Breaking Through UNIVERSITY OF NEW HAMPSHIRE STORMWATER CENTER 2016 REPORT

Stormwater

Breaking through to a new standard of stormwater management

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Fifteen years ago, we set out to study what we thought was a technical problem. Around the country, the old approaches to managing stormwater runoff were not up to the challenges of a changing world, one in which development was on the rise, clean water regulations were tightening, and climate change was bringing increasingly severe storms and flooding. *What if communities had the right technical information,* we wondered, *would they make decisions to protect their water resources and public health?*

That question led to the founding of the University of New Hampshire Stormwater Center in 2004, and we've been opening up the "black box" of how stormwater treatment systems function ever since. We've studied what makes them effective and what makes them fail in a range of conditions, including winter! We've been engaged in every aspect of the stormwater management process—from system design and installation to helping communities with maintenance and monitoring.

We've prepared thousands of students for the workforce, and we've offered professional learning opportunities for even more municipal employees, community volunteers, consultants, and educators.

These efforts, we are proud to report, are breaking through traditional approaches to stormwater management. More and more, stormwater runoff is being regarded as a resource to be reclaimed. New Hampshire, Maine, Massachusetts, New Jersey, Ohio, and Rhode Island are among the states that have incorporated our designs and recommendations in their stormwater manuals, setting a new standard for their communities and creating guideposts for them to get there. Hundreds of municipalities, state agencies, and private landowners have worked with us to install more effective stormwater treatment systems in commercial developments, along roads and highways, and in many other settings. The landscape of stormwater management is changing, slowly, but surely, for the better.

The most important thing we've learned, however, is that the "problem" we set out to solve is less about technology and more about people. Accurate, science-based knowledge is only valuable in the hands of those positioned to use it—leaders who not only have the necessary finances and skill, but also leadership and support from their organization and their community.

As we look ahead, we find our work influenced by a new question: *if the ideal stormwater treatment system design is beyond the reach of what is practical for a community, can we still find simple ways to improve water quality and control flooding?*

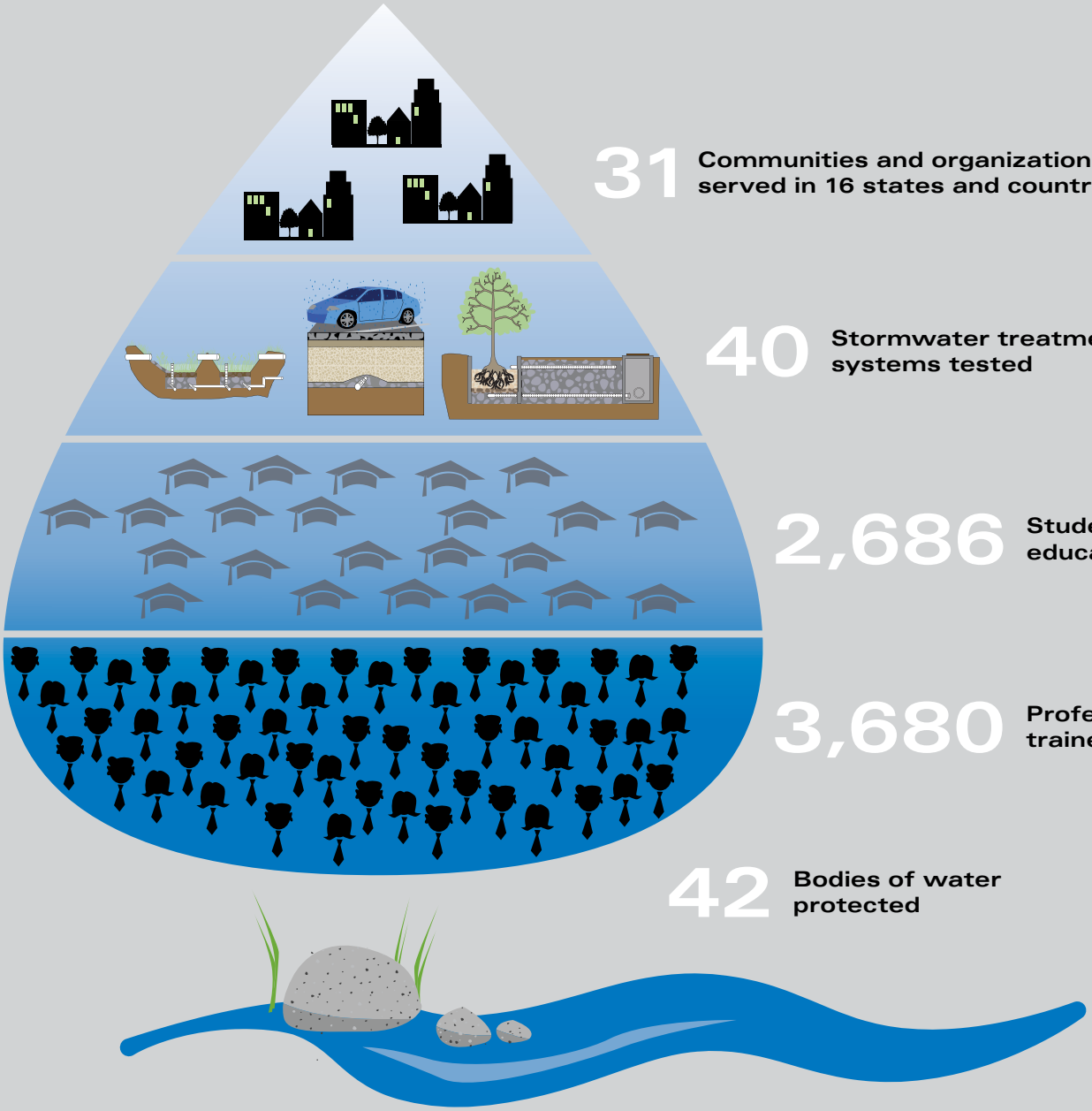
The answer is "yes." We can, we have, and through partnership, every day we learn how to do it better. It is a bright spot for us to know that stormwater drainage is a problem we can address today, one we do not have to carry into the uncertain future of climate change. Our experiences have taught us, however, that solving these problems can only be done through a collaborative process. We invite you to help us continue to put our research and experience to work for businesses, landowners, and communities around the country.

From left: Timothy A. Puls, Research Engineer; Dr. Thomas P. Ballestero, P.E. Director and Principal Investigator; and Dr. James Houle, Ph.D, CPSWQ, CPESC, Program Director

Our mission

The University of New Hampshire Stormwater Center is a dynamic research, testing, and educational facility that serves as a technical resource for water managers, planners, and design engineers in New England and throughout the United States. We are dedicated to the protection of water resources by promoting more effective stormwater management.

UNH STORMWATER CENTER BY THE NUMBERS SINCE 2004



Putting research into practice: stories from stormwater's front lines

Tight budgets, limited resources, new regulations, unexpected problems, citizen concerns, "to do" lists that stretch over decades—stormwater management at the community level is often about how people collaborate and make day-to-day decisions. When faced with a new technology, program managers need to know whether it will mesh with the culture of their organization. Will staff and contractors understand how to install the new systems? Do they have the resources on hand to build them? Can they be maintained without blowing the budget? Will they protect water quality and help meet regulatory requirements?

In 12 years of working alongside communities, we have found that the answer to such questions is "yes" when two essential ingredients are present. The first is a community's capacity to evaluate innovative designs and practices and make them their own. And the first depends on the second—a local champion with the respect, trust, and power to put new science-based stormwater management technologies into practice and inspire real cultural change for the future. These case studies illustrate what can happen when these necessary ingredients for change meet some of the biggest challenges faced by stormwater managers nationwide.

Going the distance along Dover's Berry Brook

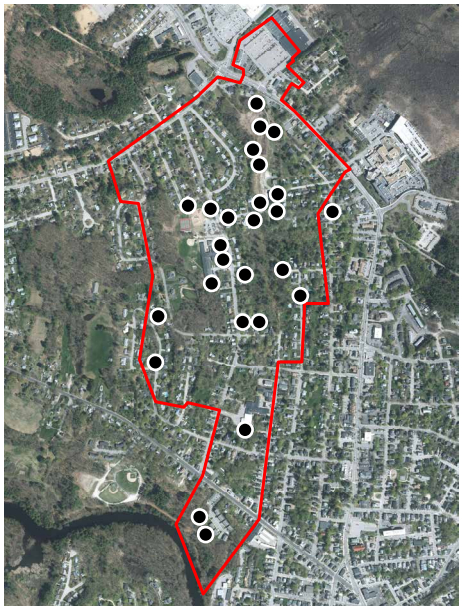
In 2006, Berry Brook became famous for the wrong reason: testing showed that its water quality was severely compromised, and it was deemed "impaired" by the United States Environmental Protection Agency (USEPA) and no longer fit for human contact. A good chunk of the watershed surrounding this short, hard-working urban stream was covered by impervious surfaces that had been channeling polluted stormwater runoff into the brook for decades.

Today, Berry Brook is famous again—this time as a model for how to improve water quality in an urban watershed by using low impact development (LID) and green infrastructure (GI) retrofits, stream restoration, community outreach, persistence, and good old fashioned ingenuity.

Why this work?

Berry Brook flows through the urban heart of Dover, New Hampshire, extending from the city's Miracle Mile through one of its older neighborhoods before joining the Cocheco River, a major tributary of Great Bay. More than 30 percent of the brook's 185-acre watershed is paved roads, parking lots, and buildings.

Stormwater runoff travels over this hardened landscape, picking up pollutants such as lawn fertilizer, pet waste, smog-related pollution, sediments, heavy metals, oil, and road salt and washes them into the brook. So much so that in 2006, Berry Brook joined thousands of other streams on USEPA's federally impaired waterways list, due to its high levels of E. coli bacteria during heavy rains and lack of the aquatic macroinvertebrates that are so important for healthy streams.



New LID retrofits in the Berry Brook watershed.

This designation prompted Dover to take action to clean up the brook. Reducing the impervious cover by ripping up roads and eliminating parking areas in neighborhoods was not in the budget. Nor would it sit well with the surrounding community. Instead, the city developed the Berry Brook Watershed Management Plan, which emphasizes the use of LID and GI retrofits, the improvement of natural resources, and education of property owners. This plan, combined with grants from the Watershed Assistance Section of the New Hampshire Department of Environmental Services (NHDES), opened up an opportunity for collaboration with the UNH Stormwater Center.

