FINAL REPORT

STORMWATER TREATMENT DEVICES SECTION 319 PROJECT

PROJECT # 99-07

SUBMITTED TO:

CONNECTICUT DEPARTMENT OF ENVIRONMENTAL PROTECTION
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ABSTRACT

The effectiveness of four stormwater treatment devices in retaining pollutants was monitored in Connecticut. The four stormwater treatment devices were the Downstream Defender ™, the Stormtreat ™, the Storm*ceptor*®, and the Vortechnics ™. In addition, a catch basin was monitored. Influent and effluent from each system was sampled for flow, and weekly composite samples were analyzed for total suspended solids (TSS), total phosphorous (TP), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), and nitrate+nitrite-nitrogen (NO_3-N). Monthly composite samples were analyzed for total copper (Cu), total lead (Pb), and total zinc (Zn). Quarterly grab samples were analyzed for fecal coliform bacteria (FC), and total petroleum hydrocarbons (TPH). Both peristaltic pump automatic samplers and Coshocton wheels were used to collect samples. The Downstream Defender ™ was only sampled for 9 mo. because it leaked. A Coshocton wheel was a more efficient sampler than the automatic sampler. Some differences existed in the quality of stormwater across sites. The street runoff at the construction site, where the Storm*ceptor*® was located, was higher in concentrations of TSS and TP. The commercial parking lot at the StormTreat ™ had runoff that was highest in TPH. Runoff from the new parking lot at the Vortechnics ™ site was highest in Zn concentrations. Retention is summarized in the table below. NO_3-N and NH_3-N were not generally retained. An exception was NO_3-N at the Vortechnics ™ (54 %) but concentrations were low. Metal retention varied among metal and system. Zn retention was highest among the metals. A study comparing the Coshocton wheel to peristaltic pumps in collecting stormwater samples should be conducted. Stormwater treatment devices are expensive. About one–half the cost is in the installation. Every effort should be made in pollution prevention so that the costs of downstream treatment can be minimized. There are numerous other stormwater treatment devices available that have not been tested. Further studies could be conducted of these new and innovative systems.

Summary Table

Mass Retention (%)	Downstream[1] Defender ™	Storm*ceptor*®	Stormtreat ™	Vortechnics ™
Suspended solids	45	34	49	77
Total phosphorus	28	29	74	67
Total Kjeldahl N	16	32	44	18
Zn	--	60	45	85
Fecal coliform bacteria	--	-15	99	-7
TPH concentration	--	12	37	16

[1] Concentration basis only

INTRODUCTION

The Long Island Sound Study (LISS) has found that stormwater runoff from urban and suburban areas of Connecticut is the primary source of nonpoint source pollution in the Sound (LISS 1994). Stormwater runoff has increased nitrogen loading, pathogens, toxic substances and floatable debris in the Sound.

Pathogen contamination in Long Island Sound has been responsible for 1,440 beach-day closures from 1986 to 1990 (LISS, 1994). Also 73 % of the shellfish beds in New York and 35 % in Connecticut have been classified as "Restricted/Prohibited" due to pathogen contamination from both point and nonpoint sources. However, some closures are due to automatic guidelines such as a certain sized rainfall event. Urban runoff, including combined sewer overflows (CSO's) are believed to be responsible for 47 % of the fecal coliform loading to Long Island Sound (LISS, 1994). Rivers, including upstream point and nonpoint sources add an additional 52 %. Floatable debris is found in the Sound, its bays and washed up on beaches. Most (74 %) is plastics. This debris is a threat to estuarine life. The floatable debris in the sound comes from stormwater discharges and CSOs, tributaries, and shoreline visitors and boaters. It is believed that 82 % of the debris is from storm sewers and CSOs (LISS, 1994).

Several stormwater treatment devices are available today that have applications in both existing stormwater systems and in new developments. Most of these systems are designed to reduce sediment, and in some cases, trap oil and grease. However, other nonpoint pollutants are likely to be reduced as well, such as those that are adhered to sediment. Currently we do not know how effective the various stormwater treatment devices are in treating the pollutants in stormwater runoff. There is a need for CT Department of Environmental Protection and the US Environmental Protection Agency to provide guidance on the effectiveness of these systems in treating nonpoint pollutants. Therefore, there is a need to monitor these systems in a uniform quality assured manner.

OBJECTIVES

The purpose of the study was to monitor the treatment effectiveness of four stormwater treatment devices installed at several locations in Connecticut. The four stormwater treatment devices were: the Downstream Defender ™ on a residential street in New London, Ct., the Stormtreat ™ System in a McDonald's parking lot in East Hartford, the Storm*ceptor*® on a new residential street in Waterford (funded from other sources), and the Vortechnics ™ in the parking lot of Timothy Edwards Middle School in South Windsor (Figure 1). In addition, in July 2000 monitoring of a catch basin was added at the Vortechnics ™ site. It is important to know that the four devices were not monitored side-by-side at the same location, during the same time period, and using the same stormwater runoff. Although that design would have been preferred, funding limitations prevented that type of direct comparison.

A secondary purpose at some of the sites was to determine if climate variables and season influenced treatment effectiveness.

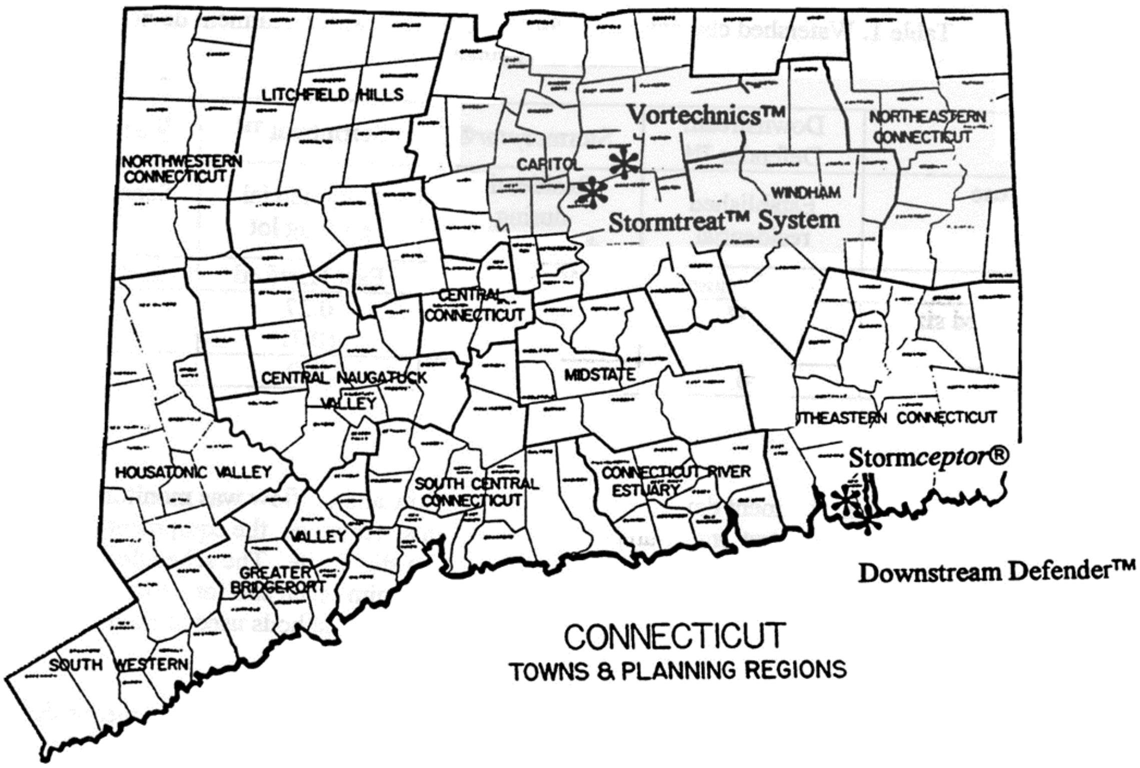


Figure 1. State of Connecticut showing locations of stormwater treatment devices.

METHODS

Table 1 summarizes the watershed characteristics for the four locations where the stormwater treatment devices were monitored. There was no attempt to standardize watershed characteristics. Sites were chosen based on the availability of a set-up for monitoring and a cooperative local sponsor.

Table 1. Watershed characteristics for the four stormwater treatment device locations in Connecticut.

	Downstream Defender ™	Storm*ceptor*®	Stormtreat ™	Vortechnics ™
Land use	Established residential	Residential during development	Commercial parking lot	School parking lot
Location	New London	Waterford	East Hartford	South Windsor
Watershed size - ha (ac)	3.07 (7.6)	1.6 (4.0)	0.27 (0.7)	0.79 (2.0)
% Impervious	26	34	100	80

For each stormwater treatment device, the stormwater inflow and outflow was monitored for both flow rate and concentrations of urban runoff pollutants. However, the equipment used to sample the water and measure the flow varied slightly from site to site. The schedule of monitoring is provided in Figure 2. The objective was to monitor each site for a total of two years and obtain four grab samples per year from each site. The methods used at each site are described below.

Flow-weighted composite sampling was used at each site. For ISCO samplers this means that the samplers were programmed to take a sample when a certain volume of water passed through the site. For the Coshocton wheel, a proportion of all water passing through the site is diverted into a collection vessel. Composite samples were retrieved weekly at each site.

Catch Basin

A catch basin with sump is used to collect runoff and sometimes trap sediment in runoff from impervious surfaces. The catch basin used in this study was 7 ft H X 4 ft W X 3 ft D with a 2 ft sump and a curb inlet. A 19-in. ID pipe entered the basin and a 21-in. ID pipe exited the basin. Flow also entered from the parking lot via the curb inlet and street grate. The catch basin was located in the parking lot for Timothy Edwards Middle School at 100 Arnold Way in South Windsor, CT. (Figure 3) immediately upstream of the Vortechnics ™ stormwater treatment system (Figure 11).

Inflow to the catch basin was sampled using an ISCO sampler located adjacent to the inlet pipe. Outflow from the catch basin was sampled using the Coshocton wheel. This outflow sample site was the same as the input to the Vortechnics™ unit described below. Flow was assumed the same as at the Vortechnics™ unit.

Sediment trapped in the catch basin was estimated April, 2001. A tape and probe was used to determine the depth of the sediment in the catch basin. Sediment levels in the catch basin were also measured at the beginning of the study in June 2000.

