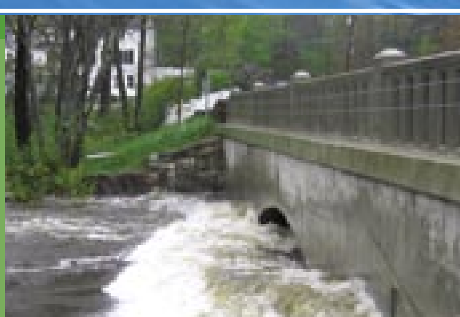
University of New Hampshire Stormwater Center

2007 Annual Report



Dedicated to the Protection of Water Resources through Effective Stormwater Management

CICEET

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About the Center

The University of New Hampshire (UNH) Stormwater Center is dedicated to the protection of water resources through effective stormwater management. It conducts research to evaluate and enhance the performance of stormwater management systems. The center's evolving outreach program supports a wide range of stormwater managers who seek to build programs that protect water quality, preserve environmental values, and reduce the impact of stormwater runoff.

The center receives primary funding and support from the Cooperative Institute for Coastal and Estuarine Environmental Technology (CICEET), a partnership of UNH and the National Oceanic and Atmospheric Administration (NOAA). It is housed within the University's Environmental Research Group, a division of the College of Engineering and Physical Sciences.

UNH Stormwater Center field site

Directors’ Message

Since we broke ground on the University of New Hampshire Stormwater Center field site in 2003, there has been a growing demand for technical and educational services we provide. The regulatory landscape surrounding stormwater is changing, and as a result, municipalities and others must change their traditional approaches to stormwater management.

The applied nature of our research places us in the midst of an energetic dialogue over stormwater, one that engages municipal officials, community activists, consultants, manufacturers, contractors, regulatory agencies, and scientists. The overarching question that everyone seeks to answer is what can we do about stormwater now to clean up our water resources and protect them for the future?

The need to answer that question has never been more crucial. In a rapidly developing landscape, the spread of impervious surfaces has dramatically increased the volume of runoff, and increased the pollutants it contains. This situation takes on new gravity with global climate change, which has made severe storms and flooding more commonplace, placing added stress on urban infrastructure. These pressures are further compounded by the Clean Water Act’s mandate for communities to treat the nonpoint source pollution in runoff.

The good news is that these challenges can be addressed. Our research data tells us that it’s possible to design and install systems that do an excellent job of treating pollutants in stormwater, dampening the peak flows of runoff, and reducing the volume of stormwater through infiltration, even in cold climates with poor soils. Similarly, our experience working with proactive stormwater managers indicates that, given the right information and resources, people are ready for change.

That’s why alongside refining and expanding the research component of our program, we have been building a bridge between our research and “real world” applications. This report is one of many tools we use to communicate our work in a way that we hope stormwater managers from many backgrounds will find useful.

We welcome your comments and questions, about this report and all of the work we do.

Sincerely,

Robert Roseen
Director

Thomas Ballestero
Senior Scientist

Jamie Houle
Research Facility Manager

Highlights from 2006 & 2007

2006 was a watershed year for the UNH Stormwater Center (UNHSC). We were able to complete a data set that charts the performance of stormwater treatment systems over the course of different seasons, which allows us to make more conclusive observations about the effectiveness of their performance. We also refined our process of system evaluation and expanded its scope to both look at new contaminants and to better characterize some that had already been under evaluation. At the same time, our work with the community laid the groundwork for new partnerships with municipal, state, and federal agencies, private industry, and nonprofit organizations all focused on nonpoint source pollution control and stormwater issues.

LIDs are Solid Performers

With the benefit of a data set that extends over two years, researchers from the UNHSC compared the water quality treatment and runoff volume reduction performance of low impact development (LID) stormwater systems over a diverse range of seasonal conditions. What we have observed disproves common assumptions that LIDs do not fair well in the harsh winters that are common in cold climate regions.

In fact, all of the LID stormwater approaches we have monitored—biorentention systems, tree filter, porous asphalt parking lot, sand filter, and gravel wetland—demonstrated excellent water quality treatment and peak flow reduction year round. Learn more about these systems and their performance on pages 10 through 19 of this report.

Porous Asphalt

UNHSC completed a two-year study of a porous asphalt parking lot at our field site in 2006. Our data and observations indicate that porous asphalt is a viable, cost-effective approach to treating water quality and reducing the volume of runoff. The system performed exceptionally well in winter and proved itself to be as durable as conventional asphalt. It also appears to require as much as 75 percent less road salt for deicing. Read more on pages 10–11 of this report.

An Evolving Process

Total phosphorus, total nitrogen, and total sediment, have been added to the suite of contaminants we monitor at the field site. Work on pollutant mass balance calculations across the range of systems and assessed contaminants is underway, as is the detailed characterization of the particle sizes of sediments in stormwater runoff. You can learn more about these and other changes to our research design by contacting the UNHSC.

Collaboration

UNHSC is collaborating with numerous private and public organizations to help implement innovative stormwater management solutions for communities throughout New England.

Here are Some Highlights:

- With UNHSC support, the New Hampshire Department of Transportation constructed two pilot gravel wetland treatments to help meet TMDL requirements for impaired waters as part of the Interstate 93 widening project.

  If successful, these innovative systems could be included in the more than 50 stormwater basins slated for installation along I-93 in the future.

- In collaboration with Nonpoint Education for Municipal Officials (NEMO), UNHSC built an inventory of innovative stormwater strategies that have been installed in New England. The inventory provides local examples of innovative designs that will be useful for anyone considering use of these techniques in the future. Learn more at http://www.erg.unh.edu/lid/index.asp

- A pervious concrete demonstration facility was built on the UNH campus in summer 2007, thanks to the joint efforts of UNH, the Northern New England Concrete Promotion Association, East Coast Excavating, and PCI Systems.

A Growing Resource

UNHSC training workshops are an established resource for New England's stormwater management community. More than 1,000 participants from more than 150 municipal, state, and federal entities and 100 private and public groups have attended these sessions. To support stormwater managers in other regions, UNHSC is working with partners in the National Oceanic and Atmospheric Administration to develop a stormwater training module, based on UNHSC data, that will be available nationwide in 2008.

Impact on Policy

Based on research findings at UNHSC and elsewhere, the Rhode Island Coastal Resources Management Council (CRMC) has limited the use of hydrodynamic separators to stormwater pretreatment for all new development and redevelopment projects. These recommendations are based on the moderate performance that these devices have demonstrated with regard to water quality.

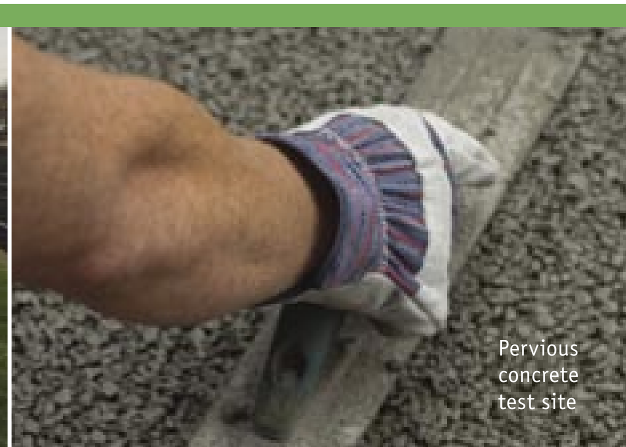
Looking Ahead

Next year's data report will include information on bacteria in stormwater treatment systems, a detailed analysis of sediment evaluation methods, and a look at how pervious pavements—asphalt and concrete—can reduce the need to apply salt for de-icing. It also will include the first year of data on five new storm-water treatments installed in fall 2006: the UpFlo Filter and Downstream Defender from Hydro International; the StormTech Isolator Row; a swale filter berm designed by Maine Department of Transportation, and a non-proprietary deep sump catch basin.

Workshop at UNHSC field site

In cold climates, LIDs outperform conventional systems.

Stormwater support for the "greenest" soccer field in Maine



Pervious concrete test site

UNHSC works with stormwater managers in the public and private sectors to advance the use of innovative stormwater approaches to protect water sources.

Stormwater support for Interstate 93

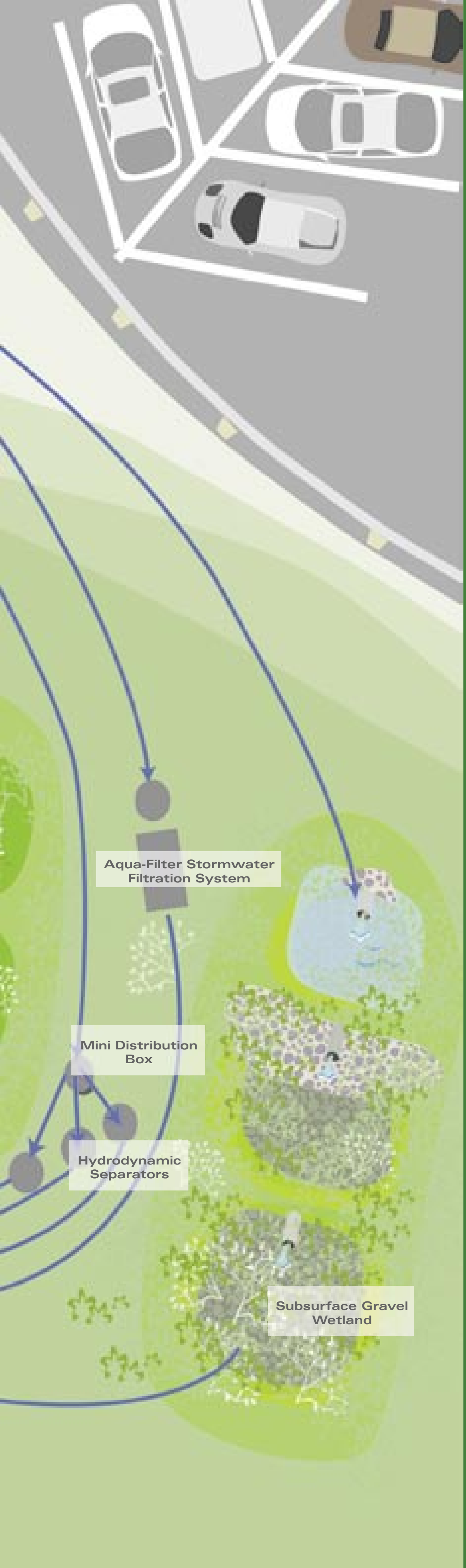
About the Field Site

The University of New Hampshire Stormwater Center's (UNHSC) field site sits adjacent to a nine-acre commuter parking lot in Durham, New Hampshire. The contributing drainage area—curbed and almost completely impervious—generates stormwater runoff typical of developed urban and suburban subcatchments. For nine months of the year, the parking lot is used near capacity by a combination of passenger vehicles and bus traffic. The pavement is frequently plowed, salted, and sanded during the winter.

The field site contains three classes of stormwater treatment systems: conventional, structural Best Management Practices (BMPs) such as swales and retention ponds; Low Impact Development (LID) stormwater designs such as tree filters, bioretention systems, and a gravel wetland; and manufactured BMPs such as hydrodynamic separators and subsurface infiltration/filtration systems.

The site is designed to test a range of stormwater treatment systems under the same conditions. The parallel but separate configuration of the systems installed at the site normalizes the variability typical in stormwater contaminant loading and regional rainfall characteristics. Each treatment is uniformly sized to address a Water Quality Volume (WQ_V) of one inch of rainfall from one acre of impervious surface.

The lot's contaminant concentrations are above, or equal to, national norms for commercial parking lot runoff. Local climate is coastal, cool temperate forest. Average annual precipitation is 48 inches, with monthly averages of 4.1 (+/-0.5) inches. The mean annual temperature is 48°F, with an average of 15.8°F in January, and an average of 82°F in July. Depth of design for frost depth is 48 inches.

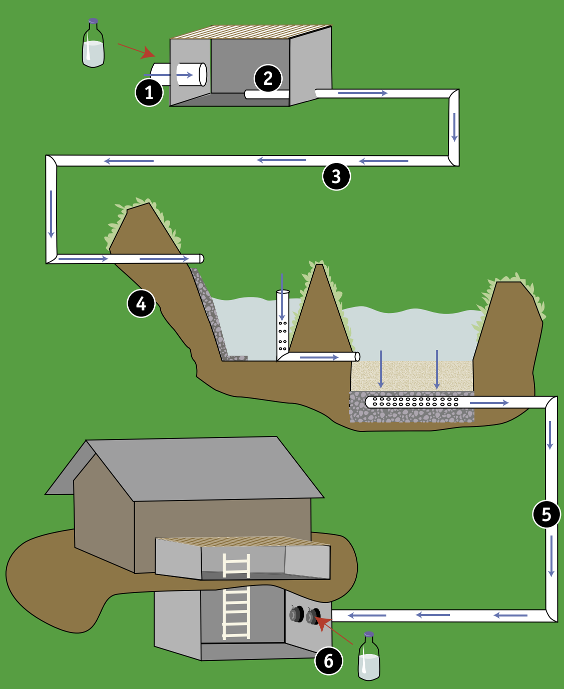


How We Evaluate Performance

A detailed quality assurance project protocol governs all UNHSC's methods, procedures, maintenance, and analyses related to the evaluation of stormwater treatment systems. All systems have an impermeable liner so that researchers can provide a strict accounting of the stormwater runoff flowing through the systems, as well as the contaminants it contains.

Here's How Our Performance Evaluation Process Works:

1. Stormwater runoff from the nine-acre parking lot is channeled into a 36-inch pipe where influent (runoff) is monitored in real time for the following characteristics: flow, pH, conductivity, dissolved oxygen, temperature, and turbidity. At the same time, automated samplers collect samples of influent at discrete time intervals over the course of the rainfall's hydrograph. These samples are processed and evaluated for a range of contaminants, or frozen for future evaluation.
2. Stormwater then flows into a distribution box with a floor that rests slightly higher than the outlet invert elevations, which direct runoff to each of the stormwater treatments. This configuration insures that runoff will scour the floor of the box, thereby preventing the accumulation of sediment. Baffles and flow splitters help to equally and evenly distribute stormwater among treatments.
3. From the distribution box, runoff influent flows into a network of pipes and is distributed into each stormwater treatment.
4. Runoff influent moves through the stormwater treatments.
5. Runoff leaving the treatments (effluent) is conveyed by perforated subdrains into a sampling gallery.
6. In the sampling gallery, the effluent is monitored in real time for the following characteristics: flow, pH, conductivity, dissolved oxygen, temperature, and turbidity. Also in the gallery, automated samplers collect samples of runoff at discrete time intervals over the rainfall hydrograph. These samples are evaluated for the same range of contaminants to generate performance characterizations.



LID & Infiltration

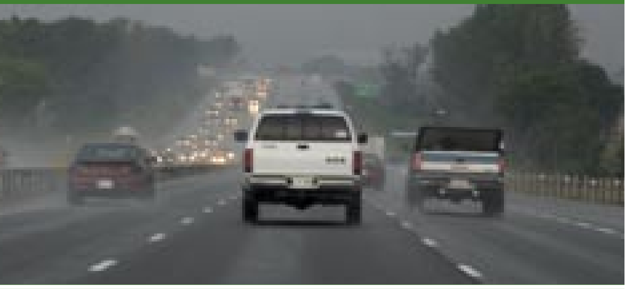
Low impact development (LID) stormwater designs and systems that rely on infiltration have much in common, but are not synonymous.

LID stormwater approaches should be used widely to protect the health of a watershed. Stormwater management systems that employ infiltration can be part of an LID approach; however, their use should be restricted in areas where they may threaten groundwater. LID designs may be used in these areas, but the systems may require linings to protect groundwater quality.

Stormwater Treatment System Comparison

The table on the opposing page compares data on the water quality treatment and runoff volume reduction performance of stormwater treatment systems analyzed at the University of New Hampshire Stormwater Center (UNHSC) to date. Systems are classified by category: low impact development (LID) systems, manufactured devices, and conventional structural approaches. Data is derived from UNHSC and a variety of sources, including the U.S. Environmental Protection Agency, manufacturers, and academic field studies.

Water quality treatment performance is assessed by pollutant; percent reduction is recorded in median values. Volume reduction is represented by percent average peak flow reduction and average lag time in minutes. (For more on these performance standards, see pages 8–9.) "NT" signifies "no treatment," indicating that the stormwater treatment did not remove the pollutant in question. "NA" indicates the system was "not analyzed" for a contaminant's removal or runoff volume reduction in a particular study. Light brown bars represent UNHSC data; white bars represent data from other sources.



