Innovative Stormwater Solutions for Ohio

Case Studies of LID Implementation and Performance 2015

Chagrin River Watershed Partners, Inc.

National Estuarine Research Reserve Old Woman Creek Ohio Division of Wildlife

National Estuarine Research Reserve System Science Collaborative

Coastal Training Program Ohio

Consensus Building Institute

Erie Soil & Water Conservation District

Firelands Coastal Tributaries Watershed Program

NC State University Bio&Ag Engineering

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About this Report

This report is designed to be a technical and educational resource for stormwater professionals and others seeking to learn about the performance of low impact development (LID) stormwater technologies in Ohio. It synthesizes key information about design, construction, and monitoring from the Stormwater Solutions for Ohio collaborative research project. Site observations, project documents, and interviews with stormwater professionals informed this document.

There are seven sections in the report: project description, project overview, case studies, lessons learned, SCM maintenance, collaborative process and LID system schematics. Each section contains overall project information or site-specific design, construction, and monitoring information.

This report was spearheaded by Will Brown and Rebecca Jacobson, graduate student project interns from the University of New Hampshire, who were assisted by the Stormwater Solutions for Ohio project team in creating this publication. Funding from the NERRS Science Collaborative and the Friends of Old Woman Creek supported the creation of this document.

Collaborative Learning Group (CLG)

Why is stormwater research important?

Impervious surfaces associated with historic and new development increase the volume and rate that stormwater runoff reaches our streams and lakes. Increased runoff volumes result in erosion, causing streambed downcutting, streambank erosion, and increased frequency and extent of streamside flooding. In communities with aging sewer infrastructure, increased runoff volume results in combined sewer overflows (CSOs) that contaminate local rivers and streams with raw sewage. Runoff flushes pollutants and nutrients into water bodies, impairs water quality, degrades habitats, and heightens the risk of waterborne disease. All of these negative impacts are expected to intensify if the frequency and severity of storm events increase in Ohio as predicted. As the built environment expands, the area of impervious surfaces in Ohio's communities will increase and exacerbate the negative impacts of stormwater runoff. Low impact stormwater technologies can help mitigate some of these problems by mimicking natural hydrologic functions in stormwater system designs. Because many engineers are still new to these technologies, there is a need for additional research, development, and implementation of these practices.

Project Description

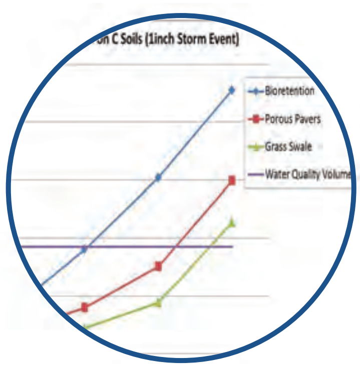
Stormwater Solutions for Ohio

This project promoted the implementation of LID stormwater control measures (SCMs) that reduce the impacts of stormwater runoff on Ohio's coastal communities and Lake Erie and worked to improve state and local stormwater policies. The project team included the Chagrin River Watershed Partners (CRWP), Old Woman Creek National Estuarine Research Reserve (OWC NERR), Ohio Department of Natural Resources Division of Soil and Water Resources (ODNR-DSWR), Erie Soil and Water Conservation District (Erie SWCD), the Consensus Building Institute (CBI), and North Carolina State University (NCSU). The National Estuarine Research Reserve System Science Collaborative (NERRS SC) funded the project.

The project team worked with stormwater professionals in northern Ohio to generate credible and locally verified information about the performance of innovative LID stormwater systems. A collaborative learning approach was used to engage a group of interested experts. The collaborative learning group (CLG) of stormwater engineers, regulators, stormwater utility managers, and watershed organizations provided iterative guidance and feedback to the project team on the design, construction, and monitoring of six SCM sites. The collaborative learning process also enabled group members to share a broad range of knowledge, concerns, and ideas for addressing complex stormwater challenges in northern Ohio.