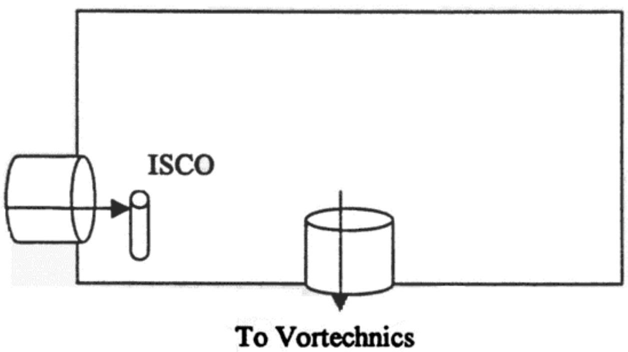
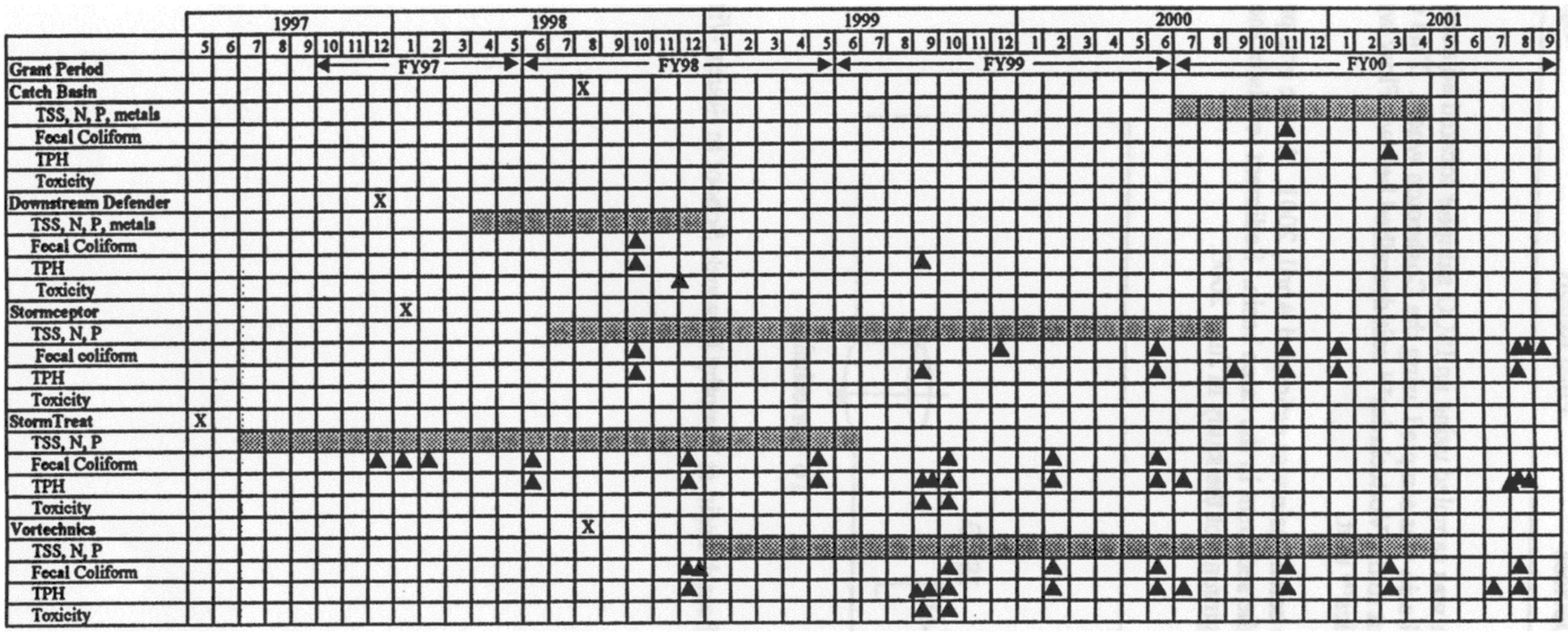


Figure 3. Top view of catch basin at Timothy Edwards School in South Windsor, CT.

University of Connecticut
Department of Natural Resources Management and Engineering
Schedule of Stormwater Treatment Devices Monitoring



▲ = grab sample
X = installation
▒ period of time monitored

Figure 2. Schedule of stormwater treatment devices monitoring.

Downstream Defender™

The Downstream Defender™ is a stormwater treatment device designed to capture sands, grits, silts and floatable materials from stormwater runoff. The Downstream Defender™ consists of a concrete cylindrical vessel with a sloped base and internal components. Raw liquid is introduced tangentially into the side of the vessel. As flow spirals down the perimeter of the vessel, the heavier particles are settled out by gravity and the drag forces on the wall and sloped base of the vessel. As the flow rotates about the vertical axis, solids are directed towards the base of the vessel where they are stored in the collection facility. A simple sump vac procedure can be used to periodically remove solids from the collection facility. A detailed sketch of the Downstream Defender™ is shown in Figure 4.

The Downstream Defender™ was designed for a peak discharge of 7.0 cfs and 5.0 cfs for optimum performance. At the optimum flow rate, the system was expected to remove 90% of all inorganic particles greater than 150 microns with a specific gravity of 2.65. No other claims are made by the manufacturer except that it also retains floatables, oils, and grease. The monitoring manhole chamber had an overflow wier for when discharge exceeded the capacity of the Downstream Defender™.

Flow into the Downstream Defender™ was monitored by continuously recording stage immediately upstream from the outflow from the Downstream Defender™. A pressure transducer connected to a Campbell Scientific CR-10 data logger was used to record stage. A stage discharge relationship was developed based on the discharge from the Downstream Defender™ using an insert v-notch weir and the stage in the Downstream Defender™. The stormwater entering the Downstream Defender™ was sampled using a Coshocton wheel (Figure 5) connected to a collection bottle. The wheel rotates as water flows over vanes on top of the wheel. A slot in the top of the wheel allows some water to flow into it. This water flows by gravity to collection bottles. Discharge from the Downstream Defender™ was sampled using an ISCO automatic sampler. An ISCO sampler collects water using a peristaltic pump. The sampler can be programmed to collect a certain amount at either time or flow-weighted intervals. This ISCO was programmed to collect a sample when a certain volume of water passed through the site. All equipment was located within the top of the monitoring manhole. The sampler and data logger were battery driven and charged with a solar panel.

Sediment in the monitoring manhole was removed June 22, 1999. The amount of material removed was estimated by the Town of New London by weighing the vacuum truck before and after the cleaning.

The Downstream Defender™ was located at the intersection of Woodlawn Rd. and Alewife Pkwy. in New London (Figure 6). The inlet sample was taken in the monitoring manhole (Figure 4). The outlet sample was taken in the Downstream Defender™ immediately upstream from the outflow pipe.

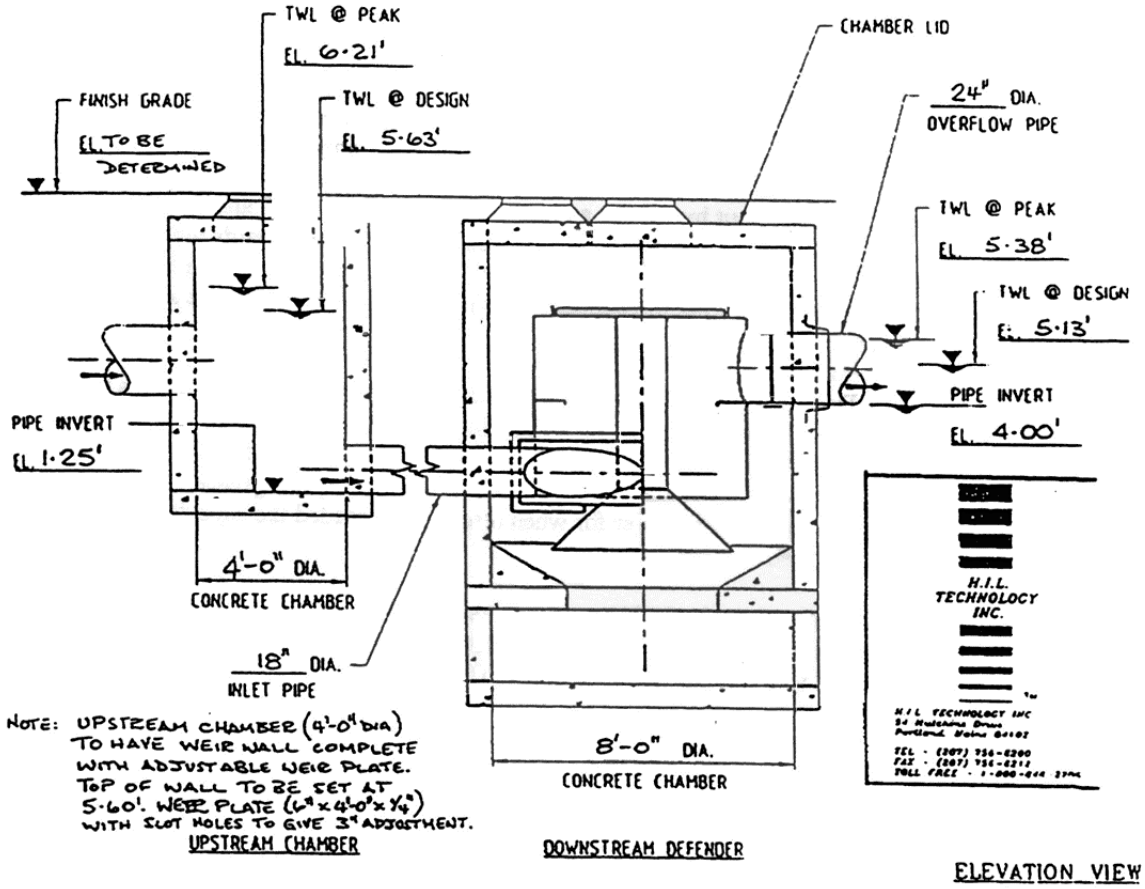


Figure 4. Cross-section drawing of Downstream Defender™ in New London, CT. showing upstream monitoring chamber.

Figure 5. Coshocton Wheel.