Stormwater Treatment System	Reference	Total Suspended Solids (% Removal)	Total Phosphorus (% Removal)	Dissolved Inorganic Nitrogen (% Removal)	Total Zinc (% Removal)	Total Petroleum Hydrocarbons in the Diesel Range (% Removal)	Average Peak Flow (% Removal)	Average Lag Time (Minutes)
Low Impact Development Systems								
Bioretention Systems								
Bio I with 48" BSM	UNH Stormwater Center	97	NA	44	99	99	85	615
Bio II with 30" BSM	UNH Stormwater Center	99	5	29	99	58	82	92
	USEPA Fact Sheet: Bioretention	90	70-83	NA	NA	NA	NA	NA
Bioretention with 12" BSM	Winogradoff, 2001	NA	NT	NT	87	NA	NA	NA
Bioretention with 24" BSM	Winogradoff, 2001	NA	73	NT	98	NA	NA	NA
Bioretention with 36" BSM	Winogradoff, 2001	NA	81	23	99	NA	NA	NA
Gravel Wetlands (submerged, horizontal flow systems)	UNH Stormwater Center	99	55	99	99	99	81	315
	Claytor & Schueler, 1996	80-93	80-89	75	55-90	NA	NA	NA
	Winer, R., 2000	83	64	81	55	NA	NA	NA
Porous Pavement	UNH Stormwater Center	99	38	NT	96	99	68	790
	NAPA, undated	89-95	65-71	NA	62-99	NA	NA	NA
	USEPA Fact Sheet: Porous Pavement	82-95	65	NA	NA	NA	NA	NA
	Winer, R., 2000	95	64	NA	99	NA	NA	NA
Surface Sand Filter	UNH Stormwater Center	51	33	NT	77	98	59	204
	USEPA Fact Sheet: Sand Filters	70	33	NT	45	NA	NA	NA
	Claytor & Schueler, 1996	85	50	NA	71	NA	NA	NA
	Bell, W., et al, 1995	61-70	NA	NA	>82	NA	NA	NA
	Winer, R., 2000	87	59	NT	80	NA	NA	NA
Tree Box Filter	UNH Stormwater Center	96	NT	37	96	88	NT	19
Manufactured Systems								
ADS Water Quality Unit & Infiltration System	UNH Stormwater Center	99	81	NT	99	99	83	294
	EPA Fact Sheet: Infiltration Trenches	NA	60	NA	NA	NA	NA	NA
Aqua-Filter Stormwater Filtration System	UNH Stormwater Center	**62**	**26**	**NT**	**52**	**59**	**NT**	**NT**
	USEPA website	84	NA	NA	NA	NA	NA	NA
Hydrodynamic Separators	UNH Stormwater Center	**27**	**1**	**NT**	**24**	**42**	**NT**	**NT**
	Low values from Bannerman, R. 2005; high values from laboratory-based testing from vendor*	15-84	NA	NA	NA	NA	NA	NA
	Claytor & Schueler, 1996	80-93	80-89	75	55-90	NA	NA	NA
	Winer, R., 2000	83	64	81	55	NA	NA	NA
Conventional Structural Systems								
Retention Pond	UNH Stormwater Center	**72**	**16**	**54**	**93**	**83**	**81**	**424**
	USEPA Fact Sheet: Wet Detention Ponds	50-90	30-90	NA	40-50	NA	NA	NA
	USEPA Fact Sheet: Wet Detention Ponds	80-90	NA	NA	NA	NA	NA	NA
	Winer, R., 2000	79	49	36	65	NA	NA	NA
Swale								
Stone Swale	UNH Stormwater Center	50	NA	NT	66	33	NT	NT
Vegetated Swale	UNH Stormwater Center	60	NT	NT	88	67	48	19
	USEPA Fact Sheet: Vegetated Swales	81	9	38	71	NA	NA	NA
	Claytor & Schueler, 1996	30-90	10-65	0-80	71	NA	NA	NA

*** Disparities between data generated in the laboratory and that derived from field studies are common.**

Reading this Report

Between September 2004 and August 2006, researchers have evaluated 16 stormwater treatment systems for their ability to improve runoff water quality and reduce runoff quantity over 30 rainfall-runoff events with a range of seasonal and storm characteristics. A summary of our analysis for these systems is presented starting on page 10 of this report.

In response to requests from the stormwater management community we also have provided basic information on how these systems work, their design, cost of installation, implementation and maintenance considerations, and where to go for more information.

As you review this information, please keep in mind that no single stormwater treatment is appropriate for all situations. Many factors must be accounted for when designing an effective stormwater management program. For this reason, treatment trains (multiple systems in series) may be the system of choice. This information was synthesized to support better decision-making—not to prefer one system as a silver bullet for all problems.

System Performance Data Key: This key was created to help you navigate the information about stormwater treatment systems, presented on pages 10–29.

About this System

1. Where to Use It

This section looks at the land use setting in which the system can be deployed and the type of application to which it is best suited.

2. Implementation

This section summarizes acceptance of the system, and includes some information on installation cost and maintenance. For the majority of the systems evaluated in this report, installation costs were incurred in 2004. Fluctuation in commodity and labor costs can significantly impact the expense of purchasing and installing these systems.

System Performance

3. Water Quality Treatment

Data in these charts are presented as annual median event mean concentration values and median removal efficiencies. This section presents data on the stormwater treatment's ability to reduce or remove contaminants from stormwater. The top chart represents collective water quality treatment data for two years, broken out according to season. "Summer" refers to the six-month period between May and October and "winter" refers to the six-month period between November and April for each monitoring year.

UNHSC researchers monitor specific contaminants in runoff—before it enters and after it leaves stormwater treatments—for the following contaminants:

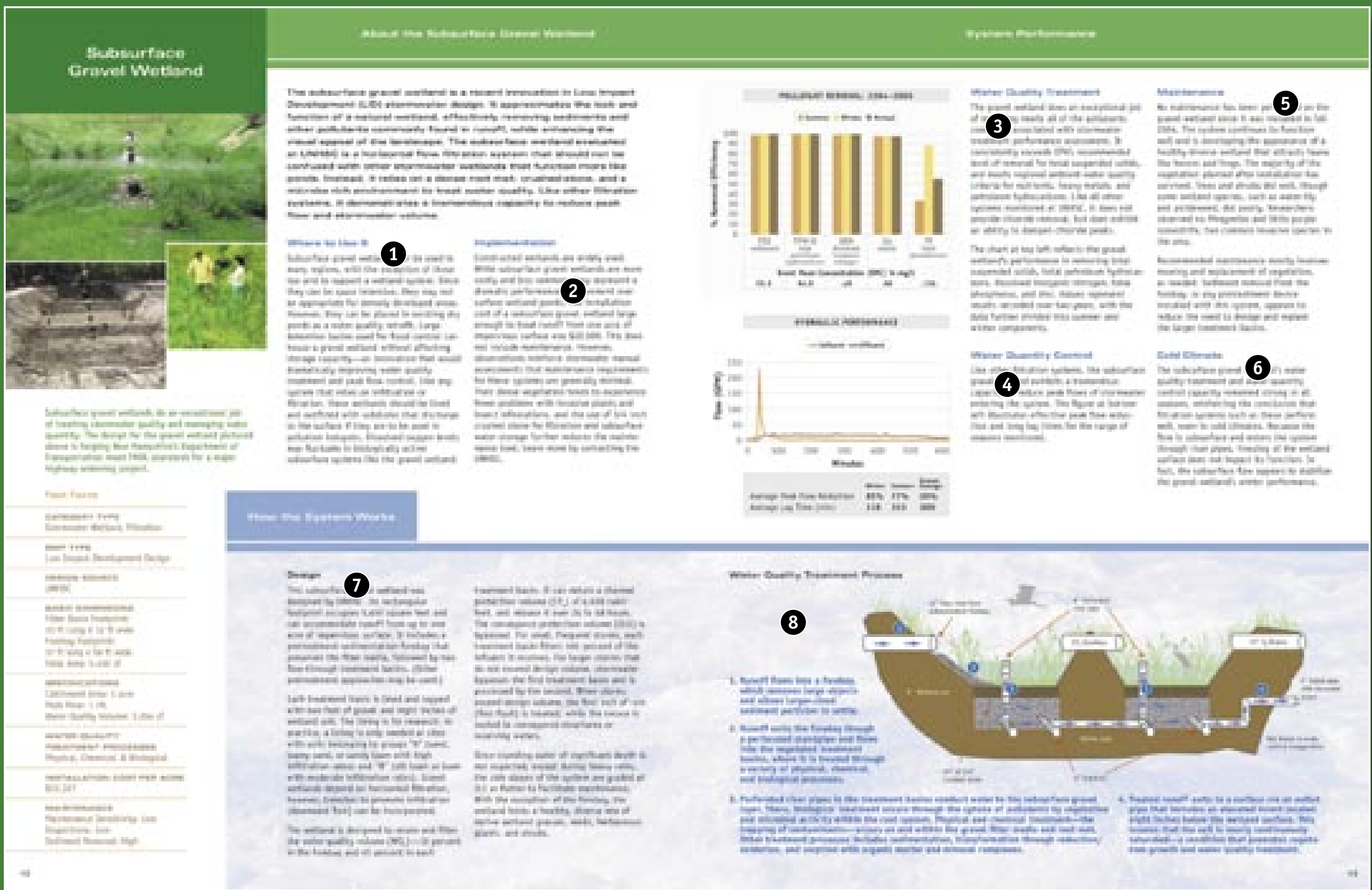
- Total suspended solids (TSS): While there is great debate over the current methods of sampling and analyzing sediments in stormwater, TSS remains the dominant yardstick of comparison for water quality performance of stormwater treatment systems nationwide.
- Total petroleum hydrocarbons in the semi-volatile (diesel) range (TPH-D): This is the only range of hydrocarbons where the concentrations in the stormwater runoff measured at UNHSC are always well above the detection limits. Petroleum hydrocarbons are often included in regional ambient water quality criteria.
- Dissolved inorganic nitrogen (DIN): DIN includes nitrate, nitrite, and ammonia. Excessive amounts of these compounds in coastal and estuarine waters can result in harmful algal blooms and oxygen poor conditions. Nutrients like nitrogen are often included in regional ambient water quality criteria.
- Total phosphorus (TP): Excessive amounts of TP in freshwater systems can result in harmful algal blooms and oxygen poor conditions. Nutrients like phosphorus are often included in regional ambient water quality criteria.
- Total zinc (Zn): Runoff can contain a range of toxic metals from a variety of sources. Zn is the metal of highest concentration for this study area. The primary sources of Zn pollution are tire wear and galvanized metal (guard rails). Heavy metals like Zn are often included in regional ambient water quality criteria.

4. Water Quantity Control

This section presents data on the ability of each stormwater treatment system to reduce the flooding characteristics of runoff associated with a specific rain event. This ability is represented by measures of peak flow reduction and lag time.

"Peak flow" is the maximum rate of runoff for each rain event. The bottom graph shows the change in peak flow of runoff coming into the system (influent) and leaving the system (effluent). This observed data is then used to calculate the system's average reduction of peak flow over time. Many communities have stormwater ordinances that require peak flow rates be reduced to a specified level.

Simply put, "lag time" is a measure of how long runoff remains within the system. Longer lag times mean that the system is reducing the "flashiness" (extreme changes in flow rate) of the runoff. This generally means that the runoff has more time to infiltrate into native soils, thus reducing total runoff and increasing the effectiveness of water quality treatment. Because the systems are all lined for research purposes, volume reduction is not considered.



5. Maintenance

UNHSC does not perform significant maintenance on the treatment systems at the field site as a matter of experimental design. Since these systems are often maintained minimally in practice, we want to be able to observe and chronicle if lack of maintenance contributes to a system's failure.

Our minimal maintenance activities include mowing slopes, vegetating bare spots, and removing trash. Our decision to perform minimal maintenance is related to the need to keep the systems working well enough to evaluate their performance. Based on our observations and the recommendations of stormwater manuals, we offer some—though not extensive—information on maintenance burden in this section.

6. Cold Climate

The performance of certain stormwater treatment system in cold climates has been the subject of much debate in the stormwater management community. This section contains observations about performance of different systems during the winters of a cold climate region.

How the System Works

7. Design

This section includes information on the treatment's basic design, as well as specific variations or improvements employed by UNHSC at the field site. Generally, this description includes water quality volume (WQ_V), or the volume of runoff produced by one inch of rainfall; channel protection volume (CP_V), or the two-year (Q2), 24-hour rain event based on an acre of impervious surface; and conveyance protection volume (Q10), or the ten-year, 24-hour storm (Q_P).

8. Water Quality Treatment Process

This section describes the system's basic mechanisms for water quality treatment. All systems evaluated at the UNHSC field site have an impermeable liner so that researchers can provide a strict accounting of the stormwater runoff flowing through the systems, as well as the contaminants it contains. The diagrams in this section reflect how these systems would manage stormwater runoff in practice, and therefore do not depict a system lining.

Porous Asphalt

Porous asphalt systems are an extremely effective approach to stormwater management. Unlike retention ponds, they do not require large amounts of additional space. Instead, rainfall drains through pavement and directly infiltrates the subsurface. This significantly reduces runoff volume, decreases its temperature, improves water quality, and essentially eliminates impervious surface. It also speeds snow and ice melt, dramatically reducing the salt required for winter maintenance. The porous asphalt design tested at UNHSC is distinctive in its use of coarse sand for a reservoir base and filter course—a refinement that enhances its effectiveness in treating water quality.

The use of porous asphalt pavement could drastically reduce the need for road salt in winter conditions. Since the application of salt can be problematic for small receiving streams and is not treated by most stormwater systems, such source reduction is crucial.

Where to Use It

The effectiveness of porous asphalt has been demonstrated over a wide range of climates, including those with winter freezing. It may be especially effective in cold climates given its durability and capacity to reduce the salt needed for deicing in winter conditions.

As with most LID stormwater practices, porous asphalt is suitable for many sites. Typically, it is recommended for parking lots and low use roadways, and is ideal for proposed developments with large areas of impervious surface. As with any infiltration system, care must be taken when locating these systems near pollution hotspots, or where seasonal high groundwater levels may lead to groundwater contamination. In such cases, the system can be lined and outfitted with a subdrain that discharges to the surface.

Implementation

Improvements in mix design, requirements for infiltration, and the need to comply with the Clean Water Act Phase II have combined to make porous asphalt a reasonable stormwater management alternative. Clogging, poor mix specifications, structural failure, and other historical barriers to implementation have been addressed. Successful implementation of these systems relies on proper mix production, construction, and installation—all of which can be achieved with qualified suppliers and engineering oversight.

The materials and installation cost of UNHSC's porous asphalt lot was approximately $2,300 per parking space; the adjacent impervious asphalt lot was $2,000 per space. The net cost for both lots would be comparable if the impervious lot's stormwater infrastructure were taken into consideration. This porous lot has proven durable year round, and has not been maintained to demonstrate a worse case scenario. Design specifications are online: www.unh.edu/erg/cstev

Fast Facts

CATEGORY TYPE
Pervious Pavement, Infiltration

BMP TYPE
Low Impact Development Design

DESIGN SOURCE
UNHSC

BASIC DIMENSIONS
Surface Area: 5,200 sf

SPECIFICATIONS
Catchment Area: 5,500 sf
Water Quality Volume: 435 cf

WATER QUALITY TREATMENT PROCESSES
Physical & Chemical

INSTALLATION COST PER ACRE
$2,300 Per Parking Space

MAINTENANCE
Maintenance Sensitivity: Low
Inspections: Low
Sediment Removal: High

How the System Works

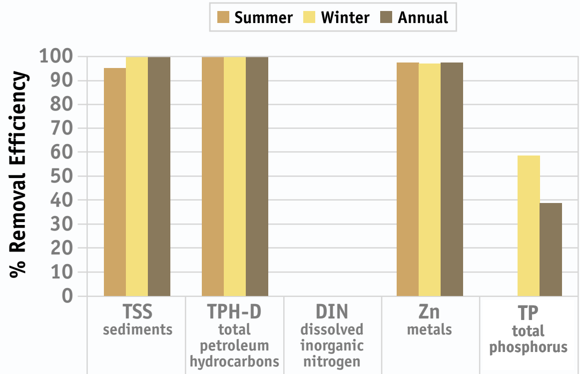
Design

Installed in 2004, the porous asphalt lot was designed with a subsurface storage capacity similar to a retention pond. An impervious asphalt lot of the same size was installed next to it for comparison. While the impervious lot requires catchbasins and piping, the porous lot stores runoff in a reservoir base and infiltration basin. Water quality volume (WQ_V), channel protection volume (CP_V), and higher flows, such as those associated with a ten-year event (QP), are managed in the system and by subdrains. A gravel edge with curbing that surrounds the porous lot prevents sediments from washing onto the surface and prematurely clogging the system. Its design consists of four basic layers:

- The top is a four-inch layer of porous asphalt. Sand particles smaller than two millimeters were removed from the mix to create pavement with an 18 to 20 percent void space.
- The second layer is a four-inch choker course consisting of 3/4 inch crushed stone, which allows runoff to pass into the next layer and offers structural support.
- The third layer consists of 24 inches of poorly graded sand, or "bank run gravel," which serves as a filter course.
- The fourth layer is 21 inches of crushed stone, with a six-inch diameter, elevated subdrain. This layer serves as an infiltration reservoir; its thickness protects against freezing and thawing, and makes it possible to locate this system in group "C" soils (sandy clay loam with low infiltration rates).

