

NJCAT TECHNOLOGY VERIFICATION

**Hydroworks HG 6 Separator
Hydroworks, LLC**

July 2009

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1. Introduction

1.1 New Jersey Corporation for Advanced Technology (NJCAT) Program

NJCAT is a not-for-profit corporation to promote in New Jersey the retention and growth of technology-based businesses in emerging fields such as environmental and energy technologies. NJCAT provides innovators with the regulatory, commercial, technological and financial assistance required to bring their ideas to market successfully. Specifically, NJCAT functions to:

- Advance policy strategies and regulatory mechanisms to promote technology commercialization;
- Identify, evaluate, and recommend specific technologies for which the regulatory and commercialization process should be facilitated;
- Facilitate funding and commercial relationships/alliances to bring new technologies to market and new business to the state; and
- Assist in the identification of markets and applications for commercialized technologies.

The technology verification program specifically encourages collaboration between vendors and users of technology. Through this program, teams of academic and business professionals are formed to implement a comprehensive evaluation of vendor specific performance claims. Thus, suppliers have the competitive edge of an independent third party confirmation of claims.

Pursuant to N.J.S.A. 13:1D-134 et seq. (Energy and Environmental Technology Verification Program) the New Jersey Department of Environmental Protection (NJDEP) and NJCAT have established a Performance Partnership Agreement (PPA) whereby NJCAT performs the technology verification review and NJDEP certifies the net beneficial environmental effect of the technology. In addition, NJDEP/NJCAT work in conjunction to develop expedited or more efficient timeframes for review and decision-making of permits or approvals associated with the verified/certified technology.

The PPA also requires that:

- The NJDEP shall enter into reciprocal environmental technology agreements concerning evaluation and verification protocols with the United States Environmental Protection Agency, other local required or national environmental agencies, entities or groups in other states and New Jersey for the purpose of encouraging and permitting the reciprocal acceptance of technology data and information concerning the evaluation and verification of energy and environmental technologies; and
- The NJDEP shall work closely with the State Treasurer to include in State bid specifications, as deemed appropriate by the State Treasurer, any technology verified under the Energy and Environment Technology Verification Program.

1.2 Technology Verification Report

On November 26, 2008, Hydroworks, LLC (50 S. 21st Street, 2nd Floor, Kenilworth, NJ 07033) submitted a formal request for participation in the NJCAT Technology Verification Program. The technology proposed – The Hydroworks Hydroguard (HG) separator (Model HG 6) – is a centrifuge hydrodynamic separator designed to remove suspended solids (and associated metals, nutrients and bacteria), oil, and floatables (trash) from stormwater.

The request (after pre-screening by NJCAT staff personnel in accordance with the technology assessment guidelines) was accepted into the verification program. This verification report covers the evaluation based upon the performance claim of the vendor, Hydroworks (see Section 4). The verification report differs from typical NJCAT verification reports in that final verification of the Hydroworks HG 6 separator (and subsequent NJDEP certification of the technology) awaits completed field testing that meets the full requirements of the Technology Acceptance and Reciprocity Partnership (TARP) – Stormwater Best Management Practice Tier II Protocol for Interstate Reciprocity for stormwater treatment technology. This verification report is intended to evaluate the Hydroworks HG 6 separator performance claim for the technology based on carefully conducted laboratory studies. The performance claim is expected to be modified and expanded following completion of the TARP required field-testing.

This verification project primarily involved the evaluation of company manuals and literature and a third party laboratory test report to verify that the Hydroworks HG 6 separator satisfies the performance claim made by Hydroworks, LLC.

1.3 Technology Description

1.3.1 Technology Status: general description including elements of innovation/unique/ competitive advantage.

In 1990, Congress established deadlines and priorities for EPA to require permits for discharges of stormwater that is not mixed or contaminated with household or industrial wastewater. Phase I regulations established that a NPDES (National Pollutant Discharge Elimination System) permit is required for stormwater discharge from municipalities with a separate storm sewer system that serves a population greater than 100,000 and certain defined industrial activities.

To receive a NPDES permit, the municipality or specific industry has to develop a stormwater management plan and identify Best Management Practices for stormwater treatment and discharge. Best Management Practices (BMPs) are measures, systems, processes or controls that reduce pollutants at the source to prevent the pollution of stormwater runoff discharge from the site. Phase II stormwater discharges include discharges from classes of smaller municipalities than those specifically classified as Phase I discharge.

The nature of pollutants in stormwater emanating from differing land uses is diverse. The Hydroworks Hydroguard (HG) separator is designed to trap these pollutants within its confines until they are properly removed via regular maintenance. Hydroguard's unique design treats both low and high flows, and contains them in separate treatment areas. The dual treatment area

configuration allows Hydroguard to minimize scour and resuspension of previously captured fines in the low flow treatment area during high flow conditions. It is the only stormwater treatment structure on the market that treats both low flow and high flow and treats them in two separate compartments.

1.3.2 Specific Applicability

The Hydroworks Hydroguard (HG) separator is a structural stormwater quality BMP designed to treat impervious areas such as parking lots and roads. Specific applications include:

- Parking lots for any facility (commercial or industrial)
- Residential areas
- Transportation-roads, bridges, and transit facilities
- New development or re-development applications

1.3.3 Range of Contaminant Characteristics

The Hydroguard stormwater treatment structure removes suspended solids, including associated contaminants such as metals and nutrients, hydrocarbons (oil) and trash (floatables) from stormwater runoff.

1.3.4 Range of Site Characteristics

The Hydroworks HG separator is manufactured in a variety of sizes from 4 ft inside diameter to 12 ft inside diameter each designed to treat a specific site flow rate (Table 1). Larger sizes may not be available in all areas. Check with Hydroworks to ensure availability of the larger model sizes.

Table 1 Hydroworks HG Separator Dimensions* and Flow Rates

Model	Structure Inside Diam. (ft)	Inner Chamber Diam. (in)	Structure Depth (ft)*	Sediment Volume (ft ³)+	Oil/Floating Trash Volume (ft ³) [gal]	Permanent Pool Wet Volume (gal)	Treatment Flow Rate (cfs) [gal]
HG 4	4	31.5	5	38	10 [76]	470	0.80 [359]
HG 5	5	40	5.5	64	16 [123]	808	1.25 [561]
HG 6	6	48	6	92	27 [203]	1269	1.80 [808]
HG 7	7	56	6.3	125	42 [313]	1823	2.45 [1100]
HG 8	8	63	6.7	163	61 [457]	2507	3.20 [1437]
HG 9	9	68.5	7.1	207	101 [754]	3371	4.05 [1818]
HG 10	10	78	7.6	268	119 [893]	4455	5.00 [2245]
HG 12	12	96	8.5	386	186 [1389]	7191	7.20 [3232]

* Typical dimensions – dimensions will vary based on project requirements/specifics

+ Volume below the outlet opening of the outer baffle wall (not 100% sediment loading volume for recommended maintenance)

Although the inlet and outlet pipe diameter are only limited by the structural integrity of the outer structure itself, it is recommended that the maximum inlet pipe diameter be limited to the values given in Table 2 since these allow the full width of flow from the pipe to enter the inner chamber. Following this recommendation ensures that water enters the inner chamber prior to the middle chamber for normal flow conditions.

Table 2 Maximum Recommended Inlet Pipe Diameter

Model	Maximum Inlet Pipe Diameter (in)
HG 4	15
HG 5	18
HG 6	24
HG 7	27
HG 8	30
HG 9	30
HG 10	36
HG 12	48

The inner chamber and baffle wall generally extend 1.5 to 2 times the inlet pipe diameter above the inlet invert. Hydroworks should be contacted for applications with inlet pipe diameters greater than 48” or shallow applications where the height of the inner chamber and outlet baffle wall need to be reduced.

1.3.5 Material Overview, Handling and Safety

The Hydroworks HG (Hydroguard) separator series consists of a concrete manhole with internal co-polymer polypropylene components. For most units, the inner chamber and outlet baffle wall are installed at the pre-cast concrete manufacturing facility. This minimizes the potential for any installation errors. HG separator access for inspection and maintenance is achieved via multiple 24” covers (The HG 4 may have a single larger 30” or 36” cover due to lack of space for multiple 24” covers). The Hydroworks HG unit is easily maintained using a vactor truck or clam shell bucket.

