VORTECHNICS TREATMENT OF PARKING LOT RUNOFF

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INTRODUCTION

A 27-month study was conducted to determine the efficiency of a Vortechnics™ unit in treating parking lot runoff. This study is the longest continuously monitored evaluation of a Vortechnics™ unit to date. The performance of the unit in retaining total suspended solids, nitrogen, phosphorus, heavy metals, bacteria, and petroleum hydrocarbons from parking lot runoff was assessed. Sampling techniques are also compared.

This thesis has two sections. The first is a literature review that discusses urban runoff, pollutants found in urban runoff, and the operating system of Vortechnics™ units. The second section is a manuscript entitled "Vortechnics™ Treatment of Parking Lot Runoff", which was written following the format specified by the journal *Environmental Science and Technology.* The manuscript discusses the efficiency of a Vortechnics™ unit in treating parking lot runoff during the 27-month study.

LITERATURE REVIEW

VORTECHNICS™ TREATMENT OF PARKING LOT RUNOFF

INTRODUCTION

The passage of the Clean Water Act in 1972 established the National Pollution Discharge Elimination System (NPDES) to regulate pollutants from industrial and municipal point sources. In 1987, the Clean Water Act was amended to include stormwater discharges. These discharges are frequently carriers of nonpoint source pollution. According to the Environmental Protection Agency (US EPA, 1983), nonpoint source pollution represents more than half of the remaining water quality problems in the United States. Nonpoint source pollution contributes bacteria, sediment, nutrients, and toxic materials to Long Island Sound (US EPA, 1991). This pollution originates from precipitation, imperviousness (accumulation and washoff), dry atmospheric deposition, traffic emissions, leaching, solids accumulation in sewers, discharges from cars, and application of fertilizers (Smolen *et al.*, 1990). Nonpoint source pollution is also known as diffuse pollution and includes urban runoff, wet and dry atmospheric deposition, and activities on land that generate wastes and contaminants (Novotny and Olem, 1994).

Stormwater management objectives concentrate on protecting the beneficial uses of water, developing a watershed-wide approach, involving the stakeholders, and meeting regulations (Roesner *et al*., 1998). Stormwater management focuses on impervious surfaces found mainly in urban areas. Currently, 16% of the land cover in Connecticut is classified as urban (CT DEP, 1997). After agriculture, pollutant loadings from runoff of urban areas were the most frequent problem reported by states from Section 305(b) of the Clean Water Act (US

EPA, 1998). In areas with storm sewers, all of the pollution on impervious surfaces that has not been removed by street cleaning, wind, or decay will end up in surface runoff (Smolen *et al*., 1990). The pollutants accumulate in the watershed over time, and loading tends to be chronic rather than episodic (DE DNR, 1997). Higher amounts of runoff increase the potential for nonpoint source pollution. Myers *et al*. (1985) reported that in Connecticut, agriculture and irrigation were localized problems, with less than half of the waters affected, whereas construction and urbanization were identified as widespread problems, and fifty percent or more of the waters were affected.

Parking Lots

Arnold and Gibbons (1996) stated that developers consistently build 51% more parking spaces than needed. Parking lots were identified by Bannerman *et al*. (1993) as critical sources of pollutant loads. Steuer *et al*. (1997) found parking lots to have the highest concentrations of polycyclic aromatic hydrocarbon (PAH) compounds. The most extremely toxic samples were found in combined sewer overflows as reported by Novotny (1991), followed by parking lot runoff. Schueler (1994) classified parking lots as hotspots; areas with significantly greater loadings of hydrocarbons and trace metals. The Long Island Sound Study began out of concern that urbanization, particularly parking lots and highways, increases the pollutants added to the Sound (CT DEP, 1989). Pitt *et al*. (1995) found that parking lot runoff contained the highest observed concentrations of organic toxicants. Parking lots were identified as sources of high amounts of metals, including copper, lead, and zinc (Line *et al*., 1996; Owe *et al*., 1982). The EPA (1993) reported that impervious surfaces act as heat collectors, and stated that intensive urbanization can increase stream temperature as much as 5-10°C during storm events.

The objectives of this literature review are to: 1) describe typical urban stormwater pollutants in runoff, and 2) assess a Vortechnics™ unit and its ability to retain these stormwater pollutants.

URBAN RUNOFF

Urban runoff is frequently a major source of contaminants, and the storm sewers associated with runoff decrease the opportunity for infiltration and create a very efficient system of deliverance for stormwater (Baumann *et al*., 1980). Urbanization is linked to the degradation of urban waterways (US EPA, 1993). The word stormwater encompasses many types of runoff: snowmelt runoff, stormwater runoff, surface runoff, and street wash waters related to street cleaning or maintenance (Smolen *et al*., 1990). Roesner *et al.* (1998) described pollutants as being constituents in stormwater runoff that have concentrations and discharges that cause an impairment of designated beneficial uses of receiving waters.

According to Novotny and Olem (1994), soil erosion from all areas is the major cause of diffuse pollution. Sediment yields from urban areas can reach values up to 50,000 $tonnes^{-1}$ km^{-2} yr^{-1}. Sediment is a primary carrier of metals, ammonium ions, phosphates, and organic toxics, all of which are pollutants of concern to US waterbodies (Novotny and Olem, 1994). Pollutants such as these are known as critical: they occur frequently in urban stormwater and their concentrations are high relative to the EPA's water quality criteria (US EPA, 1991).

Critical pollutants impact water in a number of ways: by physical impairment or habitat disruption to biota, enrichment and subsequent eutrophication of receiving waters, and exposure and physiological response to toxic substances by aquatic biota (US EPA, 1991).

Impervious materials such as asphalt prevent water from soaking into the ground (US EPA, 1989). Streets paved with asphalt have 80% higher loadings of pollutants, such as total solids, than concrete (Novotny and Olem, 1994). Runoff from nonpoint sources contributes the most waterborne lead, iron, and suspended solids to Long Island Sound and is a major source of nutrients, heavy metals, and pesticides (US EPA, 1989). Heavy metals are the most prevalent priority pollutants in urban runoff, and coliform bacteria are present at high levels (US EPA, 1983).

From 1978 to 1983, the EPA conducted a five-year study to assess the quality of loads in urban runoff. The study, which involved monitoring 28 sampling sites across the country, was titled the Nationwide Urban Runoff Program (NURP). The NURP studies evaluated the event mean concentrations (EMCs), defined as the total constituent mass discharge divided by the total runoff volume during a storm event (US EPA, 1983). Comparisons between NURP and two other studies of parking lot runoff are found on Table 1. NURP data indicates higher fecal coliform amounts than the other three studies. Also, the median lead and zinc concentrations are higher. Steuer et al. (1997) reported the highest

	Median Event Mean Concentrations			
Pollutant	**EPA, 1983**	**Bannerman et al., 1993**	**Rabanal and Grizzard, 1995**	**Steuer et al., 1997**
TSS (mg L^{-1})	69	58	20.8	138
TKN (mg L^{-1})	1.179	----	1.94	1.50
TP (mg L^{-1})	0.201	0.19	0.27	0.21
NH_3-N (mg L^{-1})	----	----	0.02	0.19
NO_3-N (mg L^{-1})	0.572	----	0.28	0.30
FC (FCU $100ml^{-1}$)	12000	1758	----	4200
Total Cu (ug L^{-1})	29	15	10.2	25
Total Pb (ug L^{-1})	104	22	6.9	40
Total Zn (ug L^{-1})	226	178	144	178
TPH (mg L^{-1})			7.0	

Table 1. Pollutant concentrations for urban land use.

concentration of total suspended solids, followed by NURP. Total Kjeldahl nitrogen and total phosphorus concentrations are similar in every study.

First Flush Effect

Novotny and Olem (1994) stated that first flush occurred when concentrations of pollutants peaked before the peak of the hydrograph. In some studies, first flush is the first inch of runoff and carries 90% of the pollution (FL DEP, 1988). Chang *et al*. (1998) described first flush as the first 0.25 in of runoff, observing highly impervious (>90%) areas. The study reported that the first half-inch carries 40% of the total storm load. Table 2 lists common stormwater pollutants that exhibit the first flush effect, together with their sources.

Common stormwater pollutants studied by researchers are: total suspended solids (TSS), total Kjeldahl nitrogen (TKN), total phosphorus (TP), nitrate+nitrite-nitrogen (NO_3-N), ammonia-nitrogen (NH_3-N), total copper (Cu), total lead (Pb), total zinc (Zn), fecal coliform bacteria (FC), and total petroleum hydrocarbons (TPH). Each of these, along with the sources of these pollutants, is listed on Table 3. The following sections describe each pollutant and explain each pollutant's importance.

Total Suspended Solids

Total suspended solids is a common stormwater pollutant, mainly because of its ability to transport other pollutants that are attached to it, including nutrients, metals, and hydrocarbons (ASCE, 1994; Makepeace *et al*., 1995). Sediment can also cover and

Table 2. Stormwater pollutants and references to first flush.

Pollutant	Reference
TSS	A, B, E, H, K, M
NH_3-N	B, I, J
NO_3-N	B, J
TKN	B, J, K
TP	B, J
FC	B, C
Cu	B, D, J, L
Pb	B, D, J
Zn	B, D, J, L
TPH	F, G

A: Adams and Strong, 1997
B: Chang *et al*., 1998
C: Davis *et al*., 1977
D: Good, 1993
E: Griffin *et al*., 1980
F: Hoffman *et al*., 1982
G: Hunter *et al*., 1979
H: Novotny, 1991
I: Pitt and Field, 1998
J: Randall *et al*., 1981
K: Richards *et al*., 1981
L: Sansalone and Buchberger, 1997
M: Sartor *et al*., 1974

Table 3. Sources and effects of stormwater pollutants (CT DEP, 1995)

Pollutant	**Sources**	**Effects**
Sediment	parking lot runoff	detrimental to aquatic life
TSS	landscaping practices	adversely affect fish and wildlife
	industrial activities	transports other pollutants
	construction activities	recreation/aesthetic loss
Nutrients	parking lot runoff	excessive growth of vegetation
NH_3-N	landscaping activities	and algae which leads to
NO_3-N	industrial activities	eutrophication
TKN	construction activities	contributes to hypoxia
TP	illegal dumping	
Bacteria	parking lot runoff	beach and shellfish closures
FC	landscaping practices	human infection
	construction activities	
	illegal dumping	
Oil and Grease	parking lot runoff	beach closures
TPH	landscaping practices	adversely affect lake, pond, and
	industrial activities	wetland ecology
	construction activities	
	illegal dumping	
Heavy Metals	parking lot runoff	toxic to aquatic life
Cu	landscaping practices	bioaccumulate in food chain
Pb	industrial activities	contamination of drinking water,
Zn	construction activities	including groundwater
	illegal dumping	

destroy an aquatic biological community and fill up lakes and impoundments (Baumann *et al*, 1980). Suspended sediment and turbidity are detrimental to aquatic life because they interfere with photosynthesis, respiration, growth, and reproduction (US EPA, 1991). Siltation also impacts receiving waters through loss of benthic habitat, reduced water storage capacity, impaired oxygen exchange, decreased light penetration, and increased water treatment costs (ASCE, 1994; US EPA, 1993). Compared to treatment plant discharges, urban runoff contributes high levels of TSS to receiving waterbodies (US EPA, 1983).

Griffin *et al*. (1980) reported that suspended sediment generally exhibits the first flush phenomena. This is confirmed by Sansalone and Buchberger (1997), who reported that all solids exhibit a first flush. Novotny (1991) studied first flush in sewer systems and found that if suspended solids are extensive in a drainage system, peak concentration and pollutant loads will precede peak flow and volume. Therefore, TSS contributes to the first flush effect (Table 2).

There is a significant correlation between the concentration of heavy metals and particle sizes, particularly small particles (<15 μm) (Sansalone *et al*., 1995). Baumann *et al*. (1980) reported between 70% and 90% of total phosphorus and lead is found on fine, clay-sized fractions. Renwick and Edenborn (1983) correlated metal concentration with sediment size, stating that finer sediments are more likely to have higher levels of organic matter. Organic matter can readily adsorb metals, as well as provide nutrients for bacteria. Sartor *et al*. (1974) found thirty to fifty percent of nutrients and slightly over half of metals were associated with smaller particle sizes (<43μm). The EPA (1991) reported that toxics attached to suspended sediment in discharge may accumulate in the bottom sediment of receiving waters where they may persist for a long time.

Since Vortechnics™ units are designed to remove 80% TSS from runoff, the amount of toxins, metals, phosphorus, and bacteria in stormwater is potentially reduced.