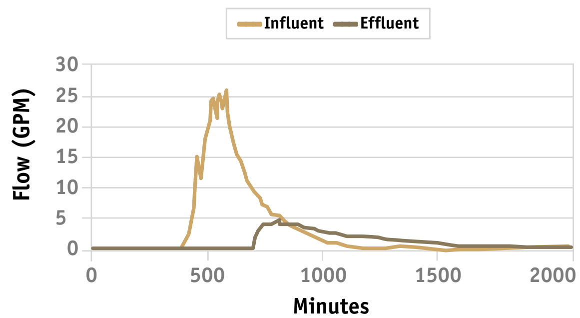
The system is lined on the bottom and sides with a non-woven geotextile fabric to prevent influx of fines. However, bottom lining is no longer recommended because it can lead to premature clogging. It is believed that stormwater fines are more problematic than those migrating in from surrounding soils.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	75%	61%	68%
Average Lag Time (minutes)	665	915	790

Water Quality Treatment

The water quality treatment performance of the porous asphalt lot generally has been excellent. It consistently exceeds EPA's recommended level of removal of total suspended solids, and meets regional ambient water quality criteria for petroleum hydrocarbons and zinc. Researchers observed limited phosphorus treatment and none for nitrogen, which is consistent with other non-vegetated infiltration systems. The system did not remove chloride. However, since it drastically reduced the salt needed for winter maintenance, it may prove effective at reducing chloride pollution. The chart at top left reflects the system's performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and total zinc. Values represent results recorded over a total of two years, with the data further divided into summer and winter components.

Water Quantity Control

The porous asphalt system's ability to manage runoff was exceptional. It has outperformed all systems tested at UNHSC. No surface runoff has been observed from this lot since its installation in 2004; this includes the 100-year storm events that New Hampshire experienced in 2006 and 2007. Groundwater recharge has been achieved despite the system's location over clay soils. The figure at bottom left illustrates effective peak flow reduction and long lag times for the range of seasons monitored.

Maintenance

Researchers performed no maintenance on this parking lot since it was installed in 2004. (Typical, annual maintenance calls for vacuuming two to four times.) After two winters, the pavement's condition remains good, with no frost heaving or rutting. It does have scars from plowing, but these do not impact the asphalt structurally. Only moderate clogging has been observed. Once significant clogging occurs, researchers will vacuum the lot and assess the system's ability to regenerate infiltration capacity.

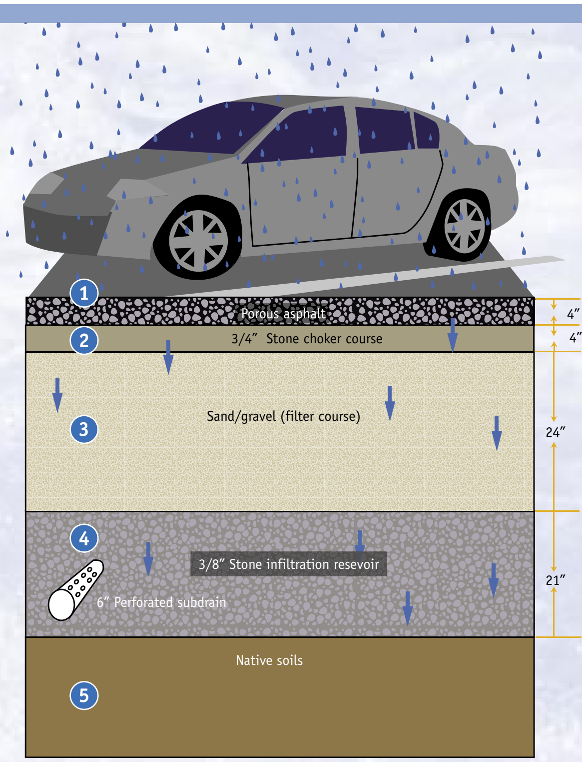
Cold Climate

This system's performance remained steady year round. Some of the highest infiltration rates were in the winter—on average more than 1,000 inches an hour. While researchers observed conditions conducive to frost penetration in the filter media, the pores remain open and drained year round. As a result, freezing and thawing did not limit infiltration. This ability to maintain drainage minimizes freeze thaw, which contributes to the porous asphalt's durability. In practice, the lifespan of these lots can exceed impervious asphalt lots, which tend to lose structural integrity in northern climates due to frost heaving.

A substantial benefit of porous asphalt is the reduced need for sodium chloride for deicing in winter. Researchers observed that winter maintenance of porous asphalt requires between zero and 25 percent of the salt routinely applied to impervious asphalt to achieve equivalent, or better, deicing and traction.

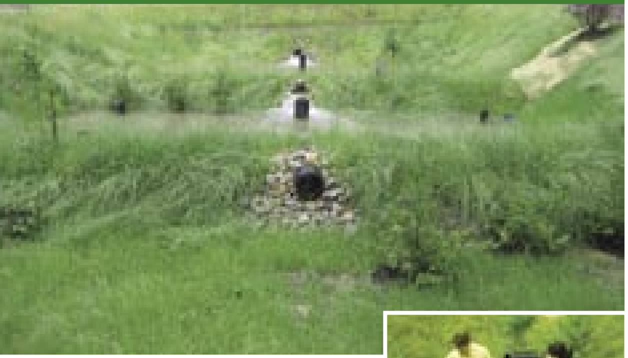
Water Quality Treatment Process

1. Rain drains through the porous asphalt and the choker course and into the sand filter course.
2. In the filter course, the physical process of filtration removes fine particulates from the solution, and the chemical process of sorption binds contaminants like heavy metals, petroleum hydrocarbons, and phosphorus to the sand surfaces. It is likely that some microbial activity also degrades petroleum hydrocarbons and nutrients.
3. Water passes into the infiltration reservoir of uniformly graded crushed stone, where infiltration into sandy clay loam soils can occur.
4. Treated water that flows below the elevated subdrain infiltrates into the subgrade, where it can recharge the groundwater supply.



5. When a storm's rainfall exceeds system design, water flows through the elevated subdrain to the surface. If the system is completely drained from a previous storm, it can store a four-inch rain event in its infiltration basin. The void spaces contained within the entire subbase provide sufficient storage for a 15-inch rain event. This design reflects the researchers' need to install in poor soils and high groundwater. UNHSC recommends other design criteria for other settings.

Subsurface Gravel Wetland



Subsurface gravel wetlands do an exceptional job of treating stormwater quality and managing water quantity. The design for the gravel wetland pictured above is helping New Hampshire's Department of Transportation meet TMDL standards for a major highway widening project.

About the Subsurface Gravel Wetland

The subsurface gravel wetland is a recent innovation in Low Impact Development (LID) stormwater design. It approximates the look and function of a natural wetland, effectively removing sediments and other pollutants commonly found in runoff, while enhancing the visual appeal of the landscape. The subsurface wetland evaluated at UNHSC is a horizontal-flow filtration system that should not be confused with other stormwater wetlands that function more like ponds. Instead, it relies on a dense root mat, crushed stone, and a microbe rich environment to treat water quality. Like other filtration systems, it demonstrates a tremendous capacity to reduce peak flow and improve water quality.

Where to Use It

Subsurface gravel wetlands can be used in many regions, with the exception of those too arid to support a wetland system. Since they can be space intensive, they may not be appropriate for densely developed areas. However, they can be placed in existing dry ponds as a water quality retrofit. Large detention basins used for flood control can house a gravel wetland without affecting storage capacity—an innovation that would dramatically improve water quality treatment and peak flow control. Like any system that relies on infiltration or filtration, these wetlands should be lined and outfitted with subdrains that discharge to the surface if they are to be used in pollution hotspots. Dissolved oxygen levels may fluctuate in biologically active subsurface systems like the gravel wetland.

Implementation

Constructed wetlands are widely used. While subsurface gravel wetlands are more costly and less common, they represent a dramatic performance improvement over surface wetland ponds. They have been used for some time in wastewater treatment. The installation cost of a subsurface gravel wetland large enough to treat runoff from one acre of impervious surface was $22,500. This does not include maintenance. Maintenance requirements for these systems are generally minimal. Their dense vegetation tends to experience fewer problems with invasive plants and insect infestations, and the use of 3/4 inch crushed stone for filtration and subsurface water storage further reduces the maintenance load. Learn more by contacting the UNHSC.

Fast Facts

CATEGORY TYPE
Stormwater Wetland, Filtration

BMP TYPE
Low Impact Development Design

DESIGN SOURCE
UNHSC

BASIC DIMENSIONS
Filter Basin Footprint:
15 ft long X 32 ft wide
Forebay Footprint:
37 ft long X 56 ft wide
Total Area: 5,450 sf

SPECIFICATIONS
Catchment Area: 1 acre
Peak Flow: 1 cfs
Water Quality Volume: 3,300 cf

WATER QUALITY TREATMENT PROCESSES
Physical, Chemical, & Biological

INSTALLATION COST PER ACRE
$22,500

MAINTENANCE
Maintenance Sensitivity: Low
Inspections: Low
Sediment Removal: High

How the System Works

Design

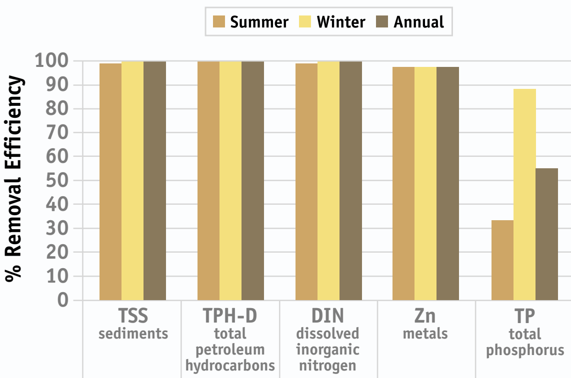
This subsurface gravel wetland was designed by UNHSC. Its rectangular footprint occupies 5,450 square feet and can accommodate runoff from up to one acre of impervious surface. It includes a pretreatment sedimentation forebay that preserves the filter media, followed by two flow-through treatment basins. (Other pretreatment approaches may be used.)

Each treatment basin is lined and topped with two feet of gravel and eight inches of wetland soil. The lining is for research; in practice, a lining is only needed at sites with soils belonging to groups "A" (sand, loamy sand, or sandy loam with high infiltration rates) and "B" (silt loam or loam with moderate infiltration rates). Gravel wetlands depend on horizontal filtration; however, trenches to promote infiltration (downward flow) can be incorporated at the end of the system.

The wetland is designed to retain and filter the water quality volume (WQ_v)—10 percent in the forebay and 45 percent in each treatment basin. It can detain a channel protection volume (CP_v) of 4,600 cubic feet, and release it over 24 to 48 hours. The conveyance protection volume (Q10) is bypassed. For small, frequent storms, each treatment basin filters 100 percent of the influent it receives. For larger storms that do not exceed design volume, stormwater bypasses the first treatment basin and is processed by the second. When storms exceed design volume, the first inch of rain (first flush) is treated, while the excess is routed to conveyance structures or receiving waters.

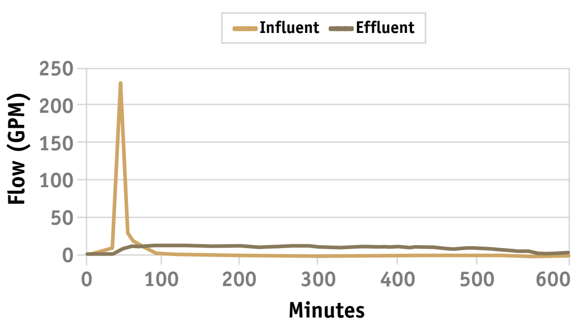
Since standing water of significant depth is not expected, except during heavy rains, the side slopes of the system are graded at 3:1 or flatter to facilitate maintenance. With the exception of the forebay, the wetland hosts a healthy, diverse mix of native wetland grasses, reeds, herbaceous plants, and shrubs.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	85%	77%	81%
Average Lag Time (minutes)	318	313	315

Water Quality Treatment

The gravel wetland does an exceptional job of removing nearly all of the pollutants commonly associated with stormwater treatment performance assessment. It consistently exceeds EPA's recommended level of removal for total suspended solids, and meets regional ambient water quality criteria for nutrients, heavy metals, and petroleum hydrocarbons. Like all other systems monitored at UNHSC, it does not provide chloride removal, but does exhibit an ability to dampen chloride peaks.

The chart at top left reflects the gravel wetland's performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over two years, with the data further divided into summer and winter components.

Water Quantity Control

Like other filtration systems, the subsurface gravel wetland exhibits a tremendous capacity to reduce peak flows of stormwater entering the system. The figure at bottom left illustrates effective peak flow reduction and long lag times for the range of seasons monitored.

Maintenance

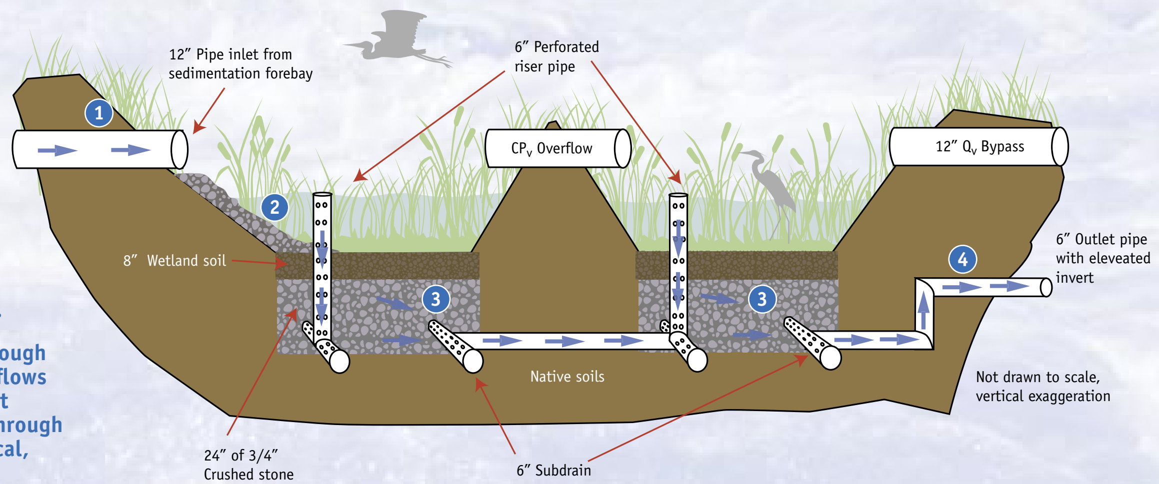
No maintenance has been performed on the gravel wetland since it was installed in fall 2004. The system continues to function well and is developing the appearance of a healthy diverse wetland. The majority of the vegetation planted after installation has survived. Trees and shrubs did well, though some wetland species, such as water lily and pickleweed, did poorly. Researchers observed no *Phragmites* and little purple loosestrife, two common invasive species in the area.

Recommended maintenance mostly involves mowing and replacement of vegetation, as needed. Sediment removal from the forebay, or any pretreatment device installed with this system will reduce maintenance on the treatment basins.

Cold Climate

The subsurface gravel wetland's water quality treatment and water quantity control capacity remained strong in all seasons, reinforcing the conclusion that filtration systems such as these perform well, even in cold climates. Because the flow is subsurface and enters the system through riser pipes, freezing of the wetland surface does not impact its function. In fact, the subsurface flow results in almost no change to seasonal performance.

Water Quality Treatment Process



1. **Runoff flows into a forebay, which removes large objects and allows larger-sized sediment particles to settle.**
2. **Runoff exits the forebay through a perforated standpipe and flows into the vegetated treatment basins, where it is treated through a variety of physical, chemical, and biological processes.**
3. **Perforated riser pipes in the treatment basins conduct water to the subsurface gravel layer. There, biological treatment occurs through the uptake of pollutants by vegetation and microbial activity within the root system. Physical and chemical treatment—the trapping of contaminants—occurs on and within the gravel filter media and root mat. Other treatment processes include sedimentation, transformation through reduction/oxidation, and sorption with organic matter and mineral complexes.**
4. **Treated runoff exits to the surface via an outlet pipe that includes an elevated invert located eight inches below the wetland surface. This insures that the soil is nearly continuously saturated—a condition that promotes vegetation growth and water quality treatment.**

Bioretention System (Bio II)

BIO II is the second bioretention system installed at UNHSC and reflects the best 2005 design standard. Its design virtually eliminates clays from the bioretention soil mix and eliminates geotextile lining. It has demonstrated strong water quality treatment and water quantity management performance in all seasons.

About the Bioretention System (Bio II)

Bioretention systems are among the most common Low Impact Development (LID) stormwater approaches. Runoff flows into landscaped depressions, where it ponds and infiltrates the soil. The engineered soil mix and vegetation provide water quality treatment and infiltration similar to undeveloped areas. UNHSC has evaluated two such systems. The first initially displayed strong performance and then experienced hydraulic failure after ten months due to design flaws. (See discussion in "Design" below.) In 2005, UNHSC installed Bio II, a smaller, more affordable system that addresses these flaws, and thus far, demonstrates better infiltration and strong water quality treatment.

Where to Use It

Bioretention systems can be used throughout the United States. To achieve maximum volume reduction, they must be located in soils that accommodate infiltration, such as those in groups "A" (sand, loamy sand, or sandy loam with high infiltration rates) and "B" (silt loam or loam with moderate infiltration rates). Careful site analysis is required to design an effective, integrated network of these systems that allows infiltration throughout a site. They are most effective as part of a well-distributed network of runoff control measures. They can also be used as an end-of-pipe system. As with any infiltration or filtration system, when used in pollution hotspots or poor soils, they should be lined and outfitted with subdrains that discharge to the surface.

