R. Pitt and J. Voorhees
October 25, 2018
Revised February 25, 2019

ADS Isolator Row and StormTech Infiltration Chambers in WinSLAMM – Performance Observations and Unit Process Descriptions

Contents

Introduction

This memo is based on a review of the manuals, technical reports, and brochures from ADS describing the Isolator Row with the StormTech infiltration chambers and the available performance reports for incorporating the calibrated unit processes in WinSLAMM. The performance data as presented in the technical reports was collated and analyzed. The goal was to examine each event for each site and, using rain characteristics, to describe the performance for the separate treatment processes, and for the combined system, as much as possible. As these performance data were evaluated, they were compared to existing process descriptions, and modified as necessary, with new algorithms being developed or existing algorithms being modified.

There are two basic flow regimes that WinSLAMM will evaluate when calculating the benefits of the Isolator Row/StormTech chambers. One flow regime is that all of the stormwater enters the Isolator Row (IR) and then exits through the surrounding rock and underdrains. The other flow regime is for larger flow rates that exceed the IR capacity. In this case, as much enters the IR as hydraulically possible, with excess stormwater flows over the diversion weir and enters the parallel StormTech chambers and then the surrounding rock and underdrains, or the outlet control structure. The suggested approach is dependent on the available data documenting the performance of the system. Some information was not available (such as effluent particle size for most monitoring studies), so various assumptions were needed to complete the calibration, most notably effluent particle size distributions. In many cases, influent particle size distributions were available and percentage reductions were measured in the system. It was assumed that the larger particles were preferentially removed in the system, as a conservative approach, leaving the finer particles. The effluent particle size distribution was then calculated based on this truncated data.

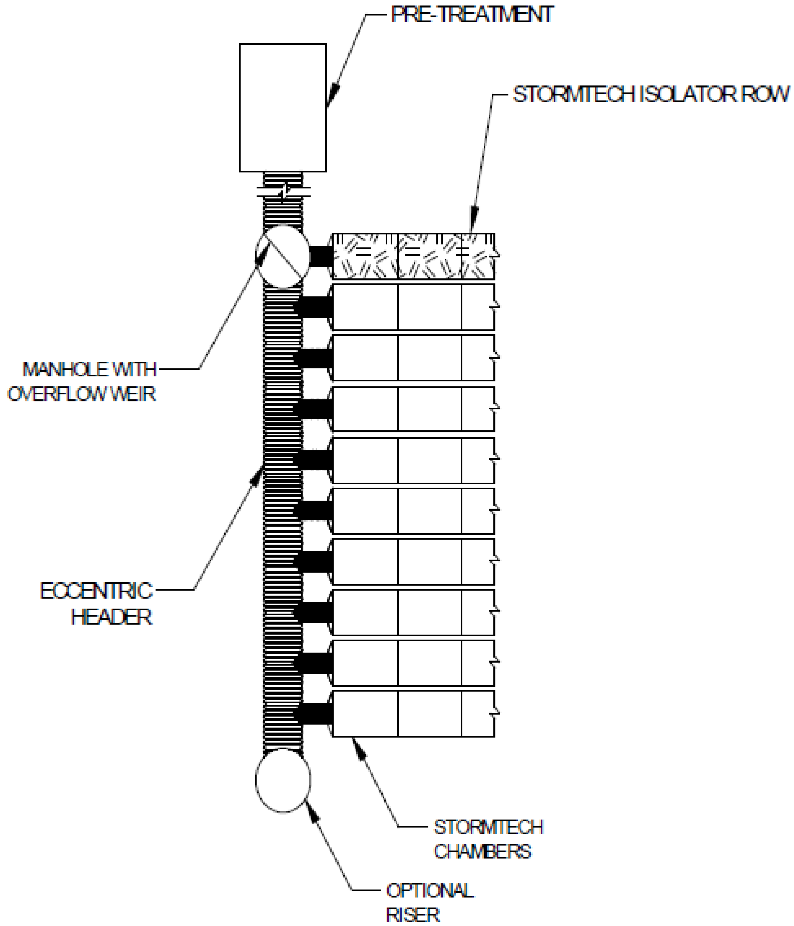
Work began on incorporating the Isolator Row into WinSLAMM in 2014. On December 18, 2018, WinSLAMM version 10.4.0, which included the Isolator Row, was released.

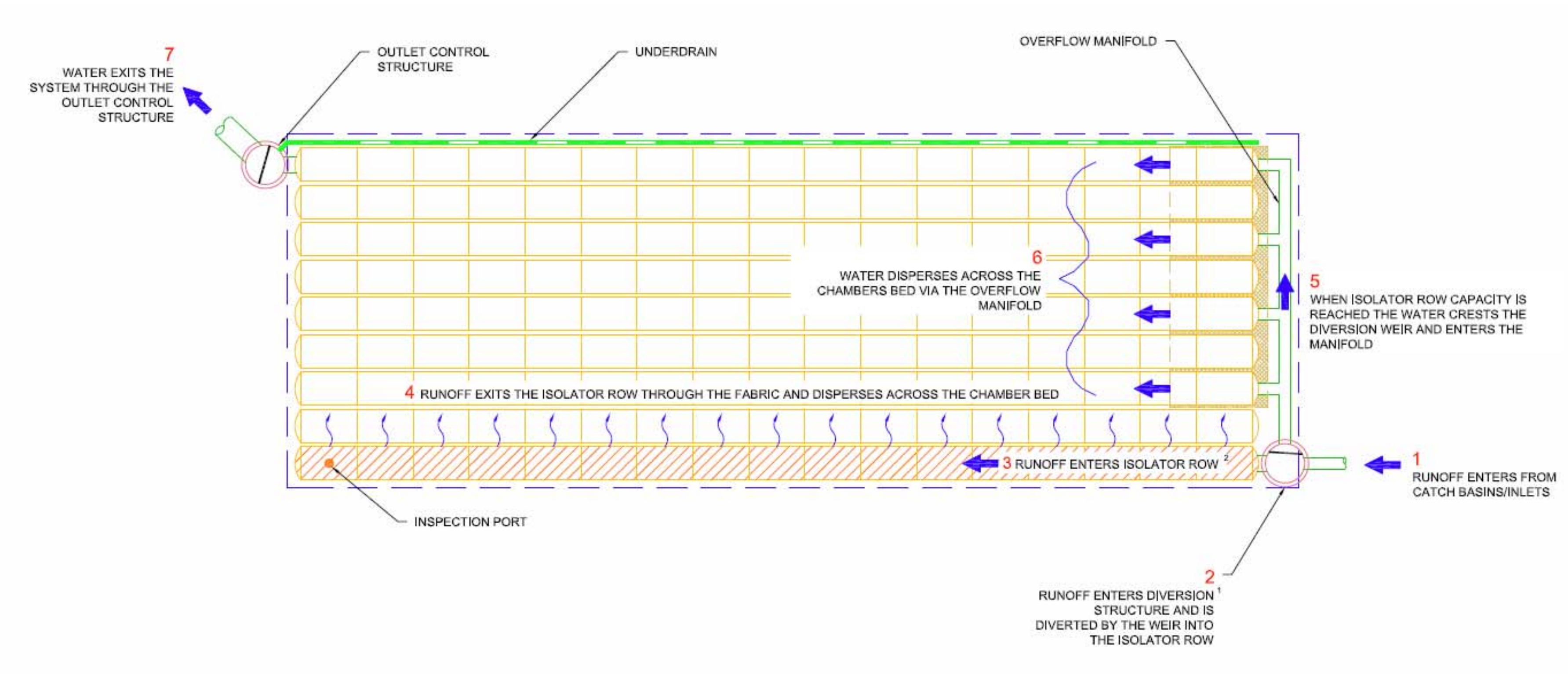
Diagrams of Isolator Row and StormTech Chambers

The following diagrams and drawings were extracted from various ADS supplied materials and describe the hydraulic functions of the various units.

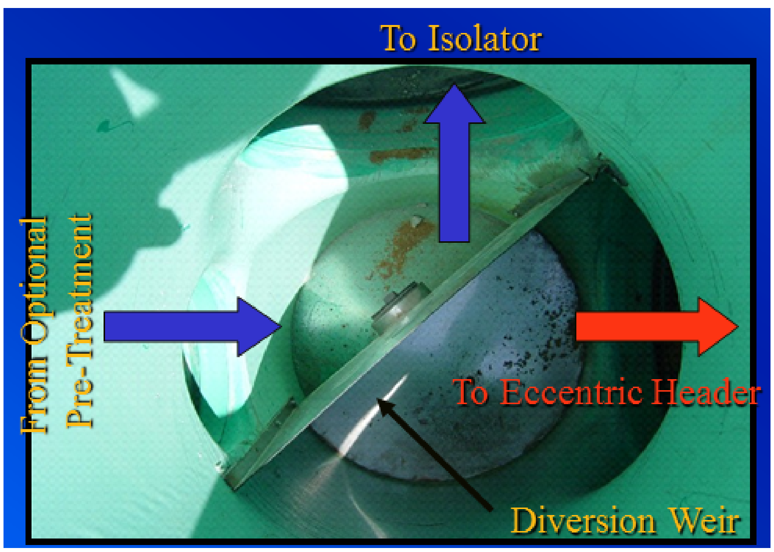
Stormwater first enters the treatment system through a manhole having an overflow weir, as shown below. The weir elevation is set to about the midpoint to the crown of the isolator row chambers and all flows less than this weir capacity are directed to the Isolator Row. The Isolator Row (IR) chambers are similar to the StormTech chambers except that the Isolator Row chambers are wrapped in filter fabric to restrict stormwater sediment. Our analyses assume that particles greater than 50 µm would be trapped in the IR and kept from moving into the gravel storage material. The water leaves the isolator chamber only through the bottom or sidewalls of the (wrapped) chamber (the ends are capped). The water flows laterally thru the gravel under the chambers to the underdrain at the lower end of the gravel area. Infiltration through the bottom of the gravel also occurs, unless the excavation is specifically lined with an impermeable membrane. As the water rises in the Isolator Row chamber, water will also rise in the adjacent StormTech chambers as they are also perforated and surrounded by the rock storage material with no separation from the Isolator Row chamber.

When the water in the Isolator Row chamber(s) fills to near the crown, incoming water flows over the weir and into the manifold and directly into the StormTech chambers. Water rising over the diversion weir will not be treated in the Isolator Row but will enter the StormTech chambers directly and then into the rock storage. Continuous low flows will still enter the Isolator Row and receive treatment. The outlet structure has a direct connection to the last StormTech chamber so excess flows would move through the manifold and last StormTech chamber to the outlet control structure. The underdrain also connects to the outlet control structure manhole. There is also a weir in this outlet control structure that is set lower than the inlet weir to prevent backwater from entering the manifold and inlet structure.


PRE-TREATMENT
STORMTECH ISOLATOR ROW
MANHOLE WITH
OVERFLOW WEIR
ECCENTRIC
HEADER
STORMTECH
CHAMBERS
OPTIONAL
RISER

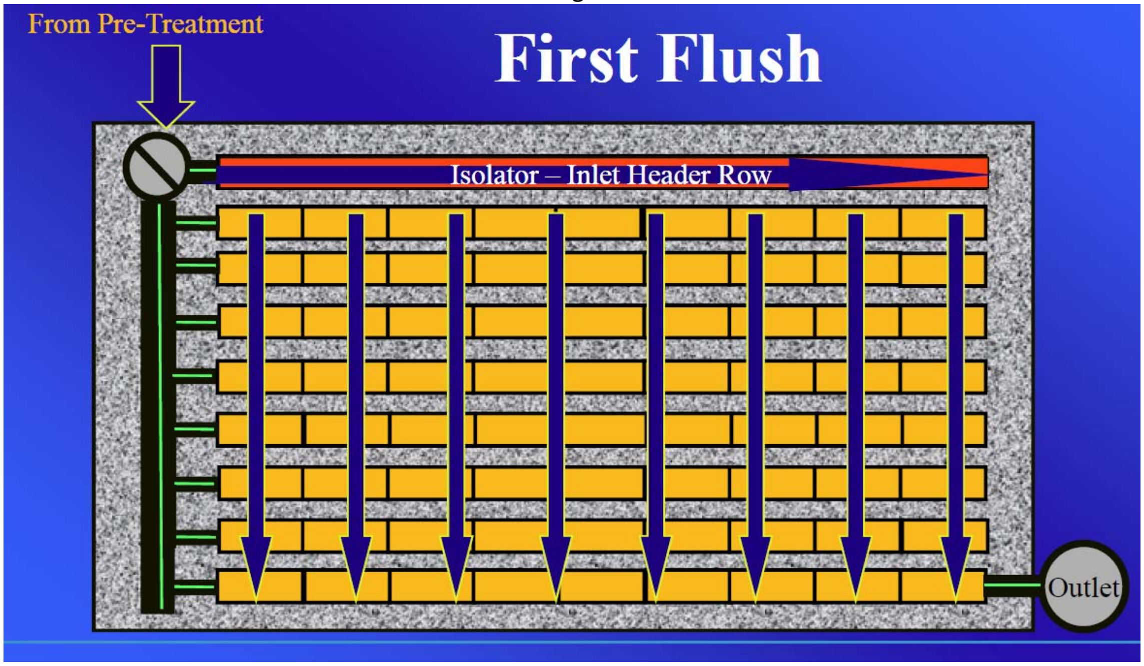

7
WATER EXITS THE SYSTEM THROUGH THE OUTLET CONTROL STRUCTURE
OUTLET CONTROL STRUCTURE
UNDERDRAIN
OVERFLOW MANIFOLD
6
WATER DISPERSES ACROSS THE CHAMBERS BED VIA THE OVERFLOW MANIFOLD
5
WHEN ISOLATOR ROW CAPACITY IS REACHED THE WATER CRESTS THE DIVERSION WEIR AND ENTERS THE MANIFOLD
4 RUNOFF EXITS THE ISOLATOR ROW THROUGH THE FABRIC AND DISPERSES ACROSS THE CHAMBER BED
3 RUNOFF ENTERS ISOLATOR ROW [2]
1
RUNOFF ENTERS FROM CATCH BASINS/INLETS
INSPECTION PORT
2
RUNOFF ENTERS DIVERSION [1] STRUCTURE AND IS DIVERTED BY THE WEIR INTO THE ISOLATOR ROW

The following photographs show how the Isolator Row is wrapped in filter fabric and receives the low flows. The StormTech chambers are not wrapped, but the holes in the side walls are smaller than the rock fill. All of the chambers are placed directly on the rock and the rock is filled over the crown of the chambers. The Isolator Row is on a double layer of woven geotextile.

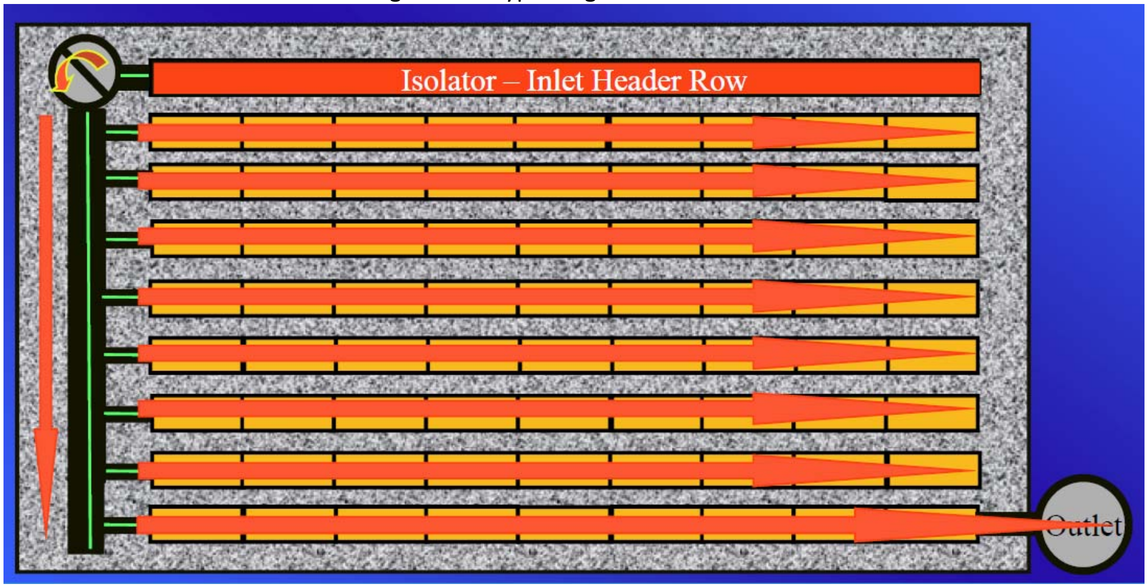


The following two diagrams illustrate the flow paths through the system: the first one for the low flows (up to the design flows for the Isolator Row) and the second one for greater flows. The low flows enter the Isolator Row and then pass thru the bottom and sidewalls after sedimentation and fabric filtering. The treated water laterally flows through the rock storage and also enters adjacent StormTech chambers if the water depth increases in the Isolator Row. As the water flows through the rock storage, infiltration into the native soil under the system can occur, along with additional sedimentation of fines in the gravel. During high flows the Isolator Row is full of water and the incoming water flows over the diversion weir, the excess water directly enters the StormTech chambers. The low flow portion during these high flows still enters the Isolator Row for some treatment of the total flow. The diverted flows that enter the StormTech chambers will also undergo some sedimentation in these open chambers, fines will be subjected to trapping in the rock layer, and all flows will continue to be subjected to infiltration. The outlet captures water from the last StormTech chamber along with the underdrain flows.

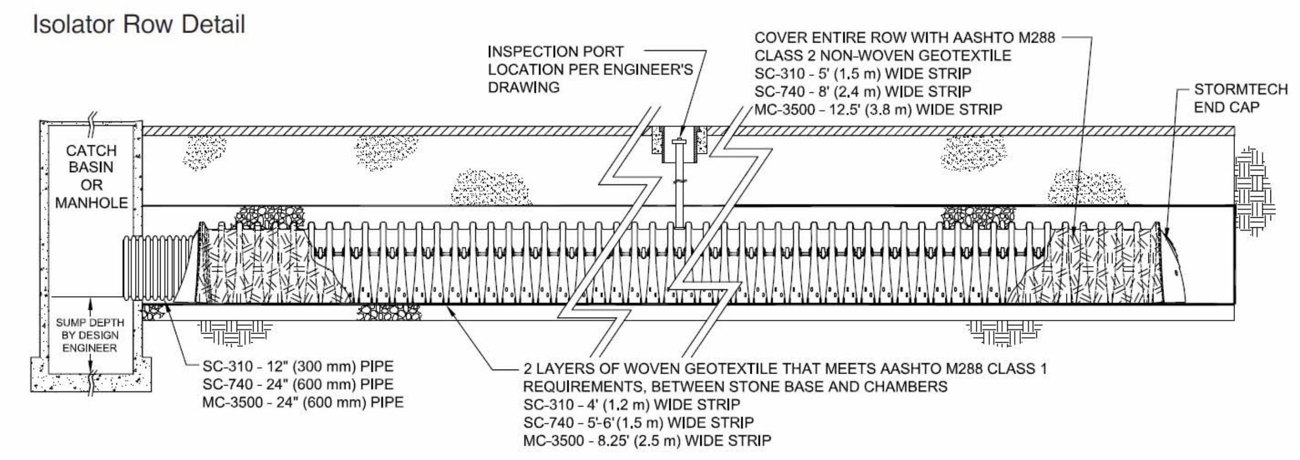
Low Flows Entering the Isolator Row



High Flows Bypassing the Isolator Row



The following Isolator Row detail drawing shows the specifications of the pipe and geotextiles.