What we did

Using the management plan as a guide, we collaborated with the Dover Department of Public Works and Utilities and other staff to filter and reduce the untreated runoff that reaches the brook. We installed 25 LID retrofits, some based on designs tested at our field site and proven for their ability to treat water quality and reduce runoff, and others re-designed by city staff to decrease costs associated with installation and maintenance. By directing stormwater to these systems and the remaining naturally forested areas in this urban watershed, we encouraged runoff to infiltrate into soil—a process that improves water quality, decreases flooding, and reduces erosion.

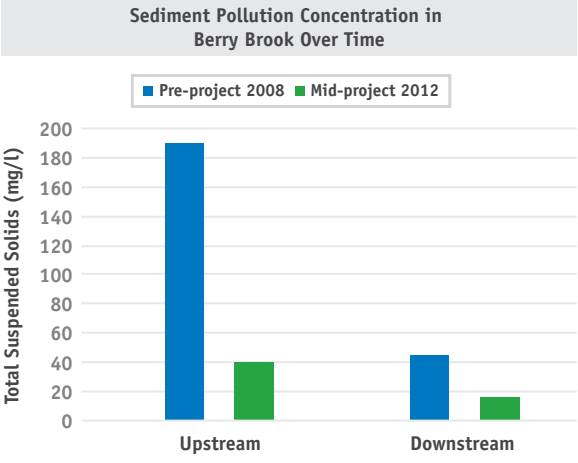
Together, we engineered a new path for parts of the brook based on historic, natural flows and brought more than 1,000 linear feet that had been channeled underground back to the surface. We planted native trees and shrubs to provide shade, prevent erosion, and filter

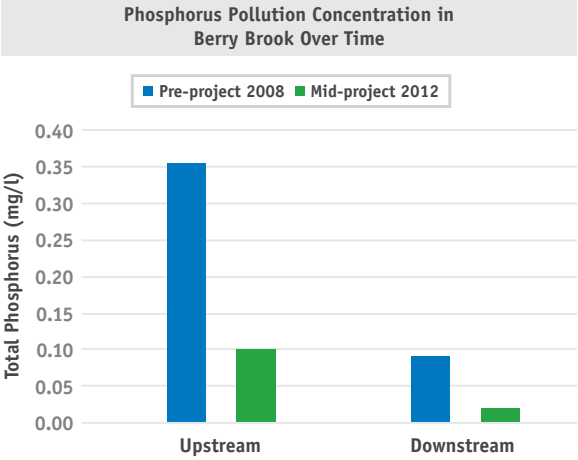
runoff, and we installed a wetland to hold water during heavy rains and slowly release it to the brook during dry spells. We also worked with the city to educate citizens about these efforts and why they were needed. With these improvements, the watershed now functions like a piece of land with less than 10 percent effective impervious cover; water quality is improving; and the city has placed itself ahead of the game in preparing for the new municipal separate storm sewer systems (MS4) permits in New Hampshire.

This project underscored the need to adapt "text book," research-based designs with what is practical for a public works department working in an urban setting. Sharing lessons learned about how to do this is an important step toward helping other communities adopt LID strategies to manage stormwater, according to Sally Soule, the NHDES program manager for the project. "Many communities in our region look to Dover as the leader in LID innovation and implementation. Their story and experience is powerful and it's important to share this knowledge with other municipalities as they set out on the LID journey."

Impacts

- Stormwater controls that effectively remove more than 19 tons of sediment, 710 lbs. of nitrogen, and 127 lbs. of phosphorus annually from the watershed.
- Thirty-six acres of impervious cover disconnected from the watershed, effectively decreasing the impervious cover from 30 percent to 10 percent.
- Dover has its own network of innovative LID stormwater treatment systems, including 16 bioretention systems, a tree filter, a restored daylighted stream, two vegetated swales, two subsurface detention/infiltration systems, three new filtering catch basin retrofits, and a subsurface gravel wetland.
- Established Dover as a regional leader in proactively addressing stormwater requirements and put it ahead of the curve in addressing MS4 permit requirements.





Stormwater Champion: Bill Boulanger

Sometimes, when it's pouring buckets, Bill Boulanger will drive over to the Horne Street School to see how its stormwater systems are handling the deluge. "I'm satisfied with their construction and performance," he says, "they've made a believer out of me."

High praise from a self-defined "construction guy" whose pragmatic attitude as superintendent has set the tone for the city's Department of Public Works and Utilities for 25 years. When he first began to work with LID stormwater systems in the Berry Brook watershed, Boulanger acknowledged it was challenging to figure out how to make these approaches work for Dover. The designs, and the concepts that make them so effective in treating water quality, were new for him, his staff, and the contractors they worked with.

"Maintenance was my major concern," says Boulanger, who was awarded an EPA Environmental Merit Award for his efforts at Berry Brook. "I could see where rain gardens and permeable pavements could collect silt and debris. We had many conversations with the UNH Stormwater Center and came up with a game plan, and it's really worked."

Boulanger collaborated with the Stormwater Center to outfit the rain gardens with catch basins to hold water and collect silt, making maintenance easier. They replaced plants with grasses that could be easily mowed. Lacking equipment to maintain the recommended permeable pavements, they developed the "Boulanginator," a system that mimics the features of permeable pavement through a subsurface storage and filtration component connected to maintainable catch basins. Not only was this system effective at treating water quality, Boulanger's crews used recycled materials they had on hand to build it. They even coordinated installations with other infrastructure upgrades to save money and time and minimize public disturbance.

"Now, my highway crew wants to think about what we can do in projects that don't have stormwater in the plan," says Boulanger (right). "It's changed our thinking."

Ten years and 25 LID systems later, Dover's Berry Brook is on its way to a clean bill of health. Perhaps even more importantly, Boulanger and his colleagues have changed how they approach stormwater across the city. "The nice thing about Berry Brook is that it's like a demonstration site for techniques that we can build and maintain. We know how they work and what they're good for," says Boulanger. "Now, my highway crew wants to think about what we can do in projects that don't have stormwater in the plan. It's changed our thinking and that's true in the community as well. People want to know what they can do on their own property."

The project has put Dover ahead of the curve, and in Boulanger's opinion, it couldn't have happened without the UNH Stormwater Center.

"They've been with us every step of the way. They gave us the initial plans for the systems and found the grant money. There was always someone to help us rethink the designs, install the systems, or talk to the public. Without them as a resource to get us started and show us what we could accomplish, none of this would have been possible."

Right sizing systems in urban areas

The small downtown of Durham, New Hampshire, and Boston's Jamaica Plain may feel worlds apart, but when it comes to managing stormwater, the two places have one thing in common—there's never enough space. While there are hundreds of stormwater designs that could meet standards for water quality in both places, trying to carve out room for them can range from being a major headache to a practical impossibility.

Until recently, this challenge has been compounded by regulations mandating that stormwater systems must be sized to treat the standard water quality volume or risk not getting any credit for water quality improvements from the United States Environmental Protection Agency (USEPA) and other regulatory agencies. But what if these systems could be a fraction of their typical design size, fit in the workable landscape, save money, and still meet water quality standards?

To answer those questions, the UNH Stormwater Center worked with the Town of Durham, Tetra Tech, USEPA Region 1, and the Boston Water and Sewer Commission to test the capacity of "undersized" systems to treat water quality. In the process, we've paved the way for a new standard of practice that can save millions of dollars for municipalities. We've also proven that when it comes to treating stormwater in an urban setting, size doesn't always matter—what used to be considered "undersized" might be the right size after all.

Why this work?

Some problems are just opportunities for learning in disguise. In 2011, Durham was struggling with two such "opportunities." One was a neighborhood stormwater outfall that had fallen into serious disrepair, creating massive erosion, slope instability, and water quality problems. The other was a parking lot in the heart of the town's urban, rapidly redeveloping center. Both places discharged runoff into streams that had been deemed impaired. Committed to a culture of sustainability, the town wanted to install low impact development (LID) approaches that would transform these problems into demonstration sites for the community. However, in both cases, there were obstacles common to stormwater retrofit projects—there was limited space, they had to maneuver around utilities, there were issues with land ownership, and they were starting with conventional drainage systems that simply piped the problem into adjacent water bodies.

Seventy miles south, the Boston Water and Sewer Commission (BWSC) was grappling with related problems. They wanted a cost-effective stormwater plan to support improvements to the ballpark at Daisy Field, one that would preserve the city's treasured "Emerald Necklace" and meet the phosphorus reductions required in the lower Charles River Watershed. Whatever solutions they landed on, both Boston and Durham needed assurance that they would pass muster with models used by USEPA Region 1 to approve site plans.

What we did

In 2014, with funding from the USEPA Region 1 Regional Applied Research Effort (RARE) Program, the UNH Stormwater Center worked with the Durham Public Works Department to evaluate the contributing drainage area and existing stormwater infrastructure at both sites, develop smaller scale designs, and install innovative subsurface gravel wetland and bioretention systems to manage runoff. Over the next two years, we evaluated the capacity of these systems to remove nitrogen and phosphorus pollution in the runoff that came from surrounding impervious cover. Today, both systems meet regulatory standards with respect to the removal of metals, sediment, and nutrients.

"We like to be out front, doing good things to set an example for our residents and other communities," observes Todd Selig, the Durham town administrator. "It's a huge benefit to our collective community for Durham and the UNH Stormwater Center to work together—it's had a real impact on what we do and how we do it. Now all new development is required to have state-of-the-art stormwater plans."

Combined with decades of empirical data collected on different stormwater management systems, the Durham data was used by USEPA Region 1 and Tetra Tech to calibrate and verify the Agency's BMP Performance Curves. These curves are part of the toolkit USEPA provides to help communities forecast the long-term performance of stormwater system and assess if they will comply with water quality standards over time. As a result, the ability to "undersize" systems (or design them to treat less than the standard water quality volume) in certain retrofit situations has become an option for New England communities.

Daisy Field watershed, Boston, Mass.

"The UNH Stormwater Center's ability to bring rigorous research standards to community demonstration sites like the one in Durham makes it an extremely valuable resource for our region," says Ken Moraff, director, Office of Ecosystem Protection, USEPA, Region 1. "They understand the science, they have relationships on the ground, and they are able to deliver reliable data to help calibrate our models so we can help communities select practical, cost-effective treatment systems, while still meeting water quality standards."