Nitrogen

Nitrogen has led to hypoxia problems in Long Island Sound, because increased N concentrations contribute to the growth of algae in estuaries (CT DEP, 1995; Frink, 1991; US EPA, 1991). Nitrogen occurs in many forms, including organic-N, NH_3-N, NO_3-N, and total Kjeldahl-N. NO_3-N is most readily used by plants and the most mobile (Smolen *et al*., 1990). Line *et al*. (1996) reported that nitrate concentrations in streams were highest downstream of urban areas; however, the drinking water standard of 10 mg L^{-1} was rarely exceeded. NH_3-N is very toxic to aquatic organisms above 7 mg L^{-1} (Makepeace *et al*., 1995). The forms of nitrogen in stormwater and their ranges in concentrations reported by Makepeace *et al*. (1995) are listed in Table 4. Frink (1991) estimated the nutrient exports to estuaries, concluding that exports of N and P from urban land are underestimated.

The NURP study evaluated TN in urban stormwater and estimated an EMC of 3.31 mg L^{-1} (US EPA, 1983). Chesters and Schierow (1985) stated that more than 90% of total nitrogen in urban stormwater comes from nonpoint source pollution, and Line *et al*.

Table 4. Nitrogen forms and concentrations in stormwater (Makepeace *et al*., 1995)

Forms of Nitrogen	Stormwater Range (mg/l)
TN	0.32-16.00
Inorganic N	0.09-5.44
Organic N	0.32-16.00
NO_3-N	0.01-12.00
NO_2-N	0.02-1.49
NH_3-N	0.01-4.30
TKN	0.32-16.00

(1997) reported the figure as 94%. There is an abrupt increase in total nitrogen when the imperviousness of a site increases past 40-50% of the total land area in a watershed (Griffin *et al*., 1980).

Nitrogen sources include the atmosphere, with more than 2.9 metric tons deposited a year in the U.S. (Puckett, 1995). Randall *et al*. (1981) reported an areal loading range for TKN of 0.002 to 0.03 kg ha^{-1}. Yang *et al.* (1996) estimated 8.3 kg ha^{-1} yr^{-1} wet and dry N deposition in CT. Puckett (1995) stated that deposition occurs primarily in the northeastern states, and 38% of this atmospheric source can be attributed to automobiles, trucks, and buses. The largest sources of nitrogen were from predominantly urban watersheds.

Nitrogen eventually washes off surfaces on which it has deposited in the early stages of precipitation and enters the hydrologic cycle through runoff (Randall *et al*., 1981). Nitrogen in urban runoff exhibits the effects of first flush (Table 2). Halverson et al. (1984) reported that precipitation contributed most of the nitrogen found in runoff from roofs and paved surfaces.

Phosphorus

Sources of phosphorus in stormwater include tree leaves, fertilizers, industrial wastes, detergents, and lubricants (Makepeace *et al*., 1995). Lubricants are typically used in vehicles, which links P to parking lots. Total P in stormwater has been found at a concentration range of 0.01 to 7.30 mg L^{-1} (Makepeace *et al*., 1995). Increased P concentrations contribute to the acceleration of eutrophication in lakes (Frink, 1991).

Novotny and Olem (1994) discussed cohesive sediments, describing them as the clay and organic fractions of washload. Cohesive sediments effectively adsorb pollutants such as phosphates (Novotny and Olem, 1994). The ASCE (1994) stated that nutrients attached to sediments delivered during storm events may eventually settle out and later be resuspended.

Total P is deposited onto surfaces by the atmosphere with an areal loading range of $1.6 \times 10^{-5} - 2.5 \times 10^{-4}$ kg ha^{-1} (Randall *et al*., 1981). In CT, P deposition is estimated around 0.042 kg ha^{-1} yr^{-1} (Yang *et al*., 1996). Phosphorus moves by adsorption or in solution (Smolen *et al*., 1990), and also exhibits first flush (Table 2). Typically, P is the most important nutrient to control in freshwaters while nitrogen is limiting in coastal waters (Frink, 1991). The EPA (1991) discussed P loadings from urban and woodland areas and found loading from urban areas to be three to seven times greater than from undeveloped woodlands.

Chesters and Schierow (1985) found P loading to receiving surface waters from nonpoint sources such as cropland, pasture, and rangeland as 70% of total loads. In urban residential areas, Chester and Schierow (1985) estimated that overuse of fertilizers where water is directly led to storm sewers leads to 100% delivery ratios of N and P. However, a literature review by Line *et al*. (1997) stated that 52% of P loading to streams is caused by nonpoint sources. EPA (1998) discussed nutrients as the leading pollutants to lakes, ponds, reservoirs, and estuaries. Nutrients were the second most prevalent pollutants to rivers, following siltation (US EPA, 1998).

Fecal Coliform Bacteria

Bacteria was listed as the second leading pollutant in estuaries to nutrients (US EPA, 1996). Fecal coliform bacteria (FC) in stormwater have a range of 0.2 to 1.9 x 10^6 CFU 100 ml^{-1} (Makepeace *et al*., 1995). The drinking water standard for FC is 0 FCU 100 ml^{-1} (Makepeace *et al*., 1995). Levels above 1100 FCU 100 mL^{-1} in stormwater have led to the closure of beach and shellfish areas in coastal Connecticut (CT DEP, 1995). The EPA (1983) reported that coliform bacteria are present at high levels in urban runoff, and exceeded water quality criteria during and immediately after storm events.

O'Shea and Field (1992) described coliform bacteria as gram-negative, nonspore-forming, and lactose-fermenting bacilli which produce gas within 48 hours at 35°C. They recommended a maximum density in stormwater of 200 FCU 100 ml^{-1}. It was also reported by O'Shea and Field (1992) that the presence of salmonella increases sharply above 200 FCU 100 ml^{-1} when FC are present. They concluded that separate storm drainage systems, not just combined sewers, present a potential health hazard.

Schillinger and Gannon (1985) reported that stormwater was a common and largely uncontrolled source of microbial pollution. Their study also discovered that bacterial adsorption to stormwater-borne particles resulted in increased settling velocities. Through this finding, it was concluded that sedimentation of attached bacteria may cause FC concentrations to be reduced in polluted surface waters.

Fecal coliform has been described as a good indicator of a possible presence of pathogenic or disease-carrying pollution (Baumann *et al*., 1980; Schillinger and Gannon, 1985). Chesters and Schierow (1985) reported that total coliforms were found in more than 90% of nonpoint sources of stormwater samples.

Bacterial density peaked at or before the hydrograph peak, confirming the first flush (Table 2) in a study by Davis *et al*. (1977). In Buzzard's Bay, MA, an assessment of sources and transport pathways of coliform bacteria revealed that urban storm drains contributed the most FC to the Bay (Line *et al*., 1997). The sources of FC in stormwater include fecal material from dogs, cats, rodents, and birds (Makepeace *et al*., 1995). Novotny and Olem (1994) reported that there are 21 times less FC in winter than summer in stormwater.

Metals

Copper (Cu), lead (Pb) and zinc (Zn) raise concern in stormwater because they can be toxic to aquatic organisms, may contaminate drinking water supplies, and can bioaccumulate (US EPA, 1983). Runoff is a major source of heavy metals (Renwick and Edenborn, 1983; US EPA, 1983). Copper, lead, and zinc in particular account for about 90% of the dissolved heavy metals in stormwater and 90-98% of the total metals (FL DEP, 1988). It is estimated that 60-70% of Zn and 40-60% of Cu in stormwater comes from nonpoint sources (Chesters and Schierow, 1985).

Myers *et al*. (1985) reported that Cu, Pb, and Zn are significant pollutants that come from transportation practices. Owe *et al*. (1982) found Cu, Pb, and Zn in parking lot runoff, and that Pb and Zn loadings were directly correlated with percent imperviousness. EPA (1983) found that metals and inorganics are the urban runoff contaminants having the greatest potential for long-term impacts on aquatic life.

Sansalone and Buchberger (1997) conducted a study that found Zn and Cu exhibit a first flush in pavement sheet flow (Table 2). Pb did not exhibit a first flush, because it is particulate-bound. Sansalone and Buchberger (1997) also related the deposition and accumulation of metals as resulting from traffic activities, vehicular component wear, pavement degradations, roadway maintenance, and fluid leakages. Sansalone and Buchberger (1997) stated that dissolved metals are readily bioavailable and very mobile. Control strategies for dissolved metals must provide for adsorption, ion exchange, or precipitation, as well as trap particulate-bound elements. Sansalone *et al*. (1995) reported a significant correlation between heavy metals and suspended sediment during long duration events (2.2-79.5 hr). There is a strong correlation between metal concentration and small particle sizes (<15 μm) (Richards *et al*., 1981; Sansalone *et al*., 1995).

CT DEP (1996) described the origins of metals and their effects on the environment. Copper is naturally occuring, and in low concentrations is a minor nutrient for plants and animals. At higher levels, however, it becomes toxic. Copper also originates from brake pads on vehicles, combustion of lubricating oils, and shows a correlation with the intensity of vehicular traffic (Makepeace *et al*., 1995). Lead is a toxic carcinogen that becomes airborne through auto exhaust and is difficult to isolate and control (CT DEP, 1996; Chesters and Schierow, 1985). It is associated with solids in stormwater runoff, and had the highest concentration in samples from traffic and parking related areas (Makepeace *et al*., 1995; Novotny, 1991). Zinc is a highly toxic metallic element that is widespread in Connecticut, originating from rubber tires, diesel fuel and gasoline exhaust, and galvanized metal. Good (1993) found Cu, Pb, and Zn to exceed water quality criteria in roof runoff samples. Of these three, the concentration of Zn was the greatest. Metal concentrations in the Vortechnics™ unit were studied, knowing that parking lots are a source of Cu, Pb, and Zn, and loads of sediment from the parking lot potentially contained sediment-bound metals.

Petroleum Hydrocarbons

Total petroleum hydrocarbons (TPH) are important because of their toxicity and ubiquity (Whipple and Hunter, 1979). Hydrocarbon compounds are toxic to aquatic organisms (CT DEP, 1995). The main sources of TPH include leaks from engines, spills at fueling stations, and overfilled tanks (CT DEP, 1995; Hoffman *et al*., 1982; Hunter *et al*., 1979; Whipple and Hunter, 1979). Steuer et al. (1997) reported that parking lots contained the highest concentrations of polycyclic aromatic hydrocarbon compounds, at 300 $\mu g\ L^{-1}$.

Schueler (1994) found that hydrocarbons are a major contributing factor to sediment contamination. This finding agrees with Whipple and Hunter (1979) and Hoffman *et al*. (1982); both stated that most oil in runoff is assimilated to particles. Hunter *et al*. (1979) studied urban runoff and hydrocarbon pollution, and found that 86% of hydrocarbons in urban stormwater were associated with particulate matter. Both Hoffman *et al*. (1982) and Hunter *et al*. (1979) confirmed that a first flush of hydrocarbons occurs in stormflow (Table 2). The most common method of treatment for TPH is an oil grit separator (OGS) (Schueler, 1994).

Anthropogenic sources of hydrocarbons have much greater impacts on water bodies than those from biogenic sources (Fam *et al*., 1987). Controlling high hydrocarbon producing areas, such as parking lots, can produce significant reductions in total mass emissions, even if these areas comprise a small fraction of the total area (Fam *et al*., 1987). Whipple and Hunter (1979) found that larger quantities of hydrocarbons occurred during storm periods, with few hydrocarbons originating during times of low flow. This agrees with Fam *et al*. (1987), who reported that water quality parameters do vary during storm events, with the higher concentration occurring at the peak. Hoffman et al. (1982) stated that chronic discharges of petroleum contributed more oil to waterbodies (in total mass) than large spills.

Toxicity

Typically, toxicity is determined by bioassays in which test organisms are exposed to various doses of concentrations of a pollutant. The lethal concentration (LC) of a pollutant implies that the test organism has died. The 50% survival concentration is also known as the LC_{50} and is representative of the acute toxicity of the pollutant (Novotny and Olem, 1994).

A literature review by Makepeace *et al*. (1995) found that copper is the major aquatic toxic metal in stormwater. The toxicity of Cu on aquatic life is between 0.017 and 10.24 mg/l at a hardness of 50 mg/l (Makepeace *et al*., 1995). The same review reported that a sample containing 9.2% of a Cu solution was toxic to 50% of *D. pulex*. Toxic metals were by far the most prevalent priority pollutants in the NURP study (US EPA, 1983). Novotny (1991) reported that the most toxic samples were found in combined sewer overflows, followed by parking lot runoff.

Good (1993) sampled the first flush of runoff to characterize the worst-case contaminant concentrations and aquatic toxicity (Table 2). That study reported that roof runoff was a major source of stormwater contamination and aquatic toxicity. Pitt *et al*. (1995) collected 87 stormwater samples and found 9% were extremely toxic, 32% were moderately toxic, and 59% had no evidence of toxicity. Toxicity definitions were suggested for 35-minute exposures. A highly toxic sample had a light decrease >60% in a photo-degradation test, and moderately toxic had a light decrease between 20 and 60%. Vehicle service and parking lot runoff samples had many of the highest observed concentrations of organic toxicants (Pitt *et al*., 1995). On the other hand, Novotny and Olem (1994) reported that the particulates contributed by traffic are inorganic.