Maintenance residuals should be disposed in accordance with local and state regulations. Solids recovered from the Hydroworks HG separator can typically be land filled and liquids disposed of at a wastewater treatment plant. There may be some specific land use activities that create contaminated solids, which will be captured in the system. Such material would have to be handled and disposed of in accordance with the appropriate regulatory requirements. With increased environmental regulations, local laws and regulations may contain stringent disposal guidelines, which vary from state to state; it is recommended the service company first check with local and state authorities prior to disposal of all pollutants removed from the HG separator.

1.4 Project Description

This verification project primarily involved the evaluation of company manuals and literature

and a third party laboratory test report to verify that the Hydroworks HG 6 separator satisfies the performance claim made by Hydroworks, LLC.

1.5 Key Contacts

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2. Evaluation of the Applicant

2.1 Corporate History

Hydroworks, LLC was founded by Graham Bryant in 2003. Mr. Bryant saw a need to improve upon existing hydrodynamic separator designs that were being promoted in the marketplace to facilitate maintenance and capture of larger solids/floatables during periods of high flow through the use of multiple flow paths through a separator (low flow/high flow). Development of the Hydroguard separator progressed through 2003 with Hydroworks, LLC being incorporated in New Jersey in October of 2003. The first unit was sold in November of 2003 in Massachusetts.

2.2 Organization and Management

Hydroworks, LLC is headquartered in Kenilworth, New Jersey and works with various manufacturers throughout the United States. Hydroworks is managed by Graham Bryant, a water resources engineer, who has 23 years of experience in water resources engineering and storm water management design. Mr. Bryant's experience in storm water includes:

- Principal author of the "Stormwater Management Practices Planning and Design Manual" for the Ministry of the Environment in Ontario Canada (1994) which was the guideline document for stormwater quality criteria in the province of Ontario from 1994-2002. The

numeric criteria for sizing stormwater quality BMPs that Mr. Bryant developed in 1994 are still being used today.

- Co-author of the MOE (Ministry of Environment) document "Stormwater Quality Best Management Practices" (1992)
- Lecturer for the MOE stormwater training program (1994)
- Updated flood damage curves for the Canadian side of the Great Lakes for the International Joint Commission (1988)
- Determined the flood damage assessment due to lake level regulation for Lake Superior (1987)
- Designed the stormwater piping network for Terminal 3 of Toronto International Airport
- Designer of numerous storm water management designs including storm drain surcharge analyses, water quality pond design, flood control pond design, infiltration recharge design, alternative municipal standards to promote LID, and watershed modeling
- Director of Engineering for Stormceptor (Imbrium) 1995-1999
- General Manager for Stormceptor for Rinker Materials (Stormceptor US licensee) 1999-2002

2.3 Operating Experience with the Proposed Technology

Hydroworks, LLC has over 850 Hydroguard separators installed in the United States. Hydroworks separators have been installed in CO, CT, FL, IL, IN, KY, MD, MN, NH, NJ, NY, OH, PA, RI, TX, VA, and WI.

Mr. Bryant has been involved in the design of storm water separators since 1998. While at Stormceptor/Rinker Materials, Mr. Bryant redesigned the standard inline Stormceptor, designed the inlet Stormceptor (STC450i), designed the submerged Stormceptor and the multiple Stormceptor separators (STC11000, STC13000, STC16000).

Hydroworks is involved in designing each Hydroguard separator. This allows customization of the internal components for any site specific concerns.

2.4 Patents

The Hydroguard is protected by patents issued by the U.S. Patent Office. Patents are pending in foreign countries. Patents for this technology and other hydrodynamic separators developed by Mr. Bryant include U.S. Patent Numbers 6,913,155, 6,951,619, and 7,022,243.

2.5 Technical Resources, Staff and Capital Equipment

Hydroworks has its corporate offices in Kenilworth, NJ. Mr. Bryant oversees all technical aspects of Hydroguard design and production. In addition, 2 full-time and one part-time staff provide inside sales, collections, and promotional support. Hydroworks also employs a field installer who visits each installation to ensure each separator is properly installed and provides field installation services when required.

In addition to the staff in the corporate office, Hydroworks promotion is conducted by its affiliates who make the concrete portion of the structure and who are involved in the regular day to day sales of drainage structures. Sales affiliates are primarily located in CT (United Concrete), MA (Hanson Pipe and Precast), WI (Wausau Concrete), and VA (Hanson Pipe and Precast).

Internal components of the Hydroguard are made by Millennium Plastics in Groveland, MA.

3. Treatment System Description

The Hydroworks HG separator is unique since it treats both high and low flows in one device, but maintains separate flow paths for low and high flows. Accordingly, high flows do not scour out the fines that are settled in the low flow path since they are treated in a separate area of the device as shown in Figure 1.

The HG separator consists of three chambers:

- an inner chamber that treats low or normal flows
- a middle chamber that treats high flows
- an outlet chamber where water is discharged to the downstream storm system

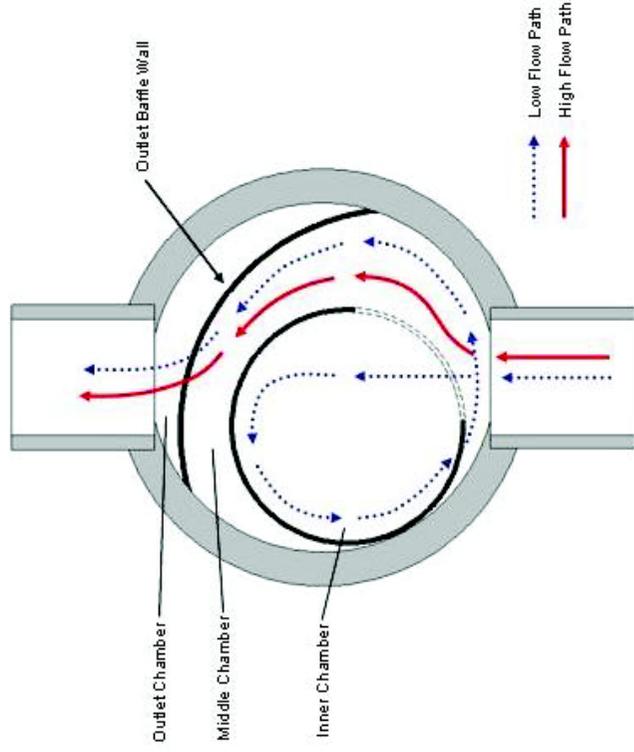


Figure 1 Hydroworks HG Operation – Plan View

Under normal or low flows, water enters the middle chamber and is conveyed into the inner chamber by momentum. Since the inner chamber is offset to one side of the structure the water strikes the wall of the inner chamber at a tangent creating a vortex within the inner chamber. The vortex motion forces solids and floatables to the middle of the inner chamber. The water spirals down the inner chamber to the outlet of the inner chamber which is located below the inlet of the inner chamber and adjacent to the wall of the structure but above the floor of the structure. Floatables are trapped since the outlet of the inner chamber is submerged. The design maximizes the retention of settleable solids since solids are forced to the center of the inner chamber by the vortex motion of water while the outlet of the inner chamber draws water from the wall of the inner chamber.

The water leaving the inner chamber continues into the middle chamber, again at a tangent to the wall of the structure. The water is then conveyed through an outlet baffle wall (high and low baffle). This enhances the collection of any floatables or suspended solids not removed by the inner chamber. Water flowing through the baffles then enters the outlet chamber and is discharged into the downstream storm drain.

During high flows, the flow rate entering the inner chamber is restricted by the size of the inlet opening to the inner chamber. This restriction of flow rate into the inner chamber minimizes the potential for the scour and re-suspension of solids from the inner chamber during periods of high flow. This is important since fines, which are typically considered highly polluted, are conveyed during low/normal flows. The excess flow is conveyed directly into the middle chamber where it receives treatment for floatables and suspended solids via the baffle system. This treatment of the higher flow rates is important since trash and heavier solids are typically conveyed during periods of higher flow rates. The Hydroworks HG separator is unique since it incorporates low and high flow treatment in one device while maintaining separate low and high flow paths to prevent the scour and re-suspension of fines.