The impact of these efforts will soon be felt in Boston as ground is broken at the Daisy Field site. There, the Stormwater Center team worked with the BWSC to use the new BMP Performance Curves to design subsurface gravel infiltration systems that will occupy a fraction of the space of conventional designs, meet the 62 percent phosphorus reduction requirement associated with Charles River TMDL (total maximum daily load), and save the city $1.89 million.

"Anyone would have been able to do this with a design that required four times the space," says John Sullivan, chief engineer at BWSC. "But we expected the UNH Stormwater Center to come up with a design that would fit our criteria in a small space; they know what works and what doesn't."

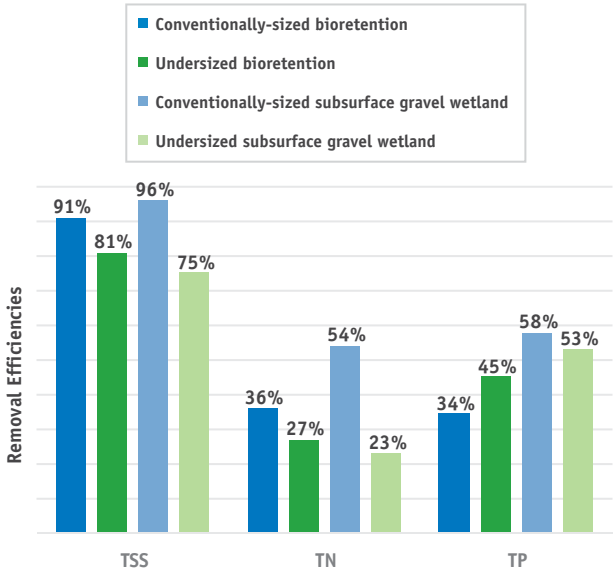
Impacts

- In the Northeast: Newly calibrated models for undersized BMPs that better represent their ability to reduce runoff volume and pollutant loads and a novel way of accounting and crediting for the use of systems sized for less than the WQV.
- In Durham: Installed two cost-effective model stormwater management systems that achieved water quality improvement at a fraction of the standard design size.
- For residential sites: Proof that a site design with an undersized system can prevent soil erosion, improve water quality, stabilize a heavily eroded and entrenched gully, effectively disconnect impervious cover, and improve site aesthetics.
- For urban retrofits: proof that undersized systems can work within the available area to manage runoff and improve water quality in a way that exceeds expectations for conventionally sized systems.
- For Boston's Daisy Field: Designs that achieve required phosphorus reduction with a system approximately one third the size of a conventional design and for $1.89 million less than expected.

Comparison of Capital Costs and Phosphorus Load Removal Efficiency at Daisy Field Site

Best Management Practice Size	Depth of Runoff Treated from Impervious Cover (in)	Storage Volume Cost ($/ft³)	Total Phosphorus Removal Efficiency (%)
Subsurface Gravel Filter: Minimum Size	0.35	$1,016,912	62%
Subsurface Gravel Filter: Moderate Size	0.5	$1,452,732	80%
Subsurface Gravel Filter: Full Size	1.0	$2,905,463	96%

Undersized Compared to Conventionally-sized Systems in Durham



Stormwater Champion: John Sullivan

John Sullivan spends more than his fair share of time asking people to let him build on their property. It can be a tough sell, he acknowledges, but as chief engineer of Boston Water and Sewer Commission (BWSC), convincing property owners that it's in everyone's best interests to work collaboratively on solutions to stormwater drainage is part of the job.

"Everyone understands why you pay for drinking and waste water, but they don't always understand the costs behind stormwater," says Sullivan. "Our job is to figure out how to get it done and educate people about what we want to do. Sometimes it's a major project like the one at Daisy Field, but it's also about routine work, like looking for creative options for infiltration so you avoid damage to underground utilities."

The work is not for the thin-skinned, but you might say Sullivan was born to it. His father was a BWSC engineer, as was his father before him. Sullivan laughs that he was "snookered into" stormwater by his dad who told him he would make "real money."

Forty-four years later, he's still at it. The millions may not have materialized, but as the chief engineer of an organization that is on the hook for managing 1,015 miles of water main and 1,435 miles of sewer pipe and storm drain, the work is always interesting. For example, after spending more than a billion dollars rehabilitating an ancient water distribution system, removing combined sewer overflows, and improving stormwater permit requirements, the BWSC received a USEPA consent decree that called for the city to use more green infrastructure (GI) to reduce the phosphorous pollution flowing into the Charles River.

The Daisy Field project is one example of the commission's response. Currently, a large pipe that collects the combined stormwater runoff from 75 urban acres runs beneath this public ball field. The BWSC saw plans for upcoming improvements to the field as an opportunity to install a GI solution to treat the water within the pipe before it reached the Charles. By focusing their stormwater improvements for those 75 acres into one area with a simpler design, the city saved the costs and headaches of siting multiple GI systems along urban streets with a complicated utility infrastructure.

"It's in the permitting stage now," says Sullivan, "but when it's built, we'll put up interpretive signage so people will know what we are doing with stormwater and how they are part of the solution —that it's their responsibility to help us achieve this goal."

It would have been nice, he observes, to install a large wetland, with natural features, but that would have been space and cost prohibitive. For designs that would meet the commission's needs and pass muster with the board of Boston's Emerald Necklace, they turned to the UNH Stormwater Center.

"Everyone understands why you pay for drinking and waste water, but they don't always understand the costs behind stormwater," says Sullivan. "Our job is to figure out how to get it done and educate people about what we want to do."

"We wanted to make sure that whatever we designed would work, so we went to them," says Sullivan. "We needed someone who understands New England soils and weather, and they have done so much research about this climate, right in our backyard."

Regulations: where effective stormwater management starts

Sea level rise, historic floods and droughts, depleting aquifers, declining water quality—as we look at the future of water resource management, who couldn't use some good news? Here's some: communities can save millions of dollars and prevent tons of pollution from entering the water supply simply by updating regulations. Even better news? It can happen at minimal cost, using existing tools, and it can start now. In the New Hampshire Seacoast region, several towns are updating regulations using model standards that the UNH Stormwater Center developed in partnership with the Rockingham Planning Commission and the Southeast Watershed Alliance. One small step for them; one big step for water quality and cost savings.

Why this work?

Along the Seacoast, stormwater is a leading cause of declining water quality and flooding. Rather than soaking into the ground, where it can replenish aquifers and provide cool, clean baseflow to water bodies, polluted runoff often flows over roads, parking lots, and other hardened surfaces directly into rivers, ponds, and streams. In this rapidly developing region, the problem could get significantly worse, particularly if regulations designed to insure that development uses best practices for stormwater management are out of date and inconsistent. By revising these codes, a community can promote stormwater practices that offer long-term economic, environmental, and social benefits. They can reduce reliance and stress on aging gutters and storm sewers, increase aquifer recharge, minimize flooding, create green space for public use, and improve water quality in local water bodies.

What we did

With support from the Southeast Watershed Alliance (SWA), the UNH Stormwater Center and the Rockingham Planning Commission developed model standards for zoning and land development regulations that minimize the impacts of increased stormwater runoff. These apply to development and redevelopment projects that are subject to site plan or subdivision review by a planning board, which accounts for most commercial, mixed-used, residential multi-family, or subdivision projects. The regulations include a 5,000 square foot "trigger threshold," after which a project must comply with up-to-date regulatory standards. They also encourage green filtration and infiltration practices and a watershed-based approach, as opposed to simply examining potential changes on a site-by-site basis.

With funding from the USEPA Pollution Prevention program, the Stormwater Center collaborated with Vanasse Hangen Brustlin (VHB) and the Strafford Regional Planning Commission to use the Oyster River watershed to compare the financial and ecological impacts of adopting enhanced stormwater regulations to maintaining the status quo. Assuming a projected 26 percent increase in population and 500 additional acres of impervious cover within the watershed by 2040, communities can expect to increase their average annual load of total suspended sediment (TSS) by approximately 109 tons, total nitrogen (TN) by nearly five tons, and total phosphorus (TP) by more than a half a ton. The cost to retrofit stormwater infrastructure to manage this additional impervious cover would be approximately $14 million. This does not account for inflation, nor the potential loss of ecological services or recreational uses as a result of decreased water quality.

However, with enhanced stormwater treatment in place as a result of updated regulations, the predicted average annual pollutant loads could be 70 percent lower. Also, redevelopment projects, which are relatively inexpensive to implement, could provide credits for water quality improvements to their respective communities. For example, over the course of a five-year permit term, municipalities could receive credit for a 1.8 percent decrease in TSS load from the existing baseline, a 1.1 percent decrease in TP load, and a 1.3 percent decrease in TN load. They also could see substantial savings by avoiding the costs associated with retrofits needed to meet future water quality regulations.

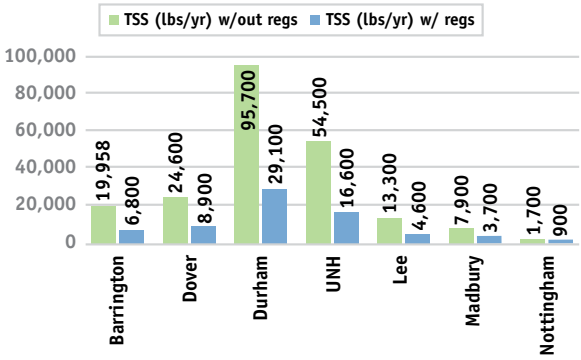
The UNH Stormwater Center worked with SWA and regional partners to share the recommended standards with Oyster River watershed communities, such as Durham and UNH, where up to 70 percent of the future increase in impervious surfaces is likely to occur. Newfields was one of the first communities to explore adoption of these regulations. (See Stormwater Champion story on next page.) With funding from the Piscataqua Region Estuaries Partnership (PREP), other communities, such as North Hampton, Rollinsford, and Greenland, are following suit.

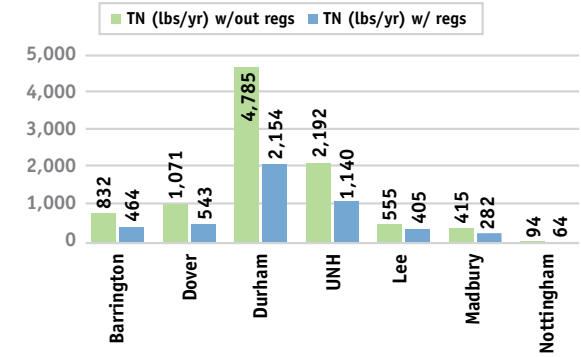
"Our region is facing increasing development pressure and protecting our natural resources is going to take effort from all communities," observes Abigail Gronberg, a technical assistance program manager with PREP. "Consistent stormwater management standards are a step in the right direction by promoting low impact development strategies."