Vortechnics™

The Vortechnics™ system is known as a structural best management practice (BMP), i.e. one constructed to aid removal of nonpoint source pollution (Richards *et al*., 1981). The Vortechnics™ system combines swirl-concentrator and flow-control technologies to eliminate turbulence within the system and remove grit, contaminated sediments, metals, hydrocarbons, and floating contaminants found in stormwater (Vortechnics™ Inc., 1998). There are three sections in a Vortechnics™ unit: the grit chamber, oil chamber and baffle wall, and the flow control chamber (Figure 1).

The primary purpose of the Vortechnics™ system is to prevent turbulence and "wash-outs" (ME DEP, 1996). There are two ways the system accomplishes this: 1) settleable particles are swept to the center of the swirl chamber, known as a vortex action, where particles then migrate toward the center and settle, and 2) flow controls within the system are sized to adjust the water depth and raise the previously trapped floatables out of the way of incoming flow (ME DEP, 1996; US EPA, 1996). Vortechnics™ units are designed to provide 80% TSS removal on a mass basis (Vortechnics™ Inc., 1998).

Reported advantages of the Vortechnics™ system are its ability to handle large capacities, up to 0.71 $m^3 s^{-1}$; units can also handle storm events as small as 0.08 $m^3 s^{-1}$ (ME DEP, 1996). This is reportedly a key factor in the success of Vortechnics™, since the vast bulk of precipitation occurs in smaller and more frequent storms (DE DNR, 1997). The baffle is always submerged, preventing sediments and pollutant residues from being flushed out (ME DEP, 1996). Oil grit separators require minimal land area, can be adapted to all regions of the US, and have a high longevity (US EPA, 1993).

Stormwater that enters the Vortechnics™ unit typically travels from a catch basin located

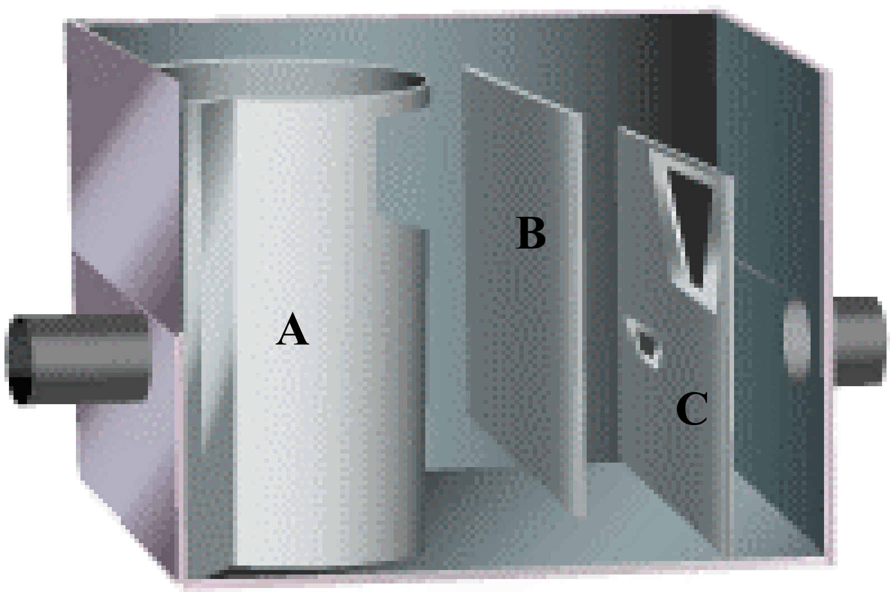

Figure 1. Cross-section of a Vortechnics™ unit. A: Grit chamber, B: Baffle wall, C: Flow control chamber (Vortechnics Inc., 1998).

upstream. Pitt and Field (1998) found that significant ($P = 0.05$) pollutant removals found with conventional catch basins were 30% of suspended solids and 20% of total solids on a concentration basis. Catch basins trap appreciable portions of coarse sediment, however relatively few pollutants are bound to coarser solids (Pitt and Field, 1998; Sartor *et al*., 1974). EPA (1993) reported probable percent removal ranges for catch basins as follows: TSS: 10-25%, TP: 5-10%, TN: 5-10%, Pb: 10-15%, and Zn: 5-10%.

Monitoring results of various Vortechnics™ units are summarized in Table 5. Results from all three studies exceeded the manufacturer's claim for a TSS removal efficiency of 80%. Greenway (2001) studied a Vortechnics™ unit in combination with a sand filter in treating stormwater concentrations on the side of a New Jersey highway. The concentration obtained in the study is higher than the manufacturer's claims, at 95% removal on a concentration basis for the Vortechnics™ unit alone. DeLorme Publishing Company in Yarmouth, Maine installed a Vortechnics™ 11000. Over 20 storms, 82% TSS was retained on a concentration basis (DeLorme, 2000). A study in Lake George, NY by West *et al*. (2001) had 88% TSS removal from stormwater on a mass basis. Their study used Manning™ vacuum pumps, whereas the other two utilized ISCO™ peristaltic pumps.

Samplers

When sampling for water quality data, many types of sampling equipment are employed. ISCO™ and Sigma™ samplers use peristaltic pumps to draw, measure, and deposit water into appropriate sample bottles (USGS, 1995). Manning™ samplers use a vacuum pump

Table 5. Results of monitoring three Vortechnics™ systems.

	DeLorme, 2001	Greenway, 2001	West et al., 2001
Pollutant	------------------Removal Efficiency (%)-----------------		
TSS	82	95	88
TPH	----	79	----
TP	----	----	3
Number of Samples	20	5	13
Location	Yarmouth, ME	Harding, NJ	Lake George, NY
Area (ha)	2.83	1.21	3.78
Model No.	11000	4000	11000

to draw the sample into a measurement chamber that collects the water before deposition into a sample bottle (USGS, 1995). In a study comparing vacuum and peristaltic samplers in Wisconsin, cross contamination of samples was twice as high in the vacuum samplers as it was in the peristaltic samplers (USGS, 1995).

A study evaluating automatic water quality samplers tested whether a representative particle size distribution for the 20 µm to 128 µm range could be collected using ISCO™ and Manning™ samplers (USGS, 1995). The ISCO samplers took an increased volume of water as the depth increased, indicating volume accuracy may be problematic (USGS, 1995). The Manning™ sampler had very good volume repeatability. All samplers took a good representative sample for the desired particle size distribution. However, Sartor *et al.* (1974) reported that 6% of stormwater is less than 43 µm, whereas 38% is between 43 and 246 µm, and the remaining 57% is greater than 246µm. Thus, much of the particle size fraction found in stormwater was not tested.

An evaluation of an oil/grit separator in Madison, WI reported that there was a 24% difference between the estimated amount of TSS removed and the actual removal, because the ISCO™ automatic samplers could not effectively collect the material (Waschbusch, 1999). Some researchers prefer to use a Coshocton wheel for stormwater sampling because Coshcoton wheels provide for continuously composited and flow-weighted samples; a constituent concentration is then gathered for the entire storm flow (Rabanal and Grizzard, 1995; USDA, 1979).

CONCLUSIONS

Urban areas, and in particular parking lots, contribute nonpoint source pollutants to waterbodies and impair use. Nutrients, metals, and sediment are pollutants found in urban stormwater runoff that degrade water quality. Heavy metals are the most prevalent pollutants in urban runoff. Pollutants are delivered in the first flush of stormwater.

Applications of structural BMPs, such as Vortechnics™ and other oil/grit separators, are increasing. Recently completed studies have shown devices such as Vortechnics™ units effectively remove solids and other pollutants from stormwater. These studies agree with the manufacturer's claims of 80% suspended sediment removal. Retaining sediment in oil/grit separators aids retention of other pollutants, since sediment is a primary carrier of metals, nutrients, and organic toxics. The reduction of pollutants in stormwater will lead to cleaner surface waters, improve stream and river quality, and decrease eutrophication.

Researchers need more information on sampling devices. The various brands of sampling devices capture stormwater differently, some more effectively than others. Additional information is recommended in order that researchers can choose the best sampler for their studies. Samplers of different brands should be compared testing larger sediment particle sizes, which are more typical of stormwater runoff.

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VORTECHNICS™ TREATMENT OF PARKING LOT RUNOFF

ABSTRACT

Urban runoff contributes to the degradation of rivers, lakes, estuaries, and wetlands in the U.S. Several stormwater treatment devices are being developed to treat runoff from urban areas, but their performance has not been extensively tested. The effectiveness of a Vortechnics™ unit in treating stormwater runoff from a 7,900 m^2 school parking lot was evaluated after monitoring from January 1999 through April 2001 in South Windsor, CT. Flow-weighted composite samples were collected from the Vortechnics™ inflow and outflow. A peristaltic sampler (outlet) and a Coshocton wheel (inlet) were used to collect samples. The Vortechnics™ retained total-Kjeldahl nitrogen (TKN) (18%), total phosphorus (TP) (67%), nitrate (NO_3-N) (54%), total suspended solids (TSS) (77%), copper (Cu) (56%), lead (Pb) (46%), and zinc (Zn) (85%) on a mass basis but not ammonia (NH_3-N) (-1%). The Vortechnics™ unit significantly reduced the concentrations of TKN, TP, NO_3-N, TSS, Cu, Pb, and Zn found in parking lot runoff.

INTRODUCTION

Stormwater runoff contributes pollutants to waterbodies that impair beneficial uses of water. Runoff from parking lots is a critical source of pollutant loads (3). Parking lots were classified by Schueler (21) as hotspots; places where greater loads of hydrocarbons and trace metals are found in the runoff. Systems such as Vortechnics™ were designed to treat parking lot runoff more effectively than catch basins alone. The Vortechnics™ unit contains a cylindrical grit chamber, where runoff from parking lots enters tangentially and swirls around (Figure 1). Within the swirl chamber, sediment is expected to settle. A baffle wall suspended from above potentially traps floating oil, grease, and debris as flow moves toward the outlet. Before exiting, water enters a flow control chamber containing a weir and an orifice. The manufacturer claims that this device will remove 80% total suspended solids.

The objective of this study was to determine how well the Vortechnics™ unit retained nutrients, metals, and total suspended solids from parking lot runoff. This study also determined how well total petroleum hydrocarbons, fecal coliform bacteria, and toxicity were reduced in stormwater runoff. Finally, this paper reports the influence of seasons on stormwater treatment.

Since this project began, monitoring of other Vortechnics™ units was initiated in the Northeast. In these other studies, there was a lack of long-term continuous monitoring. A study in Lake George, New York monitored select storm events for 11 months, in New Jersey five storm events were sampled, and in Maine, twenty storms were sampled.

METHODS

Runoff from a parking lot at Timothy Edwards Middle School in South Windsor, CT was sampled to evaluate the performance of a Vortechnics™ unit. The monitoring occurred weekly for 27 months, capturing low-flow as well as storm events. The 0.79 ha watershed was 80% impervious, with 82 parking spaces (Figure 2). On average, fifty percent of the parking spaces were utilized during a normal school day. Runoff was collected at five

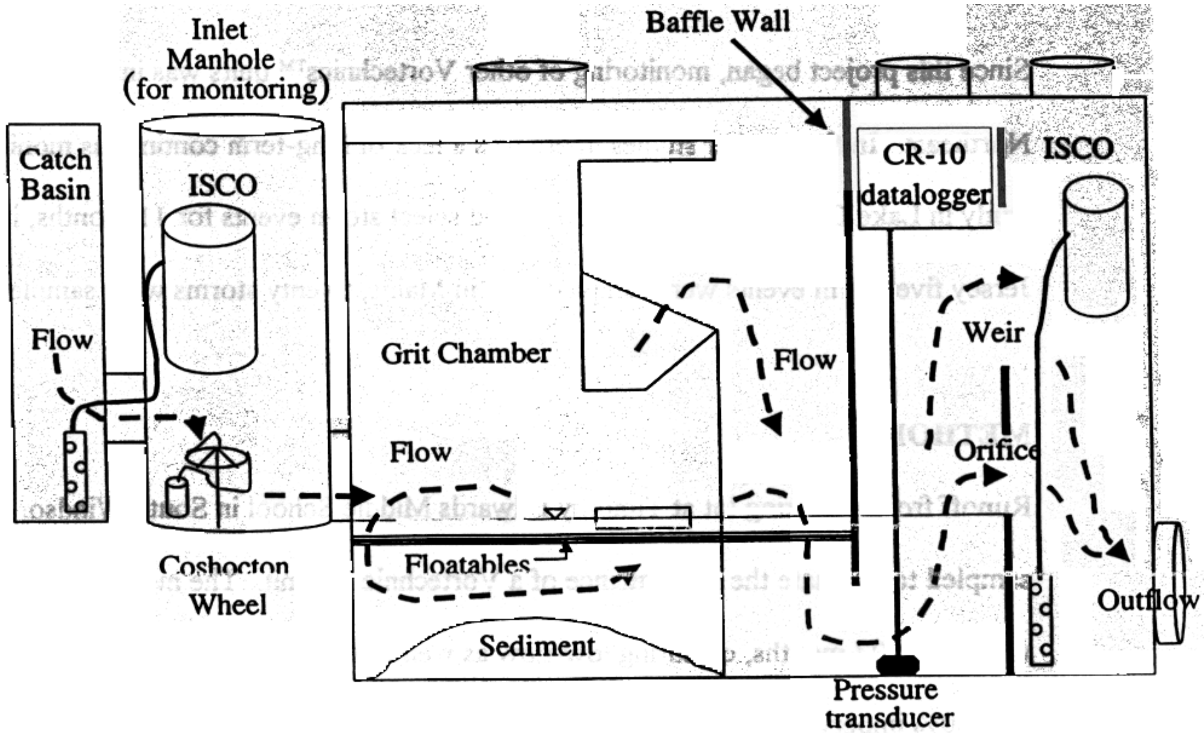


Figure 1. Cross-section of the Vortechnics™ unit, including sampling equipment and direction of flow.