Flow Regime 1: Low flows with All Flows Entering the Isolator Row Chamber(s)

This is the condition if the system is operating up to the design flow capacity of the Isolator Row, with no flows over the diversion weir. The design flow is usually specified by local stormwater regulations and the ADS design engineers then size the diversion structures and chamber dimensions appropriately.

Hydraulic Calculations

This is basically a surface storage structure with a subsurface infiltration gallery that has rock void space for the detention of the stormwater, with an underdrain that regulates the effluent flows, along with any infiltration through the bottom of the rock storage and into the native soil. There are no other hydraulic controls during low flows, as water is regulated by the underdrains after passing through the chambers and filter fabric.

Flow Rate Calculations

The performance reports include exfiltration rates from the Isolator Row through the surrounding rock (about 0.5 gal/ft^2, or about 50 in/hr). This rate is through the filter fabric and into the rock. Hydraulic capacity goals are also provided, with bypass regulators. Note that this rate is both very high and also difficult to determine exactly. Consequently, WinSLAMM assumes that the discharge rate is a function of the outlet structures, which include the discharge weir and underdrain hydraulics.

Clogging Rate Calculations

Some of the performance reports include mass balance and sediment depth measurements, and ADS has specified maximum sediment accumulation of material before cleaning is needed. Observed scour is also noted in some reports, but since the only way sediment can exit the Isolator Row is through the fabric (unless bypassing), this scour is mostly just moving sediment around and not really removing previously captured sediment and transporting it to the outfall. Because of this, scour does not occur in the Isolator Row and is not included in the analyses.

Trapping of Fines in Rock Storage

Particle settlement will also occur in the rock storage area for the fines that exit the Isolator Row. The settling area is the gravel layer area adjusted by the rock porosity.

Particulate Pollutant Capture

Several field and laboratory tests have measured particulate accumulation and effluent quality. The lab tests used SilCoSil materials and only looked at Isolator Row chambers, while most field measurements looked at whole systems and actual stormwater, but with limited info on influent PSD, flow rates, or rain depths.

Filterable Pollutant Capture

There is no removal mechanism available in these systems for retaining soluble pollutants and there are very limited data available for the removal of the filterable pollutants. There are some data on pollutant transformations for nitrogen compounds that indicated increases in NO_3, for example. We will use no filterable pollutant control, as the data do not indicate consistent transformations at the different sites.

Flow Regime 2: High Flows with Peak Portions Bypassing the Isolator Row and Directly Entering StormTech Chambers

During all flows, as the water rises in the Isolator Row, it will also rise in the adjacent StormTech chambers and rock storage because they are hydraulically connected by the rock layers. The water flowing over the diversion weir will enter the StormTech chambers directly with no Isolator Row treatment. This water will be blended with effluent from the Isolator Row(s) as the water passes through the rock. Also, the flow path through the rock will vary as some chambers will be adjacent to the underdrain, while others will be further away.

Flow Rates

The Tennessee Tech 2005 report stated that the maximum design hydraulic loading rate for two Stormtech® SC-740 chambers is 8.1 gpm/ft^2, or 0.5 cfs per chamber. The following is a plot of the discharge rate vs. stage for 4 and 2 chamber systems using SC-740 chambers. The chamber bottom is assumed to be the top of the rock.

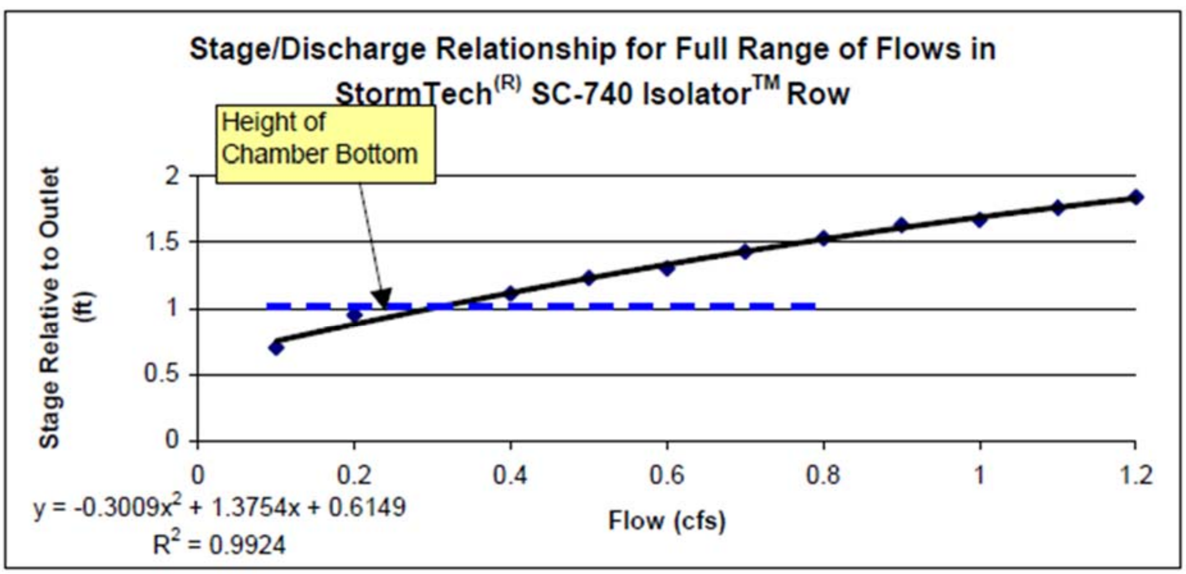


Figure 5: Stage vs. Discharge Plot (4-Chambers)

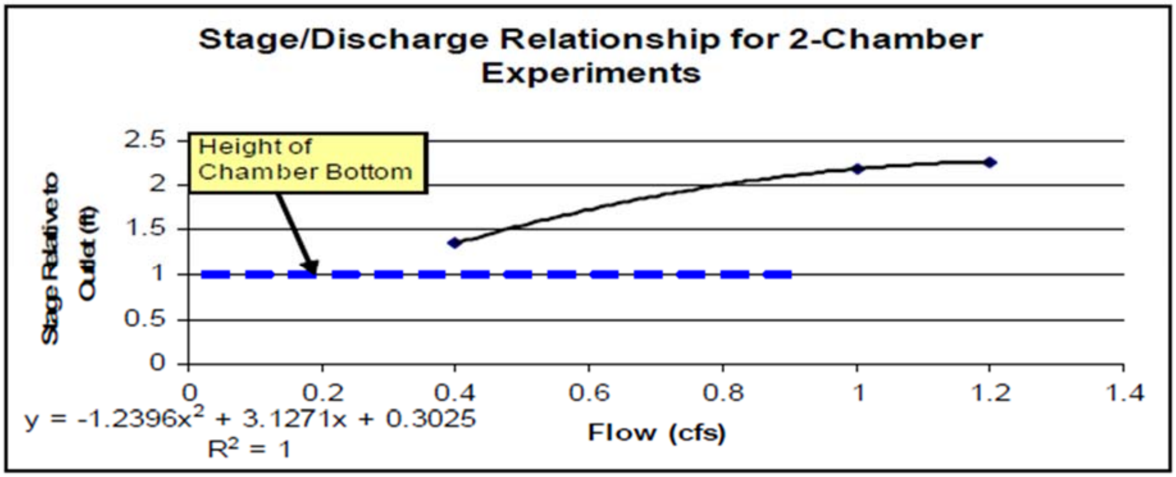


Figure 6: Stage vs. Discharge Plot (2-Chambers)

The Tennessee Tech report further stated that the stage increased steadily along with flow, and the detention time decreased as flow increased. At the maximum flow tested, 1.2 cfs, the stage reaches 1.84 feet above the invert of the outlet. The stage of the two lowest flows tested, 0.1 and 0.2 cfs, remained below the bottom of the chambers, with the 0.1 cfs stage reaching 0.7 feet above the invert of the outlet. The detention times varied from about 2 minutes at the highest flow to 6 minutes at the lowest flow. The following table shows the detention times for these flow conditions. Note that the detention times in the WinSLAMM model are determined by the algorithms developed for the model.

Flow (cfs)	Stage Relative to Invert of Outlet (ft)	Depth of Water Inside Chamber (ft)	Volume of Water in 2 Chambers (ft^3)*	Volume of Water in Gravel Beneath Both Chambers (ft^3)	Total Volume (ft^3)	Detention Time, θ (min)	15 X θ (min)	Total Sediment Injected for 15 X θ (lbs) **
0.4	1.355	0.375	23.84	23.46	47.3	1.79	26.85	8.06
1.0	2.19	1.21	58.85	23.46	82.3	1.37	20.55	15.91
1.2	2.27	1.29	62.28	23.46	85.74	1.19	17.85	16.08

Table 2: Hydraulic Properties and Detention Times for Range of Flows (2-Chambers)

Maintenance Intervals and Sediment Accumulations

The Tennessee Tech 2005 report also investigated necessary maintenance intervals. The following is summarized from their report. The example they present is for a 1-acre catchment (paved surface) with an average annual sediment inflow of 300-1000 lb/acre-yr (Neary et al 2002). The useful volume of the chambers is calculated to be 6.58 cubic feet per chamber (26.32 cubic feet for four chambers), or when the sediment accumulation reaches three inches from the bottom of the chambers. Assuming a uniform sediment distribution and a specific weight for sediment of 75-lb/cubic ft, it is estimated that 300–1000 lb/yr would be deposited. This annual mass loading would translate to 4-13 cubic ft per year, and the chamber would have to have sediment removed approximately every 2–6.5 years, with an average of approximately 3 years for a typical 1-acre catchment.

The UNH 2010 report also describes the sediment accumulation observed during their field tests. Sediment depths over the 3 year installation and monitoring period (September 2006 September 2009) had accumulated to 1.2 in, nearly half of the manufacturers recommended depth for maintenance (3 inches). By this measure, it would take another 3 years of operation before maintenance would be required, or a total of 6 years of operation.

UNH also examined the rate and trend of clogging by monitoring drain down for events at or near the maximum treatment flow rate. The maximum treatment flow rate for the system was calculated for seven events when in-system depths were at or near the maximum depth as regulated by the bypass (27.7 inches). Figure 16 illustrates the seven events of maximum treatment flow rate versus qmax. Examination of the data indicated a relatively weak correlation (r^2=0.34) due largely to the limited number of events where maximum depth at or near bypass was observed (seven of twelve) and due to the minimal trend observed. Hydraulic conductivity is dependent on driving head and therefore needs to be constant. For comparative purposes, the linear regression was solved for a condition where the filter fabric trapping efficiency would be equal to a sandy soil reference condition. Given the current accumulation rate, the filter fabric will have reduced to the reference condition (sandy soil) by September 2010, 4 years after installation (September 2006). This point does not necessarily indicate the need for maintenance, but does indicate an 89% reduction in filter fabric efficiency by September 2010. This maintenance requirement point could be determined by monitoring of water quality and occurrence of bypass. This is not the same as a reduction in initial maximum treatment flow rate. That point is not known for the starting condition, but was determined from 12/2007- 6/2009.

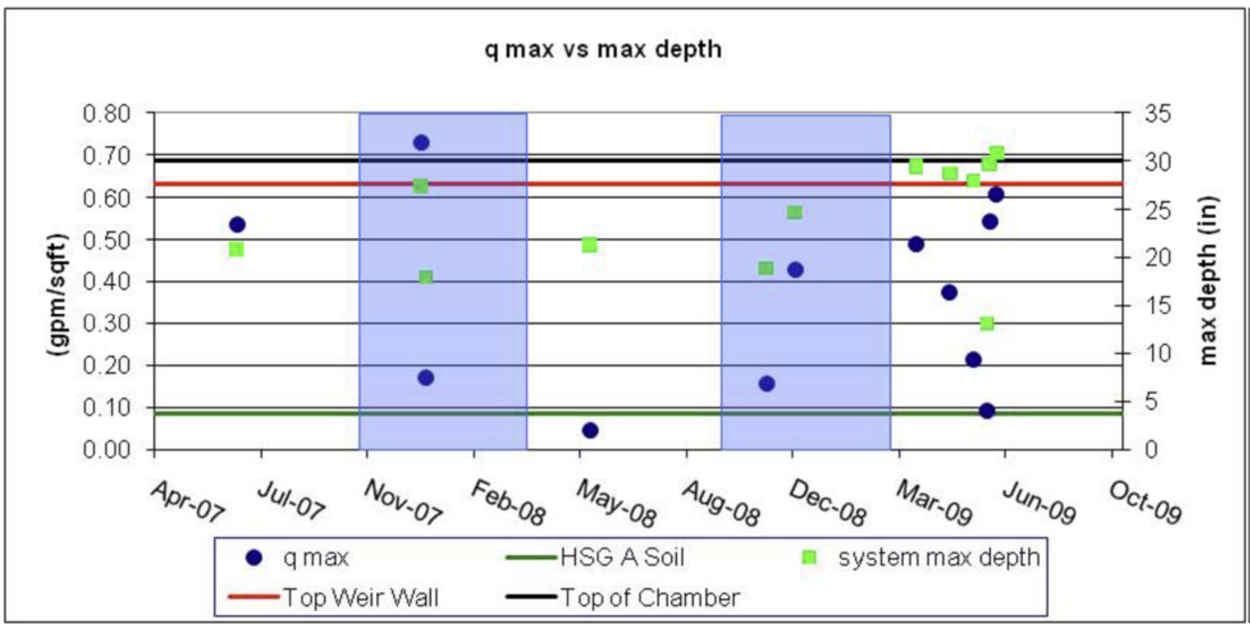


Figure 16: Plot of the stage-discharge and maximum water level measured for 12 monitored storm events. Also plotted are the hydraulic conductivity of an HSG A soil and relative elevations of the bypass weir wall and the top of the Isolator Row chamber all as horizontal lines.

Laboratory Sediment Trapping Tests of the Isolator Row and StormTech System

Tennessee Tech (2005 report) conducted laboratory tests using SilCoSil ground silica in domestic water to test the sediment trapping potential of the Isolator Row StormTech system. They used a mixture of US Silica grade OK-110 for the first series of tests. The sediment distribution in the bottom of the chambers varied with the flow magnitude. For the higher flows (0.8 – 1.2 cfs), it was deposited evenly throughout all chambers. For the low flows below 0.8 cfs, the sediment was deposited predominantly in the first two chambers. The distribution was affected by scouring by the inlet flow in the first two chambers as the pumps were shut down..

The following plot illustrates the trapping efficiency (percent capture of the OK-110 ground silica) compared to the hydraulic loading rate (expressed in gal/min/ft^2).

