September 2005
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Environmental Technology Verification Report

Stormwater Source Area Treatment Device

Vortechnics, Inc.
Vortechs® System, Model 1000

Prepared by

NSF International

Under a Cooperative Agreement with
U.S. Environmental Protection Agency

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Stormwater Source Area Treatment Device

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Vortechs® System, Model 1000

Prepared for:
NSF International
Ann Arbor, MI 48105

Prepared by:
Earth Tech Inc.
Madison, Wisconsin

With assistance from:
United States Geologic Survey (Wisconsin Division)
Wisconsin Department of Natural Resources

Under a cooperative agreement with the U.S. Environmental Protection Agency

Raymond Frederick, Project Officer
ETV Water Quality Protection Center
National Risk Management Research Laboratory
Water Supply and Water Resources Division
U.S. Environmental Protection Agency
Edison, New Jersey

September 2005

THE ENVIRONMENTAL TECHNOLOGY VERIFICATION PROGRAM

U.S. Environmental Protection Agency

NSF International

ETV Joint Verification Statement

TECHNOLOGY TYPE:	**STORMWATER TREATMENT TECHNOLOGY**	
APPLICATION:	**SUSPENDED SOLIDS AND ROADWAY POLLUTANT TREATMENT**	
TECHNOLOGY NAME:	**VORTECHS® SYSTEM, MODEL 1000**	
TEST LOCATION:	**MILWAUKEE, WISCONSIN**	
COMPANY:	**VORTECHNICS, INC.**	
ADDRESS:	**200 Enterprise Drive** **Scarborough, Maine 04074**	PHONE: **(877) 907-8676** FAX: **(207) 878-2735**
WEB SITE:	**http://www.vortechnics.com**	
EMAIL:	**info@vortechnics.com**	

NSF International (NSF), in cooperation with the U.S. Environmental Protection Agency (EPA), operates the Water Quality Protection Center (WQPC), one of six centers under the Environmental Technology Verification (ETV) Program. The WQPC recently evaluated the performance of the Vortechs® System, Model 1000 (Vortechs), manufactured by Vortechnics, Inc. (Vortechnics). The Vortechs was installed at the "Riverwalk" site in Milwaukee, Wisconsin. Earth Tech, Inc. and the United States Geologic Survey (USGS) performed the testing.

The ETV Program was created to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The ETV program's goal is to further environmental protection by accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer-reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholder groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory tests (as appropriate), collecting and analyzing data, and preparing peer-reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

TECHNOLOGY DESCRIPTION

The following description of the Vortechs was provided by the vendor and does not represent verified information.

The Vortechs is designed to remove settable and floatable pollutants from stormwater runoff. Based on the size of the grit chamber, the Vortechs Model 1000 maximum operating flow rate is 1.6 cfs (720 gpm).

Untreated stormwater enters the Vortechs through an inlet pipe that is tangential to the grit chamber. This creates a swirling motion that directs settleable solids into a pile towards the center of the grit chamber. Floating pollutants are trapped upstream of an underflow baffle. The Vortechs contains two flow controls in the last chamber of the system. The first control is designed to allow nearly-free discharge at very low flows so that very fine particles do not settle in the inlet pipe. This control begins to create a significant backwater at operating rates in excess of 5 gpm/ft^2 of grit chamber surface area such that the inlet pipe becomes submerged at an operating rate of 20 gpm/ft^2 of grit chamber surface area. This backwater creates a low-velocity entry into the grit chamber, which encourages stratification of pollutants in the inlet pipe. Under low flow rates, a small amount of material may settle out in the inlet pipe, but at higher flow rates, these relatively large particles will be transported into the grit chamber. Additional hydraulic capacity is provided over the top of the flow control wall so that the system does not cause upstream flooding at flow rates exceeding the maximum recommended operating rate of 100 gpm/ft^2 of grit chamber surface area.

The vendor claims that the Vortechs will provide a net annual removal efficiency of total suspended solids (TSS) that are typically encountered in runoff from urban environments in excess of 80%. According to the vendor's product literature, Vortechnics typically selects a system size that will provide an 80% annual TSS load reduction based on laboratory-generated performance curves for 50-µm sediment particles.

VERIFICATION TESTING DESCRIPTION

Methods and Procedures

The test methods and procedures used during the study are described in the *Final Test Plan for the Verification of Vortechs® Model 1000 Stormwater Treatment System, "Riverwalk Site," Milwaukee, Wisconsin.* (March 2004). The Vortechs was installed to treat runoff collected from a 0.25-acre portion of the westbound highway surface of Interstate 794. Milwaukee receives an average annual precipitation of nearly 33 in., approximately 31% of which occurs during the summer months. Sampling was not conducted during winter months. Street sweeping occurred monthly during summer months.

Verification testing consisted of collecting data during a minimum of 15 qualified events that met the following criteria:

- The total rainfall depth for the event, measured at the site, was 0.2 in. (5 mm) or greater;
- Flow through the treatment device was successfully measured and recorded over the duration of the runoff period;
- A flow-proportional composite sample was successfully collected for both the inlet and the outlet over the duration of the runoff event;
- Each composite sample was comprised of a minimum of five aliquots, including at least two aliquots on the rising limb of the runoff hydrograph, at least one aliquot near the peak, and at least two aliquots on the falling limb of the runoff hydrograph; and
- There was a minimum of six hours between qualified sampling events.

Automated sample monitoring and collection devices were installed and programmed to collect composite samples from the inlet and outlet during qualified flow events. In addition to the flow and analytical data, operation and maintenance (O&M) data were recorded. Samples were analyzed for:

Sediments
- TSS
- total dissolved solids (TDS)
- suspended sediment concentration (SSC)
- particle size analysis

Metals
- total and dissolved copper and zinc

Nutrients
- total and dissolved phosphorus

Water Quality Parameters
- chemical oxygen demand (COD)
- total calcium and magnesium

VERIFICATION OF PERFORMANCE

Verification testing of the Vortechs lasted approximately 16 months, and coincided with testing conducted by USGS and the Wisconsin Department of Natural Resources. Conditions during certain storm events prevented sampling for some parameters. However, samples were successfully taken and analyzed for all parameters for at least 15 of the 18 total storm events.

In addition to the vendor's claim for sediment removal (TSS), the verification test plan included measurements for other water quality parameters. These verification factors were developed by a participating stakeholder group and technology panel, and provide ancillary performance data which is considered by many municipalities in addition to primary vendor claims when purchasing stormwater treatment technology.

Environmental conditions and other factors which may have impacted TSS removal are addressed in Chapter 5 of the full report.

Test Results

Table 1. Rainfall Data Summary

Event Number	Date	Start Time	Rainfall Amount (in.)	Rainfall Duration (hr:min)	Runoff Volume (ft^3)[1]	Peak Flow Rate (cfs)[1]
1	4/30/03	22:24	1.1	3:30	847	0.352
2	5/4/03	21:34	0.72	4:05	795	0.059
3	5/9/03	0:42	0.87	4:27	717	0.084
4	5/30/03	19:07	0.54	4:07	665	0.164
5	6/8/03	3:34	0.62	11:09	847	0.466
6	6/27/03	17:35	0.57	17:25	518	0.101
7	9/12/03	15:42	0.30	3:49	156	0.039
8	9/14/03	6:09	0.47	6:35	588	2.02
9	10/14/03	1:19	0.27	2:53	268	0.057
10	10/14/03	8:54	0.23	0:39	138	0.055
11	10/24/03	17:41	0.71	5:31	613	0.138
12	3/25/04	23:08	0.85	4:57	311	0.023
13	3/28/04	15:30	0.87	4:49	216	0.025
14	4/17/04	3:29	0.24	1:18	69	0.026
15	5/12/04	18:33	0.55	9:05	311	0.076
16	5/20/04	16:39	0.24	1:02	259	1.26
17	8/3/04	20:25	1.8	3:43	2,510	2.45
18	8/24/04	20:40	0.85	3:32	449	1.02

1. Runoff volume and peak discharge rate measured at the inlet monitoring point. See the verification report for further details.
2. Peak flow rates exceeded the rated treatment capacity of the Vortechs unit indicating the unit may be undersized for the drainage area.

The monitoring results were evaluated using event mean concentration (EMC) and sum of loads (SOL) comparisons. The EMC evaluates treatment efficiency on a percentage basis by dividing the outlet concentration by the inlet concentration and multiplying the quotient by 100. The EMC was calculated for each analytical parameter and each individual storm event. The SOL comparison evaluates the treatment efficiency on a percentage basis by comparing the sum of the inlet and outlet loads (the parameter concentration multiplied by the precipitation volume) for all storm events. The calculation is made by subtracting from one the quotient of the total outlet load divided by the total inlet load, and multiplying by 100. SOL results can be summarized on an overall basis since the loading calculation takes into account both the concentration and volume of runoff from each event. The analytical data ranges, EMC range, and SOL reduction values are shown in Table 2.

Table 2. Analytical Data, EMC Range, and SOL Reduction Results

Parameter	Units	Inlet range	Outlet range	EMC range (%)	SOL reduction all events (%)	SOL reduction all events except 8 & 17 (%)[1]
TSS	mg/L	46 – 310	28 – 150	-170 – 70	18	35
SSC	mg/L	50 – 820	26 – 150	-90 – 90	58	61
TDS	mg/L	<50 – 290	<50 – 1,400	-1,100 – 25	-120	-110
Total phosphorus	mg/L as P	0.062 – 0.68	0.041 – 0.48	-82 – 52	9.3	21
Dissolved phosphorus	mg/L as P	0.014 – 0.24	0.007 – 0.15	-200 – 68	0	26
Total copper	µg/L	21 – 280	13 – 120	-83 – 70	25	33
Dissolved copper	µg/L	5.4 – 75	5.4 – 43	-250 – 52	-10	-12
Total zinc	µg/L	100 – 920	84 – 520	-80 – 58	16	24
Dissolved zinc	µg/L	17 – 350	33 – 330	-380 – 31	-24	-21
Total magnesium	mg/L	3.7 – 23	2.3 – 10	-96 – 78	42	47
Total calcium	mg/L	9.5 – 48	9.3 – 43	-120 – 65	21	22
COD[2]	mg/L	27 – 310	25 – 220	-170 – 57	-15	0

1. The SOL was recalculated excluding events 8 and 17, since the peak runoff intensity for these events exceeded the rated flow capacity of the Vortechs. Refer to the verification report for further details.
2. The outlet COD concentration for event 4 was 1,400 mg/L but considered an outlier and was not used in EMC or SOL calculations.

The calculated SOL reduction for TSS, SSC, total and dissolved phosphorus, COD, and total metals improved when omitting the two events where the peak runoff intensity exceeded the rated flow capacity of the Vortechs (shown in the last column of Table 2). The high negative TDS removals were likely influenced by road salting operations. Dissolved-phase constituents, other than dissolved phosphorous, showed relatively little change when excluding events 8 and 17. The data suggest that scouring or resuspension may have occurred as a result of the high peak flow rates encountered during events 8 and 17.

A particle size distribution procedure known as “sand-silt split” was conducted on samples as part of the SSC analysis. The sand-silt split procedure quantifies the percentage (by weight) of particles greater than 62.5 µm (defined as sand) and less than 62.5 µm (defined as silt). The percentage of sand in the inlet ranged from 2% to 58%, while the percentage of sand in the outlet ranged from 0% to 19%. This data was incorporated into the SOL calculation, revealing the reduction in the SSC sand fraction was 94% and the reduction in the SSC silt fraction was 21%.

System Operation

The Vortechs was installed in December 2001, prior to verification, so verification of installation procedures on the system was not documented. The installed system cleaned and was inspected immediately prior to and during verification. Seven inspections of the unit were also performed during the test period. Upon completing the verification testing, the sediment chamber was cleaned out and contained sediment at depths ranging from 0 to 5.75 in., and approximately 120 lb (dry weight) of sediment was removed from the sediment chamber.

Quality Assurance/Quality Control

NSF personnel completed a technical systems audit during testing to ensure that the testing was in compliance with the test plan. NSF also completed a data quality audit of at least 10% of the test data to ensure that the reported data represented the data generated during testing. In addition to QA/QC audits performed by NSF, EPA personnel conducted an audit of NSF's QA Management Program.

Original signed by
Sally Gutierrez *10/3/05*
Sally Gutierrez Date
Director
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency

Original signed by
Robert Ferguson *10/5/05*
Robert Ferguson Date
Vice President
Water Systems
NSF International

NOTICE: Verifications are based on an evaluation of technology performance under specific, predetermined criteria and the appropriate quality assurance procedures. EPA and NSF make no expressed or implied warranties as to the performance of the technology and do not certify that a technology will always operate as verified. The end user is solely responsible for complying with any and all applicable federal, state, and local requirements. Mention of corporate names, trade names, or commercial products does not constitute endorsement or recommendation for use of specific products. This report is not an NSF Certification of the specific product mentioned herein.

Availability of Supporting Documents

Copies of the *ETV Verification Protocol, Stormwater Source Area Treatment Technologies Draft 4.1, March 2002,* the verification statement, and the verification report (NSF Report Number 05/24/WQPC-WWF) are available from:

ETV Water Quality Protection Center Program Manager (hard copy)
NSF International
P.O. Box 130140
Ann Arbor, Michigan 48113-0140

NSF website: http://www.nsf.org/etv (electronic copy)
EPA website: http://www.epa.gov/etv (electronic copy)
Appendices are not included in the verification report, but are available from NSF upon request.

Notice

The U.S. Environmental Protection Agency (EPA) through its Office of Research and Development has financially supported and collaborated with NSF International (NSF) under a Cooperative Agreement. The Water Quality Protection Center (WQPC), operating under the Environmental Technology Verification (ETV) Program, supported this verification effort. This document has been peer reviewed and reviewed by NSF and EPA and recommended for public release. Mention of trade names or commercial products does not constitute endorsement or recommendation by the EPA for use.

Foreword

The following is the final report on an Environmental Technology Verification (ETV) test performed for NSF International (NSF) and the United States Environmental Protection Agency (EPA). The verification test for the Vortechs® System, Model 1000 was conducted at a testing site in downtown Milwaukee, Wisconsin, maintained by Wisconsin Department of Transportation (WisDOT).

The U.S. Environmental Protection Agency (EPA) is charged by Congress with protecting the Nation's land, air, and water resources. Under a mandate of national environmental laws, the Agency strives to formulate and implement actions leading to a compatible balance between human activities and the ability of natural systems to support and nurture life. To meet this mandate, EPA's research program is providing data and technical support for solving environmental problems today and building a science knowledge base necessary to manage our ecological resources wisely, understand how pollutants affect our health, and prevent or reduce environmental risks in the future.

