Hydro DryScreen® Performance Testing

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1 Executive Summary

Baffle boxes are horizontal settling tanks that are used for removing pollutants from waste streams, like stormwater runoff. The original Type I Baffle Box primarily targets settleable solids but more recent designs, referred to as Type II Baffle Boxes, include screens that are used to capture floating pollutants. While research has shown Type I Baffle boxes to have high removals of sandy clay sediment, the initial laboratory work showed the efficiency to be very sensitive to loading rates. Hydro International has developed a Type II Baffle Box (Hydro DryScreen®)that not only increases the loading rate range but includes a screen that ensures buoyant organic matter is captured and retained above the static water level in between rainfall events. Leaching of nutrients is prevented by keeping organic particulate matter exposed to oxygen or out of the sump where it degrades and becomes anoxic.

This report reviews results from laboratory tests on a Type I Baffle Box, compares these results to estimates using settling equations in horizontal tanks and provides efficiency estimates for the Hydro DryScreen® Type II Baffle Box using Computerized Fluid Dynamics (CFD). Full-scale laboratory testing was also completed to compare to both the CFD model and results of the original Type I Baffle Box laboratory tests.

Researchers studying a Type I Baffle Box (Pandit and Gopatakrishnan) determined that the average removal efficiency for a "sandy clay" test sand having 80% of the particle sizes between 200 and 600 µm was close to 90% for loading rates in the range of 6 to 8 gpm per square-foot of surface area. Ideal settling calculations predict Type I baffle Boxes would be challenged to remove the finer portion of the test sand gradation (D_{50}=350µm) used by Pandit and Gopatakrishnan when the hydraulic loading rate is in excess of about 50 gpm per square foot of settling.

CFD simulations with the same sandy clay particle size distribution described in Pandit's work was used to evaluate the performance of a Type I (no screen) and Hydro DryScreen® Type II Baffle Boxes. The model was used to design flow modifying components and additional CFD simulations were run with the internal components used in the Hydro DryScreen Type II Baffle Box to demonstrate a 26% increase in efficiency. To verify the CFD results, testing was completed on a full-scale 3-ft × 6-ft test unit.

Hydraulic test results showed that there would be less than a 10% reduction in flow even if pollutants blind the screens so that there is only 20% of open screen area remaining (i.e.: 80% blinded). Additionally, hydraulic data was shown to approximate a theoretical orifice equation for entrance loss into a pipe using a Cd of 0.65, which simplifies modeling impacts to the hydraulic grade line when placed into a drainage network.

Removal efficiency testing correlated well with theoretical settling calculations for 80% removal of all particles down to 100-microns at about 30 gpm/sq-ft. However, at high loading rates of 150 gpm/sq-ft 80% removals of particles down to 400 microns was measured compared to settling calculations that predicted removals down to the 700 micron range. These higher loading rates observed in the lab test results are attributed to the flow modifying internals used in the Hydro DryScreen®. Compared to the lab test results of Pandit and Gopatakrishnan, similar removals were observed but at loading rates 3-4 times higher.

2 Overview

Hydro International has traditionally focused on products that harness the energy from rotational flow to create innovative products for the control and treatment of waste streams, like stormwater runoff. While vortex separation for treatment of urban stormwater runoff has been proven to capture and retain a wide range of pollutants that float and settle, conventional baffle box separators ("Stormwater Technology Fact Sheet", United States Environmental Protection Agency, Spetember 2001.) also have a history and are an acceptable stormwater treatment technology.