Figure 2 is a profile view of the HG separator showing the flow patterns for low and high flows.

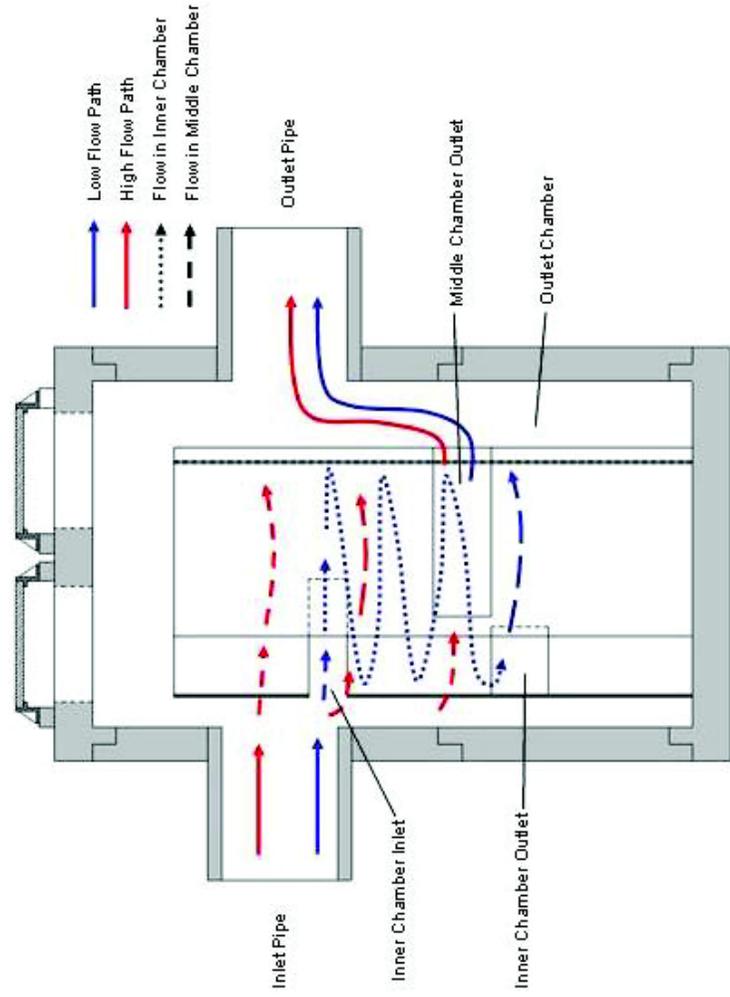


Figure 2 Hydroworks HG Operation – Profile View

The inner chamber and outlet baffle wall are designed not to be overtopped. In shallow applications where the pipe is close to the ground elevation and the drainage system is subject to full pipe flows/surcharging, the top of the outlet baffle will act as an emergency overflow if there is excess head in the unit due to surcharging or an obstruction in the device itself. Any overflow will result in the loss of floatables. In these situations an external upstream by-pass around the structure can be implemented. Hydroworks should be called for design assistance in cases where surcharging and/or high velocities/head losses are expected in the drainage system confluent to the separator.

4. Technical Performance Claim

Claim – The Hydroworks HG 6 separator, at a treatment flow rate of 1.8 cfs (808 gpm, 28.6 gpm/ft²), has been shown by mass balance testing to have a 60.5% solids removal efficiency (as per the NJDEP methodology for calculation of treatment efficiency) using NJDEP specified material with an average d_{50} particle size of 70 microns, influent concentration of 200 mg/L and 0% initial sediment loading in laboratory studies using simulated stormwater.

5. Treatment System Performance

In late 2008, under a contract from Hydroworks, LLC (Hydroworks), verification testing of a 6-foot diameter Hydroguard HG 6 hydrodynamic separator was conducted at Alden Research Laboratory, Inc. (Alden), Holden, Massachusetts. Testing was conducted in three phases: Phase 1 evaluated re-entrainment conditions, Phase 2 measured head loss values and established hydraulic characteristic curves, and Phase 3 determined the sediment removal efficiencies using a modified mass balance method. Phases 1 and 3 utilized the New Jersey Department of Environmental Protection (NJDEP) specified protocol sediment, with a PSD of 1 to 1000 microns and a specific gravity of 2.65. In addition, the weighted treatment efficiency determined in Phase 3 was calculated based on NJDEP weight factors.

5.1 Laboratory Testing

The HG 6 test unit is a circular separating device with internal structures that divide it into three chambers. The unit contains 14-inch influent and effluent pipes oriented on-center, with an influent invert elevation of 73 inches above the wetted floor and an effluent invert of approximately 72 inches. Both pipes were oriented in the test loop with 0.5% slopes. The inner chamber is 48 inches in diameter and has a 22-inch wide by 10.5-inch high rectangular opening with an invert elevation of 71.0 inches. The opening is aligned on-center with the influent pipe. The inner chamber also contains a 36-inch wide by 9-inch high rectangular opening with an invert elevation of 36 inches, which allows flow to pass from the inner chamber to the middle chamber. A two-piece (upper and lower) outlet baffle wall separates the middle chamber from the outer chamber. The lower wall extends from the floor to an elevation of 42 inches. A 15-inch high opening separates the lower and upper walls and allows flow to pass from the middle chamber into the outer chamber and then out the effluent pipe. Figure A.1 in Appendix A shows a layout drawing of the HG 6 test unit.

5.1.1 Test Facility Description

Figure A.2 shows the closed test loop, located in Alden's test facility, which was used to test the HG 6 separator. Water was supplied to the unit with either a 20HP or 50HP pump (flow capacity of approximately 9cfs), which draw water from a 50,000-gallon supply sump. One of five (5) calibrated flow meters (2, 4, 6, 8, and 12-inch), connected to a manifold, carried the test flow to a section of 12-inch piping, 90-degree elbow, 12-inch by 14-inch expansion and 12 feet (10 diameters) of 14-inch influent pipe. Water then passed through the test unit and 14-inch diameter effluent pipe to return to the laboratory sump. The effluent pipe contained an isokinetic sampling-tube array, located approximately 3 feet downstream of the test unit, to collect the effluent sediment concentration and PSD samples during re-entrainment testing. The array consisted of two (2) vertically adjustable sampling tubes (water level dependent), each containing a flow-control shut-off valve. Sediment was injected into the crown of the influent pipe through a vertical pipe connected to a tee located approximately 2 feet upstream of the test unit.

5.1.2 Instrumentation and Measuring Techniques

Flow

The inflow to the test unit was measured using one of five (5) calibrated flow meters. Each meter was fabricated per ASME guidelines and calibrated in Alden's Calibration Department prior to the start of testing. Flows were set with a butterfly valve and the differential head from the meter was measured using a Rosemount® 0 to 250-inch Differential Pressure (DP) cell, also calibrated at Alden prior to testing. The test flow was averaged and recorded approximately every 9 seconds throughout the duration of the test using a computerized data acquisition (DA) program. The accuracy of the flow measurement is estimated at $\pm 2\%$.

Temperature

Water temperature measurements within the sump were obtained using a calibrated Omega® DP41 temperature probe and readout device. The calibration was performed at the laboratory prior to testing. The temperature reading was entered into the DA program at the start of each test for use in the flow measurement calculations.

Pressure Head

The pressure head readings recorded during Phase 2 testing were measured using a Rosemount® 0 to 60-inch DP cell. The pressure cell was calibrated at Alden prior to testing. A minimum of 1-minute of pressure data was recorded for each pressure tap, under steady-state flow conditions, using a computerized DA program.

Sediment Injection

During Phase 3, NJCAT protocol sediment was injected into the test unit (PSD of 1 - 1,000 microns.) The test sand was introduced into the influent pipe using an Auger® volumetric screw feeder, model VF-1. The Auger feed screws used in testing ranged in size from 0.75 to 1 inch, depending on the test flow. Each auger screw, driven with a variable-speed drive, was calibrated with the test sediment prior to testing, in order to establish a relationship between screw RPM and feed rate in mg/minute. The feeder has a 1.5 cubic foot hopper at the upper end of the auger to provide a constant supply of dry test sand.