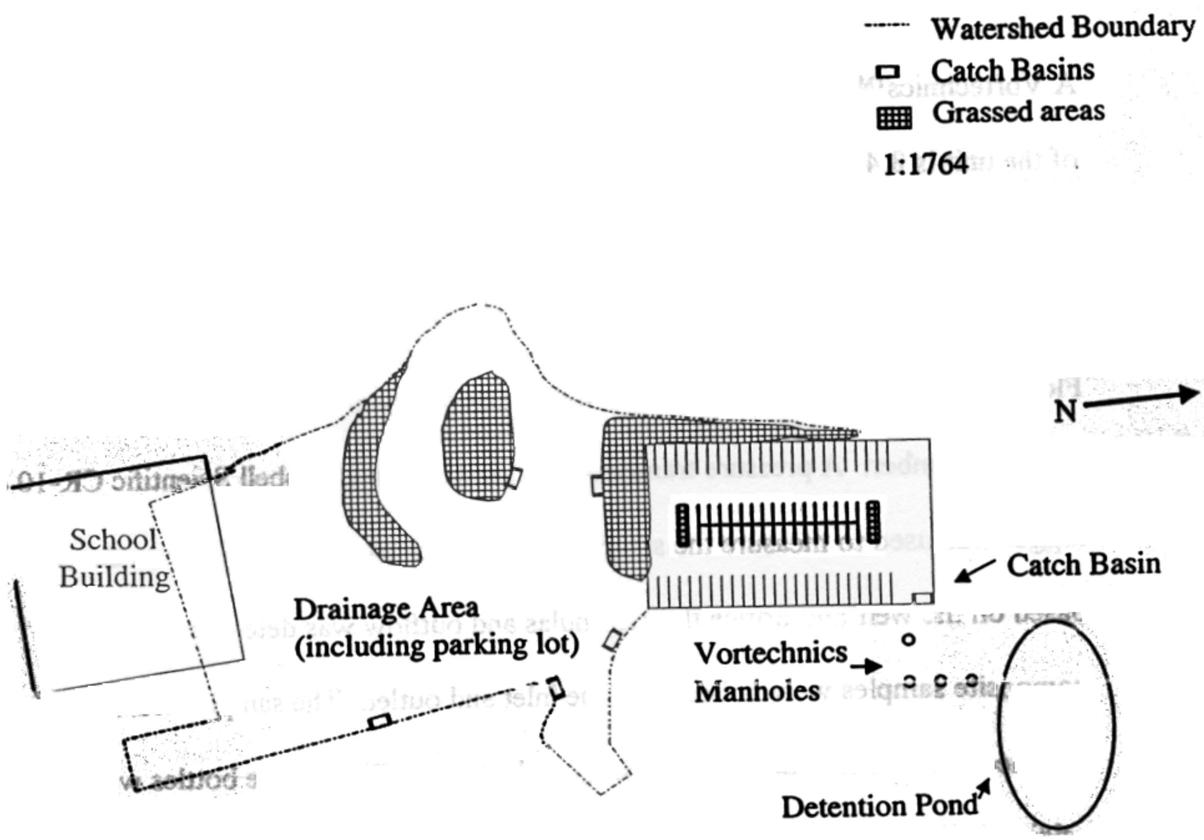


Figure 2. Vortechnics™ watershed area, South Windsor, CT.

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.

This study evaluated the performance of the Vortechnics™ unit in treating total-Kjeldahl nitrogen (TKN), total phosphorus (TP), nitrate (NO_3-N), ammonia (NH_3-N), total suspended solids (TSS), copper (Cu), lead (Pb), zinc (Zn), fecal coliform bacteria (FCU), total petroleum hydrocarbons (TPH), and toxicity from parking lot runoff. Monitoring was continuous, rather than select events, and was conducted over two years.

A Vortechnics™ model 5000 (Figure 1) was installed in November 1998. The base area of the unit is 8.4 m^2 (6). The Model 5000 is designed to store 2.48 m^3 of sediment and has a peak design flow of 0.24 $m^3\ s^{-1}$.

Flow through the Vortechnics™ unit was measured by monitoring the stage in the flow control chamber. A pressure transducer connected to a Campbell Scientific CR-10 data logger was used to measure the stage. A stage-discharge relationship was developed based on the weir and orifice flow formulas and outflow was determined. Weekly composite samples were collected at the inlet and outlet. The samples were split into two acidified and one non-acidified bottle at each station. The sample bottles were pre-acidified with H_2SO_4 for nutrient analysis and HNO_3 for metals analysis. Flow-weighted samples were collected using a model N-1 Coshocton Wheel in the inlet and an ISCO 2900 peristaltic sampler in the outlet. The data logger recorded weekly precipitation, which was measured with a tipping-bucket rain gauge.

Weekly samples were analyzed for TKN, TP, NO_3-N, NH_3-N, and TSS. Monthly composite samples were analyzed for Cu, Pb, and Zn. Grab samples were analyzed for TPH, FCU and toxicity.

A Lachat autoanalyzer was used to measure TKN, TP, NO_3-N, and NH_3-N concentrations by colorimetric flow injection (10). After collection, nutrient samples were analyzed within 28 days. Non-acidified samples were collected to measure TSS using gravimetric methods (2). FC was analyzed using the membrane filter technique (2). TPH was analyzed using methylene chloride extraction (24). The lethal concentration test was performed on toxicity samples, using 50% mortality as the median concentration (LC50) and *Daphnia pulex* as the test organism (2). Pb concentrations were analyzed using atomic absorption furnace methods, and Cu and Zn analyses utilized plasma emission spectroscopy (9).

Data was statistically analyzed using SAS (20). Concentrations of NO_3-N were sometimes below the detection limit. In these cases, half of the detection limit was entered as the concentration. For all other variables measured, values reported were above detection limits. Differences between influent and effluent on both a mass and concentration basis were analyzed using a paired *t* test. The Shapiro-Wilks test was used to determine the normality of concentration data (Appendix B1). Most data followed a log-normal distribution and the log transformation was utilized. Percent retention on a mass basis was calculated by subtracting the outlet load from the inlet load and dividing by the inlet load. Seasonal differences in mass loading as well as seasonal differences in percent retention were tested by analysis of variance (ANOVA) and Duncan's multiple range test (Appendix B2-4). Regression analyses were used to assess the relationship between influent and effluent concentrations, as well as percent retention and influent concentrations. Correlation analysis was performed to determine if loadings were related to precipitation. Log-transformed nutrient and metals concentrations were analyzed to check for correlation to TSS concentrations.

RESULTS AND DISCUSSION

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 annual precipitation of 1121 mm yr^{-1} (11). Weekly 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) (16). The influent concentrations of TSS were consistently higher than effluent concentrations (Figure 3). TSS influent concentrations were significantly (P = 0.05) higher in winter and spring,

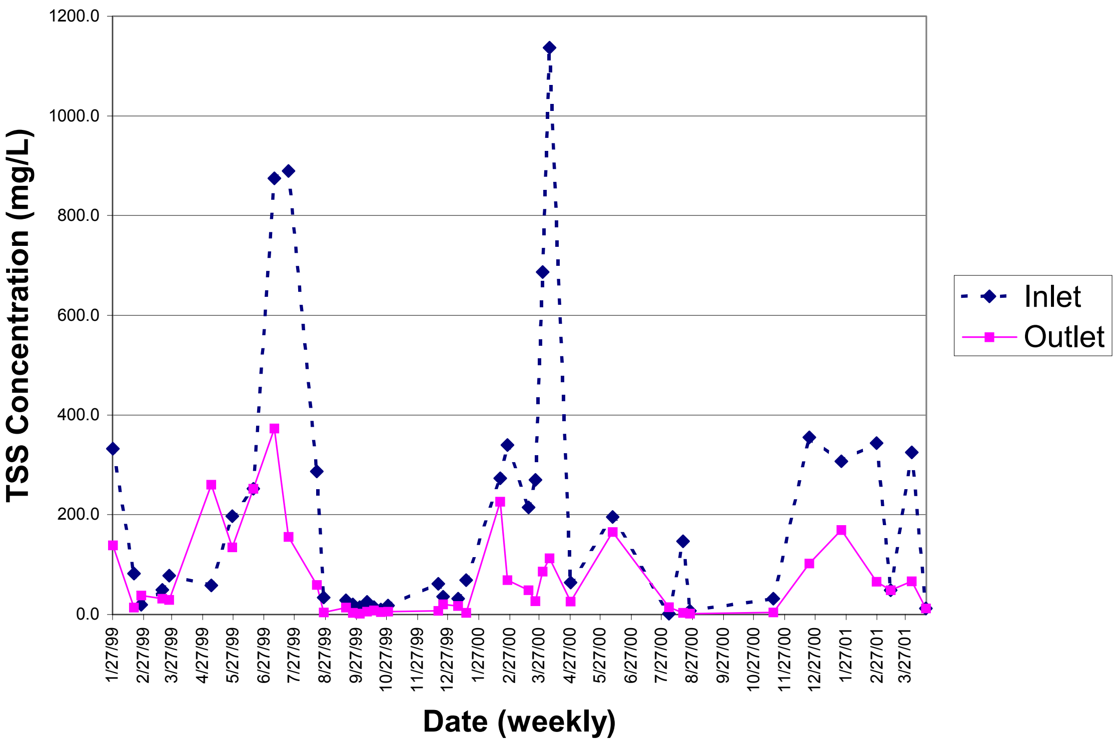


Figure 3. Vortechnics™ unit influent and effluent TSS concentrations over time, January 1999-April 2001.

probably due to winter applications of sand (Appendix B4). The mass loading of TSS was lowest in the fall (Appendix B3). TSS, NO_3-N, and Cu mean influent concentrations were similar to NURP data (Table 1). The exceptions were Zn, which was higher, and FCU and Pb, which were lower than the NURP results. However, the median influent concentration at Vortechnics™ for NH_3-N was 0.16 mg L^{-1}, similar to Steuer *et al*. (23), who reported 0.19 mg L^{-1} in urban runoff. Rabanal and Grizzard (15) reported a TPH median concentration of 7.0 mg L^{-1} in commercial site runoff, which was higher than that observed at the Vortechnics™.

A study conducted on a Vortechnics™ model 11000 in Lake George, New York sampled urban residential runoff for 13 storm events from February to December 2000 (26). The median influent TP concentration at Lake George was 0.14 mg L^{-1}, similar to the South Windsor Vortechnics™ influent value of 0.25 mg L^{-1}. The Lake George total nitrogen influent concentration was also similar. However, the TSS influent concentration from Lake George was 88% higher than observed at South Windsor and the value reported by NURP.

Based on the paired *t* test, there were significant reductions in concentrations ($P = 0.05$) from the influent to the effluent for all variables except NH_3-N, TPH, and FCU (Table 1). However, mean concentrations were near the detection limit for NH_3-N. Thirty-two percent of NO_3-N influent concentrations were below the detection limit of 0.2 mg L^{-1} (Appendix A1).

Table 1. Median concentrations in runoff from the NURP results, anti-log mean concentrations for the Vortechnics™ unit, and *t* value and *P* value from paired *t* test of influent and effluent means (January 27, 1999-April 30, 2001).

		VORTECHNICS				
Variable	Median (1)	# paired samples	Influent mean	Effluent mean	*t* value	*P* =0.05
TKN (mg L^{-1})	1.179	53	1.0	0.8	2.31	0.025
TP (mg L^{-1})	0.201	51	0.175	0.065	4.58	<0.0001
NO_3-N (mg L^{-1})	0.572	53	0.4	0.2	4.59	<0.0001
NH_3-N (mg L^{-1})	0.02	54	0.16	0.13	1.06	0.293
TSS (mg L^{-1})	69	43	89	29	6.79	<0.0001
Cu (ug L^{-1})	29	20	26	13	5.23	<0.0001
Pb (ug L^{-1})	104	13	18	11	2.77	0.017
Zn (ug L^{-1})	226	20	416	73	9.93	<0.0001
FCU	12,000	7	395.8	422.6	-1.16	0.290
TPH (mg L^{-1})	6.6	6	0.44	0.37	0.77	0.475

(1) USEPA (16), except for TPH (22) and NH_3-N (15).