The original Type I Baffle Box (Figure 1) was similar in design to septic tanks used for removing solids prior to pumping or flowing to leach fields. These designs included one or two baffle walls installed perpendicular to the flow direction within a rectangular precast structure. The baffle walls function to: reduce the flow velocity and allow particles with a settling velocity greater than the horizontal flow velocity to settle into the sump; and minimize particle movement. Heavier or larger particles tend to settle and accumulate in the first chamber while smaller particles usually settle out in subsequent chambers. The sediment removal efficiency of a typical Type 1 Baffle Box has been investigated in the laboratory to take advantage of being able to control loading rates and test sand particles sizes and concentrations ("Physical Modeling of a Stormwater Sediment Removal Box", Pandit and Gopatakrishnan, June 1996). The study defined the overall efficiency as the ratio of total mass of sediment captured to the total mass of sediment injected during the experiment, which is conservative but arguably more accurate than efficiency determined by influent and effluent concentrations. The average removal efficiency for a "sandy clay" test sand having 80% of the particle sizes between 200 and 600 µm was close to 90% and found not to be dependent on concentration. Removal efficiency of "silty clay" test sand was lower at about 30% but the particle sizes were mostly less than 50µm and almost 60% less than 20µm. The tested loading rates were about 6 and 8 gpm per square-foot of surface area. Since the decrease in efficiency of these fine particles was believed to be caused by resuspension within the chamber, researchers speculated that modifications to the baffles to reduce turbulence and minimize resuspension could increase retention of particles less than 50µm or allow for higher loading rates without significant decrease in capture.

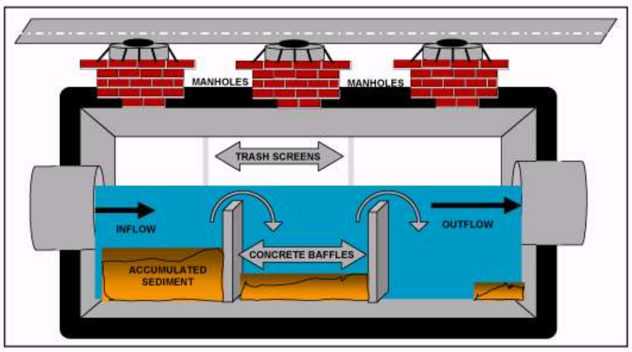

Figure 1. Type I Baffle Box

Type 2 baffle boxes (Figure 2) include horizontal screens above pipe inverts that trap floating organic matter and suspended sediments above the static water elevation. By suspending organic matter above the water filled sump, it is kept dry or exposed to oxygen, which is needed to keep them from decaying and leaching nutrients. Additionally, material that is captured and retained can form a mat on the screen surface, reducing the effective size of openings, which captures particles that are smaller than the screen openings. The horizontal screen used in Type 2 baffle boxes has been proven to be more effective than

Type I baffle boxes for removing Total Nitrogen (TN) and Total Phosphorus (TP) *("Final Report – Baffle Box Effectiveness Monitoring Project", FL DEP and GPI Southeast. Jan. 7, 2010).*

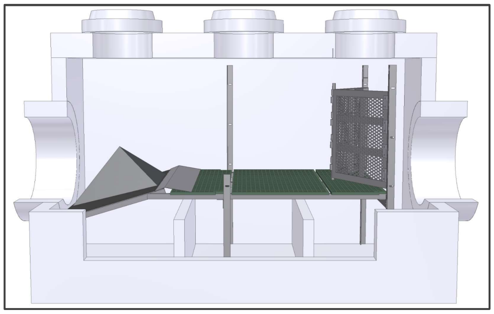

Figure 2. Type II Baffle Box – Hydro DryScreen®

The Type II Baffle Box shown in Figure 2 is a rendering of the Hydro DryScreen® by Hydro International. It is a second-generation baffle box that augments the typical baffle box design with a patented flow-diffusing deflector to improve sediment capture. The horizontal screens not only vertically adjust to keep screenings dry if tailwater conditions exist but they are sectionalized for ease of access to the separate storage chambers in the sump. A vertical screened weir is positioned at the outlet to retain all screened material for the full design flow rate. The screens are sized to capture 100% of all material greater than 0.75-inches.

Settling of discrete particles in a horizontal settling tank has been mathematically defined for some time now, Hazen(1904) and Camp(1946). The idea that a particle will settle depending on its settling velocity before it leaves a tank and that it is dependent on the surface loading rate of the tank is often used to estimate how large the settling tank needs to be for a given flow rate. Using an ideal or theoretical settling equation ("A Simple Universal Equation for Grain Settling Velocity", Ferguson and Church, 2006.), a hydraulic loading rate greater than about 150gpm per square-foot of settling area would not capture particles smaller than about 750µm (Figure 3). For more typical loading rates of 25 gpm per square foot of settling area, particles smaller than about 160µm would not have enough time to settle. Given the test sand gradation used by Pandit and Gopatakrishnan that had a D_{50}=350µm, a hydraulic loading rate in excess of about 50 gpm per square foot of settling area would not capture the finer portion of the distribution.