Sample Collection

As described in Section 5.1.1, isokinetic sampling tubes were located within the effluent piping to collect the sediment concentration samples during Phase 1 testing. The sampling tubes were 0.50 and 0.75 inches in diameter. The tube array was vertically adjusted and calibrated prior to testing, to match the velocities for each flow condition.

Sample Concentration Analysis

Concentration samples were analyzed using the Suspended Solids Concentration (SSC) method which utilizes the entire sample in the analysis. The samples were processed at Alden as described below.

Collected samples were filtered and analyzed by Alden in accordance with Method B, as described in ASTM Designation: D 3977-97 (Re-approved 2002), “Standard Test Methods for Determining Sediment Concentration in Water Samples”. The required silica sand used in the sediment testing did not result in any dissolved solids in the samples and therefore, simplified the ASTM testing methods for determining sediment concentration.

Samples were collected in graduated 2-Liter beakers which were cleaned, dried and weighed to the nearest 0.1-gram, using an Ohaus® 4000g x 0.1g digital scale, model SCD-010, prior to sampling. Collected samples were also weighed to the nearest 0.1-gram using the Ohaus® digital scale. Each collected sample was filtered through a pre-rinsed Whatman® 934-AH, 47-mm, 1.5-micron, glass microfibre filter paper, using a laboratory vacuum-filtering system. Prior to processing, each filter was rinsed and placed in a designated dish and dried in an Oakton® StableTemp gravity convection oven, model 05015-59, at 225 degrees F for a minimum of 2 hours. Each dried filter/dish set was then weighed to the nearest 0.0001-gram, using an AND® analytical balance, model ER-182A. Once filtered, each sample and dish was dried at a temperature between 175 and 210 degrees F (below boiling) for 20 to 30 minutes until visually dry. The oven temperature was increased to 225 degrees F and the samples were dried for an additional 2-½ to 3 hours. The dry samples and dishes were then weighed to the nearest 0.0001-gram, using the AND® balance. Net sediment weight (mg) was determined by subtracting the dried filter weight from the dried sample weight and multiplying the result by 1,000. The net sample volume, in liters, was determined by subtracting the beaker and net sediment weight from the overall sample weight and dividing by 1,000. Each sample sediment concentration, in mg/liter, was determined by dividing the net sediment weight by the net sample volume. The effluent concentration for each flow condition was adjusted for background. The background samples were collected at the pump effluent and processed as described above.

Test Sediment Mix and Particle Size Distribution

NJ#00N, OK110 and Min-U-Sil 40 silica sand, available from US Silica, was used to produce the test sediment as required by the NJDEP testing protocol. Table 3 shows the theoretical PSD of each grade of sand, as well as the mix ratios and resulting percentages. Random dry samples were analyzed for PSD with a resulting average d_{50} of approximately 70 microns which, as shown on Figure 3, matches the NJDEP estimated d_{50} of 67 microns.

Table 3 Test Sediment Mix Using Commercially Available US Silica Sand

Range	Target	Mesh	Microns	NJ # 00N	OK-110	Min-U-Sil 40	%	%	%	Total
	NJCAT			11%	46%	43%				
500-1000	5%	20	850	45			5.0			5.0
250-500	5%	40	425	52			5.7			6.1
		50	300	3			0.3			
100-250	30%	70	212		1			0.5		
		100	150		15			6.9		
		120	125		48			22.1		29.4
		140	106							
50-100	15%	170	88		24			11.0		
		200	75		9.7			4.5		
		270	53		1.9			0.9		16.4
8-50	25%					60			25.8	25.8
2-8	15%					28			12.0	12.0
1-2	5%					12			5.2	5.2
		Total		100	99.6	100				99.8

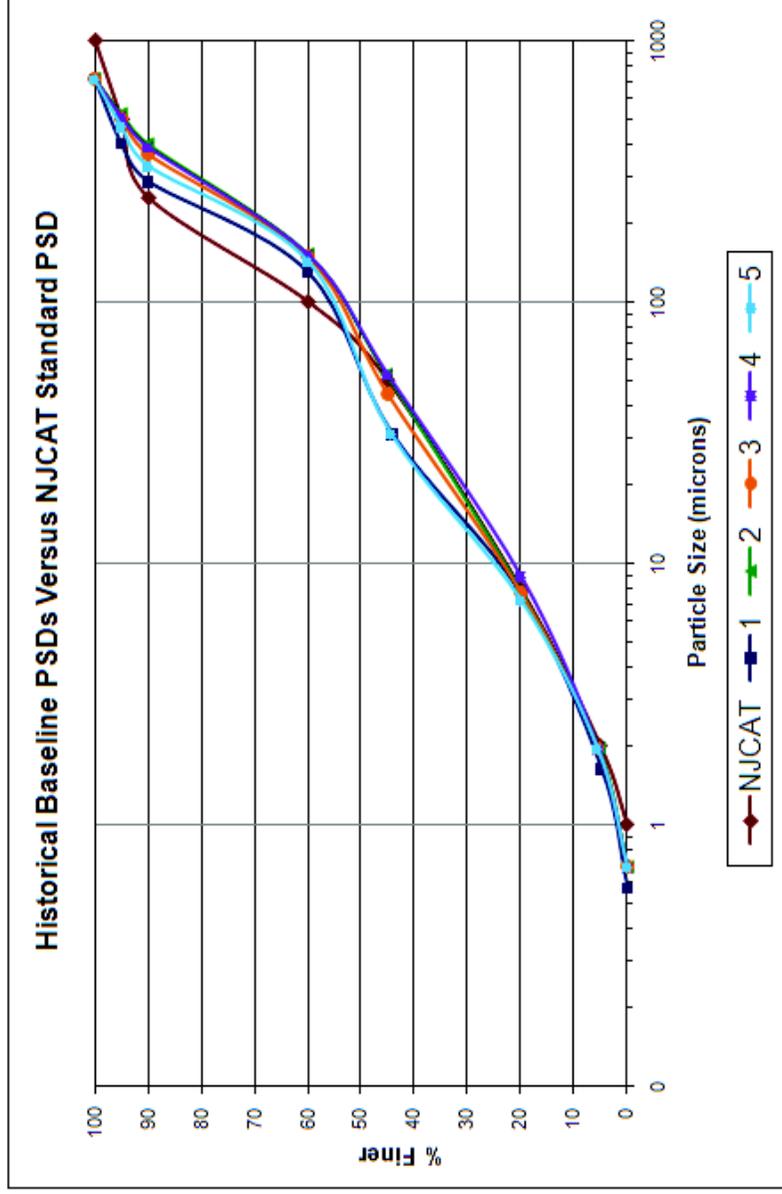


Figure 3 Test Sediment Mix PSD

Mass Balance Analysis

For tests completed during Phase 3, a modified mass balance method was used to determine sediment removal efficiency. A true mass balance test accounts for all the mass within a system, including total influent, and captured and effluent quantities. However, with flows ranging from 0.45 to 2.25 cfs, it is extremely difficult and consequently, expensive to capture the fine effluent sediment without compromising the integrity of the test. Therefore, modified mass balance tests, in which the influent and captured sediment is accounted for, were performed on the HG 6 unit. The weight of injected sediment was determined by weighing the loaded screw feeder, which was mounted on a hydraulic table, before and after testing. The scale used was a 0-500 lb Ohaus® Champ SQ digital scale, model CQ250-XL11W, equipped with a 0.05 resolution CW11 digital controller. This provided the total mass of sediment introduced into the test unit.

After the completion of each test, water was decanted from the test unit by means of a gravity siphon. The captured sediment and any remaining water were then collected from the test unit using a pre-cleaned wet vacuum. The collected sediment was placed in pre-weighed trays and dried in a Modern Laboratory Equipment® oven, model 155-SS, for approximately 24 hours. The dried sediment was then weighed with the Ohaus scale and the captured weight was calculated by subtracting the tray weight from the gross weight. The removal efficiency for each flow condition was calculated using the following equation:

$$\% \text{ Efficiency} = \frac{\text{Net Captured Weight}}{\text{Net Injected Weight}} \times 100$$

5.2 Test Procedures

The test procedures for the HG 6 unit, developed by Hydroworks in coordination with Alden, were not consistent with NJDEP protocols. However, the partial mass balance method employed is equivalent to the SSC influent and effluent method typically employed. The testing was conducted in three phases as described below.