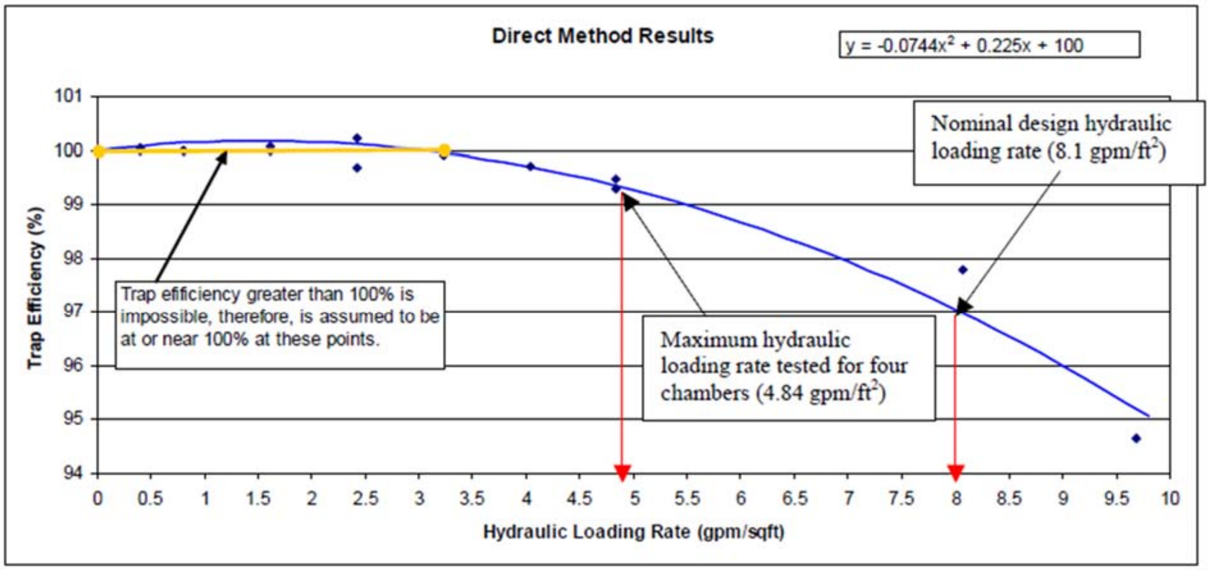
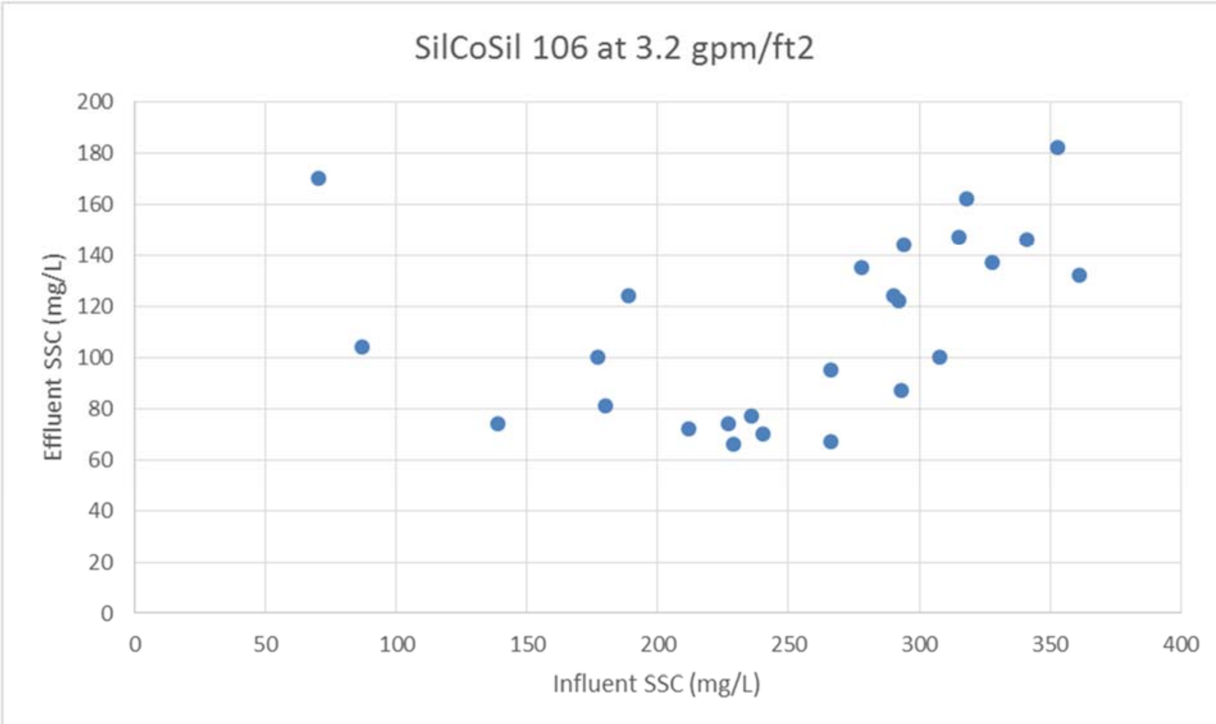
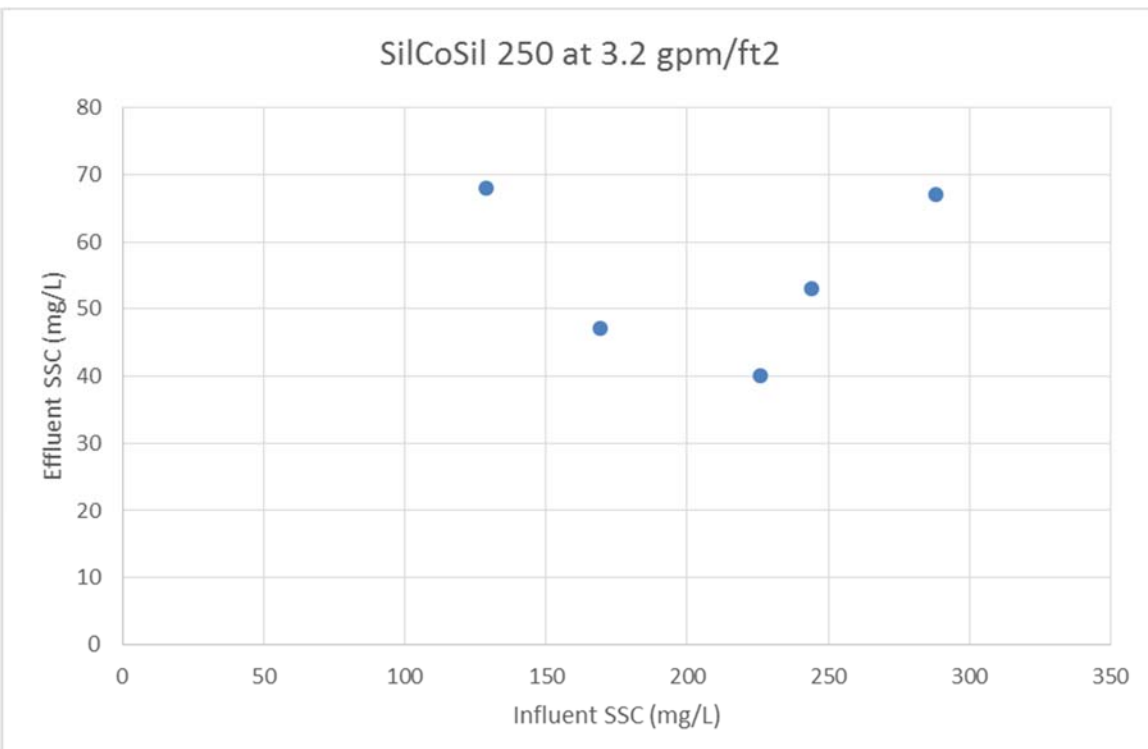
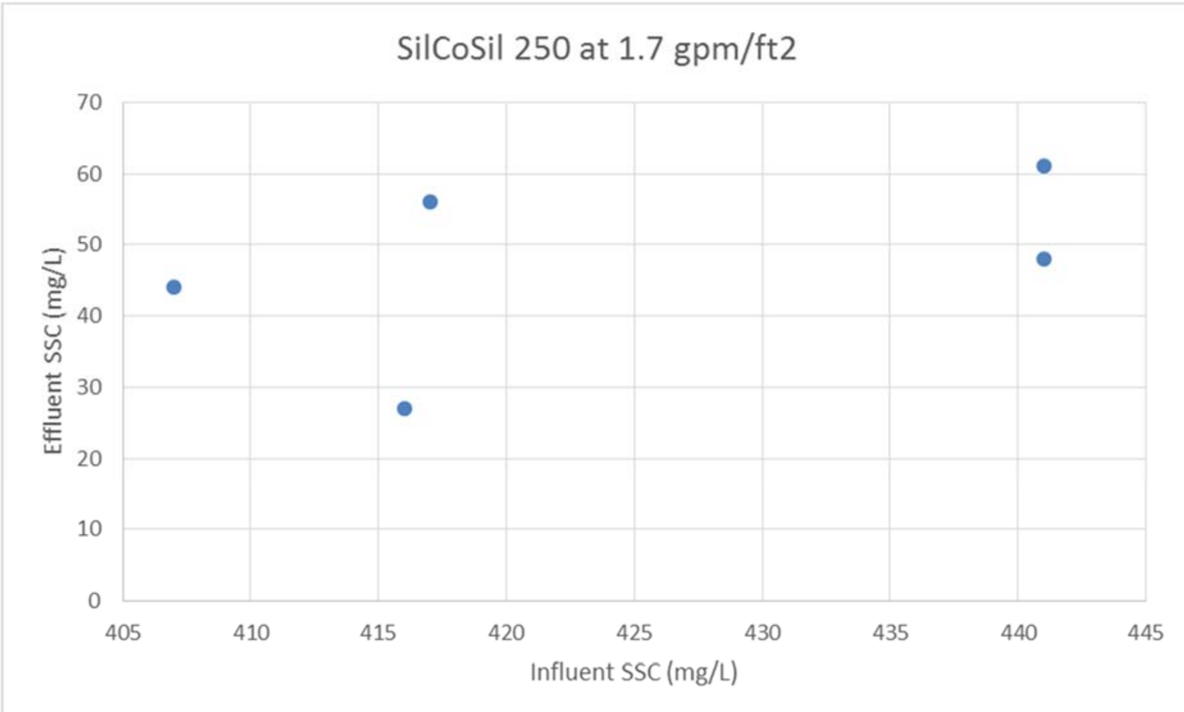


Figure 7: Trap Efficiency vs. Hydraulic Loading Rate (Direct Method)

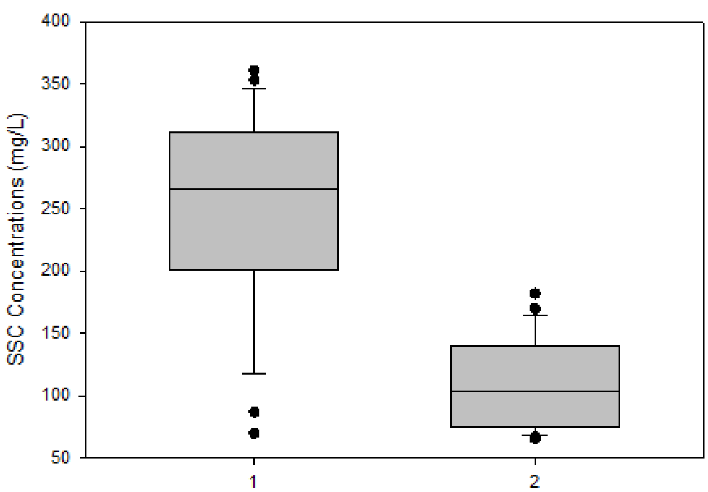
Tennessee Tech also tested the Isolator Row using other test particles and flow rates, as shown below with scatterplots showing the influent and effluent SSC concentrations for each test. The SilCoSil 106 test included a wide range of influent SSC values, all at one treatment flow rate (3.2 gpm/ft^2), while the SilCoSil 250 tests were conducted over wide and narrow SSC concentration ranges for two different treatment flow rates (129 to 288 mg/L at 3.2 gpm/ft^2 and 407 to 441 at 1.7 gpm/ft^2).


SilCoSil 106 at 3.2 gpm/ft2
Effluent SSC (mg/L)
0
20
40
60
80
100
120
140
160
180
200
0
50
100
150
200
250
300
350
400
Influent SSC (mg/L)

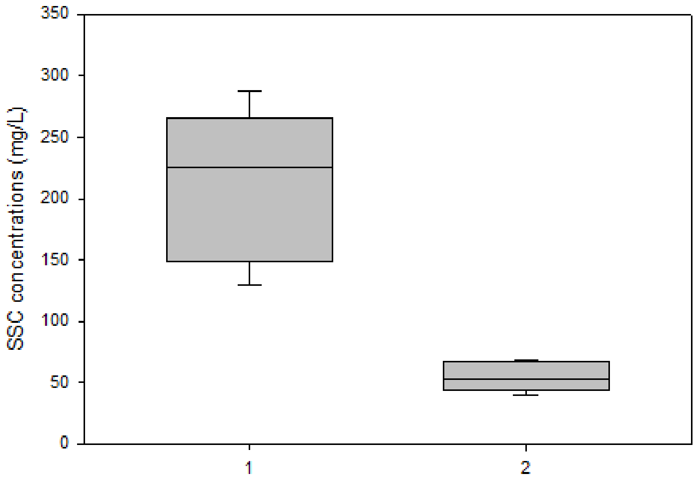

SilCoSil 250 at 3.2 gpm/ft2
Effluent SSC (mg/L)
0
10
20
30
40
50
60
70
80
0
50
100
150
200
250
300
350
Influent SSC (mg/L)



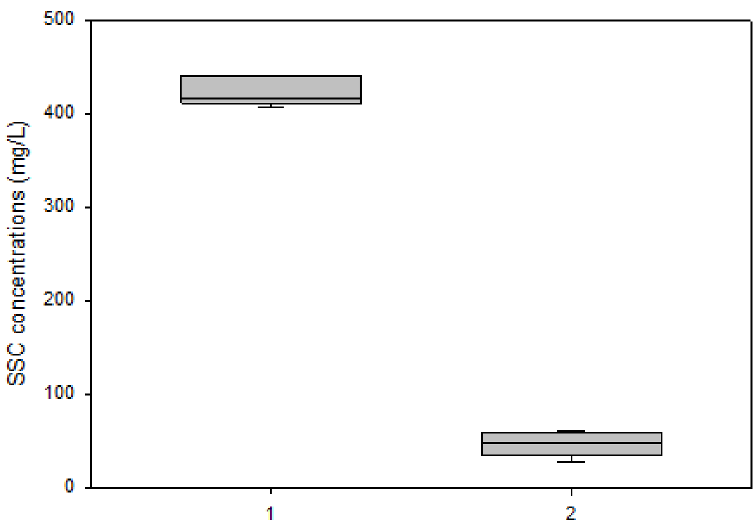
Statistical tests using ANOVA on the regressions indicated that none of these three test series resulted in significant regressions (the overall regression, and the intercept and slope terms were all $p>0.05$). However, paired Student's t tests indicated significant concentration reductions between the influent (box and whisker plot 1) and the effluent (box and whisker plot 2) ($p<<0.05$ for all three test series), as illustrated in the following box and whisker plots:



SilCoSil 106 tests at 3.2 gpm/ft^2 ($p = 7.5 \times 10^{-10}$)



SilCoSil 250 tests at 3.2 gpm/ft^2 ($p = 0.003$)



SilCoSil 250 tests at 1.7 gpm/ft^2 ($p = 2.7 \times 10^{-7}$)

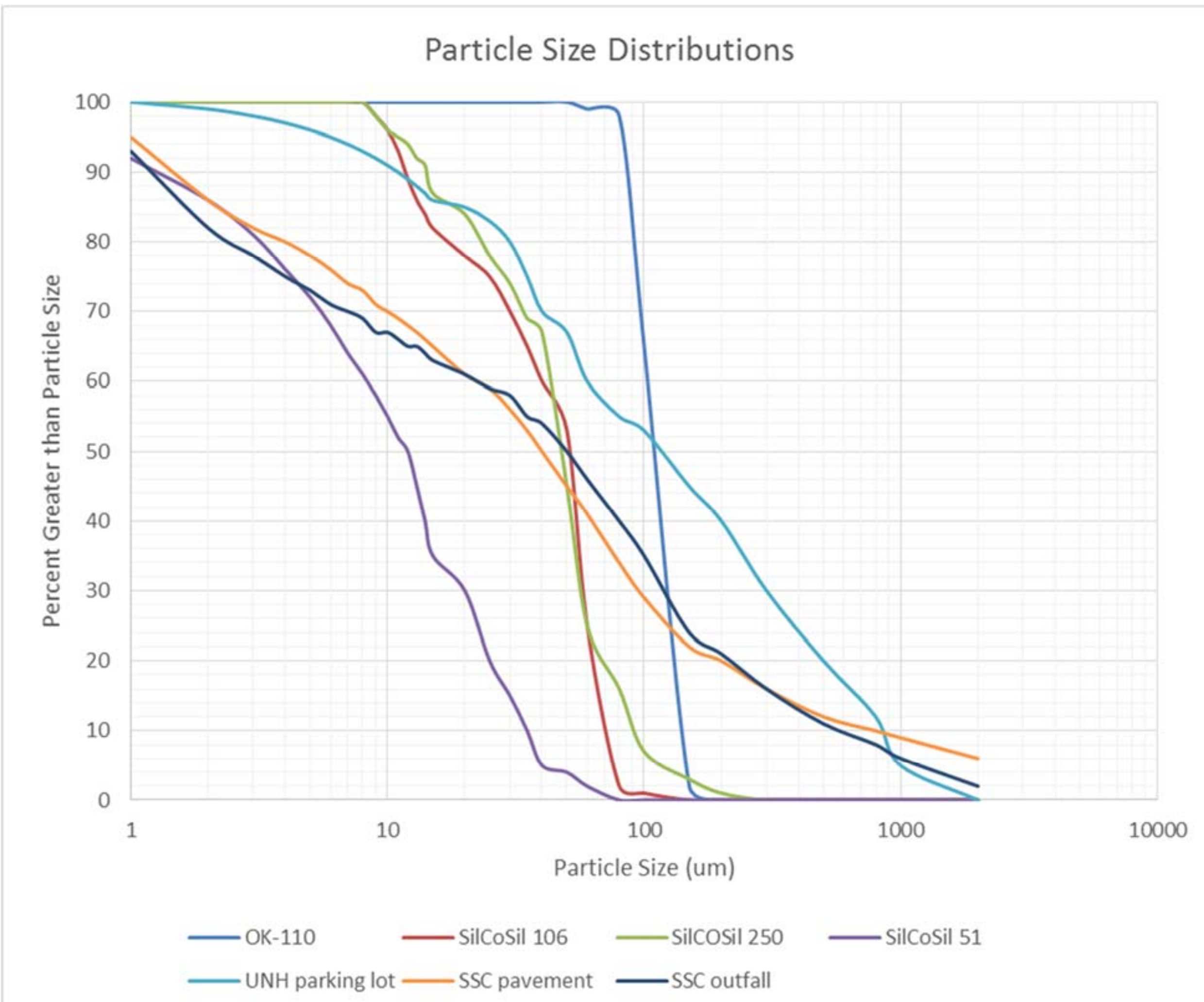
Particle Size Distributions of Test Materials

The particle size distribution (PSD) of the sediment in the stormwater and test solutions can have dramatic effects on the performance of a stormwater control device. As an example, the ADS Isolator Row and StormTech chamber system was tested at Tennessee Tech using several different US Silica ground silica materials: OK-110, SilCoSil 106, and SilCoSil 250. The field tests at the University of New Hampshire used actual runoff from their parking lot test drainage area and also provided some PSD information. The following plot shows the PSDs for these test materials, in addition to SilCoSil 51 (another material sometimes used in lab testing of stormwater controls), along with SSC PSDs of pavement runoff and outfall discharges from many stormwater research projects. These plots show the percentage of the particulates, by mass, which are greater than the particle size indicated. For stormwater controls using sedimentation processes, this directly relates to the fraction of the total sediment in the water that would be trapped in the device. The following list shows the approximate median particle size (µm) (along with the 10th and 80th percentile values) for these test mixtures and field observation PSDs:

Approximate Particle Size Distributions for Different Test Materials and Stormwater (µm) (% larger than size indicated; the critical particle size to be controlled for different SSC targeted reductions)

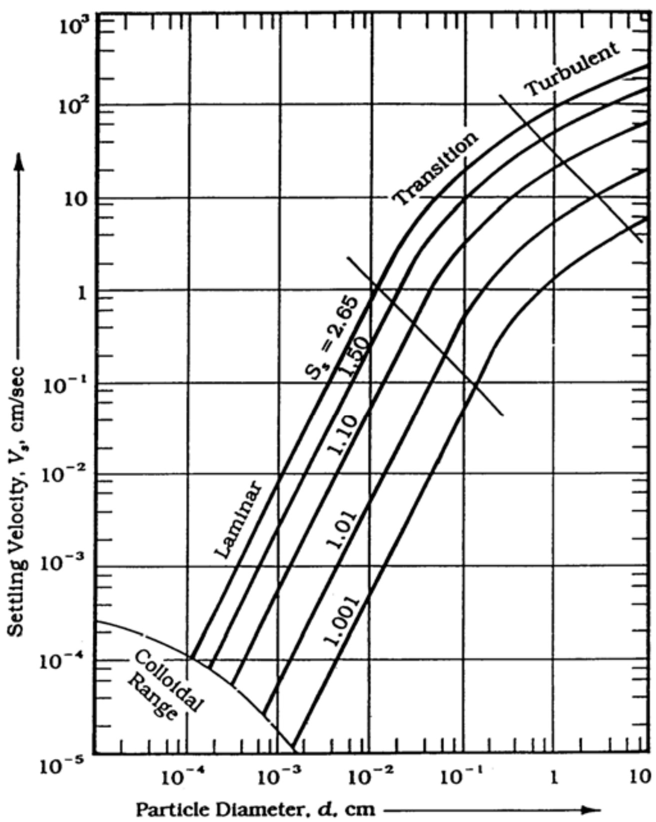
	10th percentile (target for 10% SSC reductions)	50th percentile (median) (target for 50% SSC reductions)	80th percentile (common target for 80% SSC reductions)
OK-110	130	110	90
SilSoSil 106	70	52	15
SilCoSil 250	90	45	22
SilCoSil 51	33	12	3.1
UNH parking lot	830	115	30
SSC pavement	800	40	4.0
SSC outfall	560	51	2.2

The figure and table indicate that these PSDs can result in a wide range expected performance, depending on the test conditions.