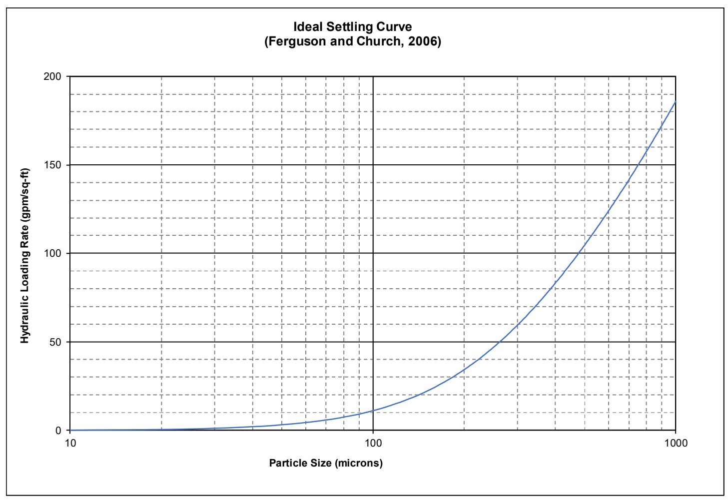

Figure 3. Hydraulic Loading Rates for Settling Different Particle Sizes

To benchmark the actual efficiency at these loading rates with the Hydro DryScreen® Type II baffle box, a 3-ft × 6-ft full scale model was tested. This report summarizes these tests and the results.

3 Product Description and Operation

The Hydro DryScreen® product components are shown below in Figure 4. The inlet pipe (1) conveys flow into the structure from the left. A screened inlet ramp (6) with integral prismatic flow splitter directs any screenable material up onto the horizontal screened platform (4). Additionally, the flow splitter directs flow to the sides of the vessel, interrupting a "short-circuit" between the inlet and outlet. The smooth, sloped shape of the flow splitter deflects and prevents accumulation of buoyant material likely to collect on the surface.

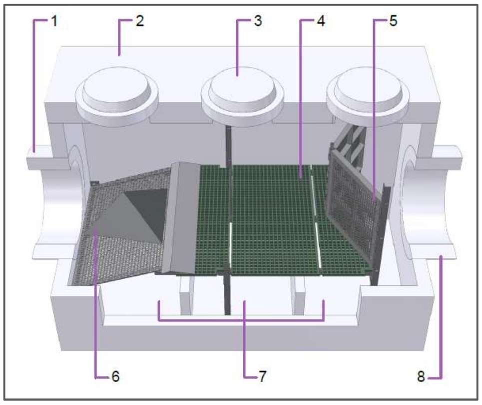

Figure 4: Component diagram of Hydro's dry screen product

Figure 5 and Figure 6 show the flow path when the system is operating below and above the design treatment flow rate. When the runoff flow rate is less than the design treatment flow rate (Figure 5), incoming flow, floating debris and sediment pass through the sump region and across the horizontal screen. Flow unscreened by the inlet ramp or screened platform is treated by the vertical screened weir (5) positioned over the outlet pipe (8).

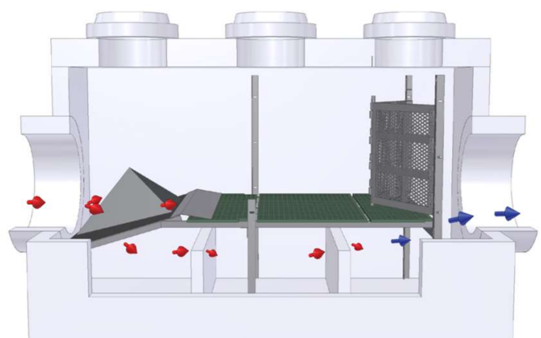

Figure 5: Flow Path with runoff less than peak treatment flow rate

Energy from the inflow continues to deposit any floating debris on the horizontal platform. Settleable solids are collected in the three sump areas (7) located under the horizontal screen. Treated flow then exits the system from the overflow pipe located on the right (8).