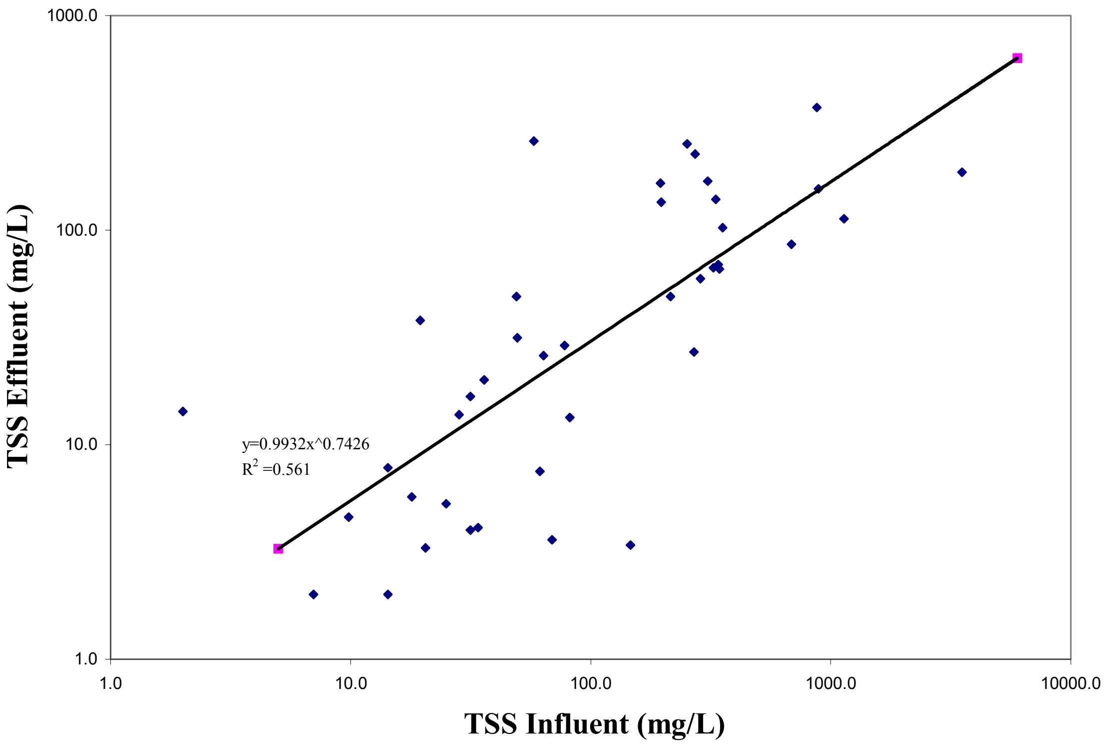
Of variables studied, NO_3-N, Cu, and Pb have drinking water Action Levels set by the EPA (12). NO_3-N influent and effluent concentrations were below the EPA's level of 10 mg L^{-1} 100% of the time. Cu was also below the Action Level of 1300 µg L^{-1} for 100% of the study. Pb concentrations exceeded the drinking water Action Level of 15 µg L^{-1} 69% of the time in the influent and 31% of the time in the effluent.

Effluent concentrations were significantly related to influent concentrations for TKN ($P <$ 0.001, r = 0.554), TP ($P = 0.003$, r = 0.392), NO_3-N ($P < 0.001$, r = 0.507), TSS ($P < 0.001$, r = 0.749), and Cu ($P = 0.002$, r = 0.623) (Appendix B5-6). For example, the effluent concentration of TSS increased with a corresponding increase in influent concentration (Figure 4).

In a Vortechnics™ study in New Jersey, five storms from May 1999 to November 2000 were sampled (5). The Vortechnics™ unit was used to treat a 1.21 ha parking lot. Automatic samplers collected raw stormwater directly from the surface of the parking lot. Removal efficiencies were calculated based on influent and effluent concentrations. The Vortechnics™ unit retained 93% of the TSS and 67% of the TPH. In the Lake George study, the Vortechnics™ unit treated a 3.78 ha watershed that was 95% impervious (26). The 13 events that were sampled between February and December 2000 indicate that the system retained 88% of the TSS and 3% of TP on a concentration basis.

Nutrient and metal concentrations have been correlated to TSS concentrations in other studies of stormwater runoff (4, 14, 17, 18). For example, Sansalone *et al*., (18) found a

Figure 4. Regression analysis of effluent concentration versus influent concentration of



TSS in the Vortechnics™ unit, January 1999-April 2001.

positive correlation during runoff events between metal and suspended solids concentrations.

This finding agrees with the correlation results from the South Windsor Vortechnics™ unit, which indicated that TKN (r = 0.470), NO_3-N (r = 0.386), Cu (r = 0.894), and Zn (r = 0.592) were positively correlated (P = 0.05) with TSS, and NH_3-N (r = -0.417) was negatively correlated with TSS. Based on the ANOVA and Duncan's mutiple range tests, NO_3-N concentrations in influent were significantly (P = 0.05) lower in summer than in the other three seasons. TKN influent concentrations were significantly (P = 0.05) higher in spring and summer than in winter. Cu concentrations were significantly (P = 0.05) higher in winter and spring than in fall (Appendix B4).

Results of the toxicity testing showed no reductions between influent and effluent. 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 (16) (Table 2). TP, TSS, and Zn had higher mass loadings than the ranges reported by Novotny and Olem for commercial runoff (13). 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 (1). The Vortechnics™ in South Windsor had similar values, except for TSS, which was higher (Table 2).

Table 2. Annual loading and cumulative mass retention of the South Windsor, CT Vortechnics™, and typical mass loading values for commercial land use.

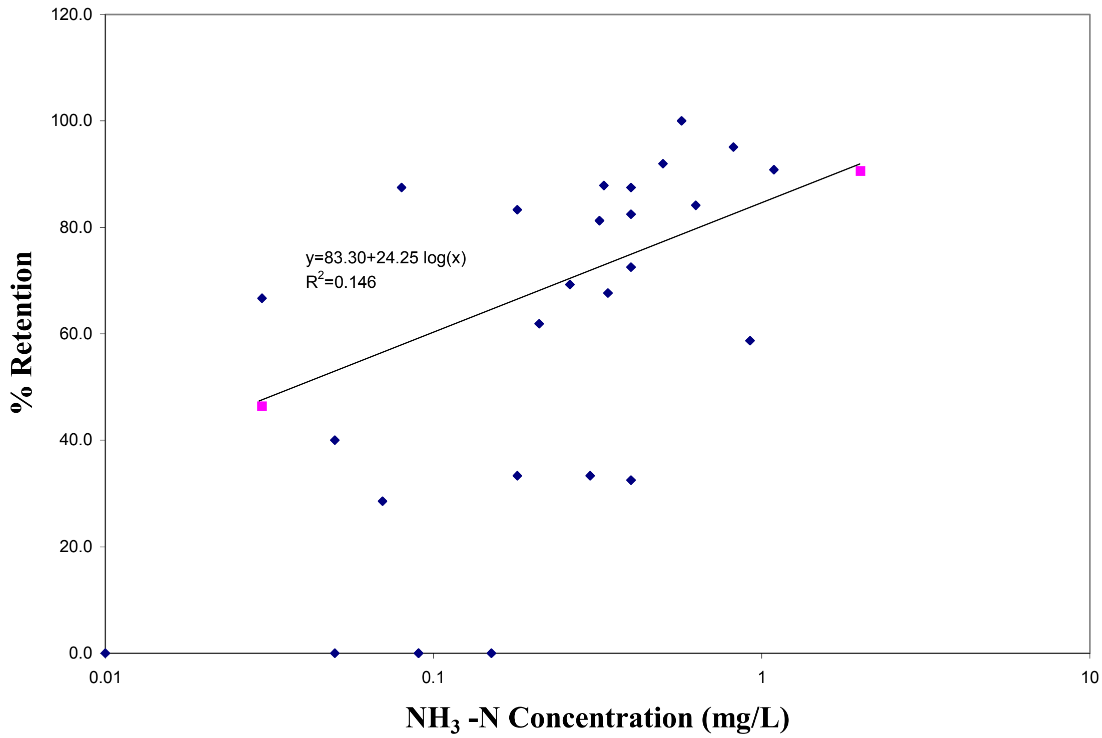
Variable	Annual Loading kg/ha/yr	Cumulative Mass Retention (%)	USEPA (1983) kg/ha/yr	Novotny and Olem (1994) kg/ha/yr
TKN	3.87	18	15.4	1.9-11
TP	1.34	67	3.4	0.1-0.9
NO_3-N	1.85	54	7.0	---
NH_3-N	0.88	-1	---	---
TSS	990.40	77	1460	50-830
Cu	0.056	56	0.35	0.07-0.13
Pb	0.02	46	1.48	0.17-1.1
Zn	0.96	85	1.64	0.25-0.43
FC	14.44	-6	---	---

In South Windsor, the unit retained 18% TKN, 67% TP, 54% NO_3-N, -1% NH_3-N, and 77% TSS on a mass basis (Table 2). In addition, the Vortechnics™ in the South Windsor study retained 56% Cu, 46% Pb, and 85% Zn. FC was not retained (<0%). The *t* test performed on paired weekly samples of mass input and export indicated significant (P = 0.05) reductions for TP, NO_3-N, TSS, Cu, Pb, and Zn. TKN, NH_3-N, TPH, and FCU did not have significant differences between mass input and export. There was no significant (P = 0.05) trend in TSS retention over the life of the study.

As the concentrations of TKN and NH_3-N in parking lot runoff increased, percent retention values also increased significantly (P = 0.05) (Figure 5). 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 retentions were lower in winter than the other three seasons (Appendix B3). TKN mass loads were significantly higher in spring and summer than winter or fall.

CONCLUSIONS

The Vortechnics™ unit significantly reduced effluent concentrations of TKN, TP, NO_3-N, TSS, Cu, Pb, and Zn. The mean influent and effluent concentrations of NH_3-N were near detection limits and retention was not significant. Annual loading to the Vortechnics™ was moderate compared to other studies. Existing studies on the Vortechnics™ system are smaller and less extensive than the one in South Windsor, CT. There was a lack of long-term continuous monitoring in the studies in New York, New Jersey, and Maine.



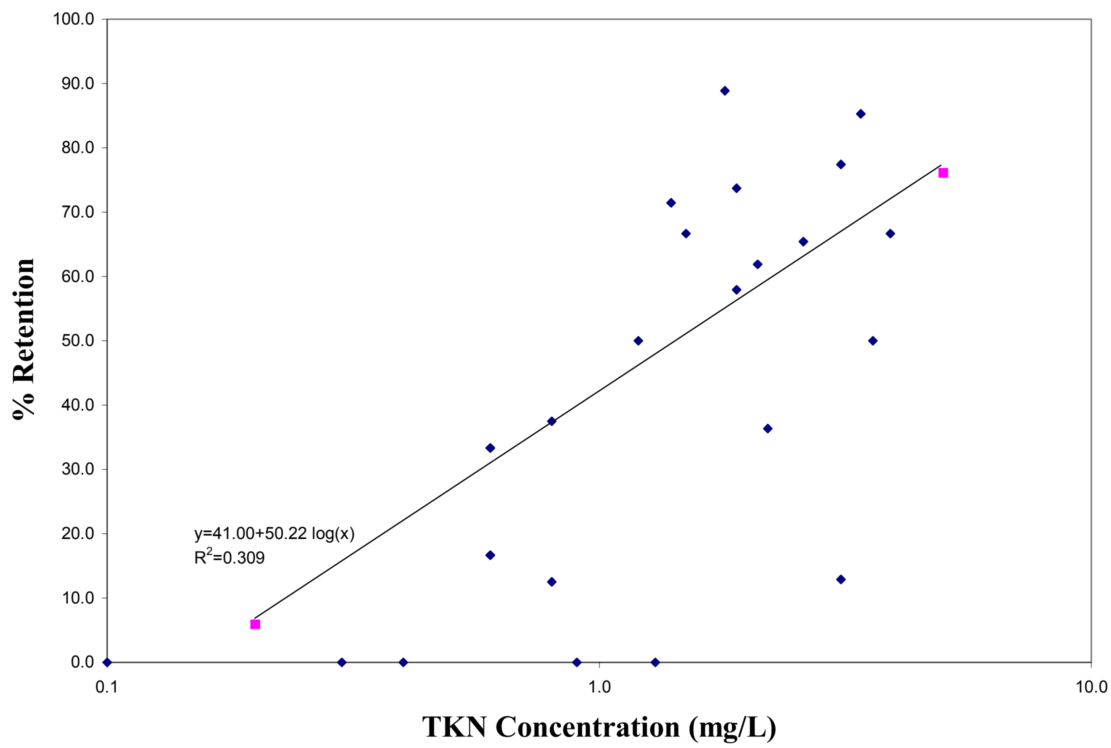


Figure 5. Percent retention versus NH_3-N and TKN influent concentration for the Vortechnics™ unit, January 1999-April 2001.