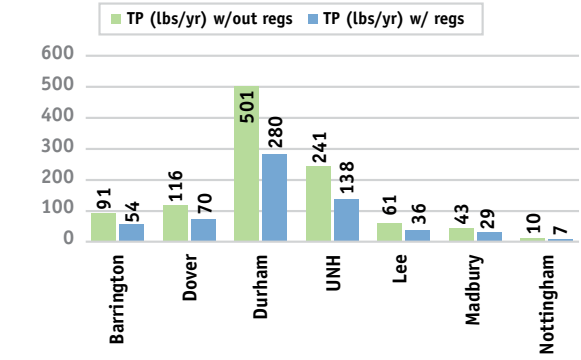
Impacts

- Nine New Hampshire communities adopted, or are poised to adopt, stormwater regulations to protect water quality and reduce cost to communities; PREP pledged $48,000 to assist towns with adoption of updated standards in 2016.
- Communities throughout the Great Bay watershed have resources to change their stormwater regulations and save hundreds of millions of dollars in avoided costs.
- Through updated standards, hundreds of pounds of harmful pollutants will be prevented from reaching threatened waterways through the redevelopment process.
- New development projects throughout the state's Seacoast are implementing up-to-date stormwater management controls that promote hydrologic transparency and minimize polluted runoff.

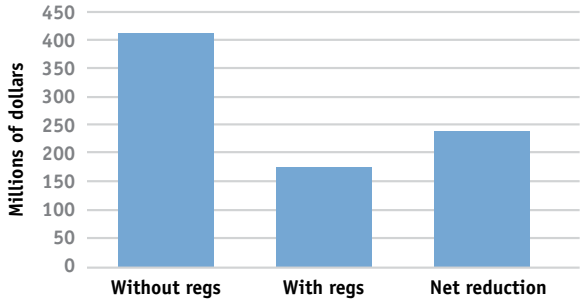
Estimated Effect on Future TSS, TP and TN Loads (lbs/yr) Due to Stormwater Regulations







Cost Avoidance for Great Bay Watershed



Stormwater Champion: Clay Mitchell

Can't sleep? Try reading a stormwater regulation. The dry legalese can be more effective than counting sheep and safer than sleeping pills. Unless you're Clay Mitchell, that is. When he looks at the new stormwater regulations for the Town of Newfields, he sees a story that anyone can engage in.

"Newfield's regulations were developed with a flexible, narrative structure that everyone can understand and use in meetings," says Mitchell, who became the town planner in 2008. "This supports the culture of our planning board. They are very collaborative and focused on reducing the pollution that flows into Great Bay."

"It's great to be part of a community where you are starting with so much green space," says Mitchell. "People know we have a responsibility to protect it and the Great Bay."

The board took a hard look at becoming more progressive about stormwater back in 2012, when Newfields was identified as a possible Municipal Separate Storm Sewer System (MS4) community by the United States Environmental Protection Agency. "For a small town like ours, having to upgrade our sewage infrastructure could be traumatizing," says Mitchell. "We realized we could look for other ways to divert nitrogen from flowing into the Bay and stormwater was the logical next step."

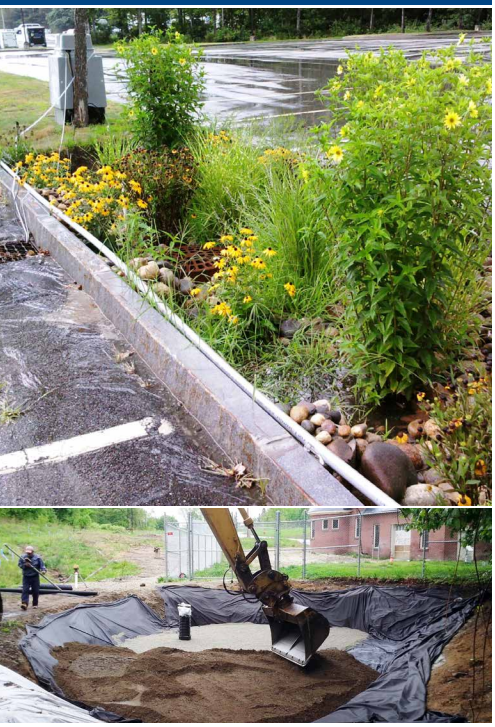
Using the model regulations developed by the UNH Stormwater Center and the Southeast Regional Watershed Alliance as a foundation, the planning board developed a new set of rules that emphasized reduction of nitrogen. "Working with the Stormwater Center's recommendations gave us objective data about stormwater solutions that would meet our goals," observes Mitchell. "Knowing before we started what would work and what wouldn't saved a lot of time and effort."

It also led to regulations that have allowed Newfields to be more creative as it works to reduce nonpoint source pollution. "Now, the application process creates opportunities for us to make real change," says Mitchell, citing a recent redevelopment application that led to an opportunity to improve the town's drainage system. "Everyone is getting more aggressive about sustainability at their sites. We're committed to it, and we've legislated that commitment."

With these regulations in place, Newfields is already looking for other ways to improve stormwater drainage infrastructure in the village center and along state roads that run through the town. Efforts like these will put Newfields in a stronger position to comply with MS4 requirements should it become a designated community in the future.

"It's so much better to be able to discuss these changes in this context than under a federal mandate," says Mitchell. "I grew up in Arizona where you talk about developments in terms of miles, not acres. It's great to be part of a community where you are starting with so much green space and people know we have a responsibility to protect it and the Great Bay."

Bioretention systems



Soil media composition largely determines a bioretention system's ability to treat water quality.

Overview

Bioretention systems and rain gardens are a flexible, reliable approach to treating stormwater runoff. Although these were some of the earliest low impact development (LID) systems to be put into practice, we still have much to learn about their design functions and optimization. On face value, their water quality treatment process is simple. Runoff collects in a landscaped depression, where it ponds, filters through the soil media, infiltrates into the ground or is collected by underdrains, and then discharges to the surface. The nuances of the design are fundamentally driven by perspective: are these intended to be media filters that support vegetation, or are they landscape features that allow for filtration of runoff? This distinction may be subtle, but it has led to an extraordinary variety of designs and soil specifications that impact water quality treatment performance. For example, many designs call for compost and other organic materials that may improve vegetation growth, but unfortunately also can leach nutrients, such as phosphorus and nitrogen, into the system and out into receiving waters.

Since 2004, we have evaluated seven bioretention system designs at our field site. We've also conducted more than two dozen laboratory studies that explore water quality treatment performance of different soil configurations. We have found that the composition of the soil media largely determines the effectiveness of water quality treatment, yet standardized soil specifications to support this treatment capacity are in short supply. In contrast, soil specifications for landscaping features are prolific; however, their focus is on sustaining plant health. Based on our research, we developed a bioretention soil mix (BSM) specification for systems that are used predominantly for urban drainage control and the management of nutrient pollution that can be found here: https://www.unh.edu/unhsc/sites/default/files/media/unhsc_bsm_spec_10-3-16.pdf

Plants stabilize the soil and their dense vegetative mats tend to reduce clogging and minimize maintenance burdens, but their overall role in water quality treatment is less clear. Swapping native landscape plants for fescue and ryegrasses, for example, did not reduce the pollutant removal efficiency of any bioretention systems monitored to date. Landscaping with native plants may offer other benefits, such as providing habitat or improving curb appeal; however, it changes the maintenance burden. If the goal is to use bioretention systems to manage large areas of runoff, maintenance concerns should dictate

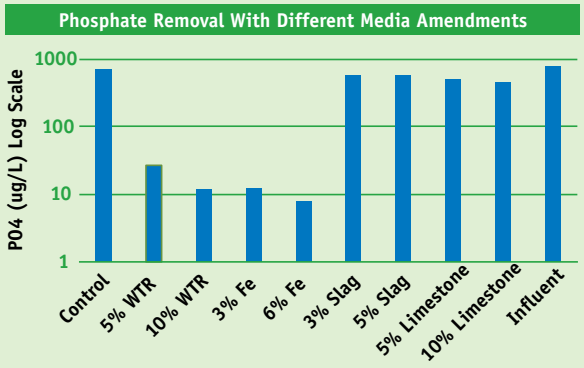
SOIL MEDIA AMENDMENTS FOR BIORETENTION SYSTEMS

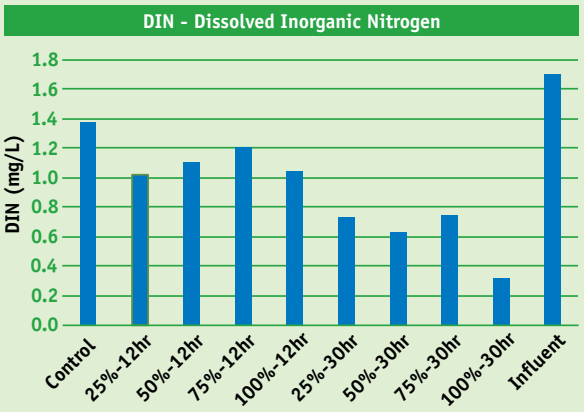
Recommendations on the type of compost that may be added to soil media vary. Unfortunately, the stormwater literature offers few details about the impact of different types of compost on a system's water quality treatment, leaving designers to incorporate compost that may or may not lead to expected pollutant load reductions.

After extensive study of this issue, we found that bioretention systems routinely demonstrated nutrient removal efficiencies that are far below common values used in historical pollutant loading models. This prompted us to conduct dozens of column studies of various configurations of soil media in order to identify an optimized bioretention soil mix (BSM) for nutrient removal.

As a result of these studies, we eliminated compost, a common source of phosphorus, in our soil specifications. In situations where phosphorus reduction is desired, we recommend a BSM that includes processed drinking water treatment residuals (WTR) or iron filings at 5 percent (by volume). For nitrogen removal, the inclusion of an internal storage reservoir (ISR) is necessary. We tested multiple ISR configurations, focusing on two primary variables: the size of the ISR as a fraction of the WQV (water quality volume) and the residence time.