The National Risk Management Research Laboratory (NRMRL) is the Agency's center for investigation of technological and management approaches for preventing and reducing risks from pollution that threaten human health and the environment. The focus of the Laboratory's research program is on methods and their cost-effectiveness for prevention and control of pollution to air, land, water, and subsurface resources; protection of water quality in public water systems; remediation of contaminated sites, sediments and ground water; prevention and control of indoor air pollution; and restoration of ecosystems. NRMRL collaborates with both public and private sector partners to foster technologies that reduce the cost of compliance and to anticipate emerging problems. NRMRL's research provides solutions to environmental problems by: developing and promoting technologies that protect and improve the environment; advancing scientific and engineering information to support regulatory and policy decisions; and providing the technical support and information transfer to ensure implementation of environmental regulations and strategies at the national, state, and community levels.

This publication has been produced as part of the Laboratory's strategic long-term research plan. It is published and made available by EPA's Office of Research and Development to assist the user community and to link researchers with their clients.

Contents

Figures

Tables

Abbreviations and Acronyms

ASTM	American Society for Testing and Materials
BMP	Best Management Practice
cfs	Cubic feet per second
COD	Chemical oxygen demand
EMC	Event mean concentration
EPA	U.S. Environmental Protection Agency
ETV	Environmental Technology Verification
ft^2	Square feet
ft^3	Cubic feet
g	Gram
gal	Gallon
gpm	Gallon per minute
hr	Hour
in.	Inch
kg	Kilogram
L	Liters
lb	Pound
LOD	Limit of detection
LOQ	Limit of quantification
m^3	Cubic meter
mm	Millimeter
NRMRL	National Risk Management Research Laboratory
µg/L	Microgram per liter (ppb)
µm	Micron (micrometer)
mg/L	Milligram per liter
min	Minute
MS/MSD	Matrix spike/matrix spike duplicate
NSF	NSF International, formerly known as National Sanitation Foundation
NIST	National Institute of Standards and Technology
O&M	Operations and maintenance
QA	Quality assurance
QAPP	Quality Assurance Project Plan
QC	Quality control
RPD	Relative percent difference
SSC	Suspended sediment concentration
SOL	Sum of loads
SOP	Standard operating procedure
Std. Dev.	Standard deviation
TDS	Total dissolved solids
TO	Testing Organization
TP	Total phosphorus
TSS	Total suspended solids
USGS	United States Geological Survey
VA	Visual accumulator
VO	Verification Organization (NSF)

WDNR	Wisconsin Department of Natural Resources
WQPC	Water Quality Protection Center
WisDOT	Wisconsin Department of Transportation
WSLH	Wisconsin State Laboratory of Hygiene
yd^3	Cubic yard

Chapter 1
Introduction

1.1 ETV Purpose and Program Operation

The U.S. Environmental Protection Agency (EPA) has created the Environmental Technology Verification (ETV) Program to facilitate the deployment of innovative or improved environmental technologies through performance verification and dissemination of information. The goal of the ETV program is to further environmental protection by substantially accelerating the acceptance and use of improved and more cost-effective technologies. ETV seeks to achieve this goal by providing high quality, peer reviewed data on technology performance to those involved in the design, distribution, permitting, purchase, and use of environmental technologies.

ETV works in partnership with recognized standards and testing organizations; stakeholders groups, which consist of buyers, vendor organizations, and permitters; and with the full participation of individual technology developers. The program evaluates the performance of innovative technologies by developing test plans that are responsive to the needs of stakeholders, conducting field or laboratory (as appropriate) testing, collecting and analyzing data, and preparing peer reviewed reports. All evaluations are conducted in accordance with rigorous quality assurance protocols to ensure that data of known and adequate quality are generated and that the results are defensible.

NSF International (NSF), in cooperation with the EPA, operates the Water Quality Protection Center (WQPC). The WQPC evaluated the performance of the Vortechs® System, Model 1000 (Vortechs), a stormwater treatment device designed to remove suspended solids, and other stormwater pollutants from wet weather runoff.

It is important to note that verification of the equipment does not mean that the equipment is "certified" by NSF or "accepted" by EPA. Rather, it recognizes that the performance of the equipment has been determined and verified by these organizations for those conditions tested by the Testing Organization (TO).

1.2 Testing Participants and Responsibilities

The ETV testing of the Vortechs was a cooperative effort among the following participants:

- U.S. Environmental Protection Agency
- NSF International
- U.S. Geologic Survey (USGS)
- Wisconsin Department of Transportation (WisDOT)
- Wisconsin Department of Natural Resources (WDNR)
- Wisconsin State Laboratory of Hygiene (WSLH)
- USGS Sediment Laboratory
- Earth Tech, Inc.
- Vortechnics, Inc. (Vortechnics)

The following is a brief description of each ETV participant and their roles and responsibilities.

1.2.1 U.S. Environmental Protection Agency

The EPA Office of Research and Development, through the Urban Watershed Branch, Water Supply and Water Resources Division, National Risk Management Research Laboratory (NRMRL), provides administrative, technical, and quality assurance guidance and oversight on all ETV Water Quality Protection Center activities. In addition, EPA provides financial support for operation of the Center and partial support for the cost of testing for this verification.

The key EPA contact for this program is:

Mr. Ray Frederick, ETV WQPC Project Officer
(732) 321-6627
email: Frederick.Ray@epamail.epa.gov

U.S. EPA, NRMRL
Urban Watershed Management Research Laboratory
2890 Woodbridge Avenue (MS-104)
Edison, New Jersey 08837-3679

1.2.2 Verification Organization

NSF is the verification organization (VO) administering the WQPC in partnership with EPA. NSF is a not-for-profit testing and certification organization dedicated to public health, safety, and protection of the environment. Founded in 1946 and located in Ann Arbor, Michigan, NSF has been instrumental in development of consensus standards for the protection of public health and the environment. NSF also provides testing and certification services to ensure that products bearing the NSF name, logo and/or mark meet those standards.

NSF personnel provided technical oversight of the verification process. NSF also provided review of the test plan and this verification report. NSF's responsibilities as the VO include:

- Review and comment on the test plan;
- Review quality systems of all parties involved with the TO, and qualify the TO;
- Oversee TO activities related to the technology evaluation and associated laboratory testing;
- Conduct an on-site audit of test procedures;
- Provide quality assurance/quality control (QA/QC) review and support for the TO;
- Oversee the development of the verification report and verification statement; and
- Coordinate with EPA to approve the verification report and verification statement.

Key contacts at NSF are:

Mr. Thomas Stevens, P.E. Program Manager (734) 769-5347 email: stevenst@nsf.org	Mr. Patrick Davison, Project Coordinator (734) 913-5719 email: davison@nsf.org

NSF International
789 North Dixboro Road
Ann Arbor, Michigan 48105

1.2.3 Testing Organization

The TO for the verification testing was Earth Tech, Inc. of Madison, Wisconsin (Earth Tech), with assistance from USGS in Middleton, Wisconsin. USGS provided testing equipment, helped to define field procedures, conducted the field testing, coordinated with the analytical laboratories, and conducted initial data analyses.

The TO provided all needed logistical support, established a communications network, and scheduled and coordinated activities of all participants. The TO was responsible for ensuring that the testing location and conditions allowed for the verification testing to meet its stated objectives. The TO prepared the test plan; oversaw the testing; and managed, evaluated, interpreted and reported on the data generated during the testing, as well as evaluated and reported on the performance of the technology. TO employees set test conditions, and measured and recorded data during the testing. The TO's Project Manager provided project oversight.

The key personnel and contacts for the TO are:

Earth Tech:

Mr. Jim Bachhuber, P.H.
(608) 828-8121
email: jim_bachhuber@earthtech.com

Earth Tech, Inc.
1210 Fourier Drive
Madison, Wisconsin 53717

USGS:

Ms. Judy Horwatich
(608) 821-3874
email: jawierl@usgs.gov

USGS
8505 Research Way
Middleton, Wisconsin 53562

1.2.4 Analytical Laboratories

The WSLH, located in Madison, Wisconsin, analyzed the stormwater samples for the parameters identified in the test plan. The USGS Sediment Laboratory, located in Iowa City, Iowa, performed the suspended sediment concentration separations and particle size analyses for the first qualified event.

The key analytical laboratory contacts are:

Mr. George Bowman
(608) 224-6279
email: gtb@mail.slh.wisc.edu

WSLH
2601 Agriculture Drive
Madison, Wisconsin 53718

Ms. Pam Smith
(319) 358-3602
email: pksmith@usgs.gov

USGS Sediment Laboratory
Federal Building Room 269
400 South Clinton Street
Iowa City, Iowa 52240

1.2.5 Vendor

The Vortechs is designed by Vortechnics, headquartered in Scarborough, Maine and manufactured by a local pre-cast company (Wiesser Concrete in Maiden Rock, Wisconsin). Vortechnics is owned by Contech Construction Products Inc., headquartered in Middletown, Ohio. Vortechnics was responsible for providing technical support, and was available during the tests to provide technical assistance as needed.

The key contact for Vortechnics is:

Mr. Vaikko P. Allen II, Technical Manager
(207) 885-9830, ext. 275
email: vallen@vortechnics.com

Vortechnics, Inc.
200 Enterprise Drive
Scarborough, Maine 04074

1.3 System Owner/Operator

The Vortechs was installed in a parking lot under Interstate 794 on the east side of the Milwaukee River in downtown Milwaukee, Wisconsin. The Vortechs treated storm water collected from the decking of Interstate 794. The unit was installed in cooperation with WisDOT, the current owner/operator of the system.

The key contact for WisDOT is:

Mr. Robert Pearson
(608) 266-7980
email: robert.pearson@dot.state.wi.us

Bureau of Environment
Wisconsin Department of Transportation
4802 Sheboygan Avenue, Room 451
Madison, Wisconsin 53707

Chapter 2
Technology Description

The following technology description data was supplied by the vendor and does not represent verified information.

2.1 Treatment System Description

The Vortechs is designed to remove settable and floatable pollutants from stormwater runoff. When the system is operating at its peak design capacity, the maximum operating rate is approximately 100 gpm/ft^2 of surface area. The Vortechs has been tested in a laboratory at flows up to and including this maximum treatment rate and has been shown to produce positive sediment removal efficiencies throughout this range. Based on the size of the grit chamber for the Vortechs Model 1000, the maximum treatment flow rate is 1.6 cfs (720 gpm).

Additional hydraulic capacity is provided over the top of the flow control wall so that the system does not cause upstream flooding at flow rates exceeding the maximum recommended operating rate of 100 gpm/ft^2. The actual hydraulic capacity of on-line Vortechs Systems is typically at least as great as the 100-year peak flow rate or the drainage system conveyance capacity, whichever is less.

A schematic of the Vortechs is shown in Figure 2-1 The Vortchs consists of an inlet pipe, grit chamber, baffle walls, and an outlet pipe, enclosed in a concrete vault. Untreated stormwater enters the Vortechs through an inlet pipe that is tangential to the grit chamber. This creates a swirling motion that directs settleable solids downward and towards the center of the grit chamber. Floating pollutants are trapped upstream of an underflow baffle. The Vortechs contains two flow controls in the last chamber of the system. The first control is designed to allow nearly free discharge at very low flows so that very fine particles do not settle in the inlet pipe. This control begins to create a significant backwater at operating rates in excess of 5 gpm/ft^2 such that the inlet pipe becomes submerged at an operating rate of 20 gpm/ft^2. This backwater creates a low-velocity entry into the grit chamber, which encourages stratification of pollutants in the inlet pipe. Under low flow rates, a small amount of material may settle out in the inlet pipe, but at higher flow rates, these particles will be transported into the grit chamber.

At operating rates in excess of 20 gpm/ft^2, a portion of the flow will pass through the high flow control. The flow controls were sized to create up to 3.5 ft of backwater at peak operating rates, depending on available head. This backwater effect increases the residence time in the system, thereby maximizing pollutant removal and retention. The backwater effect also increases the separation between captured floating pollutants and the bottom of the baffle wall. Both flow controls are Cipoletti shape with a flat crest and a side slope of 4:1.

The Vortechs installed at the Riverwalk site in Milwaukee is designed to treat all flows up to 1.6 cfs. There is no bypass, so flows exceeding peak hydraulic capacity will pass through the system. At high flows, the inlet pipe’s capacity becomes the limiting factor.

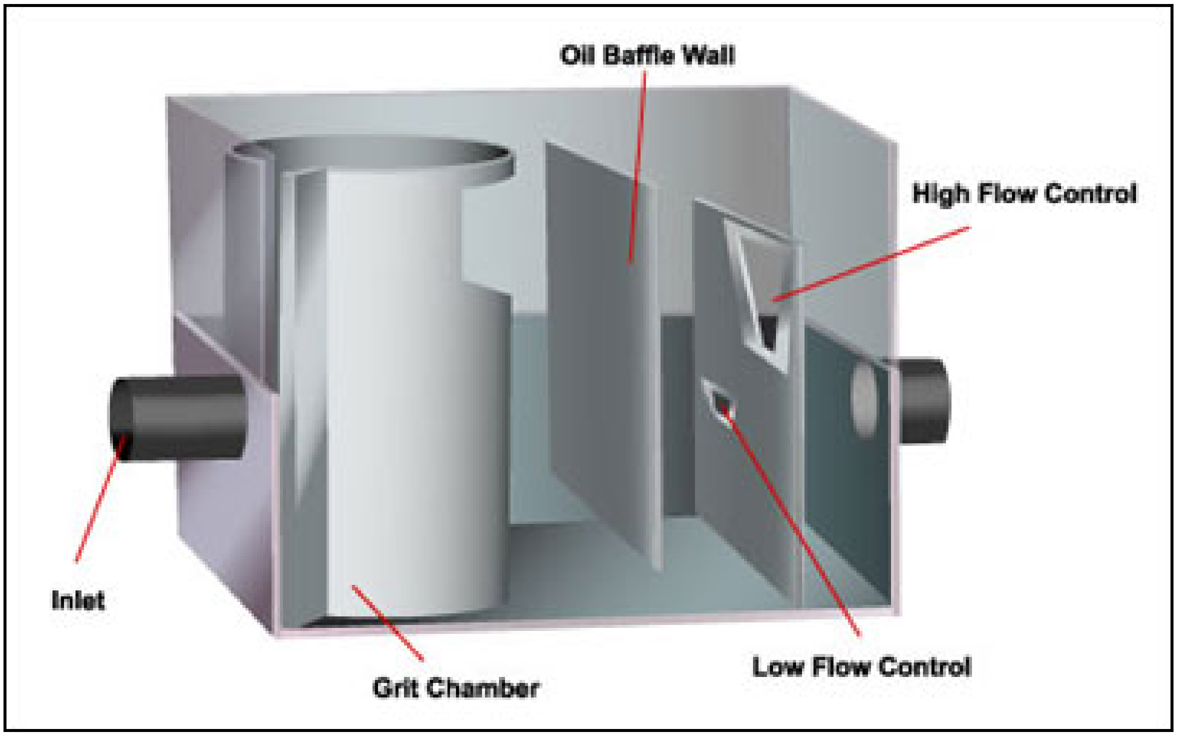

Figure 2-1. Schematic drawing of a typical Vortechs.