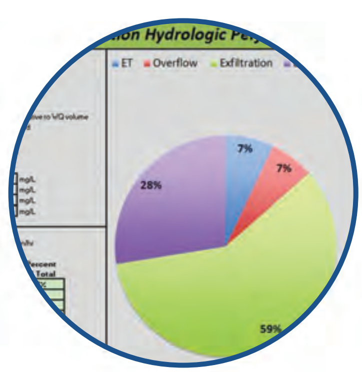
Design Stormwater Retrofit Projects:
Funding and technical assistance for stormwater control measures at Holden Arboretum, Orange Village, Pepper Pike, Ursuline College, Willoughby Hills, Perkins Township and Old Woman Creek

Monitor amount of runoff from sites



Model performance of Stormwater Control Measures:
Characterize stormwater control measures' hydrologic performance under current and projected future precipitation patterns

The project team collected monitoring data to evaluate hydrologic performance of SCMs and validate models to predict SCM effectiveness under projected climate scenarios. Information generated from this project is being used to improve local and state stormwater regulations.



Develop Tools & Guidance:
Case studies, model codes, revised design standards, credit recommendations

Monitoring

Hyrdologic monitoring at Holden Arboretum

Why monitor stormwater control measures?

Some stormwater professionals in Ohio had expressed uncertainty about whether LID SCMs work in Ohio's soils and climate. Monitoring precipitation and outflow from 6 sites with bioretention and permeable pavement demonstrated that these SCMs are effective in Ohio.

How are stormwater control measures designed for monitoring?

ODNR characterized each site during the design and evaluation process to evaluate infiltration of surface and subgrade soils, SCM drainage area, land cover types, and local climate. Information from site evaluations influenced SCM design parameters (i.e. sizing, aspect, location, etc.), and the types of equipment used for monitoring. Monitoring contractors and the project team collaborated with design engineers to ensure each site plan would accommodate the installation of monitoring equipment and allow performance results to be transferable and scalable to similar LID installations. Monitoring equipment selected for each site had to be durable, reasonably priced, and capable of recording data on a sufficiently short interval (2 minutes) to produce accurate runoff hydrographs. A primary goal was to collect discharge data from every rainfall and runoff event up to and exceeding a 2-3 inch depth. The ability to record nearly all storm events during the monitoring period ensured the data would provide information about SCM performance under a variety of conditions.

V-notch weirs at Orange Village

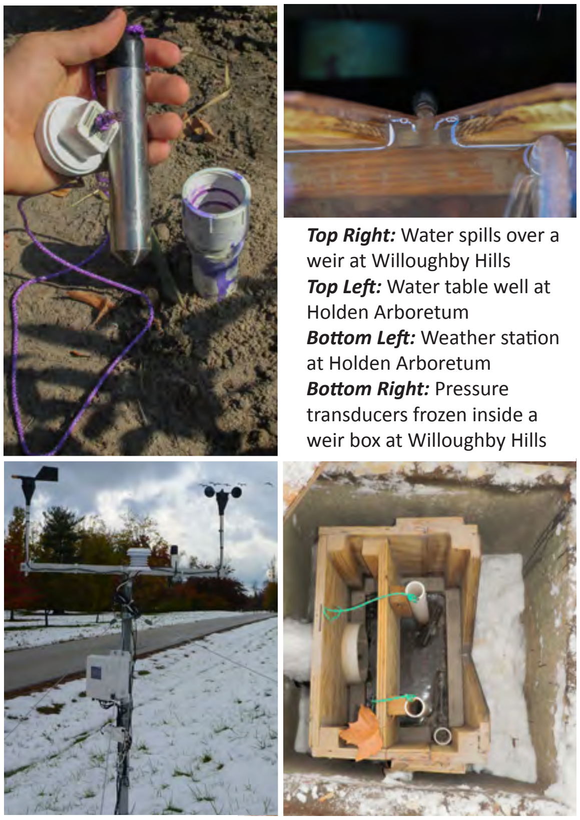
Each SCM needed to be hydrologically isolated from other SCMs in its treatment train to determine individual performance. At least 3 inches of fall from a piped outlet is needed to measure outflow without backflow effects, although six inches is preferred. The cost of monitoring equipment ranged from $6,000-$10,000 per site with NCSU contractors fabricating water table wells and weir boxes to reduce overall costs. At the more expensive sites, the team monitored multiple SCMs and installed monitoring equipment to support additional studies. Inflow to LID SCMs is generally as sheet flow making it difficult to accurately measure. Therefore, inflow at project sites was estimated using drainage area characterization and rainfall. Inflow estimates are best when the contributing drainage area is impervious.