Regression analyses indicate that as concentrations of TKN and NH_3-N increased, percent retention also increased. TP was positively correlated with precipitation. TKN, NO_3-N, Cu, and Zn were positively correlated with TSS, and NH_3-N was negatively correlated. Retention of TSS in the Vortechnics™ unit was 77% on a mass basis.

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APPENDICES

APPENDIX A

DATA SUMMARY

Appendix **A1.** **Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and** precipitation data at the **Vortechnics™ unit.**

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
12/08/98	8054	1								60	0.215	
12/22/98	8070	1								1000		
01/27/99	8155	1	1.14	10850.8	0.4	0.163	1.3	0.15	332.5			
02/03/99	8159	1	4.04	197.8	0.3	0.142	0.7	0.18	280.0			
02/10/99	8166	1	0.23	47.826	0.2	0.053	0.9	0.1	64.5			
02/17/99	8172	1	0.25		0.7	0.570	0.5	0.17	82.0			
02/24/99	8184	1	0.78		0.2	0.050	0.8	0.11	19.5			
03/03/99	8200	1	1.69	20947	0.4	0.202	0.8	0.21	86.0			
03/10/99	8210	1	0.98	23745.5	0.3	0.169	0.7	0.09	185.0			
03/17/99	8215	1	0.42	0	0.4	0.075	0.4	0.05	49.5			
03/24/99	8224	1	1.47	7911.4	0.6	0.084	0.6	0.07	78.0			
03/31/99	8246	1	0.57	13016.4	0.7	0.115	0.3	0.02	126.0			
04/07/99		1	0.02	0								
04/14/99	8253	1	0.20	2148.6	1.4	0.222	1.4	0.222	101.0			
04/21/99		1	0.42	4480.14								
04/28/99	8275	1	0.46	341.22	2.0	0.147	2.0	0.147	110.0			
05/05/99	8278	1	0.67	1747.7		0.135	0.6	0.07	58.0			
05/13/99		1	0.18	0								
05/19/99			1.27	0								
05/26/99	8298	1	1.11		3.7	0.422	0.1	0.08	197.0			
06/02/99		1	0.00	0								
06/09/99		1	0.03	0								
06/16/99	8308	1	0.47	0					252.0			
06/23/99		1	0.14	0								
06/30/99		1	0.09	15670.2								
07/07/99	8321	1	1.25	4554.2	3.6	0.995	0.1	0.4	874.8			
07/14/99		1	0.08	0								

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
07/21/99	8334	1	1.22	5,014.9	3.9	0.639	0.1	0.66	889.7			
07/28/99	8338	1	0.04	998.4	3.8	0.858	0.1	0.82	236.2			
08/04/99		1	0.00	0								
08/11/99	8351	1	0.33	2829.46	2.6	0.652	0.1	0.27	267.5			
08/18/99	8359	1	1.68	2694.8	3.4	0.016	0.1	0.67	287.0			
08/25/99	8364	1	0.49	0	1.8	0.198	0.6	0.19	34.0			
09/02/99		1	0.16	929.46								
09/09/99	8387	1	0.98	2806.68	0.4	0.339	0.1	0.08	11.3			
09/16/99	8387	1	8.84	18,379.1	0.4	0.653	0.1	0.05	28.3			
09/16/99	8395	1									0.76	
09/21/99	8407	1									1.49	100
09/23/99	8409	1	0.62	21130.5	0.3	0.019	0.2	0.01	20.5			
09/30/99	8418	1	0.78	405.2	2.1	0.054	2.3	0.82	14.3			
10/07/99	8435	1	0.93	2732.1	0.6	0.119	0.3	0.01	25.0			
10/14/99	844[illegible]	1	0.98	1106.7	1.6	0.201	1.1	0.13	14.3			
10/20/99	8446	1								396	0.3	
10/21/99	8450	1	1.05	7366.2	0.6	0.089	0.3	0.03	9.8			85
10/28/99	8467	1	0.58	3239.5	0.6	0.039	1.0	0.08	18.0			
11/04/99	8469	1	1.42	3715.6	1.9	0.392	1.5	0.5	28.0			
11/23/99	8500	1	0.20		1.1	0.285	1.1	0.27	22.0			
12/03/99	8521	1	1.90	29288.4	0.6	0.277	0.3	0.4	11.5			
12/09/99	8530	1	0.57	1175.5	1.2	0.047	0.8	0.48	31.1			
12/17/99	8532	1	1.02	296.7	0.8	0.135	0.7	0.28	61.5			
12/22/99	8541	1	0.88	2307.5	0.1	0.005	0.2	0.06	36.0			
01/06/00	8554	1	0.77	2633.2	0.1	0.005	0.8	0.3	31.5			
01/14/00	8559	1	1.44	543.4	0.1	0.005	0.5	0.1	69.0			
02/14/00	8626	1								25	11.5	100

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
02/17/00	8633	1	1.10	5378.1	0.6	0.254	0.4	0.13	273.0			
02/24/00	8636	1	0.41	4902.9	0.8	0.239	0.2	0.06	340.0			
03/02/00	8650	1	0.65	11915.5	1.5	0.843	1.2	0.26	199.0			
03/16/00	8658	1	2.05	6634.7	1.4	0.559	1.0	0.4	215.0			
03/23/00	8670	1	0.62	6383.8	1.8	0.392	1.6	0.4	269.7			
03/30/00	8676	1	1.03	4575.5	3.1	0.627	1.3	0.57	687.0			
04/06/00	8684	1	0.48	941.1	2.2	0.345	1.5	0.4	1137.0			
04/13/00			0.83	9840.06								
04/20/00	8700	1	0.22	1117.2	1.1	0.558	0.2	0.21				
04/27/00	8705	1	2.64	25888.6	0.1	0.320	0.5	0.18	63.7			
05/04/00	8725	1	0.10	3501.4	2.0	0.281	2.1	0.35	130.0			
05/10/00	8726	1	0.87	6140.6	1.9	0.490	0.8	0.75	662.2			
05/18/00	8743	1	0.96	187.2			0.9	0.63				
05/25/00	8748	1	2.54	44877.4								
06/06/00	8768	1								420		
06/08/00	8772	1	5.15	11682.3	1.5	0.335	0.2	0.5	195.1			
06/15/00	8773	1	1.01	6549	1.7	0.255			111.3			
07/20/00	8846	1	1.23	15600	3.1	0.438	0.7	0.81	2.5			
07/27/00	8849	1									0.45	
08/03/00	8860	1	0.90	2706.2	0.6	0.025	0.2	0.01	2.0			
08/17/00	8875	1	2.58	31829.1	0.2	0.146	0.1	0.18	146.8			
08/24/00	8885	1	0.23	0	1.1	0.067	0.5	0.53	7.0			
11/02/00	8952	1	0.00	0	1.5	0.084	0.5	0.47				
11/10/00	8954	1								10	0.22	
11/15/00	8989	1	0.05	3097.4	0.8	0.120	0.1	0.32	31.5			
11/30/00	9000	1	0.90	0	0.8	0.159	0.1	0.24				
12/14/00	9012	1	0.64	0	0.7	0.169	0.1	0.08	143.0			

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE mm/dd/yy	LAB NO.	STA.**	Precip in	Flow cf/wk	TKN mg/l	TP mg/l	NO3+2 mg/l	NH3 mg/l	TSS mg/l	FCU #/100 ml	TPH mg/l	Toxicity % mortality
12/21/00	9016	1	2.53	10051.7	0.9	0.255	0.1	0.05	355.1			
01/11/01	9047	1	0.25	0	3.5	0.329	1.6	0.42				
01/22/01	9063	1	0.56	1266.2	1.1	0.416	0.5	0.09	307.0			
01/29/01	9148	1	0.00	0	2.2	0.557		0.03				
02/05/01	9154	1	2.19	689.4	1.5		0.4	0.15	755.0			
02/12/01	9159	1	0.28	0	1.3	0.541	0.6	0.25	161.0			
02/19/01	9169	1	0.29	0	1.6	0.387	0.9	0.06				
02/26/01	9180	1	0.68	10661.1	0.8	0.401	0.5	0.21	344.0			
03/05/01		1	0.45	150.3								
03/12/01	9195	1	0.65	0	1.6		1.3	0.09	49.0			
03/19/01	9207	1	0.89	4598.4	0.9	0.363	0.1	0.09	3521.0			
03/26/01	9211	1	2.31	12676.1	1.1	0.357	0.1	0.08	300.0			
03/30/01	9231	1								860		
04/02/01	9234	1	1.83	12918.3	1.3	0.221	0.1	0.34	325.0			
04/09/01	9244	1	0.84	4116.6	1.9	0.844	0.1	0.33	350.0			
04/16/01	9252	1	0.26	1012.2	2.6	0.051	0.1	1.09	12.0			
04/23/01	9257	1	0.05	364.9	3.1	0.578	1.5	0.19	645.0			
04/30/01	9263	1	0.07	351.4	5.2	1.154	2.3	0.92				

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
12/08/98	8055	2								240	0.466	
12/22/98	8071	2								390		
01/27/99	8157	2	1.14	10850.8	1.7	0.0025	0.1	0.82	139.0			
02/03/99		2	4.04	197.8								
02/10/99		2	0.23	47.826								
02/17/99	8173	2	0.25		0.2	0.041	0.8	0.005	13.4			
02/24/99	8185	2	0.78		0.1	0.044	0.4	0.05	38.0			
03/03/99		2	1.69	20947								
03/10/99		2	0.98	23745.5								
03/17/99	8216	2	0.42	0	0.4	0.067	0.4	0.07	31.5			
03/24/99	8225	2	1.47	7911.4	0.5	0.067	0.5	0.05	29.0			
03/31/99		2	0.57	13016.4								
04/07/99		2	0.02	0								
04/14/99		2	0.20	2148.6								
04/21/99		2	0.42	4480.14								
04/28/99		2	0.46	341.22								
05/05/99	8278	2	0.67	1747.7	0.0	0.196	0.4	1.49	260.0			
05/13/99		2	0.18	0								
05/19/99		2	1.27	0								
05/26/99	8299	2	1.11		1.1	0.175	0.1	0.18	135.0			
06/02/99		2	0.00	0								
06/09/99		2	0.03	0								
06/16/99		2	0.47	0					252.0			
06/23/99		2	0.14	0								
06/30/99		2	0.09	15670.2								
07/07/99	8322	2	1.25	4554.2	1.8	0.438	0.1	0.27	372.9			
07/14/99		2	0.08	0								

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
07/21/99	8335	2	1.22	5,014.9	3	0.210	0.1	0.78	155.6			
07/28/99		2	0.04	998.4								
08/04/99		2	0.00	0								
08/11/99		2	0.33	2829.46								
08/18/99	8360	2	1.68	2694.8	0.5	0.105	0.1	1.16	59.5			
08/25/99	8365	2	0.49	0					4.1			
09/02/99		2	0.16	929.46								
09/09/99		2	0.98	2806.68								
09/16/99	8388	2	8.84	18,379.1	0.4	0.005	0.3	0.03	13.8			
09/16/99	8396	2									0.28	
09/21/99	8408	2									1.52	
09/23/99	8410	2	0.62	21130.5	0.3	0.005	0.1	0.01	3.3			100
09/30/99	8419	2	0.78	405.2	0.8	0.005	0.8	0.04	2.0			
10/07/99	8436	2	0.93	2732.1	0.5	0.005	0.2	0.21	5.3			
10/14/99	8442	2	0.98	1106.7	5.8	0.816	0.2	0.28	7.8			
10/20/99	8447	2								792	0.2	100
10/21/99	8451	2	1.05	7366.2	0.4	0.058	0.1	0.01	4.6			
10/28/99	8468	2	0.58	3239.5	0.4	0.022	0.1	0.1	5.7			
11/04/99	8470	2	1.42	3715.6	0.8	0.036	0.2	2.94				
11/23/99	8501	2	0.20									
12/03/99	8522	2	1.90	29288.4	0.3	0.175	0.1	0.07	1.7			
12/09/99	8531	2	0.57	1175.5	0.6	0.005			0.0			
12/17/99	8533	2	1.02	296.7	0.5	0.005	0.2	0.51	7.5			
12/22/99	8542	2	0.88	2307.5					20.0			
01/06/00	8555	2	0.77	2633.2	0.4	0.025	0.2	0.2	16.8			
01/14/00	8560	2	1.44	543.4	0.8	0.005	0.2	1.55	3.6			
02/14/00	8627	2								19		100