Hydraulic Loading Rate (Surface Overflow Rate) and Particulate Control in the Isolator Row

WinSLAMM uses Stokes (laminar flow settling) and Newton's (turbulent flow settling) laws to calculate the settling characteristics of particulates. The following figure illustrates the settling rates for different sized particulates having different specific gravities:

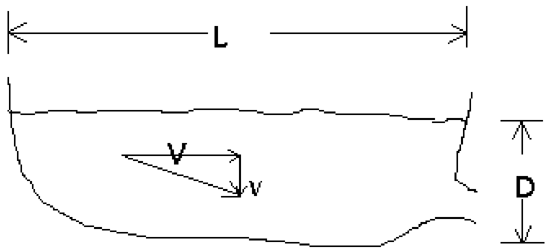


Type 1 (discrete) settling of spheres in water at 10° C (Reynolds 1982)

The ground silica material has a specific gravity of 2.65, although the specific gravities of stormwater solids are usually in the range of about 1.5 to 2.5. As noted in the figure, stormwater particulates from about 1 to 100 um have laminar settling under Stokes law. As the particles increase in size, they approach turbulent flow settling (Newton's law), but most would fall in the transition zone.

In an ideal system incorporating sedimentation, particles that do not settle below the bottom of the outlet will not be trapped, while particles that do settle below/before the outlet will be retained. With the Isolator Row, there is no outlet for the ponded water except through the perforations through the filter fabric and into the rock surrounding the underdrain, plus any hydraulic overflow at the end of the StormTech chambers during high flow periods. The following discussion of the mathematics of particle settling describes the basic concept of the sedimentation with standing water, as incorporated in WinSLAMM, and will be used to show how sediment is trapped in the Isolator Row and StormTech chambers.

The path of any particle is the vector sum of the water velocity (V) passing through the water and the particle settling velocity (v). Therefore, if the water velocity is slow, slowly falling particles can be retained. If the water velocity is fast, then only the heaviest (fastest falling) particles are likely to be retained. The critical ratio of water velocity to particle settling velocity must therefore be equal to the ratio of the sedimentation length (L) to depth to the bottom of the outlet (D):



Critical Velocity and Dimensions

The water velocity is equal to the water volume discharge rate (Q, such as measured by cubic feet per second) divided by the cross-sectional area (a, or depth times width: DW):

$$V = \frac{Q}{a}$$

or

$$V = \frac{Q}{DW}$$

The outflow rate equals the inflow rate under steady state conditions. The critical time period for steady state conditions is the time of travel from the inlet to the outlet. During critical portions of a storm, the inflow rate (Q_{in}) will be greater than the outflow rate (Q_{out}) due to freeboard storage. Therefore, the outflow rate controls the water velocity through the pond. By substituting this definition of water velocity into the critical ratio:

$$\frac{Q_{out}}{WDv} = \frac{L}{D}$$

The water depth to the outlet bottom (D) cancels out, leaving:

$$\frac{Q_{out}}{Wv} = L$$

Or

$$\frac{Q_{out}}{v} = LW$$

However, length (L) times width (W) equals surface area (A). Substituting leaves:

$$\frac{Q_{out}}{v} = A$$

and the definition of upflow velocity:

$$v = \frac{Q_{out}}{A}$$

where Q_{out} = outflow flow rate (cubic feet per second),
A = surface area (square feet: pond length times pond width), and
v = upflow velocity, or critical particle settling velocity (feet per second).

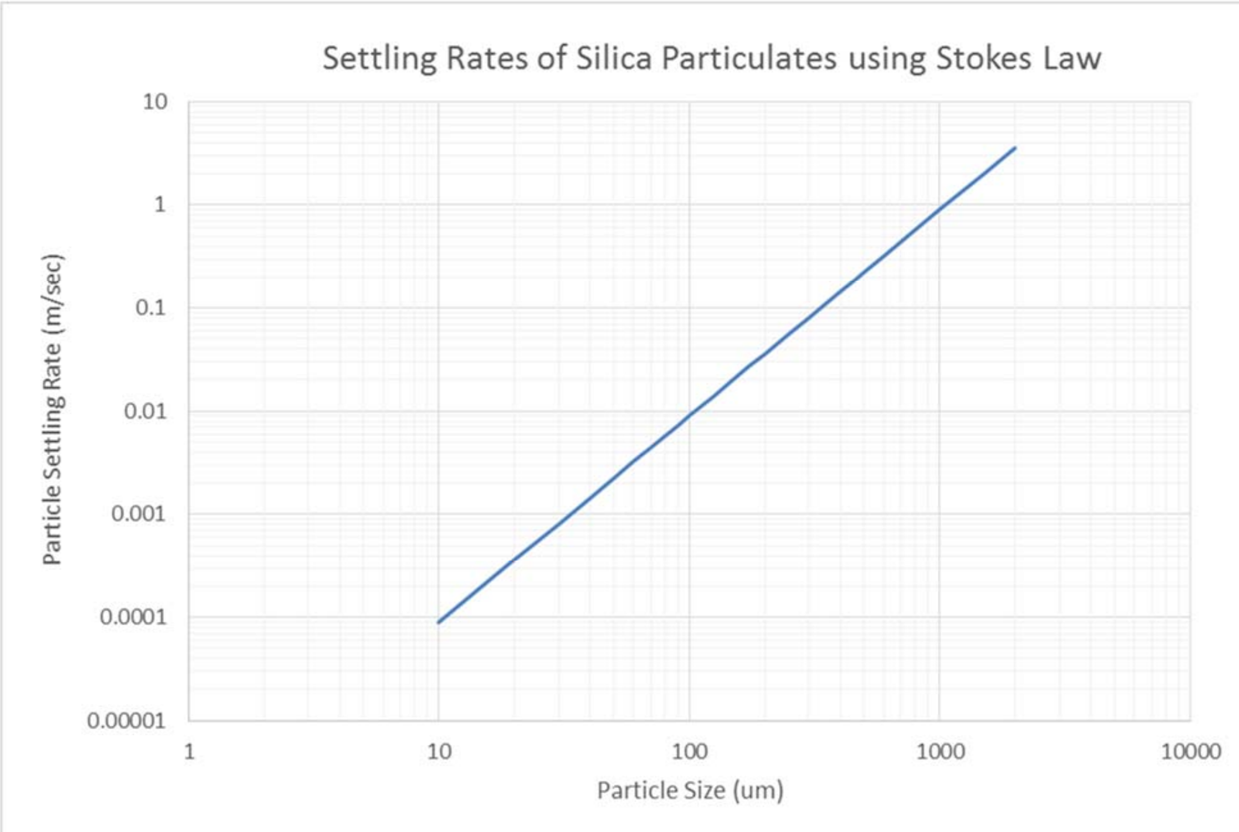
Therefore, for an ideal sedimentation system, particles having settling velocities less than this upflow velocity (usually all larger particles) will be removed. Only increasing the surface area, or decreasing the outflow rate, will increase settling efficiency.

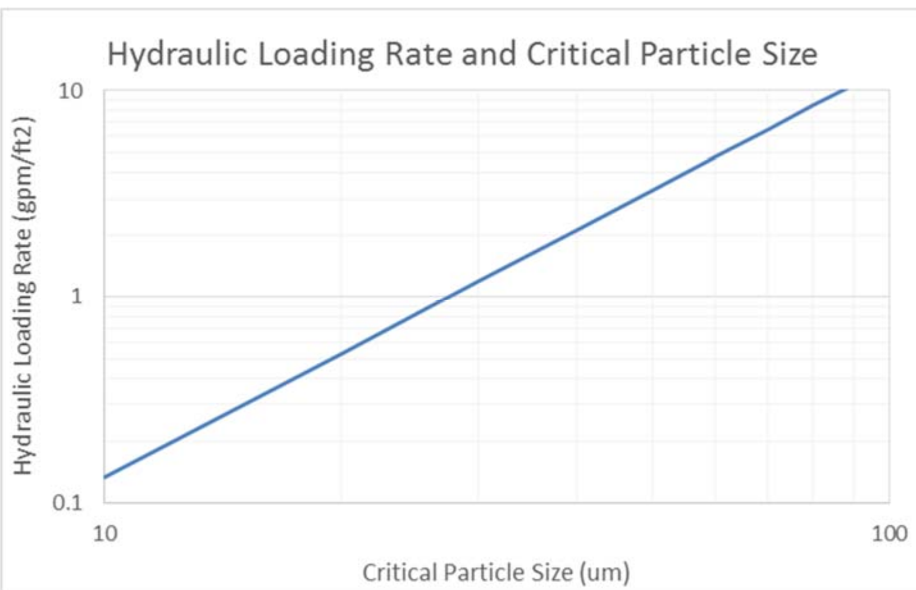
Stokes law was used to calculate the settling characteristics of the silica particulates in the range of hydraulic loadings (equivalent to the settling rates of the critical particle sizes), using the following factors along with the range of hydraulic loading conditions for the Isolator Row:

- dynamic viscosity at 20^{o}C = 0.001 kg/m-sec
- acceleration of gravity = 9.81 m/sec^{2}
- density of water at 20^{o}C = 1,000 kg/m^{3}
- density of silica = 2,650 kg/m^{3}

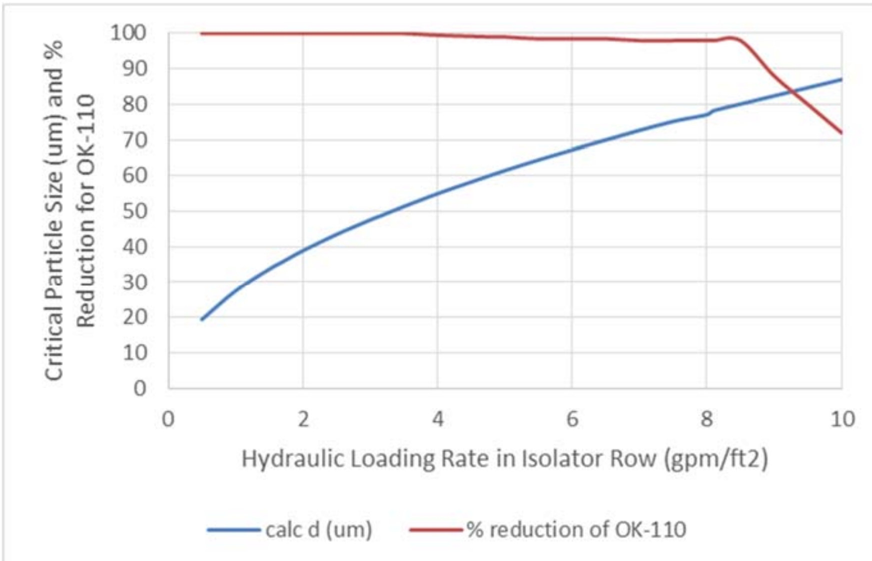
The following plot illustrates the settling rates for the different particle sizes for these conditions. This relationship is a straight line in log-log space, as also shown on the above figure of particle settling. This example is only based on Stokes law, but as noted before, turbulent settling occurs for the larger particles. WinSLAMM uses a combination of both laminar and turbulent settling equations, as appropriate.

As noted above, particles having settling rates larger than the hydraulic loading rate, or surface overflow rate, will be trapped in the settling device. The following plot shows the relationship between the critical particle size that would be trapped for different hydraulic loading rates in the range of the values for the Isolator Row. As an example, a hydraulic loading rate of 4.84 gpm/ft^{2}, the maximum loading rate tested for the four chambers by Tennessee Tech, corresponds to a critical particle size of about 60 µm. The design hydraulic loading rate of 8.1 gpm/ft^{2} corresponds to a critical particle size of about 80 µm.





The particle settling rates and the hydraulic loading rates were then used with the PSD for OK-110 to predict the performance of the Isolator Row as tested by Tennessee Tech. The following plot shows that the Isolator Row basically provided 100% control up to about 8 gpm/ft^2 for this test solution, and then started to decrease with increasing loading rates. This response is very similar to the prior plot from the laboratory tests, indicating the satisfactory use of the settling methods included in WinSLAMM. The falloff in performance in the figure below is steeper than the lab tests indicated, which is probably due to the use of laminar settling in these simple calculations, and because the lab tests also include further reductions due to the settling of particulates in the rock surrounding the Isolator Row, which are not included in this calculation but are in the WinSLAMM implementation of the Isolator Row.



The other tests conducted with single flows confirmed the use of this modeling approach:

- During the SilCoSil 106 tests, the 3.2 gpm/ft^2 hydraulic loading corresponds to a critical particle size of about 49 µm. This particle size is the 54th percentile of the SilCoSil 106 PSD. The overall reported reduction during these tests were from about 250 mg/L to 112 mg/L, or about 55%, a very close match.

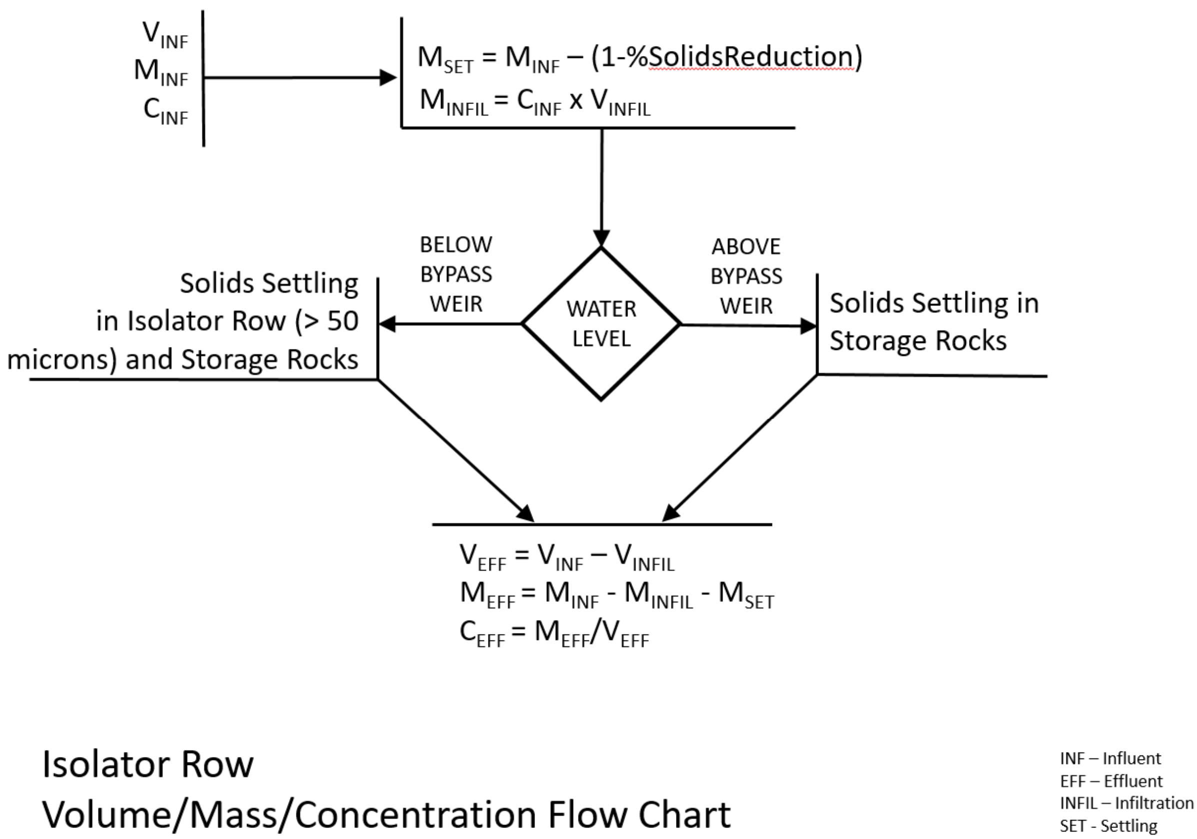
- During the SilCoSil 250 tests, the 3.2 gpm/ft^2 hydraulic loading also corresponds to a critical particle size of about 49 µm. This particle size is the 60th percentile of the SilCoSil 250 PSD. The overall reported reduction during these tests were from about 211 mg/L to 55 mg/L, or about 74%.

- During the SilCoSil 250 tests, the 1.7 gpm/ft^2 hydraulic loading corresponds to a critical particle size of about 36 µm. This particle size is about the 65th percentile of the SilCoSil 250 PSD. The overall reported reduction during these tests were from about 424 mg/L to 47 mg/L, or about 89%.

The calculated removals range from very close to somewhat less than what was observed. The reduced values calculated likely were due to the laminar flow assumptions and not considering the filter fabric or rock storage layer sedimentation, as briefly described below. These other removal processes will be incorporated in WinSLAMM.

Use of Filter Fabric in Isolator Row Installations

The GEOTEX 310 has flow rate of 4 gpm/ft^2, and an apparent opening of about 212 µm, according to the manufacture's spec sheet. According to the hydraulic loading plot, a hydraulic loading rate of 4 gpm/ft^2 corresponds to a critical particle size of about 55 µm. Particle trapping in filter fabrics (or other sized material) is usually about 1/3 of the opening, corresponding to about 70 µm. Therefore, we expect these finer particles that are not retained by the filter fabric layer will be transported into the rock storage layer where they will be subjected to further settling and trapping. As sediment builds up on the surface, the apparent pore openings and the flow rates decrease and finer and finer particles are trapped. Eventually, the material clogs when the accumulation of material reduces the flows below critical values. Therefore, it is expected that any Isolator Row or StormTech chamber wrapped in this material would be able to trap all particles larger than about 50 µm. As shown above, this particle size is still smaller than almost all of the material in the OK-110 test mixture, indicating 100% control for those conditions. As shown on the PSD plots, 50 µm can provide a wide range of SSC control depending on the actual PSD in the stormwater. This treatment process is incorporated in WinSLAMM, and is illustrated in the flow chart below.



Particle Trapping in Rock Storage Layer beneath Isolator Row and StormTech Chambers

It is expected that additional trapping of particulates would occur in the rock storage layer beneath the Isolator Row and StormTech chambers. The model routes the finer particles (<50 µm) that are not captured in the chambers (including filtered by the filter fabric) into the rock storage. As this water flows through the rocks, further sediment trapping will occur before the water exits through the underdrains. The model calculates the flow rates, minus any infiltration occurring through the bottom of the rock layer, and the pore volume, and further calculates the removal of finer particles in this material. WinSLAMM also tracks the accumulation of these trapped materials and reduces the infiltration rates as appropriate and reduces the pore volume as they become filled with fines. The remaining water then enters the underdrains where it is blended with StormTech chamber excess flows and discharged. The flow through the rock storage layer and the underdrains is assumed to be controlled by the outlet weir.