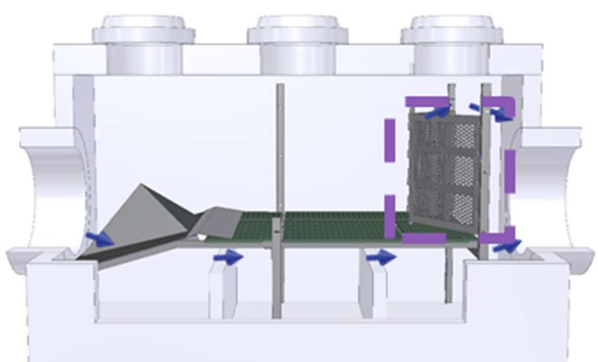

Figure 6: Flow Path with runoff greater than peak treatment flow rate

As shown in Figure 6, once the peak treatment flow rate is exceeded, high water elevations that could cause upstream flooding are managed by diverting flows over the screened vertical weir. In general, the vertical weir is the same height as the pipe diameter to allow full pipe flow prior to bypassing. This ensures that 100% of the flows are screened with no bypass up to the peak treatment flow rate, such as the 25-year return frequency.

4 Performance Testing Overview

A two-phase test plan that used Computerized Fluid Dynamics (CFD) simulations and controlled testing was completed. CFD was used to understand the limitations of a standard Type I Baffle Box with no flow modifying components and predict the benefits of the prismatic flow splitter. Controlled sediment tests with known particle size distribution, concentration and flows or loading rates were assessed.

CFD simulations with the same "Sandy Clay" particle size distribution described in Pandit's work was used to evaluate the performance of a Type I (no screen) and Hydro DryScreen® Type II Baffle Boxes. The CFD simulation was first calibrated against Pandit's lab work using a Type I Baffle Box to gain confidence in the model. Removal efficiencies at surface loading rates of 6 and 8 gpm/sq.ft. were simulated within 1% of results reported by Pandit using second order momentum equations and Lagrangian Particle tracking methods. Velocity contour plots of the baseline vessel showed significant short circuiting between the inlet and outlet pipes at higher velocities (Figure 7-top). The model was used to design flow modifying components that interrupt the "short circuit" and increase residence time and the particle retention rate. Additional CFD simulations were run with the internal components used in the Hydro DryScreen Type II Baffle Box (Figure 7-bottom) to demonstrate a 26% increase in efficiency.

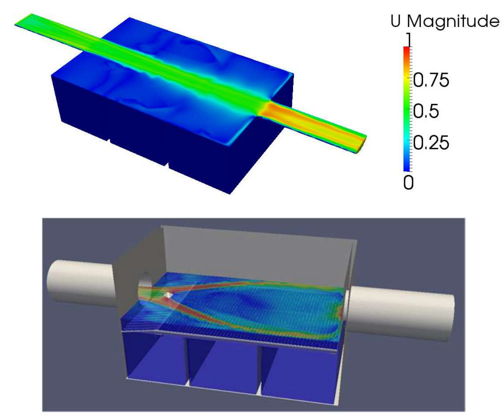

Figure 7: CFD Models of Type I and II Baffle Boxes

Following the CFD simulations, a full-scale 3-ft × 6-ft Hydro DryScreen separator was tested to confirm the modeling efficiency results reported by Pandit. In general, the test procedures used were designed to mimic those used by Pandit with the addition of recording water elevations to determine headlosses with and without the screen being partially blinded. The controlled efficiency tests were also completed with and without internal components to quantify the benefits of the prismatic flow splitter.

Clean water was pumped via an 8-inch variable speed Flygt pump from a 23,000 gallon reservoir, through a 12-inch pipe network to the inlet of the 3-ft × 6-ft full-scale Hydro DryScreen® test unit. Figure 8 shows the laboratory at Hydro International with, reservoir, piping and test unit. Test sand was manually feed into a standpipe cored into the crown of the inlet pipe. The feed rate was calibrated to have an inlet concentration of 200 mg/L. Like the tests completed by Pandit, the efficiency was determined by removing and measuring the mass of the captured sediment from the sump at the end of each test run. The sediment removed from the sump was also sieved to quantify the removal efficiency of different particle size ranges.