These studies showed that systems need to be designed to increase the residence time of runoff in the ISR to allow for more interaction with the BSM. This is done by reducing the system's outlet control to increase overall residence time. While this may increase system bypass, the penalty on other potential pollutant removals has not been well studied. Modeled results suggest that the benefits for TN removal far outweigh the potential negatives for other pollutants of concern. Regardless, site specific design configurations should be tailored to the overall pollutant of concern.





plant selection. In general, our research has indicated that it is better for systems to be maintained so they function correctly, rather than to look beautiful for a year or two, then fall into disrepair due to lack of upkeep. Naturally, one of the primary benefits of bioretention systems is that they can provide both functions, given appropriate design and maintenance.

Implementation

While bioretention systems and rain gardens are used throughout the United States, their acceptance varies regionally. In general, a bioretention system has hydraulic design components, such as underdrains and high-flow bypass structures, that are more appropriate for managing larger areas of urban runoff. Rain gardens typically lack such features and are used to manage smaller watersheds in more residential areas. There is generally little risk associated with their installation, thus designs tend to be simple with less oversight.

Siting these systems in appropriate soils is key to the ensuring their effectiveness. To maximize their capacity to reduce runoff volume, they should be located in infiltrative soils, those in the hydrologic soils group "A" (sand, loamy sand, or sandy loam with high infiltration rates) and group "B" (silt loam or loam with moderate infiltration rates). We have observed that properly designed and installed bioretention systems often exceed design expectations for runoff volume reduction, largely due to the fact that infiltration flows through the bottom and sides of these systems. Most models typically account only for bottom infiltration; they also assume saturated flow conditions, which seldom occurred in the systems we evaluated.

Design and Sizing

Design and sizing of these systems is often dictated by local stormwater management regulations or state standards. The most common design approaches involve static sizing, in which the storage volume capacity of the system equals the water quality volume of the drainage area. Other design methods include dynamic sizing, where infiltration rates of the bioretention soil mix (BSM) are used to determine the necessary filter area, and percent watershed sizing, in which the filter area is required to be a certain percentage (typically 5 percent) of the contributing drainage area.

The BSM is central to a bioretention system's capacity for flow control and water quality treatment. The hydraulic conductivity or infiltration rate capacity of a BSM varies with its composition. Often a BSM (mostly sand) will far exceed the older, and often referenced, standard infiltration rate of 0.5 inches per hour by 20 to 40 inches. Many of the original targets for infiltration rates are artifacts of old specifications still found in many state stormwater manuals. Modern mix designs should be based on the soil's particle size distribution, which is more representative of the system's true infiltration capacity, particularly in urban areas where hydraulic loading ratios of drainage area to treatment area are high.

There are diverse opinions on the appropriate vegetation for these systems. In general, we have found that vegetation cover should be determined by the system owner's ability to maintain the plantings. There are many examples of beautiful bioretention systems that become overgrown with weeds and inundated with sediment and trash due to lack of maintenance. Mowing is a commonly employed maintenance practice for many municipalities, while tending perennial plants might be unfamiliar and perceived as more labor intensive. Our research has not uncovered any water quality advantage or disadvantage dictated by the selected vegetation. Dense and stable coverage, however, is important for maintaining infiltration rate capacity.

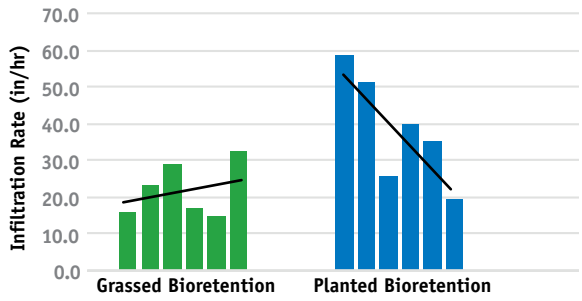
Maintenance

With appropriate vegetation, bioretention systems require minimal maintenance. The highest maintenance burden occurs during the first two years of operation as the plants grow and the system stabilizes. Once vegetation is established, maintenance generally decreases and becomes more predictable, similar to what is required for standard landscaping. Common maintenance tasks include seasonal mowing, raking, and pruning of vegetation. The average annual maintenance costs and personnel hours required for the bioretention systems we studied were $1,820 and 21 hours of labor per acre of impervious cover treated.

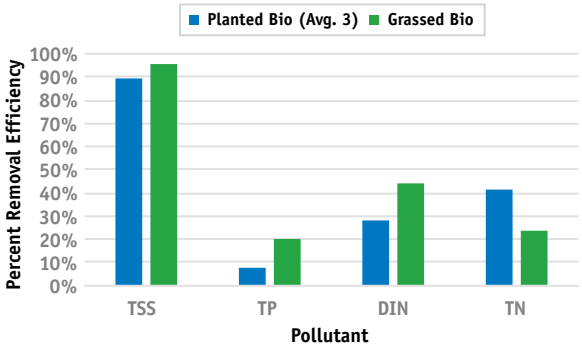
Performance

All of the bioretention system designs we studied were effective at removing most stormwater sediment-bound pollutants. (See chart at top right.) However, nutrient removal capacity is more variable. Performance changes seasonally. Total phosphorus (TP) treatment trended toward 20 to 30 percent removal, a performance that could be improved through limiting phosphorus levels in the soil media by reducing the amount of compost and/or the addition of amendments that scavenge phosphorus, such as water treatment residuals (WTR) and iron filings. These limitations have led to the emergence of innovative bioretention systems that incorporate additional unit operations and processes to address nutrient removal. **More information may be found on our website at www.unh.edu/unhsc.**

Average Infiltration Rates of a Planted (blue) versus Grassed (green) Bioretention Systems Over Time



Comparison of Pollutant Removal Efficiency Planted vs Grassed Bioretention

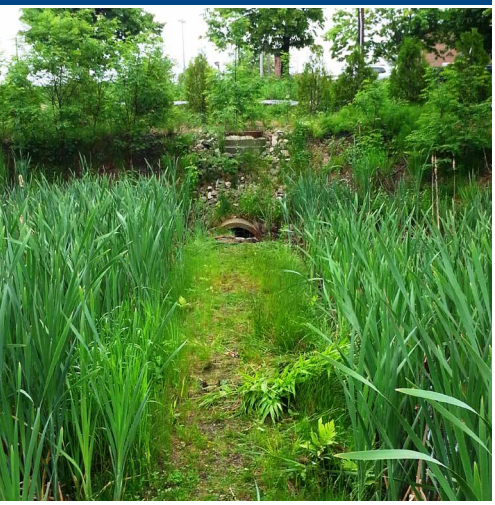


Installation Cost

To support the use of green infrastructure in New England, the UNH Stormwater Center worked with the United States Environmental Protection Agency Region I, Tetra Tech, and other partners to estimate the cost of stormwater treatments like bioretention systems in 2016 dollars. The cost memorandum used to arrive at the figures in the table below can be found at https://www.unh.edu/unhsc/sites/default/files/media/epa-cost-memo.pdf.

Bioretention System	Materials & Installation Cost ($/cf)	Design cost ($/cf)
Low difficulty	10.05	5.41
Moderate difficulty	20.10	10.82
High difficulty	30.15	16.23

Subsurface gravel wetland



Subsurface gravel wetlands have demonstrated exceptional water quality treatment in a range of land uses, including commuter parking, high-density commercial development, and along major transportation corridors.

Overview

After 12 years of study at the UNH Stormwater Center field site and at installations around the Northeast, we've found the subsurface gravel wetland to be one of the most highly effective stormwater management systems in practice today. This horizontal flow filtration system approximates the look and function of a natural wetland, while effectively removing pollutants from runoff, reducing peak stormwater flows, and enhancing the visual appeal of the landscape.

With its diverse vegetation, dense root mat, internal storage reservoir, and anaerobic microbe rich environment, this system incorporates most of the unit operations processes (UOPs) that support water quality treatment, making it an ideal testbed for design improvements to single UOP systems, such as ponds or basins.

Iterations of the designs we've tested are now part of the stormwater manuals for the states of New Hampshire, Rhode Island, New Jersey, and likely many others. We've worked directly with public agencies and private firms to install dozens of these systems throughout the Northeast, most notably along Interstates 95 and 93, New Hampshire's Route 16, and in developments in Greenland and Durham, N.H.

These installations have given us better insight into how this system functions and allowed us to modify its design over time. Most notably, we've modified this system so it can be better adapted for popular locations for installation, such as along linear highways or in rights of way.

Implementation

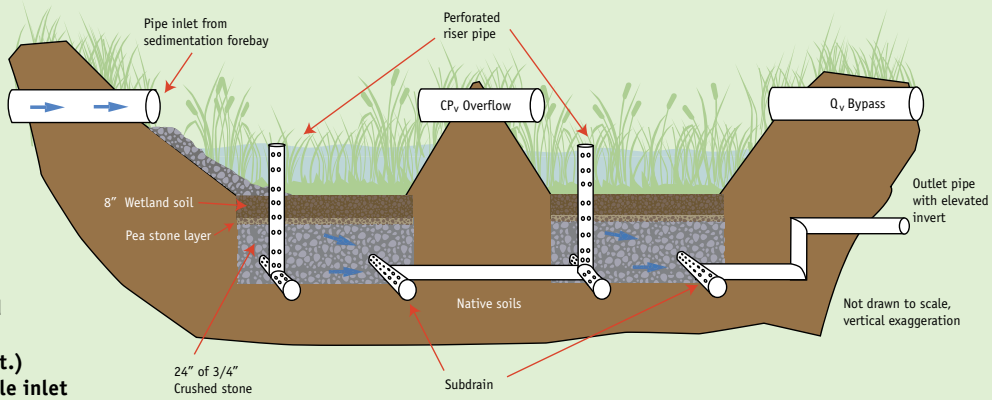
Subsurface gravel wetland use is increasing, especially in areas that have impaired waters or other needs for higher standards of water quality treatment. They can be used in most regions, with the exception of extremely arid areas or those in which native soils are too permeable to support a saturated wetland system. Subsurface gravel wetlands have demonstrated exceptional water quality treatment in a range of land uses, including commuter parking, high-density commercial development, and along major transportation corridors. While they can be space intensive, they can be easily retro-fitted. (See page 6.) Like any infiltration or filtration system, if these wetlands are to be used in pollution hotspots, they should be lined and outfitted with subdrains that discharge to the surface. Dissolved oxygen levels may fluctuate within biologically active subsurface systems like these. If this is a problem for local receiving waters, it can easily be dealt with by introducing turbulence and aeration in the outlet design.