Product Specification:

- Housing – Six-inch thick concrete rectangular structure.
- Dimensions – inside dimensions - length: 9 ft (2.7 m); width: 3 ft (1 m); height: 7 ft (2.1 m).
- Peak Treatment Capacity – 1.6 cfs (720 gpm).
- Sediment Storage – 0.75 yd^3 (0.57 m^3).
- Sediment Chamber Diameter – 3 ft (1 m).

Additional equipment specifications, test site descriptions, testing requirements, sampling procedures, and analytical methods are detailed in the *Final Test Plan for the Verification of Vortechs® Model 1000 Stormwater Treatment System "Riverwalk Site" Milwaukee, Wisconsin* (March 22, 2004). The test plan is included in Appendix A.

2.2 Maintenance

The Vortechs System should be inspected periodically and cleaned when inspection reveals the sediment depth has accumulated to within six inches of the dry-weather water level. Maintaining the Vortechs is easiest when there is no flow entering the system. Cleanout of the Vortechs with a vacuum truck is generally the most effective and convenient method of excavating pollutants from the system.

Accumulated sediment is typically evacuated through the manhole over the grit chamber. As water is evacuated, the water level outside of the grit chamber will drop to the same level as the crest of the lower aperture of the grit chamber. It will not drop below this level due to the fact that the bottom and sides of the grit chamber are sealed to the tank floor and walls. This "Water Lock" feature prevents water from migrating into the grit chamber, exposing the bottom of the baffle wall. Floating pollutants will decant into the grit chamber as the water level there is drawn down. This allows most floating material to be withdrawn from the same access point above the grit chamber. If maintenance is not performed as recommended, sediment may accumulate outside the grit chamber. If this is the case, it may be necessary to inspect or pump out all chambers.

2.3 Technology Application and Limitations

The Vortechs is used for several project applications, including:

- commercial developments such as office complexes and hotels;
- industrial developments such as vehicle storage yards and material transfer stations;
- retail developments such as gas stations and shopping centers;
- high-density residential such as housing developments; and
- urban roadways.

2.4 Performance Claim

The vendor claims that the Vortechs will provide a net annual removal efficiency of total suspended solids (TSS) that are typically encountered in runoff from urban environments in excess of 80%. According to the vendor's product literature, Vortechnics typically selects a system size that will provide an 80% annual TSS load reduction based on laboratory-generated performance curves for 50-µm sediment particles. The vendor also claims that the Vortechs will capture and contain floatables in stormwater runoff, although this claim was not verified.

Chapter 3
Test Site Description

3.1 Location and Land Use

The Vortechs is located in a municipal parking lot beneath an elevated freeway (I-794) and just east of the Milwaukee River, in downtown Milwaukee, Wisconsin. The parking lot is located just west of Water Street, between Clybourn Street and St. Paul Avenue. Figure 3-1 shows the location of the test site.

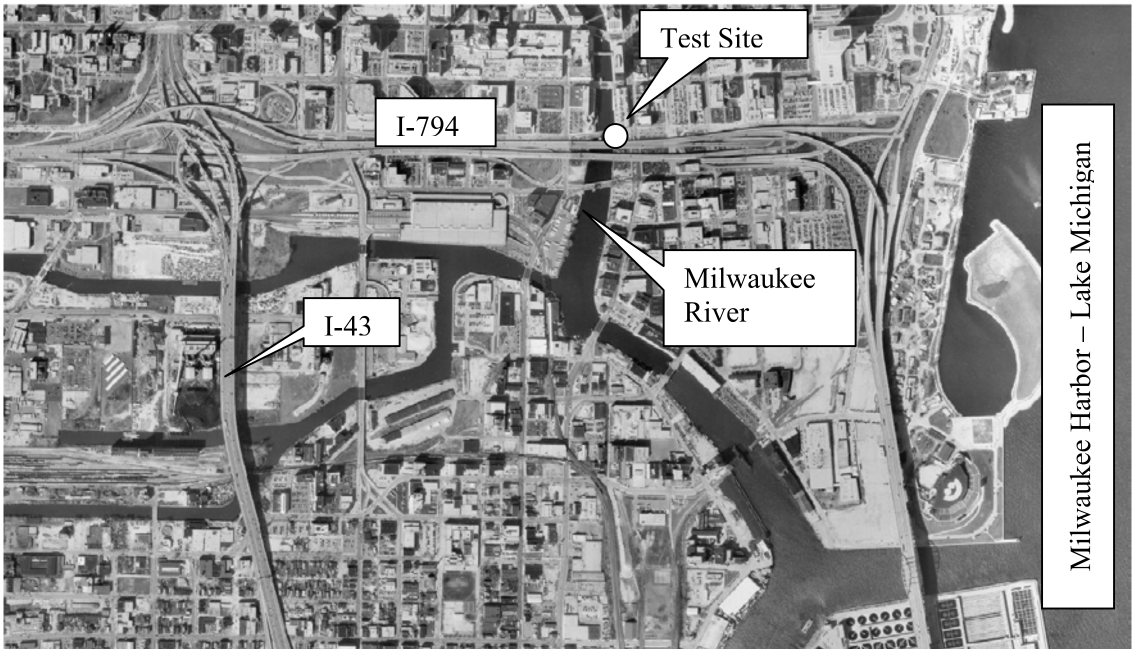

Figure 3-1. Test site location.

The Vortechs receives runoff from 0.25 acres of the westbound highway surface of I-794, as shown in Figure 3-2. The interstate surface is elevated at this location so there is no other land use in the drainage area, as shown in Figure 3-3. Surface inlets on the highway, shown in Figure 3-3), collect the runoff and convey the water to the treatment device via downspouts from the deck surface to beneath the parking lot below the highway deck. The drainage area determination was based on the following information and assumptions:

1. WisDOT design plans for Interstate 794 dated 1966 (scale: 1 in. equals 20 ft) and rehabilitation plans dated 1994;
2. The assumption that resurfacing the deck did not change the basic slope or relative drainage area to each inlet; and
3. The assumption that adjacent storm drains were capable of capturing all the flow in their respective drainage areas, forming a hydrologic barrier.

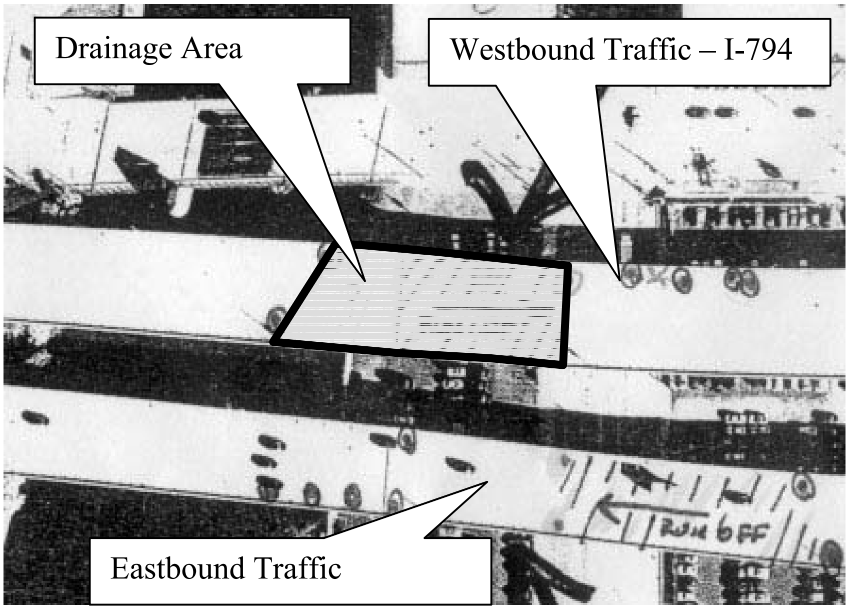

Figure 3-2. Drainage area detail.

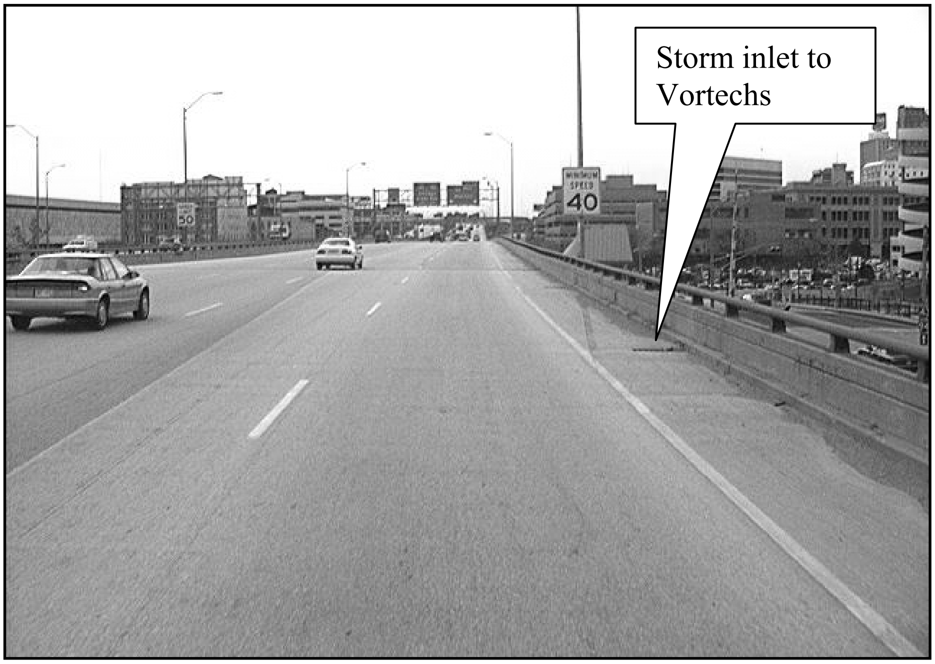

Figure 3-3. Vortechs drainage area condition.

3.2 Contaminant Sources and Site Maintenance

The main pollutant sources within the drainage area are created by vehicular traffic, atmospheric deposition, and winter salt applications. The storm sewer catch basins do not have sumps. Conventional (mechanical) street sweeping is done on a monthly basis in the summer months (June through August). There are no other stormwater best management practices (BMPs) within the drainage area.

3.3 Stormwater Conveyance System

The entire drainage area is served by a storm sewer collection system. Before installation of the Vortechs, the drainage area discharged storm water directly to the Milwaukee River through the system under the parking lot.

The highway deck is elevated approximately 15 ft above the parking lot. Originally, the storm sewer conveyance system dropped vertically to a point below the parking lot surface, then traveled about 6.5 ft horizontally to the monitoring (flow and quality) sites, and another two feet to the Vortechs. After the initial installation of the Vortechs, the velocity meter location was frequently inundated with sediment during and after events. Vortechnics considered the 2 to 5 ft of nearly flat storm pipe leading to the grit chamber (this area is affected by backwater effect of the slot opening to the grit chamber) as part of the treatment system. As a result, sediment was settling out in this portion of the pipe. The TO and VO decided to reconfigure the storm pipe (see Figure 3-4) to avoid the interference of the sediment with the velocity meter. The reconfiguration took place prior to verification testing.

3.4 Water Quality/Water Resources

Stormwater from the site is discharged directly to the Milwaukee River, just upstream of the mouth to Milwaukee Harbor, and then into Lake Michigan. The river and harbor have had a history of severe water quality impacts from various sources, including contaminated river sediments, urban non-point source runoff, rural non-point sources, combined sewer overflows, and point source discharges. The water quality in the river suffers from low dissolved oxygen, high nutrient, metals, bacteria levels, and toxic contamination. The Milwaukee River at this location is on Wisconsin's 303(d) list for dissolved oxygen, aquatic toxicity, polychlorinated biphenyls, and fish consumption advisory.

Most of the urban communities within the Milwaukee River watershed, including the City of Milwaukee, are under the State of Wisconsin stormwater-permitting program (NR 216). This program meets or exceeds the requirements of EPA's Phase I stormwater regulations.

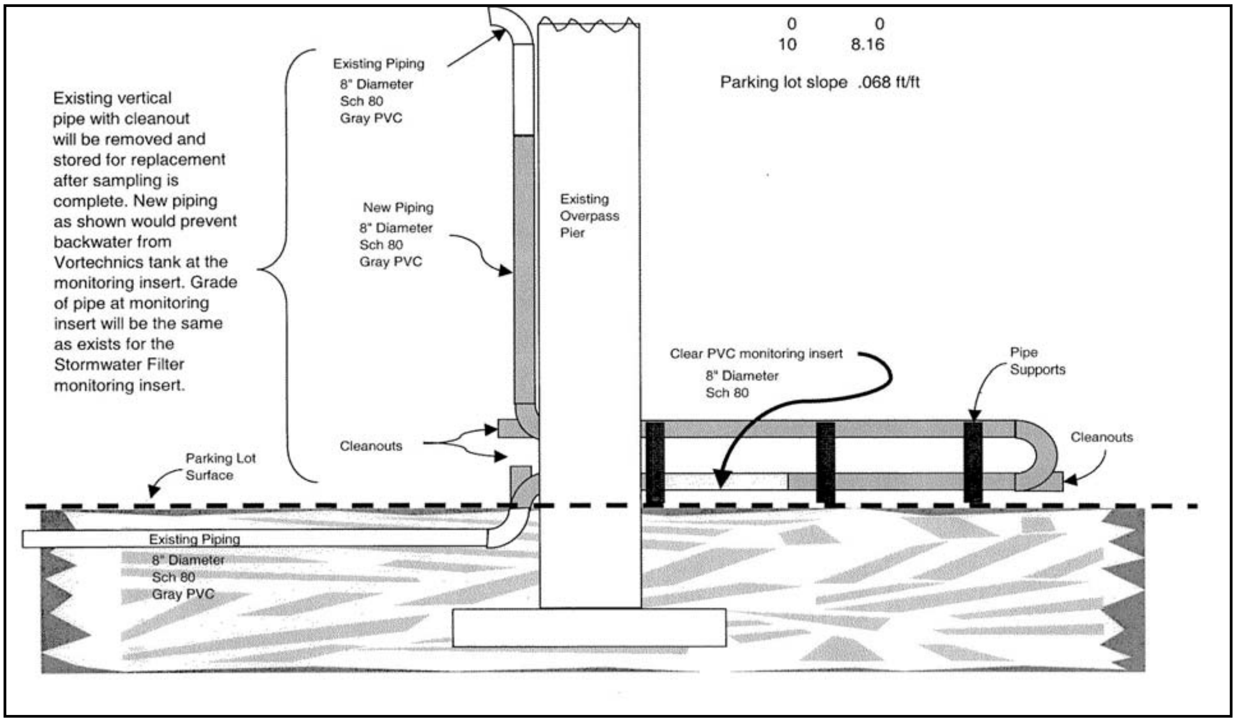

Figure 3-4. Reconfigured inlet to Vortechs.

