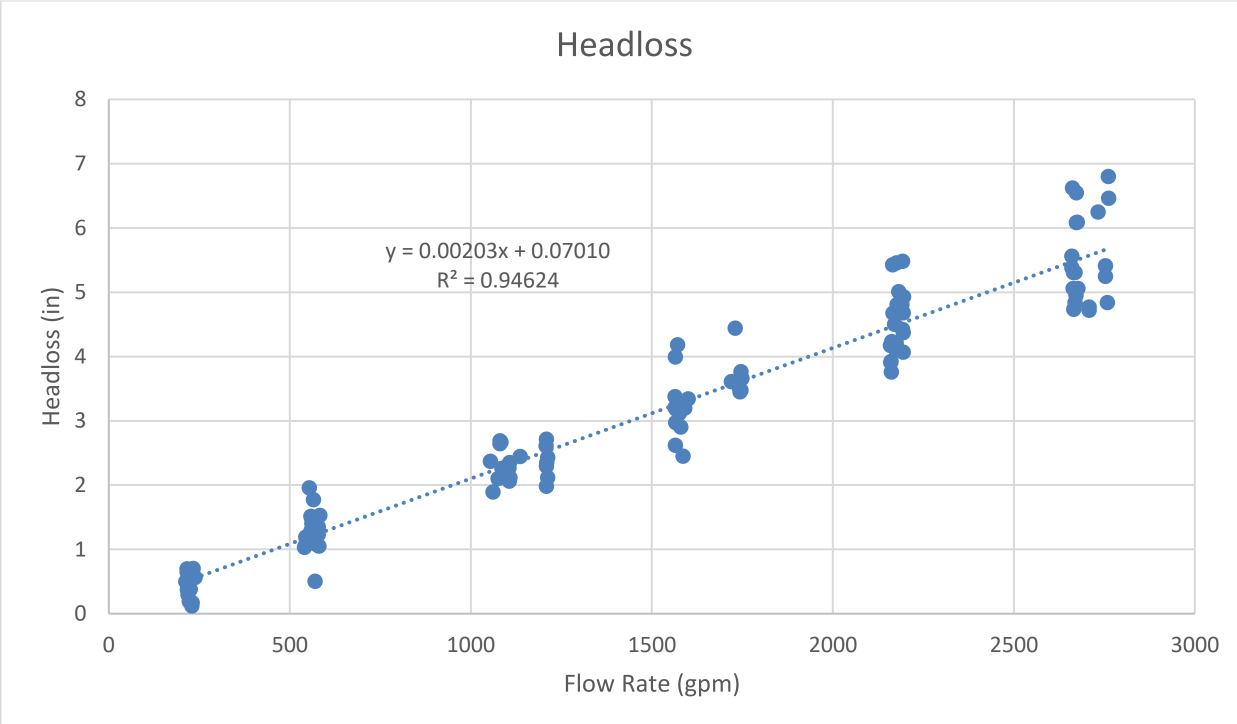
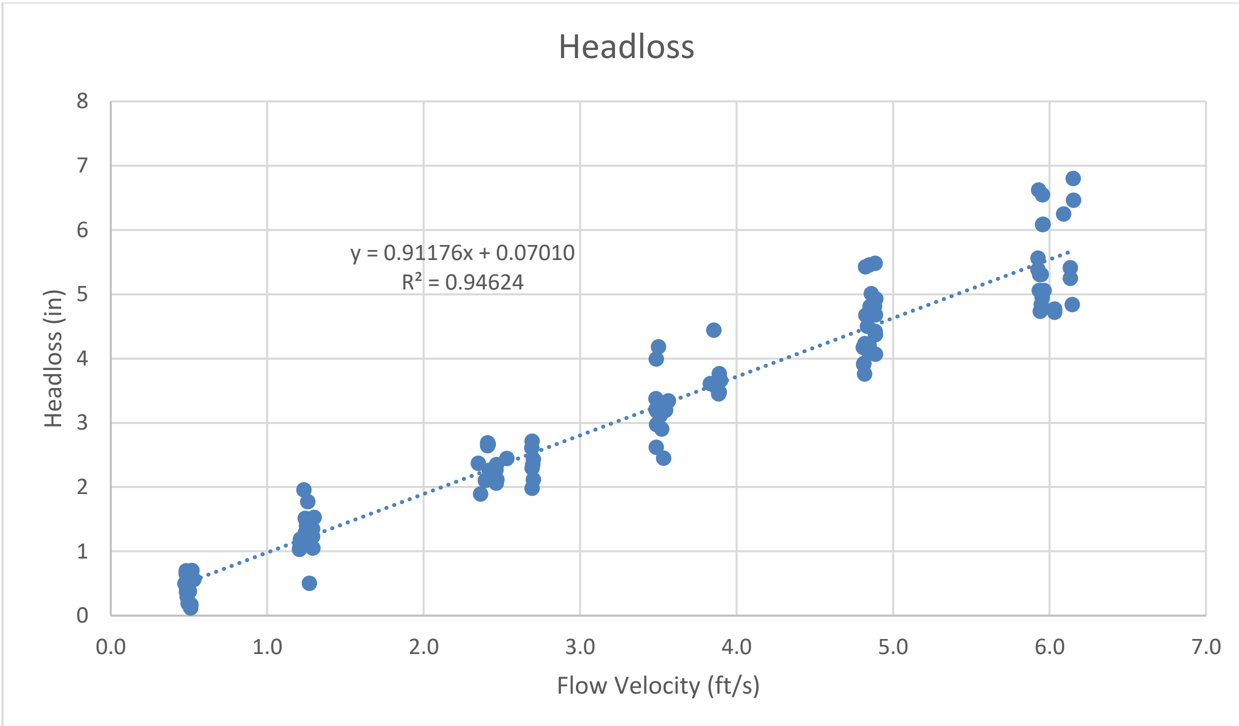
Figure 15 – Headloss vs Flow, Data to 3000 gpm



4.3.6 Scaling Hydraulics

The result of sections 4.3.1 to 4.3.5 indicates that headloss is simply a function of flow rate, it is not significantly affected by the properties of the net. From the headloss equation it is given that headloss is, in fact, a function of velocity so in order to scale, the flow equation must be converted to a velocity equation, shown graphically in Figure 16. This is simplified by the fact that the opening area is 1 ft^2 so the velocity, in ft/s, is simply equal to the value of the flow in cfs.

Figure 16 – Δh vs. Velocity, Data to 7 cfs (3000 gpm)



Equation 18 $\Delta h = 0.91176*v + 0.07010$ $R^2 = 0.95$

Where v = flow velocity in ft/s

The 95% confidence interval for the regression parameters are:

m = 0.873 – 0.950

b = – 0.0718 – 0.212

Equation 18 is the one to be used for calculating headloss for different sized systems.

4.3.7 Hydraulic Bypass

The elevation of the top of the frame was 15.5" above the channel floor. Above this level, flow would be unobstructed so the headloss equation would be expected to change to that of a vertical weir. This effect was not confirmed since, due to pump capacity limitations, the elevations did not get high enough during the headloss testing.

4.4 Percent Restriction Testing

The overall physical hypothesis, introduced in Section 4.3.4, that the headloss coefficient, k_L, only increases when the open area of the net is less than the aperture area leads to two expected phenomena during the percent restriction testing. First, as the nets fill there should be a point at which headloss increases dramatically and, second, the ‘bypass’ point should be at the same open area, regardless of net length.

Percent restriction testing was conducted in accordance with section 9.2 of ASTM E3332, using a garbage bag filled with discs of Styrofoam to mimic the volume and buoyancy of the appropriate amount of trash corresponding to the required fill levels (10, 30, 50, 70 and 90%). This allowed each ‘plug’ to be re-used, increasing consistency and saving time. Based on observations during trial runs this method conformed with the E3332 requirement for “mimicking expected blockage in actual conditions”.