In cold climates, the subsurface gravel wetland's water quality treatment and peak flow control capacity remained strong year round. Because the system's primary flow path is subsurface and water enters the system through perforated riser pipes or other appropriate hydraulic inlets, freezing of the wetland surface does not as easily impact flow through the system. While nitrate removal declines during the winter season, it still surpasses the performance of any other treatment system we have studied in cold climate areas. This is due to the

SUBSURFACE GRAVEL WETLAND SCHEMATIC

Our research indicates that the design of hydraulic inlet and outlet controls for subsurface gravel wetlands can be flexible.

If an inlet control has a greater hydraulic capacity and efficiency than the primary outlet control, numerous configurations are possible. For example, we've tested the use of slotted hydraulic inlet pipes as backup for a primary inlet composed of woven geotextile laid on the subsurface pea stone and covered in 6– to 8–inch diameter stone around the outfall of the inlet pipe. (See figure at right.) This provides a more accessible and maintainable inlet at the surface, protects the stone filter, and is easier and less costly to construct.



Advances in the use of precast concrete structures have led to outlet controls that also are more maintainable and allow for multiple hydraulic controls. The most important design parameter is to ensure protection of the "clean" side of the low flow orifice control from any windblown or high flow conveyed debris that could clog the system and increase the need for maintenance. (See figure at far right.)

wetland's use of microbial mediated processes to remove nitrogen, rather than relying on the seasonal uptake into vegetation.

Design and Sizing

The rectangular footprint of the UNH Stormwater Center design occupies 5,450 square feet and can accommodate runoff from up to one acre of impervious surface. It includes a pretreatment forebay, followed by two flow-through treatment basins, though other pretreatment approaches may be used. Each basin is lined and topped with 24 inches of gravel and 8 inches of wetland soil. The treatment cells host a diverse mix of native wetland grasses, reeds, herbaceous plants, and other wetland species.

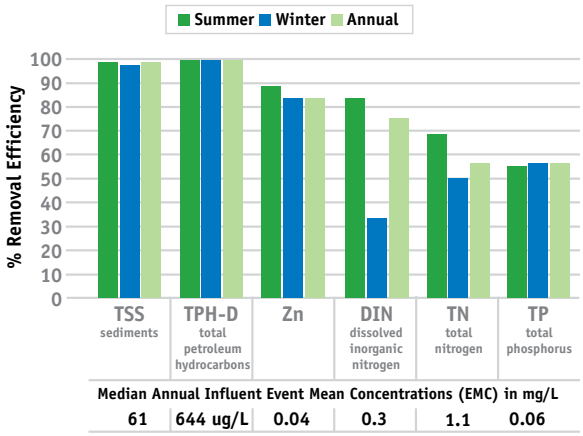
Maintenance

Removal of vegetation should occur at least once every three growing seasons. The dense vegetation appears to have little problem with invasive plants. Maintenance also includes the removal of accumulated sediment and plant biomass in the forebay and treatment cells, a procedure that supports long-term nutrient uptake. Overall maintenance is critical to ensure that runoff flowing into the system remains well-aerated before it enters the denitrifying environment of the subsurface. Forebay maintenance prevents the reintroduction of pollutants, particularly nitrogen and phosphorus, and reduces the maintenance burden on the treatment cells.

Performance

The subsurface gravel wetland does an exceptional job of removing nearly all of the pollutants commonly associated with stormwater treatment performance assessments. Subsurface gravel wetlands consistently exceed USEPA's recommended level of removal for total suspended solids and meet regional ambient water quality criteria for nutrients, heavy metals, and petroleum hydrocarbons. The chart at the upper right reflects the subsurface gravel wetland's performance in removing total suspended solids, dissolved inorganic nitrogen, total nitrogen, and total phosphorus. Values represent results recorded over seven years, with the data further divided into summer and winter components.

Pollutant Removal: 2004–2010



Subsurface Gravel Wetland Soil Specifications

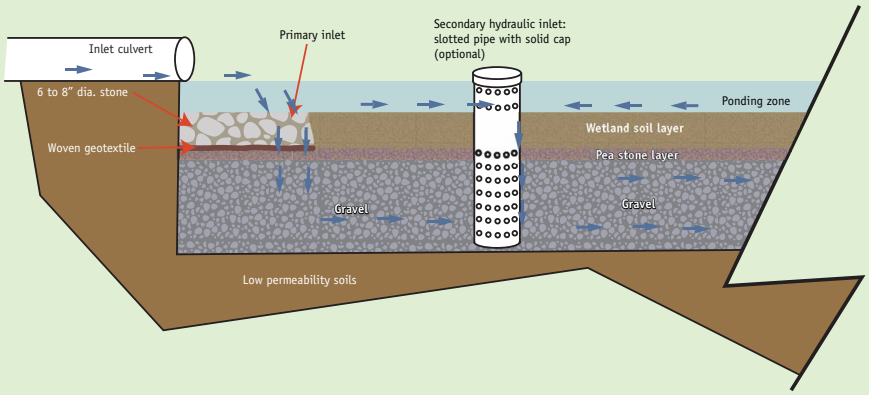
US Standard Sieve Size in/mm	Percent Passing	Percent Passing Testing Tolerances
0.5/12.5	100	± 10.0
#10/2.00	75-90	± 5.0
#100/0.15	40-50	± 5.0
#200/0.075	25-50	± 5.0

Installation Cost

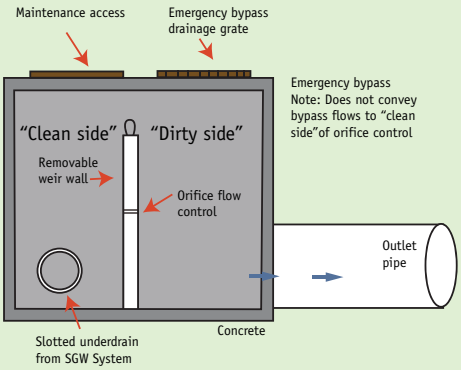
To support the use of green infrastructure in New England, the UNH Stormwater center worked with the United States Environmental Protection Agency Region I, Tetra Tech, and other partners to estimate the cost of stormwater treatment systems like the subsurface gravel wetland in 2016 dollars. The cost memorandum used to arrive at the figures in the table below can be found at https://www.unh.edu/unhsc/sites/default/files/media/epa-cost-memo.pdf

Subsurface Gravel Wetland	Materials & Installation Cost ($/cf)	Design cost ($/cf)
Low difficulty	5.71	3.07
Moderate difficulty	11.41	6.15
High difficulty	17.12	9.22

ALTERNATIVE INLET



ALTERNATIVE OUTLET



Tree filter

Though small, tree filters can manage runoff from the numerous lighter rain events that make up the majority of the annual rainfall in most regions. This makes them valuable assets in treating areas with large amounts of impervious cover.

Overview

An excellent example of the inherent adaptability of low impact development (LID) systems, the tree filter leverages landscaping to improve drainage in an urban setting. On the surface, these systems present much like conventional street trees. Underground, however, they are designed to facilitate filtration, infiltration, and even storage of stormwater runoff. These designs can vary widely—from single-tree, off the shelf, proprietary structures to large-scale urban retrofits, known as "tree trenches," with multiple trees connected by underground infiltration and a reservoir that maximizes runoff storage and retention. The tree filters we've tested have outperformed our expectations for volume reduction. Though small, they are able to manage runoff from the numerous smaller rain events that make up the majority of the annual rainfall in most regions. This capability makes them valuable assets for managing areas with large amounts of impervious cover.

Implementation and Practice

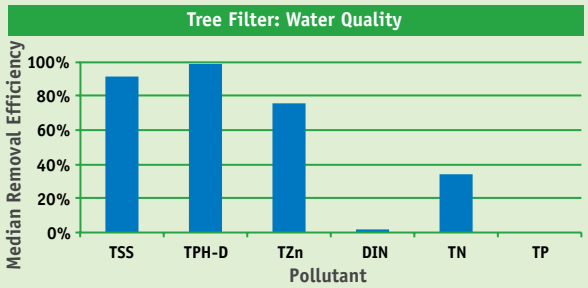
Tree filters can be used in many development and LID retrofit scenarios; they are especially useful in settings where minimal space is available. In urban areas like Philadelphia and New York City, they are used in the design of integrated street landscapes—a choice that transforms isolated street trees into stormwater filtration devices. They can be installed in open-bottomed chambers in locations where infiltration is desirable, or in close-bottomed chambers if infiltration is impossible (clay soils) or undesirable (high groundwater or contaminated soils). These chambers can include lateral openings or be combined with structural cells to provide soil and space for root growth under sidewalks and other pavements.

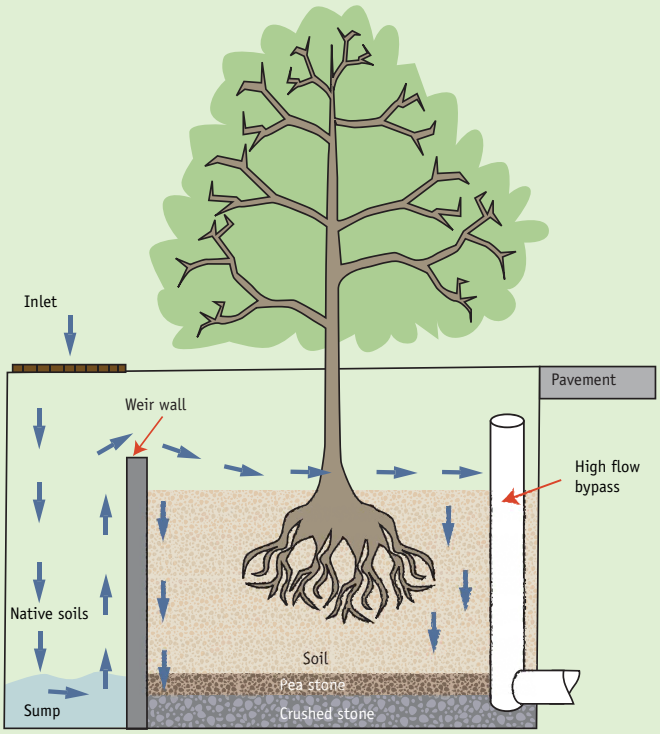
Sizing and Design

In general, tree filters are sized and spaced much like catch basin inlets. When the primary objective is stormwater runoff storage or long-term detention, their designs can be adjusted for more reservoir storage space and detailed underdrain and orifice control configurations.