3.5 Local Meteorological Conditions

The test plan includes summary temperature and precipitation data from the National Weather Service station from the Mitchell Field Airport in Milwaukee. The statistical rainfalls for a series of recurrence and duration precipitation events are presented in the test plan. The climate of Milwaukee, and Wisconsin in general, is typically continental with some modification by Lakes Michigan and Superior. Milwaukee experiences cold snowy winters, and warm to hot summers. Average annual precipitation is approximately 33 in., with an average annual snowfall of 50.3 in.

Chapter 4
Sampling Procedures and Analytical Methods

Descriptions of the sampling locations and methods used during verification testing are summarized in this section. Additional detail may be found in the test plan.

4.1 Sampling Locations

Two locations in the test site storm sewer system were selected as sampling and monitoring sites to determine the treatment capability of the Vortechs.

4.1.1 Site 1 - Inlet

This sampling and monitoring site was selected to characterize the untreated stormwater from the drainage area. A velocity/stage meter and sampler suction tubing were located in the inlet pipe, upstream from the Vortechs, so that potential backwater effects of the treatment device would not affect the velocity measurements. The monitoring station and test equipment are shown in Figures 4-1, 4-2, and 4-3.

Figure 4-1. View of monitoring station.

4.1.2 Site 2 - Treated Outlet

This sampling and monitoring site was selected to characterize the stormwater treated by the Vortechs. A velocity/stage meter and sampler suction tubing, connected to the automated sampling equipment, were located in an eight-inch diameter plastic pipe downstream from the Vortechs.

Figure 4-2. View of ISCO samplers.

Figure 4-3. View of data logger.

4.1.3 Other Monitoring Locations

In addition to the two sampling and monitoring sites, a water-level recording device was installed inside the Vortechs vault. The purpose of the water level recording device was used to help verify inlet and outlet flows.

A rain gauge was located adjacent to the drainage area to monitor the depth of precipitation from storm events. The data were used to characterize the events to determine if they met the requirements for a qualified storm event. The rain gauge is shown in Figure 4-4.

Figure 4-4. View of rain gauge.

4.2 Monitoring Equipment

The specific equipment used for monitoring flow, sampling water quality, and measuring rainfall for the upstream and downstream monitoring points are listed below:

- Sampler: ISCO 3700 refrigerated automatic sampler;
- Sample Containers: Four 10-L sample containers;
- Flow Measurement: Marsh-McBirney Velocity Meter Model 270
- Stage Meter (inside Vortechs vault): Campbell Scientific Inc. SWD1;
- Data Logger: Campbell Scientific, Inc. CR10X; and
- Rain Gauge: Rain-O-Matic.

4.3 Contaminant Constituents Analyzed

The list of constituents analyzed in the stormwater samples is shown in Table 4-1. The vendor's performance claim addresses reductions of sediments, from the runoff water.

Table 4-1. Constituent List for Water Quality Monitoring

Parameter	Reporting Units	Limit of Detection	Limit of Quantification	Method[1]
Total dissolved solids (TDS)	mg/L	50	167	SM 2540C
Total suspended solids (TSS)	mg/L	2	7	EPA 160.2
Total phosphorus	mg/L as P	0.005	0.016	EPA 365.1
Suspended sediment concentration (SSC)	mg/L	0.1	0.5	ASTM D3977-97
Total calcium	mg/L	0.2	0.7	EPA 200.7
Total copper	µg/L	1	3	SM 3113B
Dissolved copper	µg/L	1	3	SM 3113B
Total magnesium	mg/L	0.2	0.7	EPA 200.7
Dissolved zinc	µg/L	16	50	EPA 200.7
Total zinc	µg/L	16	50	EPA 200.7
Dissolved phosphorus	mg/L as P	0.005	0.016	EPA 365.1
Dissolved chloride	mg/L	0.6	2	EPA 325.2
Chemical oxygen demand (COD)	mg/L	9	28	ASTM D1252-88(B)
Sand-silt split	NA	NA	NA	Fishman *et al.*
Five point sedigraph	NA	NA	NA	Fishman *et al.*
Sand fractionation	NA	NA	NA	Fishman *et al.*

[1] EPA: *EPA Methods and Guidance for the Analysis of Water* procedures; SM: *Standard Methods for the Examination of Water and Wastewater (19th edition)* procedures; ASTM: American Society of Testing and Materials procedures; Fishman et al.: *Approved Inorganic and Organic Methods for the Analysis of Water and Fluvial Sediment* procedures.

4.4 Sampling Schedule

USGS personnel installed the monitoring equipment under a contract with the WDNR. The monitoring equipment was installed in December, 2001. During several trial events in 2002, it was discovered that the inlet velocity meter was frequently inundated with sediment from the backwater effect of the Vortechs. In January, 2003 the storm pipe was reconfigured to avoid this problem (see Figure 3-3). Verification testing began in April, 2003, and ended after the last qualified event was monitored in August, 2004. Testing was suspended during winter weather. Table 4-2 summarizes the sample collection data from the storm events.

Table 4-2. Summary of Events Monitored for Verification Testing

	Inlet Sampling Point (Site 1)					Outlet Sampling Point (Site 2)				
Event Number	**Start Date**	**Start Time**	**End Date**	**End Time**	**No. of Aliquots**	**Start Date**	**Start Time**	**End Date**	**End Time**	**No. of Aliquots**
1	4/30/03	22:24	5/1/03	1:13	26	4/30/03	22:32	5/1/03	0:17	11
2	5/4/03	21:34	5/5/03	0:54	20	5/4/03	21:47	5/5/03	7:10	16
3	5/9/03	0:42	5/9/03	3:41	5	5/9/03	1:53	5/9/03	4:35	8
4	5/30/03	19:07	5/30/03	23:05	21	5/30/03	19:09	5/30/03	22:33	7
5	6/8/03	3:34	6/8/03	13:44	18	6/8/03	3:35	6/8/03	5:00	7
6	6/27/03	17:35	6/28/03	10:46	20	6/27/03	17:37	6/28/03	10:15	10
7	9/12/03	15:42	9/12/03	19:22	16	9/12/03	15:47	9/12/03	17:24	8
8	9/14/03	6:09	9/14/03	12:02	18	9/14/03	11:47	9/14/03	11:59	6
9	10/14/03	1:19	10/14/03	3:04	15	10/14/03	1:23	10/14/03	3:11	14
10	10/14/03	8:54	10/14/03	9:29	8	10/14/03	8:58	10/14/03	9:31	7
11	10/24/03	17:41	10/24/03	21:43	32	10/24/03	17:41	10/24/03	21:42	29
12	3/25/04	23:08	3/26/04	3:34	31	3/25/04	23:33	3/26/04	3:33	12
13	3/28/04	15:30	3/28/04	20:12	29	3/28/04	15:31	3/28/04	18:58	13
14	4/17/04	3:29	4/17/04	4:11	7	4/17/04	3:31	4/17/04	4:12	7
15	5/12/04	18:33	5/13/04	3:27	14	5/12/04	18:36	5/13/04	3:10	7
16	5/20/04	16:39	5/20/04	17:33	9	5/20/04	16:39	5/20/04	17:38	9
17	8/3/04	20:25	8/3/04	23:34	34	8/3/04	20:25	8/3/04	23:53	26
18	8/24/04	20:40	8/25/04	0:02	17	8/24/04	20:42	8/24/04	23:54	14

Storm events met the requirements of a “qualified event,” as defined in the test plan:

1. The total rainfall depth for the event, measured at the site rain gauge, was 0.2 in. (5 mm) or greater (snow fall and snow melt events did not qualify).

2. Flow through the treatment device was successfully measured and recorded over the duration of the runoff period.

3. A flow-proportional composite sample was successfully collected for both the inlet and outlet over the duration of the runoff event.

4. Each composite sample collected was comprised of a minimum of five aliquots, including at least two aliquots on the rising limb of the runoff hydrograph, at least one aliquot near the peak, and at least two aliquots on the falling limb of the runoff hydrograph.

5. There was a minimum of six hours between qualified sampling events.

Table 4-3 summarizes the storm data for the qualified events. Detailed information on each storm’s runoff hydrograph and the rain depth distribution over the event period are included in Appendix B.

Table 4-3. Rainfall Summary for Monitored Events

Event Number	Date	Rainfall Amount (inches)	Rainfall Duration (hr:min)	Runoff Volume (ft^3)[1]	Peak Discharge Rate (cfs) [1]
1	4/30/03	1.1	3:30	847	0.352
2	5/4/03	0.72	4:05	795	0.059
3	5/9/03	0.87	4:27	717	0.084
4	5/30/03	0.54	4:07	665	0.164
5	6/8/03	0.62	11:09	847	0.466
6	6/27/03	0.57	17:25	518	0.101
7	9/12/03	0.30	3:49	156	0.039
8	9/14/03	0.47	6:35	588	2.02
9	10/14/03	0.27	2:53	268	0.057
10	10/14/03	0.23	0:39	138	0.055
11	10/24/03	0.71	5:31	613	0.138
12	3/25/04	0.85	4:57	311	0.023
13	3/28/04	0.87	4:49	216	0.025
14	4/17/04	0.24	1:18	69	0.026
15	5/12/04	0.55	9:05	311	0.076
16	5/20/04	0.24	1:02	259	1.26
17	8/3/04	1.8	3:43	2,510	2.45
18	8/24/04	0.85	3:32	449	1.02

1. Runoff volume and peak discharge volume measured at the inlet monitoring point.

The vendor sized the Vortechs for the Milwaukee Riverwalk site based on the peak flow rate of the 1.6 cfs), as noted in Section 2.1. The recorded peak discharge rate for events 8 and 17 exceeded both the peak flow treatment capacity of the Vortechs. Additionally, event 16 nearly exceeded the peak flow treatment capacity of the Vortechs. At these flow rates, the system was operating beyond the point at which significant sediment removal is expected.

The sample collection starting times for the inlet and outlet samples, as well as the number of sample aliquots collected, varied from event to event. The inlet sampler was activated when the inlet velocity meter sensed flow in the pipe. The outlet sampler was activated when flow was detected in the outlet pipe.

4.5 Field Procedures for Sample Handling and Preservation

Data gathered by the on-site data logger were accessible to USGS personnel by means of a modem and phone-line hookup. USGS personnel collected samples and performed a system inspection after storm events.

Water samples were collected with ISCO automatic samplers programmed to collect one-liter aliquots during each sample cycle. A peristaltic pump in the sampler pumped water from the sampling location through Teflon™-lined sample tubing to the pump head where water passed through approximately three feet of silicone tubing and into one of four 10-L sample collection bottles. Samples were capped and removed from the sampler after the event by the WisDOT or USGS personnel depending upon the schedule of the staff. The samples were forwarded to USGS personnel if the WisDOT personnel collected them. The samples were then transported to the USGS field office in Madison, Wisconsin, where they were split into multiple aliquots using a 20-L Teflon™-lined churn splitter. When more than 20 L (two 10-L sample collection bottles) of sample were collected by the auto samplers, the contents of the two full sample containers would be poured into the churn, a portion of the sample in the churn would be discarded, and a proportional volume from the third or fourth sample container would be poured into the churn. The analytical laboratories provided sample bottles. Samples were preserved per method requirements and analyzed within the holding times allowed by the methods. Particle size and SSC samples were shipped to the USGS sediment laboratory in Iowa City, Iowa (after event 2, SSC samples were analyzed at WSLH). All other samples were hand-delivered to WSLH.

The samples were maintained in the custody of the sample collectors, delivered directly to the laboratory, and relinquished to the laboratory sample custodian(s). Custody was maintained according to the laboratory's sample handling procedures. To establish the necessary documentation to trace sample possession from the time of collection, field forms and lab forms (see Appendix B of the test plan) were completed and accompanied each sample.

Chapter 5
Monitoring Results and Discussion

The verification testing results related to contaminant reduction are reported in two formats:

1. Efficiency ratio comparison, which evaluates the effectiveness of the system for each qualified storm event on an event mean concentration (EMC) basis.

2. Sum of loads (SOL) comparison, which evaluates the effectiveness of the system for all qualified storm events on a constituent mass (concentration times volume) basis.

The test plan required that a suite of analytical parameters, including solids, metals, and nutrients be evaluated based on the vendor's performance claim.

5.1 Monitoring Results: Performance Parameters

5.1.1 Concentration Efficiency Ratio

The concentration efficiency ratio reflects the treatment capability of the device using the event mean concentration (EMC) data obtained for each runoff event. The concentration efficiency ratios are calculated by:

$$\text{Efficiency ratio} = 100 \times (1-[\text{EMC}_{\text{outlet}}/\text{EMC}_{\text{inlet}}]) \qquad (5\text{-}1)$$

The inlet and outlet sample concentrations and calculated efficiency ratios are summarized by analytical parameter categories: sediments (TSS, SSC, and TDS); nutrients (total and dissolved phosphorus); metals (total and dissolved copper and zinc); and water quality parameters (COD, dissolved chloride, total calcium and total magnesium). The water quality parameters were not specified in the vendors' performance claim and were monitored for other reasons outside the scope of the ETV program.

Sediments: The inlet and outlet sample concentrations and calculated efficiency ratios for sediment parameters are summarized in Table 5-1.