Preliminary testing showed that the headloss graph has a ‘hockey stick profile”, and this was confirmed during the official testing. Headloss jumps sharply when the unrestricted open area of the net approaches the aperture area at the net entrance, which supports our first hypothesis. Given that the aperture size is 1 ft^2, depending on net length and hole opening size, the headloss jump is expected to be between ~60% restricted to ~90% restricted. This is an important parameter for scaling, so we conducted some additional runs, for example 80% restricted, in order to narrow down the location of this jump.

As discussed in Section 4.2, the downstream elevation data was not entirely reliable due to the downstream flow patterns changing with net length and hole opening size while the sensor location remained fixed. This effect was exaggerated during the % restriction testing because now % restriction was a third variable factor. This results in hundreds of possible combinations, which could not all be analyzed. The problem was overcome by focusing on upstream elevation, which was a much more stable reading.

4.4.1 Calculating Percent Restriction

ASTM E3332 requires restricting a certain percentage of the open area for this test. Using the assumption that the net forms a cylinder as it fills, the % restriction can be calculated in terms of length blocked. For example, a 2’ long net has an open length of 20”, because the top 4” is used to secure it to the frame, so a 10% restriction would be 2”, 50% would be 10”, etc.

In order to achieve the different levels of restriction in the different length nets, a large number of foam discs, 2” thick and 12” in diameter were cut. These were then stacked into cylinders with the required height and then wrapped in plastic garbage bags to form plugs of different lengths, as shown in Figure 17. The appropriate length of plug was then inserted into the net to get the required % restriction. Figure 18 is an example of a 70% plugged 4FT 5 MM net during a run.

Figure 17 – Plugs Used for % Blockage Test

Figure 18 – Top View of % Restriction Test Run

4.4.2 Percent Restriction Test Results

Tests were conducted on all 6 net length and mesh size combinations (2FT 5MM, 2FT HI, 2FT IN, 4FT 5MM, 4FT HI, 4FT IN), at a minimum of 5 % restrictions: 10, 30, 50, 70 & 90%. Raw data can be found in Appendix V. In most cases several other conditions were tested in order to find the % restriction at which the headloss increased sharply. Each net configuration and % restriction was tested at 5 flows. This exceeds the requirement of 3 flows in E3332 but was appropriate given the headloss behaviour we observed.

Figure 19 – 2FT 5MM Net % Restriction Test

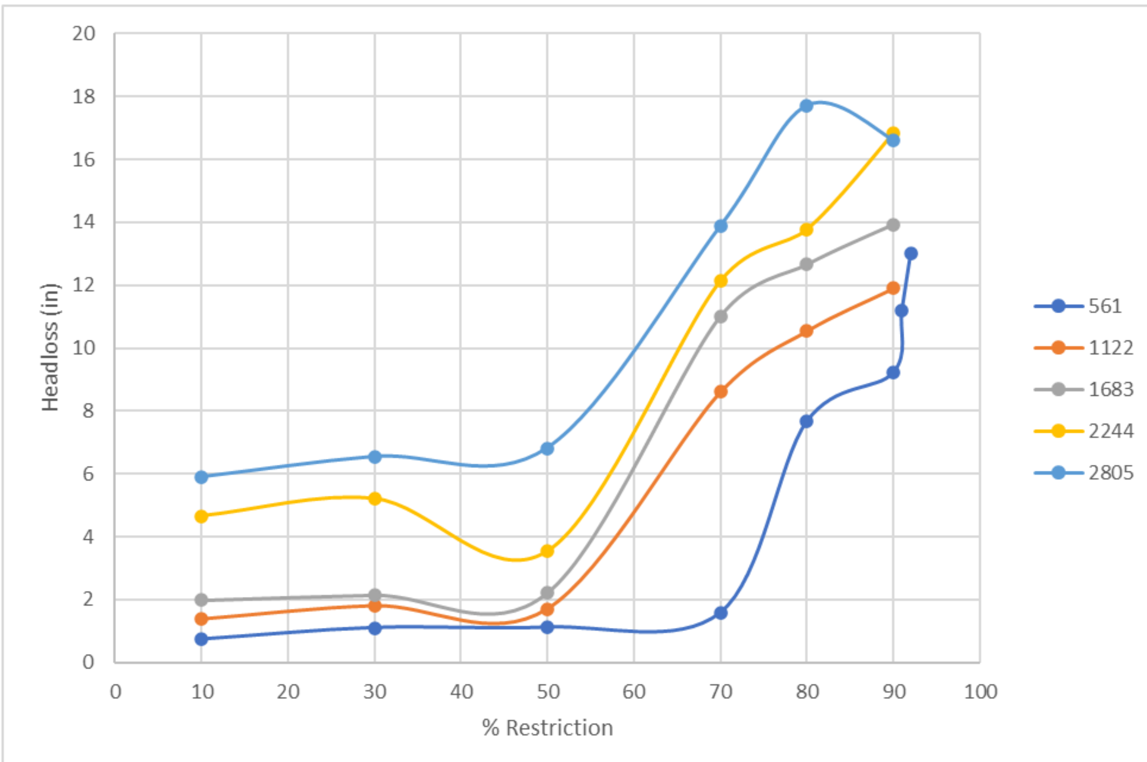
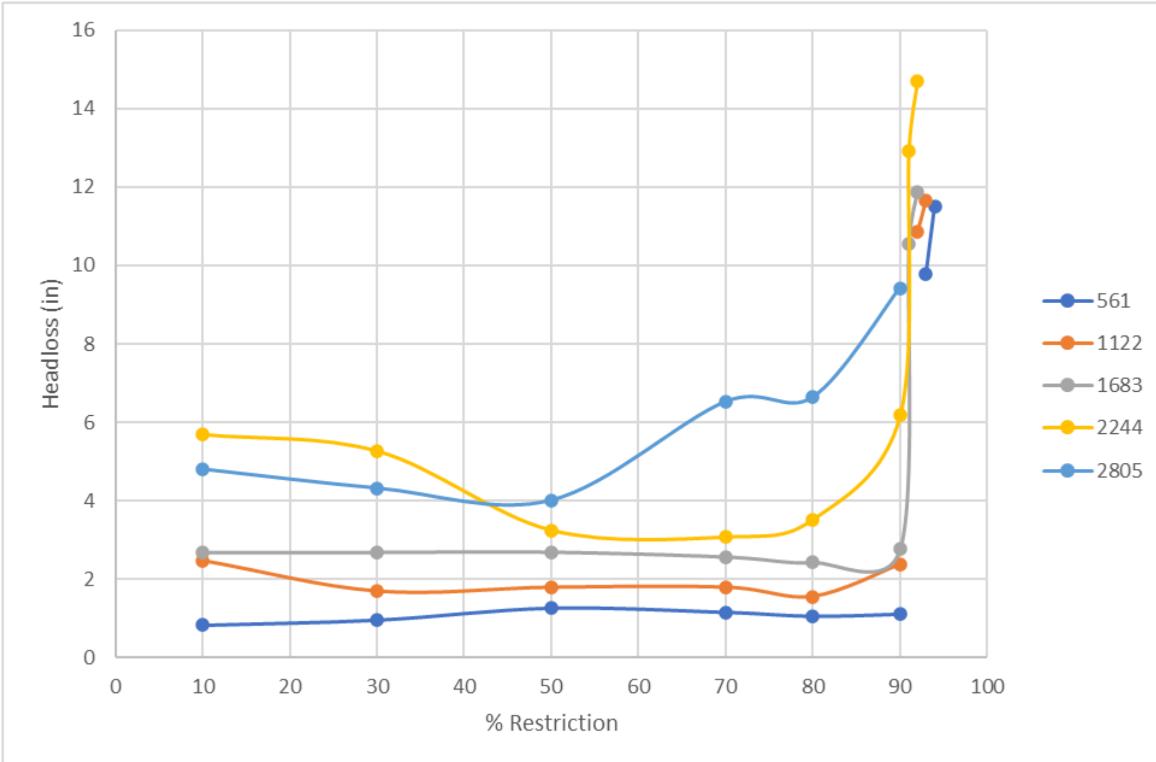


Figure 20 – 2FT HI Net % Restriction Test



Although the lines in Figure 19 and Figure 20 all start flat then rise sharply up, they clearly illustrate the expected trends:

1. Headloss is greater at higher flow rates
2. Headloss is stable at low precent restriction then rises rapidly at an inflection point at a critical available open area.