Common catch basin drainage areas may range from 3,000 to 30,000 square feet of impervious cover. Alternatively, they can be sized to support a desired water quality flow rate or storage capture volume. We have evaluated multiple tree filter systems that drain areas ranging from 5,000 to more than 250,000 square feet.

TREE FILTER DESIGN SCHEMATIC





Our research indicates that while tree filters can provide shade, habitat, street beautification, and stormwater control, they can't be designed to maximize all of these benefits simultaneously. Therefore, the primary management objectives should inform their final configuration. If that goal is stormwater management, then soil media composition and tree selection are critical. Tree species should be selected for the growing zone and street conditions. Because these trees typically receive large volumes of water during storms, they need to tolerate wet and dry conditions well. In cold climates, where street de-icing regularly occurs, they should have high salt tolerance. Soil media is the dominant factor in determining pollutant removal. Prescribed soils are typically coarse with high infiltration rate capacities. In such cases, trees may need to be replaced every seven to 12 years. If the primary objectives are street beautification, habitat creation, and shading, then one could consider different tree species and combine them with design elements that prevent soil compaction from foot and vehicle traffic, such as grates and Silva Cells.

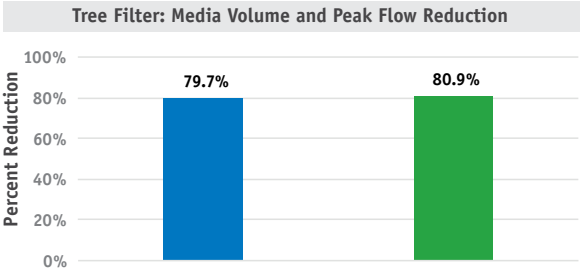
Maintenance

Both conventional street trees and stormwater tree filters require maintenance, which can vary from routine litter collection to raking and removal of the fine sediments that collect on the surface of the soil media. Other activities may include replanting or removal of certain tree species every seven to 12 years. While there are few commercially available tools for maintaining the surface of these systems, Vactor truck attachments and handheld power rakes could be modified to accomplish relatively simple maintenance tasks.

Installation Cost

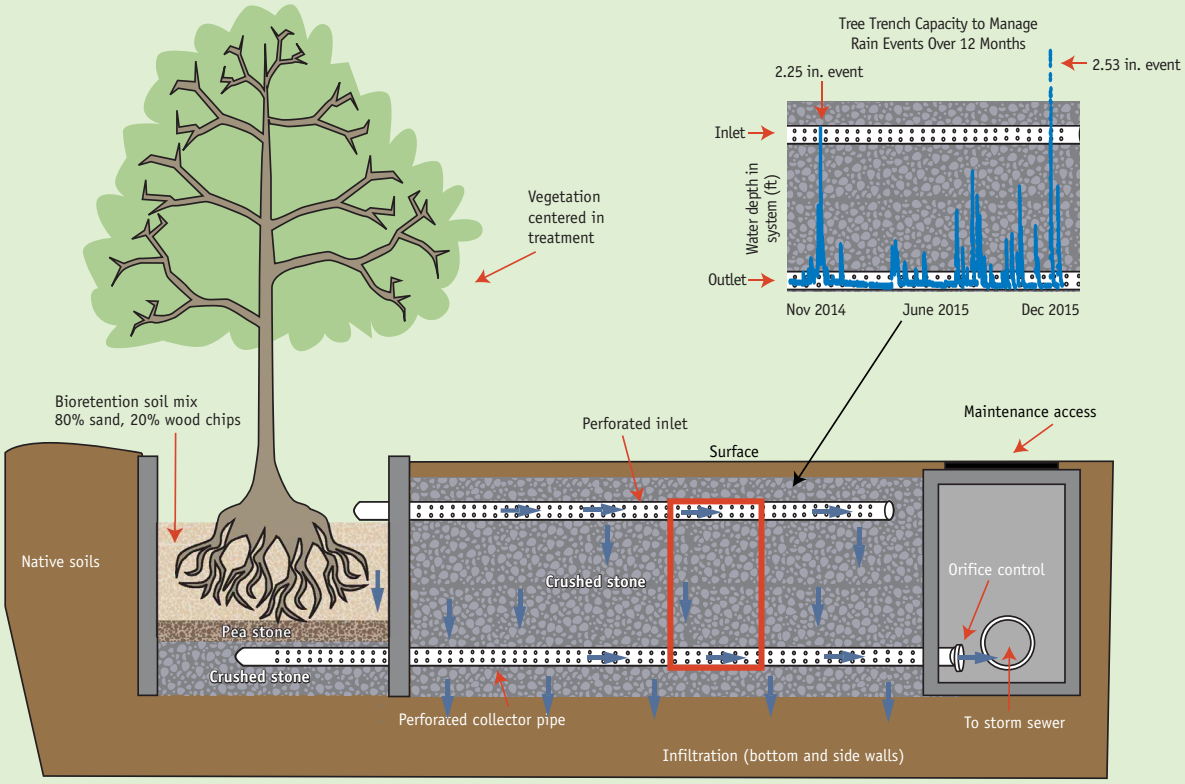
The cost of tree filters ranges from roughly $3,000 to more than $20,000 for proprietary systems. Since they are often sized for water quality flow rates, cost estimates per cubic yard of storage capacity are difficult to calculate. Recent innovations in these technologies approximate typical bioretention or infiltration trench design. The Philadelphia tree trench is more of a linear infiltration trench with trees planted in it for aesthetic reasons.

To support the use of green infrastructure in New England, the UNH Stormwater Center worked with the United States Environmental Protection Agency Region I, Tetra Tech, and other partners to estimate the cost of stormwater treatment systems like the tree filter in 2016 dollars. The cost memorandum used to arrive at the figures in the table below can be found at https://www.unh.edu/unhsc/sites/default/files/media/epa-cost-memo.pdf.

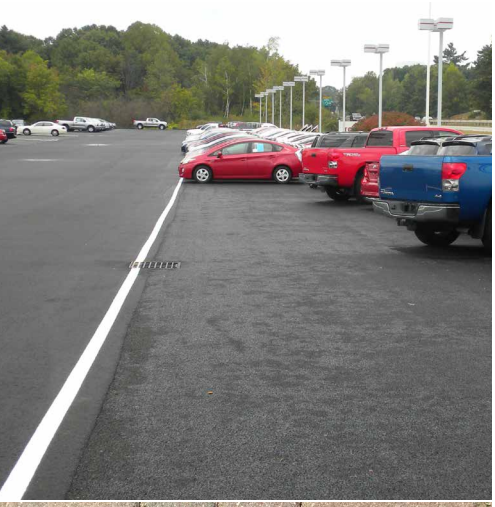


Tree Filter	Materials & Installation Cost ($/cf)	Design cost ($/cf)
Low difficulty	8.12	4.37
Moderate difficulty	16.24	8.74
High difficulty	24.36	13.11

ALTERNATIVE SCHEMATIC



Permeable pavement



Permeable pavements like porous asphalt (above) and permeable interlocking concrete pavements (below) are powerful tools for addressing water quality targets in urban areas.

Overview

One of the most rapidly expanding practices used to protect urban watersheds and aquifers, permeable pavements have come a long way in the past ten years. Recent advancements in technical design specifications and improved material selection have made these systems a powerful tool for engineers and developers who work in urban areas and face ever tightening water quality treatment and volume reduction performance standards.

Each of the three primary types of permeable pavements use different surface materials to transform what would be an impervious road or parking lot into a tool to encourage stormwater infiltration. Porous asphalts (PA) combine bituminous binders with polymers and open graded gravel to create a surface that allows water to freely flow into the subbase. Permeable interlocking concrete pavements (PICP) are comprised of precast paving units with open spaces filled with permeable stone; and pervious concrete (PC) uses open graded gravel aggregate and high strength cement mixtures to yield a high porosity surface. Regardless of the type of permeable surface, the subsurface is where the action is; the materials there create a multi-function system that can support vehicle use and retain, filter, and infiltrate large volumes of stormwater runoff.

Implementation

With proper design, production, installation, and maintenance, we have found that permeable pavements can function as excellent transportation structures and stormwater treatment systems. Choosing the right system for a particular situation, however, depends on its design and composition. Recent advancements in performance grade asphalt binders have largely solved durability and tensile strength issues with PA, making it a strong choice for many situations and regions. Some performance grade asphalt binders (PGAB), such as 64-28 with fibers, are no longer suitable for a pavement's top layer. Instead, we recommend polymer-modified PGAB.

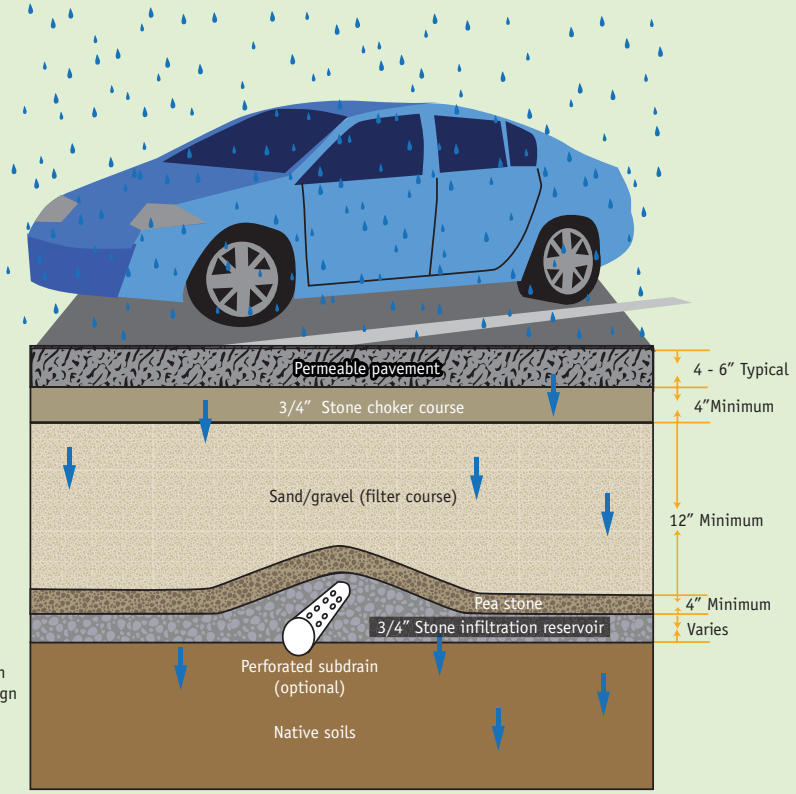
PICP remains a highly effective and durable option as well. While installation costs may exceed other options, the product quality and aesthetic appeal are difficult to rival. PICP can add a strong architectural flair to a site, while providing tremendous water quality and volume reduction benefits. PC is not yet practical for cold climates, due to its tendency to deteriorate as a result of winter salt applications. However, for locations where salt and deicing chemicals are not applied, it remains an excellent option.