Implementation

The acceptance of bioretention systems varies regionally. In areas such as Prince Georges County, Maryland—the birthplace of the bioretention system—regulations encourage their proliferation. In other areas, local acceptance may be hindered by lack of performance data, unfamiliarity with the design, and seasonal functionality. The hydraulic efficiency and concern over clogging has restricted their use in the past. However, improvements in the design specifications of the bioretention soil mix (BSM) and the elimination of fabric can address these concerns. The cost to install Bio II to treat runoff from a one-acre parking area was $18,000. This does not include maintenance expenditures, which may involve routine inspection and the periodic mowing of side slopes and replacement of vegetation, as needed.
For more information about Bio II, please consult the UNHSC.

Fast Facts

CATEGORY TYPE
Infiltration

BMP TYPE
Low Impact Development Design

DESIGN SOURCE
Low Impact Development Center

BASIC DIMENSIONS
Filtration Basin:
8 ft wide X 34 ft long X 25 ft deep
Forebay Area: 71 ft long X 46 ft wide
Total Area: 272 sf

SPECIFICATIONS
Catchment Area: 1 acre
Peak Flow: 1 cfs
Water Quality Volume: 3,300 cf

WATER QUALITY TREATMENT PROCESSES
Physical, Chemical, & Biological

INSTALLATION COST PER ACRE
$18,000

MAINTENANCE
Initial Maintenance Sensitivity: High
Long-term Maintenance Sensitivity: Low
Inspections: Moderate

How the System Works

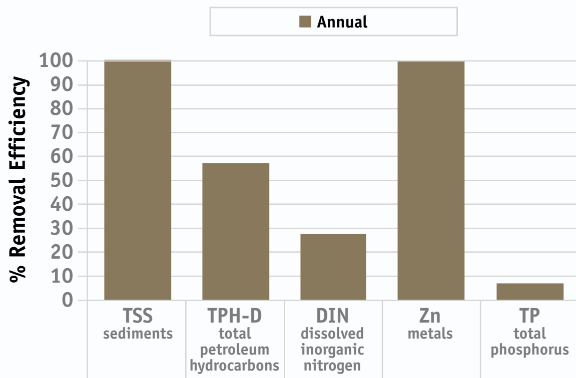
Design

Bio II is comprised of a sedimentation forebay and a bioretention filtration basin. The basin is filled with a bioretention soil mix (BSM) 30 inches in thickness, and consisting of 60 percent sand, 20 percent woodchips, ten percent compost, and 10 percent native soil. The filtration basin is well vegetated. Researchers selected vegetation for flood and drought tolerance, the capacity for maximum ground cover, and aesthetics.

The forebay holds 25 percent of the water quality volume (WQ_V), and drains through a standpipe into the bioretention basin, which holds 75 percent of the WQ_V. The basin allows eight inches of ponding, and the BSM permits an infiltration rate of eight feet per day. Overflow contingencies exist for channel protection volume (CP_V) and conveyance protection volume (Q10) events. Typically Q2 events are conveyed over 24 to 48 hours, and Q10 events bypass to the surface.

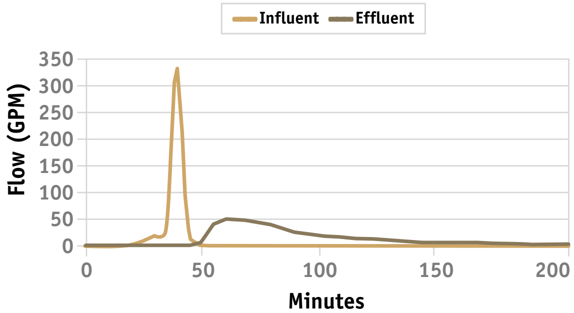
Bio II is the second bioretention system installed at UNHSC, and reflects the 2005 best design standard. The first, Bio I, had a BSM that was higher in clay and silt—as much as 7.5 percent of the total mix—and it used non-woven geotextile between the BSM and the crushed stone bedding. Both features were consistent with 2001 BMP manual specifications; however, Bio I experienced hydraulic failure in 2005. Analysis indicated the primary reason was clogging and infiltration loss. UNHSC then solicited design input—primarily from the Maryland Low Impact Development Center. The result is Bio II, which maintains a higher infiltration rate than Bio I, virtually eliminates silts and clays from the BSM, and eliminates the geotextile under the BSM. The BSM rests on a graded subbase, the bottom of which consists of crushed stone overlain with pea gravel, which graduates to coarse sand just below the BSM.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	NA	NA	82%
Average Lag Time (minutes)	NA	NA	92

Water Quality Treatment

Bio II has proven effective at removing nearly all of the pollutants commonly associated with stormwater treatment performance assessment. It consistently exceeded EPA's recommended level of removal for total suspended solids and meets regional ambient water quality criteria for petroleum hydrocarbons. However, it exhibits almost no discernable removal of total phosphorus. Like the other systems monitored at UNHSC, it does not provide chloride removal, although it does exhibit an ability to dampen chloride peaks.

The chart at top left reflects the bioretention performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results from a half-year monitoring period.

Water Quantity Control

Like other infiltration and filtration systems, Bio II has a tremendous capacity to reduce peak flows and runoff volume in appropriate soils, i.e., those belonging to groups A and B. In the figure at bottom left, it demonstrates effective peak flow reduction and large lag times regardless of season. Vegetation contributes to stormwater volume reduction through the process of evapotranspiration.

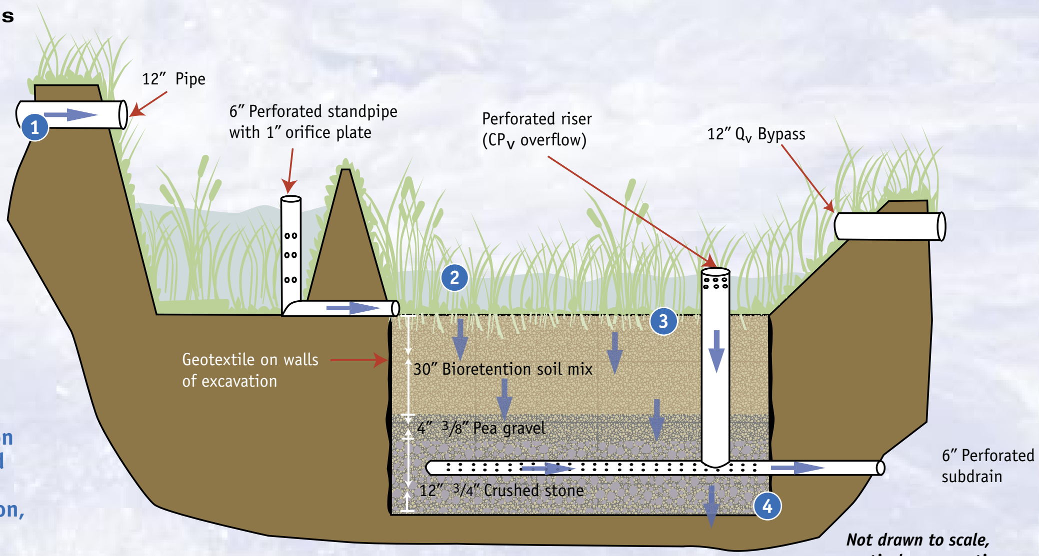
Maintenance

Bioretention systems are designed to minimize maintenance. For the most part, the highest maintenance burden coincides with the initial stabilization of the system over the first three to four months. However, once vegetation is established and the system has been stabilized, the maintenance decreases and becomes similar to that required for standard landscaping, such as seasonal mowing and raking. With the exception of the stabilization period, no maintenance has been performed on Bio II since it was installed in fall 2005, and the system continues to function well.

Cold Climate

Bio II's ability to treat water quality and control water quantity remained relatively consistent in all seasons. UNHSC researchers have observed that most LID stormwater systems, when properly designed and installed, are not negatively impacted by cold climate. In fact, these systems showed less seasonal variation than many conventional approaches that depend on sedimentation as primary removal mechanism. While some seasonal variation did occur in Bio II, significant design alterations do not appear to be necessary for cold weather applications of this system.

Water Quality Treatment Process



Not drawn to scale, vertical exaggeration

1. **Runoff flows into a sedimentation forebay or other pretreatment chamber. From there, it is slowly released into the filter basin through a perforated standpipe. When forebay capacity is reached, the overflow spills across a weir into the bioretention basin.**
2. **Biological treatment occurs through the uptake of pollutants by vegetation and soil microorganisms. Physical and chemical treatment (occurring within the soil media) includes sedimentation, filtration, and sorption with organic matter and mineral complexes.**
3. **Nutrients like nitrogen are taken up by the roots of the vegetation and metabolized by the system's plants, shrubs, and trees.**
4. **The treated runoff can be allowed to infiltrate the native soils, or collected in a perforated subdrain and returned to a storm drain system or discharged to the surface.**

Tree Box Filter

Unlike many other forms of urban landscaping, tree filters are not isolated behind curbs and deprived of water and nutrients from runoff. Instead, they receive runoff through breaks in the curbing, and demonstrate strong water quality treatment.

About the Tree Box Filter

Tree box filters are mini bioretention systems that combine the versatility of manufactured devices with the water quality treatment of vegetated systems. They serve as attractive landscaping and drainage catchbasins. Unlike many other forms of urban landscaping, they are not isolated behind curbs and deprived of water and nutrients in runoff. Their water quality treatment performance is high, often equivalent to other bioretention systems, particularly when well distributed throughout a site.

Where to Use It

Tree box filters can be used throughout the United States, and are especially useful in settings where available space is at a premium. They can be installed in open- or closed-bottomed chambers where infiltration is undesirable or not possible, such as clay soils, sites with high groundwater, and areas with highly contaminated runoff.

Tree box filters are often installed along urban sidewalks, but they are highly adaptable and can be used in most development scenarios. In urban areas, tree filters can be used in the design of an integrated street landscape—a choice that transforms isolated street trees into stormwater filtration devices. They also can be used in designs that seek to convert entire non-functional streetscapes into large stormwater or combined sewer flow filtration systems.

Implementation

These systems are a relatively recent innovation that is growing in usage, especially in urban areas. The cost to install a tree box filter to replace a catchbasin is $2,500. This does not include maintenance. UNHSC observations thus far reinforce stormwater manual assessments that maintenance requirements for these systems are generally minimal.

In general, tree box filters are sized and spaced much like catchbasin inlets, and design variations for these systems are abundant. The system evaluated at UNHSC was designed by center researchers. A similar patented design made by AmeriCast, the Filterra, is also available. Contact the UNHSC for more information about the design of the tree box filter.

Fast Facts

CATEGORY TYPE
Filtration, Infiltration,
Urban Retrofit

BMP TYPE
Low Impact Development Design

DESIGN SOURCE
UNHSC

BASIC DIMENSIONS
Diameter: 6 ft
Depth: 4 ft

SPECIFICATIONS
Catchment Area: 0.1 acre
Peak Flow: 0.1 cfs
Water Quality Volume: 425 cf
Tree: Two-inch Caliper Ash

WATER QUALITY TREATMENT PROCESS
Physical, Chemical, & Biological

INSTALLATION COST
$2,500 Per Unit
($22,000 Per Acre Treated)

MAINTENANCE
Maintenance Sensitivity: Low
Inspections: Medium
Sediment Removal: Low

How the System Works

Design

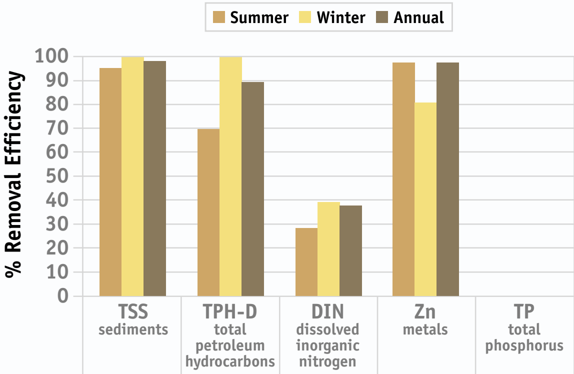
The tree box filter's basic design is a concrete vault filled with a bioretention soil mix (BSM), planted with vegetation, and underlain with a subdrain. The system evaluated at the UNHSC field site is a six-foot diameter, concrete vault with an internal bypass. It is underlain by a subdrain that discharges to existing stormwater drainage. The vault is open-bottomed to enhance infiltration.

The filter media is three feet deep, and composed of 80 percent sand and 20 percent compost. The mix was designed to maximize permeability while providing minimum organic content (at least 10 percent) to sustain vegetation.

Vegetation selected for these systems should consist of native, drought- and salt-tolerant species. Plants with aggressive root growth may clog the subdrain, and therefore may not be suitable for this type of system.

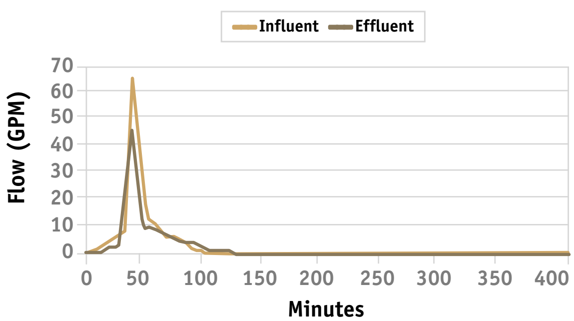
This tree box filter was sized for the water quality volume (WQ_v), and should allow for four to six inches of ponding. Larger storm events will be bypassed. The system's filter media accommodates a high infiltration rate of 120 feet per day.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	37%	0%	0%
Average Lag Time (minutes)	14	26	19

Water Quality Treatment

The tree box filter does a good job of removing many of the pollutants commonly associated with stormwater treatment performance assessment. It consistently exceeded EPA's recommended level of removal for total suspended solids and meets regional ambient water quality criteria for petroleum products, nitrogen, and total zinc. However, UNHSC research demonstrates that water quality treatment effectiveness can be negatively influenced by an increased hydraulic loading rate, i.e., the filtration of a large surface area by a small filter area. The system does not remove chloride, but does exhibit an ability to dampen chloride peaks.

The chart at top left reflects system performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over two years, with data further divided into summer and winter components.

Water Quantity Control

Unlike other filtration systems, the tree box filter does not reduce peak flows unless sited in appropriate soils, such as those in groups "A" (sand, loamy sand, or sandy loam with high infiltration rates) and "B" (silt loams or loams with moderate infiltration rates). In the figure at bottom left, the tree box filter displays no significant peak flow reduction or lag time for the range of seasons monitored.

Maintenance

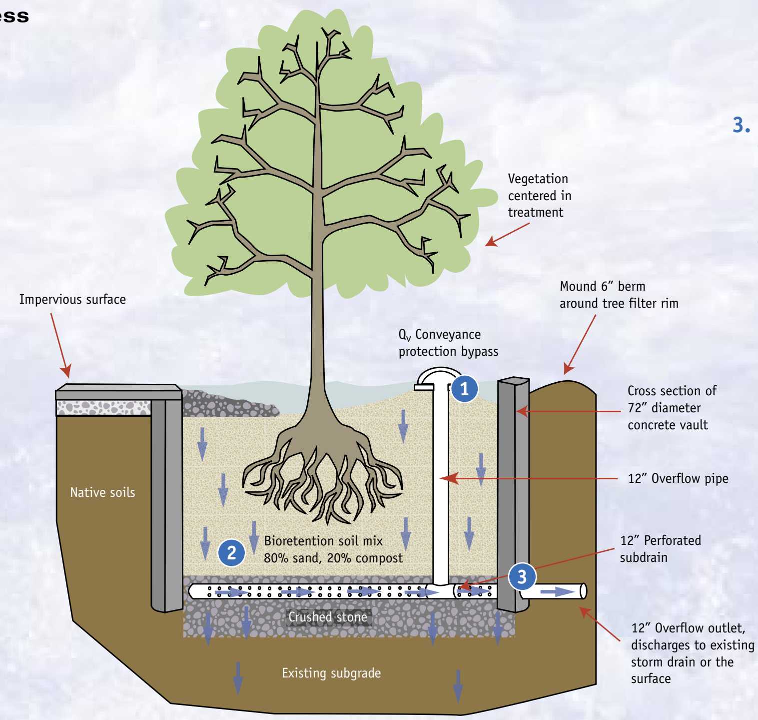
No maintenance has been performed on the tree box filter since it was installed in fall 2005, and the system continues to function well. Generally speaking, these systems are designed to minimize maintenance. Aside from routine trash removal, the highest maintenance burden generally coincides with the establishment of vegetation over the first several months after installation. Once vegetation is established, the maintenance demand decreases. The tree may need to be replaced, depending on hardiness of the selected species. Adaptations to design can prevent root constriction in the planting vault.

Cold Climate

The tree box filter's ability to treat water quality remained relatively stable in all seasons. This is consistent with UNHSC observations of most LID stormwater systems—when they are properly designed and installed, they are not dramatically impacted by seasonal fluctuations. While some seasonal variation in infiltration capacity and nitrogen removal does occur, cold conditions do not seem to warrant significant design alterations.