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
02/17/00	8634	2	1.10	5378.1	0.8	0.244	0.2	1.79	226.0			
02/24/00	8637	2	0.41	4902.9					69.2			
03/02/00	8651	2	0.65	11915.5	0.5	0.162	0.4	0.08				
03/16/00	8659	2	2.05	6634.7	0.4	0.023	0.2	0.07	49.0			
03/23/00	8671	2	0.62	6383.8	0.2	0.005	0.2	0.05	27.0			
03/30/00	8677	2	1.03	4575.5	0.7	0.052	0.2	0	86.0			
04/06/00	8685	2	0.48	941.1	1.4	0.067	0.2	0.11	113.0			
04/13/00		2	0.83	9840.06								
04/20/00		2	0.22	1117.2								
04/27/00	8706	2	2.64	25888.6	0.1	0.082	0.1	0.03	26.0			
05/04/00		2	0.10	3501.4								
05/10/00		2	0.87	6140.6								
05/18/00	8744	2	0.96	187.2			0.4	0.1	88.2			
05/25/00	8749	2	2.54	44877.4	0.8	0.097	0.2	0.02	10.0			
06/06/00	8769	2								610		
06/08/00	8773	2	5.15	11682.3	1.7	0.239	0.2	0.04	165.2			
06/15/00		2	1.01	6549								
07/20/00		2	1.23	15600								
07/27/00	8850	2									0.38	
08/03/00	8861	2	0.90	2706.2	0.0	0.197	0.3	0.09	14.3			
08/17/00	8876	2	2.58	31829.1	0.3	0.031	0.3	0.12	3.4			
08/24/00	8887	2	0.23	0	0.4	0.033	0.1	0.29	2.0			
11/02/00	8953	2	0.00	0	2.0	0.117	0.1	1.41				
11/10/00	8955	2								220	0.16	
11/15/00	8990	2	0.05	3097.4	0.7	0.176	0.1	0.06	4.0			
11/30/00	9001	2	0.90	0	1.1	0.131	0.1	0				
12/14/00	9013	2	0.64	0	1.0	0.167	0.1	0				

Appendix A1. Summary of weekly nutrient, TSS, FCU, TPH, and toxicity influent and effluent concentrations, as well as flow and precipitation data at the Vortechnics™ unit (cont.).

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH	Toxicity
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l	% mortality
12/21/00	9017	2	2.53	10051.7	1.4	0.322	0.2	0.05	102.5			
01/11/01	9048	2	0.25	0	0.7	0.049	0.3	0.04				
01/22/01	9064	2	0.56	1266.2	1.7		0.3	0.09	169.5			
01/29/01	9149	2	0.00	0	2.3	0.213	0.1	1.24				
02/05/01	9155	2	2.19	689.4	1.7		0.3	0.15				
02/12/01	9160	2	0.28	0	1.1	0.268	0.6	0.17				
02/19/01	9170	2	0.29	0	1.3	0.292	0.8	0.11				
02/26/01	9181	2	0.68	10661.1	1.4	0.149	0.2	0.08	66.0			
03/05/01		2	0.45	150.3								
03/12/01	9196	2	0.65	0	1.6	0.125	1.3	0.09	49.0			
03/19/01	9208	2	0.89	4598.4	0.9	0.208	0.1	0.09	186.4			
03/26/01	9212	2	2.31	12676.1	1.3	0.267	0.1	0.01				
03/30/01	9232	2								687		
04/02/01	9235	2	1.83	12918.3	1.3	0.075	0.1	0.11	66.8			
04/09/01	9245	2	0.84	4116.6	0.5	0.043	0.1	0.04				
04/16/01	9253	2	0.26	1012.2	0.9	0.091	0.6	0.1	12.0			
04/23/01	9258	2	0.05	364.9	2.7	0.359	1.3	0.39				
04/30/01	9264	2	0.07	351.4	5.6	1.265	1.9	0.38				

**Station 1=inlet, 2=outlet

Appendix A2. Summary of monthly metals influent and effluent concentrations at the Vortechnics unit.

DATE	LAB NO.	STA.**	Flow cf/wk	Cu ug/L	Zn ug/L	Pb ug/L
Jan-99	8186	1	10850.8	26	301	15
Feb-99	8187	1	122.813	19	288	6
Mar-99	8248	1	7911.4	15	289	
Apr-99	8276	1	1742.49	17	286	11
May-99	8298	1	1747.7	17	413	9
Jul-99	8344	1	4784.6	43	642	42
Aug-99	8378	1	2694.8	32	173	22
Sep-99	8427	1	13304.9	8	315	
Oct-99	8471	1	3611.1	7	253	
Nov-99	8510	1	3715.6	16	387	
Dec-99	8548	1	1259.9	30	310	12
Jan-00	8621	1	1588.3	17	217	5
Feb-00	8663	1	5140.5	30	219	
Mar-00	8678	1	7377.4	81	1416	47
Apr-00	8737	1	13414.8	61	1032	19
May-00	8756	1	187.2	94	633	26
Aug-00	8906	1	17267.6	8	75	4
Nov-00	9005	1	3097.4	12	546	
Dec-00	9041	1	10051.7	24	302	22
Jan-01	9177	1	1266.2	51	1710	25
Feb-01	9219	1	5675.3	51	1620	27
Mar-01	9222	1	5808.30	50	442	22
Apr-01	9268	1	3752.7	28	292	7
Jan-99		2	10850.8			
Feb-99		2	122.813			
Mar-99	8249	2	7911.4	10	39	
Apr-99		2	1742.49			
May-99	8299	2	1747.7	14	55	12
Jul-99	8345	2	4784.6	20	100	20
Aug-99	8379	2	2694.8	12	76	6
Sep-99	8428	2	13304.9	5	53	
Oct-99	8472	2	3611.1	5	150	
Nov-99	8511	2	3715.6	8	60	
Dec-99	8549	2	1259.9	14	32	6
Jan-00	8622	2	1588.3	11	44	7
Feb-00	8664	2	5140.5	14	80	
Mar-00	8679	2	7377.4	16	62	9
Apr-00	8737	2	13414.8	12	51	6
May-00	8756	2	187.2	9	65	7
Aug-00	8906	2	17267.6	6	83	
Nov-00	9005	2	3097.4	8	60	
Dec-00	9041	2	10051.7	23	100	25
Jan-01	9178	2	1266.2	53	173	29
Feb-01	9220	2	5675.3	29	201	16
Mar-01	9223	2	5808.30	17	68	13
Apr-01	9269	2	3752.7	23	77	8

**Station 1=inlet, 2=outlet

Appendix A3. Summary of weekly nutrient, TSS, FCU, and TPH catch basin and Vortechnics™ inlet concentrations, as well as flow and precipitation data.

DATE	LAB NO.	STA.**	Precip	Flow	TKN	TP	NO3+2	NH3	TSS	FCU	TPH
mm/dd/yy			in	cf/wk	mg/l	mg/l	mg/l	mg/l	mg/l	#/100 ml	mg/l
07/20/00	8847	3	1.23	15600	0.1	0.037	4.1	0.08	17.3		
08/03/00	8862	3	0.90	2706.2	0.3	0.051	0.6	0.17	8.7		
08/17/00	8877	3	2.58	31829.1	0.2	0.076	3.9	0.33	16.4		
08/24/00	8888	3	0.23	0	0.2	0.021	0.4	0.79	5		
11/10/00	8956	3								30	
11/15/00	8991	3	0.05	3097.4	0.8	0.165	0.1	0.05	8		
11/30/00	9002	3	0.90	0	0.8	0.097	0.1	0			
12/14/00	9014	3	0.64	0							
12/21/00	9018	3	2.53	10051.7	1.3	0.364	1.4	0.08	351		
01/11/01	9049	3	0.25	0	2.5	0.482	1.5	0.45			
01/22/01	9065	3	0.56	1266.2	1.7		0.3	0.11	243		
01/29/01	9150	3	0.00	0	1.3	0.204	0.1	1			
02/05/01	9156	3	2.19	689.4	1.9		0.5	0.18	589.9		
02/12/01	9161	3	0.28	0	1.2	0.324	1.1	0.16	80.7		
02/19/01	9171	3	0.29	0	3.3	0.1	1.4	0.336			
02/26/01	9182	3	0.68	10661.1	1.9	0.247	0.9	0.15	31.7		
03/05/01		3	0.45	150.3							
03/12/01	9197	3	0.65	0	1.3	0.212	0.1	0.23	38.5		
03/19/01	9209	3	0.89	4598.4	1.8	0.293	0.1	0.08	207.1		
03/26/01	9213	3	2.31	12676.1	0.8	0.122	0.4	0.1	28.6		
03/30/01	9233	3								10	0.05
04/02/01	9236	3	1.83	12918.3	1.2	0.079	0.1	0.11			
04/09/01	9246	3	0.84	4116.6	0.7	0.085	1.7	0.12	38.6		
04/16/01	9254	3	0.26	1012.2	1	0.069	5.9	0.05	65		
04/23/01	9259	3	0.05	364.9	1.6	0.138	1.1	0.27	10.36		
04/30/01	9265	3	0.07	351.4	3.8	0.392	2.2	0.31			

Appendix A3. Summary of weekly nutrient, TSS, FCU, and TPH catch basin and Vortechnics™ inlet concentrations, as well as flow and precipitation data (cont.).

DATE mm/dd/yy	LAB NO.	STA.**	Precip in	Flow cf/wk	TKN mg/l	TP mg/l	NO3+2 mg/l	NH3 mg/l	TSS mg/l	FCU #/100 ml	TPH mg/l
07/20/00	8846	1	1.23	15600	3.1	0.438	0.7	0.81	2.5		
08/03/00	8860	1	0.90	2706.2	0.6	0.025	0.1	0.01	2.0		
08/17/00	8875	1	2.58	31829.1	0.2	0.146	0.1	0.18	146.8		
08/24/00	8886	1	0.23	0	1.1	0.067	0.5	0.53	7.0		
11/10/00	8954	1								10	
11/15/00	8989	1	0.05	3097.4	0.8	0.120	0.1	0.32	31.5		
11/30/00	9000	1	0.90	0	0.8	0.159	0.1	0.24			
12/14/00	9012	1	0.64	0	0.7	0.169	0.1	0.08	143.0		
12/21/00	9016	1	2.53	10051.7	0.9	0.255	0.1	0.05	355.1		
01/11/01	9047	1	0.25	0	3.5	0.329	1.6	0.42			
01/22/01	9063	1	0.56	1266.2	1.1	0.416	0.5	0.09	307.0		
01/29/01	9148	1	0.00	0	2.2	0.557		0.03			
02/05/01	9154	1	2.19	689.4	1.5		0.4	0.15	755.0		
02/12/01	9159	1	0.28	0	1.3	0.541	0.6	0.25	161.0		
02/19/01	9169	1	0.29	0	1.6	0.387	0.9	0.06			
02/26/01	9180	1	0.68	10661.1	0.8	0.401	0.5	0.21	344.0		
03/05/01		1	0.45	150.3							
03/12/01	9195	1	0.65	0	1.6		1.3	0.09	49.0		
03/19/01	9207	1	0.89	4598.4	0.9	0.363	0.1	0.09	3521.0		
03/26/01	9211	1	2.31	12676.1	1.1	0.357	0.1	0.08	300.0		
03/30/01	9231	1								860	0.05
04/02/01	9234	1	1.83	12918.3	1.3	0.221	0.1	0.34	325.0		
04/09/01	9244	1	0.84	4116.6	1.9	0.844	0.1	0.33	350.0		
04/16/01	9252	1	0.26	1012.2	2.6	0.051	0.1	1.09	12.0		
04/23/01	9257	1	0.05	364.9	3.1	0.578	1.5	0.19	645.0		
04/30/01	9263	1	0.07	351.4	5.2	1.154	2.3	0.92			

**Station 3=Catch basin, 1=Vortechnics™ inlet

Appendix A4. Summary of monthly catch basin and Vortechnics™ inlet metals concentrations for the catch basin.