5.2.1 Phase 1 – Re-entrainment and Washout

Re-entrainment tests were performed at flows ranging from 0.4 to 2.0 cfs, with sediment loadings of 100% (9.3 ft³) and 50% (4.6 ft³) of the unit's capacity (as stated by Hydroworks). It was estimated (by Hydroworks) that the inner chamber retains approximately 80% of sediment captured by the unit and the remaining 20% is retained in the middle chamber. Therefore, an 80/20 split was used for the sediment loading. The area of the inner chamber is 12.6 ft² and the area of the middle chamber is 8.8 ft². For the 100% tests, 7 inches of sediment was loaded in the inner chamber and 2.5 inches in the middle chamber. For the 50% tests, 3.5 inches of sediment was loaded in the inner chamber and 1.25 inches in the middle chamber. Two re-entrainment tests were performed at 100% and 50% loading with NJCAT mix (1 to 1,000 microns).

The unit was slowly filled to the invert of the effluent pipe. The shape of the sediment bed was established by incrementally increasing the flow to 1.2 cfs, allowing the system to run until the effluent was clear or for a maximum duration of one hour. The system remained idle for a minimum of 24 hours prior to testing to let the newly established sediment bed settle. Testing was conducted by incrementally increasing the flow of clean water (no influent sediment) into the unit under steady-state conditions, while continuously obtaining flow data. Effluent samples, for SSC and PSD analyses, were obtained at the targeted flows (0.4, 0.8, 1.2, 1.6 and 2.0 cfs.) A series of four (4) samples were collected every 5 minutes at each steady-state target flow, to allow insight into trends and/or anomalies of sediment movement.

5.2.2 Phase 2 – Hydraulic Capacity and Characteristics

The unit was tested without sediment to determine its hydraulic characteristics. Flow and pressure head measurements across the unit were recorded for 16 conditions. Each test flow was set and allowed to reach steady state, at which time a minimum of 1 minute of flow and pressure data were recorded and averaged for each pressure tap location. Observations were documented throughout the test, including conditions in the inner, middle and outer chambers (internal measurements) and water elevations in the influent and effluent pipes (system measurements). Pressure head measurements were recorded at 5 locations (see Figure A.3): approximately one pipe diameter upstream of the test unit (Tap A), along the wall in the inner chamber (Tap B), along the wall in the middle chamber (Tap C), along the wall in the outer chamber (Tap D), and one pipe diameter downstream of the test unit (Tap E). The discharge and loss coefficients (Cd and K) were calculated for both the internal and system losses.

5.2.3 Phase 3 – Sediment Removal Efficiency Testing

The test unit was thoroughly cleaned prior to the start of each test. The test flow was set and allowed to reach steady state. The test sediment was injected into the influent line at a target concentration of 200 mg/L for duration of time sufficient to introduce approximately twenty (20) pounds of sediment into the unit. The sediment injection was stopped and 3 system volumes of water were allowed to pass through the system prior to the termination of the test. The unit was drained and cleaned, and the removal efficiency determined utilizing the modified mass balance methodology described in Section 5.1.2.

It was observed that each collection tray contained both settled and suspended sediment particles when placed in the drying oven. After full drying of the sediment was complete, an encrusted top layer was present in each tray, which was the result of the fine particles bonding together during the drying process. This bonding of particles did not affect the resulting removal efficiencies. However, the reported PSD results show that the particles still possessed some cohesive qualities, as the smallest measured particle sizes do not correlate well with the resulting removal efficiencies. Passing the dried sediment through fine screens and preparing the samples as wet samples prior to shipping may have corrected this problem.

5.3 Verification Procedures

All the data provided to NJCAT were reviewed to fully understand the capabilities of the Hydroworks HG 6 separator. To verify Hydroworks' claim, the Alden laboratory test procedures and data were reviewed and compared to the NJDEP TSS laboratory testing procedure.

5.3.1 Laboratory Testing Results

Re-entrainment and Washout

Re-entrainment tests were performed at flows ranging from 0.4 to 2.0 cfs, with initial sediment loadings of 100% (9.3 ft³) and 50% (4.6 ft³) of the unit's capacity (as stated by Hydroworks). The sediment beds were prepared with a varying deposition profile, as described in Section 5.2.1, based on field observations supplied by Hydroworks. Each test was conducted by incrementally increasing the flow while collecting effluent samples. A series of four (4) effluent samples were collected for SSC analysis and one for PSD analysis, at the steady-state target flows of 0.4, 0.8, 1.2, 1.6 and 2.0 cfs.

Fifty percent (50%) loading

Measured sediment concentrations (SSC) adjusted for background concentrations increased from 2.2 mg/L at 0.4 cfs, to 36.1 mg/L at 2.0 cfs. Background sample concentrations increased from 4.41 mg/L at the beginning (~5 min) of the re-entrainment and washout testing to 13.7 mg/L at the end of the 100 minute test period. Effluent concentrations were low (<2.5 mg/L) up to 0.80 cfs and increased steadily thereafter with increasing flow rate as shown in Figure 4. The effluent PSD data indicated that, at the maximum flow of 2.0 cfs, the unit was able to retain particles over 25 microns (d₉₅).

One hundred percent (100%) loading

Measured sediment concentrations (SSC) adjusted for background concentrations increased from 4.3 mg/L at 0.4 cfs, to 44.1 mg/L at 1.6 cfs, then decreased to 41.5 mg/L at 2.0 cfs. Background sample concentrations increased from 1.7 mg/L at the beginning (~5 min) of the re-entrainment and washout testing to 18.9 mg/L at the end of the 100 minute test period. Effluent concentrations were low (<5.5 mg/L) up to 0.80 cfs and increased steadily thereafter with increasing flow rate to 1.6 cfs, before slightly decreasing. The effluent PSD data indicated that, at the maximum flow of 2.0 cfs, the unit was able to retain particles over 30 microns (d₉₅).

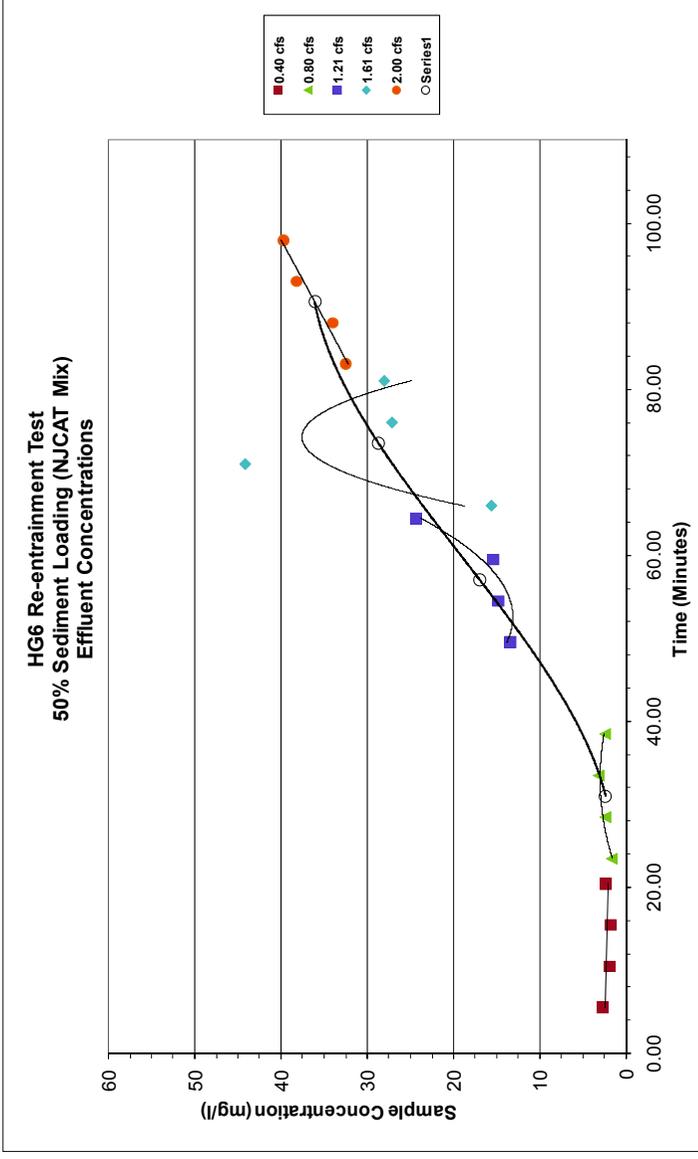


Figure 4 Re-entrainment Effluent Sample Concentrations at 50% Loading Capacity

Hydraulic Capacity

Flow (gpm) and water level (inches) within the unit were measured for 19 flows ranging from 0.4 to 7.9 cfs. The influent pipe was estimated to be flowing full at approximately 3.3 cfs. The entrance to the effluent pipe was submerged at approximately 3.3 cfs, and the effluent pipe was measured to be flowing full at the tap at approximately 5 cfs. The flow did not overtop the baffle walls at maximum flow.