The results show differences between inlet TSS and SSC concentrations. Comparing the inlet concentrations, SSC always exceed TSS, with the range of difference between the two parameters ranging from 6 to 90%. the TSS and SSC analytical parameters measure sediment concentrations in water; however, the TSS analytical procedure requires the analyst to draw an aliquot from the sample container, while the SSC procedure requires use of the entire contents of the sample container. If a sample contains a high concentration of settleable (generally heavy, large particle) solids, acquiring a representative aliquot from the sample container is very difficult. Therefore a disproportionate amount of the settled solids may be left in the container, and the reported TSS concentration would be considerably lower than SSC. For this data set, the TSS and SSC concentrations were relatively close. This implies that the inlet samples contained a higher proportion of finer, lighter sediment particles.

Table 5-1. Monitoring Results and Efficiency Ratios for Sediment Parameters

	TSS			SSC			TDS		
Event No.	**Inlet (mg/L)**	**Outlet (mg/L)**	**Reduction (%)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Reduction (%)**	**Inlet (mg/L)**	**Outlet (mg/L)**	**Reduction (%)**
1	79	87	-10	91	86	5.5	54	84	-56
2	110	38	65	160	36	78	100	120	-20
3	89	28	69	98	27	72	80	60	25
4	110	70	36	120	69	43	88	180	-100
5	47	64	-36	50	64	-28	<50	140	ND
6	190	100	47	290	100	66	120	180	-50
7	310	120	61	550	100	82	290	390	-34
8[1]	55	150	-170	79	150	-90	<50	96	ND
9	46	33	28	57	26	54	82	240	-190
10	130	39	70	140	34	76	110	130	-18
11	98	83	15	110	83	25	56	130	-130
12	160	140	13	180	140	22	180	840	-370
13	270	92	66	290	90	69	160	530	-230
14	110	110	0	130	110	15	120	1,400	-1,100
15	70	42	40	79	41	48	80	146	-83
16	97	93	4.1	130	92	29	82	120	-46
17[1]	74	87	-18	220	87	60	<50	<50	ND
18	78	69	12	820	79	90	60	150	-150

ND: Not Determined.

[1] The Vortechs peak hydraulic capacity was exceeded during events 8 and 17.

The TSS inlet concentrations ranged from 55 to 310 mg/L the outlet concentrations ranged from 28 to 150 mg/L, and the efficiency ratio ranged from -170 to 70%. The SSC inlet concentrations ranged 57 to 820 mg/L, the outlet concentrations ranged from 26 to 153 mg/L, and the efficiency ratio ranged from -90 to 90%.

The highest inlet TDS concentrations were observed from events 7, 12 and 13. Events 12 and 13 occurred in March 2004, and it is possible that these results were influenced by road salting operations. This reasoning does not explain the high TDS concentrations found in event 7, which occurred in September of 2003. For all but one event, the TDS concentrations increased in the outlet samples. The vendor made no performance claim for TDS.

Phosphorus: The inlet and outlet sample concentrations and calculated efficiency ratios are summarized in Table 5-2. The total phosphorus inlet concentration ranged from 0.062 mg/L to 0.68 mg/L, and the dissolved phosphorus inlet concentration ranged from 0.014 mg/L to 0.24 mg/L. Reductions in total phosphorus EMCs ranged from -82 to 52%, while reductions in dissolved phosphorus EMCs ranged from -200 to 68%.

Metals: The inlet and outlet sample concentrations and calculated efficiency ratios are summarized in Table 5-3. Reductions in metal EMCs followed a similar pattern as the phosphorus results, in that the total fraction all showed higher concentrations and greater EMC reductions than the dissolved faction. The total copper inlet concentration ranged from 21 to 280 µg/L, and the EMC reduction ranged from -83 to 70%. The total zinc inlet concentration ranged from 102 to 920 µg/L, and the EMC reduction ranged from -80 to 58%.

The dissolved copper inlet concentration ranged from less than 5 to 75 µg/L, and the EMC reduction ranged from -250 to 52%. The dissolved zinc inlet concentration ranged from 17 to 348 µg/L, and the EMC reduction ranged from -380 to 31%.

Water quality parameters: The inlet and outlet sample concentrations and calculated efficiency ratios for water quality parameters are summarized in Table 5-4. Total magnesium inlet concentrations ranged from 3.7 to 23 mg/L, and the EMC reduction ranged from -96 to 78%. Total calcium inlet concentrations ranged from 9.5 to 48 mg/L, and the EMC reduction ranged from -120 to 65%. COD inlet concentrations ranged from 27 to 310 mg/L, and the EMC reduction ranged from -2,000 to 57%. The event with the -2,000% EMC reduction had an outlet concentration of 1,400 mg/L, which is an outlier. The other COD outlet concentrations ranged from 25 to 220 mg/L, making the 1,400 mg/L concentration an apparent outlier.

Table 5-2. Monitoring Results and Efficiency Ratios for Phosphorus Parameters

	Total Phosphorus			Dissolved Phosphorus		
Event No.	Inlet (mg/L)	Outlet (mg/L)	Reduction (%)	Inlet (mg/L)	Outlet (mg/L)	Reduction (%)
1	0.062	0.079	-27	0.014	0.019	-36
2	0.23	0.12	48	0.11	0.056	49
3	0.086	0.041	52	0.016	0.007	56
4	0.17	0.12	29	0.029	0.023	21
5	0.098	0.13	-33	0.038	0.028	26
6	0.35	0.27	23	0.098	0.033	66
7	0.68	0.48	29	0.24	0.15	38
8[1]	0.11	0.2	-82	0.032	0.024	25
9	0.13	0.15	-15	0.072	0.03	58
10	0.18	0.12	33	0.053	0.048	9.4
11	0.14	0.17	-21	0.042	0.11	-160
12	0.13	0.14	-7.7	0.021	0.017	19
13	0.18	0.089	51	0.017	0.009	47
14	0.16	0.17	-6.3	0.056	0.019	66
15	0.13	0.12	7.7	0.058	0.028	52
16	0.15	0.14	6.7	0.037	0.012	68
17[1]	0.098	0.11	-12	0.024	0.071	-200
18	0.23	0.14	39	0.042	0.03	29

1. The Vortechs peak hydraulic capacity was exceeded during events 8 and 17.

Table 5-3. Monitoring Results and Efficiency Ratios for Metals

	Total Copper			Dissolved Copper			Total Zinc			Dissolved Zinc		
Event No.	Inlet (µg/L)	Outlet (µg/L)	Reduction (%)	Inlet (µg/L)	Outlet (µg/L)	Reduction (%)	Inlet (µg/L)	Outlet (µg/L)	Reduction (%)	Inlet (µg/L)	Outlet (µg/L)	Reduction (%)
1	25	34	-36	5.4	8.8	-63	120	160	-33	46	68	-48
2	64	24	63	14	11	21	270	130	52	100	78	22
3	29	13	55	8.1	5.4	33	160	84	48	64	48	25
4	56	52	7.1	16	19	-19	220	170	23	78	96	-23
5	26	33	-27	9.9	13	-31	100	130	-30	43	62	-44
6	100	75	25	33	32	3.0	370	250	32	120	110	8.3
7	280	120	57	73	35	52	920	520	43	350	330	5.7
8[1]	35	64	-83	9.3	10	-7.5	150	270	-80	42	70	-67
9	27	33	-22	26	33	-27	120	130	-8.3	17	81	-380
10	77	31	60	75	32	57	240	100	58	48	33	31
11	51	51	0	12	42	-250	180	190	-5.6	47	170	-260
12	64	73	-14	12	16	-33	240	280	-17	35	61	-74
13	99	43	57	14	12	14	410	190	54	85	59	31
14	21	36	-71	25	43 J	-72	240	310	-29	110	160	-45
15	41	39	4.9	13	19	-46	190	150	21	53	70	-32
16	55	46	16	16	14	13	250	170	32	60	67	-12
17[1]	36	28	22	7.5	7.8	-4.0	130	130	0	33	38	-15
18	200	60	70	13	10	23	270	170	37	50	52	-4.0

J. Estimated concentration; USGS notes indicate possible filter contamination.

[1] The Vortechs peak hydraulic capacity was exceeded during events 8 and 17.

Table 5-4. Monitoring Results and Efficiency Ratios for Water Quality Parameters

	Total Magnesium			Total Calcium			COD		
Event No.	Inlet (mg/L)	Outlet (mg/L)	Reduction (%)	Inlet (mg/L)	Outlet (mg/L)	Reduction (%)	Inlet (mg/L)	Outlet (mg/L)	Reduction (%)
1	8.5	6.5	24	20	18	10	27	39	-44
2	9.1	3	67	25	14	44	69	69	0
3	7.2	2.3	68	20	9.3	54	58	25	57
4	7.5	5.2	31	18	23	-28	66	1,400[2]	-2,000
5	3.8	5.3	-39	9.5	21	-120	36	60	-67
6	20	7.7	62	48	31	35	130	120	8
7	19	8.4	56	45	33	27	310	220	29
8[1]	4.7	9.2	-96	10	20	-100	31	85	-170
9	3.7	3.2	14	15	19	-27	52	86	-65
10	7.7	2.8	64	20	15	25	90	55	39
11	7.0	5.5	21	17	17	0	53	81	-53
12	11	10	9.1	29	32	-10	76	82	-7.9
13	21	6.8	68	47	24	49	100	55	45
14	7.4	8	-8.1	20	43	-120	72	140	-94
15	5.1	3.1	39	13	12	7.7	60	59	1.7
16	6.8	5.8	15	16	16	0	57	56	1.8
17[1]	9.5	5.2	45	19	12	37	33	51	-55
18	23	5	78	48	17	65	78	84 J	-7.7

J: Estimated concentration, sample exceeded holding time.

1. The Vortechs peak hydraulic capacity was exceeded during events 8 and 17.
2. COD outlet concentration for event 4 is an apparent outlier and is not used in SOL calculations (Table 5-8).

5.1.2 Sum of Loads

The sum of loads (SOL) is the sum of the percent load reduction efficiencies for all the events, and provides a measure of the overall performance efficiency for the events sampled during the monitoring period. The load reduction efficiency is calculated using the following equation:

$$\% \text{ Load Reduction Efficiency} = 100\times(1-(A/B)) \qquad (5\text{-}2)$$

where:
A = Sum of Outlet Load = (Outlet EMC_1)(Flow $Volume_1$) + (Outlet EMC_2)(Flow $Volume_2$) + (Outlet EMC_n)(Flow $Volume_n$)
B = Sum of Inlet Load = (Inlet EMC_1)(Flow $Volume_1$) + (Outlet EMC_2)(Flow $Volume_2$) + (Outlet EMC_n)(Flow $Volume_n$)
n= number of qualified sampling events

Flow was monitored in the inlet and outlet, as discussed in Chapter 3. However, the TO experienced operational issues with the outlet flow monitor and data, as discussed in Chapter 6. Therefore, for the purposes of SOL calculations, the inlet flow data was used to calculate both the inlet and outlet SOL values.

The SOL values are calculated using two approaches:

1. using the flow volumes and concentrations from all qualified events; and
2. using the flow volumes and concentrations from all qualified events except events 8 and 17, where the measured peak runoff intensity exceeded the rated hydraulic capacity of the Vortechs.

Sediment: Table 5-5 summarizes results for the SOL calculations. When every qualified event is used in the calculations, the SOL analyses indicate a TSS reduction of 18%, an SSC reduction of 58%, and a TDS reduction of –130%. When events 8 and 17 are omitted from the calculations, the SOL analyses indicate a TSS reduction of 35%, an SSC reduction of 61%, and a TDS reduction of –130%. During event 8, there was a negative removal efficiency for both TSS and SSC, however, during event 17 there was a positive removal efficiency for SSC. The difference in TSS versus SSC is likely due to the particle size distribution in the runoff, as discussed in 5.1.1. The improvement in the TSS and SSC SOL reduction when events 8 and 17 are omitted suggest that the Vortechs is ineffective or may resuspend sediment when it encounters flows exceeding its rated hydraulic capacity. Since TSS showed a higher change than SSC in SOL reduction, it appears that higher flows allow a greater proportion of fine sediment to pass from the system. The TDS SOL reduction was –120%, however the vendor made no claims for TDS removal.

Nutrients: The SOL data for nutrients are summarized in Table 5-6. When every qualified event is used in the calculations, the SOL analyses indicate a total phosphorus reduction of 9.3% and no reduction of dissolved phosphorus. When events 8 and 17 are omitted from the calculations, the SOL analyses indicate a total phosphorus reduction of 21% and a dissolved phosphorus reduction of 26%.

Table 5-5. Sediment Sum of Loads Results

		TSS		SSC		TDS	
Event No.	**Runoff Volume (ft^3)**	**Inlet (lb)**	**Outlet (lb)**	**Inlet (lb)**	**Outlet (lb)**	**Inlet (lb)**	**Outlet (lb)**
1	847	4.2	4.6	4.8	4.5	2.9	4.4
2	795	5.5	1.9	7.9	1.8	5.0	5.9
3	717	4.0	1.3	4.4	1.2	3.6	2.7
4	665	4.6	2.9	5.0	2.9	3.6	7.5
5	847	2.5	3.4	2.6	3.4	ND	ND
6	518	6.1	3.2	9.4	3.2	3.9	5.8
7	156	3.0	1.2	5.4	0.97	2.8	3.8
8	588	2.0	5.5	2.9	5.5	0.92	3.5
9	268	0.77	0.55	0.95	0.43	1.4	4.0
10	138	1.1	0.34	1.2	0.29	0.95	1.1
11	613	3.7	3.2	4.2	3.2	2.1	5.0
12	311	3.1	2.7	3.5	2.7	3.5	16
13	216	3.6	1.2	3.9	1.2	2.2	7.1
14	69	0.47	0.47	0.56	0.47	0.52	6
15	311	1.4	0.81	1.5	0.8	1.6	2.8
16	259	1.6	1.5	2.1	1.5	1.3	1.9
17	2,510	12	14	34	14	ND	ND
18	449	2.2	1.9	23	2.2	1.7	4.2
Sum of the loads – all events		**62**	**51**	**120**	**50**	**38**	**82**
Reduction efficiency (%)		**18**		**58**		**-120**	
Sum of the loads – events except 8 & 17		**48**	**31**	**80**	**31**	**37**	**78**
Reduction efficiency (%)		**35**		**61**		**-110**	

ND: Not determined.