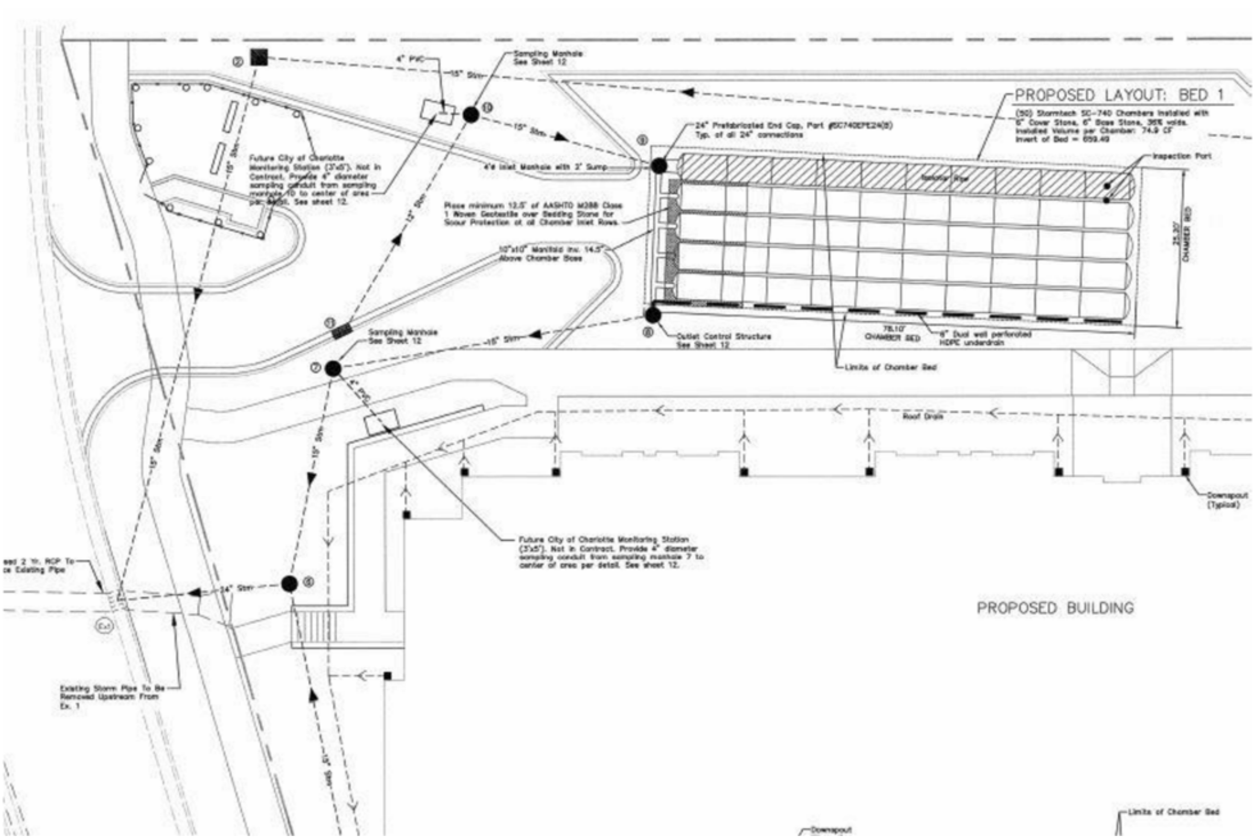
Full-Scale Performance Monitoring of the Isolator Row and StormTech Chambers

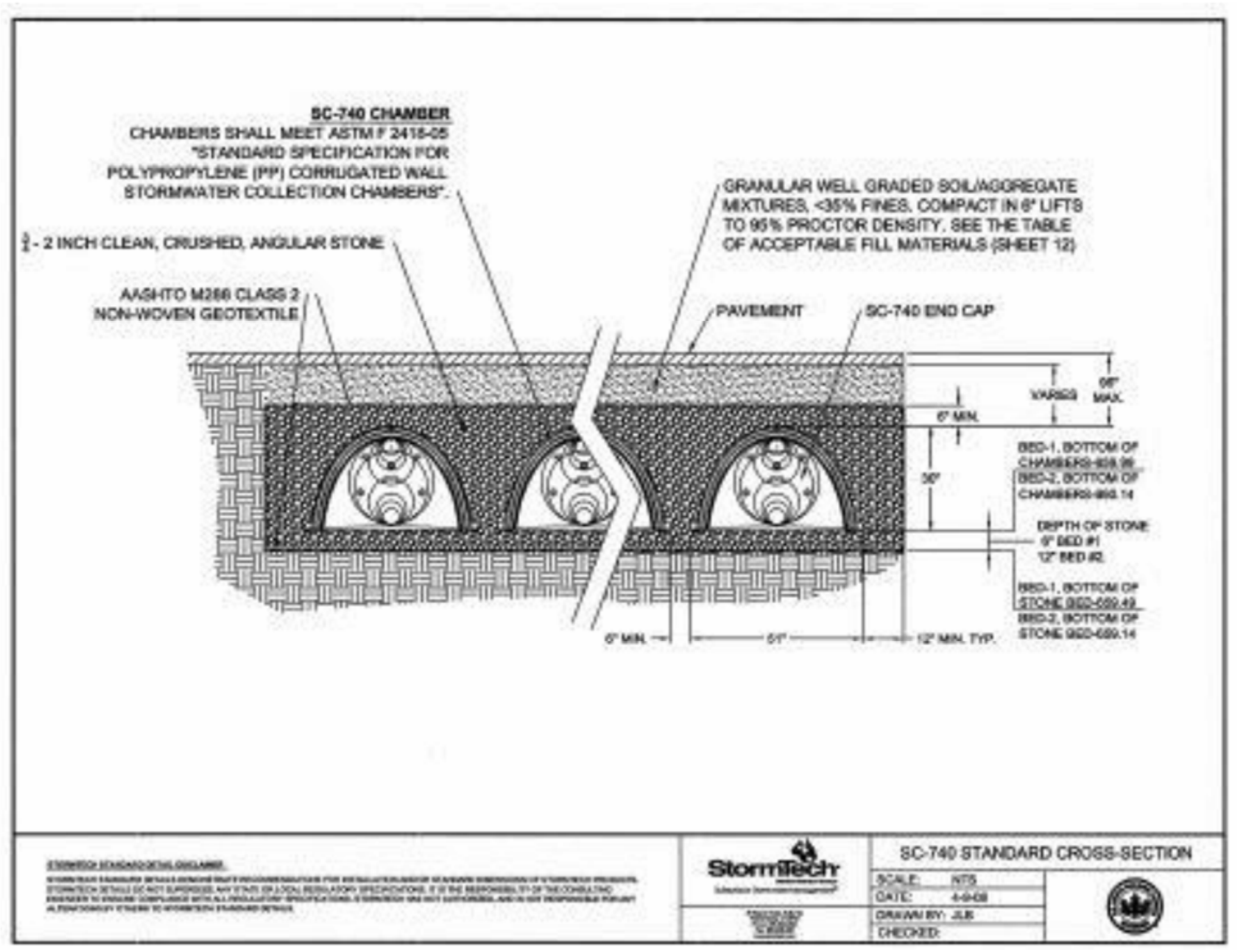
Several field test results are available describing the performance of the Isolator Row and StormTech chambers. Most of these studies do not have all of the data necessary to conduct a complete evaluation of the information (as-built descriptions, rainfall and runoff rates, particle size distributions, in addition to the event by event influent and effluent concentrations of the tested constituents). The following is a summary of four studies with reports made available by ADS.

Cherry Gardens Apartments (Charlotte, NC)

The project design called for the installation of a Storm Tech Chamber system to treat 0.41 acres of the site. The watershed area draining to the system consisted of approximately 85% impervious surface comprised of a parking lot and adjoining sidewalk within a residential land use. The system was designed to treat the 1-inch water quality volume and meet the stormwater detention requirements for Charlotte. The system was also designed with a bypass pipe to allow higher flows to bypass the isolator row and flow directly into adjoining chambers in the system. The overall system design called for five rows of StormTech chambers, one of which was the isolator row.

The total area of the system (about 25 by 75 ft) at the 0.41 acre site (85% impervious) was about 10% of the total area and about 12% of the impervious area. These are relatively large for stormwater management practices, but since the Isolator Row and StormTech chambers were underground, some surface use is possible. The following are figures from the reports illustrating the layout of the devices.





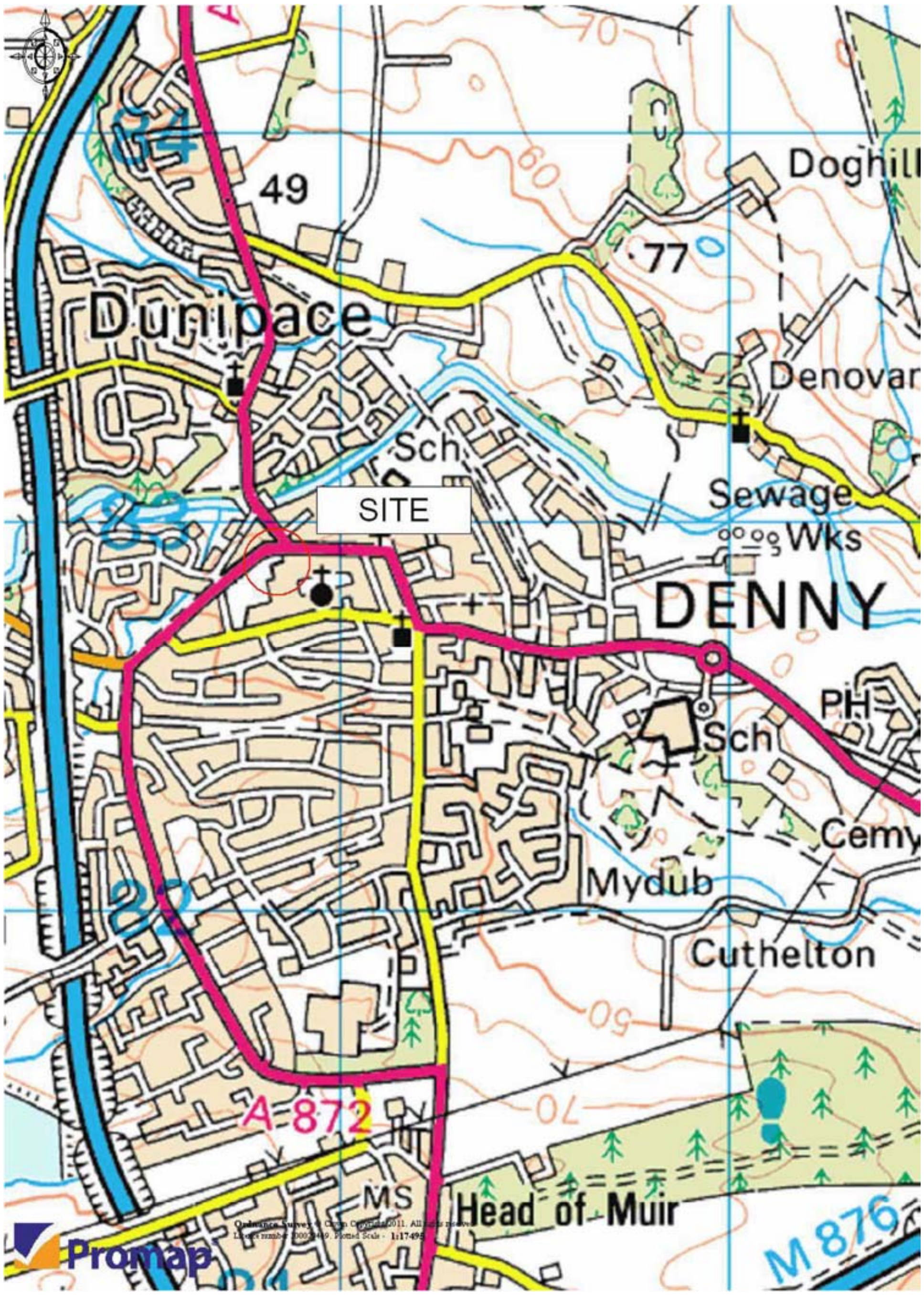
There were no event based performance data reported, but median influent and effluent concentrations from 13 to 14 paired sets of samples are available, as shown below.

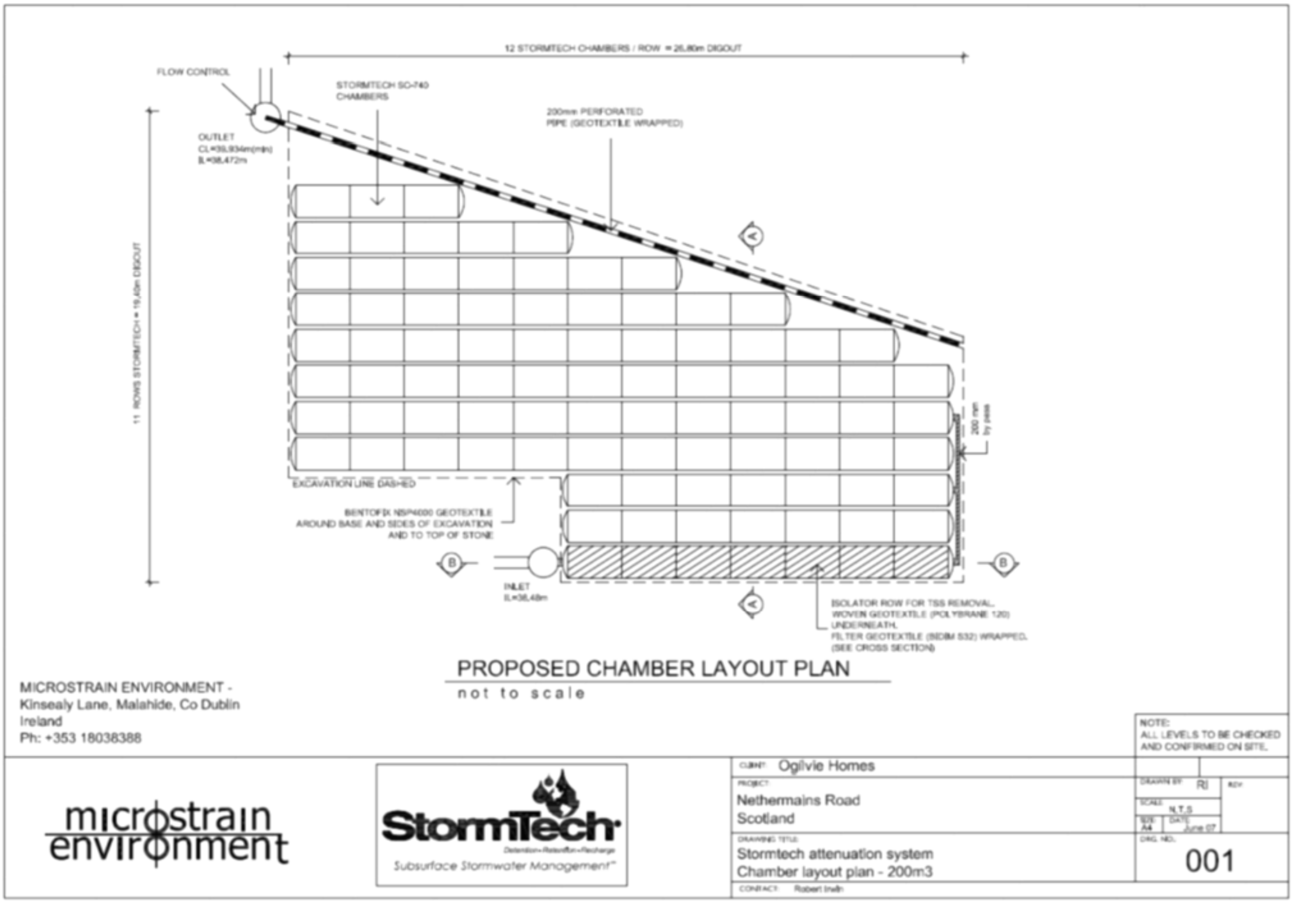
Influent and Effluent Median Concentrations and Reductions for Cherry Gardens Apartments Site

Constituent	Influent (median concentration)	Effluent (median concentration)	Percent Reduction	Significance of reduction (p value)
SSC (mg/L)	98	5.9	94	0.0017
TSS (mg/L)	54	5.6	90	0.0001
Turbidity (NTU)	18	6.9	62	0.0001
Ammonia N (mg/L)	0.32	0.09	72	0.018
Nitrite + Nitrate (mg/L)	0.28	0.35	not significant.	0.97
Total Kjeldahl N (mg/L)	1.1	0.45	60	0.0001
Total Phosphorus (mg/l)	0.19	0.06	68	0.0001
Copper (µg/L)	10	9.5	not significant.	0.60
Zinc (µg/L)	55	13	76	0.0001

Denny, Falkirk, Scotland Field Test Site

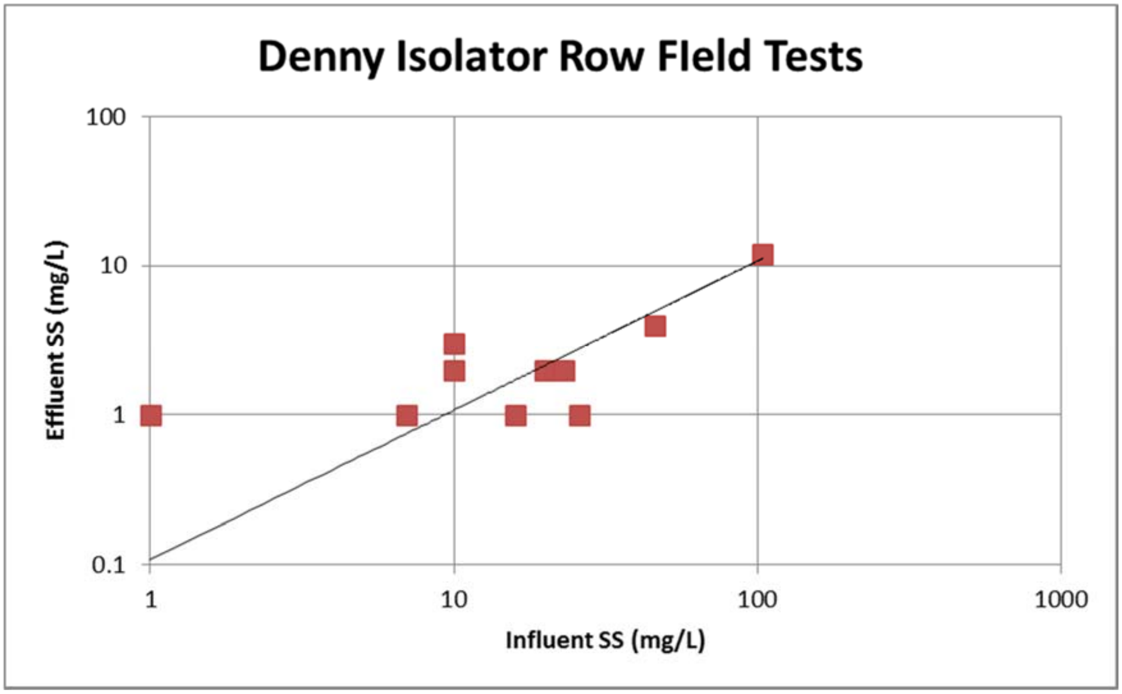
This site consists of 30 flats at Nethermains Road, Denny. All surface water from roofs, access roads and car parking is directed via a positive drainage system to a Stormtech attenuation system equipped with the proprietary Isolator Row to apply treatment. Treated water exits the system via a Hydrobrake and is discharged to Scottish Water's combined sewerage network. The area of treatment system is about 8% of the drainage area. Maps and site drawings are below.