In Figure 21-25, the data also follows the expected trends, though at the higher flow rate, the headloss data is more erratic, going up and down instead of rising steadily. Looking at the upstream data in Figure 25, which is Figure 21 with upstream elevation (h1) data instead of headloss (Δh) data, this anomaly disappears, and the data looks exactly as expected. The same is true for all the other figures but they are omitted for brevity. This is consistent with our observation that the downstream elevation data is problematic.

Figure 21 – 2FT 1IN Net % Restriction Test

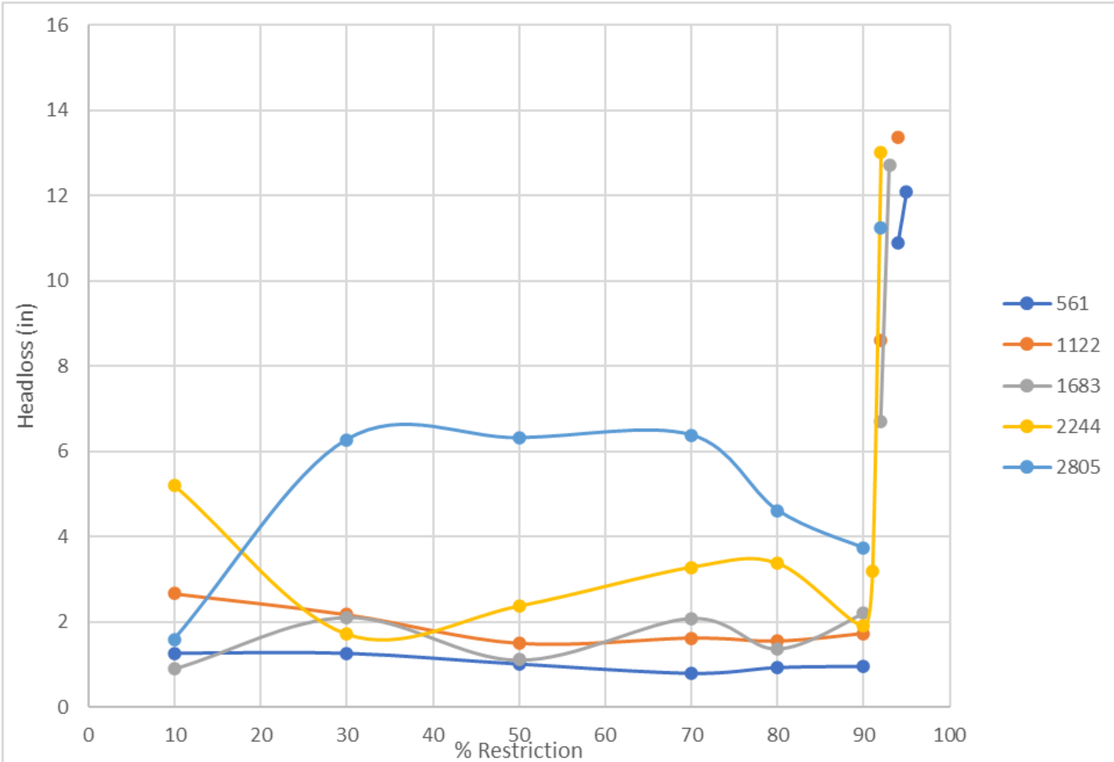


Figure 22 – 4FT 5MM Net % Restriction Test

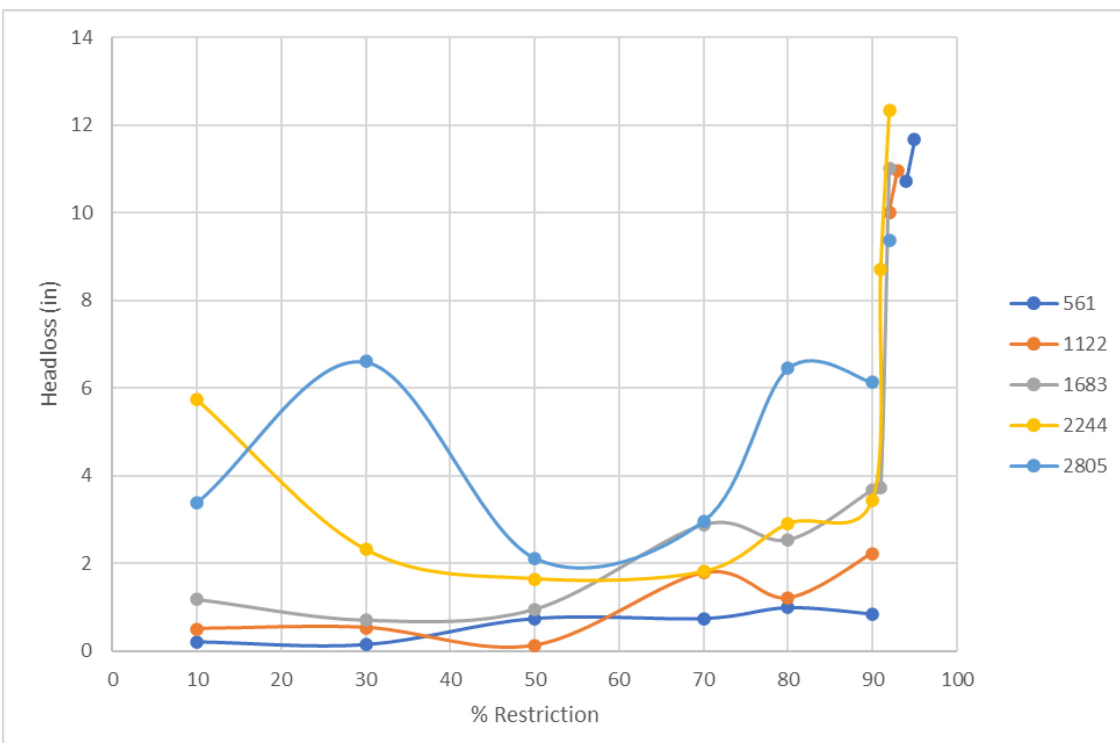


Figure 23 – 4FT HI Net % Restriction Test

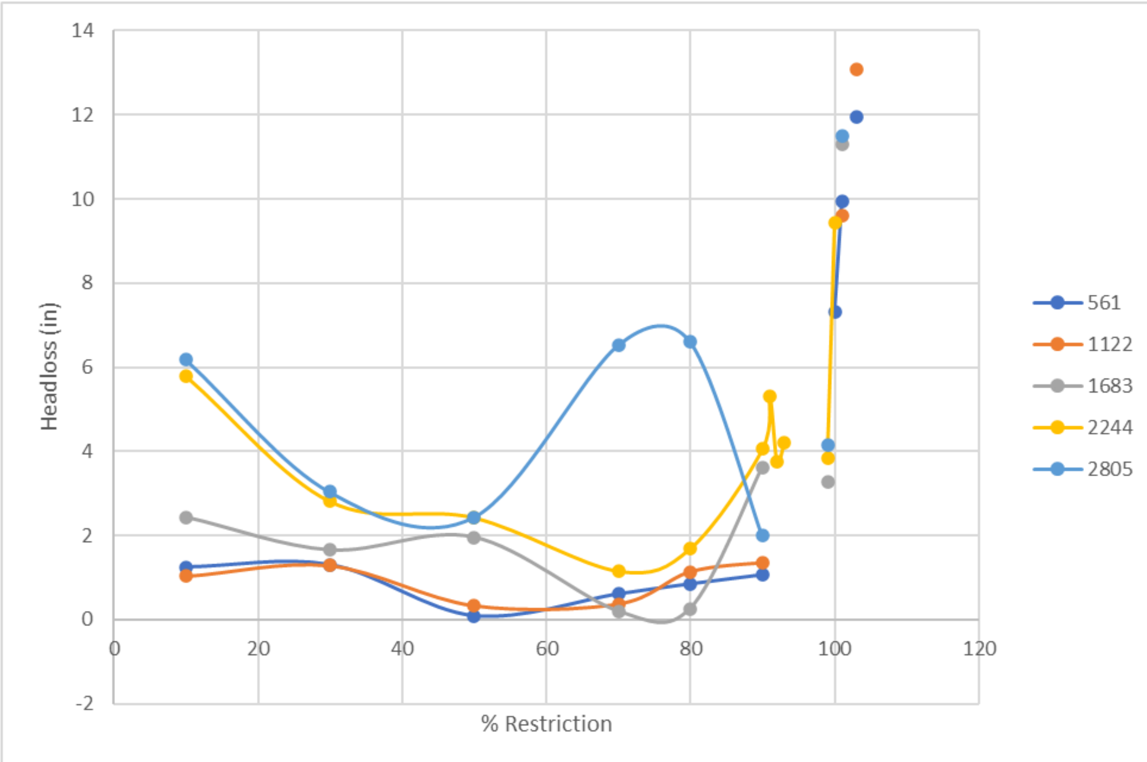