Sediment Removal Efficiency

Removal efficiency tests were conducted at five (5) flows ranging from 0.45 to 2.25 cfs with a target influent sediment concentration of 200 mg/l. One random sample was collected from the captured sediment during each test for particle size distribution (PSD) analysis. Each sample was analyzed using the Beckman Multisizer3 Coulter Counter. It needs to be noted that the smallest measured particle size for all tests except the 0.75 cfs test (26 microns) do not correlate with the measured removal efficiency results. This is most likely due to the limitations of the PSD analysis methodology to break down the coagulated particles (caused by the drying process, as described in Section 5.2.3) to their smallest grain size.

Sediment Removal Efficiency – 2.25 cfs

The average flow recorded for the entire test was 1014.5 gpm (2.26 cfs), with a standard deviation (SD) of 1.96. The recorded temperature for the test was 65.0 degrees F. The net

weight of sediment injected was 21.7 lbs. The net weight captured was 9.35 lbs. The resulting sediment removal efficiency was 43.1%. The background concentrations taken at the start and end of the test were 5.31 and 11.55 mg/L.

The smallest captured particle measured was greater than 88 microns. This data correlates fairly well with the measured removal efficiency of 43.1%, which has an estimated particle size of approximately 100 microns.

Sediment Removal Efficiency – 1.88 cfs

The average flow recorded for the entire test was 847.7 gpm (1.89 cfs), with a standard deviation (SD) of 3.48. The recorded temperature for the test was 63.1 degrees F. The net weight of sediment injected was 24.2 lbs. The net weight captured was 11.70 lbs. The resulting sediment removal efficiency was 48.3%. The background concentrations taken at the start and end of the test were 1.40 and 5.96 mg/L.

The smallest captured particle measured was greater than 88 microns. This data shows a larger particle size than anticipated for a removal efficiency of 48.3%, which has an estimated particle size of approximately 80 microns.

Sediment Removal Efficiency – 1.5 cfs

The average flow recorded for the entire test was 677.6 gpm (1.51 cfs), with a standard deviation (SD) of 1.43. The recorded temperature for the test was 70.6 degrees F. The net weight of sediment injected was 21.0 lbs. The net weight captured was 11.50 lbs. The resulting sediment removal efficiency was 54.8%. Background concentration samples were not taken during the test; however, background levels were observed to be minimal.

The smallest captured particle measured was greater than 74 microns. This data shows a larger particle size than anticipated for a removal efficiency of 54.8%, which has an estimated particle size of approximately 60 microns.

Sediment Removal Efficiency – 0.75 cfs

The average flow recorded for the entire test was 337.6 gpm (0.75 cfs), with a standard deviation (SD) of 1.04. The recorded temperature for the test was 63.5 degrees F. The net weight of sediment injected was 26.4 lbs. The net weight captured was 16.90 lbs. The resulting sediment removal efficiency was 64.0%. The background concentrations taken at the start and end of the test were 0.29 and 5.08 mg/L.

The smallest captured particle measured was greater than 26 microns. This data correlates fairly well with the measured removal efficiency of 64.0%, which has an estimated particle size of approximately 25 microns.

Sediment Removal Efficiency – 0.45 cfs

The average flow recorded for the entire test was 203.3 gpm (0.45 cfs), with a standard deviation (SD) of 0.50. The recorded temperature for the test was 64.1 degrees F. The net weight of sediment injected was 18.5 lbs. The net weight captured was 13.70 lbs. The resulting sediment removal efficiency was 74.1%. The background concentrations taken at the start and end of the test were 5.13 and 6.26 mg/L.

The smallest captured particle measured was greater than 62 microns. This data shows a larger particle size than anticipated for a removal efficiency of 74.1%, which has an estimated particle size of approximately 12 microns.

Summary

The calculated removal efficiencies ranged from 43.1% to 74.1% for the five tests conducted. The testing data summary is shown in Table 4 and the removal efficiency curve is shown on Figure 5.

Table 4 Sediment Removal Efficiency Testing Summary
Modified mass balance method

Target Flow (cfs)	Recorded Flow (cfs)	Injected Wt. (lbs)	Captured Wt. (lbs)	Efficiency (%)
2.25	2.26	21.7	9.35	43.1
1.88	1.89	24.2	11.7	48.3
1.50	1.51	21.0	11.5	54.8
0.75	0.75	26.4	16.9	64.0
0.45	0.45	18.5	13.7	74.1

The HG 6 removal efficiency curve plotted in Figure 5 was used to determine removal efficiencies at 25%, 50%, 75%, 100% and 125% of the treatment flow (1.8 cfs) in order to calculate an NJCAT weighted efficiency of 60.5%. The removal efficiencies and the weighted efficiency data are shown in Table 5.

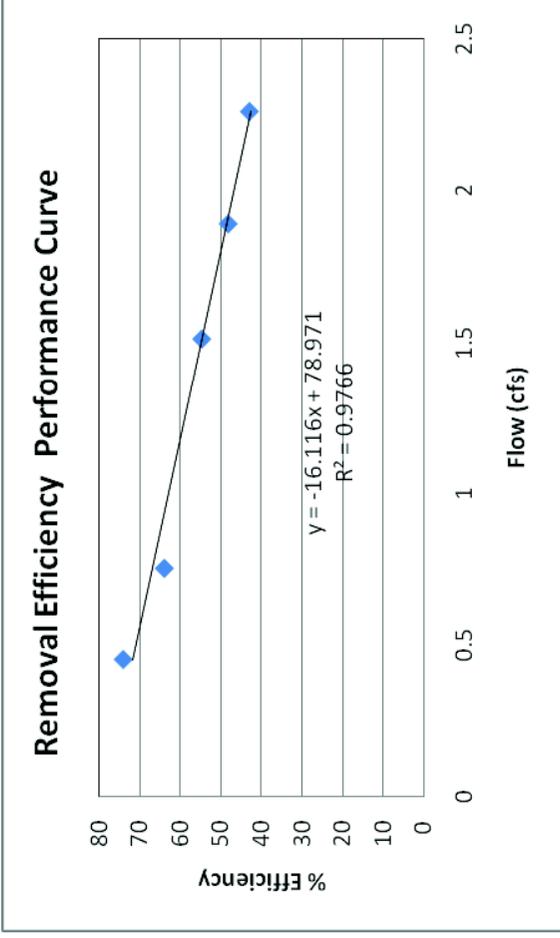


Figure 5 HG 6 Removal Efficiency Curve

Table 5 Sediment Removal Weighted Efficiency

	Flow (cfs)	Efficiency	NJ Weighting	Weighted Eff.
125%	2.25	42.7	0.1	4.3
100%	1.80	50.0	0.15	7.5
75%	1.35	57.2	0.2	11.4
50%	0.90	64.5	0.3	19.4
25%	0.45	71.7	0.25	17.9
				60.5

5.4 Maintenance

Although all parts of the Hydroguard should be inspected, inspection and maintenance should focus on the inner and middle chambers since this is where the pollutants (floatables and sinking) will accumulate. A visual inspection can be conducted for floatables by removing the covers and looking down into the separator. Multiple covers are provided on Hydroworks HG unit to access all areas of the separator (The HG 4 may have a single larger (30" or 36") cover due to the lack of space for multiple 24" covers). Inspection for TSS build-up can be conducted using a Sludge Judge®, Core Pro®, AccuSludge® or equivalent sampling device that allows the measurement of the depth of TSS/sediment in the unit. The Hydroworks HG unit is typically maintained using a vactor truck or clam shell bucket. There are numerous companies that can maintain the HG separator. Envirocalm, LLC, an affiliated company of Hydroworks, offers inspection and maintenance services and can inspect and maintain the HG separator. (www.envirocalm.com).