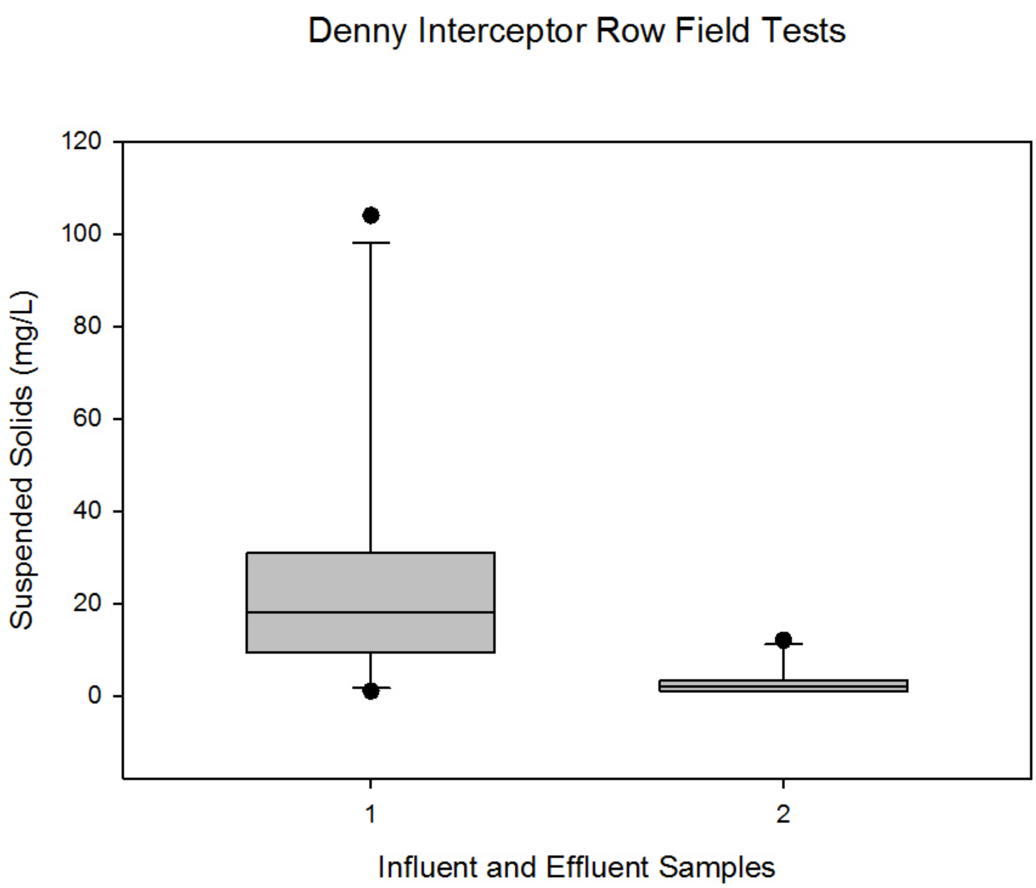




12 STORMTECH CHAMBERS / ROW = 26.80m DIGOUT
FLOW CONTROL
STORMTECH SC-740
CHAMBERS
200mm PERFORATED
PIPE (GEOTEXTILE WRAPPED)
OUTLET
CL=39.934m(min)
IL=38.472m
11 ROWS STORMTECH = 15.40m DIGOUT
200 mm
by pass
EXCAVATION LINE DASHED
BENTOFIX NSP4000 GEOTEXTILE
AROUND BASE AND SIDES OF EXCAVATION
AND TO TOP OF STONE
INLET
IL=38.48m
ISOLATOR ROW FOR TSS REMOVAL.
WOVEN GEOTEXTILE (POLYBRANE 120)
UNDERNEATH.
FILTER GEOTEXTILE (SEDM 532) WRAPPED.
(SEE CROSS SECTION)
PROPOSED CHAMBER LAYOUT PLAN
not to scale
MICROSTRAIN ENVIRONMENT -
Kinsealy Lane, Malahide, Co Dublin
Ireland
Ph: +353 18038388
NOTE:
ALL LEVELS TO BE CHECKED
AND CONFIRMED ON SITE.
microstrain
environment
StormTech
Subsurface Stormwater Management
CLIENT Ogilvie Homes
PROJECT
Nethermains Road
Scotland
DRAWN BY RI
REV
SCALE N.T.S
SIZE A4
DATE June 07
DRAWING TITLE
Stormtech attenuation system
Chamber layout plan - 200m3
DRG. NO.
001
CONTACT Robert Irwin

About 10 events were sampled for TSS and for oil and grease. TSS performance plots are shown below.

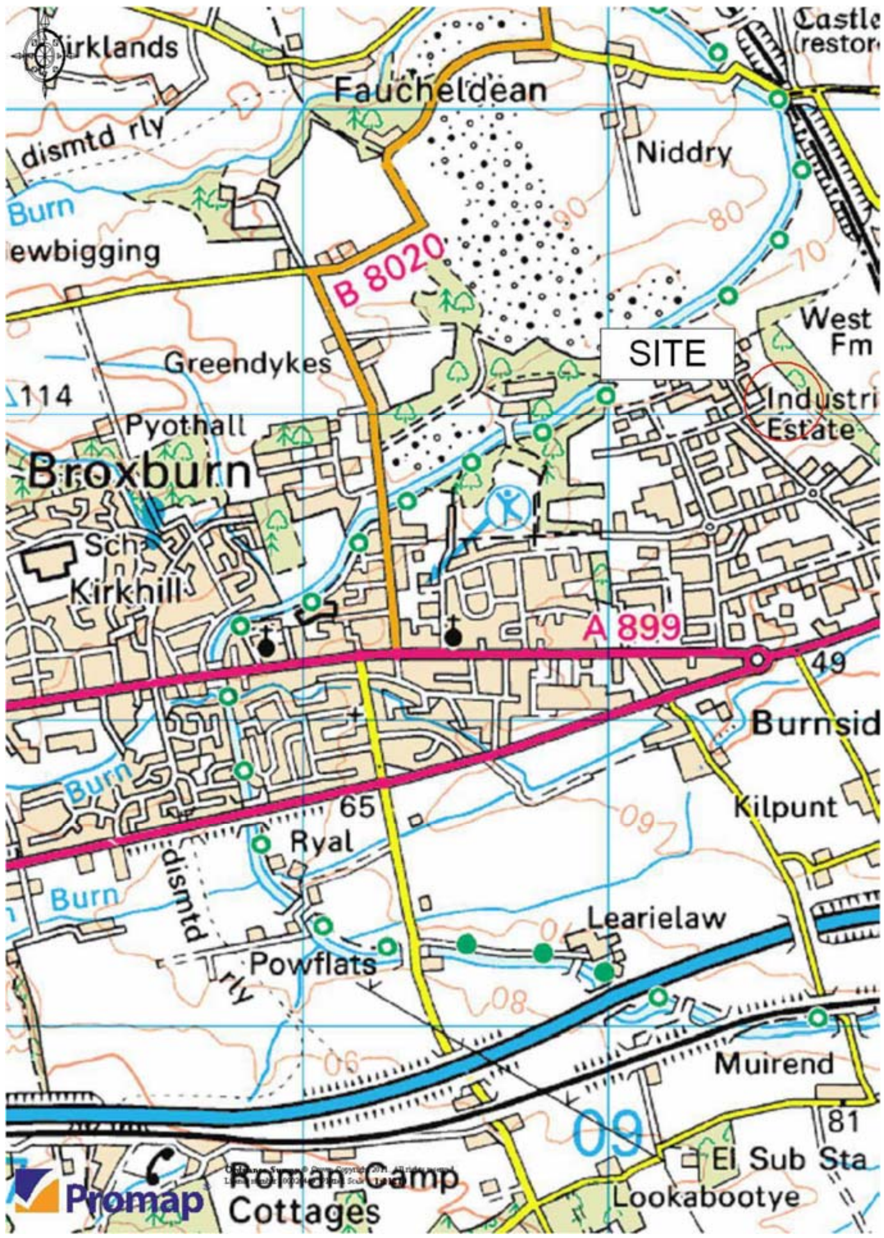


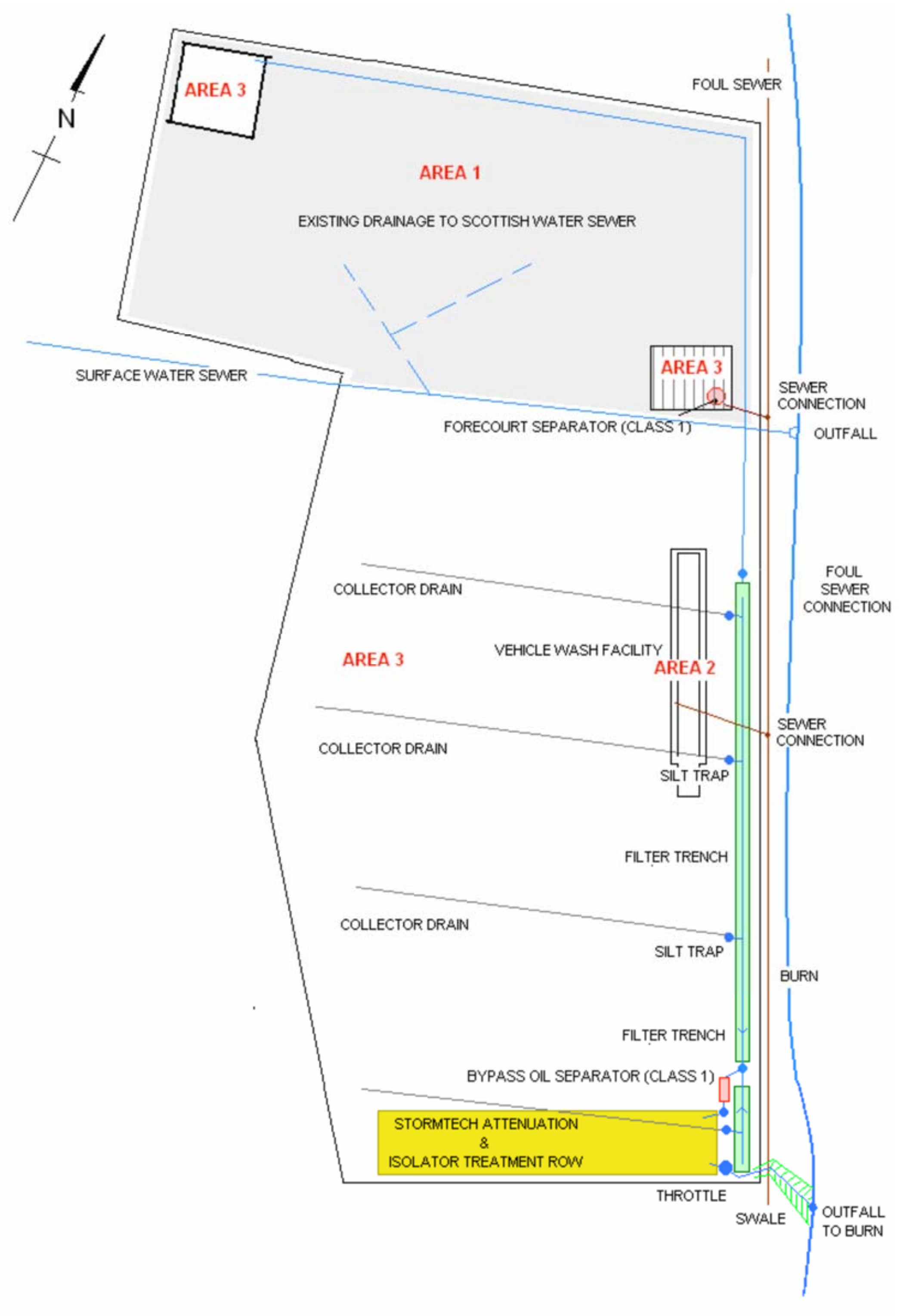


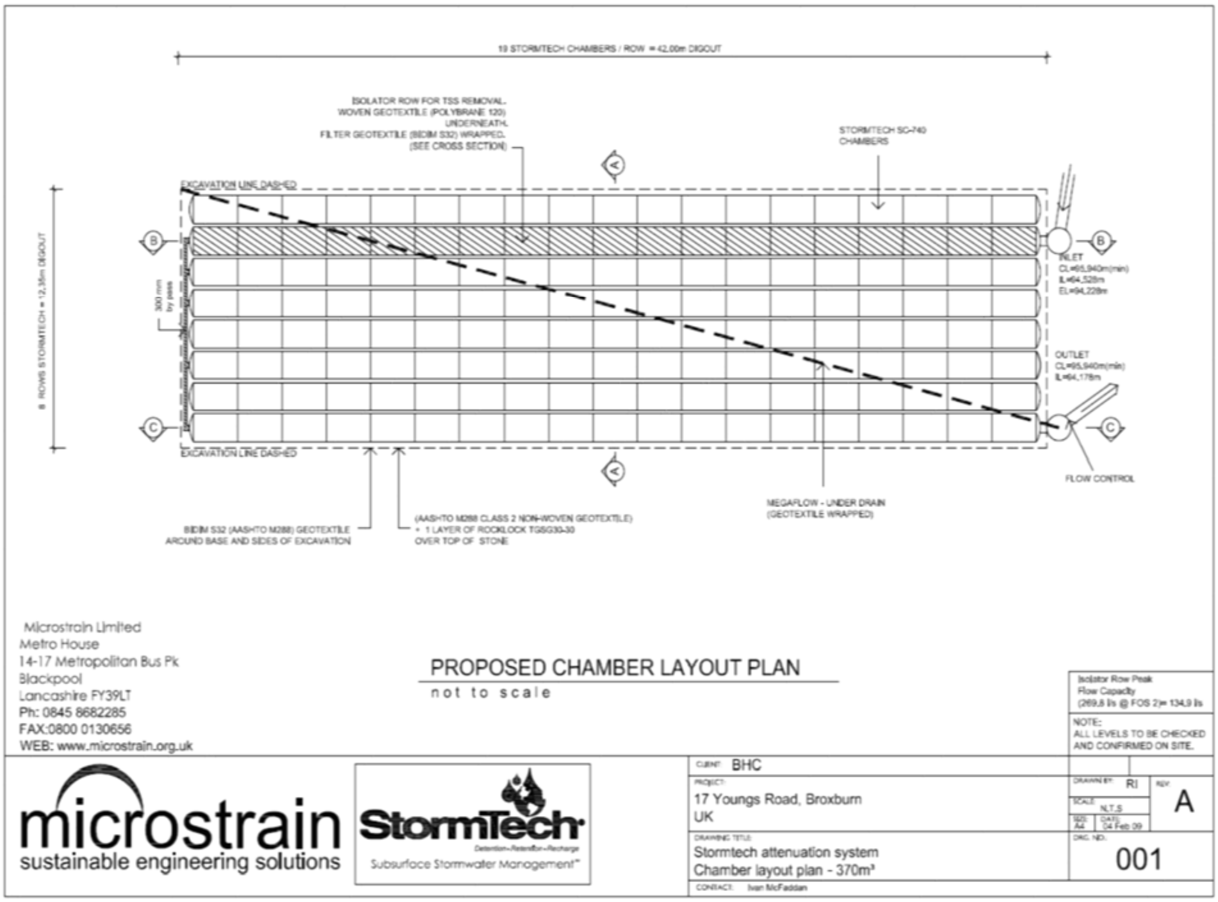
There were obvious reductions in the TSS concentrations with treatment, with the Mann-Whitney Rank Sum statistical tests showing a highly significance difference in the influent and effluent paired concentrations ($p = 0.003$). The average influent concentration was about 26 mg/L and the average effluent TSS concentration was about 3 mg/L. The regression of the scatterplot was significant with a significant slope, and indicated a TSS reduction of about 89%. The adjusted R^2 value was 0.83. These all indicate excellent performance, especially considering the very low influent TSS concentration. This is likely due to the large footprint of the stormwater control at this site due to CSO control objectives.

Broxburn, Scotland Field Test Site

This site is a commercial development with large yard areas within an existing industrial estate, East Mains Industrial Estate, in Broxburn, West Lothian. The site consists of a commercial office and yard of a refrigerated haulage firm. The total impervious area is approximately 1 hectare. Surface water arising from roofs, access roads, car parking and yard areas is directed via filter trenches to a StormTech attenuation system equipped with the Isolator Row. Treated water exits the system via a Stormbrake and discharges into a short section of swale before entering the watercourse adjacent to the site. The footprint of the system is estimated to be about 5% of the drainage area. The following are maps and site drawings.

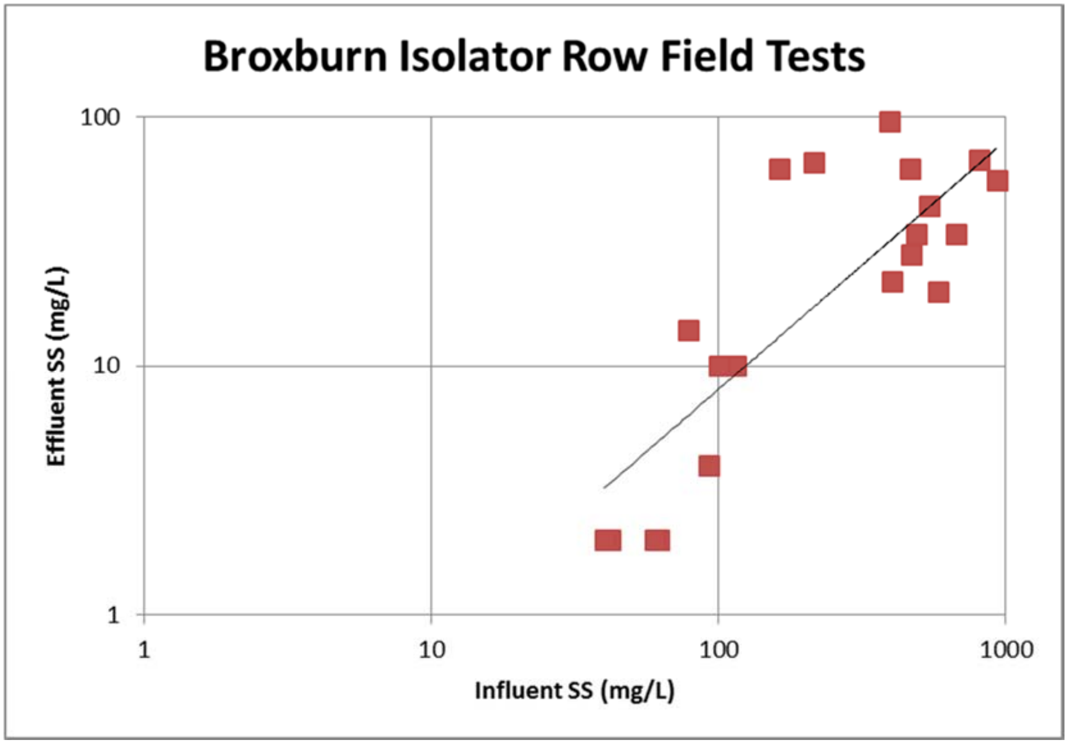


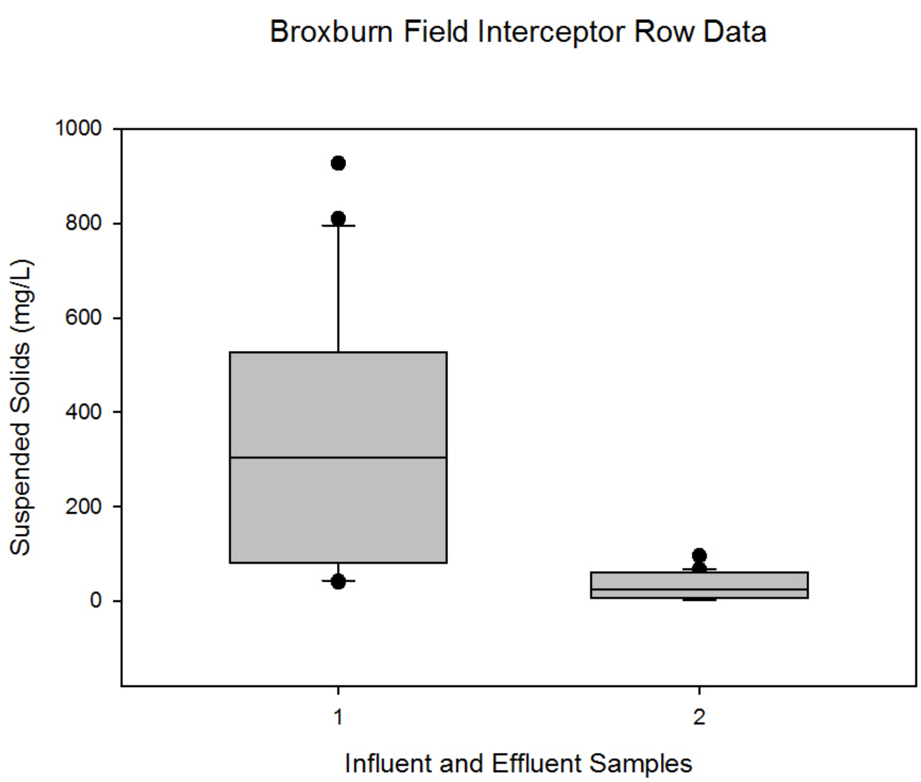

N
AREA 3
AREA 1
EXISTING DRAINAGE TO SCOTTISH WATER SEWER
FOUL SEWER
SURFACE WATER SEWER
AREA 3
SEWER CONNECTION
FORECOURT SEPARATOR (CLASS 1)
OUTFALL
COLLECTOR DRAIN
FOUL SEWER CONNECTION
VEHICLE WASH FACILITY
AREA 3
AREA 2
SEWER CONNECTION
COLLECTOR DRAIN
SILT TRAP
FILTER TRENCH
COLLECTOR DRAIN
SILT TRAP
BURN
FILTER TRENCH
BYPASS OIL SEPARATOR (CLASS 1)
STORMTECH ATTENUATION
&
ISOLATOR TREATMENT ROW
THROTTLE
SWALE
OUTFALL TO BURN