DATE	LAB NO.	STA.**	Flow	Cu	Zn	Pb
			cf/wk	ug/L	ug/L	ug/L
Jul-00	8868	3	15600	7	3	53
Aug-00	8908	3	17267.6	84	51	220
Nov-00	9007	3	3097.4	14		83
Dec-00	9043	3	10051.7	16	12	57
Jul-00	8867	1	15600	63	16	1369
Aug-00	8906	1	17267.6	8	4	75
Nov-00	9005	1	3097.4	12		546
Dec-00	9041	1	10051.7	24	22	302

**Station 3=Catch basin, 1=Vortechnics™ inlet

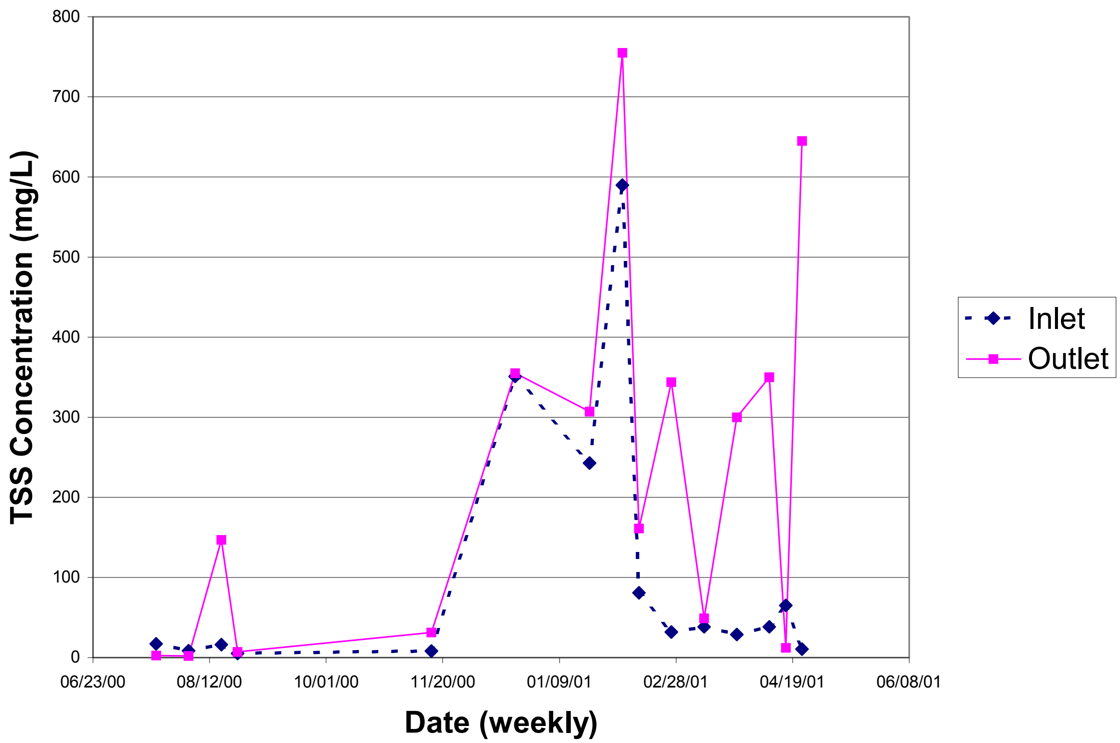
Appendix A5. Anti-log mean concentrations of the catch basin directly upstream of the Vortechnics™ unit, and *t* value and *P* value of the paired *t* test (July 2000-April 2001).

Variable	# Paired Samples	Influent Mean	Effluent Mean	*t* value	*P* value
TKN (mg L^{-1})	20	0.9	1.4	-1.61	0.123
TP (mg L^{-1})	18	0.130	0.245	-3.43	0.003
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	0.987
TSS (mg L^{-1})	15	42	92	-2.04	0.059
Cu (ug L^{-1})	4	19	20	-0.03	0.981
Pb (ug L^{-1})	4	86	361	-1.58	0.212
Zn (ug L^{-1})	3	12	11	0.07	0.951
TPH (mg L^{-1})	1	0.05	0.05	---	---
FCU	2	17	93	-0.60	0.654

Appendix A6. Annual loading and cumulative mass retention of the South Windsor catch basin located directly upstream of the Vortechnics™ unit.

Variable	Annual Loading kg/ha/yr	Cumulative Mass Retention (%)	Expected Retention (9)
TKN	4.12	9	5-10%
TP	0.66	-81	5-10%
NO_3-N	8.19	91	---
NH_3-N	0.84	-4	---
TSS	319.9	-417	10-25%
Cu	0.08	75	---
Pb	0.22	71	10-15%
Zn	0.05	-30	5-10%
FC	<1	-2075	---

Appendix A7. Catch basin influent and effluent TSS concentrations over time, July 2000-April 2001.



APPENDIX B

STATISTICAL ANALYSIS DATA

Appendix B1. Summary of W statistic for non-transformed and log-transformed Vortechnics™ concentration data.

Station	Variable	Non-transformed		Log-Transformed	
		W statistic	p<0.005	W statistic	p<0.005
1	TSS	0.456727	<0.0001	0.979311	0.6206
2	TSS	0.778481	<0.0001	0.949391	0.0566
1	TKN	0.883363	0.0001	0.948048	0.0241
2	TKN	0.681968	<0.0001	0.976927	0.4049
1	TP	0.887885	0.0002	0.926642	0.0037
2	TP	0.629414	<0.0001	0.928538	0.0044
1	NO_3-N	0.853135	<0.0001	0.890911	0.0002
2	NO_3-N	0.647694	<0.0001	0.869678	<0.0001
1	NH_3-N	0.870242	<0.0001	0.948635	0.0217
2	NH_3-N	0.599474	<0.0001	0.96401	0.1236
1	FC	0.864801	0.1671	0.887623	0.2625
2	FC	0.950655	0.7357	0.790663	0.0331
1	Cu	0.88984	0.0267	0.96126	0.5693
2	Cu	0.774627	0.0004	0.974136	0.8386
1	Pb	0.92407	0.2845	0.925276	0.2952
2	Pb	0.832344	0.0170	0.892203	0.1046
1	Zn	0.77096	0.0003	0.951697	0.3936
2	Zn	0.815861	0.0015	0.954861	0.4469
1	TPH	0.795755	0.0538	0.906053	0.4109
2	TPH	0.700516	0.0063	0.913349	0.4588

Appendix B2. Summary of ANOVA-duncan's test on seasonal differences in mass input. Groups with the same letters are not significantly different.

Variable	F value	*P* = F	Duncan Grouping	Mean	N	Season
TKN	3.01	0.043	A	2.48	5	summer
			B A	2.19	12	spring
			B	1.83	11	winter
			B	1.74	10	fall
TSS	4.48	0.010	A	4.40	11	winter
			A	4.33	6	summer
			A	4.32	9	spring
			B	3.12	8	fall

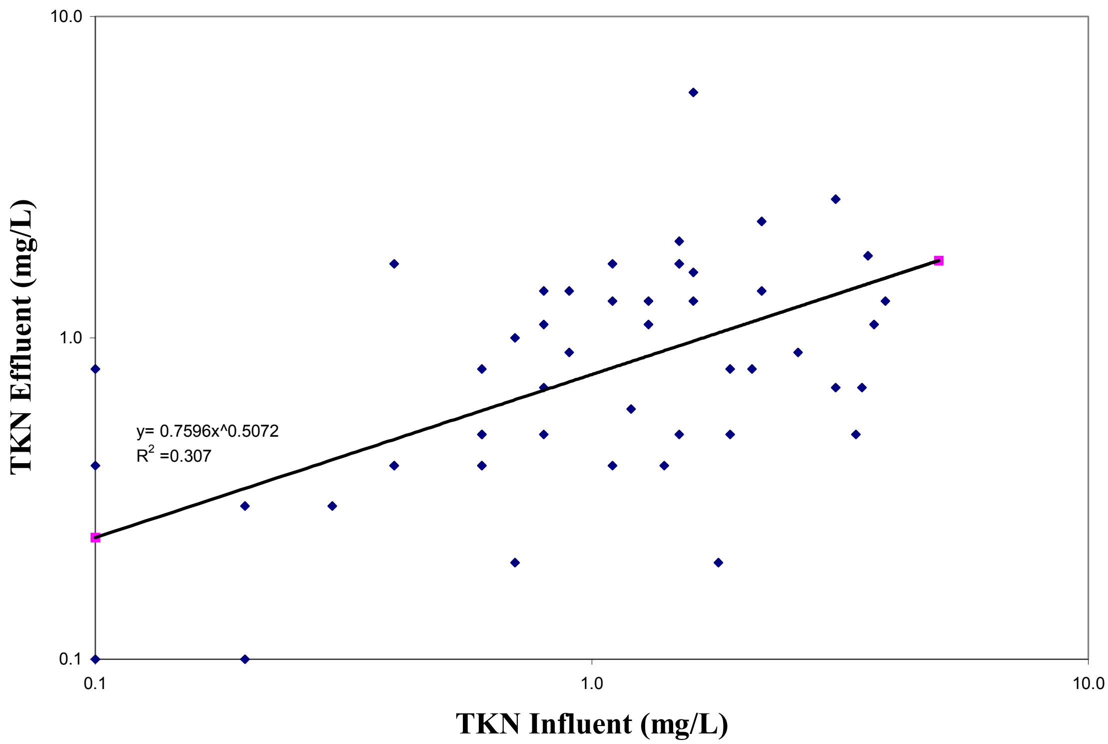
Appendix B3. Summary of ANOVA-duncan's test on seasonal differences in percent retention. Groups with the same letters are not significantly different.

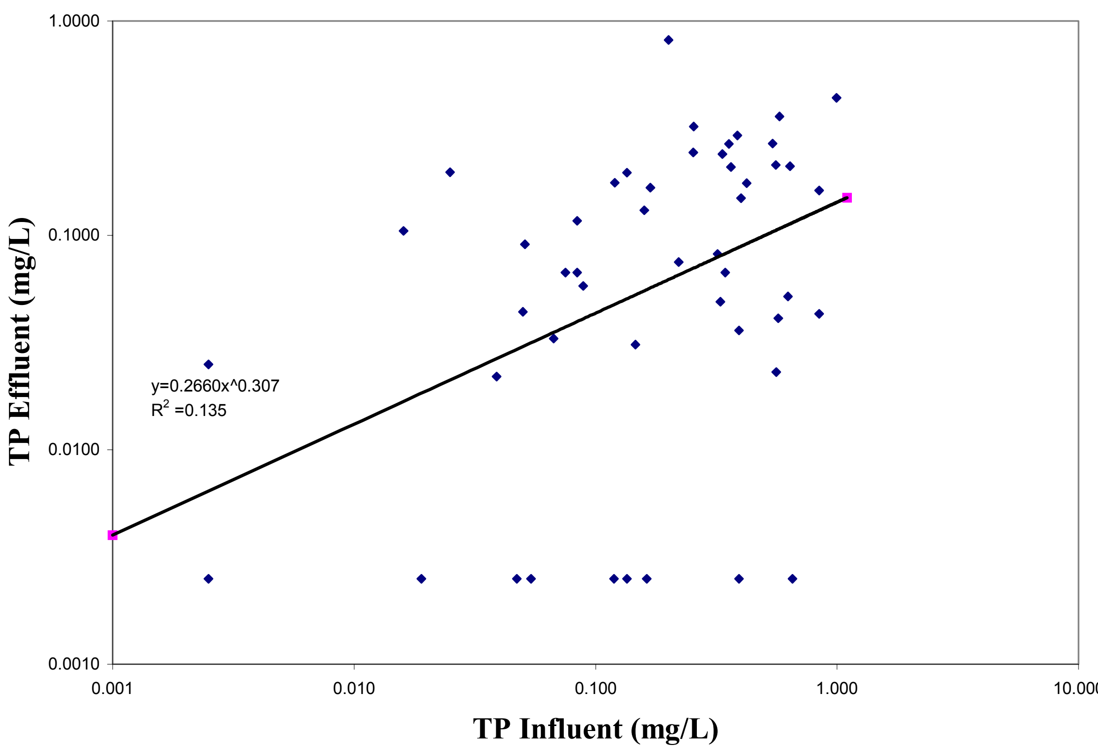
Variable	F value	*P* = F	Duncan Grouping	Mean	N	Season
TKN	3.05	0.044	A	38.0	4	summer
			A	33.2	10	spring
			B A	4.51	9	fall
			B	-142	10	winter
NO_3-N	3.19	0.040	A	68.1	8	fall
			A	44.9	10	winter
			A	-2.49	10	spring
			B	-150	3	summer
NH_3-N	4.39	0.015	A	81.0	3	fall
			A	76.4	11	spring
			A	65.1	8	winter
			B	37.8	4	summer

Appendix B4. Summary of ANOVA-duncan's test on seasonal differences in influent concentration. Groups with the same letters are not significantly different.

Variable	F value	*P* = F	Duncan Grouping	Mean	N	Season
TKN	4.83	0.004	A	0.191	20	spring
			A	0.145	12	summer
			B A	-0.050	15	fall
			B	-0.214	25	winter
NO_3-N	4.09	0.010	A	-0.258	24	winter
			A	-0.286	21	spring
			A	-0.347	15	fall
			B	-0.761	11	summer
TSS	7.75	0.001	A	2.26	19	spring
			A	2.19	22	winter
			B	1.74	12	summer
			B	1.39	13	fall
Cu	4.36	0.020	A	1.60	7	spring
			A	1.50	6	winter
			B A	1.35	3	summer
			B	1.01	4	fall

Appendix B5. Regression analysis of effluent concentration versus influent concentration of TKN and TP in the Vortechnics™ unit, January 1999-April 2001. Many of the TP concentrations were below the detection limit of 0.005 mg L^{-1}, therefore, half the detection limit was entered.





Appendix B6. Regression analysis of effluent concentration versus influent concentration of NO_3-N and Cu in the Vortechnics™ unit, January 1999-April 2001. Many of the NO_3-N concentrations were below the detection limit of 0.2 mg L^{-1}, therefore, half the detection limit was entered.