Figure 24 – 4FT 1IN % Restriction Test

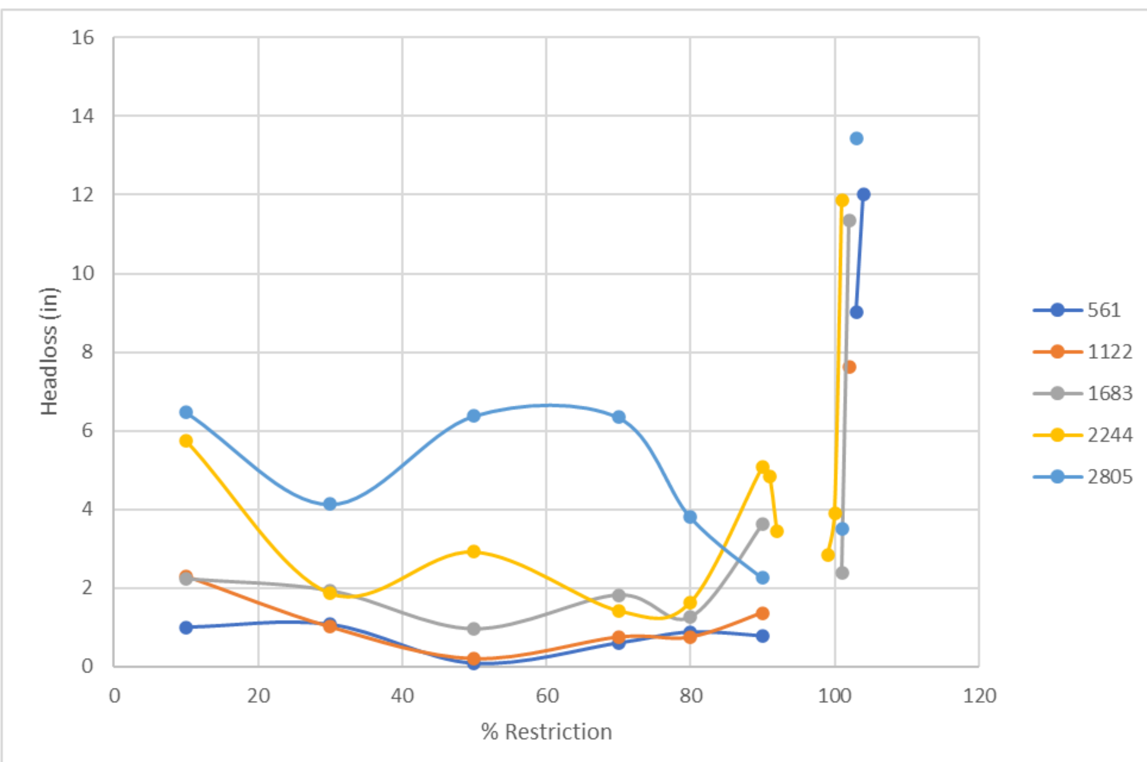
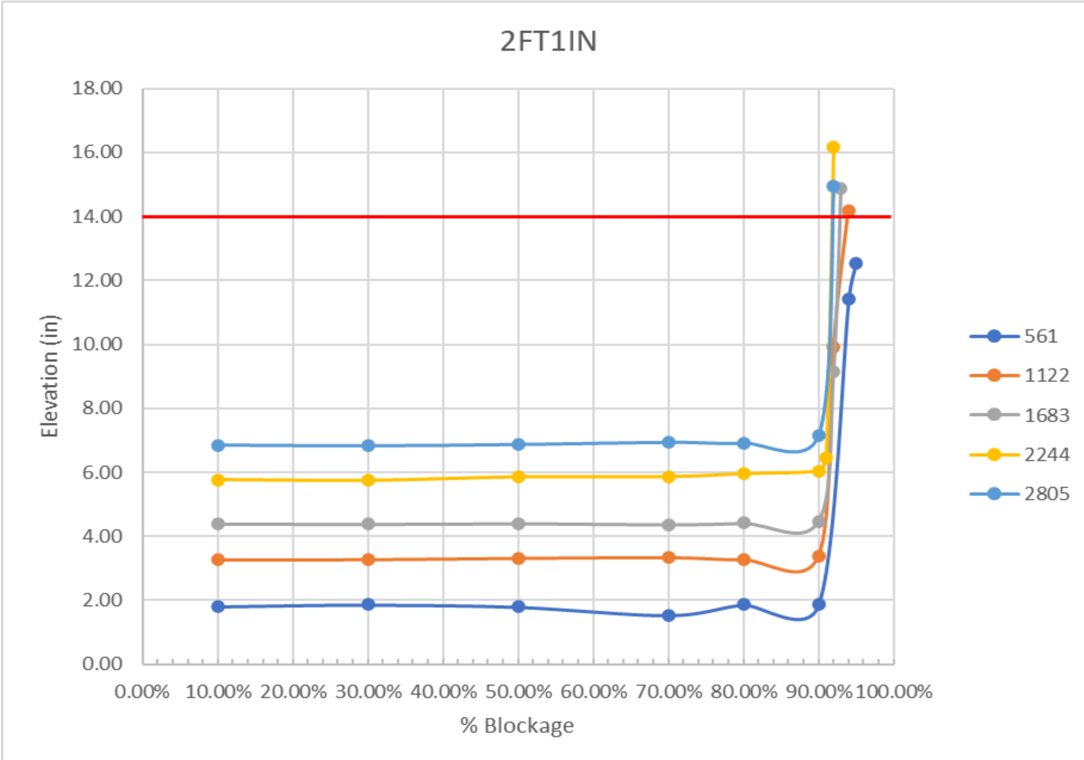


Figure 25 – 2FT 1IN Net % Restriction Test h1 Data



4.4.3 Discussion of Percent Restriction Results

The second phenomenon hypothesized in Section 4.4 is that the inflection (bypass) point should be at the same mesh open area, regardless of net length. Initially this hypothesis was tested looking at the % restriction data in Section 4.4.2, but it became clear that the nets were stretching a little. In addition, the hypothesis that the open area would be constant meant that the critical percent restriction would be a function of net length, adding a confounding variable. This makes the % restriction data a poor metric for nets.