What monitoring equipment was used to measure hydrology?

NCSU installed monitoring equipment during or shortly after SCM construction. This section discusses the primary types of hydrologic monitoring equipment used at every project site. More specific details about the installation differences between sites are discussed in the individual case studies.

Weather stations at each project site provided reliable local data about precipitation, wind speed and direction, solar radiation, relative humidity, and ambient air temperature. To gather these data, each weather station was equipped with a tipping bucket rain gauge, anemometer, wind direction sensor, pyronometer, and temperature/humidity sensor. These precipitation data and other site data were used to calculate the runoff inputs to each SCM. Calculated runoff inputs were compared to measured outflow data to determine hydrologic performance for each storm event. Additional weather parameters were used to estimate evapotranspiration.

V-notch weirs and pressure transducers were used to measure outflow rates. V-notch weirs were chosen because they give the best low flow accuracy. Additionally, pressure transducers were calibrated after every data download to prevent equipment drift. Post-processing was required to translate depth measurements to flow rate using standard weir equations. Water table wells equipped with pressure transducers allowed for continuous depth measurement of subsurface ponding in each SCM to ascertain depth of the internal water storage layer in the aggregate as a function of time and to increase understanding of infiltration at the site. Select project sites were also monitored for water quality, clogging rates of permeable pavement installations, and soil moisture variations in bioretention cells. Temperature measurements were made at all SCMs to determine their capacity to protect coldwater streams that host sensitive fish and macroinvertebrate communities.



Top Right: Water spills over a weir at Willoughby Hills
Top Left: Water table well at Holden Arboretum
Bottom Left: Weather station at Holden Arboretum
Bottom Right: Pressure transducers frozen inside a weir box at Willoughby Hills

Is winter monitoring viable in Northern Ohio?

During the winter of 2013-2014, the project team evaluated the viability of monitoring during the winter season to determine if the benefits exceed the risks and costs associated with data collection during the winter months. Some CLG members had requested winter monitoring to improve understanding of how SCMs process rain or snowmelt when the ground is frozen. In January and February 2014, snow was on the ground constantly, with frequent plowing and salting of parking lots. Other challenges and difficulties with monitoring during the Ohio winter included:

- Equipment accessibility in catch basins because of piles of snow and frozen manhole covers.
- Equipment needs to be extremely durable and may need to be moved to a heated location to make an electrical connection and download data.
- Water quality monitoring was not possible because of the potential for snowplows to cause damage to tubing. To facilitate winter water quality monitoring, tubing must be fed through the side of catch basins rather than run over the parking lot surface.
- Monitoring in catch basins or at surface flow points becomes problematic during extended periods of below freezing temperatures because ice forms behind the weir.
- Snowplowing can change the size of the monitored watershed. To address this, plow drivers need to be educated or a defined inflow monitoring point must be created. This can be difficult to achieve for practices such as permeable pavement, where no elevation drop or defined inflow location exists.

Modeling

How else did the project team evaluate SCM performance?

A modeling contractor used SWMM to examine the effect of design decisions on the performance of bioretention, permeable pavement, underground detention, grass swales, filter strips, soil renovation, dry detention basins, infiltration trenches, and green roofs. Monitoring data was used to calibrate and validate stormwater models (SWMM and DRAINMOD) to further evaluate the hydrologic performance of bioretention and permeable pavement. These calibrated models were used with projected climate scenarios to assess how these systems may perform in the future.