Figure 8: Hydro International Test Facility

Figure 9 is a photograph taken during hydraulic testing with view looking down into the test unit from above. The 12-inch inlet pipe is on the left, followed by prismatic flow diverter, horizontal platform screen and 18-inch screened vertical weir covering the outlet pipe on the far right. Flow rates and water elevations were measured with a static pressure tap in the inlet pipe, a rule in the upstream section of the vessel and a rule installed downstream of the vertical screens. To determine the hydraulic impact of screen blinding, a fully open-screen system was compared to a system with 80% of the open screen area blocked or covered as shown in Figure 10. The flow/water elevation plots (Figure 11) showed that the water level overflowed the bypass weir height at 3.9 cfs with screens 80% blocked compared to 4.2 cfs when left open. The translation of these results to actual field installations suggest that there would be less than a 10% reduction in flow even if pollutants blind the screens so that there is only 20% of open screen area remaining (i.e.: 80% blinded). Additionally, the hydraulic curve approximates a theoretical orifice equation for entrance loss into a pipe using a Cd of 0.65. This allows designers to easily estimate the influence to the drainage network’s hydraulic grade at various flow rates.

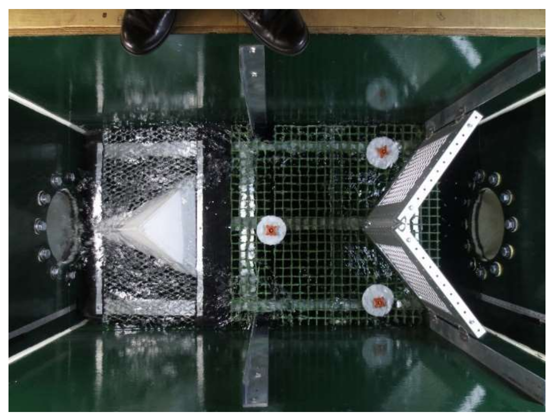

Figure 9: Top View of 3-ft × 6-ft Test Unit

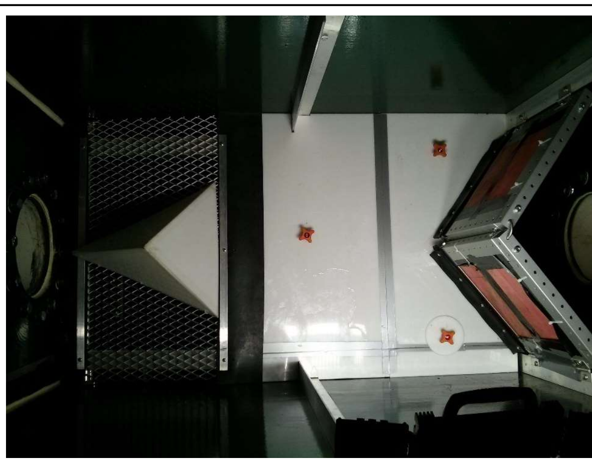

Figure 10: Hydraulic Testing with 80% Open Area Blocked

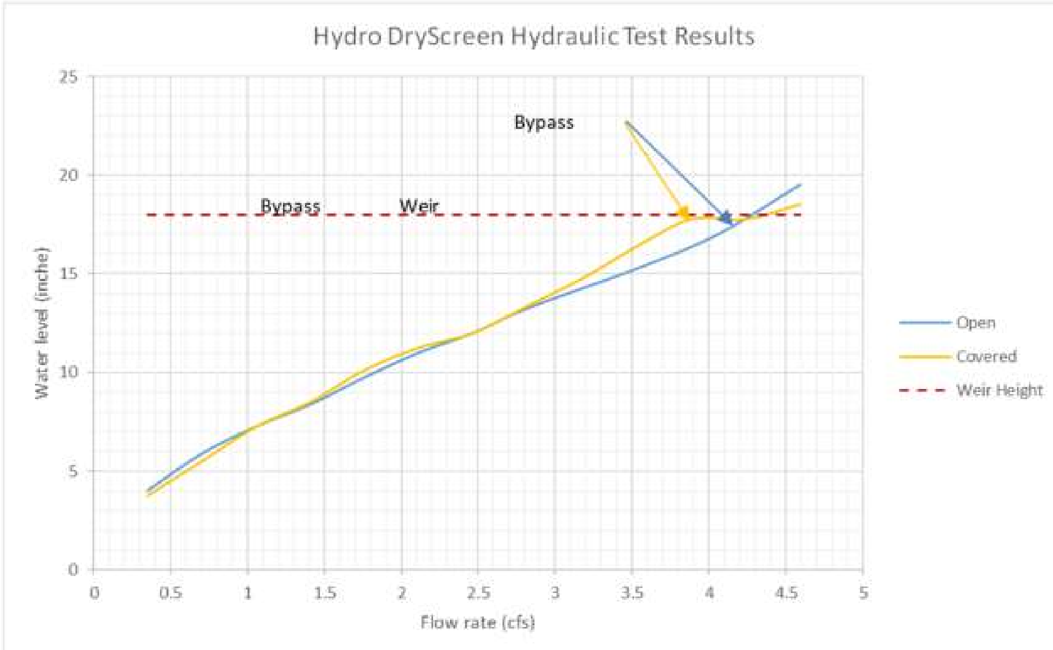

Figure 11: Comparison of water elevations and flow rates – Open Screen Vs. 80% Covered Screen.

4.1 Removal Efficiency Testing

To quantify removal efficiency, test sand was introduced into a standpipe approximately eighteen inches upstream of the vessel. The test sand chosen was similar to the "Sandy Clay" gradation used in the research completed by Pandit. The target and measured PSD of the blended mix were very similar as shown in Figure 12. Removal efficiencies for a range of surface loading rates and particle sizes are reported in Figure 13. As shown, the efficiency for particles "down to" five different sizes were analyzed. For example, greater than 80% efficiency was measured for all particles down to 106 microns at a surface loading rate of about 30 gpm/sq-ft and at 150 gpm/sq-ft, all particles down

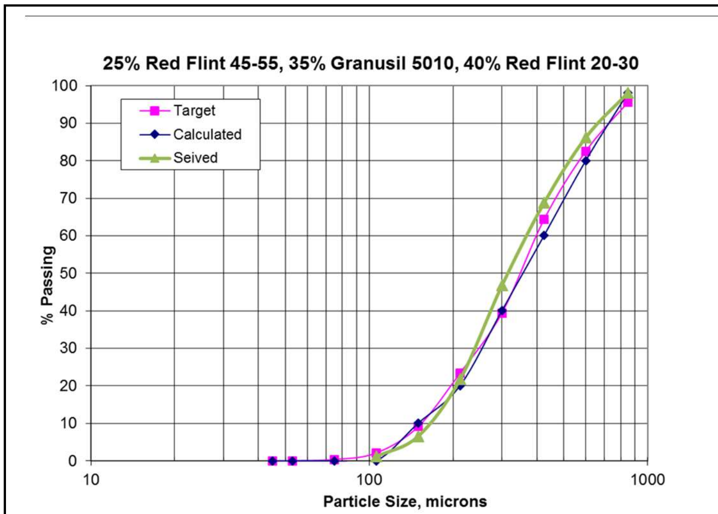

Figure 12: Target, Calculated and Sieved particle size distributions of Pandit's "Sandy Clay".

to 400 microns was measured. This correlates well with the theoretical hydraulic loading rates used to predict removals of the 100 micron particle size range. However, the theoretical settling calculations