To overcome this limitation the unblocked length at bypass, which we will refer to as the Critical Unblocked Length (CUL), was chosen as the parameter for analysis and it was measured directly in each of the runs. In other words, instead of measuring the blocked area from the bottom of the net, which is what % restrictions does, we measured the unblocked area from the top of the net. The unblocked length for the different configurations at the design velocity of 5 ft/s is shown in Table 8. Given the large amount of raw data, unblocked length data is not included here but can be found in Appendix VI.

Table 8 – Critical Unblocked Length at Bypass @ 5 ft/s

	2FT	**4FT**
5MM	2.5”	5.75”
HI	4”	4.25”
1IN	3.5”	3.75”

Under the basic hypothesis that the inflection occurs when the unblocked area of the net is the same as the area of the aperture, then the 5MM net should have the greatest CUL since it has the smallest open are per square foot. By the same reasoning the HI would have a shorter CUL and the 1IN net the shortest CUL. Table 8 shows that this trend holds for the 4FT net and for the 2FT HI and 2FT 1IN nets. The 2FT 5MM data point does not fit the expected trend but it is most likely an outlier, given that it is very different from any of the other data, and it does not have a physical explanation.

Statistical analysis confirms what looks obvious in Table, CUL is not a function of net length, except in the 5MM net data. It is expected that this is due to the sensor placement issue described in Section 3.1. Since the values in Table 8 are a single point, they could not be compared using a simple t-test. Instead, the CUL vs flow curves were analyzed using ANCOVA. The results of the ANCOVA are given in Table 9.

Table 9 – ANCOVA of Critical Unblocked Length (CUL) vs. Flow Data

Configuration	p for Intercept	p for Length	p for Flow
5MM	0.17	**0.03**	**0.004**
HI	0.20	0.46	**0.00003**
1IN	0.71	0.61	**0.0014**

The values in bold indicate that the variable is significant, and we reject the null hypothesis that the variable is not a function of hole opening size. This data suggests that critical unblocked length is a function of flow for all mesh opening sizes, but it is only a function of length for the 5 MM net. The data for the 2FT 5MM is an outlier and based on the preponderance of evidence it can be discounted, leading to the conclusion that unblocked length is not a function of net length, which makes physical sense.

To be conservative, the larger of the two CUL values in Table 7 will be used and the final data is shown in Table 10.

Table 10 – Unblocked Length at Bypass, 5 ft/s (CUL)

	L (in)
5MM	5.75
HI	4.25
1IN	3.75

To scale this data, and to be consistent with the reporting requirements of the standard, it is useful to convert CUL back into percent restriction at bypass. This was done by dividing the CUL by the starting length of the net. In order to simplify the claim with respect to % restriction, StormTrap decide to make the unblocked length at bypass the same for every mesh opening size and choose the largest value, 5.75” and rounded it to 6”. This is conservative in that StormTrap is claiming a lower capacity than is supported by the data. The results are shown in Table 11.

Table 11 – % Restriction at Bypass, 5 ft/s Flow

Net length (ft)	Critical % Restriction
2	75%
4	88%
6	92%
8	94%

4.4.4 Hydraulics Bypass

As discussed in Section 4.3.5, the system would be expected to behave as a weir once it goes into bypass. This was not confirmed because testing was stopped at the point of bypass.

4.5 Mass Loading (Trash Removal) Testing

Trash removal testing was conducted in accordance with section 9.3 of ASTM E3332. Once again tests were done, in triplicate, with 6 net configurations. Testing was also expanded to look at the effect of an optional grate installed. The grate was not included in prior tests since it sits above the top of the frame and does not impact the Headloss or % Restriction tests significantly.

The artificial trash to be used was blended under the scrutiny of the third-party observer, according to the recipe in Table 1 of ASTM E3332-22, “Standard Test Method for Determining Trash and/or Debris Capture Performance of Stormwater Control Measures.” The trash recipe is shown in Table 12.

Table 12 – Standard Trash Blend

Component	Description	Dimensions ±10 %	% by Dry Mass
Cigarette Filter	regular cigarette filters (ex. OCB brand) ~0.32 oz (9.15 g)/100 filters	0.28 in. (7 mm) diameter by 0.59 in. (15 mm)	14
Disposable wipes	Standard baby wipes	7.5 in. by 2 in. (19 cm by 5 cm)	17[A]
Wood	Popsicle sticks	4.3 in. by 0.37 in. by 0.08 in. (11 cm by 0.95 cm by 0.2 cm)	11
Plastic-Moldable	PET/ PETE plastic, 0.01 in. – 0.02 in. (0.3 – 0.5 mm) thick, cut in strips	3.5 in. by 1.0 in. (9 cm by 2.5 cm)	23
Plastic-Film	Plastic shopping bag split in half and cut in strips	15.7 in x 3.1 in (40 cm x 8 cm)	8
Cardboard/Chipboard	Cardboard box cut in strips	9 in. by 1 in. (23 cm by 2.5 cm)	10
Cloth	Cotton linen fabric cut in strips	13.8 in. by 2 in. (35 cm by 5 cm)	6
Metal – Foil, Molded	Rigid aluminum, 0.01 in. – 0.02 in. (0.3-0.5 mm) thick, cut in strips	4 in. by 1 in. (10 cm by 2.5 cm)	7

Styrofoam	Standard "S"-shaped peanut packing material, non-disintegrating	1.2 in. by 1.4 in. by 0.7 in. (3 cm by 3.5 cm by 1.5 cm)	4

[A] Disposable wipes can be weighed as they come from the package, drying is not necessary.

The artificial trash was blended onsite and sealed upon completion of blending. During testing, the seals were removed only by the observer and the trash was immediately manually transferred into 5-gallon pails. Upon completion of each test run, any unused trash was re-sealed by the observer.

Once a pail was created and the dry weight confirmed by the observer, it was conditioned by adding water to the bucket and sealing the bucket using a lid for at least 10 minutes prior to addition to the test channel. Trash addition was manual, the bucket was poured into the channel as slowly and steadily as practical.

4.5.1 Artificial Trash QC

Not all of the items in the trash recipe can be purchased directly. A few of them, specifically the plastics, the cardboard, the cloth and the metal need to be cut to size. This introduces a source of variability that is not addressed in the standard. For this testing the decision was made to test the incoming material based on the requirements of the Acceptance Quality Limit (AQL) Chart, which is made up of two tables. They are also often referred to as the ANSI/ASQ Z1.4 tables. This is a standard procedure for quality control (QC) of incoming materials. Copies of the charts appear in Appendix VII.

Given that nature of the testing and materials, the inspection level chosen was AQL level: General Inspection Level I. A defect was defined as a dimension falling outside the requirements listed in Table 1, 2 or 3 of ASTM E3332 and all defects were considered major for the sake of the AQL table. Minor or critical defects did not seem relevant in the context of this test.

In addition to prescribing the Inspection Level, The AQL criteria requires an acceptance level and a batch size in order to determine how many incoming samples must be tested and how many defects are allowed. This information is listed in Table 13. Note that batch size was estimated based on the mass of some sample pieces and the expected mass required for a test.

Table 13 – AQL Incoming Inspection QC Requirements

	Est. Batch size	**Sample Size**	**Defect limit (≤)**
Wipes	3201-10,000	80	5
Plastic – moldable	3201-10,000	80	5
Plastic – film	3201-10,000	80	5
Cardboard	1201-3200	50	3
Cloth	501-1200	32	2
Metal strips	501-1200	32	2

Inspection of incoming materials all conformed to requirements as outlined per the AQL incoming inspection QC requirements.

4.5.2 Mass Load Testing Results

Mass was added by emptying 5-gallon buckets of conditioned ‘trash’, in water, into the test channel. This was done by hand, and the rate was made to be as consistent as possible and the rate of mass addition was in the range of 2 pounds per minute. All tests lasted 10 minutes, in order to simplify data collection and analysis, but trash addition was always completed in the first few minutes.