Maintenance intervals are determined from monitoring the Hydroguard separator during its first

year of operation. After completion of the first year of operation, the established inspection and maintenance intervals will keep pollutant loadings within their respective limits. Establishing and adhering to a regular maintenance schedule ensures optimal performance of the system. Depending on the site, some maintenance activities may have to be performed on a more frequent basis than others. All inspection and maintenance activities should be recorded in an Inspection and Maintenance Log.

Sediment, vegetation, and gross debris can generally be disposed of at the local landfill in accordance with local regulations. The toxicity of the residues produced will depend on the activities in the contributing drainage area and testing of the residues may be required if they are considered potentially hazardous. Settling chamber water can generally be disposed of at a licensed water treatment facility, but the local sewer authority should be contacted for permission prior to discharging the liquid. Significant accumulations of oil removed separately from the Hydroguard separator should be transported to a licensed hazardous waste treatment facility for treatment or disposal. In all cases, local regulators should be contacted about disposal requirements. Maintenance of the Hydroworks HG separator typically takes 1 to 2 hours.

6. Technical Evaluation Analysis

6.1 Verification of Performance Claim

Based on the evaluation of the results from laboratory studies, sufficient data are available to support Hydroworks' claim.

Claim – The Hydroworks HG 6 separator, at a treatment flow rate of 1.8 cfs (808 gpm, 28.6 gpm/ft²), has been shown by mass balance testing to have a 60.5% solids removal efficiency (as per the NJDEP methodology for calculation of treatment efficiency) using NJDEP specified material with an average d₅₀ particle size of 70 microns, influent concentration of 200 mg/L and 0% initial sediment loading in laboratory studies using simulated stormwater.

6.2 Limitations

As with any stormwater quality treatment practice, lack of inspections and maintenance will lead to reduced performance.

6.2.1 Factors Causing Under-Performance

As stormwater treatment structures fill up with pollutants they become less and less effective in removing new pollution. Therefore it is important that stormwater treatment structures be maintained on a regular basis to ensure that they are operating at optimum performance. The Hydroguard separator is no different in this regard. During the construction period, the Hydroguard separator should be inspected every two weeks and after every large storm (>0.5" of rain). During the post-construction period, the Hydroworks Hydroguard separator should be inspected once per year for normal stabilized sites (grassed or paved areas). If the unit is subject

to oil spills or runoff from unstabilized (storage piles, exposed soils) areas, the HG separator should be inspected more frequently (4 times per year). If the Hydroguard separator has reached maximum storage capacity of floatables or sediment and has not been serviced, one would expect to see an increase in resuspension of captured pollutants or sediment. Maintenance of the Hydroguard separator should be performed by properly trained and certified personnel utilizing all required OSHA requirements. The actual maintenance interval is driven by the site pollutant loading characteristics. Quarterly field inspections will minimize the potential for a failure.

Upon completion of the construction project the system should be cleaned and cleared of any debris or sediment prior to release to the owner. This process will prevent a need for early cleanout or the potential for under performance.

6.2.2 Pollutant Transformation and Release

The Hydroworks HG 6 separator will not create additional pollutants in the downstream environment; however if the system is not inspected and serviced on a regular maintenance cycle due to the constant water pool in the chambers there may be a transformation of the trapped pollutants that could occur inside the system. Organic matter is one example where studies have shown that the decomposition of the collected matter has produced phosphates or nitrates. Sediment collected in the system will not be lost during normal operating conditions with the use of a regular maintenance program as dictated during inspections.

6.2.3 Sensitivity to Heavy Sediment Loading

Heavy sediment loads may require a shorter maintenance interval or potentially cause the system to re-suspend captured pollutants. If unforeseen excessive pollutants are collected from the site and washed into the system (e.g. due to construction activities on or around the site, excessive or other than normal site traffic, construction activity in the path of traffic entering the treatment area) when the system is near full capacity, resuspension of sediment may result. Regular inspection or increased inspection during these times of potential increased sediment loading is recommended to minimize any failure in Hydroguard separator performance.

6.2.4 Mosquitoes

The Hydroworks Hydroguard separator is a wet chamber system that will contain water collected during normal operation and retained after events. The volume of water contained may decrease during long dry spells due to evaporation; however there is the possibility for this to be an area of concern for the breeding of mosquitoes.

7. Net Environmental Benefit (NEB)

Once the Hydroworks HG separator has been granted interim certification by the NJDEP, Hydroworks, LLC will proceed to install and monitor a system in the field for the purpose of achieving goals set by the Tier II Protocol and final certification. At that time a net environmental benefit evaluation will be completed. However, it should be noted the

Hydroworks HG separator has no moving parts, and therefore, uses no water or energy.

8. References

Mailloux, J. T., and Humphrey, A. N. (2008). Verification Testing of the Hydroguard HG6 Hydrodynamic Separator Stormwater Treatment Unit. Prepared for Hydroworks, LLC, Kenilworth, NJ. December 23, 2008.