Table 5-6. Nutrient Sum of Loads Results

		Total phosphorus		Dissolved phosphorus	
Event No.	**Runoff Volume (ft^3)**	**Inlet (g)**	**Outlet (g)**	**Inlet (g)**	**Outlet (g)**
1	847	1.5	1.9	0.34	0.46
2	795	5.2	2.7	2.5	1.3
3	717	1.7	0.83	0.32	0.14
4	665	3.2	2.3	0.55	0.43
5	847	2.4	3.1	0.91	0.67
6	518	5.1	4.0	1.4	0.48
7	156	3.0	2.1	1.1	0.66
8	588	1.8	3.3	0.53	0.4
9	268	0.99	1.1	0.55	0.23
10	138	0.7	0.47	0.21	0.19
11	613	2.4	3	0.73	1.9
12	311	1.1	1.2	0.18	0.15
13	216	1.1	0.54	0.1	0.055
14	69	0.31	0.33	0.11	0.037
15	311	1.1	1.1	0.51	0.25
16	259	1.1	1.0	0.27	0.088
17	2,510	7.0	7.8	1.7	5.0
18	449	2.9	1.8	0.53	0.38
Sum of the loads – all events		**43**	**39**	**13**	**13**
Reduction efficiency (%)		**9.3**		**0**	
Sum of the loads – events except 8 & 17		**34**	**27**	**10**	**7.4**
Reduction efficiency (%)		**21**		**26**	

Metals: The SOL data for metals are summarized in Table 5-7. When every qualified event is used in the calculations, the SOL analyses indicate a total copper reduction of 25%, a dissolved copper reduction of -10%, a total zinc reduction of 16%, and a dissolved zinc reduction of -24%. When events 8 and 17 are omitted from the calculations, the SOL analyses indicate a total copper reduction of 33%, a dissolved copper reduction of -12%, a total zinc reduction of 24%, and a dissolved zinc reduction of -21%.

Water quality parameters: The SOL data for water quality parameters are summarized in Table 5-8. When every qualified event is used in the calculations, the SOL analyses indicate a total magnesium reduction of 42%, a total calcium reduction of 21%, and a COD reduction of -100%. When events 8 and 17 are omitted from the calculations, the SOL analyses indicate a total magnesium reduction of 47%, and a total calcium reduction of 22%, and a COD reduction of -190%. When event 4 (with an apparently outlying outlet COD concentration) is taken out of the data set, the COD reduction is –15% for all events, and 0% when events 8 and 17 are omitted from the calculations.

Discussion: The calculated SOL reduction for TSS, SSC, total and dissolved phosphorus, COD, and total metals improved when omitting the two events where the peak runoff intensity exceeded the rated flow capacity of the Vortechs, while dissolved-phase constituents other than dissolved phosphorous showed relatively little change. The data suggest that scouring or resuspension may have occurred as a result of the high peak flow rates encountered during events 8 and 17.

Table 5-7. Metals Sum of Loads Results

		Total copper		Dissolved copper		Total zinc		Dissolved zinc	
Event No.	Runoff Volume (ft^3)	Inlet (g)	Outlet (g)	Inlet (g)	Outlet (g)	Inlet (g)	Outlet (g)	Inlet (g)	Outlet (g)
1	847	0.6	0.82	0.13	0.21	2.9	3.8	1.1	1.6
2	795	1.4	0.54	0.32	0.25	6.1	2.9	2.3	1.8
3	717	0.59	0.26	0.16	0.11	3.2	1.7	1.3	0.97
4	665	1.1	0.98	0.30	0.36	4.1	3.2	1.5	1.8
5	847	0.62	0.79	0.24	0.31	2.4	3.1	1.0	1.5
6	518	1.5	1.1	0.48	0.47	5.4	3.7	1.8	1.6
7	156	1.2	0.53	0.32	0.15	4.1	2.3	1.5	1.5
8	588	0.58	1.1	0.15	0.17	2.5	4.5	0.7	1.2
9	268	0.20	0.25	0.20	0.25	0.91	0.99	0.13	0.61
10	138	0.30	0.12	0.29	0.13	0.94	0.39	0.19	0.13
11	613	0.89	0.89	0.21	0.73	3.1	3.3	0.82	3.0
12	311	0.56	0.64	0.11	0.14	2.1	2.5	0.31	0.54
13	216	0.61	0.26	0.086	0.073	2.5	1.2	0.52	0.36
14	69	0.041	0.07	0.049	0.084	0.47	0.61	0.21	0.31
15	311	0.36	0.34	0.11	0.17	1.7	1.3	0.47	0.62
16	259	0.40	0.34	0.12	0.10	1.8	1.2	0.44	0.49
17	2,510	2.6	2.0	0.53	0.55	9.2	9.2	2.3	2.7
18	449	2.5	0.76	0.17	0.13	3.4	2.2	0.64	0.66
Sum of loads – all events		**16**	**12**	**4.0**	**4.4**	**57**	**48**	**17**	**21**
Reduction efficiency (%)		**25**		**-10**		**16**		**-24**	
Sum of loads – events except 8 & 17		**13**	**8.7**	**3.3**	**3.7**	**45**	**34**	**14**	**17**
Reduction efficiency (%)		**33**		**-12**		**24**		**-21**	

Table 5-8. Water Quality Parameters Sum of Loads Results

		Total magnesium		Total calcium		COD	
Event No.	Runoff Volume (ft^3)	Inlet (lb)	Outlet (lb)	Inlet (lb)	Outlet (lb)	Inlet (lb)	Outlet (lb)
1	847	0.45	0.34	1.1	0.95	1.4	2.1
2	795	0.45	0.15	1.2	0.69	3.4	3.4
3	717	0.32	0.1	0.89	0.42	2.6	1.1
4	665	0.31	0.22	0.75	0.95	NC	NC
5	847	0.2	0.28	0.5	1.1	1.9	3.2
6	518	0.65	0.25	1.6	1.0	4.2	3.9
7	156	0.18	0.082	0.44	0.32	3	2.1
8	588	0.17	0.34	0.37	0.73	1.1	3.1
9	268	0.062	0.053	0.25	0.32	0.87	1.4
10	138	0.066	0.024	0.17	0.13	0.77	0.47
11	613	0.27	0.21	0.65	0.65	2	3.1
12	311	0.21	0.19	0.56	0.62	1.5	1.6
13	216	0.28	0.092	0.63	0.32	1.3	0.74
14	69	0.032	0.034	0.086	0.19	0.31	0.6
15	311	0.099	0.06	0.25	0.23	1.2	1.1
16	259	0.11	0.094	0.26	0.26	0.92	0.9
17	2,510	1.5	0.81	3.0	1.9	5.2	8
18	449	0.64	0.14	1.3	0.48	2.2	2.4
Sum of loads – all events		**6.0**	**3.5**	**14**	**11**	**34**	**39**
Reduction efficiency (%)		**42**		**21**		**-15**	
Sum of loads – events except 8 & 17		**4.3**	**2.3**	**11**	**8.6**	**28**	**28**
Reduction efficiency (%)		**47**		**22**		**0**	

NC: Not calculated; outlet COD sample for event 4 was an apparent outlier (see Table 5-4).

5.2 Particle Size Distribution

Particle size distribution analysis was completed on selected events. The ability of the lab to conduct the specific analysis depended on the available sample volume, the sediment concentration, and the particle sizes in the sample. The ISCO samplers did not always collect an adequate volume of sample to conduct the full suite of particle size analyses. Two types of analyses were conducted.

1. A “sand/silt split” analysis determined the percentage of sediment (by weight) larger than 62.5 µm (defined as sand) and less than 62.5 µm (defined as silt). This analysis was performed on the inlet and outlet samples of events 2, 5, 7, 8, 9, 10, 11, and 16.
2. A Visual Accumulator (VA) tube analysis (Fishman et al., 1994) defined the percentage of sediment (by weight) sized less than 1000, 500, 250, 125, and 62 µm. The analyses were conducted on the inlet samples of events 2, 7, 11, and 16.

The particle size distribution results are summarized in Table 5-9. In each event where particle size analysis was conducted, the outlet samples had a higher percentage of particles in the silt category (<62.5 µm) than the equivalent inlet sample. This is a result of the gravitational separation treatment mechanism of the Vortechs removing a higher percentage of the larger, heavier sediment particles.

The SOL can be recalculated for SSC concentrations and “sand/silt split” data to determine the proportion of sand and silt removed during treatment. This evaluation, summarized in Table 5-10, shows that the Vortechs was highly effective in removing sand particles, and that the mass of silt particles in the inlet was nearly five times higher than the mass of sand. Particle size distribution is affected by such things as site conditions and use, maintenance (e.g. street sweeping), and weather. The data also show that the highest mass of silt in the outlet occurred during event 8, when the Vortechs encountered peak flow intensities at a rate higher than its rated flow capacity. Additionally, the Vortechs is generally more effective in removing silt particles during events with lower treatment volumes.

Table 5-9. Particle Size Distribution Analysis Results

		Percent Less Than Particle Size (µm)									
Event No.	**Location**	**<1000**	**<500**	**<250**	**<125**	**<62.5**	**<31**	**<16**	**<8**	**<4**	**<2**
2	Inlet	100	96	83	79	76					
	Outlet					95					
5	Inlet					42					
	Outlet					98					
7	Inlet	100	100	93	85	81	74	67	55	43	28
	Outlet					98					
8	Inlet					74					
	Outlet					98					
9	Inlet					64					
	Outlet					94					
10	Inlet					83					
	Outlet					98					
11	Inlet		100	99	98	98	97				
	Outlet					100					
16	Inlet		98	92	86	83					
	Outlet					97					

Table 5-10. Particle Size Distribution SOL Results

		SSC Conc.		Sands (>62.5 µm)		Fines (<62.5 µm)		Sand SOL		Silt SOL	
Event No.	Volume (ft^3)	Inlet (mg/L)	Outlet (mg/L)	Inlet (%)	Outlet (%)	Inlet (%)	Outlet (%)	Inlet (lb)	Outlet (lb)	Inlet (lb)	Outlet (lb)
2	795	160	36	24	5	76	95	1.9	0.09	6.0	1.7
5	847	50	64	58	2	42	98	1.5	0.07	1.1	3.3
7	156	550	100	2	19	81	98	1.0	0.02	4.3	0.95
8	588	79	150	26	2	74	98	0.75	0.11	2.1	5.4
9	268	57	26	36	6	64	94	0.34	0.03	0.61	0.41
10	138	140	34	17	2	83	98	0.20	0.01	1.0	0.29
11	613	110	83	2	0	98	100	0.08	0.00	4.1	3.2
16	259	130	92	17	3	83	97	0.36	0.04	1.7	1.4
			Sum of loads (all events)					**6.2**	**0.36**	**21**	**17**
			Removal efficiency (percent)					**94**		**21**	
			Sum of loads (all events except event 8)					**5.4**	**0.25**	**19**	**11**
			Removal efficiency (percent)					**95**		**41**	

Chapter 6
QA/QC Results and Summary

The Quality Assurance Project Plan (QAPP) in the test plan identified critical measurements and established several QA/QC objectives. The verification test procedures and data collection followed the QAPP. QA/QC summary results are reported in this section, and the full laboratory QA/QC results and supporting documents are presented in Appendix C.

6.1 Laboratory/Analytical Data QA/QC

6.1.1 Bias (Field Blanks)

Field blanks were collected at both the inlet and outlet samplers on two separate occasions to evaluate the potential for sample contamination through the entire sampling process, including automatic sampler, sample-collection bottles, splitters, and filtering devices. “Milli-Q” reagent water was pumped through the automatic sampler, and collected samples were processed and analyzed in the same manner as event samples. The first field blank was collected on June 30, 2003 (between event 6 and 7). The second field blank was collected on May 3, 2004 (between events 14 and 15).

Results for the field blanks are shown in Table 6-1. All but four analyses were below the limits of detection (LOD). Of the four analyses above the LOD; only one was greater than the LOQ. This analysis was a COD analysis conducted on the second blank test at the outlet location. Field notes and lab notes do not note any unusual circumstances or reasons for a possible contamination of this sample. These results show a good level of contaminant control in the field procedures was achieved.

Table 6-1. Field Blank Analytical Data Summary

		Blank 1 (06/30/03)		Blank 2 (05/03/04)			
Parameter	**Units**	**Inlet**	**Outlet**	**Inlet**	**Outlet**	**LOD**	**LOQ**
TDS	mg/L	<50	<50	<50	<50	50	167
TSS	mg/L	<2	<2	<2	<2	2	7
SSC	mg/L	<2	<2	<2	<2	2	7
Calcium, total	mg/L	<0.2	<0.2	<0.2	<0.2	0.2	0.7
COD	mg/L	<9	<9	<9	55	9	28
Copper, total	µg/L	<1	<1	2	1	1	3
Copper, dissolved	µg/L	1.7	1.7	1.6	<1	1	3
Magnesium, total	mg/L	<0.2	<0.2	<0.2	<0.2	0.2	0.7
Phosphorus, total	mg/L	<0.005	<0.005	<0.005	<0.005	0.005	0.016
Phosphorus, dissolved	mg/L	<0.005	<0.005	<0.005	<0.005	0.005	0.016
Zinc, total	µg/L	<16	<16	<16	<16	16	50
Zinc, dissolved	µg/L	<16	<16	<16	<16	16	50

6.1.2 Replicates (Precision)

Precision measurements were performed by the collection and analysis of duplicate samples. The relative percent difference (RPD) recorded from the sample analyses was calculated to evaluate precision. RPD is calculated using the following formula:

$$\%RPD = \left(\frac{|x_1 - x_2|}{\bar{x}}\right) \times 100\% \qquad (6\text{-}1)$$

where:
x_1 = Concentration of compound in sample
x_2 = Concentration of compound in duplicate
$\bar{x}$ = Mean value of x_1 and x_2

Field precision: Field duplicates were collected to monitor the overall precision of the sample collection procedures. Duplicate inlet and outlet samples were collected during three different storm events to evaluate precision in the sampling process and analysis. The duplicate samples were processed, delivered to the laboratory, and analyzed in the same manner as the regular samples. Summaries of the field duplicate data are presented in Table 6-2.

Overall, the results show good field precision. Below is a discussion on the results from selected parameters.

TSS and SSC: Results were within targeted limits. Outlet samples (lower concentrations and smaller particle sizes) showed higher precision. The poorer precision for the inlet samples could be due to the sample handling and splitting procedures, or sampling handling for analysis, or a combination of factors. Tests on the sample splitting capabilities of a churn splitter showed the bias and the precision of the splits is compromised with increasing sediment concentrations and particle size. The tests identified the upper particle size limits for the churn splitter is between 250 and 500 µm (Horowitz, et al, 2001).