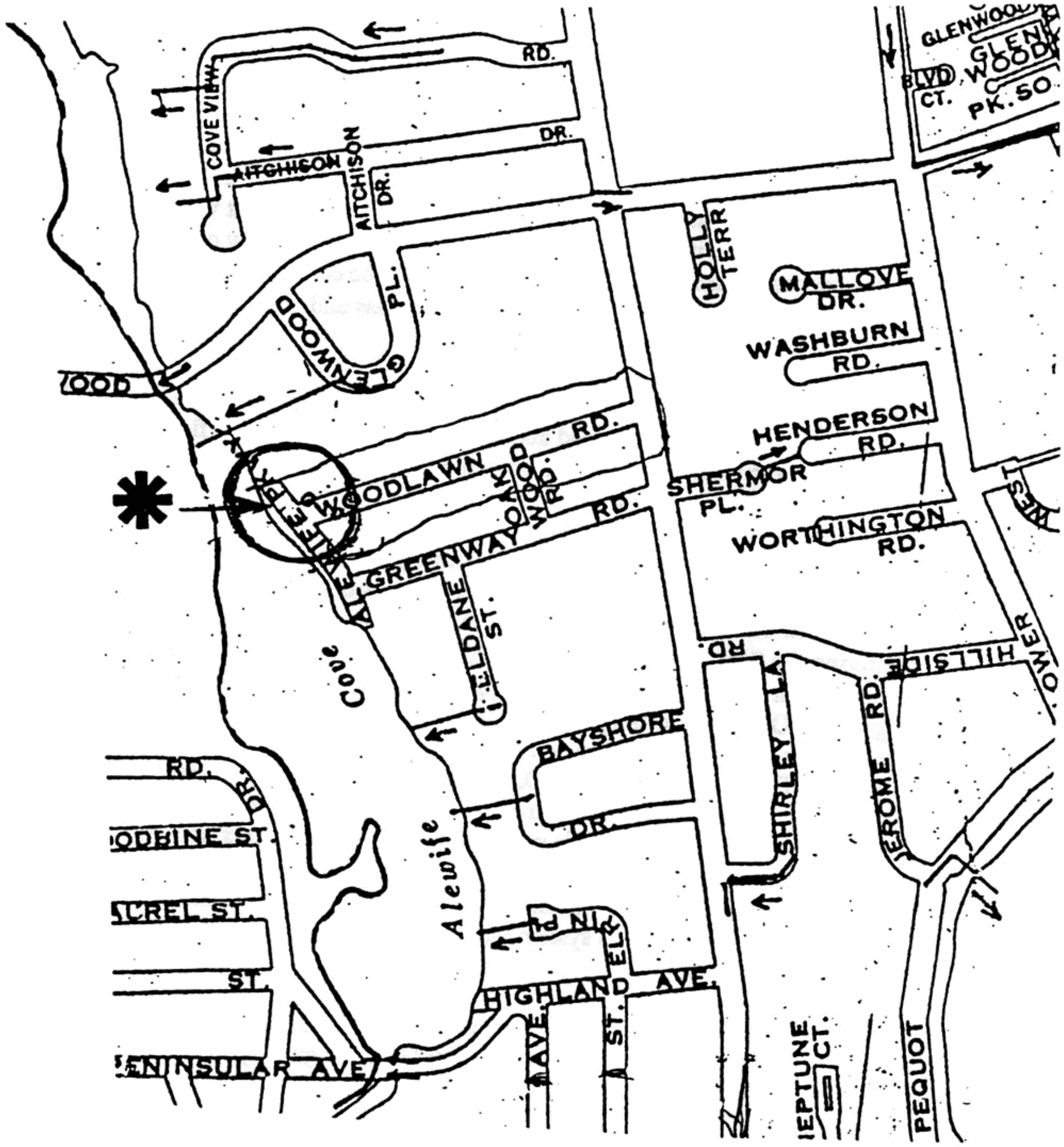


Figure 6. Street map showing location of Downstream Defender in New London, CT.

Storm*ceptor*®

The Storm*ceptor*® is a pollution prevention device that removes oil and sediment from storm flow. The Storm*ceptor*® replaces a conventional manhole in the storm sewer system. Stormwater flows in to the by-pass chamber via the storm sewer pipe. Low flows are diverted into the treatment chamber by a weir and drop pipe arrangement. Water flows through the treatment chamber to the outlet pipe which is submerged similar to the drop inlet pipe. Water flows up through the outlet pipe based on the head at the inlet weir, and is discharged back into the by-pass chamber downstream of the weir. Oil and other liquids will rise in the treatment chamber and become trapped since the outlet pipe is submerged. Sediment will settle to the bottom of the chamber by gravity and centrifugal forces. During high flow conditions, stormwater in the by-pass chamber will overtop the weir and be conveyed to the outlet sewer directly. The Storm*ceptor*® is manufactured in both fiberglass and concrete. A detailed sketch of the Storm*ceptor*® is shown in Figure 7.

A Storm*ceptor*® STC 1800 was installed at the site. This system is intended to be capable of removing 50-80% of the total sediment load and remove free oil during low flow conditions. This system was design to treat a maximum flow rate of 0.64 cfs without by-pass, and a maximum by-pass flow rate of 11.9 cfs.

Flow into the Storm*ceptor*® was measured in a monitoring manhole installed immediately upstream from the Storm*ceptor*®. A Palmer-Bowles flume was installed in the stormwater pipe for flow measurement. An ISCO bubbler meter was used to measure stage in the flume. The stormwater entering the Storm*ceptor*® was sampled in the monitoring manhole using an ISCO automatic sampler with flow proportional sampling. Discharge from the Storm*ceptor*® was sampled using an ISCO automatic sampler. The ISCO sampler was located in the monitoring manhole. The samples were split into one non-acidified and two acidified composite bottles. The bottles were pre-acidified with 2 ml L^{-1} H_2SO_4 or HNO_3 for subsequent nutrient or metals analyses, respectively. Sample bottles were transported in a cooler with ice packs. All equipment was powered by 115v AC. This system was funded from other sources.

Sediment stored in the Storm*ceptor*® was sampled November 30, 1999 at the time of annual cleaning. The depth of sediment in the system was estimated using a tape. A subsample was taken for bulk density analysis.

The Storm*ceptor*® was located at 25 Fog Plain Road in Waterford, CT at the intersection with Giovanni Dr. at a new subdivision called Glenn Brook Green (Figure 8). This subdivision was undergoing construction and development during the monitoring period.

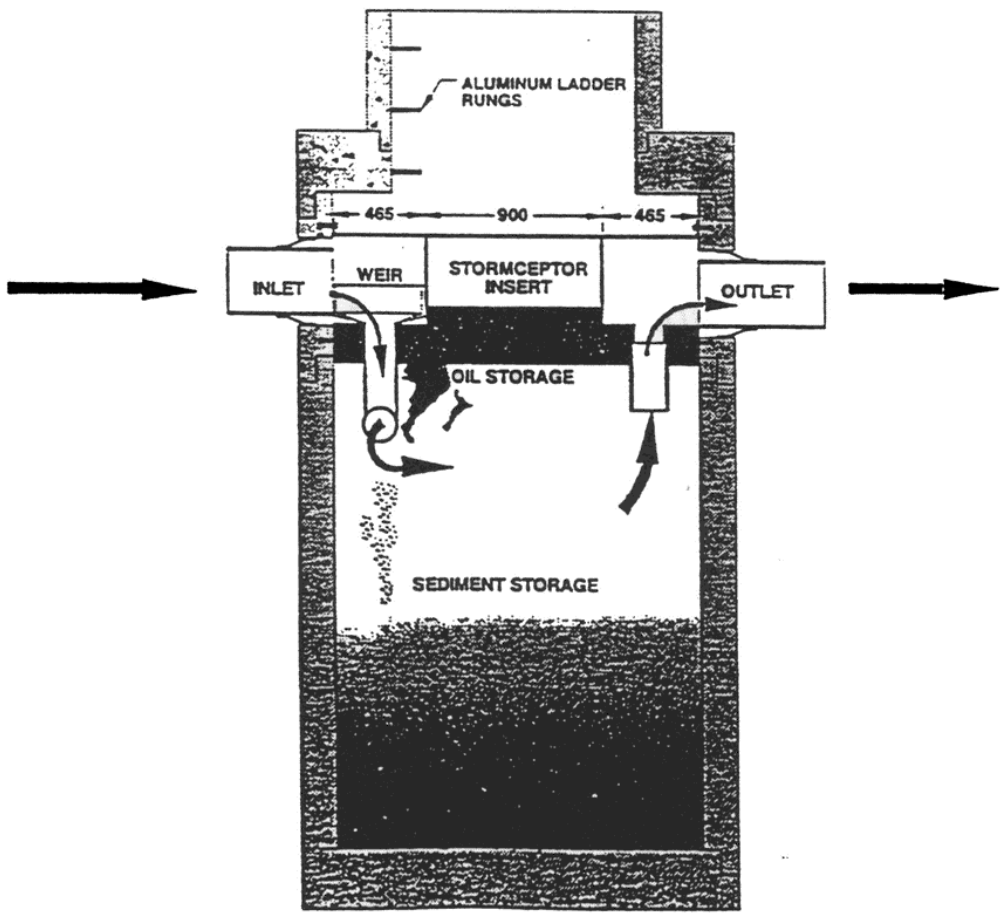


Figure 7. Cross-section drawing of the Storm*ceptor*® in Waterford, CT.

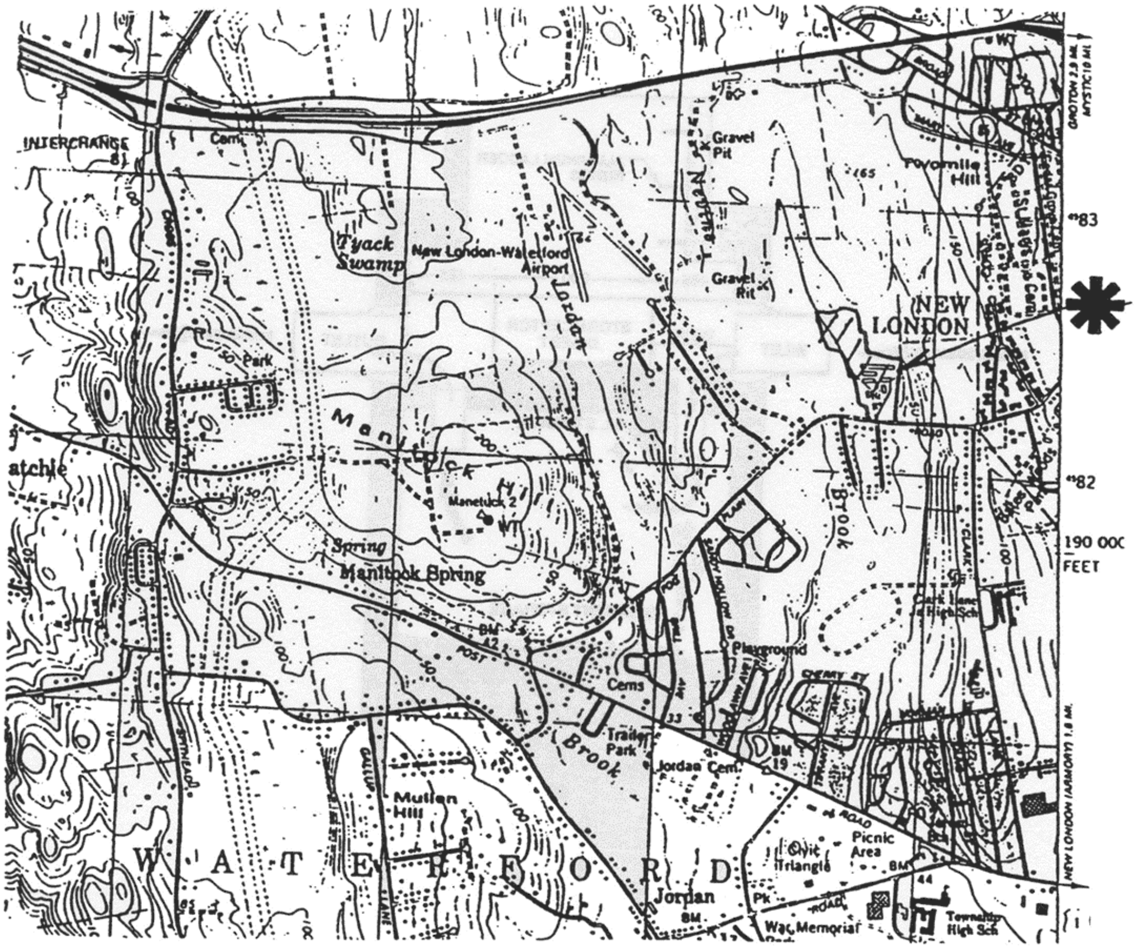


Figure 8. Quadrangle map showing location of Storm*ceptor*® in Waterford, CT.