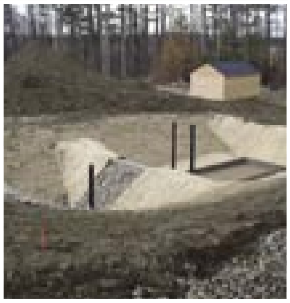
Water Quality Treatment Process

1. **Runoff flows into the tree filter basin from the street and passes into the filter media.**
2. **In the filter media, biological treatment occurs through the uptake of pollutants, such as nitrogen and petroleum hydrocarbons, by vegetation and soil microorganisms. Physical and chemical treatment also occurs within the soil media. Other treatment unit processes include sedimentation and sorption with organic matter and mineral complexes.**



3. **Filtered runoff is collected in a perforated subdrain and returned to a storm drain system, infiltrated into the subgrade, or discharged to the surface.**

Surface Sand Filter



The surface sand filter demonstrated a moderate capacity to reduce peak flow and treat water quality. Routinely used with great success for drinking water treatment, surface sand filters have not been as widely applied for stormwater management. Local acceptance may be hindered by lack of data.

Fast Facts

CATEGORY TYPE
Filtration

BMP TYPE
Low Impact Development Design

DESIGN SOURCE
New York State Stormwater Management Design Manual

BASIC DIMENSIONS
Filter Bed Footprint: 8 ft X 20 ft
Forebay Footprint: 31 ft X 41 ft

SPECIFICATIONS
Catchment Area: 1 acre
Peak Flow: 1 cfs
Water Quality Volume: 3,300 cf

TREATMENT FUNCTION
Physical & Chemical

INTALLATION COST TREATED
$12,500

MAINTENANCE
Maintenance Sensitivity: High
Inspections: High
Sediment Removal: High

About the Surface Sand Filter

Surface sand filters are a Low Impact Development (LID) stormwater approach in use since the early 1980s. These relatively affordable systems generally consist of two serial components. The first provides pretreatment and/or sedimentation, and the second offers water quality treatment and runoff reduction through infiltration and filtration. In the right soils, they provide infiltration similar to undeveloped areas. At UNHSC, the surface sand filter demonstrated a moderate capacity to reduce peak flow and treat water quality.

Where to Use It

As with most LID stormwater practices, surface sand filters are suitable for many situations. To achieve maximum reduction of peak flow and stormwater runoff, it is important to locate them in soils that accommodate infiltration and to minimize ponding depth. Careful site analysis is required to design an effective, integrated network of these systems throughout a landscape.

Design depends largely on the drainage area's characteristics. Underground sand filters are suited to urban areas with limited open space and a high percentage of impervious surface. Above-ground systems are suited to large drainage areas with adequate open space—such as highway interchanges—that have soils suitable for infiltration. As with any infiltration/filtration system, when sand filters are used in pollution hotspots or in poorly draining soils, they should be lined and outfitted with subdrains that discharge to the surface.

Implementation

Acceptance of sand filters varies regionally. Routinely used with great success for drinking water treatment, surface sand filters have not been as widely applied for stormwater management. Local acceptance may be hindered by lack of data and unfamiliarity with the design.

The cost to install a surface sand filtration system to treat the runoff from one acre of impervious surface was $12,500. This does not include maintenance, which may involve routine inspection, mowing of side slopes, and periodic scraping and replacement of the top inch of sand, as needed.

For more information on the design of sand filters like the one evaluated at the UNHSC field site, see the *New York State Stormwater Management Design Manual*.

How the System Works

Design

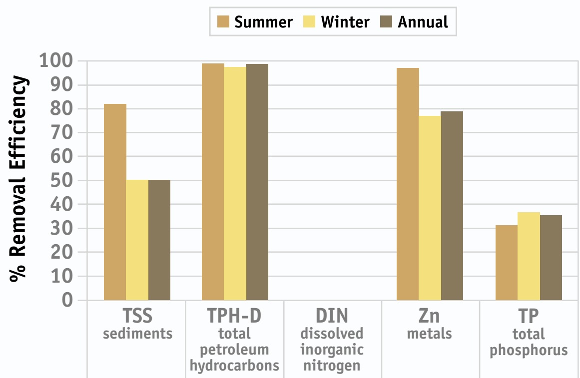
The surface sand filter system tested at the UNHSC is comprised of a sedimentation forebay and a surface sand filtration basin. The common practice of oversizing sand filters to reduce maintenance burden was not applied to this design. This led to an increased hydraulic loading rate, the filtration of a relatively large surface area by a small filter area, and, potentially, a weaker water quality treatment performance.

The basin contains a filter bed composed of coarse to medium grain sand. The filter bed's thickness is 30 inches, within the 18- to 36-inch range typically used in the design of these systems. It is designed to allow for five feet of ponding—which appears to be excessive and reduce performance—over a 24- to 48-hour period.

The filter bed was not vegetated; however, vegetation of the bed is a design option for these systems. Attempts to grow grass over the sandy surface of the filter bed proved to be a challenge. The surrounding slopes of the system were stabilized over three months, during which no monitoring data was collected.

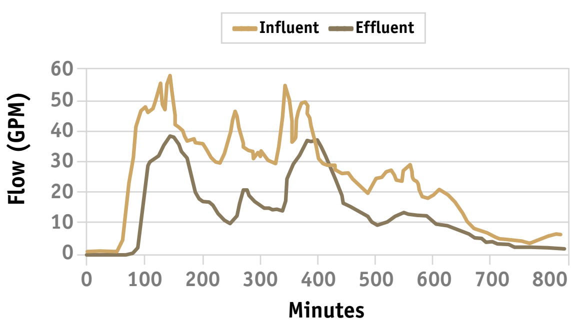
The forebay holds 25 percent of the water quality volume (WQ_V), and drains slowly through a restrictive standpipe into the surface sand filtration basin, which holds the remaining 75 percent of the WQ_V. The standard drain time is 24 hours and extends to no more than 72 hours to prevent standing water and mosquito habitat. Typically, channel protection volume (CP_V) events are conveyed through the system within 24 to 48 hours, while ten-year events (Q_p) bypass to adjacent conveyance systems.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	67%	45%	59%
Average Lag Time (minutes)	233	154	204

Water Quality Treatment

The surface sand filter performed only moderately well at removing most pollutants commonly associated with stormwater treatment performance assessment. While its performance did not meet EPA's recommended level for total suspended solids, other studies demonstrated stronger performance results for this system. This discrepancy may be due, in part, to design-related in-system erosion, relatively high hydraulic loading rates, and excessive ponding (five feet) above the filter media. In this study, the system demonstrated a strong ability to remove petroleum hydrocarbons and metals, but only moderate phosphorus removal. Like the other systems monitored, the sand filter does not treat chloride, but does exhibit an ability to dampen chloride peaks.

The chart at top left reflects system performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over a two-year monitoring period, with the data further divided into summer and winter components.

Water Quantity Control

The surface sand filter exhibits a moderate capacity to reduce peak flows and runoff volume in sites with well draining soils. In the figure at bottom left, it demonstrates moderate peak flow reduction and moderate lag times regardless of season.

Maintenance

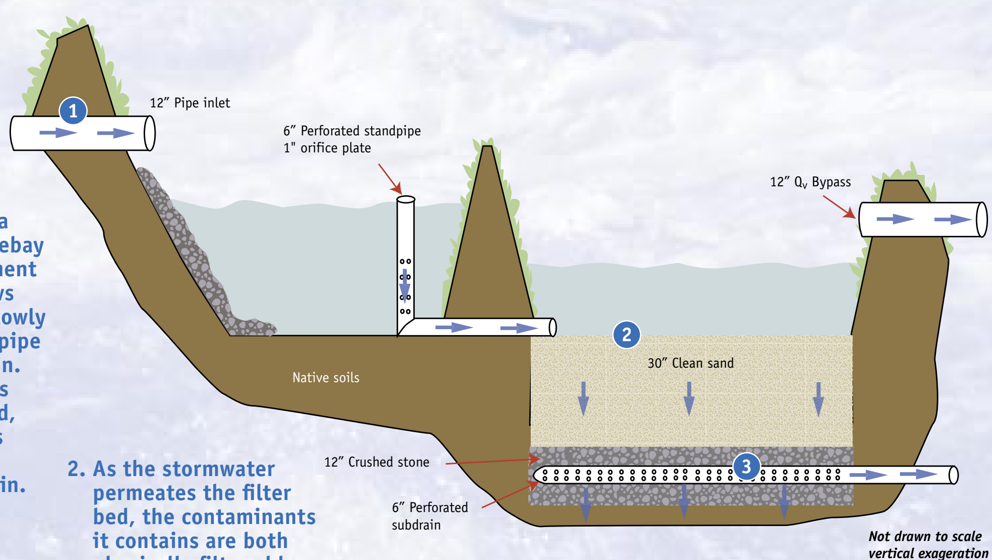
Unlike most other systems evaluated at the UNHSC, the surface sand filter receives semi-annual maintenance. It continues to function well.

In general, the maintenance requirements for surface sand filters are simple but critical for proper operation. Maintenance typically involves scraping fines from the surface of the filter bed. The frequency of this activity depends on how much sediment is in the stormwater runoff; depending on the size of the basin, sediment removal can be done by hand or with heavy machinery. After repeated maintenance, sand may need to be added to the filter bed to maintain the required two feet of media. Proper site stabilization through vegetation is key to preventing clogging from fines.

Cold Climate

The surface sand filter's ability to treat water quality and reduce the volume of runoff remained relatively consistent in all seasons. UNHSC researchers have observed that most LID systems, when properly designed and installed, are not dramatically impacted by seasonal fluctuations. While some seasonal variation does occur, significant design alterations do not appear necessary for cold weather application.

Water Quality Treatment Process

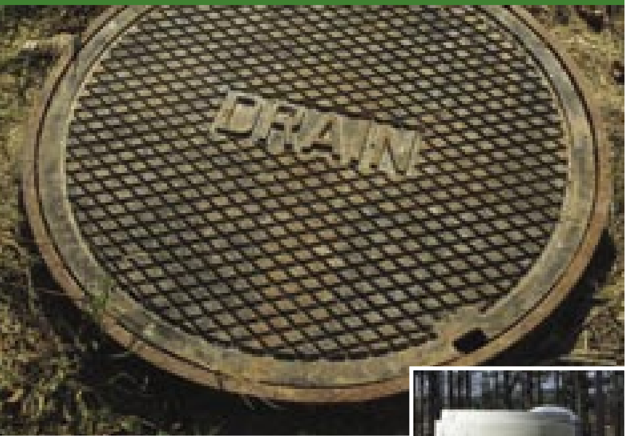


1. Runoff flows into a sedimentation forebay or other pretreatment chamber. Low-flows are metered out slowly through the standpipe into the filter basin. When the forebay's capacity is reached, the overflow spills across a weir into the sand filter basin.

2. As the stormwater permeates the filter bed, the contaminants it contains are both physically filtered by sand particles and chemically sorbed to particle surfaces.

3. If located in suitable soils, such as those belonging to groups A and B, the treated runoff is allowed to infiltrate into the subsurface beneath the system. Otherwise, it is collected in a perforated subdrain and returned to a storm drain system or discharged to the surface.

Hydrodynamic Separators



Many states allow hydrodynamic separators for primary stormwater treatment; however, there has been a trend toward limiting their use to pretreatment. The systems evaluated at UNHSC all demonstrated water quality treatment performances appropriate for pretreatment usage.

Fast Facts

CATEGORY TYPE
Manhole Retrofit, Swirl Separation

BMP TYPE
Manufactured Device

DESIGN SOURCE
Various

BASIC DIMENSIONS
Varies

SPECIFICATIONS
According to Manufacturer

TREATMENT FUNCTION
Physical: Hydrodynamic Separation & Sedimentation

INSTALLATION COST PER ACRE TREATED
$18,000 – $20,000

MAINTENANCE
Maintenance Sensitivity: High
Inspections: High
Sediment Removal: High

About Hydrodynamic Separators

Hydrodynamic separators (HDS) are small, flow-through devices that remove sediment, trap debris, and separate floating oils from runoff. UNHSC evaluated four HDS designs from 2004 through 2006: the VortSentry, the Continuous Deflection Separator (CDS), the V2B1, and the Aqua-Swirl. While their proprietary designs vary, they all primarily rely on swirl action and particle settling to remove pollutants. The 2005 UNHSC Data Report presents individual results for these systems. In this report, performance data is presented as median values reflecting the class of systems. Their ability to address water quality was marginal. They appear to be most effective when used for pretreatment in areas where runoff is expected to contain sediment particles greater than 100 microns in diameter.

Where to Use It

Manufactured HDS devices are widely used throughout the United States, and there are many options on the market. Their small footprint makes them particularly suitable for urban areas, or as retrofits to existing stormdrain networks. They are relatively simple to maintain, making them ideal for use as pretreatment components in treatment trains that also include filtration or infiltration systems.

Implementation

The approved use of HDS devices varies from state to state. This variability is due, in part, to the discrepancies that exist between laboratory-based and field-based performance data.

Many states approve the use of HDS devices for primary stormwater treatment, however, there is a trend toward limiting their use to pretreatment. Currently, some states require field-performance certification before HDS systems can be used for primary treatment. Other states restrict their use to pretreatment, or require that they are used in combination with other stormwater systems as part of a treatment train. This trend, combined with the widespread adoption of HDS devices, reflects the need for programs that provide independent, certified field-testing of system performance.

The installation cost of HDS devices ranges between $18,000 to $20,000 per acre of runoff treated, and this does not include system maintenance.

Designs for HDS devices are available from the manufacturers.

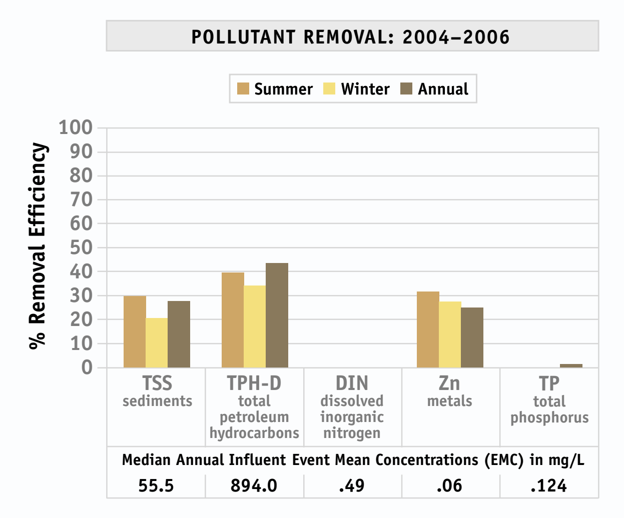
How the System Works

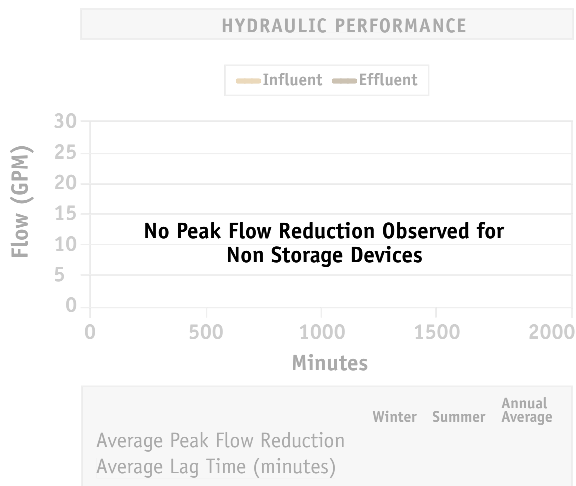
Design

The design of HDS devices varies, and is completed by the manufacturer in accordance with local watershed conditions and target water quality treatment objectives. Often, these systems are designed to replace or retrofit existing catchbasins.

Typically, HDS devices consist of a chamber that is configured for tangential flow, meaning that stormwater enters the device through an angled inlet that creates a swirl action to enhance particle settling. Many also contain a flow partition to minimize sediment re-suspension during times when flow rates exceed the design target.

Typically, HDS devices are equipped with a baffled outlet to remove floating debris, oil, and grease in stormwater runoff. To prevent the re-suspension of captured solids during times of high flow volume, some manufacturers have adapted HDS designs to include internal, online bypasses. When appropriate, these systems also can be outfitted with external, offline bypasses so that high flows can bypass the system completely.





Water Quality Treatment

Water quality performance was moderate to poor across the range of pollutants commonly associated with stormwater treatment performance assessment. The following observations are based on median values that reflect the performance of the four systems evaluated at UNHSC: the VortSentry, the CDS, the V2B1, and the Aqua-Swirl.

The median annual average for removal of total suspended solids in these systems was well below the EPA's recommended level for removal—they performed in the 30 percent range during the warmer months and 20 percent range in the winter. Likewise, they did not meet regional ambient water quality criteria for removal of petroleum hydrocarbons and zinc. No removal was recorded for nutrients, dissolved inorganic nitrogen, or total phosphorus.

The chart at top left is based on median values for the class of HDS systems evaluated; it reflects their performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over 18 storms, with the data further divided into summer and winter components.

Water Quantity Control

Typically, HDS devices are flow-through systems. Therefore, they exhibit no peak flow reduction, volume detention, or lag time, as demonstrated by the chart at bottom left.