Applying the Research

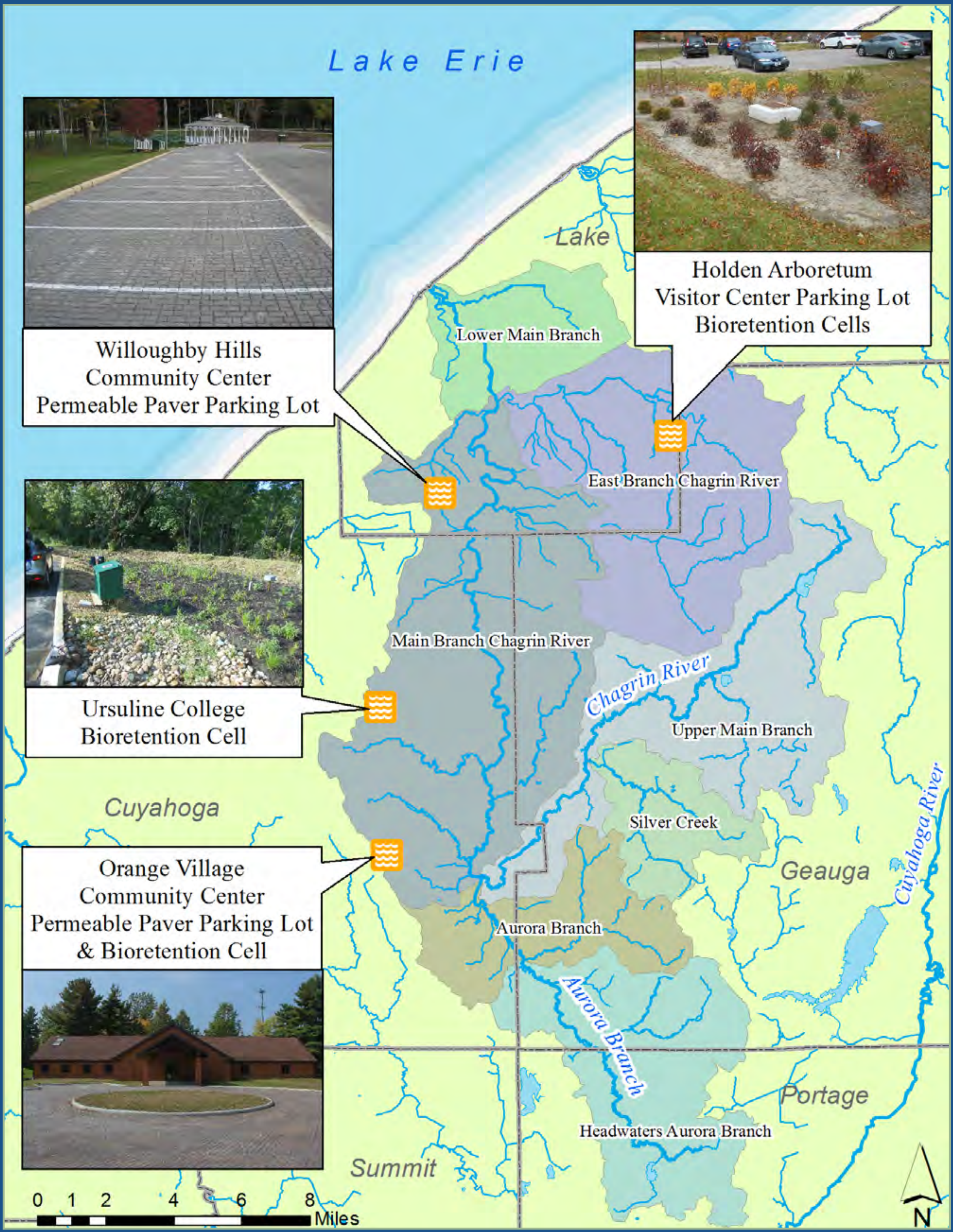
How is the information generated by this project being used?

CRWP used lessons learned from this project to update its model comprehensive stormwater management code and will work with communities to adopt and implement these suggested changes. This project has informed changes to the bioretention specification in the Rainwater and Land Development Manual. Additionally, ODNR is using the performance information gathered in this project to develop a crediting mechanism for the runoff volume reduction and peak flow mitigation functions provided by LID SCMs towards meeting the state water quality volume and local peak discharge requirements.