Stormtreat™ System

The Stormtreat™ System utilizes a pre-fabricated structure to treat stormwater by employing sedimentation, sand filtration, and skimmers within an enclosed tank. A constructed wetland around the tank's perimeter provides additional filtration and biochemical attenuation. A catch basin upstream of the Stormtreat™ System collects stormwater runoff from the parking lot. Stormwater fills the catch basin to a level before flowing in the line connected to the Stormtreat™ System tanks. A detailed sketch of the Stormtreat™ System is shown in Figure 9.

The Stormtreat™ System was located in the McDonald's parking lot on Burnside Avenue in East Hartford, CT. (Figure 10). Manufacture's literature indicates that the Stormtreat™ System should remove 99% of total suspended solids, 97% of fecal coliform, 90% of total petroleum hydrocarbons, 90% of phosphorus, 77% of lead, and 90% of zinc.

Runoff from a 0.27-ha commercial parking lot in East Hartford, CT was sampled prior to flow into the StormTreat™ (Figure 10). The parking lot was exposed to an average of 650 vehicles day^{-1} (A. Lopez, personal communication, 1999) and moderate automotive duration (10 to 30 min vehicle^{-1}). The asphalt surface had a 3.4 % slope and was in good condition with few cracks. Sand and salt were applied to the parking lot during winter storms. Runoff originated from the parking lot, contributing rooftop area, and the periodic wash-down of the trash and grease dumpsters (D. Askew, personal communication, 1998).

In June 1997 two parallel StormTreat™ tanks were installed in the parking lot. Together the tanks treated the first 0.46 cm of runoff from the drainage area (D. Askew, personal communication, 1998). Inflow to the StormTreat™ system came from a double catch basin fed from pre-existing drainage structures. An overflow weir allowed excess stormwater flow to bypass the StormTreat™. Each tank was 1.2 m high and 2.9 m in diameter, with a storage capacity of 5,261 L. The outflow was controlled by a ball valve at a maximum of 0.76 L min^{-1} and discharged via a 5.1cm pipe (Figure 9).

The wetland substrate consists of #7 ASTM gravel approximately 1.00-1.25 cm in size (D. Askew, personal communication, 1998). The surface was planted in June 1997 with woolly sedge (*Scirpus cyperinus* L.), tussock sedge (*Carex stricta* Lam.), umbrella sedge (*Cyperus diandrus* Torr.), and soft rush (*Juncus effusus* L.). The plants were hand-watered in the first few weeks to encourage survival. During maintenance of the system the plant rooting depth was determined to be 1 m (D. Askew, personal communication, 2000).

Stage in the catch basin was measured by a pressure transducer and recorded on a Campbell Scientific CR-10 data logger. Weekly flow-weighted samples were collected at the StormTreat™ inlet and outlet. The samples were split into one non-acidified and two acidified composite bottles. The bottles were pre-acidified with 2 ml L^{-1} H_2SO_4 or HNO_3 for subsequent nutrient or metals analyses, respectively. Sample bottles were transported in a cooler with ice packs. An ISCO automated sampler collected flow-weighted composite samples at the inlet. Effluent was measured using a calibrated tipping bucket, with tips recorded by a mechanical counter. A passive splitter device at the outlet directed flow into composite bottles. Weekly precipitation was measured with a tipping bucket rain gauge and recorded by the data logger. One 5 cm monitoring well was installed in the wetland of each StormTreat™.

Weekly *in situ* dissolved oxygen measurements, taken in the monitoring wells, were made using a YSI dissolved oxygen meter. Annual gravel and grit bag samples were collected from the StormTreat™ wetlands and chambers, respectively. Analyses of pH, beginning in May 1998, were performed using a pH meter (APHA, 1989).

Means for censored data were determined using UNSENSOR (Newman *et al.*, 1989). Comparisons for Cu and Pb were made both between values just above detection limits and between all values by replacing the values below the detection limit with half the detection limit. Pearson correlation coefficients were used to examine the relationships between percent retention and storm size, chamber stage, discharge rate, and hydraulic retention time. Correlation analyses represent only weeks when samples were collected from both the inlet and outlet. Mean concentrations, mass loading, and cumulative mass retention values represent all data obtained.

Hydraulic residence time (HRT) was calculated as the volume of the StormTreat™, adjusted for porosity, divided by the discharge. HRT was determined to have a mean (anti-log) of 9.2 d. Therefore, effluent concentrations were compared to influent concentrations from the preceding week in statistical analyses.

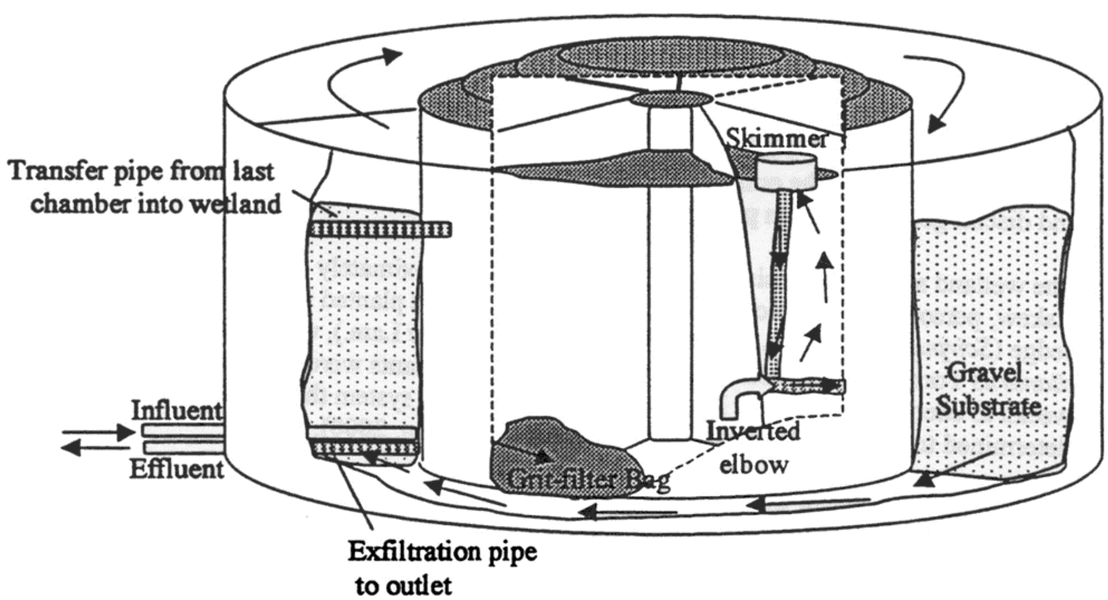
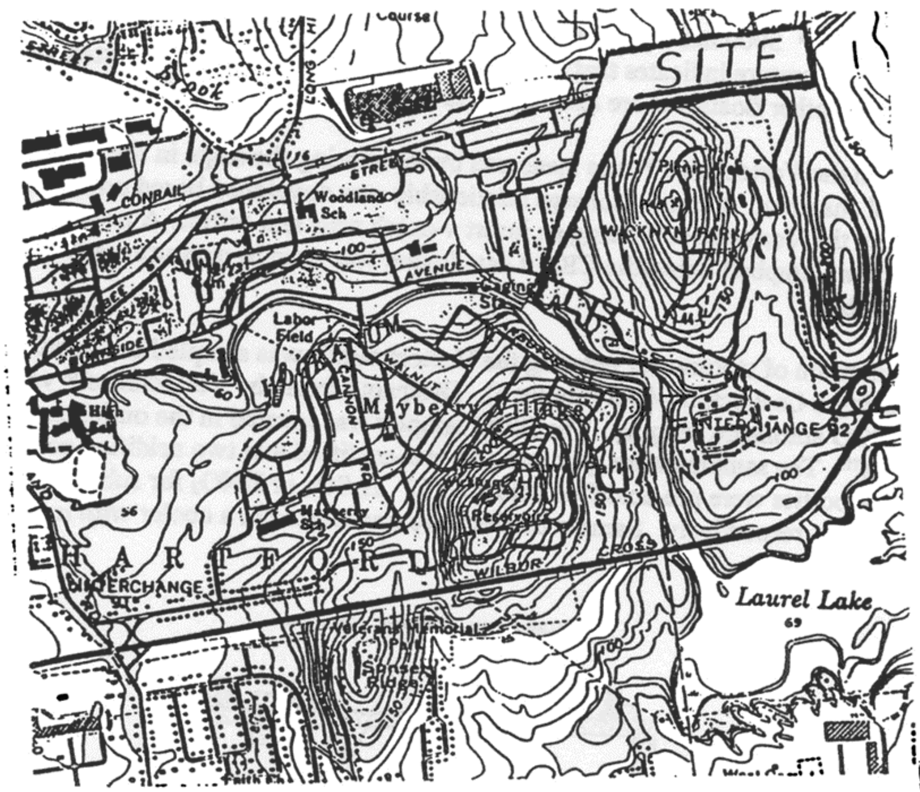


Figure 9. Cross-section drawing of the Stormtreat™ System in East Hartford, Ct.



LOCATION SKETCH

MANCHESTER, CT. QUADRANGLE

SCALE: 1:24,000

Figure 10. Quadrangle map showing location of Stormtreat™ System in East Hartford, CT.