As with prior tests, mass loading was conducted with both net lengths and all three hole opening sizes. All three configurations were tested 3 times. The entire set of runs was then repeated without a grate installed. Table 14 reports the averages of the three runs, with a grate installed. Table 15 reports the averages without the grate. Data for the individual runs can be found in Appendix VIII. All tests were run at the design flow rate, 2250 gpm, ± 10%.

The purpose of the grate is to prevent large objects from getting past the TrashTrap during periods of high flows when the net is bypassed. The impact of the grate was not specifically tested and no claims will be made about its performance.

It was discovered during testing that some components air dried very slowly, specifically the cloth and cigarette butts. In order to accelerate the drying process material was dried in a commercial dryer on low heat. This did lead to some loss of mass. The amount lost was < 5% in all cases, and it should be roughly the same for captured and bypassed amounts, so it was neglected when calculating precent removal.

Table 14 – Average Mass Capture Results – Grate Installed

	Starting Mass (lbs)	**Mass of Trash Captured in Net (lbs)**	**Mass of Trash Captured by Grate (lbs)**	**Mass of Trash Bypassed (lbs)**	**Mass Lost on Drying (lb)**	**% Trash Captured**
2FT 5MM	1.60	1.37	0.11	0.08	0.05	85
2FT HI	2.40	1.87	0.12	0.29	0.11	78
2FT 1IN	2.40	1.91	0.09	0.34	0.06	79
4FT 5MM	4.00	3.61	0.15	0.07	0.17	90
4FT HI	6.00	4.67	0.25	0.67	0.41	78
4FT 1IN	6.00	4.74	0.13	0.77	0.36	79

Table 15 – Average Mass Capture Results – No Grate

	Starting Mass (lbs)	Mass of Trash Captured in Net (lbs)	Mass of Trash Bypassed (lbs)	Mass Lost on Drying (lb)	% Trash Captured
2FT 5MM	1.60	1.38	0.19	0.03	86
2FT HI	2.40	1.74	0.59	0.07	73
2FT 1IN	2.40	1.89	0.43	0.08	79
4FT 5MM	4.00	3.58	0.45	0.06	89
4FT HI	6.00	4.76	1.37	0.14	80
4FT 1IN	6.00	4.41	1.49	0.10	73

4.5.3 Discussion of Mass Load Testing Results

Implementing the protocol described in ASTM E3332 revealed a number of interesting outcomes that will need to be addressed in the next revision of the standard. One discovery was that the test and reporting requirements are not always consistent with each other, leading to some necessary deviations.

The biggest issue is that the protocol requires gathering mass data during a run, but this is not possible because the captured trash cannot be removed and dried in real time. This requires some deviation from the reporting requirements in Section 9.3.7 of the protocol. These are outlined in Section 4.5.3.1 below.

The issue with not being able to measure mass in real time is that it means that the end point of the test is not clearly defined. In our case we continued to empty the last bucket once the system went into bypass. This resulted in % removal numbers in the 70-90 range when, in fact, removal was 100% up until the point of bypass. The final number is just a function of how much trash was left in the bucket once bypass started.

This number will not be constant and that explains the variation in percent capture in Table 14 and Table 15. In retrospect, we should have stopped as soon as the first couple peanuts bypassed, then weighed the unused influent trash separately to do our calculations. Given this issue, we will not make a % removal performance claim but will claim a mass captured instead.

A second discovery was that the Styrofoam peanuts were always the first material to bypass. This creates a challenge in interpreting results for the real world because peanuts weigh very little. This means they have a minimal impact on the % captured data, which is mass based, but they have a large impact on perceived failure because they are visually obvious. Finally, there is the issue of reporting the results in terms of dry mass. The trash components are all relatively light when dry so, while the dry mass is a reproducible way to compare results, it is not very informative in terms of what users can expect in the field. Section 4.5.3.2 addresses this by providing bulk density data for a wetted trash mixture.

Figure 26 shows the beginning of bypass during a 2FT 5MM net test. You can see the last of the second bucket of trash being added to the channel and peanuts flowing over the grate. Closer inspection will reveal that the peanuts have clogged the grate at this point.

Figure 26 – Bypass of 2FT 5MM Net

4.5.3.1 Deviations from Mass Capture Test Procedure in ASTM E3332

Section 9.3.7.5 requires recording the total mass added at the point of bypass. This would require stopping the test to recover and dry the mass, then restarting the test to go to failure. The best we can do is claim that the mass added at bypass equals the total mass in the net. In other words, assume no mass was captured after bypass. This is not true, some of the heavier components would still be captured, but it is conservative.

Section 9.3.7.6 requires a graphical representation of mass load versus headloss. As with Section 9.3.7.3 and 9.3.7.5, this would require measuring the mass added in real time and this is not possible. A good approximation can be obtained by looking at the headloss from the % restriction testing and converting the % restriction to a mass based assuming the total mass captured equals 100% blocked. In other words, repeating Figures 19-24 with the % restriction on the x-axis changed so that 100% restriction = the appropriate mass in Table 12.

4.5.3.2 Wetted Trash Mass Calculations

In order to determine a conversion factor from dry trash to wet trash we filled three 5-gallon buckets with trash and then topped them up with water and let them sit for 90 minutes. The bucket volumes were 0.68 ft^3. The buckets were then drained and the wet trash weighed. The results are shown in Table 16.

Table 16 – Mass of Wet and Dry Trash

	Bucket #1	Bucket #2	Bucket #3	Average
Dry trash wt (lbs)	1.78	1.38	1.50	1.55
Wet trash wt. (lbs)	5.64	4.58	4.94	5.05
Ratio				3.26

This ratio was used, along with the normalized mass data in Table 19 in the section on scaling, Section 5.1, to generate the performance claims for the TrashTrap.

4.5.4 Hydraulic Bypass

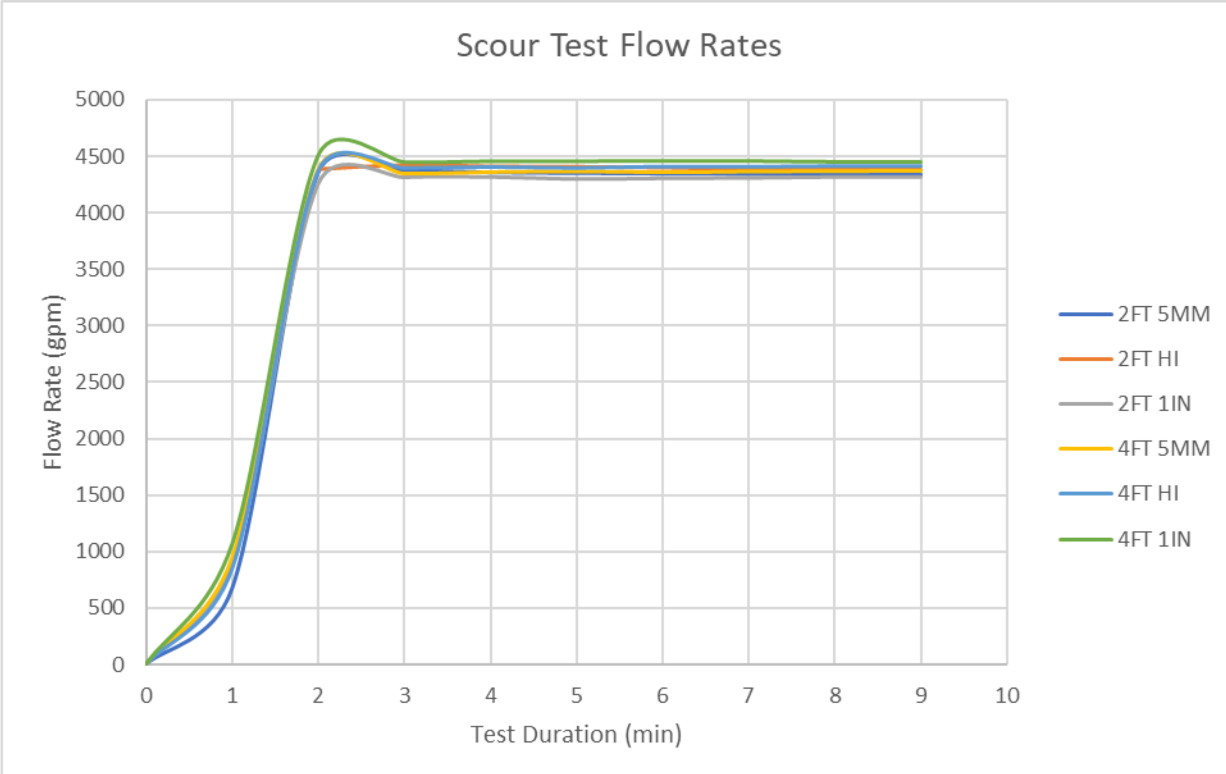
As discussed in Section 4.3.5, the system would be expected to behave as a weir once it goes into bypass. This was not confirmed because testing was stopped at the point of bypass.