Dissolved constituents (sediment, phosphorus, and metals): These parameters consistently had very low RPD (very high precision). This supports the idea that the sample splitting operation may be the source of higher RPD in the high particulate samples.

Total metals: The total copper, total magnesium, and total zinc data had RPD values exceeding the targeted limits. Similar to the particulate sediment results, the highest RPDs occurred in the inlet samples, which had higher particulate concentrations; however, total copper had high RPDs for the outlet samples as well. The total calcium data showed higher precision.

Total phosphorus: This parameter was consistently below or near the acceptable RPD value of 30%. Again, the highest discrepancies occurred at the inlet analyses, with very good duplicate agreement at the outlet samples.

Table 6-2. Field Duplicate Sample Relative Percent Difference Data Summary

			6/27/03			9/12/03			8/24/04			
Parameter	**Unit**		**Rep 1a**	**Rep 1b**	**RPD (%)**	**Rep 1a**	**Rep 1b**	**RPD (%)**	**Rep 1a**	**Rep 1b**	**RPD (%)**	**Limit (%)**
TDS	mg/L	Inlet	120	120	**0**	280	290	**4**	54 [2]	[2]	**11**	**30**
		Outlet	180	180	**0**	390	390	**0**	130 [2]	150 [2]	**14**	
TSS	mg/L	Inlet	190	190	**0**	310	-- [1]	**--**	60 70	78	**11**	**30**
		Outlet	100	100	**0**	94	120	**4**	73	69	**6**	
SSC	mg/L	Inlet	260	290	**11**	500	550	**10**	970	820	**17**	**ND**
		Outlet	110	100	**10**	98	100	**2**	75	79	**5**	
COD	mg/L	Inlet	130	130	**0**	360 [3]	310	**15**	53	78 [3]	**38**	**ND**
		Outlet	110	120	**9**	240	220	**9**	84 [3]	[3]	**0**	
Calcium, total	mg/L	Inlet	38	48	**23**	48	45	**9**	66	48	**32**	**25**
		Outlet	30	31	**3**	32	33	**3**	84 17	17	**0**	
Copper, total	µg/L	Inlet	110	100	**10**	200	280	**33**	110	200	**58**	**25**
		Outlet	76	75	**1**	160	120	**29**	35	60	**53**	
Copper, dissolved	µg/L	Inlet	32	33	**3**	75	73	**3**	13	13	**0**	**25**
		Outlet	33	32	**3**	35	35	**0**	9.9	10	**1**	
Magnesium, total	mg/L	Inlet	15	20	**29**	20	19	**5**	32	23	**33**	**25**
		Outlet	7.4	7.7	**4**	8.3	8.4	**1**	4.9	5	**2**	
Phosphorus, total	mg/L	Inlet	0.34	0.35	**3**	0.73	0.68	**7**	0.20	0.23	**14**	**30**
		Outlet	0.27	0.27	**0**	0.49	0.48	**2**	0.14	0.14	**0**	
Phosphorus, dissolved	mg/L	Inlet	0.1	0.1	**0**	0.24	0.24	**0**	0.04	0.04	**0**	**30**
		Outlet	0.03	0.03	**0**	0.15	0.15	**0**	0.03	0.03	**0**	
Zinc, total	µg/L	Inlet	360	370	**3**	960	920	**4**	350	270	**26**	**25**
		Outlet	240	250	**4**	520	520	**0**	150	170	**13**	
Zinc, dissolved	µg/L	Inlet	110	120	**9**	340	350	**3**	51	50	**2**	**25**
		Outlet	110	110	**0**	320	330	**3**	49	52	**6**	

1 Lab error; no result reported
2 Laboratory duplicate sample QA/QC objective exceeded for this batch of samples.
3 Holding time exceeded
ND not determined

Laboratory precision: The WSLH analyzed duplicate samples from aliquots drawn from the same sample container as part of their QA/QC program. Summaries of the laboratory duplicate data are presented in Table 6-3.

Table 6-3. Laboratory Duplicate Sample Relative Percent Difference Data Summary

Parameter[1]	Count[2]	Average (%)	Maximum (%)	Minimum (%)	Std. Dev. (%)
TDS	16	4.3	18	0.00	4.5
TSS	19	2.2	8.6	0.00	2.5
Calcium, total	15	1.7	4.1	0.13	1.0
Copper, total	16	1.7	5.5	0.09	1.6
Copper, dissolved	16	2.0	6.5	0.07	2.1
Magnesium, total	15	1.3	4.7	0.01	1.3
Phosphorus, total	21	1.3	7.9	0.00	1.9
Phosphorus, dissolved	15	0.14	1.6	0.00	0.4
Zinc, total	13	2.6	8.1	0.00	2.4
Zinc, dissolved	15	2.0	6.9	0.04	1.9

1 Laboratory precision may also be evaluated based on absolute difference between duplicate measurements when concentrations are low. For data quality objective purposes, the absolute difference may not be larger than twice the method detection limit.

2 Analyses where both samples were below detection limits were omitted from this evaluation.

The data show that laboratory precision was maintained within target limits throughout the course of the verification project.

The field and analytical precision data combined suggest that the solids load and larger particle sizes in the inlet samples are the likely cause of poor precision, and apart from the field sample splitting procedures for inlet samples, the verification program maintained high precision.

6.1.3 Accuracy

Method accuracy was determined and monitored using a combination of matrix spike/matrix spike duplicates (MS/MSD) and laboratory control samples (known concentration in blank water). The MS/MSD data are evaluated by calculating the deviation from perfect recovery (100%), while laboratory control data are evaluated by calculating the absolute value of deviation from the laboratory control concentration. Accuracy was in control throughout the verification test. Tables 6-4 and 6-5 summarize the matrix spikes and lab control sample recovery data, respectively.

Table 6-4. Laboratory MS/MSD Data Summary

Parameter	Count	Average (%)	Maximum (%)	Minimum (%)	Std. Dev. (%)	Range (%)
Calcium, total	16	98	113	94	4.7	80-120
Copper, total	15	98	116	86	8.6	80-120
Copper, dissolved	16	101	116	92	6.5	80-120
Magnesium, total	16	99	102	97	1.5	80-120
Phosphorus, total	20	103	109	97	3.2	70-130
Phosphorus, dissolved	16	101	106	97	2.5	70-130
Zinc, total	16	97	103	91	3.2	80-120
Zinc, dissolved	15	97	105	93	3.3	80-120

Table 6-5. Laboratory Control Sample Data Summary

Parameter	Count	Mean (%)	Maximum (%)	Minimum (%)	Std. Dev. (%)
Total calcium	13	97	105	91	3.6
Total copper	27	100	106	91	3.9
Dissolved copper	7	101	106	92	4.5
Total magnesium	13	97	103	92	3.1
SSC	15	99	108	87	5.6
TSS	15	100	117	89	7.9
Dissolved phosphorus	11	101	107	97	2.9
TDS	15	105	118	98	6.1
Total phosphorus	16	101	106	96	2.4
Total zinc	16	98	103	95	2.3
Dissolved zinc	4	96	98	94	1.7

The balance used for solids (TSS, TDS, and total solids) analyses was calibrated routinely with weights that were NIST traceable. The laboratory maintained calibration records. The temperature of the drying oven was also monitored using a thermometer that was calibrated with a NIST traceable thermometer.

6.1.4 Representativeness

The field procedures were designed to ensure that representative samples were collected of both inlet and outlet stormwater. Field duplicate samples and supervisor oversight provided assurance that procedures were being followed. The challenge in sampling stormwater is obtaining representative samples. The data indicated that while individual sample variability might occur, the long-term trend in the data was representative of the concentrations in the stormwater.

The laboratories used standard analytical methods, with written SOPs for each method, to provide a consistent approach to all analyses. Sample handling, storage, and analytical methodology were reviewed to verify that standard procedures were being followed. The use of standard methodology, supported by proper quality control information and audits, ensured that the analytical data were representative of actual stormwater conditions.

Regarding flow (velocity and stage) measurements, representativeness is achieved in three ways:

1. The meter was installed by experienced USGS field monitoring personnel familiar with the equipment, in accordance with the manufacturer's instructions;
2. The meter's individual area and velocity measurements were converted to a representation of the flow area using manufacturer's conversion procedures (see Chapter 9 of Marsh-McBirney's O&M Manual in Appendix A of the test plan);
3. The flow calculated from the velocity/stage measurements was calibrated using the procedure described in Section 6.2

To obtain representativeness of the sub-samples (aliquots) necessary to analyze the various parameters from the event sample, a churn splitter was used. As noted in Radtke, et al. (1999), the churn splitter is the industry standard for splitting water samples into sub-samples. However, inconsistencies were noted in the sub-samples, especially when the sample contained high concentrations of large-sized sediments. The even distribution of the larger particulates becomes problematic, even with the agitation action of the churn within the splitter. The issue of the potential for uneven distribution of particulates has not been fully resolved. (Horowitz, et al, 2001).

6.1.5 Completeness

The flow data and analytical records for the verification study are 100% complete. There were instances of velocity "dropouts" during some events. A discussion of the calibration procedures for flow data (velocity and stage measurements), including how velocity dropouts were addressed, is provided in Section 6.2.

6.2 Flow Measurement Calibration

6.2.1 Stage Measurement Corrections

Static gauge height measurements were made at the inlet pipe by constricting the pipe to a steady-state water level. An inflatable ball was used to block the pipe. Water level readings from a measuring tape inside the pipe were compared to the water surface level recorded by the flow meters (located within the inlet pipe,). Gauge heights were checked thirteen times during the project. A gauge height correction curve with three gauge height points—bottom, middle, and top (approximately 0.0 ft, 0.3 ft, and 0.6 ft above the invert pipe elevation)—was developed for the pipe, as shown in Table 6-6. Most of the correction factors for the inlet lowered the recorded gauge height by approximately 5%. Corrections for the outlet pipe were also small (less than ± 2%).

Table 6-6. Stage Height Corrections

	Gauge Height: Low		Gauge Height: Medium		Gauge Height: High	
Date	**Gauge Height (ft)**	**Correction (unitless)**	**Gauge Height (ft)**	**Correction (ft)**	**Gauge Height (ft)**	**Correction (ft)**
2/20/03	0	0	0.417	-0.083	0.635	-0.017
4/11/03	0	0	0.417	-0.083	0.63	-0.017
4/11/03	0	0.01	0.35	-0.03	0.635	-0.07
8/20/03	0	0.01	0.35	-0.03	0.635	-0.07
8/20/03	0	-0.002	0.29	0.04	0.4	0.05
8/25/03	0	-0.002	0.29	0.04	0.4	0.05
8/25/03	0	0.061	0.29	0.059	0.4	0.056
8/26/03	0	0.061	0.29	0.059	0.4	0.056
8/26/03	0	-0.052	0.29	-0.009	0.4	-0.004
11/4/03	0	-0.052	0.29	-0.009	0.4	-0.004
11/5/03	0	-0.003	0.35	0.011	0.69	0.02
3/9/04	0	-0.003	0.35	0.011	0.69	0.02
3/9/04	0	0.006	0.31	0.002	0.63	0.012

6.2.2 Flow Calibration – Inlet Flume Measurements

Flow meters at the inlet and outlet of the Vortechs were calibrated on April 18, 2003 and November 8, 2003 using similar procedures. A 3-in. Parshall flume attached to 2.5 ft width by 8 ft length by 2 ft depth chamber was mounted in the bed of a boom truck. Hydraulics on the boom truck was used to level the flume. Water was pumped from the Milwaukee River into the chamber minimizing flow turbulence in the approach section of the flume. Four different pumping rates were used to calibrate the flow meters. A 2-in. pump generated discharge rates of approximately 0.1 and 0.15 cfs, a 4-in. pump generated discharge rate of approximately 0.4 cfs and the two pumps together generated approximately 0.55 cfs. Flow from the flume was discharged through a 6-in. corrugated pipe upstream of the installed area-velocity meters. Water level in the flume was measured and discharge for the 3-in. Parshall flume was recorded. A 10 to 20 min pumping test was run for each rate and pertinent information from the meters was recorded manually from the CR10 data logger.

Several steps were needed to correct each area-velocity meter flow using raw data. First, meters outputted point velocity, which was converted to an average area velocity by applying an equation created by the manufacturer. Overall, this decreased flows by an average of 10%. Second, the area of the pipe was reduced to the portion of the flowing pipe by subtracting the meter and cord area; this could be as much as half of the area at depth less then 0.1 ft. Flows were then calculated by multiplying the average velocity by the effective-cross-sectional area based on the water level. Because the velocity dropouts occurred at low and high flows the velocities from the meter were used only to assist in developing the flow rating described below.

6.2.3 Developing the Rating Curve

Discharge was estimated for each meter after gage height corrections were applied, then corrected stage values and flume discharges were plotted. Using this plot, a stage vs. discharge rating was developed that tracked through the flume-recorded points at gage heights ranging from 0.08 to 0.20 ft. The following USGS rating curve for stable channels was used, which is a modified form of Manning's equation (Ratz, 1982):

$$Q = \frac{C(G-e)S}{2n} \qquad (6\text{-}2)$$

where:
Q = discharge
C = discharge coefficient
G = gage height of the water surface
e = effective zero control
S = energy slope loss
n = Manning's roughness coefficient

Flows were estimated using Manning's equation where flume discharge was not available. Calibration data was not available at low flows (less than 0.08 ft.) because the velocities did not register until the meter was submerged or at high flows (greater than 0.20 ft, or 0.55 cfs) because this exceeded the calibration pumping rate capabilities. Manning's roughness coefficient was adjusted to fit the USGS rating curve for low flows and Manning's roughness coefficient was adjusted to fit the calibrated rating curve and corrected meter flow.

The Manning's rating curve is expressed by the following equation:

$$Q = (1.486/n)AR^{2/3}S^{1/2} \qquad (6\text{-}3)$$

where:
1.486 converts to English units
A = cross-sectional area based on the water level
R = hydraulic radius based on the water level
S = energy slope loss

Figure 6-1 shows the rating curve developed as a result from this process.