Vortechnics™

The Vortechnics™ stormwater treatment system is designed to remove grit, contaminated sediments, metals, hydrocarbons and other floatable materials from surface runoff. The Vortechnics™ contains a grit chamber that is loaded with stormwater tangentially, which directs settleable solids toward the center. A center barrier traps floatables in the oil chamber. A final flow control chamber causes the inlet pipe to become submerged. A detailed sketch of the Vortechnics™ is shown in Figure 11. The Vortechnics™ was located in the parking lot for Timothy Edwards Middle School at 100 Arnold Way in South Windsor, CT. (Figure 12).

The Vortechnics™ 5000 has a peak design flow of 8.5 cfs and no by-pass system. Manufacture's literature indicates that 80% of TSS will be removed by the system on an annual basis. Oils and other floatables are also expected to be removed.

Flow through the Vortechnics™ was measured by monitoring the stage in the Vortechnics™ flow control chamber. A stage discharge relationship was developed based on weir formula and outflow from the Vortechnics™ using an insert v-notch weir and orifice. A pressure transducer connected to a Campbell Scientific CR-10 data logger was used to measure stage in the flow control chamber.

The concentration of stormwater entering the Vortechnics™ was sampled in a monitoring manhole using a Coshocton wheel (Figure 5). Discharge from the Vortechnics™ was sampled using an ISCO automatic sampler. The ISCO sampler was located in the outlet chamber of the Vortechnics™. The samples were split into one non-acidified and two acidified composite bottles. The bottles were pre-acidified with 2 ml L^{-1} H_2SO_4 or HNO_3 for subsequent nutrient or metals analyses, respectively. Sample bottles were transported in a cooler with ice packs.

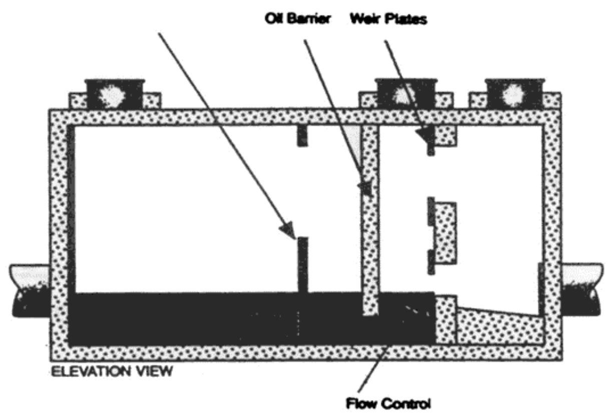


Figure 11. Cross-section drawing of the Vortechnics™ in South Windsor, CT.

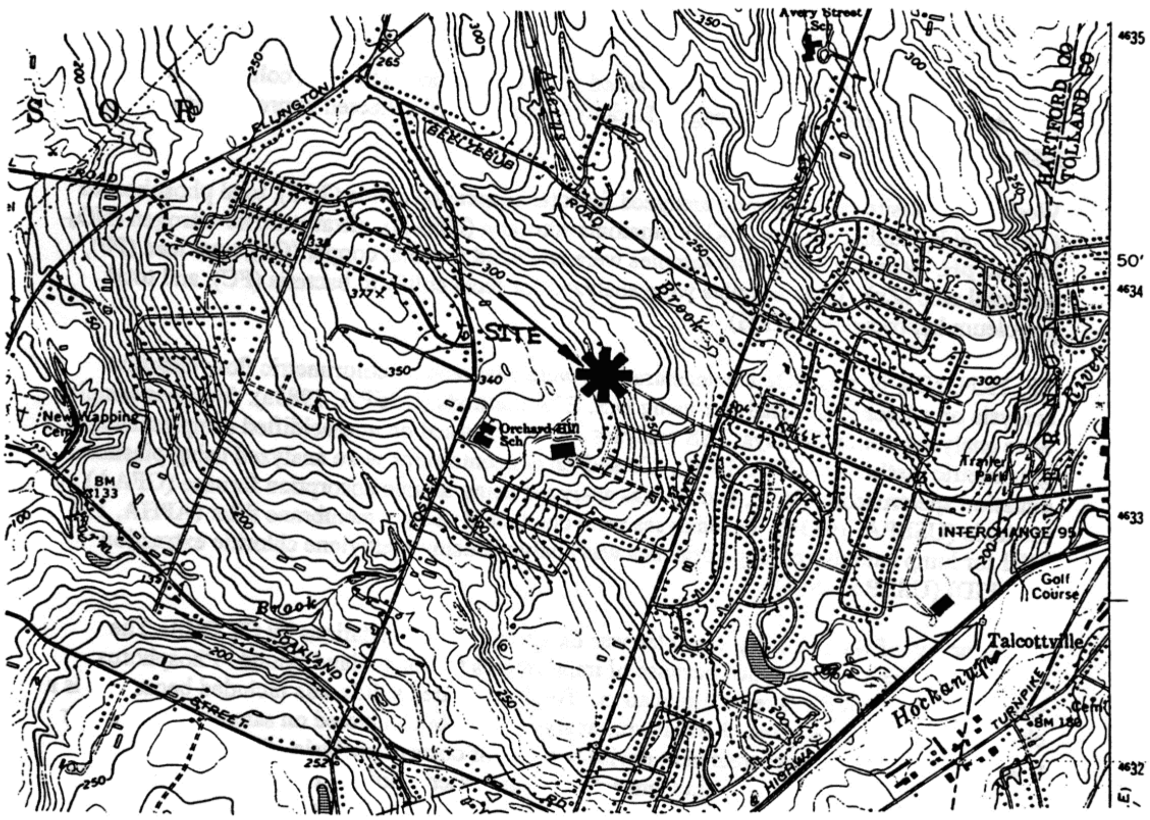


Figure 12. Map showing location of Vortechnics™ in South Windsor, CT.

Sample analysis

At each location, flow-weighted composite samples were collected in three separate bottles. One bottle was pre-acidified with sulfuric acid for nutrient analysis. A second bottle was acidified with nitric acid for metal analysis. A non-acidified bottle was used for total suspended solids analysis. The method of flow-weighted compositing varied somewhat among sites and is discussed separately for each devise monitored. Briefly, ISCO composites are collected by programming the ISCO to collect a certain volume of sample when a certain volume of flow passes the station. This program requires that a stage-flow formula also be programmed in the ISCO. Coshocton wheel composites are collected passively. A portion of all water passing through the station is diverted into bottles through an opening in the wheel. Thus, for all sites, there was no attempt to collect discrete samples during events or the first flush. Bottles were kept cool in coolers with ice packs, refrigerated, or picked up within 24 hours of an event.

The TPH sample was collected in pre-washed glass containers. The fecal coliform sample was collected in sterilized whirl-pac bags. Toxicity samples were collected in pre-washed gallon jugs.

Weekly composite samples were analyzed for total suspended solids (TSS), total phosphorous (TP), total Kjeldahl nitrogen (TKN), ammonia-nitrogen (NH_3-N), nitrate+nitrite-nitrogen (NO_3-N), and pH. Monthly composite samples were analyzed for total copper (Cu), total lead (Pb), and total zinc (Zn). Grab samples were analyzed for fecal coliform bacteria (FC), and total petroleum hydrocarbons (TPH).

TP, TKN, NH_3-N, and NO_3-N concentrations were analyzed by colorimetric flow injection analysis on a Lachat autoanalyzer using U.S. EPA methods (USEPA, 1983a). Nutrient samples were analyzed within 28 days. TSS analyses were performed on non-acidified samples using gravimetric methods (APHA, 1989). Cu and Zn concentrations were analyzed using plasma emission spectroscopy (ICP), and Pb was analyzed using atomic absorption furnace (GFAA) methods (USEPA, 1983a). FC analyses were conducted using a membrane filter (APHA, 1989). TPH for lump sum diesel range organics was analyzed using methylene chloride extraction (GC/FID) (USEPA, 1996).

The selection of water quality variables was based on recommendations by CT DEP. The nitrogen species were included because of impairments to Long Island Sound. Phosphorus would be important for lake eutrophication. Total suspended solids was included because it is a claim by most manufactures. Particle size analysis was not conducted on samples collected or retained by the stormwater treatment devise because of costs of analysis. Cu, Pb, and Zn are recognized as chronic problems in Connecticut stormwater runoff. TPH is also recognized as a stormwater problem and one manufacturer claims that their devise removes TPH.

Statistical Analysis

Statistical analyses were performed using JMP® (SAS, 1995). The Shapiro-Wilks test was used to assess normality. Most data were found to follow log-normal distributions; therefore, the log transformation was used in those cases. Percent mass retention was calculated from: % = 100 X (influent-effluent)/influent. Percent retention values were normalized with a square root transformation. Percent retention was calculated as Significant differences between influent and effluent concentrations and percent retention efficiency between winter and summer seasons were determined using the Student's *t* test. This test is used for paired-sample hypotheses when examining for differences between two populations sampled. A *t* value is calculated from the difference between the two means and the standard deviation of the difference between the means. The calculated *t* is compared to a critical *t* found in a statistics book. If the calculated *t* is greater than the critical *t*, the means are considered not the same.

Quality Assurance

A quality assurance project plan (QAPP) was approved for this project in September 1998 and revised in October 2000 to conform to new US EPA guidance. The QAPP is provided in the Appendix and describes the methods used for maintaining quality control.

RESULTS AND DISCUSSION

Catch Basin

Concentration

Using the *t*-test to compare means, the concentrations of NO_3-N and TP increased significantly (P=0.05) as stormwater flowed through the catch basin (Table 2). TSS concentrations also increased at a significance level of P=0.059. There were only two bacteria samples and concentrations did not change. There was only one TPH sample and concentrations were lower than observed during longer monitoring at the inlet to the Vortechnics unit. There were no other significant changes in stormwater concentrations as it flowed through the catch basin. These findings were not expected and were likely caused by differences in sampling techniques used at the inlet and outlet of the catch basin. A peristaltic pump was used at the inlet and a Coshocton wheel was used at the outlet. This data suggests that the Coshocton wheel collected more solids and therefore TP than did the peristaltic pump. Given these differences, it is not believed that the inflow concentrations obtained by the peristaltic pump are totally reliable. Grab samples were unaffected by these differences. Alternatively, it is possible that flushing of sediment was occurring out of the catch basin sump during storms. Negative sediment removal efficiency was reported by Schuler (1997) for a study sampling 13 storms for an oil-grit separator in Maryland.

Mass Retention

Because concentrations increased while stormwater flowed through the catch basin, the mass retention was negative for TSS, TP, NH_3-N and Zn (Table 3). However, this mass retention is an artifact of the sampling method used and should not be considered as representative of the effectiveness of a catch basin. That is, the mass retentions reported are suspected because the peristaltic sampler and the Coshocton wheel may not be taking equivalent samples. Previous studies have suggested that a catch basin can retain up to 57 % of coarse (undefined) solids (U. S. EPA, 1999). US EPA (1993a) summarized data suggesting that a water quality inlet has removal efficiencies of 35 % for TSS, 5 % for TP, 20 % for TN, 15 % for Pb, and 5 % for Zn.