4.6 Scour

Scour testing was conducted in accordance with section 9.5 of ASTM E3332. Once the 50% capacity level was determined by mass capacity testing, nets were pre-loaded to 50% capacity with conditioned trash. The flow was ramped up to an average of 9.77 cfs, across all six tests, within 3 minutes and then ran for a minimum of 5 minutes. Residence time for the net is not really defined but it can be estimated by assuming the net is a cylinder 1 ft^2 in diameter and either 2 or 4 ft long. This gives a volume of 2 or 4 ft^3 and, at 10 cfs, residence time of 0.2 or 0.4 seconds so 5 minutes is significantly longer than 5 residence times.

The hypothesis was that a half full net would not scour, since the incoming water would be pushing any captured material back into the net. No bypass was observed in any of the tests, supporting this hypothesis. The flow rates for all the tests are shown in Figure 27. Note that the hump at ~2 minutes in all the lines is an artifact of the way Excel draws line graphs. It should be a flat line, there is no local maximum in the data. There is one missing data point at minute 1 in the 2FT HI run. The data point does not appear in the log file for the flow meter so it must have been a brief malfunction. This “explains” why the curve from 2-3 minutes is flat for 2FT HI but is a maximum for all the other datasets.

Figure 27 – Flow Rate During Scour Tests



5.0 Additional Considerations

The testing was conducted on a small-scale system in order to keep the flow requirement manageable. In order for the data to have practical value it needs to be scaled. Scaling in terms of hydraulics is discussed in section 4.3.7. Section 5.1 addresses scaling for performance.

5.1 Scaling performance

Assuming a constant bulk density, which is valid for the purpose of this testing, mass capacity should scale with volume. The test system had a constant cross section area of 1 ft^2. The mass captured can be divided by the length of the net to give a normalized mass/volume in lbs/ft^3. It is acknowledged that the net will not form a perfect cylinder, so the volume is approximate.

Table 17 and Table 18 show the calculated mass capacity of the tested nets in lbs/ft, with and without a grate.

Table 17 – Normalized Mass Capacity – Net + Grate

Opening Size	2 FT Net Mass Capacity (lb/ft^3)	4 FT Net Mass Capacity (lb/ft^3)
5 MM	0.85	0.90
HI	0.78	0.78
1 IN	0.79	0.79

Table 18 – Normalized Mass Capacity – Net Only

Opening Size	2 FT Net Mass Capacity (lb/ft^3)	4 FT Net Mass Capacity (lb/ft^3)
5 MM	0.86	0.89
HI	0.73	0.80
1 IN	0.79	0.73

There is not enough data for a robust ANCOVA but inspection of the data shows that the mass capacity is not a significant function of the grate or the net length. This allows the results to be condensed as shown in Table 19. These are the numbers to be used for scaling.

Table 19 – Normalized Mass Capacity – Combined Data

Opening Size	Avg. Mass Capacity (lbs./ft^3)
5 MM	0.88
HI	0.77
1 IN	0.78

For example, an 8’ long net with a 30” x 30” opening and 5 MM holes would have a cross-section area (assuming the net forms a cylinder) of 4.91 ft^2 and a volume of 39.3 ft^3. This would result in a mass capacity of 35 lbs. of dry trash of the same composition prescribed in E3332.

This number is useful for comparing different sizes and types of system, since dry mass is a reproducible value, but it does not help with maintenance since dry mass is practically impossible to measure in an installed system. A practical method for determining the maintenance capacity is described in section 5.1.1.

5.1.1 Scaling Maintenance Capacity

The mass capacity determined in section 5.1 is useful for comparing technologies that have been tested according to ASTM E3332, but for determining the effective capacity in the field, volume capacity is more useful. This is because mass is highly variable and not easily measured in the field.

TrashTraps have different opening sizes and net lengths so in principle, scaling needs to consider length, width and height, where length is measured the flow direction and height is perpendicular to the ground. However, it was shown in Section 4.3.4 that net length is not a factor in scaling. As long as there is a critical open area available, the length of the net beyond the critical length does not matter. Thus, TrashTrap scaling is based on the opening area, width x height, not the net volume.

TrashTraps are scaled geometrically in order to maintain a maximum design flow velocity of 5 ft/s. This velocity limit ensures the physical integrity of the system at maximum load and flow. Since all TrashTraps have the same maximum velocity, they have the same unblocked length as shown in Table 20, since this capacity was determined at the maximum velocity.

In order to use the unblocked length for scaling it needs to be normalized in terms of the opening area. The system tested had a 1” x 1” opening. To convert this to a hydraulic radius, R_h, the equation is:

Equation 19 $$R_h = A/P$$

Where A = the area of the opening and P equals the perimeter.

A 1 ft x 1ft square has an area of 1 ft^2 and a perimeter of 4 ft, giving it a hydraulic radius of 0.25 ft. Assuming that, during flow, the net has the same hydraulic radius as the opening and the unblocked length gives the critical unblocked area/square foot of opening shown in Table 20.

Table 20 – Unblocked Area/ft^2 of Opening for Different Hole Sizes

	Unblocked length (ft)	Unblocked area/sq ft of opening (dimensionless)
5 MM	0.479	0.120
HI	0.354	0.089
1 IN	0.3125	0.078

The numbers in the second column of Table 20 can be used to determine the critical unblocked of all net openings as a function of hole size. These are shown in Table 21.

Table 21 – Critical Unblocked Area for Different Net Opening Sizes

Net Opening Size	Opening area (ft^2)	Critical Unblocked Area 5 MM (ft^2)	Critical Unblocked Area HI (ft^2)	Critical Unblocked Area 1IN (ft^2)
24” x 24”	4.00	0.480	0.356	0.312
30” x 30”	6.25	0.750	0.556	0.488
36” x 36”	9.00	1.08	0.801	0.702

This can then be applied to each available net length in terms of a % volume capacity. Due to the large number of combinations, each of the hole sizes is a separate table.