PERMEABLE PAVEMENT DESIGN SCHEMATIC

All permeable pavement designs are complete systems. They include the same components of any effective stormwater control measure, but these can be designed and configured to meet site-specific objectives.

For example, the permeable component—whether it's asphalt, pavers, or concrete—can be viewed simply as a hydraulic inlet that can be supplemented with secondary inlets in case the surface clogs. Similarly, putting the reservoir course above the filter course creates unique configurations that reduce mounding and protect adjacent properties. Subbases also can be altered to enhance nutrient removal. We've even had success with designs that combine a subbase characteristic of permeable pavements with alternative hydraulic inlets, thereby allowing the use of impermeable pavements at the surface.

In general, our research has shown that as long as there is a deep subbase and appropriate materials are used, permeable pavements tend to be resistant to freeze-thaw and effective in reducing stormwater volume and pollutant load.



Please note: This design includes a subbase design for cold climates and drainage for low permeability soils.

Design and Sizing

Design and sizing considerations for the subbase that lies beneath the top surface of any permeable pavement are similar. These subbases consist of a choker or leveling course, an optional filter course, a filter blanket or setting bed, and a reservoir course where the water quality volume is stored.

We have studied the use of a filter course in many of our permeable installations to improve the system's water quality performance and found its fine gradation enhances filtration and delays runoff by slowing the downward flow of water. This function is complemented by an underlying filter blanket or setting bed that prevents downward migration of finer materials into the reservoir course. There, the high air void content of the uniformly graded crushed stone maximizes storage of filtered water and allows more time for water to infiltrate into the native soil below. It also creates a capillary barrier that arrests any upward vertical water movement.

An optional perforated or slotted drainpipe can be installed in the reservoir course to provide hydraulic relief; this pipe is typically raised off the bottom of the stone layer for enhanced infiltration or groundwater recharge. Nonwoven geotextile filter fabric (geotextile) is used only for stabilizing the sloping sides of the pervious pavement system excavation: in general, it is not to be used on the bottom or in the vertical cross-section of the system unless needed for structural reasons. Filter fabrics are not recommended as a horizontal layer in any filtration or infiltration system as they frequently clog and can't be maintained. There are a variety of guidance materials, which should be consulted for proper design, including:

- Porous Asphalt: UNHSC Design Specifications for Porous Asphalt Pavement and Infiltration Beds;
- Permeable Interlocking Concrete Pavement: ICPI Permeable Interlocking Concrete Pavement 4th For Design Professionals;
- Pervious Concrete: ACI 522.1-13 Specification for Pervious Concrete Pavement.

Maintenance

If the goal is long-term, effective performance, then permeable pavements require maintenance. In general, this involves inspections that measure surface infiltration rates and routine vacuuming two to four times annually to remove solids and debris and keep void spaces open. Vacuuming costs commonly range from $350 to $500 per acre per trip, but an increase in the number of vacuum sweeping services could make costs more competitive over time. Maintenance of PICP is slightly different, as the units themselves are not permeable. Instead, they have a small gap filled with chip stone that allows infiltration. Generally, a regenerative air vacuum or true vacuum is recommended to maintain these systems; however, this could be enhanced by periodic removal of debris by blowers or pressure washers.

In all cases, a design that minimizes the "run-on" of stormwater and associated sediment is the best way to minimize clogging and maintenance. Sediment from vehicles and organic litter build up and get ground into the pavement's void spaces over time. And as with any system, personal experience and experimentation with site-specific maintenance operations are critical to long-term system effectiveness.

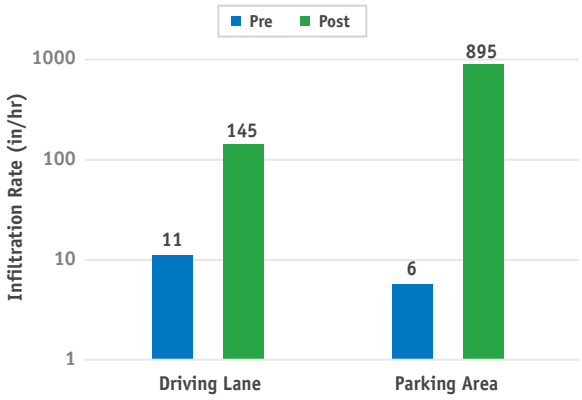
System Performance

Permeable pavements can achieve substantial pollutant load and volume reductions. (See charts at right.) This is dependent on the suitability of native soils, which impact the degree of volume reduction and treatment efficiency relative to the pollutant of concern. Some pollutants, such as phosphorus, are tightly bound in mineral complexes within the system or in the soil, while others, such as nitrate or dissolved chloride,are far more mobile.

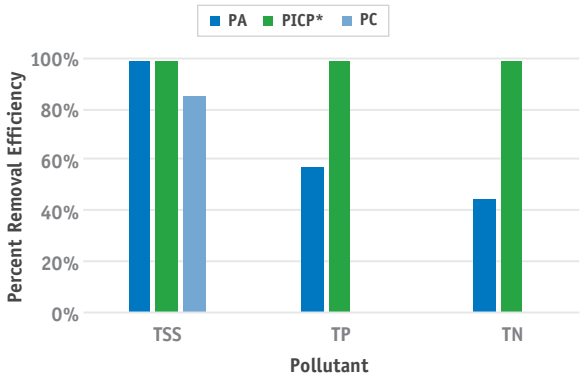
Implementation Costs

To support the use of green infrastructure in New England, the UNH Stormwater Center worked with the United States Environmental Protection Agency Region I, Tetra Tech, and other partners to estimate the cost of stormwater treatment systems like permeable pavements in 2016 dollars. The cost memorandum used to arrive at the figures at right below can be found at https://www.unh.edu/unhsc/sites/default/files/media/epa-cost-memo.pdf.

UNH Permeable Pavement Demo Site: Infiltration Rate Pre & Post Maintenance



Median Pollutant Removal Efficiency of Permeable Pavement Systems



*Reduction in pollutant load for PICP was not observed directly. Instead, due to the exceptional volume reduction exhibited by this system, the reduction in pollutant load had to be calculated. While runoff influent volumes ranged from 500 to 10,000 gallons, effluent volumes did not exceed five gallons for any single storm over the course of the two-year study. The result was an average volume reduction of 99.93 percent, which constitutes all of the pollutant load reductions calculated.

System	Materials & Installation Cost ($/cf)	Design cost ($/cf)
PA – low difficulty	3.46	1.86
PA – moderate difficulty	6.92	3.72
PA – high difficulty	10.37	5.59
PC/PICP – low difficulty	11.75	6.32
PC/PICP – moderate difficulty	23.49	12.65
PC/PICP – high difficulty	35.24	18.97

Looking ahead

The art and science of stormwater management can be like climbing a mountain. You work hard to reach what you think is the top, only to find the real summit is still ahead. The view from where you are is great, but you know you have further to go.

At the UNH Stomwater Center, our work has helped us see that managing the rain falling on our cities, towns, neighborhoods, and roads is a complex undertaking, with many players and moving parts. We have learned a great deal about how this system works and have used this knowledge to help protect rivers, lakes, and streams and the health of surrounding communities. It is clear that managing stormwater to ease the impacts of droughts and flooding is one thing we all can do now to make the future brighter despite the other problems associated with climate change.

At the same time, we can see other summits in the distance. There are many questions to answer about how stormwater management interacts with the larger systems of the natural world and society. We are just beginning to take science out of the ivory tower and ground it in the practical realities of day-to-day management. We have much to learn about how to track the impacts of stormwater programs so we know we are reaching common goals. These are exciting challenges and we look forward to meeting them with you in the years to come.

Here's how...

- **Technical assistance for MS4 communities:** We are helping communities reinvent their stormwater programs. We can help you think creatively about how to apply the latest science in ways that match your community's resources and pass muster with regulating agencies. We can explore how what you are already doing can satisfy MS4 permit requirements. Our breadth of experience in research, performance testing, monitoring, and community partnership can prepare you for what to expect with installation, troubleshooting, and maintenance of new stormwater systems. In the process, you can save time and money, and eliminate the need to reinvent the wheel.

- **Track stormwater program performance:** We collaborate with regulatory agencies and communities to articulate which activities should receive credit under stormwater permits and to develop ways to track whether these actions are having a positive impact on the environment. With funding from the New Hampshire Department of Environmental Services, we are in the second phase of a pilot Pollutant Tracking and Accounting Project (PTAP). We are working with NH Granit, regional planning groups, and Strafford and Rockingham county communities to quantify metrics associated with long-term trends that effect nonpoint source pollution loading. We are interested in new community partners that have a Total Maximum Daily Load (TMDL) in these counties, and in the work of similar efforts in New England and other regions.

- **Expanding our research:** We are always open to new partners as we expand our scientific inquiry. We want to answer management-relevant questions about how stormwater treatment systems function, interact with the surrounding environment, and impact communities and their water quality goals. Our current projects include:

  - Real-time sensing technology: Traditional techniques to monitor the effectiveness of stormwater systems are labor, time, and equipment intensive. New technologies are emerging that could address these hurdles and increase the reliability of monitoring data. With funding from the USEPA's RARE program, we are testing the use of optical sensors to collect data on sediment, nitrogen, and phosphorus in stormwater treatment system effluent streams.

  - Environmental fingerprinting: When it comes to bacteria, stormwater runoff is likely to include the good, the bad, and the ugly. In partnership with the Boston Water and Sewer Commission and the UNH Hubbard Center for Genome Studies, we are testing DNA fingerprinting to identify the different kinds of bacteria in stormwater runoff that flows through a treatment system, pinpoint where they come from, and understand their role in pollutant mediation.

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