Mass stored in the catch basin was estimated to be 536.56 kg. The mass balance for the period of monitoring based on inflow and outflow samples indicated that –790.31 kg was stored in the catch basin. This value is obviously incorrect.

Table 2. Mean (anti-log) water quality concentrations, and Student's *t* for paired *t*-tests for the catch basin (July 2000 through April 2001).

Variables	n	Influent Mean	Effluent Mean	Student's *t*	*p*
TSS (mg L^{-1})	15	42	92	-2.04	0.059
TKN (mg L^{-1})	20	0.9	1.4	-1.61	0.123
NO_3-N (mg L^{-1})	19	0.6	0.3	2.28	0.034
NH_3-N (mg L^{-1})	20	0.17	0.18	0.02	0.986
TP (mg L^{-1})	18	0.126	0.245	-3.43	0.003
Pb (μg L^{-1})	4	86	360	-1.58	0.212
Cu (μg L^{-1})	4	19	20	-0.03	0.981
Zn (μg L^{-1})	3	12	11	0.07	0.951
FCU (cfu/100 mL)	2	17	93	-0.60	0.654
TPH (mg L^{-1})	1	0.05	0.05	----	----

Table 3. Annual mass loading to the catch basin and cumulative mass percent retention (July 1998 through August 2000).

Variable	Annual Loading Kg ha^{-1} yr^{-1}	Cumulative Mass Retention (%)
TSS	319.93	-416.9
TKN	4.12	8.6
NO_3-N	8.19	90.7
NH_3-N	0.84	-4.5
TP	0.66	-80.9
Pb	0.22	71.0
Cu	0.08	74.8
Zn	0.05	-30.1
FC		

Downstream Defender™

The Downstream Defender™ was connected to the catch basin on December 17, 1997. The first sample was taken April 16, 1998. On December 2, 1998, sampling at the outlet was terminated because it was determined that the Downstream Defender™ connection to the monitoring manhole was leaking. Thus, when a storm began, some stormwater was stored in the Downstream Defender™ before it could flow out. The monitoring manhole was cleaned and regrouted by the Town of New London. However the leak continued, indicating that the leak was at the connection to the Downstream Defender™.

Concentration

During the period of monitoring there were five paired samples collected from the Downstream Defender™. The paired t-test on log-transformed data indicated that there was no significant difference between inlet and outlet concentrations for those five samples (Table 4). Fecal coliform bacteria and TPH could not be statistically analyzed due to there being too few samples.

There were 27 samples taken in runoff from Woodlawn Rd. collected as influent samples. Generally this runoff was similar in solids (Table 5) concentrations to runoff from the parking lots but lower than solids runoff during construction from a street in Waterford (Table 6). Nitrogen and phosphorus concentrations in runoff were similar to other sites. Cu, Pb and Zn concentrations were similar to those observed at the Storm Treat. Pb was lower than at the Storm*ceptor*® and Zn was lower than at the Vortechnics™. TPH was similar to other sites, except at the Stormtreat™ parking lot, which had higher concentrations in runoff. There are no other known studies of the efficiency of the Downstream Defender™.

Mass Retention

The retention of pollutants in the Downstream Defender™ could not be evaluated because the system leaked and effluent flow values were not reliable. It could not be determined if the devise removed 90% of inorganic solids as claimed. On June 22, 1999 2,340 lb of primarily road sand was removed from the system.

Table 4. Mean (anti-log) water quality concentrations, and Student's *t* for paired *t*-tests for the Downstream Defender™ (April 1998 through September 1999).

Variables	n	Influent Mean	Effluent Mean	Student's *t*	*p*
TSS (mg L^{-1})	5	56	31	1.56	0.193
TKN (mg L^{-1})	5	5.1	4.3	0.66	0.546
NO_3-N (mg L^{-1})	5	0.6	0.6	-0.05	0.960
NH_3-N (mg L^{-1})	5	0.57	0.75	-0.88	0.429
TP (mg L^{-1})	5	0.695	0.500	0.95	0.396
Pb (μg L^{-1})	3	9	23	-0.99	0.428
Cu (μg L^{-1})	3	30	36	-0.71	0.552
Zn (μg L^{-1})	3	93	146	-1.91	0.196
FCU (cfu/100 mL)	1	>1200	720		
TPH (mg L^{-1})	2	0.22	0.49		

Table 5. Mean (anti-log) water quality concentrations for influent to the Downstream Defender™ (April 1998 through September 1999).

Variables	n	Influent Mean
TSS (mg L^{-1})	27	16
TKN (mg L^{-1})	27	1.9
NO_3-N (mg L^{-1})	27	0.3
NH_3-N (mg L^{-1})	25	0.36
TP (mg L^{-1})	27	0.270
Pb (μg L^{-1})	3	9
Cu (μg L^{-1})	3	30
Zn (μg L^{-1})	3	93
FCU	1	>1200
TPH (mg L^{-1})	2	0.22

Storm*ceptor*®

A STC 1800 Storm*ceptor*® was installed January 15, 1998. Sampling was conducted from July 30, 1998 through August 1, 2000. The Storm*ceptor*® was cleaned out twice during the study, once in November 1998, and November 30, 1999. During the first year of the study, the by-pass flow rate of 0.64 cfs was not exceeded. However, after August 1999 the by-pass flow rate was exceeded 48% of the events. Overall, 28% of the total events involved by-pass.

Concentration

The influent to the Storm*ceptor*® was higher in the concentrations of TSS and TP than at the other sites (Table 6). This finding is likely due to construction activities being conducted at the site during the monitoring period. The Storm*ceptor*® was not found to significantly decrease the concentrations of pollutants measured (Table 6), although TSS concentrations decreased at $p=0.065$.

Mass Retention

The Storm*ceptor*® retained TSS, TKN, NH_3-N, TP, Cu, and Zn (Table 7). The TSS removal of 25% did not meet the manufacture's claim of 50-80%. NO_3-N and Pb were not retained. The low retention of NO_3-N is likely due to reducing conditions that occurred in the Storm*ceptor*® between runoff events. Reducing conditions would promote the reduction of NO_3-N to NH_3-N. On a concentration basis, NH_3-N increased in the effluent, which also suggests reducing conditions. Sampling of inflow and outflow suggest that 1,516.34 kg of sediment was retained by the Storm*ceptor*®. However, based on sampling when the system was cleaned, only 138.5 kg was recovered. The sampling methods used for cleanout were not as rigorous as sampling inflow and outflow and therefore are considered less reliable. Also, based on findings at the Vortechnics™ site, peristaltic pump sampling may not pull up coarse sediment. Peristaltic pump sampling could then be biased by missing coarse sediment transport. However, the pumps were used for both influent and effluent sampling. Flushing out of sediment could also be occurring but the flushed out sediment should have been measured sampled by the pump. There was no noticeable effect of cleaning the system on retention, except that the device could store some of the initial runoff from the first event following cleaning as it filled.

Erosion and sediment controls at this site were found to be followed by the developer (Phillips et al., 2002). Methods employed included silt fencing, temporary seeding, and catch basin covers. The developer also hand swept the road gutters when sediment was noticed.

In Madison, WI a monitored Storm*ceptor*® treating runoff from a public works maintenance yard retained 25 % of suspended solids and 19 % of TP (Waschbusch, 1999). This was a 9-mo. study and 45 flow-weighted composite samples were collected. Mean concentrations were not reported. These Wisconsin mass retentions were similar, but less, than we observed (Table 6). Based on laboratory testing in Canada, Berg and Bryant (1996) state that sediment removal of sand-sized and larger particles was 95 % for low flows and 68 % when the weir was slightly overtopped. We did not have the ability to control particle sizes of inflows to the Storm*ceptor*®, and, therefore, can not compare our findings to this laboratory study. In Storm*ceptor*® literature, Bryant (1996) describes laboratory test results from Coventry University, UK indicating that the Storm*ceptor*® retained 83 % of sand and 73 % of peat.

Table 6. Mean (anti-log) water quality concentrations, and Student's *t* for paired *t*-tests for the Storm*ceptor*® (July 1998 through August 2000).

Variables	n	Influent Mean	Effluent Mean	Student's *t*	*p*
TSS (mg L^{-1})	43	315	222	1.90	0.065
TKN (mg L^{-1})	44	1.8	1.7	0.60	0.553
NO_3-N (mg L^{-1})	49	0.7	0.7	0.30	0.768
NH_3-N (mg L^{-1})	44	0.15	0.19	-1.28	0.206
TP (mg L^{-1})	45	0.767	0.701	0.66	0.516
Pb (μg L^{-1})	10	23	19	1.25	0.244
Cu (μg L^{-1})	14	27	23	0.96	0.352
Zn (μg L^{-1})	14	139	116	0.61	0.550
FCU (cfu/100 mL)	7	247	285	-0.45	0.668
TPH (mg L^{-1})	6	0.16	0.14	0.23	0.829

Table 7. Annual mass loading to the Storm*ceptor*® system and cumulative mass percent retention (July 1998 through August 2000).

Variable	Annual Loading Kg ha^{-1} yr^{-1}	Cumulative Mass Retention (%)	Mass Retention (%) Waschbusch, 1999
TSS	114.668	34.4	25
TKN	0.356	31.9	--
NO_3-N	0.060	-88.2	6
NH_3-N	0.022	10.9	19
TP	0.205	28.8	19
Pb	0.007	-6.5	28
Cu	0.001	7.1	30
Zn	0.012	59.5	21

Stormtreat™

Two Stormtreat™ tanks were installed June 1997. Sampling was conducted from July 1997 through July 1999. During the 2-yr study period, 104 influent and effluent composite samples were collected. Average annual precipitation at the site was 1005 mm yr^{-1}, a -11 % departure from the normal annual precipitation at the Hartford WSO Airport, located approximately 7.5 km north of the site (NOAA, 1995). The vigor of the wetland plants did not seem to be adversely affected by the stormwater runoff. Actually, during maintenance one year, wetland plants were removed to be added elsewhere in another project.

Concentration

Mean influent concentrations (Table 8) were lower than those reported for similar commercial land uses, and parking lots, by the Nationwide Urban Runoff Program (NURP) (USEPA, 1983b). However, the commercial land use concentrations reported by NURP may be higher than observed in runoff from small commercial lots. Rabanal and Grizzard (1985) compared event mean concentrations (EMC) in runoff from a fast food restaurant parking lot in Virginia to those reported by NURP for urban runoff. They found their concentrations to be low relative to the EMCs reported by NURP. The mean stormwater concentrations at this CT study site were similar to those reported by the Virginia study for TSS, Cu, Pb, and Zn. Also, the lower concentrations observed in this study may be attributed to the influent being sampled in the stormwater catch basin, rather than directly from the parking lot surface.