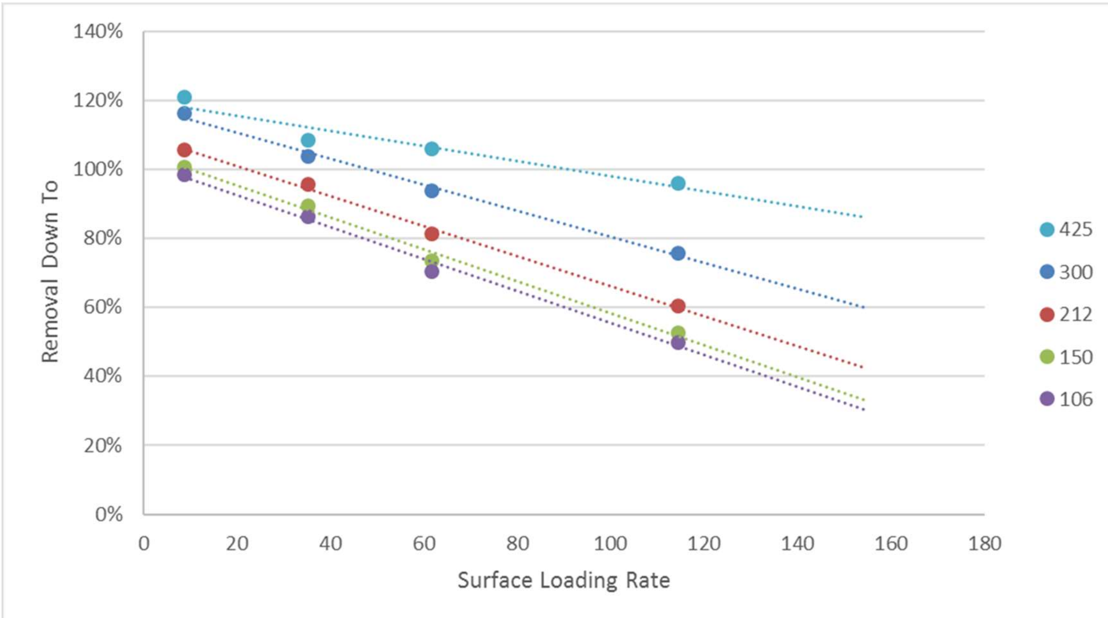

Figure 13: Removals Down to Particle Size using Pandit's "Sandy Clay" blend

estimate 80% removals of particles in the 700 micron range. Given the test results show removal of 400 micron particles, the results indicate that at higher loading rates, the flow modifying internals improve the settling capability. Compared to the lab test results of Pandit and Gopatakrishnan, similar removals were observed but at loading rates 3-4 times higher.

5 Standard Model Sizes

Using the hydraulic data, screen open area, maximum pipe size and efficiency data, five Hydro DryScreen models are standardized for commercial availability. Custom sizes are also available and some changes to the key dimensions shown may be necessary depending on local precast supply. Table 5 includes the key design requirements for each model size.

For on-line installations, the maximum pipe size, Peak Online Flow Rate and either Typical Treatment flow rate or 80% TSS flow rate can be used to correctly size a system based on specific site and catchment area criteria. For off-line installations that allow for control of the peak runoff flow, the pipe size, Bypass Flow Rate and either Typical Treatment or 80% flow rates can be used to select the appropriate size system.

Table 5: Sizing table

Unit Dims (feet)			Pipe Dia.	Pipe Area	Bypass[1]	Peak Online[2]	Typ. Treat.[3]	80% TSS[4]
W	**L**	**A**	**(feet)**	**(sq.ft)**	**(cfs)**	**(cfs)**	**(cfs)**	**(cfs)**
4	8	32	2.5	4.91	28.6	20	11	1.8
6	12	72	3.5	9.62	66.4	47	24	4.0
8	14	112	4	12.57	92.7	65	37	6.2
10	16	160	4.5	15.90	124	87	53	8.9
12	24	288	5	19.63	162	113	96	16.0

1. ***Bypass Flow:*** The flow rate at which the water level will crest the vertical screened bypass weir. Can be used for offline installations that use an external bypass to control the peak runoff flow rates. Runoff rates exceeding the Bypass Flow Rate can release captured pollutants.
2. ***Peak Online Flow:*** The Maximum Bypass flow less a safety factor of at least 1.4. Can be used for online installations having peak runoff flow rates pass through the treatment system. No release of captured pollutants for runoff flow rates that are less than the Peak Online Flows.
3. ***Typical Treatment Flow Rate:*** This is the flow rate at which the device would remove 80% of a "Sandy Clay" particle size distribution down to 425 microns. This flow rate is based on 150 gpm/sq.ft.. Compare to a common "wet-season" storm event (example: 1-2 year return frequency).
4. ***80% TSS Flow Rate:*** This is the flow rate at which the device would remove 80% of "Sandy Clay" particle size distribution down to its minimum particle size. This flow rate is based on 25 gpm/sq.ft. Compare to a frequent but low intensity storm event (example: captures the first 0.5-1 inches of rainfall or 70-80% of the annual runoff volume).