Maintenance

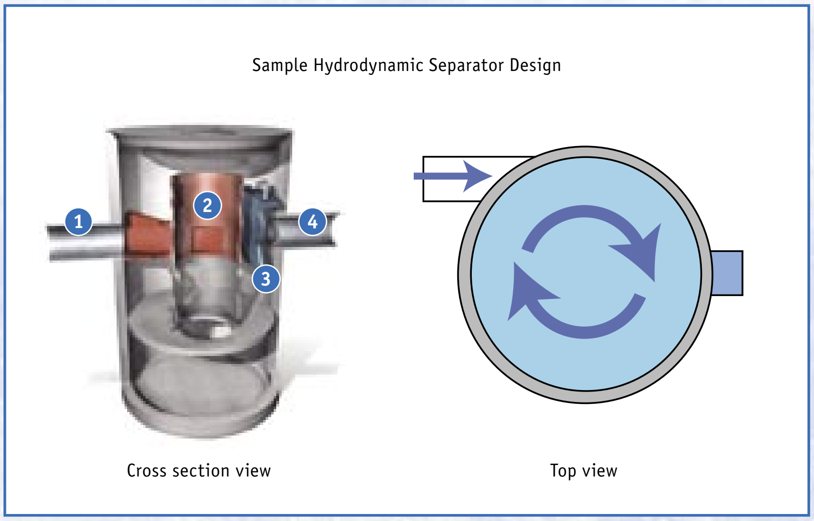
Maintenance of HDS devices includes the periodic inspection for floating debris, oil, and grease and the removal of solids by a vacuum truck. Systems in which the catchbasin is designed to be open and accessible allow for more thorough removal of sediment and are less costly to maintain. These devices did not requiure cleaning during their evaluation at the field site.

Cold Climate

As a class, the ability of HDS devices to remove sediments was significantly impacted during cold winter months. This is due to the increased viscosity of stormwater runoff and high concentrations of chloride, both of which combine to reduce particle settling velocity. Calculations of particle settling velocities at temperatures and chloride concentrations typically found in winter runoff demonstrated that HDS devices need about twice the time necessary to settle the same size particles in cold weather. When designed for installation in prolonged cold climate conditions, HDS devices that rely on particle settling for sediment removal need to be oversized to account for these changes in system performance.

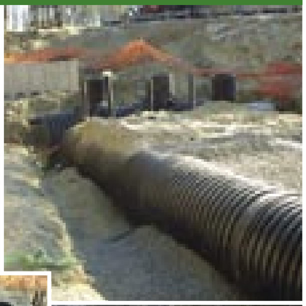
Water Quality Treatment Process

1. Runoff flows into the HDS device.
2. Typically, water quality treatment is achieved through a variety of sedimentation processes that involve the physical settling of particles.
3. Water typically leaves the system by flowing under a baffle in front of the outlet. Trash and other floatables remain in the chamber, a process referred to as “indirect filtration.”
4. If the HDS is part of a treatment train, the water is routed to the next component of the system. Otherwise it is channeled to a stormdrain system or discharged to the surface.



ADS Water Quality Unit & Infiltration System

About the ADS Water Quality Unit & Infiltration System

The subsurface Advanced Drainage Systems (ADS) Water Quality Unit & Infiltration System is a treatment train that combines a water quality treatment unit (WQU) for pretreatment with a larger infiltration unit (IU). At UNHSC, it has demonstrated a strong water quality treatment performance and a tremendous capacity to reduce peak flows. It should be noted that the design tested at the UNHSC is distinctive in its use of coarse sand for a reservoir base and filter course, a refinement that enhances its effectiveness in treating water quality.

Where to Use It

Treatment trains like the ADS Water Quality Unit & Infiltration System can be used in most parts of the country. In general, they are best suited to locations where space is at a premium, and are often used in urban areas, where they generally are located beneath parking lots and other transportation infrastructure.

As with any infiltration system, care must be taken when locating these systems near pollution hotspots, or where seasonal high groundwater levels may lead to groundwater contamination. In such cases, the systems should be lined to prevent infiltration into groundwater, and outfitted with subdrains that discharge to the surface.

Implementation

ADS Water Quality Unit & Infiltration Systems are widely used, and the implementation of similar underground infiltration systems is becoming increasingly common in urban development.

While they tend to be more expensive than conventional stormwater treatments, the cost of these systems is ameliorated by the increase in available space for development. The cost to install an ADS system large enough to treat runoff from one acre of impervious surface was $50,000. No maintenance was performed on this system during two years of service.

Designs for the ADS Water Quality Unit & Infiltration System are available from the manufacturer.

The ADS Water Quality Unit & Infiltration System does an exceptional job of removing nearly all of the pollutants commonly associated with stormwater performance assessment. It also exhibits a tremendous capacity to reduce peak flows and reduce runoff volume in appropriate soils.

Fast Facts

CATEGORY TYPE
Subsurface

BMP TYPE
Manufactured Device

DESIGN SOURCE
Advanced Drainage Systems (ADS)

FOOTPRINT (VERTICAL PROFILES VARY)
Water Quality Unit: 5 ft X 20 ft
Detention Infiltration Unit: 22 ft X 40 ft

SPECIFICATIONS
Catchment Area: 1 acre
Peak Flow: 1 cfs
Water Quality Volume: 3,300 cf

TREATMENT FUNCTION
Water Quality Unit: Physical
Detention Infiltration Unit: Physical & Chemical

COST PER ACRE
$50,000

MAINTENANCE
Maintenance Sensitivity: High
Inspections: High
Sediment Removal: High

How the System Works

Design

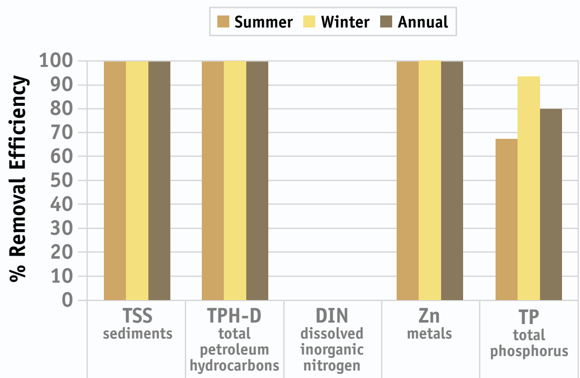
The ADS Water Quality Unit & Infiltration System is a treatment train that consists of a water quality unit (WQU) that provides pretreatment through the process of sedimentation, and an infiltration unit (IU) that performs much like a leach field. Both units are made of high-density polyethylene (HDPE) pipe and are designed to bear loads consistent with those experienced by parking lots. The design is completed by the system manufacturer in accordance with local watershed conditions and target treatment objectives.

The WQU is constructed from a 60-inch diameter HDPE pipe with a series of weirs for removal of coarse solids and floatables. The IU consists of three, 40-foot sections of 48-inch diameter, perforated HDPE pipe, laid over an infiltration base composed of two feet of bank run gravel. The top and sides of the excavation basin are wrapped in non-woven geotextile to protect the system from the migration of fine particles from the surrounding soil. The bottom of the treatment unit should not be lined to prevent premature clogging of the system from fines carried by runoff.

A three- to five-foot separation from seasonal high groundwater tables (as designated by regulations) and a proper sandy subbase are necessary to prevent groundwater contamination.

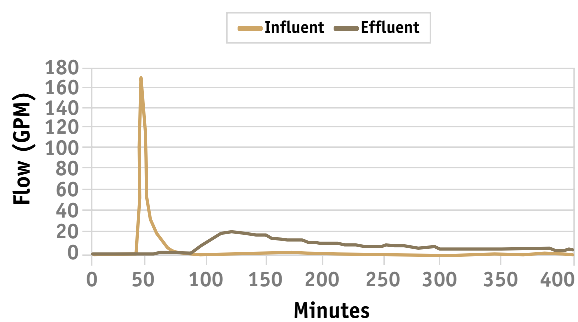
Stormwater flows of one cubic foot per second (cfs) enter the treatment train through the WQU and then flow into the IU. Flows exceeding one cfs bypass the WQU and flow directly into the IU, which prevents the re-suspension of solids. During channel protection volume (Q2) events, stormwater bypasses the WQU and fills the IU, which typically drains over a 24- to 48-hour period. During ten-year (Q10) events, stormwater bypasses the WQU, fills the IU, and then discharges directly to the surface, largely bypassing treatment.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	85%	80%	83%
Average Lag Time (minutes)	385	212	294

Water Quality Treatment

The ADS Water Quality Unit & Infiltration System does an exceptional job of removing nearly all of the pollutants commonly associated with stormwater performance assessment. It consistently exceeds EPA's recommended level of removal for total suspended solids, and meets regional ambient water quality criteria for total phosphorus, heavy metals, and petroleum hydrocarbons. However, it did not demonstrate an ability to treat nitrogen. This is typical in non-vegetated aerobic systems. Like all other systems monitored at UNHSC, it does not provide chloride removal, but does exhibit an ability to dampen chloride peaks.

The chart at top left reflects the system's performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over a two-year monitoring period, with the data further divided into summer and winter components.

Water Quantity Control

Like other infiltration and filtration systems, the ADS system exhibits a tremendous capacity to reduce peak flows and could be used to reduce runoff volume in appropriate soils, such as those belonging to groups A or B. In the figure at bottom left, it demonstrates effective peak flow reduction and lag times in all seasons.

Maintenance

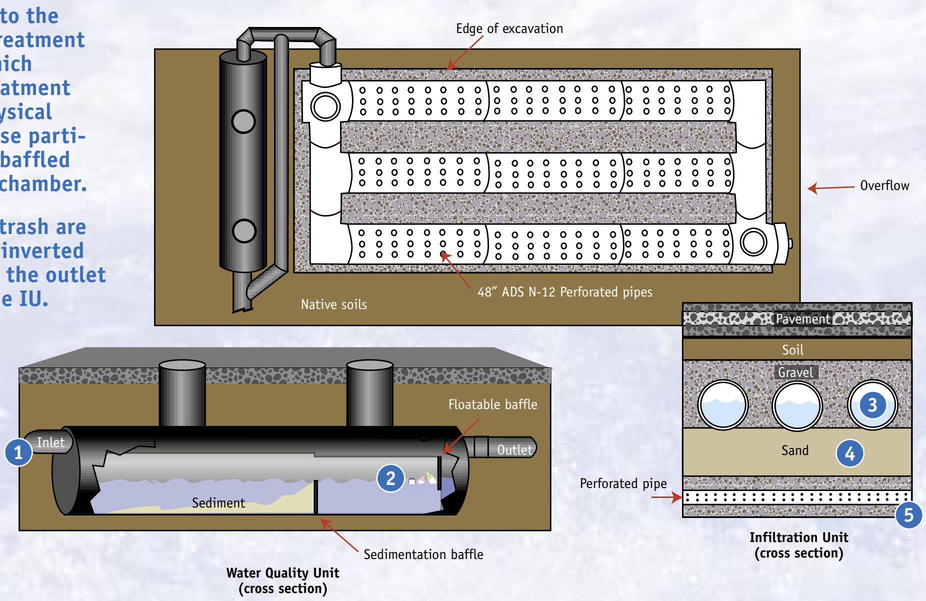
The maintenance requirements of the ADS Water Quality Unit & Infiltration System includes periodic inspection for, and removal of, trash and floating contaminants in the WQU, and the periodic removal of solids by a vacuum truck from both units. The WQU has two manholes for easy access and clean out. Proper maintenance of the accessible WQU prevents costly maintenance of the larger IU. System maintenance was not needed during its evaluation at the field site.

Cold Climate

This system's water quality treatment and volume control capacity remained strong in all seasons, reinforcing the conclusion that filtration and infiltration systems perform well, even in cold climates.

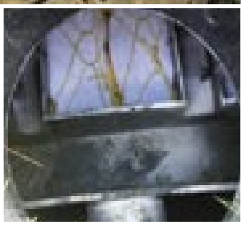
Water Quality Treatment Process

1. **Runoff flows into the water quality treatment unit (WQU), which provides pretreatment through the physical settling of coarse particles in a large, baffled sedimentation chamber.**
2. **Floatables and trash are detained by an inverted weir in front of the outlet that leads to the IU.**



3. **Additional particle settling occurs in the infiltration chamber, creating a filter cake. Over time, filter cake and deposited sediment will build up and require removal.**
4. **As stormwater permeates the infiltration bed in the infiltration unit (IU), the contaminants it contains are both physically filtered by sand particles and chemically sorbed to particle surfaces.**
5. **In appropriate soils, water infiltrates. If the system is lined, perforated subdrains carry the treated runoff to the surface.**

Aqua-Filter Stormwater Filtration System



About the Aqua-Filter Stormwater Filtration System

Manufactured by AquaShield, the Aqua-Filter Stormwater Filtration System is composed of two units in series: the Aqua-Swirl, a hydrodynamic separator that provides pretreatment through sedimentation, and the subsurface Aqua-Filter filtration chamber. UNHSC researchers evaluated the performance of these two components as a combined treatment train. The system demonstrated moderate water quality treatment.

Where to Use It

This system can be used in most parts of the country. Its compact subsurface design makes it especially well suited to space-constrained sites, where larger, surface systems are impractical. It is commonly used beneath parking lots, transportation structures, and in other urban settings.

Implementation

Though often used in tandem as a "treatment train," each component of this system can be used a stand alone device, or as a pretreatment in conjunction with other stormwater systems, depending on regulations. The Aqua-Filter Stormwater Filtration System uses an Aqua-Swirl for pretreatment. The treatment train configuration enables greatly improved performance, beyond that of a single system. (For more information on UNHSC's evaluation of hydrodynamic separators, see page 20.)

The installation cost of the Aqua-Filter Stormwater Filtration System is $31,500 per acre of runoff treated, and this does not include system maintenance.

Designs for this system are available from the manufacturer.

The Aqua-Filter Stormwater Filtration System combines a hydrodynamic separator that provides pretreatment through sedimentation and a subsurface filtration unit that physically removes contaminants. The system performed moderately well at removing most analyzed pollutants from stormwater runoff.

Fast Facts

CATEGORY TYPE
Manhole Retrofit, Filtration

BMP TYPE
Manufactured Device

DESIGN SOURCE
AquaShield, Inc.

DIMENSIONS (AF 4.2 COMPONENT SIZES)
Aqua-Swirl (vertical):
4.5 ft diameter, 8 ft tall
Aqua-Filter (horizontal):
6.75 ft diameter, 12 ft long

SPECIFICATIONS
Catchment Area: 1 acre
Peak Flow: 1 cfs

TREATMENT FUNCTION
Aqua-Swirl: Sedimentation
Aqua-Filter: Physical & Chemical

INSTALLATION COST PER ACRE TREATED
$31,500

MAINTENANCE
Maintenance Sensitivity: High
Inspections: High
Sediment Removal: High

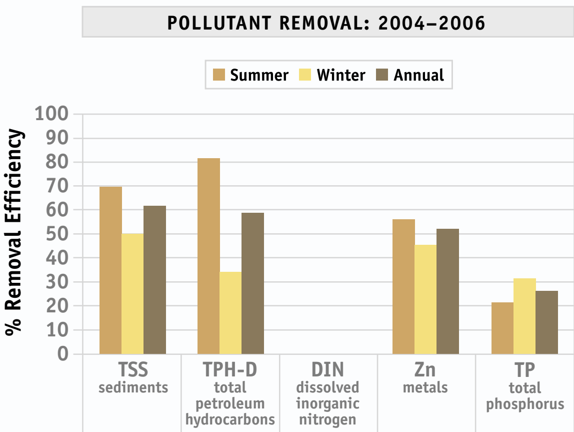
How the System Works

Design

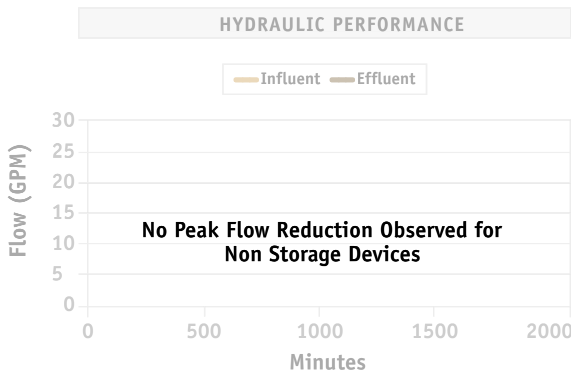
The Aqua-Filter Stormwater Filtration System is a treatment train comprised of the Aqua-Swirl, a hydrodynamic separator that induces pretreatment through sedimentation, and the Aqua-Filter, a subsurface filtration unit that physically removes contaminants through a layer of perlite filter cartridges. Both are made from high-density polyethylene (HDPE); thus installation is simplified and does not require use of cranes. In systems constructed from HDPE, anti-floatation reinforcement is lighter than concrete and should be considered in their design when they are sited in areas with high seasonal groundwater.

The Aqua-Swirl is a six-foot diameter sedimentation chamber with an angled inlet that creates a swirl action to enhance particle settling, and a baffled outlet that promotes the removal of floating debris, oil, and grease. The Aqua-Filter tested at UNHSC consisted of a large tank with a filtration platform outfitted with 24 cartridges (one-cubic foot, nylon bags, filled with perlite beads). System design is completed by the system manufacturer to accommodate local watershed conditions and target water quality treatment objectives. Specific attention to contaminants of concern is critical in designing systems. The Aqua-Filter can be installed with different filter media mixes that target different spectrums of pollutants.