Based on paired *t*-tests, effluent from the Stormtreat™ was found to be significantly ($P < 0.05$) lower in the concentrations of TSS, TKN, TP, Cu, Zn, and FC than the stormwater influent over the study period (Table 8). There was no difference in influent and effluent concentrations for NH_3-N and NO_3-N, but those concentrations were near detection limits. TPH concentrations were not significantly different between influent and effluent while the pH of stormwater was increased. Mean dissolved oxygen concentrations within the StormTreat™ were 0.4 mg L^{-1} (s = 0.442 mg L^{-1}).

The concentrations of Cu and Pb were frequently below detection limits (censored). There was no difference in influent and effluent concentrations of Pb when all values below detection limits were replaced with half the detection limit (Table 8) or when only values above the detection limits were used. For Cu, 12 % of influent and 25 % of effluent samples were below the detection limit of 2.0 µg L^{-1}. For Pb, 43 % of influent and 38 % of effluent samples were below the detection limit of 5.0 µg L^{-1}. Therefore, means were determined using techniques for censored data (Newman *et al.*, 1989). This method adjusts the means based on the statistical properties of the non-censored portion of the data, and adjusts for theoretical effects caused by the defined intensity of censoring. No relationship existed between the frequency of detectable levels and whether the sample was influent or effluent, for total Cu ($\chi^2 = 0.46, P > 0.30$) and total Pb ($\chi^2 = 0.03, P > 0.30$). Mean effluent StormTreat™ concentrations were below the U.S. EPA drinking water Action Levels for copper and lead of 1300 µg $L^{-1}$and 15 µg L^{-1}, respectively (USEPA, 1998). The U.S. EPA has not set an Action Level for zinc in drinking water.

Horsley (1995) reported mean concentration data and treatment efficiencies using five samples collected at the first StormTreat™ installation site in Kingston, MA. The system treated a 0.174 ha drainage area, consisting of a road and parking lot. Percent retention efficiencies were calculated from mean influent and effluent concentrations. Influent samples were collected in the sedimentation chamber. Horsley (1995) reported retention of 99 % TSS, 89 % TP, 44 % total dissolved nitrogen (NH_3-N + NO_3-N), and 97 % FC. Additionally, the Kingston, MA StormTreat™ retained 90 % TPH, 77 % Pb, and 90 % Zn. Using the same method for calculating percent retention, the StormTreat™ in East Hartford, CT retained 50 % TSS, 68 % TP, 0 % TDN, and 99 % FC. This StormTreat™ also retained 60 % TPH, 0 % Pb, and 74 % Zn. Differences in percent retention values between the two studies are partly due to differences in mean influent concentrations which were larger at the Kingston, MA site. Mean effluent concentrations were similar at both sites.

Mass Retention

Mass loadings to the StormTreat™ were lower than mass export values for commercial land uses estimated by NURP (USEPA, 1983b) (Table 9). NURP found that land-use categories including residential, commercial, and mixed did not explain site-to-site variability in pollutant contributions and concluded that the best general characterization of urban runoff would be provided by pooling the data from all urban sites (USEPA, 1983b). The median concentrations for urban runoff along with an annual rainfall value (1016 mm) and a land-use runoff coefficient for commercial sites (0.8) were used to estimate annual export from commercial areas. Parking lot loading to the StormTreat™ was low relative to the values estimated by NURP, because the mean influent concentrations at this site were lower than the median concentrations for urban runoff used by NURP.

Modest TSS retention (48.8 %) by the StormTreat™ was attributed to low influent TSS concentrations and the consistent presence of iron bacteria in the effluent. The TSS removal did meet the claim of 99% by the manufacturer. The catch basin retained solids prior to the StormTreat™. Using results from prior studies, the EPA (1993a) reported TSS removal by catch basins to be 10-25 %. The iron bacteria increased the amount of TSS in the effluent, thereby reducing the percent retention. The grit bag stored 50.7 % of TSS input.

Most of the nitrogen retained by the StormTreat™ system was organic (Table 9). The main mechanisms for nitrogen removal in constructed wetlands include sedimentation, volatilization, and denitrification (Reed et al., 1995). Filtration by the grit bag removed 2.2 % of total N. Low mass retention of NH_3-N resulted from concentrations often being near the detection limits. Also, reducing conditions within the StormTreat™ hindered the oxidation of NH_3-N to NO_3-N, sometimes resulting in higher NH_3-N concentrations in the effluent than influent. Similar results have been documented by Herskowitz et al. (1987) and Newman and Clausen (1997). Surplus NH_3-N is thought to result from the decomposition of organic-N in combination with insufficient oxygen required for nitrification (Reed and Brown, 1992, 1995).

Table 8. Median concentrations in commercial runoff, mean (anti-log) water quality concentrations, and Student's *t* for paired *t*-tests for the StormTreat™ (July 1997 through July 1999).

Variables	Median (1)	Influent Mean	Effluent Mean	Student's *t* (2)
TSS (mg L^{-1})	69	14	7	4.581***
TKN (mg L^{-1})	1.179	1.6	1.0	4.494***
NO_3-N (mg L^{-1})	0.572	0.2	0.2	1.001
NH_3-N (mg L^{-1})	0.02	0.13	0.17	-1.341
TP (mg L^{-1})	0.201	0.143	0.048	6.089***
Pb (μg L^{-1})	104	5	5	0.184
Cu (μg L^{-1})	29	7	4	2.711*
Zn (μg L^{-1})	226	151	53	2.695*
FCU (cfu/100 mL)	12,000	590	<1	2.790*
TPH (mg L^{-1})	6.6	2.43	1.52	1.319
pH		6.8	7.0	-2.473*

1) USEPA (1983b), except for NH_3-N (Rabinal and Grizzard, 1985) and TPH (Shepp, 1996).
2) * $P = 0.05$, ** $P = 0.01$, *** $P = 0.001$

Table 9. Annual mass loading to the StormTreat™ system and cumulative mass percent retention (July 1997 through July 1999).

Variable	Annual Loading Kg ha^{-1} yr^{-1}	Cumulative Mass Retention (%)
TSS	11.49	48.8
TKN	1.41	44.1
NO_3-N	0.21	-0.2
NH_3-N	0.24	-32.0
TP	0.24	73.7
Pb	0.005	1.9
Cu	0.008	28.9
Zn	0.16	45.3
FC		99

Anoxic conditions, like those found in this system, are typically conducive to denitrification (Reed *et al.*, 1995); however, mass retention of NO_3-N was not observed. In this system, denitrification likely was limited by an inadequate NO_3-N source. Despite favorable anaerobic conditions, insufficient NO_3-N (Groffman, 1994) and carbon (Groffman, 1994; Van Oostrom and Russell, 1994; Zhu and Sikora, 1995) sources can limit denitrification. As the system ages, carbon supplies may increase due to the buildup and decay of organic materials (Reed *et al.*, 1995); yet denitrification will continue to be hampered by low influent NO_3-N.

Removal of TP was near the date reported by the manufacturer of 90%. The primary mechanisms for TP removal in constructed wetland systems are plant uptake, settling, adsorption onto substratum, precipitation, and complexation reactions (Mann and Bavor, 1993; Reed *et al.*, 1995). The main retention mechanisms operating in the StormTreat™ system were sedimentation and filtration, followed by adsorption to the gravel. The grit bag trapped 5.8 % of TP as particulate bound P, leaving the dissolved P to undergo further treatment in the fringing wetland. Phosphorus taken up by plants during the summer months was released back into the system during plant senescence. Phosphorus removal may become limited as the system ages due to the saturation of adsorption sites (Tanner *et al.*, 1998) and reduced uptake by mature plants (Reed *et al.*, 1995).

The removal of Pb and Zn was less than the expected 77 and 90%, respectively, presented by the manufacturer Sedimentation and filtration were the likely retention mechanisms for particulate-bound Cu, Pb, and Zn in this system. The dissolved forms may have been removed through precipitation and adsorption. Gersberg *et al.* (1984) and Scholze *et al.* (1993) found anaerobic environments, like the one in this system, to be conducive to the immobilization of Cu and Zn through binding to sulfides. Petroleum hydrocarbons, which have been found to be associated with particles (Hoffman *et al.*, 1982; Pitt *et al.*, 1995), likely were removed by sedimentation and filtration.

FC removal exceed the manufactures claim of 97%. High FC retention can be attributed to entrapment, filtration, and pathogen die-off (Reed *et al.*, 1995). Generally, there is at least a 90 % reduction of FC in effluent from constructed wetlands (Kadlec and Knight, 1996; Ottova *et al.*, 1997).

Climatic and Hydrologic Effects

There was no significant ($P = 0.05$) correlation between weekly precipitation, chamber stage, discharge, HRT and percent retention for all water quality variables ($r = 0.032$ to $r = 0.383$). Comparing winter to summer, only Zn and NH_3-N retention varied between seasons (Table 10). The percent retention of Zn was greater ($P = 0.05$) in winter than summer. Less retention of NH_3-N occurred in winter than summer ($P = 0.01$) because winter concentrations were often near detection levels, resulting in 0 % retention. Although cooler temperatures lower biological reaction rates, Reed *et al.* (1995) found that longer HRTs observed during the winter months may compensate for slower reaction rates. Possibly the mean HRT of 9.2 d within the StormTreat™ was sufficient enough to counteract for decreased reaction rates during the winter.

Treatment efficiency has been found to level off after one day for TSS (Reed and Brown, 1995) and 1.5 days for Cu, Pb, or Zn (Crites *et al.*, 1997). However, at least 6 to 8 days has been cited as the minimum necessary for effective treatment of NH_3-N (Reed and Brown, 1995). These studies imply that beyond an HRT of 1.5 d, the treatment efficiency for TSS, metals, and other adsorbed pollutants will not increase. Mean HRT within the StormTreat™ system was 9.2 d and was greater than 1.5 d for 95 % of the study period; thus HRT would not have been a significant control factor in the removal of solids and metals in the StormTreat™.

Table 10. Seasonal comparison of mean weekly percent retention and Student's *t* for a non-paired t-test. (Summer = May through October; Winter = November through April).