10 STORMTECH CHAMBERS / ROW = 42,00m DIGOUT
ISOLATOR ROW FOR TSS REMOVAL.
WOVEN GEOTEXTILE (POLYBRANE 120)
UNDERNEATH.
FILTER GEOTEXTILE (BIDIM S32) WRAPPED.
(SEE CROSS SECTION)
STORMTECH SC-740
CHAMBERS
EXCAVATION LINE DASHED
8 ROWS STORMTECH = 12,35m DIGOUT
300 mm
by pass
INLET
CL=95,940m(min)
IL=94,528m
EL=94,228m
OUTLET
CL=95,940m(min)
IL=94,178m
EXCAVATION LINE DASHED
FLOW CONTROL
MEGAFLOW - UNDER DRAIN
(GEOTEXTILE WRAPPED)
BIDIM S32 (AASHTO M288) GEOTEXTILE
AROUND BASE AND SIDES OF EXCAVATION
(AASHTO M288 CLASS 2 NON-WOVEN GEOTEXTILE)
+ 1 LAYER OF ROCKLOCK TGSG30-30
OVER TOP OF STONE
Microstrain Limited
Metro House
14-17 Metropolitan Bus Pk
Blackpool
Lancashire FY39LT
Ph: 0845 8682285
FAX:0800 0130656
WEB: www.microstrain.org.uk
PROPOSED CHAMBER LAYOUT PLAN
not to scale
Isolator Row Peak
Flow Capacity
(269,8 l/s @ FOS 2)= 134,9 l/s
NOTE:
ALL LEVELS TO BE CHECKED
AND CONFIRMED ON SITE.
microstrain
sustainable engineering solutions
StormTech
Detention•Retention•Recharge
Subsurface Stormwater Management™
CLIENT: BHC
PROJECT:
17 Youngs Road, Broxburn
UK
DRAWING TITLE:
Stormtech attenuation system
Chamber layout plan - 370m³
CONTACT: Ivan McFaddan
DRAWN BY: RI
REV: A
SCALE: N.T.S
SIZE: A4
DATE: 04 Feb 09
DWG. NO.: 001

The following graphs summarize the performance data.





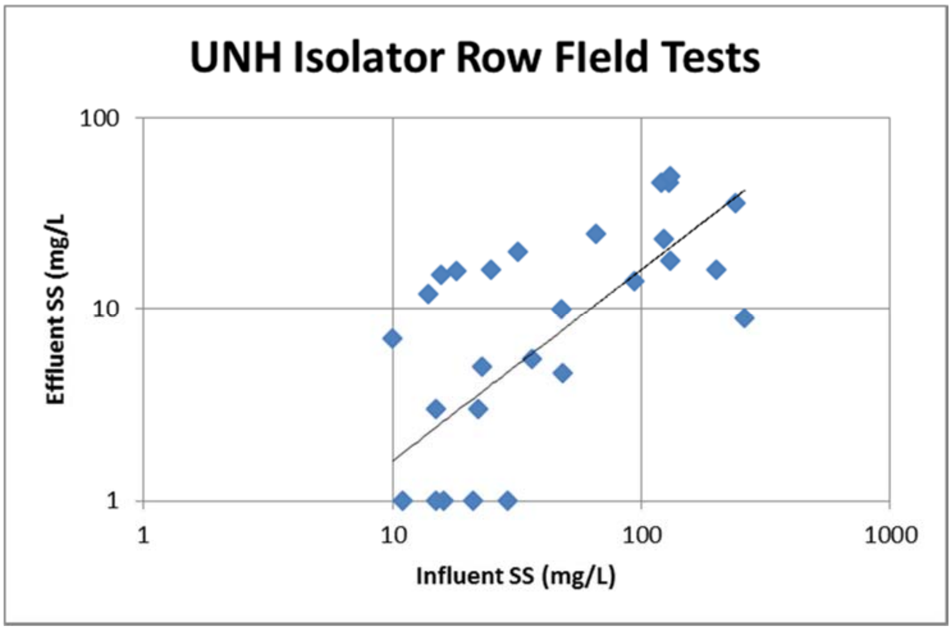
There were obvious reductions in the TSS concentrations with treatment at this site also, with the Mann-Whitney Rank Sum statistical tests showing a highly significance difference in the influent and effluent paired concentrations (p = <0.001). The average influent concentration was about 335 mg/L and the average effluent TSS concentration was about 32 mg/L, much larger than for the apartment catchment. The regression of the scatterplot was significant with a significant slope, and indicated a TSS reduction of about 92%. The adjusted R^2 value was 0.63. These all indicate excellent performance, although some of the effluent concentrations were as high as about 100 mg/L. These were no flow data so it was not possible to examine performance as a function of hydraulic loading rate, nor were there any particle size data available.

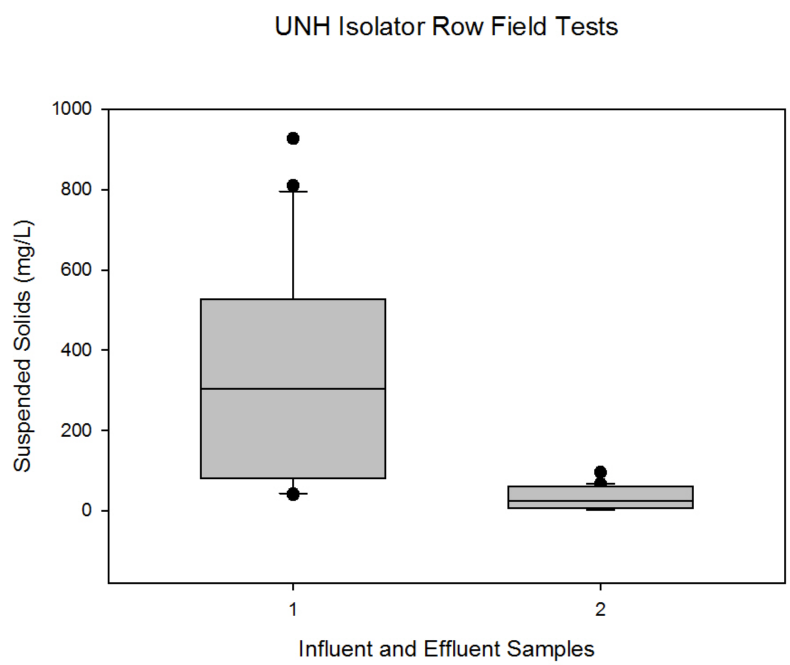
University of New Hampshire Isolator Row Field Performance Data

Detailed test data are available from these monitoring activities which were conducted from December 2006 through March 2008. Monitoring included 17 events in this period, but the effluent monitoring did not include sampling of any bypassed flows. This system footprint was a relatively small 0.4% of the paved drainage area and excessive flows are therefore expected. The tested system configuration was for a single Isolator Row with no additional StormTech chambers.

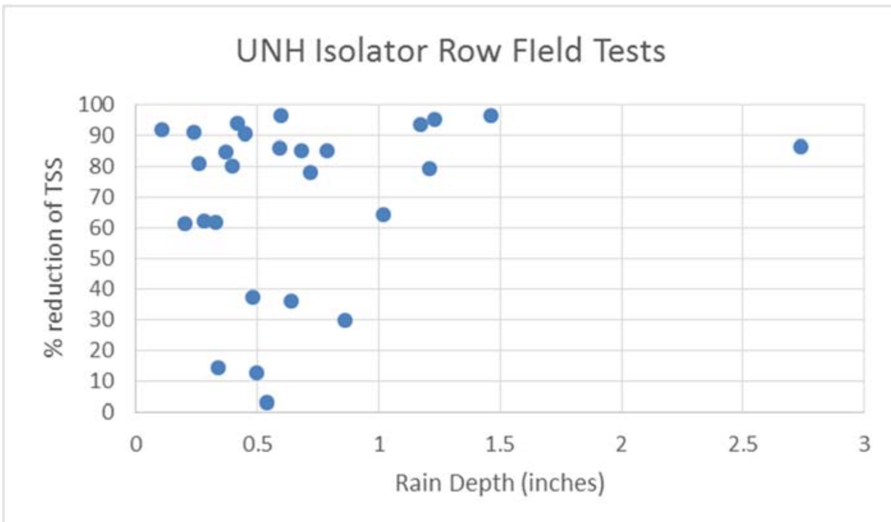
A five chambered Isolator Row system constructed in one pipe row was tested in an offline configuration. A 6 foot diameter manhole with a 4 foot sump was installed upstream of the Isolator Row. The manhole was connected to the Isolator Row with a short length of 24 inch diameter HDPE pipe. Within the manhole a high-flow bypass was constructed using a broad-crested weir. A 12" bypass pipe routes bypass flows around the Isolator Row® to discharge downstream. The bypass and treated effluent are monitored separately. The crest of the overflow weir was set 0.2 feet below the top of the Isolator Row chamber. This allows stormwater in excess of the Isolator Row's storage capacity to bypass in an offline configuration without routing through the system and avoids any potential for pressurized flow through the underlying geotextile. Each chamber of the Isolator Row is 51" in width, 30" in height, and 85.4" in length. Five chambers are connected. The system has a design peak flow rate of 1 cfs (cubic feet per second). The system is lined with HDPE liner and effluent is collected by a 6" perforated underdrain that is continuously monitored. Non-design flows (flow rates > 1 cfs) bypassed the treatment system and were only monitored for occurrence. The following figures show system installation. The system was installed in late September 2006. System monitoring began in early 2007 to allow for system flushing and to prevent influences that may be construction associated.

The Isolator Row system was designed for a 1 CFS treatment flow rate, or the equivalent of runoff from about a 0.75 in/hr rainfall on a 1 acre impervious surface. This is a five chamber system of the StormTech SC-740 chambers (51" x 30" x 85.4"). Storage per chamber is 45.9 ft^3 or a total storage of 229.5 ft^3. The bottom of the chambers were double-lined with ADS 9750 woven geotextile. The tops and sides of the chambers were single lined with ADS 6600 woven geotextile. The bottom area of the chamber is about 150 ft^2, and with a 1 CFS design flow, the hydraulic loading rate (surface overflow rate) is 0.0066 ft/sec. This corresponds to a critical particle size of about 48 um. When compared to the UNH particle size distribution shown previously, there are about 70% of the particles larger (by mass) than this size, which is therefore the approximate reduction in particulate solids expected, at peak flows. The following are the monitored performance plots for this installation, again with no untreated bypass stormwater effects.

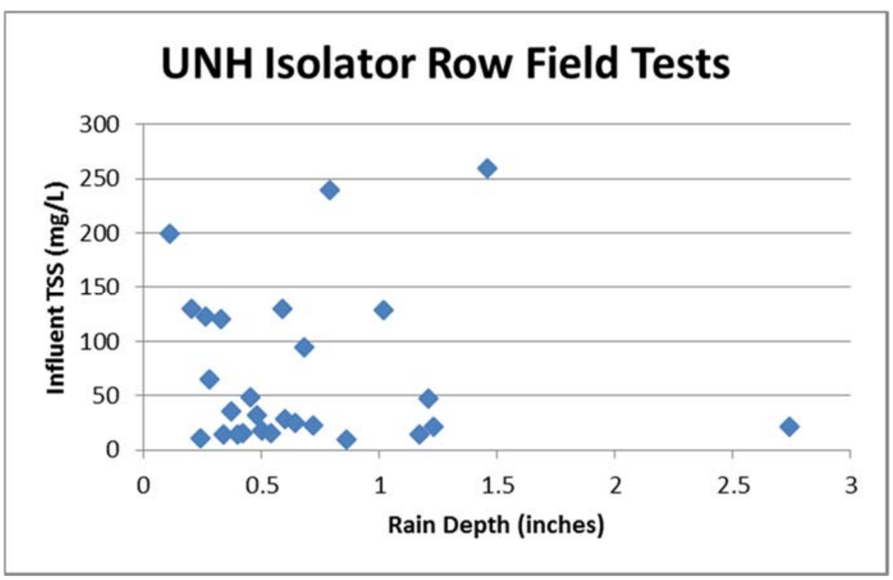


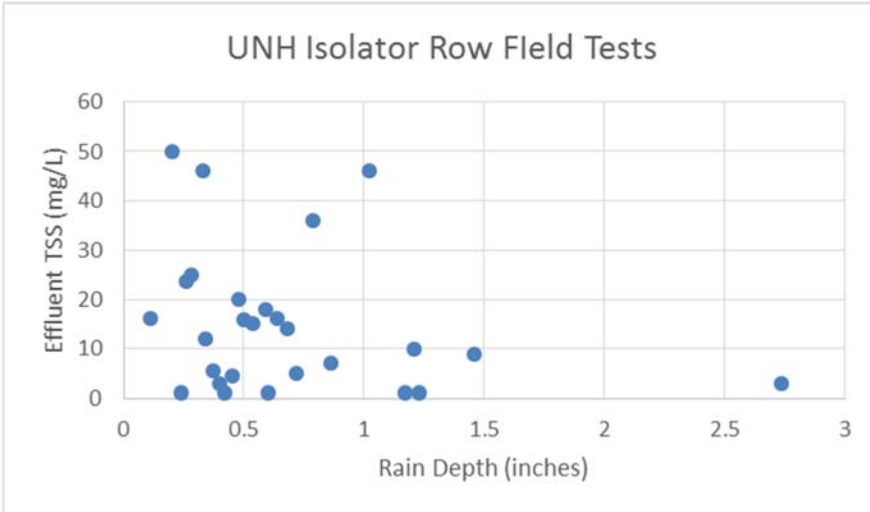


There were obvious reductions in the TSS concentrations with treatment at this site also, with the Mann-Whitney Rank Sum statistical tests showing a highly significance difference in the influent and effluent paired concentrations (p = <0.001). The average influent concentration was about 70 mg/L and the average effluent TSS concentration was about 15 mg/L, although there was a wide variation in concentrations and performance. The regression of the scatterplot was significant with a significant slope, and indicated a TSS reduction of about 60%. The adjusted R^2 value was 0.56. These all indicate good performance levels, considering the small size of the facility compared to the drainage area (but again, peak flows bypassed the system and were not monitored). The overall average 60% observed TSS reductions is close to the calculated 70% reduction level. The difference is likely because only a few events were represented in the PSD samples. It is expected that these will vary substantially throughout the study period.



Because the site information also included rain depths for the monitored events, the following scatterplots were used to identify any possible trends in influent or effluent concentrations, or removal, for different rain depths. As shown, no obvious trends are indicated, except that there are many more of the smaller rains than large rains. In fact, the rains <1.5 inches all show a wide range of information, and there is only rain larger than this depth.





Depth of sediment accumulation was measured at the same time the sediment grab samples were taken. Comparison of the PSD results taken at the influent by the auto-sampler and by grab sample at 2 feet from the inlet to the chamber show that the sediments filtered out by the system are approximately a magnitude larger at the D_{50} particle size. The data also illustrates a longitudinal differentiation in particle settling in the chamber with larger diameter particles settling toward the front of the system and smaller diameter particles settling toward the back. The following figure shows depth of sediment across the longitudinal profile of the system from 2 feet to 30 feet from the inlet. The chart shows a consistent sediment depth over the 2 year monitoring period except at the 30 foot mark. An increase in depth at the 10 foot mark represents consistent sediment deposition due to flow dissipation. At the 30 foot mark, there is an increase in sediment depth from 0.25 in to 1.17 in.

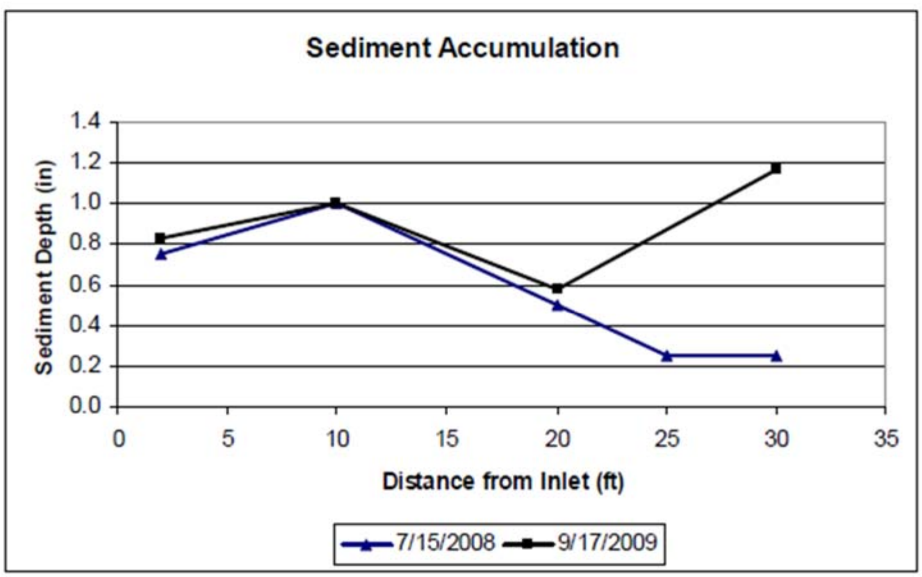


Figure 15: Record of sediment depth inside the StromTech Isolator Row at 1 and 2 year monitoring intervals.