Runoff up to one cubic foot per second (cfs) enters the treatment train through the Aqua-Swirl and then moves into the Aqua-Filter unit. To prevent the re-suspension of particles and other contaminants, runoff exceeding one cfs is directed around the filter bed though an internal bypass.



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124



	Winter	Summer	Annual Average
Average Peak Flow Reduction			
Average Lag Time (minutes)			

Water Quality Treatment

The Aqua-Filter performed moderately well at removing most analyzed pollutants from stormwater runoff. Its performance did not meet EPA's recommended level for removal of total suspended solids. The system demonstrated a moderate ability to remove petroleum hydrocarbons and metals, but no significant capacity for nitrogen and phosphorus removal. Like the other systems monitored at UNHSC, the Aqua-Filter does not treat chloride.

The chart at top left reflects this system's performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over a two-year monitoring period, with the data further divided into seasonal components.

Water Quantity Control

The Aqua-Filter Stormwater Filtration System is designed to be a flow through structure. In general, compact, subsurface systems like this one do not provide peak flow reduction, or runoff volume reduction.

Maintenance

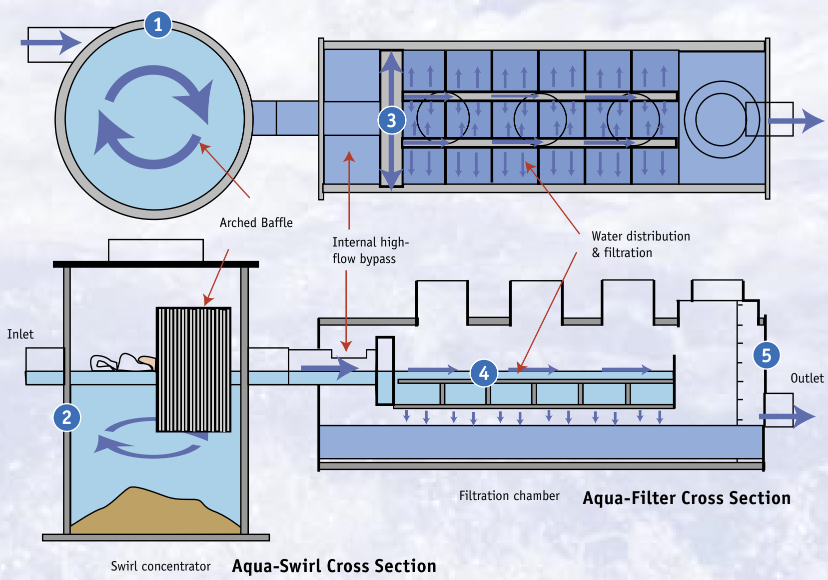
UNHSC researchers replaced the perlite filter cartridges in the Aqua-Filter unit annually, according to manufacturer guidelines. Maintenance requirements include the removal of sediments and floatable contaminants from the Aqua-Swirl, which has one manhole for inspection and clean out. The Aqua-Filter, which has two manholes for inspection and maintenance, requires the periodic replacement of the perlite filter cartridge. Filter cartridge replacement is a "confined space entry," which requires training and a permit. Both units require frequent inspection and cleaning to maintain effectiveness.

Cold Climate

The Aqua-Filter Stormwater Filtration System's water quality treatment and water quantity control performance showed some seasonal variations, but not enough to warrant design alterations for cold climates.

Water Quality Treatment Process

1. Runoff flows into the Aqua-Swirl, which provides pretreatment through the physical settling of particles.
2. Floating contaminants such as trash, oil, and grease are detained by an internal baffle in the Aqua-Swirl.
3. Water flows under the baffle and into the Aqua-Filter.



4. Once in the Aqua-Filter, the stormwater flows through pores in the perlite filter cartridges, which provides physical and chemical treatment that removes suspended sediments and other associated contaminants. Over time, the filtration media clogs—slowing down the infiltration rate—and the perlite cartridges must be replaced.
5. Treated runoff is channeled through an outlet pipe to the surface.

Vegetated Swale

Vegetated swales like the one pictured above are widely accepted and implemented. While this system demonstrated better water quality treatment performance than the stone-lined swale previously evaluated at UNHSC, it did not meet EPA treatment requirements and is negatively influenced by cold climate conditions.

Fast Facts

CATEGORY TYPE
Open Channel System, Sedimentation

BMP TYPE
Conventional, Structural

DESIGN SOURCE
New Hampshire Green Book

BASIC DIMENSIONS
Length: 280 ft
Width: 10 ft

SPECIFICATIONS
Catchment Area: 2 acres
Peak Flow: 2 cfs

TREATMENT FUNCTION
Sedimentation, Some Filtration

INSTALLATION COST PER ACRE TREATED
$12,000

MAINTENANCE
Maintenance Sensitivity: Low
Inspections: Low
Sediment Removal: Low

About Vegetated Swales

Vegetated, dry, wet, or stone-lined—stormwater swales are open, channel-like structures that are used to convey stormwater runoff. The vegetated swale evaluated at the UNHSC should not be confused with the more complex "water quality swales," or "bioswales," which are often designed with modified soils and subdrains. It is a trapezoidal channel designed for minimal slope and maximum flow velocity. Its ability to remove pollutants is modest at best, and—being vulnerable to large, high-velocity storm flows—its effectiveness will likely decline with age.

Where to Use It

Though their designs vary widely, vegetated stormwater swales are the most commonly employed stormwater management system. They often serve as stormwater drainage infrastructure in lieu of curbs, gutters, and stormwater sewer systems. Frequently, they are located along property boundaries or roads and constructed to suit the natural grade. They can be used wherever the site provides adequate space and elevation.

Design and space constrictions generally restrict the use of swales in urban settings, in areas with highly erosive soils, or where dense vegetative cover is difficult to maintain.

Implementation

Vegetated swales are widely accepted. Since they are inexpensive and require little site modification, they are the stormwater treatment of choice in many areas.

In some places, they are used for pretreatment and combined with another system that provides primary water quality treatment. While designed to function like streams, vegetated swales rarely have a stream's structural complexity, and as such are prone to sedimentation and erosion. This is compounded by poor—or nonexistent—maintenance, which leads to contaminant export into receiving waters and the degradation of the swale's channel.

The cost to install a vegetated swale to treat runoff from one acre of impervious surface was $12,000. This does not include maintenance expenditures, which may involve routine inspection and the periodic mowing or removal of collected sediments, as needed. However, our observations reinforce stormwater manual assessments that maintenance requirements for these systems are generally minimal. That being said, vegetated swales do need inspection, since in-system erosion can lead to failure and/or the export of pollutants.

You can access more information about the design for this system by contacting UNHSC.

How the System Works

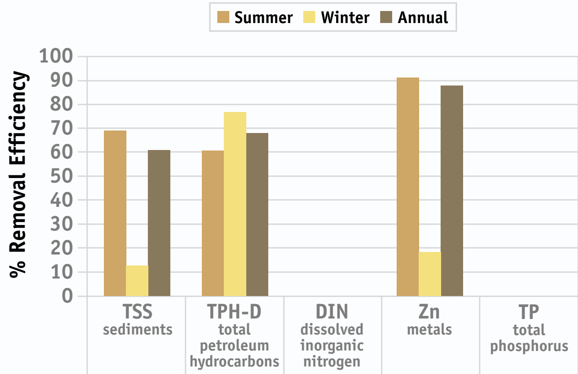
Design

Swales are easy to design and build. They can be rock-lined or vegetated, broad or narrow, curving or linear, natural or engineered. Vegetated swales are generally designed with a trapezoidal or parabolic shape to accommodate large fluctuations in the flow of stormwater runoff.

Dense vegetation is key to a swale's stabilization and function, yet it is often not established until years after the construction is complete. This lag is common, and results from the fact that dense root mats may take up to three months to develop depending on the local growing season—a requirement that often is not accommodated by construction calendars.

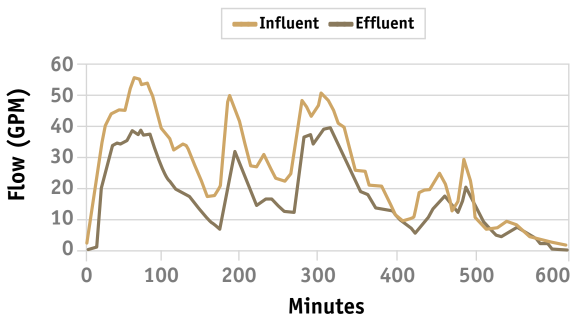
Typically, state design criteria for all swales, including those that are vegetated, specifies slopes of less than one percent, and flow velocities of less than one foot per second for 10-year (Q10) and lower flows. In general, swales installed in steeply sloped areas do not meet the design requirements for slope and velocity. Other common sizing criteria, such as water quality volume (WQ_V), channel protection volume (CP_V), and conveyance protection volume (Q_P), were not used in the design of this system.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	37%	55%	48%
Average Lag Time (minutes)	27	15	19

Water Quality Treatment

The vegetated swale was moderately effective in removing the pollutants commonly associated with stormwater performance assessment. Its performance appeared somewhat better than that of the stone-lined swale tested in the same location the previous year. This system's median annual average for removal of total suspended solids was in the sixty percent range—below EPA's recommended level for removal. Likewise, it did not meet regional ambient water quality criteria for removal of petroleum hydrocarbons. Its ability to treat metals was generally strong, but dramatically declined in winter when vegetation was dormant and sediment removal was low. Researchers observed no removal for dissolved inorganic nitrogen or total phosphorus. Like all systems monitored at UNHSC, it does not treat chloride.

The chart at top left reflects the system's removal of total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over one year, with the data further divided into summer and winter components.

Water Quantity Control

Swales typically exhibit no peak flow reduction or lag time. Studies have shown they are often prone to destabilization by large storm flows, a tendency that may negatively affect downstream geomorphology. In the figure at bottom left, the vegetated swale demonstrates limited peak flow reduction with short lag times during the summer months. What little impact the swale demonstrated with respect to water quantity control diminished with the onset of winter.

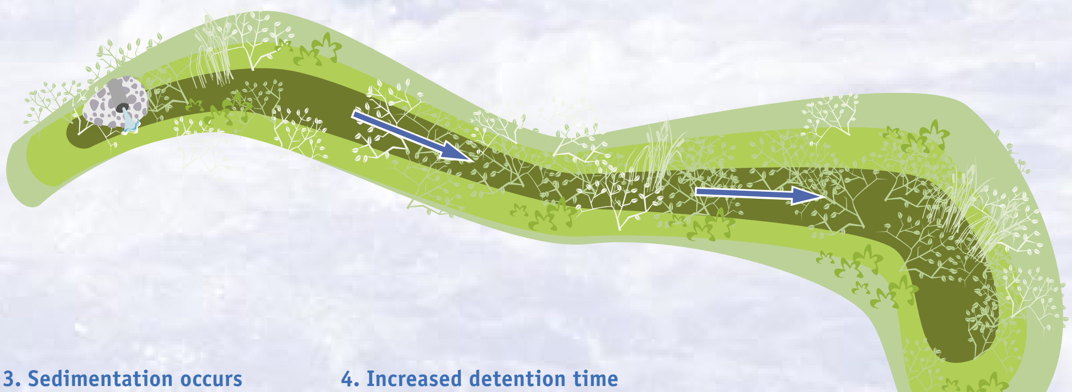
Maintenance

The maintenance requirements of vegetated swales include periodic inspection for erosion and channel destabilization, removal of trash, leaves, and other natural debris, and sediment buildup. Some may also require periodic mowing. No maintenance was performed on the vegetated swale during its year of evaluation at the UNHSC field site.

Cold Climate

In general, winter conditions significantly limit the vegetated swale's ability to treat water quality and manage water quantity. While it exhibited modest removal of sediment, petroleum products, and metals in the summer, the onset of winter eliminated or significantly reduced its effectiveness. Its performance also varied dramatically in winter months, likely as a result of icing within the system.

Water Quality Treatment Process



1. **Stormwater runoff flows into and along the swale's channel, where water quality performance is a function of channel dimensions, density of vegetation, and its ability to dampen the influent flow rate.**
2. **Runoff undergoes physical filtration through the standing vegetation. In systems with more robust vegetation, additional treatment via plant uptake and sorption to organic sediments may occur. Water quality performance typically increases with vegetation density, and declines during high flows when vegetation is submerged, frozen, and/or bent.**
3. **Sedimentation occurs between the large stones lining the flow pathway. If the swale is constructed above highly conductive soils and flow is of low velocity, infiltration also can be expected.**
4. **Increased detention time from check dams within the channel coupled with low velocity flows will enhance filtration, sedimentation, and infiltration.**
5. **Water leaving the system is directed to a receiving water.**

Retention Pond

About Retention Ponds

Retention ponds, or "wet ponds," are among the most common stormwater treatment systems used today. They are not to be confused with detention basins or "dry basins," which hold runoff for a specified period of time, and then release the entire volume of the runoff. Retention ponds retain a resident pool of standing water, which improves water quality treatment between storms. Retention ponds demonstrate a reasonably strong water quality treatment, particularly in comparison to dry pond systems. However, lack of maintenance often leads to pollutant export and a gradual erosion within the system for large flows.

Where to Use It

Acceptance of retention ponds is widespread, and examples of these systems can be found all over the world in any climate, soil, and development setting.

In many areas, retention ponds are the system of choice, a preference likely due to their ease of design, which can be adapted to provide water quality treatment and water quantity control in a variety of settings.

Implementation

While retention ponds are common, their use raises concerns related to human and ecosystem health. Standing water, for example, can be a drowning hazard. They also serve as a habitat for mosquitoes associated with diseases. Ponds that contain excess nutrients can foster eutrophication. In hot weather, retention ponds can superheat already warm parking lot runoff, impacting aquatic habitats and cold water fisheries. Some innovative retention pond outlet designs include the use of gravel subdrains to cool effluent.

The cost to install a retention pond system to treat runoff from one acre of impervious surface was $13,500. This does not include maintenance expenditures, which may involve routine inspection, periodic mowing, and sediment dredging, as needed. For more information about this design, contact the UNHSC.

During the first year of operation, the retention pond at UNHSC was reasonably effective in removing many of the pollutants commonly found in runoff. However, during its second year, researchers observed a reduction in its water quality performance. This indicates that its performance may continue to diminish over time.

Fast Facts

CATEGORY TYPE
Stormwater Pond, Sedimentation

BMP TYPE
Structural, Conventional

DESIGN SOURCE
New York State Stormwater Management Design Manual

BASIC DIMENSIONS
Surface Area: 46 ft X 70 ft (varies)

SPECIFICATIONS
Catchment Area: 1 acre
Peak Flow: 1 cfs
Water Quality Volume: 3,264 cf

TREATMENT FUNCTION
Physical Settling & Biological

INSTALLATION COST PER ACRE TREATED
$13,500

MAINTENANCE
Maintenance Sensitivity: Low
Inspections: Low
Sediment: Low

How the System Works

Design

The retention pond tested at the UNHSC is comprised of a sedimentation forebay and a larger basin sized to hold a resident pool of water. It was installed below the water table to maintain a permanent pool of water, and in clay soils, which effectively act as a lining for the system. Side slopes were stabilized with grass, and spillways with stone and geotextile.

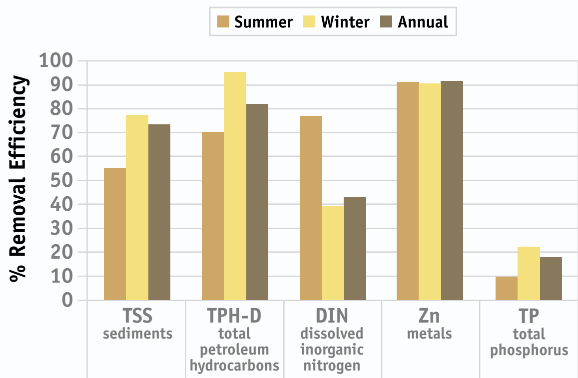
Improved designs, not used here, would include stabilization of wetland perimeter with stone and fabric. This perimeter was the location of failure for the pond. In this area, vegetation could not establish and soils were prone to erosion.

In general, these ponds can be designed either above or below the groundwater table. Ponds are commonly designed for both aesthetic and habitat function.

The system is designed to treat the water quality volume. Typically, channel protection volumes (CP_V) are conveyed through the system within 24 to 48 hours.

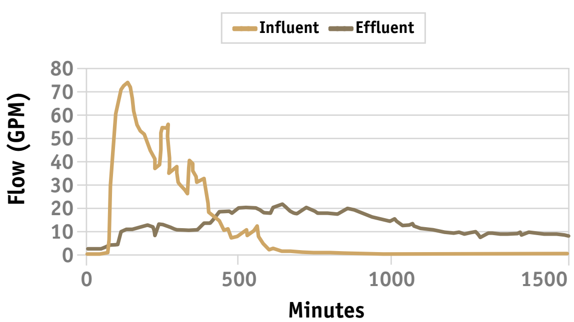
During conveyance protection volume (Q_P) rain events, stormwater is conveyed through the system, and bypasses the water quality treatment process.