	Retention %			
Variables	Annual	Summer	Winter	Student's *t*
TSS	49	58	41	1.360
TKN	54	56	52	0.377
NH_3-N	45	81	19	3.438**
NO_3-N	23	21	28	-0.541
TP	69	66	72	-0.553
Total Zn	75	67	85	-2.193*

*P = 0.05, ** P = 0.01

Vortechnics™

The Vortechnics™ was installed August 12, 1998 at the parking lot for Timothy Edwards Middle School at 100 Arnold Way in South Windsor, CT. Sampling was conducted from January 27, 1999 through April 30, 2001. The 0.79 ha watershed was 80% impervious, with 82 parking spaces (Figure 2). However, the parking lot was never observed at capacity, and averaged fifty percent of spaces filled during the day. Runoff was collected at five catch basins and directed to a sixth, upstream of the Vortechnics™ unit. Between December and March of each winter, about 13.6 tonnes of sand and salt were applied to the parking lot. Fertilizer was applied to the surrounding grass and spilled onto the asphalt in the fall of 2000.

Fifty-eight paired composite samples were collected during the 27-month study of influent and effluent from the Vortechnics™. Hartford's average annual precipitation over the 27 months was 973 mm yr^{-1}, a -13.2% difference from the normal precipitation of 1121 mm yr^{-1} (NOAA, 1999, 2000). Precipitation collected at the site and that collected in Hartford showed no significant ($t = 1.94$, $P = 0.08$) differences. Hartford precipitation data was used since rainfall was not measured at the site for the entire 27-month study.

Concentration

The mean influent concentrations of nutrients, metals, TPH, and FCU were similar to those reported by the Nationwide Urban Runoff Program (NURP) (US EPA 1983b). TSS influent concentrations were significantly ($P = 0.05$) higher in winter and spring, probably due to winter applications of sand. However, the median influent concentration at Vortechnics™ for NH_3-N was 0.16 mg L^{-1}, similar to Steuer *et al.* (1997), who reported 0.19 mg L^{-1} in urban runoff. Rabanal and Grizzard (1995) reported a TPH median concentration of 7.0 mg L^{-1} in commercial site runoff, which was higher than that observed at the Vortechnics™.

Stormwater at the Vortechnics™ was higher in concentrations of Zn than at the other sites (Table 11); otherwise, concentrations were similar to stormwater at the other locations monitored. The Vortechnics™ unit significantly ($p=0.05$) decreased the concentrations of TSS, TKN, NO_3-N, TP, Cu, Pb, and Zn in stormwater runoff (Table 11). However, mean concentrations were near the detection limit for NH_3-N.

Based on the ANOVA and Duncan's mutiple range tests, NO_3-N concentrations in runoff were significantly ($P = 0.05$) lower in summer than in the other three seasons entering the Vortechnics™. TKN influent concentrations were significantly ($P = 0.05$) higher in spring and summer than in winter; fall showed no significance. Cu concentrations were significantly ($P = 0.05$) higher in winter and spring than in fall.

Results of the toxicity testing showed no reductions between influent and effluent of copper nitrate. Only one influent sample had a mortality rate of *Daphnia pulex* that was less than 100%. However, there was no significance ($P = 0.05$) in paired data.

Mass Retention

Loading to the Vortechnics™ unit was lower than reported for the NURP results for commercial site runoff (US EPA 1983b). Stormwater runoff from an urban area in Madison, Wisconsin had loadings of 1.12 kg ha^{-1} yr^{-1} for TP, 0.90 kg ha^{-1} yr^{-1} for NH_3-N, 1.48 kg ha^{-1} yr^{-1} for NO_3-N, and 429 kg ha^{-1} yr^{-1} for TSS (Ahern et al. 1981.). The Vortechnics™ in South Windsor had similar values, except for TSS, which was higher.

The Vortechnics™ retained TSS, TKN, NO_3-N, TP, and Pb, Cu, and Zn (Table 12). The unit did not retain NH_3-N or bacteria. Retention of suspended solids was the highest of all systems monitored, and was very close to the 80% claimed by the manufacturer. As the concentrations of TKN ($r^2 = 0.309$) and NH_3-N ($r^2 = 0.146$) in parking lot runoff increased, percent retention values also increased significantly ($P = 0.05$). However, TP, NO_3-N, TSS and metals retention was not related to inlet concentration. TP loadings were significantly ($P = 0.05$) related to precipitation ($r = 0.356$), but no other variables were significantly related to precipitation. TKN and NO_3-N percent retention was lower in winter than the other three seasons. TKN mass loads were significantly higher in spring and summer than winter or fall.

The effectiveness of a Vortechnics™ has been studied in Maine, New Jersey, and New York. Based on seven months of event mean concentration sampling in Maine in 1999, suspended sediment in stormwater from a parking lot was reduced 81.6 % on a mass basis (DeLorme Publishing Co., 2000). Monitoring of runoff from a rest stop in New Jersey occurred on five days in 1999 (Greenway, 2000). On a concentration basis, the Vortechnics™ in New Jersey reduced TPH by 67.0 % and TSS by 92.9 %. In Lake George, NY, 13 events were sampled in 2000 with automatic samplers (West et al., 2001). Mass retention of TSS was 88 % for that study.

Table 11. Mean (anti-log) water quality concentrations, and Student's t for paired t-tests for the Vortechnics™ (January 1999 through April 2001).

Variables	n	Influent Mean	Effluent Mean	Student's t	p
TSS (mg L^{-1})	43	85	27	6.79	<0.001
TKN (mg L^{-1})	53	1.0	0.8	2.31	0.025
NO_3-N (mg L^{-1})	53	0.4	0.2	4.59	<0.001
NH_3-N (mg L^{-1})	54	0.17	0.13	1.06	0.293
TP (mg L^{-1})	51	0.176	0.066	4.58	<0.001
Pb (µg L^{-1})	13	18	11	2.77	0.017
Cu (µg L^{-1})	20	26	13	5.23	<0.001
Zn (µg L^{-1})	20	416	73	9.93	<0.001
FCU	7	396	423	-1.16	0.290
TPH (mg L^{-1})	6	0.44	0.37	0.77	0.475

Table 12. Annual mass loading to the Vortechnics™ system and cumulative mass percent retention (January 1999 through April 2001).

Variable	Annual Loading Kg ha^{-1} yr^{-1}	Cumulative Mass Retention (%)
TSS	990.40	77.0
TKN	3.87	18.3
NO_3-N	1.85	54.1
NH_3-N	0.88	-1.1
TP	1.34	66.9
Pb	0.023	46.5
Cu	0.055	56.2
Zn	0.96	85.3
FC		-6.7

System Costs

Table 13 summarizes the costs of the stormwater treatment monitoring devices. Installation costs were affected by whether it was new construction or a retrofit project. Generally, it is cheaper to install a device during new construction than it is to retrofit a device. Retrofit required asphalt cutting and replacement costs. The design and installation costs are primarily installation costs. Design costs were generally donated or provided by the towns. Monitoring added costs included the addition of monitoring manholes where needed. Maintenance costs were not available for this study but would likely vary among devices. Costs would be similar for the Downstream Defender™, Storm*ceptor*®, and Vortechnics™ units since they are all oil-grit separators. Maintenance of the catch basin would cost less than the oil-grit separators. Maintenance of the Stormtreat™, requires annual changing of the grit bags, maintenance of the wetland plants, and oil removal when the grit bags are changed. This maintenance is different than for the oil-grit separators but probably is not substantially more expensive.

Table 13. Costs of stormwater treatment devices.

System	Construction Type	System Cost ($)	Design & Installation Cost ($)	Monitoring Added Cost ($)	Total Cost($)
Catch basin	new	2,500	600	0	3,100
Downstream Defender™	retrofit	24,795	8,000	donated	32,795
Storm*ceptor*®	new	12,500	2,500	1,000	16,000
Stormtreat™	retrofit	6,600	20,000	0	26,600
Vortechnics™	new	16,500	8,000	804	25,304

CONCLUSIONS

Some differences existed in the water quality of stormwater across sites. The street runoff at the construction site, where the Storm*ceptor*® was located, was higher in concentrations of TSS and TP. The commercial parking lot at the StormTreat™ had runoff that was highest in TPH concentrations. Runoff from the new parking lot at the Vortechnics™ site was highest in Zn concentrations.

Retention varied among sites partly due to different stormwater treatment devices, different sources of stormwater pollutants, and different methods of sampling (Coshocton wheel vs peristaltic sampler).

Suspended sediment retention varied among the different devices: Downstream Defender™ (45 %, concentration basis), Storm*ceptor*® (34 %), Stormtreat™ (49 %), and Vortechnics™ (77 %). TP retention varied among system: Downstream Defender™ (28 %, concentration basis), Storm*ceptor*® (29 %), Stormtreat™ (74 %), and Vortechnics™ (67 %). TKN was retained by the stormwater treatment devices: Downstream Defender™ (16 %, concentration basis), Storm*ceptor*® (32 %), Stormtreat™ (44 %), and Vortechnics™ (18 %) but NO_3-N and NH_3-N were not generally retained. An exception was NO_3-N at the Vortechnics™ (54 %) but values were low. Metal retention varied among metal and system. Zn retention was highest among the metals and was: Storm*ceptor*® (60 %), Stormtreat™ (45 %), and Vortechnics™ (85 %). Fecal coliform bacteria reduction was: Storm*ceptor*® (-15 %), Stormtreat™ (99 %), and Vortechnics™ (-7 %). TPH concentrations were not greatly reduced by the treatment devices: Storm*ceptor*® (12 %), Stormtreat™ (37 %), and Vortechnics™ (16 %).

The StormTreat™ reduced the concentrations and mass of TSS, TP, organic N, and Zn , as well as effluent concentrations of FC in parking lot runoff. Concentrations of NH_3-N and NO_3-N were not significantly reduced due to their concentrations being often at detection levels. The system retained NH_3-N more efficiently during the summer than winter, and retained Zn less efficiently during the summer than winter, but season did not affect treatment of TSS, TP, TKN, or NO_3-N. The system operated independently of hydrologic factors, including storm size, chamber stage, discharge rate, and hydraulic retention time. The effects of these factors likely were dampened by StormTreat™ design controls, including a maximum allowable inflow rate, regulated via an overflow weir, and a maximum discharge rate controlled by a valve.

The StormTreat™ system appears to offer additional treatment of stormwater runoff well beyond that provided by a catch basin. The system was particularly effective in treating bacteria and TP. TSS treatment was probably greater than reported because iron bacteria produced solids in the effluent.

Regression analyses indicated that as concentrations of TKN and NH_3-N in stormwater increased, percent retention at the Vortechnics™ also increased. TP loadings were significantly related to precipitation.

RECOMMENDATIONS

1. A study comparing the Coshocton wheel to peristaltic pumps in collecting stormwater samples should be conducted.

2. Stormwater treatment devices are expensive. About one–half the cost is in the installation. Every effort should be made in pollution prevention so that the costs of downstream treatment can be minimized.

3. There are numerous other stormwater treatment devices available that have not been tested. Further studies could be conducted of these new and innovate systems.

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