Modeling Approach for StormTech and Isolator Row Chambers in WinSLAMM

WinSLAMM models the basic performance of the Isolator Row and StormTech chamber system using infiltration and sedimentation unit processes. The biggest challenge is describing the system hydraulics with the appropriate bypasses and underdrains and re-combining the flows. The following discussion summarizes information on the system dimensions (storage volumes for water depth), flow rates through the filter fabrics, and the bypass weir hydraulics.

Treatment (particulate removal) is due to settling. WinSLAMM calculates the overall settling into the system using the total surface area of the device, adjusted for the porosity of the rock. Of this total, all of the sediment that has a particle size greater than 50 µm that settled while the water is flowing through the IR is transferred to the IR. Fifty µm was selected because we assumed that all particles less than one-third the aperture size of the fabric (150 µm) would be trapped in the IR. The balance is routed in the surrounding rock where further settling is calculated. When the settled material in the IR row reaches a depth of four inches, cleaning occurs, setting the depth of the sediment in the IR back to zero. No removal occurs from the sediment that was captured in the surrounding rock due to lack of access. Infiltration is allowed, but test model runs show that infiltration drops off rapidly because the captured silt material that is in the rock base clogs the bottom of the device rather quickly – the clogging depth of the silt material is set at 0.25 inches.

Chamber Dimensions

The volume and area in the chambers are critical in modeling the performance of the Isolator and StormTech chamber system. The following summarizes the reported information from the ADS literature.

According to information from the NJCAT Verification report:

- The StormTech® SC-740 is 85.4" x 51.0" x 30.0" (L x W x H) and has a chamber storage of 45.9 ft^3. The StormTech® SC-310 is 85.4" x 34.0" x 16.0" (L x W x H) and has a chamber storage of 14.7 ft^3.

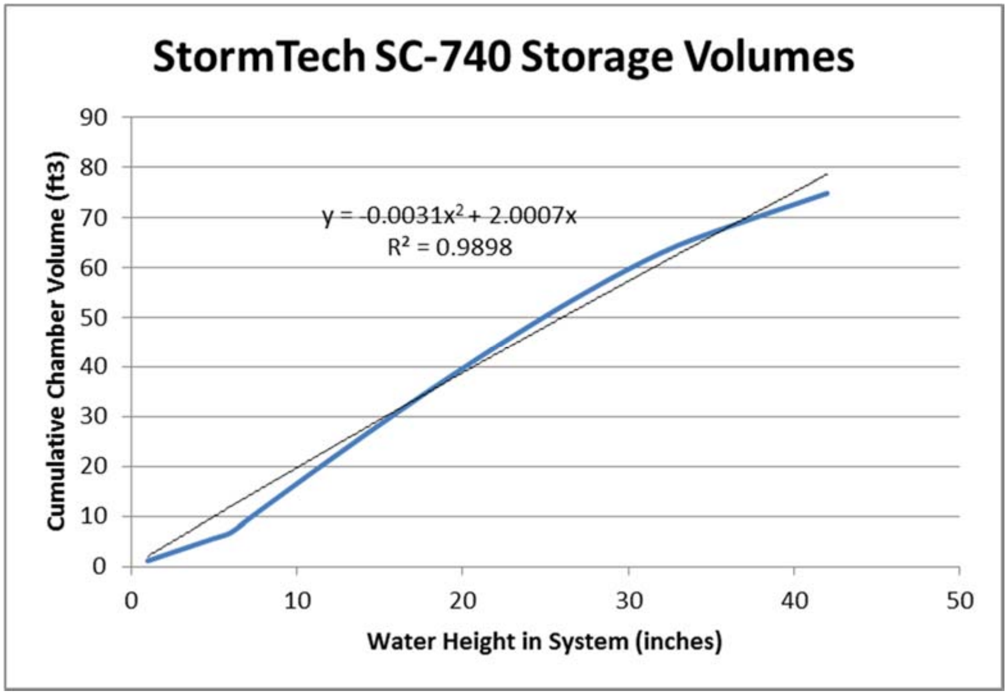
- The Isolator™ Row is a row of StormTech® chambers (either SC-740 or SC-310 models) that is surrounded with filter fabric and connected to a manhole.

- The Isolator™ Row typically rests on a 6-18 inch foundation of No. 3 gravel overlaid with a woven geotextile filter fabric (GEOTEX® 315 ST). A double-layer of fabric was introduced in accordance with NJDEP requirements. StormTech® implemented the double layer approach to enhance protection of infiltration surfaces by targeting finer particles for removal.

- A non-woven fabric is used on the upper part of the Isolator™ Row. The fabric is the GEOTEX® 601, which is a polypropylene, staple fiber, needle punched, non-woven geotextile.

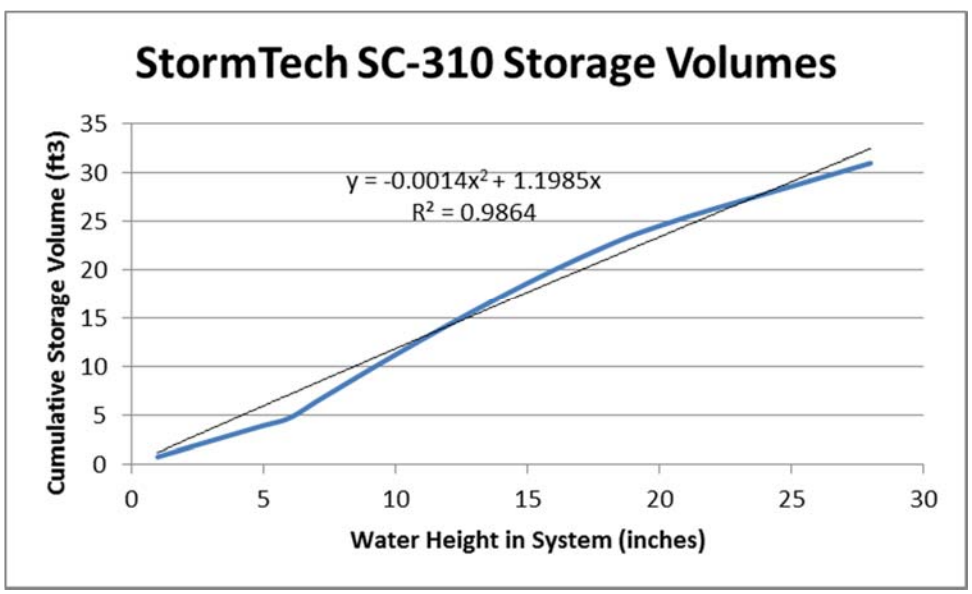
- GEOTEX 315 has flow rate of 4 gpm/ft^2, while the GEOTEX 601 has flow rate of 110 gpm/ft^2

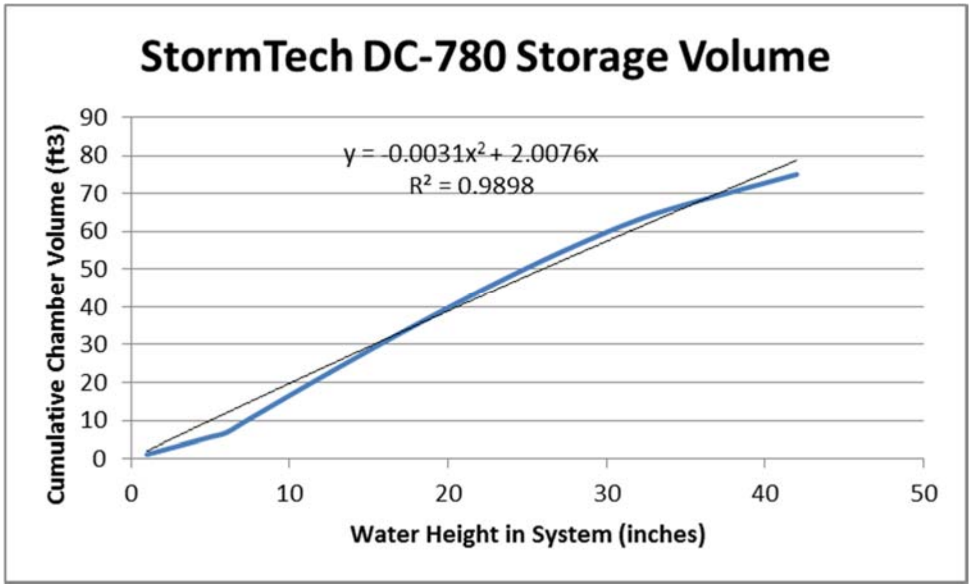
The StormTech Cumulative Storages Spreadsheet 2014.xls contains cumulative (and incremental) storage volumes by water depth for all chamber types (chamber, stone, and combined; 6 inches stone above and in chamber). The following figures shows the plot of water storage depth and available storage volumes for the SC-740, SC-310, and DC-780 chambers and surrounding rock, along with the best-fit regression line used in WinSLAMM to describe these relationships.

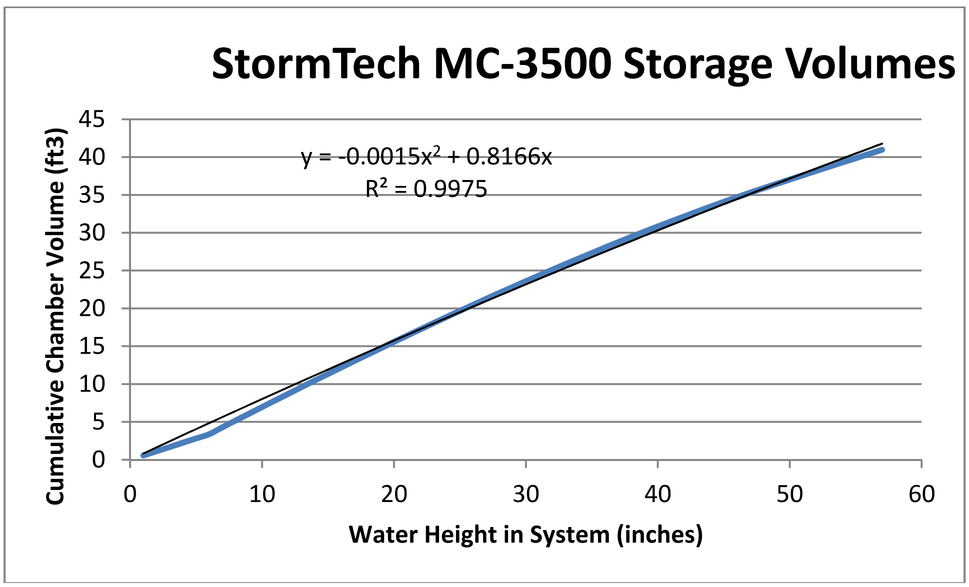


Chamber SC-740 Construction Characteristics for each Chamber Unit

Number of chambers	1
Voids in the stone (porosity)	40 %
Base of Stone Elevation	1 ft
Amount of Stone Above Chambers	6 in
Amount of Stone Below Chambers	6 in
Area of system	34 ft^2





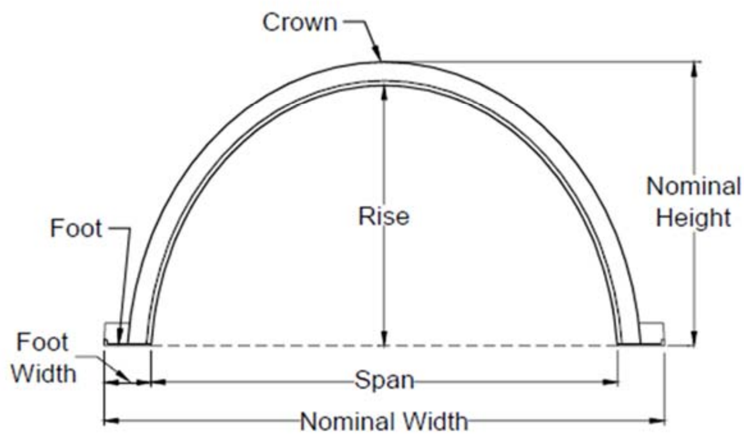


The Tennessee Tech 2005 report further includes the following illustrations and data concerning the dimensions of the StormTech chambers.

Dimensions for StormTech® chambers are defined as follows in *Figure 2*:

Chamber Designation	Nominal Height (in)	Nominal Width (in)	Installed Length (in)	Rise (in)	Span (in)	Average[1] Open Bottom Area (Footprint) (sqft)	Sidewall Orifice Area 24 at 0.63 sqin ea (sqin)
SC-740[2]	30	51	85.4	26.7	43	27.8	15
SC-310	16	34	85.4	13.1	26	17.7	15

1 See Appendix 1 for detailed calculation of average bottom areas (footprints).
2 Rows of SC-740 chambers were tested for this evaluation.



Open Bottom Area Calculations (Footprint)

SC-740 CHAMBER

SECTION	Width In.	Length In.	%Open[1] %	Area In^2	Area Ft^2
SPAN	43.0	85.4	NA	3672.2	25.5
CORRUGATED	5.0	85.4	77	328.8	2.3

27.8 Open Bottom Area per Chamber

SC-310 CHAMBER

SECTION	Width In.	Length In.	%Open[1] %	Area In^2	Area Ft^2
SPAN	26.0	85.4	NA	2220.4	15.4
CORRUGATED	5.0	85.4	77	328.8	2.3

17.7 Open Bottom Area per Chamber

[1] The corrugated section has an alternating pattern of blocked and open parts along the length of the chamber. 77% is open and is included in the open bottom area. 33% is blocked off and not included in the open area calculation.

Diversion Weir Hydraulic Calculations

The diversion weir is fundamental for all flow phases and is described below, which is an excerpt from an ADS specification report that describes the diversion weir sizing and elevations for the manifold. WinSLAMM does not perform any sizing calculations, but uses the elevations provided by the design engineer in its flow hydraulic calculations. WinSLAMM calculates the flow splitting at the diversion weir based on the given weir dimensions, assuming a sharp crested weir.

Diversion Weir

The weir is situated to divert the runoff initially into the Isolator Row. The maximum weir crest elevation is determined by subtracting the head required to pass the peak flow from the maximum allowable water surface elevation. Typically the weir crest elevation ranges from the midpoint of the chamber up to the top of the chamber (see figure 2). The design of the weir is performed in several steps. The desired sized structure is drawn on the engineer's plans with the pipe connections. A weir is drawn in and the length is determined. The design engineer then determines the allowable water surface elevation over the weir crest in the structure (typically it is set at the same elevation as the top of the stone above the chambers). The weir crest elevation is then estimated. Start by assuming the elevation of the weir crest is at the same elevation as the top of the chambers. Thus the approach head (H) is the distance from the weir crest to the allowable water surface elevation.

The equation of a sharp crested weir can be written as follows [1]:

$$Q = C\sqrt{2g}\,LH^{3/2}$$

$$C = 0.40 + 0.05\frac{H}{P}$$

Q = flow rate (cfs)
C = discharge coefficient
L = length of weir (ft)
H = approach head on the crest (ft)
P = height of crest above channel bottom (ft)
g = gravity (32.2 ft/s^2)

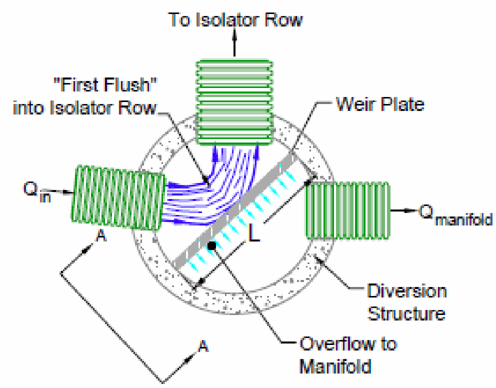


Figure 2A, Plan View of Diversion Structure

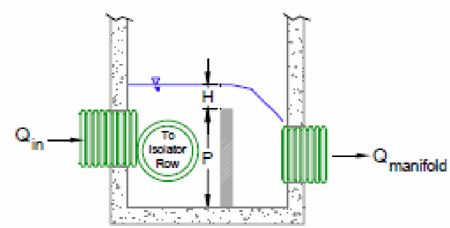


Figure 2B, Section A_A of Diversion Structure

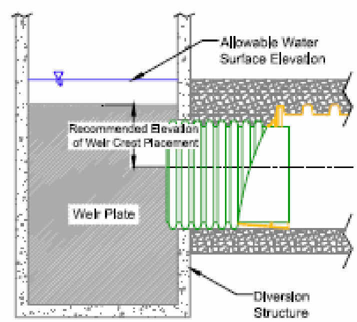


Figure 2C, Profile of Diversion Structure and Isolator Row

The flow over the weir can be calculated using these equations. This calculated flow is then compared to the design flow rate entering the structure. If this calculated flow is greater than the design flow rate then the weir is sufficient to pass the flows. If not, then the weir crest can be lowered and the calculations repeated. As mentioned previously StormTech recommends the weir crest be set between the top of the chamber and the midpoint of the chamber (see figure 2C). If the lowered crest cannot meet the design flow rate a larger structure can be analyzed which allows for a longer weir crest.

This memo completes the summary of the laboratory and field evaluation tests, and also includes manual calculations showing how the WinSLAMM calculations will be performed. The statistical evaluations of the available data support the sedimentation approach in the model.

References

Christensen, A. and V. Neary, *Hydraulic Performance and Sediment Trap Efficiency for the StormTech SC-740 Isolator Row*. Dept. of Civil and Environmental Engineering, Tennessee Tech University. February 2005.

Jadlocki, S., K. Hall, and J. Price. *City of Charlotte Pilot SCM Monitoring Program, Cherry Gardens Senior Apartments, StormTech Chambers Stormwater Treatment Structure*. Final Monitoring Report. July 2013.

Neary, V. *Performance Evaluation of Sediment Removal Efficiency Stormtech Isolator Row*. Dept. of Civil and Environmental Engineering, Tennessee Tech University. October 2006.

NJCAT Technology Verification, *StormTech Isolator Row*. August 2007.

Roseen, R.M., T.A. Puls, J.J. Houle, and T.P. Ballestero. *Performance Evaluation Report of the StormTech Isolator Row Treatment Unit*. University of New Hampshire Stormwater Center. September 2010.

StormTech. *Isolator Row Testing Summary*.

University of New Hampshire Stormwater Center. *Final Report on Field Verification Testing of the Stormwater Isolator Treatment Unit*. June 2008.

University of New Hampshire Stormwater Center. *Examination of Thermal Impacts from Stormwater Best Management Practices*, January 2011.