POLLUTANT REMOVAL: 2004–2006



Median Annual Influent Event Mean Concentrations (EMC) in mg/L				
55.5	894.0	.49	.06	.124

HYDRAULIC PERFORMANCE



	Winter	Summer	Annual Average
Average Peak Flow Reduction	84%	79%	81%
Average Lag Time (minutes)	540	321	424

Water Quality Treatment

During the first year of operation, the retention pond was reasonably effective in removing many of the pollutants commonly found in runoff. It consistently met EPA's recommended level of removal for total suspended solids, as well as regional ambient water quality criteria for petroleum products, metals, and nutrients. However, during its second year, researchers observed a 25 percent reduction in its TSS median removal efficiency—from 81 percent down to 71 percent. This indicates that while the pond still effectively treats most contaminants, its performance may continue to diminish. Like the other systems evaluated at UNHSC, it does not provide chloride removal, but can dampen chloride peaks.

The chart at top left reflects the system's performance in removing total suspended solids, total petroleum hydrocarbons, dissolved inorganic nitrogen, total phosphorus, and zinc. Values represent results recorded over a two-year monitoring period, with the data further divided into summer and winter components.

Water Quantity Control

Retention ponds exhibit a tremendous capacity to reduce peak flows, retain channel protection volume, and provide flood protection for up to 48 hours. In the figure at bottom left, the retention pond demonstrates effective peak flow reduction and long lag times, regardless of season. However, in general, these systems do not reduce runoff volume.

Research indicates that the extended duration effluent flows typical of retention ponds negatively impact receiving streams, particularly when post-development runoff subjects streams to erosive flows for long periods. This phenomenon is observed in urban areas, where it leads to channel instability and lost ecological value and function.

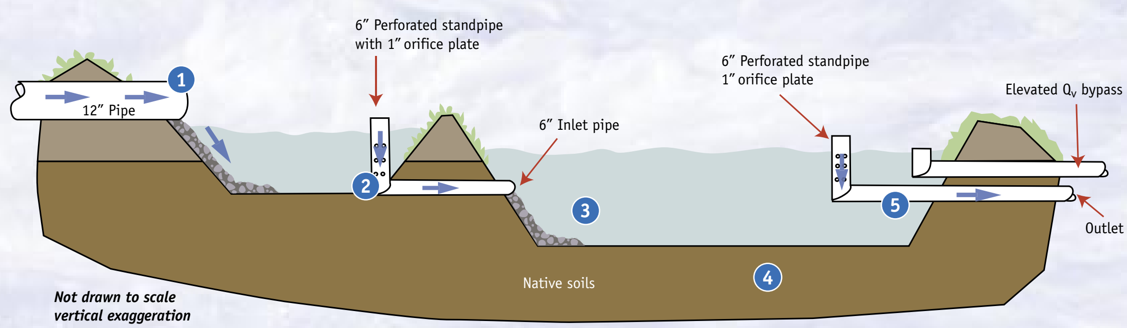
Maintenance

Minimal need for maintenance contributes to the popularity of retention ponds. However, while little maintenance may be required to support their ability to manage peak flow and floods, more frequent attention is critical for effective water quality treatment. Previous research has demonstrated that erosion and re-suspension of benthic sediments in these systems leads to sediment export. Since sedimentation is the main water quality treatment mechanism, inspections are critical to maintaining performance in sites with heavy sediment loads. Dredging for debris and trash is also needed. While not necessary for these systems to function, the establishment of a viable pond ecosystem can enhance treatment, prolong the system's lifespan, and increase aesthetic appeal.

Cold Climate

The system's ability to treat water quality and manage water quantity remained effective during cold winter months. While some variation in both kinds of performance does occur in cold conditions, it does not warrant significant alterations to system design to compensate.

Water Quality Treatment Process



1. Runoff flows into a forebay that removes large objects and allows larger sediment particles to settle.
2. Runoff exits the forebay though a perforated standpipe and flows into the pond. When forebay capacity is reached, the overflow spills across a weir into the retention pond basin.
3. Water quality treatment is a function of storage volume and retention time, i.e., larger storage volumes and longer retention times promote better treatment. The removal of TSS, some phosphorus, petroleum hydrocarbons, and metals occurs primarily through sedimentation.
4. Several components contribute to biological treatment. Nutrients removal occurs primarily through the activity of macroinvertebrates, microorganisms, and plants. Long-term breakdown of petroleum hydrocarbons is through microbial processes. Metals that accumulate in the sediment may be taken up by the roots of aquatic vegetation.
5. The runoff is conveyed by a perforated standpipe modified with a one-inch outlet which regulates flow from the system.

Resources for Land & Water Management

Clean water supplies are essential to life, yet many factors threaten our water resources. In particular, the increase in impervious surfaces and dwindling of natural land from development pressure often impair water quality and disrupt the connection between surface waters and groundwater. These negative impacts are compounded by severe storms and sea level rise, phenomena that are expected to increase with global climate change.

Effective water resource management requires that local gov-ernments, businesses, community organizations, and residents not only work together, but also that they adopt an integrated approach. Stormwater management is just one of a range of strategies at their disposal. Foremost are policies, programs, and regulations designed to restore watershed function, to manage developed areas, and to protect natural resources.

These pages provide an overview of the major challenges to water resource management in a developing landscape, and the strategies—voluntary, regulatory, and those in between—that communities can use to manage the impacts of land use practices on water quality and quantity.

Impacts of Development: Impervious Surface

Impervious surfaces are those in which development—such as rooftops, parking lots, and roads—or compacted earth prevent rainfall from infiltrating into the ground. If stormwater is not properly managed, the increased volume and velocity of runoff from impervious surfaces results in the degradation of water quality and aquatic habitat as well as an increase in erosion and flooding. There is a strong relationship between the increase in impervious surfaces and the decline in water quality and aquatic habitats. There are many regulatory, planning, and site design techniques that can reduce the negative impacts of impervious surfaces and balance the need for social and economic development with the protection of natural resources.

Resources

- Local Government Commission: clearinghouse for information and resources related to the co-management of land and water resources: http://water.lgc.org/resource-tools
- Impervious Surface Analysis Tool (ISAT) from the NOAA Coastal Services Center and UCONN NEMO: www.csc.noaa.gov/crs/cwq/isat.html
- "Effects of Urbanization on Stream Quality at Selected Sites in the Seacoast Region in New Hampshire": http://pubs.usgs.gov/sir/2005/5103/
- Impervious Surface Mapping in Coastal New Hampshire:http://www.nhep.unh.edu/resources/maps.htm

Climate Change: Coastal Hazards & Municipal Infrastructure

Coastal areas are subjected to regularly occurring storms and hurricanes, which can cause damage from floods, winds, and erosion. These natural events stress municipal services and disrupt communities. Global climate change has added to these stressors by making storms larger and more powerful, resulting in larger volumes of runoff. The resilience of a community to handle these events requires the successful implementation of plans designed to address these emergent threats. One such plan is the use of low impact development (LID) designs to increase recharge and reduce flood volumes. The reduction of storm volumes through recharge could save municipalities significant costs associated with the need to update undersized infrastructure due to climate change. Adoption of LID practices can shift the cost of adoption from the municipalities to developers and owners of new- and re-development projects. The cost benefit of hazard mitigation from stormwater recharge may be significant for many communities.

Resources

- NOAA Sea Grant Coastal Natural Hazards: A nationwide network of 30 university-based programs that work with coastal communities: www.seagrant.noaa.gov/themesnpa/coastalnaturalhazards.html
- Northeast Climate Impacts Assessment (NECIA): Provides guidance on climate change impacts in the northeast: http://www.northeastclimateimpacts.org/
- CLIMB, 2004. Climate's Long-term Impacts on Metro Boston (CLIMB) Final Report. Civil and Environmental Engineering Department, Tufts University. 2004. EPA Grant No. R.827450-01
- Great Bay NERR Coastal Training Program, (603) 778-0015, ext. 305 or steve@greatbay.org

Voluntary Strategies → Regulatory Strategies

Land Conservation

Many communities are using voluntary land conservation strategies, such as easements, to permanently protect parcels of natural land. However, since it is highly unlikely that most communities can secure sufficient funding to acquire conservation easements or ownership for all lands identified as critical for protection, it's safe to assume that the remaining unprotected areas will face development pressure in the near future. As a result, it's important for communities to also adopt land use regulations that provide guidance and tools to limit the impacts of development that does occur.

Resources

- Land Conservation Plan for New Hampshire's Coastal Watersheds: provides information on land conservation planning, and land use regulations: from the Nature Conservancy, www.nature.org/newhampshire, and the New Hampshire Estuaries Project, www.nhep.unh.edu
- Developing a Conservation Plan: includes information about land conservation planning: http://www.unh.edu /CommDev/CCAP.htm#CC_Pub
- Conserving your land: Options for N.H. Landowners: assists landowners with understanding options for land conservation: http://www.spnhf.org/landconservation/conserve-your-land.asp

Buffers

A buffer is a naturally vegetated area along a shoreline, wetland, or stream where development is restricted or prohibited. Its primary function is to physically protect the water body from future disturbance or encroachment. Benefits of buffers are plentiful and include protection of municipal infrastructure and private property from floods and erosion; recharge of aquifers and groundwater resources; prevention of erosion; and water quality protection for surface waters including lakes, streams, and wetlands.

Resources

- Aquatic Buffers, U.S. Environmental Protection Agency Nonpoint Source Pollution: provides technical guidance to create stream buffer for the protection of water quality, streams, wetlands, and floodplains: www.epa.gov/owow/nps/ordinance/buffers.htm
- Stream Buffer Characterization Data and Maps: town-specific maps that assess 150 and 300 foot buffer areas: www.nhep.unh.edu/resources/actions.htm
- Buffer Data Mapper: http://mapper.granit.unh.edu/viewer.htm
- Buffers for Wetlands & Surface Waters: Guide for N.H. Municipalities: http://extension.unh.edu/CommDev/Buffers.pdf
- New Hampshire Buffer Outreach Program and Community Technical Assistance Program: provides buffer workshops and professional consultants on buffer protection: www.nhep.unh.edu/resources/actions.htm

Low Impact Development

Low impact development (LID) is an innovative approach that uses natural, or predevelopment hydrology, as guide for design. In the area of stormwater management, LID uses a combination of processes—infiltration, filtration, and detention/storage—to manage rainfall at the source (ideally) and to mimic predevelopment hydrology. LID stormwater strategies are applicable in nearly all locations. However, infiltration into groundwater is only appropriate in certain situations. LID is most effective when used in conjunction with land conservation efforts.

Resources

- Low Impact Development Center, Beltsville, Maryland: www.lowimpactdevelopment.org
- Evaluation of Best Management Practices for Highway Runoff Control: Transportation Research Board: www.trb.org/news/blurb_detail.asp?id=7184
- U.S. Environmental Protection Agency Low Impact Development Center: www.epa.gov/nps/lid
- Prince Georges County Maryland LID web site: www.co.pg.md.us/Government/AgencyIndex/DER/ESD/low-impact.asp
- Jordan Cove Annual Report: http://www.csc.noaa.gov/alternatives/conserve_info.html

Stormwater Utilities

Stormwater utilities are a way for communities to collect user fees to fund a range of stormwater management activities such as catchbasin cleaning, street sweeping, and stormwater infrastructure upgrades required by the Clean Water Act Phase II. User fees are generally proportional to the amount of runoff generated by a parcel. There are many different types of stormwater utilities, ranging from taxes to user fees. A common stormwater utility strategy used in the Northeast incorporates a dedicated enterprise fund, similar to those used to manage water and sewer utilities. An enterprise fund is based on a flat fee per unit of impervious area.

Resources

- User-Fee-Funded Stormwater Utilities: Water Environment Federation (1994).
- "The Stormwater Utility: Will it Work for Your Community?" from *Stormwater Magazine:* www.forester.net/sw_0011_utility.html
- "How to Create A Stormwater Utility": From the towns of Chicopee and S. Hadley, Mass. by a 319 Grant: www.pvpc.org/web-content/docs/landuse/storm_util.pdf
- N.H. Department of Environmental Services, Watershed Assistance Bureau, (603) 271-7889 or bmcmillan@des.state.nh.us

Land Use Regulations

Land use regulations are the second essential component in a two-pronged approach to protecting water resources in a developing landscape. When paired with land conservation practices, the regulation of the location, density, and design of development can help reduce the negative impacts on water resources. For example, land use ordinances may include environmental characteristics zoning, cluster/conservation development, and performance standards.

Resources

- Sample land use regulations are available from the Rockingham Planning Commission: www.rpc-nh.org, and the Stafford Regional Planning Commission: www.strafford.org
- National Association of Counties—Local Tools for Smart Growth: http://www.naco.org/Content/ContentGroups/Programs_and_Projects/Community_Development/Center_for_Sustainable_Communities/LocalTools_SmartGrowth.pdf
- NOAA Coastal Services Center: http://www.csc.noaa.gov/alternatives/conserve_info.html
- "Conservation Development Manual" from the Office of Sustainable Watersheds, Rhode Island Department of Environmental Management: http://www.dem.ri.gov/programs/bpoladm/suswshed/pubs.htm

Administration

UNHSC Faculty & Staff

Robert M. Roseen, PE, Ph.D
Director and Research
Professor of Engineering
242 Gregg Hall
Durham, NH 03824
603.862.4024
robert.roseen@unh.edu

Thomas P. Ballestero, PE, Ph.D, PH, CGWP, PG
Senior Scientist and Professor
of Civil Engineering
38 Gregg Hall
Durham, NH 03824
603.862.1405
tom.ballestero@unh.edu

James J. Houle, CPSWQ
Program Manager and
Outreach Coordinator
346 Gregg Hall
Durham, NH 03824
603.767.7091
jjhoule@unh.edu

Alison Watts, Ph.D
Post-doctoral Associate
Civil Engineering

Heather Gilbert
Facilities Manager
346 Gregg Hall
Durham, NH 03824
603.767.7091
heather.gilbert@unh.edu

Graduate Students

UNHSC is indebted to the hard work and engagement of the following UNH graduate students, past and present:

Pedro M. Avellaneda
Research Assistant
Civil Engineering
Doctoral Candidate

Iulia Barbu
Research Assistant
Civil Engineering
Doctoral Candidate

Joshua F. Briggs
Research Assistant
Civil Engineering
Masters Recipient

Kristopher Houle
Research Assistant
Civil Engineering
Masters Candidate

Julie Maimes
Research Assistant
Natural Resources
Masters Student

George Fowler
Research Assistant
Civil Engineering
Masters Candidate

New study is looking at parking lot sealant contaminants.

Undergraduate Students

UNHSC supports the University's commitment to undergraduate participation in research. The following UNH undergraduates have been involved in UNHSC research:

Joel Ballestero
Darlene Brown
Andrew Clements
Angela Gong
Eric Hadley
John Heaney
Tim Puls
Matt Shump
Greg Sine
Allison Wasiewski

Technical Advisory Board

The UNHSC thanks the following technical advisory board members for lending their experience and support to the University of New Hampshire Stormwater Center:

Dave Allen
Department of Public Works, Portsmouth, NH

Bob Andoh
Hydro International

Henry Barbaro
Massachusetts Department of Transportation

Dan Cobb
Contech, Inc

Steve Earsom
Federal Highway Administration, Washington, D.C.

Rod Frederick
U.S. Environmental Protection Agency Headquarters

Masoud Kayhanian
Center for Environmental and Water Resources Engineering, University of California, Davis

Ridge Mauck
New Hampshire Department of Environmental Services

Kevin Miller
Department of Public Works, Advanced Drainage Systems, Inc

Dean Peschel
Department of Public Works, Dover, NH

John Sansalone
University of Florida, Gainesville

Theresa Walker
Rockingham County Conservation Commission, NH

Don Waye
U.S. Environmental Protection Agency

Neil Weinstein
Executive Director, Low Impact Development Center

Ex Officio Technical Advisory Board Members

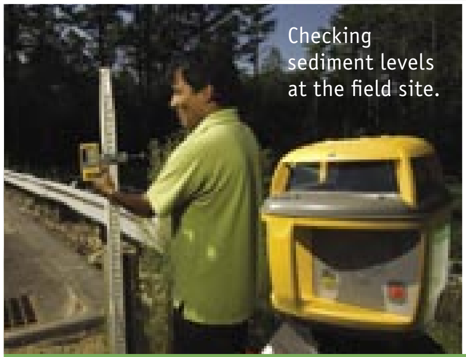
Thomas Ballestero
University of New Hampshire Stormwater Center

Richard Langan
Cooperative Institute for Coastal and Estuarine Environmental Technology

Robert Roseen
Department of Public Works, University of New Hampshire Stormwater Center

Dwight Trueblood
Cooperative Institute for Coastal and Estuarine Environmental Technology


Porous asphalt evaluation is ongoing.


Checking sediment levels at the field site.


In the sampling shed.


Sampling pathogens.

University of New Hampshire Stormwater Center

Gregg Hall, 35 Colovos Road, University of New Hampshire,
Durham, NH 03824 www.unh.edu/erg/cstev

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