Table 22 – Capacity of Nets with 5 MM holes

Net Opening Size	Net Length (ft)	Hydraulic Radius (ft)	Net Area (ft^2)	Critical Unblocked Area (ft^2)	Net Capacity before Maintenance
24” x 24”	2	0.500	6.28	0.48	92%
24” x 24”	4	0.500	12.57	0.48	96%
24” x 24”	6	0.500	18.85	0.48	97%
24” x 24”	8	0.500	25.13	0.480	98%
30” x 30”	2	0.625	7.85	0.750	90%

Net Opening Size	Net Length (ft)	Hydraulic Radius (ft)	Net Area (ft^2)	Critical Unblocked Area (ft^2)	Net Capacity before Maintenance
30” x 30”	4	0.625	15.71	0.750	95%
30” x 30”	6	0.625	23.56	0.750	97%
30” x 30”	8	0.625	31.42	0.750	98%
36” x 36”	2	0.750	9.42	1.08	89%
36” x 36”	4	0.750	18.85	1.08	94%
36” x 36”	6	0.750	28.27	1.08	96%
36” x 36”	8	0.750	37.70	1.08	97%

Table 23 – Capacity of Nets with HI Holes

Net Opening Size	Net Length (ft)	Hydraulic Radius (ft)	Net Area (ft^2)	Critical Unblocked Area (ft^2)	Net Capacity before Maintenance
24” x 24”	2	0.500	6.28	0.356	94%
24” x 24”	4	0.500	12.57	0.356	97%
24” x 24”	6	0.500	18.85	0.356	98%
24” x 24”	8	0.500	25.13	0.356	99%
30” x 30”	2	0.625	7.85	0.556	93%
30” x 30”	4	0.625	15.71	0.556	96%
30” x 30”	6	0.625	23.56	0.556	98%
30” x 30”	8	0.625	31.42	0.556	98%
36” x 36”	2	0.750	9.42	0.801	92%
36” x 36”	4	0.750	18.85	0.801	96%
36” x 36”	6	0.750	28.27	0.801	97%
36” x 36”	8	0.750	37.70	0.801	98%

Table 24 – Capacity of Nets with 1 IN Holes

Net Opening Size	Net Length (ft)	Hydraulic Radius (ft)	Net Area (ft^2)	Critical Unblocked Area (ft^2)	Net Capacity before maintenance
24” x 24”	2	0.500	6.28	0.312	95%
24” x 24”	4	0.500	12.57	0.312	98%
24” x 24”	6	0.500	18.85	0.312	98%
24” x 24”	8	0.500	25.13	0.312	99%
30” x 30”	2	0.625	7.85	0.488	94%
30” x 30”	4	0.625	15.71	0.488	97%
30” x 30”	6	0.625	23.56	0.488	98%
30” x 30”	8	0.625	31.42	0.488	98%
36” x 36”	2	0.750	9.42	0.702	93%
36” x 36”	4	0.750	18.85	0.702	96%
36” x 36”	6	0.750	28.27	0.702	98%
36” x 36”	8	0.750	37.70	0.702	98%

For the purpose of making a simple, practical, claim StormTrap will choose a Net Capacity of 85% by volume.

6.0 Design Limitations

The StormTrap TrashTrap is an engineered system designed to meet site-specific requirements. Design should be completed in consultation with StormTrap. Some general design parameters and limitations are listed below.

Maximum Treatment Flow Rate

The maximum treatment flow rate (MTFR) for StormTrap TrashTrap is based on water velocity so it varies with system dimensions. StormTrap recommends that systems should be sized for a flow velocity of $\leq$5 ft/s at the net opening.

Maintenance Requirements

TrashTrap systems should be inspected and maintained following the recommendations and guidelines included in the TrashTrap Manufacturer’s Instruction Manual available at: https://stormtrap.com/products/trashtrap/.

Installation Limitations

StormTrap provides contractors with detailed installation and assembly instructions prior to delivery.

Configurations

TrashTrap is available in 3 basic configurations: in-line, end-of-pipe and floating. The primary difference between them is how the net and frame are mounted in the flow. All configurations use the same nets and can be expected to behave as described in this report.

Appendix I – 3rd Party Observer Resume and Statement of Qualification

Jason Wiesbrock, P.E.

Vice President

Joined Spaceco: **2005** Years of Experience: **29**

As Vice President, Mr. Wiesbrock is responsible for the management of Spaceco's Morris office and is responsible for management and oversight of infrastructure, transportation, and industrial, commercial, and residential site development projects for both public and private sector clients. He also supervises a support staff including Senior Project Managers, Project Managers, Design Engineers, and CAD operators and is responsible for business development activities. His duties include oversight and design of grading and utility layout, earthwork analysis, cost estimation, stormwater management, permitting, and construction observation.

Project Experience

Creekside Estates – Channahon, IL

A 33-acre luxury residential development including 112 duplexes on 56 individual lots.

Towne Place Suites – Minooka, IL

The development of a four story, 87-room hotel on 3 acres of land.

G.E. Appliances – Morris, IL

A 180-acre development including a 1.2-million square foot CSX rail-served distribution facility.

EDUCATION

- *Bachelor of Science | Civil Engineering University of Illinois, 1995*

REGISTRATION

Professional Engineer

- *Illinois | 062-057654 (2004)*

CAREER SUMMARY

2005 - Present

- *Spaceco, Inc.*

1996-2005

- *Jacob & Hefner Associates, Inc.*

1995-1996

- *Spaceco, Inc.*

AFFILIATIONS

- *Grundy County Chamber of Commerce*
- *Grundy Economic Development Council*
- *I-39 Logistics Corridor Association*
- *Illinois Valley Area Chamber of Commerce*
- *Village of Lostant Zoning Board, Chairman*
- *Lostant Fire Protection District, Board of Directors, Treasurer*
- *Lostant Volunteer Fire Department, Certified Fire Fighter II*
- *Hope Township, Board of Directors*

Spaceco
Civil Engineering & Surveying

Jason Weisbrock, PE
Vice President, Spaceco Inc.
224½ N. Liberty St, Morris, IL 60450

Supplement to resume

Requirement	Experience
hydraulic testing, water quality monitoring and analytical measurements	Designed/reviewed the stormwater management (ponds and storm sewers) for multiple project in multiple locations in Chicagoland. Most recent is the 1.3-million square foot warehouse building with associated stormwater management, semi/tractor-trailer/auto parking, and utilities.
experimental design and setup	Multiple projects where "wet" and "dry" stormwater management facilities were evaluated. Most recently an industrial development in unincorporated Grundy County, IL.
sampling methods, handling sample security (i.e., chain of custody)	In years past I inspected various project sites for SWPPP compliance during construction.
task documentation and data management	Multiple projects in the Chicagoland area where I've designed and/or managed projects from the frontend land surveying to the engineering design, to the construction staking, and through the as built/record drawing stage. Currently reviewing design plans and stormwater calculations for a project in Channahon, IL prepared by a different firm for submittal to the governing agencies.
Knowledge of QA/QC	I QA/QC multiple projects annually that my staff prepares. A recent one is the Tractor Supply Company site in Beach Park, IL.
Knowledge of ASTM	Designed/reviewed multiple projects using IDOT and ASTM standards. Current project is US Rt. 6 roadway widening in Morris, IL.
Knowledge of laboratory or field testing or monitoring procedures	I review all existing field data (topography, utilities, Geotech reports, wetland reports, etc.) prior to starting the site design. Most recently a proposed 1.2-million square foot warehouse in Coal City, IL.

Appendix II – ANCOVA Discussion

The basic method looks at the dependent (y) variable as a function of a series of multiple dependent variables with a covariate. In Section 3, the analysis is headloss versus flow with run number or net type as the covariant. The ANCOVA tests the null hypothesis, H_0, that the datasets are the same. It is fundamentally a combination of regression and ANOVA that allows the identification of the source of error. If the error is mainly due to the model, then headloss is a function of flow, if not then the error is either random and headloss is not a function of flow or headloss is a function of flow and one or more covariant.

The test statistic for regression and ANOVA is “F”. Excel outputs “Significance F” which is the same as p value. If $p \geq \alpha$ then the covariate is not significant, the null hypothesis is accepted, and the three data sets are statistically the same. Unless otherwise noted, $\alpha = 0.05$ for all tests.

(Note: If the ANCOVA shows that H_0 must be rejected, further work is required to determine which dataset is different, in other words which covariant is a factor.)

The easiest way to implement ANCOVA in Excel is necessary to use n-1 dummy variables. In the case of the Hydraulics runs there are three series of runs so N = 2 and 2 dummy variables are required. In this report Series 1 was coded d1 = 1, d2 = 0, series 2 was coded d1 = 0 d2 = 1 and series 3 was coded d1 = 0, d2 = 0. This makes Series 3 the reference curve, so the results are compared to the Series 3 curve. If neither Series 1 nor Series 2 is significantly different from Series 3 then all three curves are, statistically, the same.