Appendix A

Figure A.1 Hydroworks HG 6 Test Unit

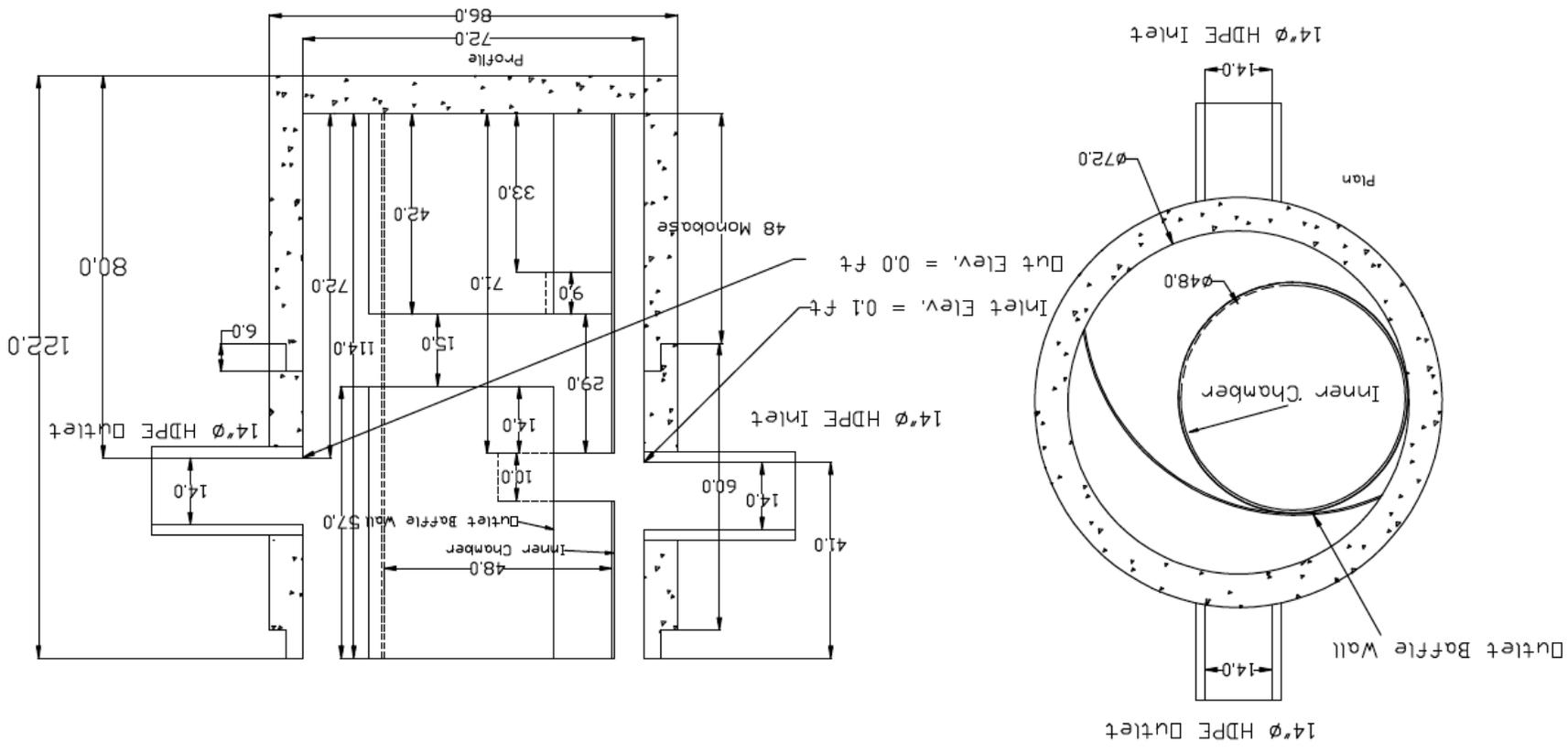
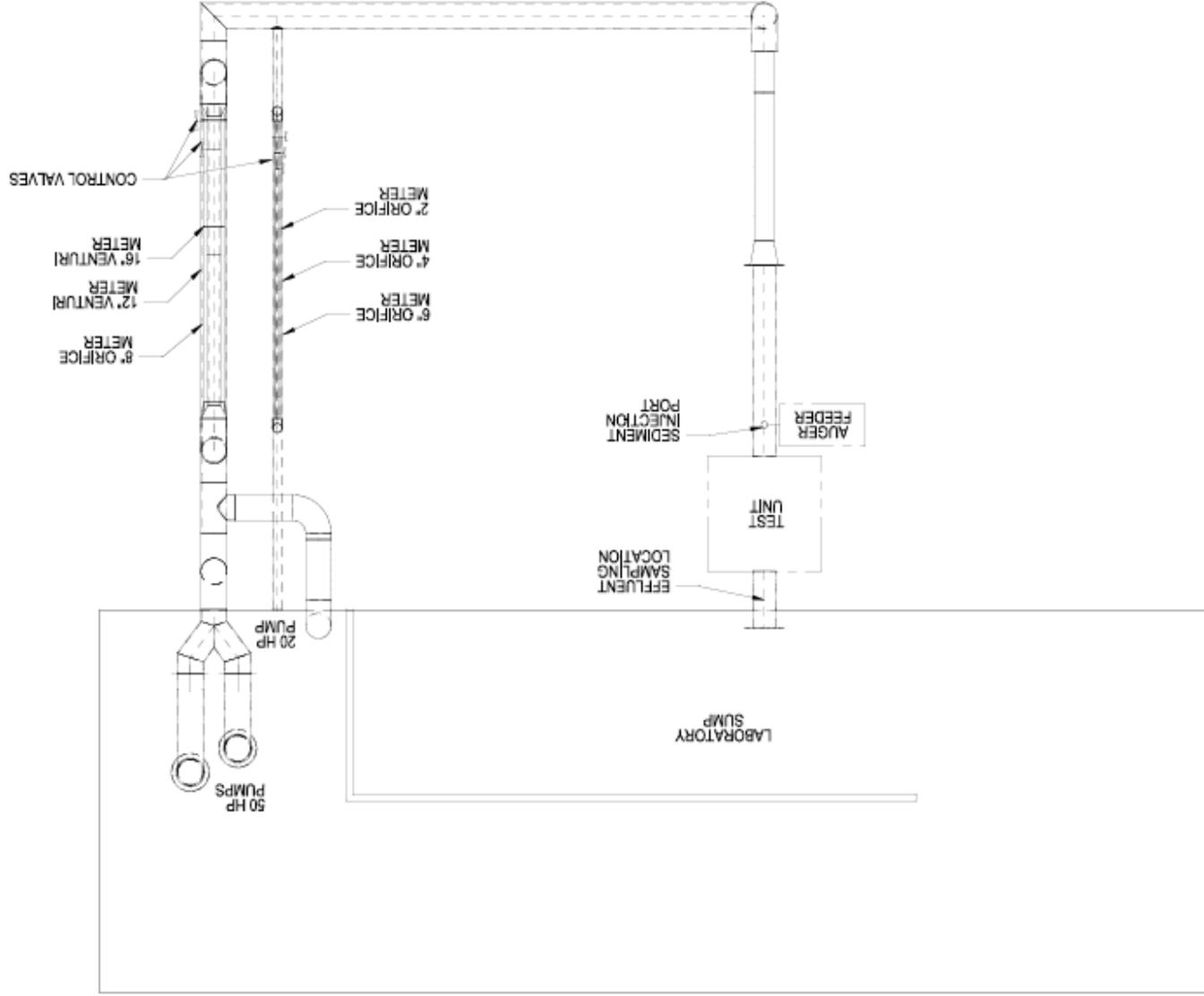


Figure A.2 Alden's Stormwater Laboratory Flow Loop



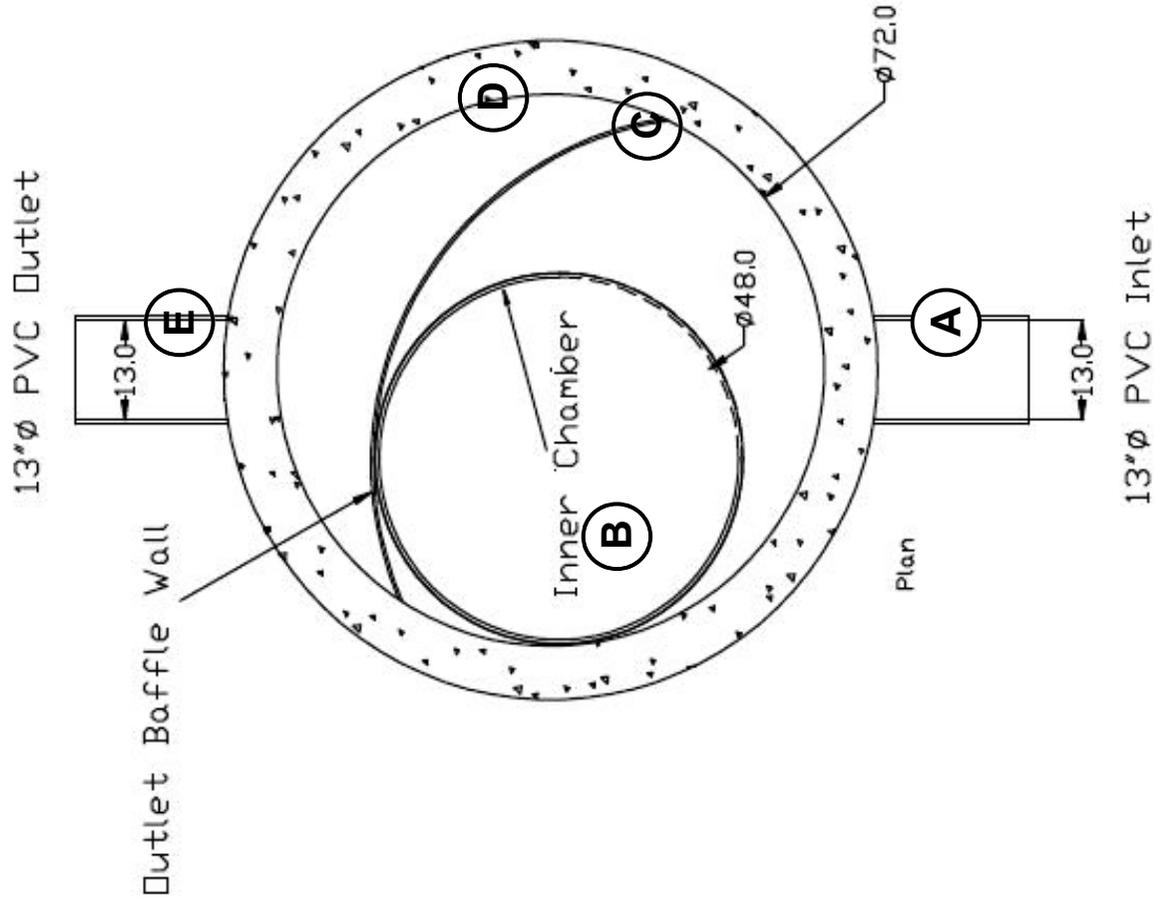


Figure A.3 Pressure Tap Locations