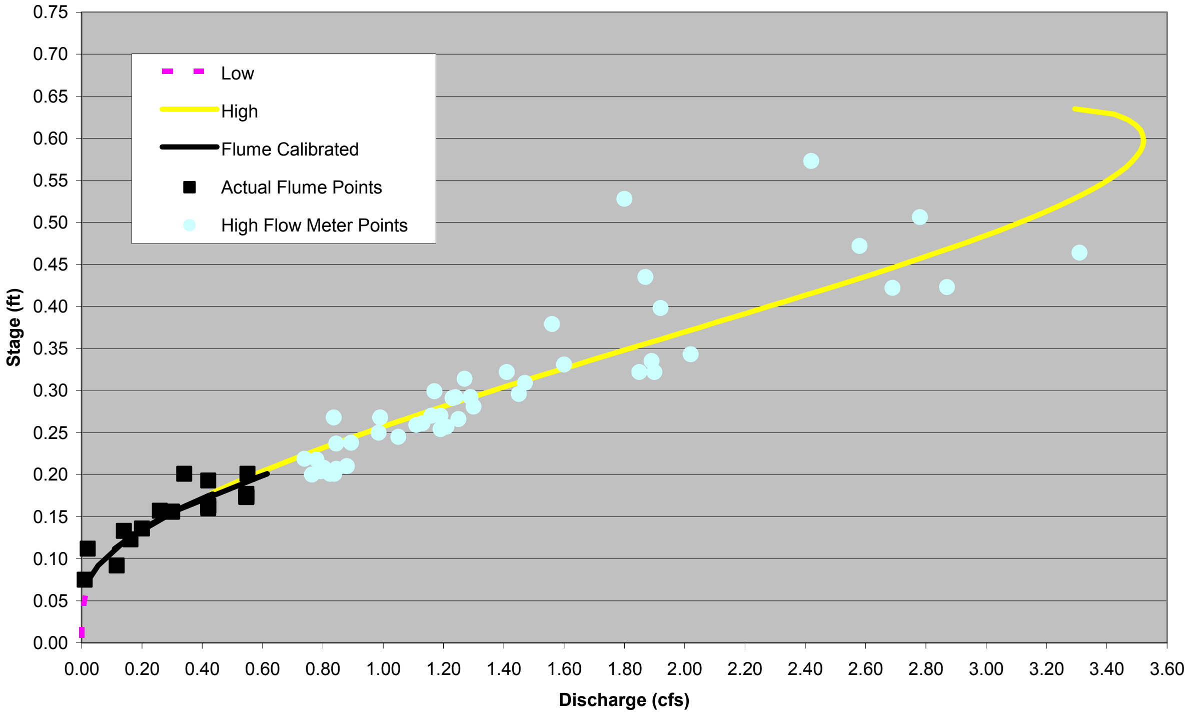

Figure 6-1. Calculated rating curve for Vortechs inlet site.

6.2.4 Outlet Volume Comparison

This Vortechs configuration did not have an external bypass mechanism, so the calculated inlet and outlet event volumes should be the same, and a comparison of the calculated inlet and outlet volumes can be used to ensure both flow monitors worked properly. However, the outlet site area velocity meter experienced frequent problems. Because of these problems, a comparison of inlet and outlet volumes was not conducted as part of the QA/QC process.

6.2.5 Comparison of Runoff Volumes: Rainfall Depth vs. Inlet Measurements

A final comparison of instrument measurements was to compare the measured rainfall depth over the drainage area to the runoff volume calculated at the inlet meter. The rational method was used to convert rainfall depth to runoff volume. The rational method is expressed by the following equation:

$$Q = CIA \tag{6-4}$$

where:
Q = Total Flow Volume (ft^3)
C = Runoff Coefficient (dimensionless)
I = Rainfall Depth (ft)
A = Drainage Basin Area (ft^2)

This data is summarized in Table 6-7. The runoff coefficient was 1 (since the entire surface is paved) and the drainage basin area is 10,890 ft^2 (0.25 acres).

Table 6-7. Comparison of Runoff Volumes

		Event Runoff Volume (ft^3)		
Event	**Date**	**Based on Rainfall Depth**	**Based on Inlet Velocity Meter**	**Percent difference (absolute value)**
1	4/30/03	998	847	15
2	5/4/03	653	795	22
3	5/9/03	790	717	9.2
4	5/30/03	490	665	36
5	6/8/03	563	847	51
6	6/27/03	517	518	0.1
7	9/12/03	272	156	43
8	9/14/03	427	588	38
9	10/14/03	245	268	9.4
10	10/14/03	209	138	34
11	10/24/03	644	613	4.9
12	3/25/04	771	311	60
13	3/28/04	790	216	73
14	4/17/04	218	69	68
15	5/12/04	499	311	38
16	5/20/04	218	259	19
17	8/3/04	1,630	2,510	54
18	8/24/04	771	449	42
			Average	34
			Median	37
			Maximum	73
			Minimum	0.1
			Std. Dev.	22

The comparison shows that calculations for seven of the eighteen events are within 25% of each other. The rest of the events showed greater differences. There are several possibilities for differences in these readings including:

- Inherent accuracy of each instrument (rain gauge and velocity meter).
- Accuracy of the drainage area delineation. As stated previously, the drainage area was calculated from WisDOT design drawings and maintenance update documents (see Section 3.1). It is likely that the actual contributing area for each event varies depending

on the rain depth, intensity, and duration. Small features in the highway decking (joints, cracks, etc.) will affect the drainage characteristics.
- Inlet capacity may also affect the volume of rainfall entering the storm sewer system.

6.2.6 Point Velocity Correction

Equations have been developed by the flow monitoring equipment manufacturer to correct for velocity measurements recorded at a single point. A point velocity can be different than the average velocity over the entire depth of the water in the pipe. The equation for the flow equipment lowered all the measured velocities by approximately 10%.

Chapter 7
Operations and Maintenance Activities

7.1 System Operation and Maintenance

Vortechs recommends inspecting the system on a quarterly basis. The main point of the inspection is to check that the sediment and debris trapped in the grit chamber (see Figure 2-1) does accumulate any higher than to within 6 inches of the dry weather standing water elevation. The dry-weather standing water elevation was about three feet from the bottom of the grit chamber. Inspections conducted by the TO and the USGS never found the accumulation of sediment and debris in the grit chamber to reach this level.

The TO followed the manufacturer's guidelines for maintenance on the Vortechs system during the verification testing. Installation of the Vortechs was completed in December 2001. In the spring of 2002 the monitoring equipment was installed and initial monitoring began. Over the summer and fall of 2002, the inlet velocity meter and area around the inlet sampling intake was frequently inundated with sediment from the backwater effects of the Vortechs. It was decided to re-configure the inlet pipe system and move the velocity meter and sampling intake line above this backwater area. This allowed for better measurements. The pipe reconfiguration was completed in January 2003. No events monitored in 2002 were used for the verification evaluation. In the spring of 2003, the system was placed into operation and adjustments to the system were completed, ETV monitoring of the system began in April 2003. Table 7-1 summarizes O&M activities undertaken by the TO and USGS once verification testing was initiated.

Table 7-1. Operation and Maintenance During Verification Testing

Date	Activity	Personnel Time/Cost
4/18/03	USGS conducted velocity meter/flow measurement calibration. Sediment in Vortechs grit chamber observed at depths ranging from less than 1 inch to 2.5 inches.	2 USGS staff @ 12 hours each. (most time spent on calibration work; less than 1 hour for checking Vortechs
04/29/03	General Pipe Services jet-vac and vacuumed out Vortechs grit chamber (pre-monitoring cleanout).	½ day invoice = \$985.00. Landfill fee for waste = \$263.13
11/08/03	USGS conducted velocity meter/flow measurement calibration.	No maintenance conducted

Table 7-1 (cont'd)

Date	Activity	Personnel Time/Cost
05/07/04	Vortechs inspection by Earth Tech; measured sediment depth in grit chamber. Sediment relatively evenly distributed throughout chamber. Depths ranged from 1 to 2 in. Floatables covered about 5 – 10% of the surface. Oil sheen also observed.	2 staff @ 2 hours each.
08/30/04	USGS inspected Vortechs and measured sediment depth in grit chamber. Measured depths ranged from 1 to 5.5 in. Water in chamber cloudy; sediment very soft and organic, not much sand or gravel. Very little floatables observed.	1 staff @ 1 hour.
09/09/04	Earth Tech inspected Vortechs; measured sediment depth in grit chamber. Depths ranged from 0 to 5.75 in. Also observed oil sheen and floatables in chamber. Outlet chamber also inspected, with a very thin layer of sediment observed. Some scum and oil observed in this chamber.	2 staff @ 1 ½ hours each.
09/24/04	Post monitoring clean out of Vortechs. Clean out conducted by Earth Tech, WDNR and USGS. A complete description of the process and results is presented in Section 7.2.	4 staff @ 8 hours each (time commitment to capture all sediment and debris for drying and analysis).

7.2 Description of Post Monitoring Cleanout and Results

7.2.1 Background

On September 24, 2004, the Vortechs was cleaned out so that as much of the solid material as possible from the device could be dried, weighed, and characterized. The weather was sunny and clear, with temperatures in the low 70s, and there had been no rain for the previous two weeks.

The general steps followed were:

1. Take sample of standing water before any disturbance to analyze for TSS of water above the settled material.

2. Measure the standing water depth and sediment depth in the Vortechs before any removal of material

3. Decant the standing water using a hand held sump pump to a level 0.5 ft above the settled material layer.

4. Decant the next layer of water using hand held sump pump into five-gallon containers. Obtain a water sample from each five-gallon container, composite into one container for analysis of TSS.

5. Remove sediment from grit chamber and all accessible portions of the vault and place in five-gallon containers.

6. Transport containers to USGS lab in Middleton, Wisconsin for drying and weighing.

7.2.2 Field Procedures

For purposes of solids and water measurements and removal, the system is divided into the following sections (from upstream to downstream in the system):

- Inlet pipe
- Grit chamber (tank 1)
- Oil and Flow Control Chamber (tank 2)
- Outlet Chamber (tank 3)

Tanks 1 and 2 are hydraulically connected and have the same water surface elevation. Tank 3 is hydraulically separated from the upper two tanks with an independent standing water elevation.

Standing water TSS samples:

- Grit chamber: tank 1, bottle 1
- Lower chamber: tank 3, bottle 1

Water and sediment depth measurements in grit chamber (tank 1):

• Manhole rim to top of water:	5.20 ft
• Manhole rim to top of sediment:	8.10 ft
• Manhole rim to bottom of grit chamber:	8.40 ft
• Depth of water in vault:	3.20 ft
• Depth of sediment in grit chamber:	0.30 ft

7.2.3 Measurement Results

Table 7-2 summarizes the results of the material analysis. The term “sediment” is avoided in this analysis, because much of the material consisted of leaves, trash, and larger debris. The dry weight reported includes all the debris removed. The particle size analysis was conducted only upon the material after the larger debris was sifted out. As shown in Table 7-2, approximately 82% of the sediment retained in the sediment chamber had a particle size of 125 µm or larger.

Table 7-2: Analysis of Vortechs Cleanout Material

Sediment Source	**Material Dry Weight (lb)**	**Percent Less Than Particle Size (µm)**											
		<4000	**<2000**	**<1000**	**<500**	**<250**	**<125**	**<63**	**<31**	**<16**	**<8**	**<4**	**<2**
Weir Chamber (tank 3)	15	87	82	73	54	37	21	14	10	6.9	4.4	3.4	2.5
Inlet Pipe	8.1	88	83	76	62	39	18	11	6.4	4.6	3.5	2.8	2.0
Grit Chamber (tank 1) (1 of 2 samples)		95	92	87	75	40	16	7.2	5.4	3.8	2.6	2.3	1.6
Grit Chamber (tank 1) (2 of 2 samples)		89	85	69	59	41	20	11	8.3	6.3	4.3	3.1	2.2
Grit Chamber (tank 1) average of 2 sub-samples)	100	92	88	78	67	41	18	9	6.9	5.1	3.5	2.7	1.9
Total	**120**	**91**	**86**	**78**	**64**	**39**	**18**	**10**	**7**	**5**	**3**	**3**	**2**

Chapter 8
References

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Glossary

Accuracy - a measure of the closeness of an individual measurement or the average of a number of measurements to the true value and includes random error and systematic error.

Bias - the systematic or persistent distortion of a measurement process that causes errors in one direction.

Comparability – a qualitative term that expresses confidence that two data sets can contribute to a common analysis and interpolation.

Completeness – a quantitative term that expresses confidence that all necessary data have been included.

Precision - a measure of the agreement between replicate measurements of the same property made under similar conditions.

Protocol – a written document that clearly states the objectives, goals, scope and procedures for the study. A protocol shall be used for reference during Vendor participation in the verification testing program.

Quality Assurance Project Plan – a written document that describes the implementation of quality assurance and quality control activities during the life cycle of the project.

Residuals – the waste streams, excluding final outlet, which are retained by or discharged from the technology.

Representativeness - a measure of the degree to which data accurately and precisely represent a characteristic of a population parameter at a sampling point, a process condition, or environmental condition.

Wet-Weather Flows Stakeholder Advisory Group - a group of individuals consisting of any or all of the following: buyers and users of in drain removal and other technologies, developers and Vendors, consulting engineers, the finance and export communities, and permit writers and regulators.

Standard Operating Procedure – a written document containing specific procedures and protocols to ensure that quality assurance requirements are maintained.

Technology Panel - a group of individuals with expertise and knowledge of stormwater treatment technologies.

Testing Organization – an independent organization qualified by the Verification Organization to conduct studies and testing of mercury amalgam removal technologies in accordance with protocols and Test Plans.

Vendor – a business that assembles or sells treatment equipment.

Verification – to establish evidence on the performance of in drain treatment technologies under specific conditions, following a predetermined study protocol(s) and Test Plan(s).

Verification Organization – an organization qualified by EPA to verify environmental technologies and to issue Verification Statements and Verification Reports.

Verification Report – a written document containing all raw and analyzed data, all QA/QC data sheets, descriptions of all collected data, a detailed description of all procedures and methods used in the verification testing, and all QA/QC results. The Test Plan(s) shall be included as part of this document.

Verification Statement – a document that summarizes the Verification Report reviewed and approved and signed by EPA and NSF.

Verification Test Plan – A written document prepared to describe the procedures for conducting a test or study according to the verification protocol requirements for the application of in drain treatment technology. At a minimum, the Test Plan shall include detailed instructions for sample and data collection, sample handling and preservation, precision, accuracy, goals, and quality assurance and quality control requirements relevant to the technology and application.

Appendices

A Vortechs Design and O&M Guidelines
B Test Plan
C Event Hydrographs and Rain Distribution
C Analytical Data Reports with QC