BMP construction workshop at Perkins Township

Old Woman Creek & Pipe Creek Watersheds

Chagrin River Watershed



Perkins Township

Quick Facts

Installed SCMs with Area
Monitored Pervious Concrete- 2,592 ft²

Catchment Area
Monitored Pervious Concrete- 23,087 ft²

Installation Costs:
Pervious Concrete- $8.08/ ft²

Installation Date
November 2012

Monitoring Period
April 2013 - November 2014

Precipitation Observations
89 Storm events
Rainfall range 0.1-2.6 in.

About this Project

The Stormwater Solutions for Ohio project evaluated bioretention and permeable pavement performance on poorly draining soils at 6 sites. The information gathered through this project is being used to improve design guidance and stormwater policies at the state and local level. The pervious concrete at the Perkins Township Services Facility was one of the stormwater control measures monitored through this project.

The Perkins Township Trustees incorporated innovative stormwater practices into their plans to redevelop an abandoned commercial plaza as the new site of the Perkins Township administrative offices. This site drains to Pipe Creek, which is a warm water habitat stream that directly flows into East Sandusky Bay. The Township replaced parts of the existing parking lot with pervious concrete. This project monitored the pervious concrete west of the building. This pervious concrete area accepts runoff from the impervious concrete drive lane and from the roof.

Site Evaluation

This project is a redevelopment in Erie County. The soil map units for this site are Bennington silty clay loam and Del Rey silt loam; both classified as poorly draining soils. Using a single ring infiltrometer, ODNR-DSWR measured infiltration rates of 0.04 - 0.08 inches per hour within the pervious concrete subgrade.

Design

Incorporating existing drainage infrastructure and addressing the physical conditions of the site presented significant design challenges. A proposed bioretention cell was eliminated because the required depth for surface ponding and soil media could not be achieved given the lack of elevation change between the stormwater control measure and the existing storm sewer.

This site was designed such that impervious concrete drive lanes are crowned to drain into adjacent pervious concrete parking bays. Additionally, runoff from the 12,632 square foot roof is piped into the subgrade of the pervious concrete application to the west of the building. The engineers considered the high hydraulic loading ratio acceptable since much of the contributing drainage is cleaner roof top water. To maximize the infiltration potential of this area, the drive lane between the pervious concrete bays to the west of the building is also underlain by 17 inches of #57 stone to add reservoir storage. The cross-section for the pervious concrete bays west of the building consists of 6 inches of pervious concrete, over 2 inches of #8 stone, over 13 inches of #57 stone. The 4 inch diameter underdrains in this western parking area are raised 6 inches above the bottom of the subgrade to create a sump to store and exfiltrate stormwater.

The north and east parking areas that only accept runoff from the drive lanes do not have a sump. In these areas, 6 inches of pervious concrete surface was placed over a 2 inch choker course of #8 stone over an 8 inch subbase of #57 stone. Four inch diameter underdrains run along the face of the curb line on top of the nonwoven geotextile filter fabric at the soil interface. Drive aisles are standard impervious concrete surface with no reservoir beneath them.

For all pervious concrete applications on the site, the subgrades are level to allow water to pond evenly. Since the underdrains for the pervious concrete had very little slope, the design engineers added multiple clean-outs.

Construction

The Township hired RMH Concrete, a certified pervious concrete installer, for this project. The subgrade of the northern and eastern parking areas was not scarified prior to placement of geotextile fabric and stone, but the subgrade of the western area was scarified. The washed limestone aggregate was compacted with machine traffic during placement of the stone. Further compaction was unnecessary because of the absence of fines. Pervious concrete was placed into forms and rolled by hand to achieve the desired grade and structural density. The construction crew prevented drying during the initial installation by using sprayers and rollers to moisten and mold the surface.

Immediately after grading and rolling, the pervious concrete was covered with plastic to facilitate proper curing and protect it from rapid drying. Pervious concrete must be covered with plastic sheeting within 10-12 minutes of placement and must stay completely covered for a week. The crew had some difficulty working with the concrete in areas adjacent to curbs, and ultimately weather became the most significant challenge. Strong winds removed plastic covering and exposed a section of the curing concrete during the initial 10 day curing process. This resulted in some surface raveling. The structural integrity of the uncovered pervious concrete section appears to be sound, but this section is not as aesthetically pleasing as the other pervious concrete areas.

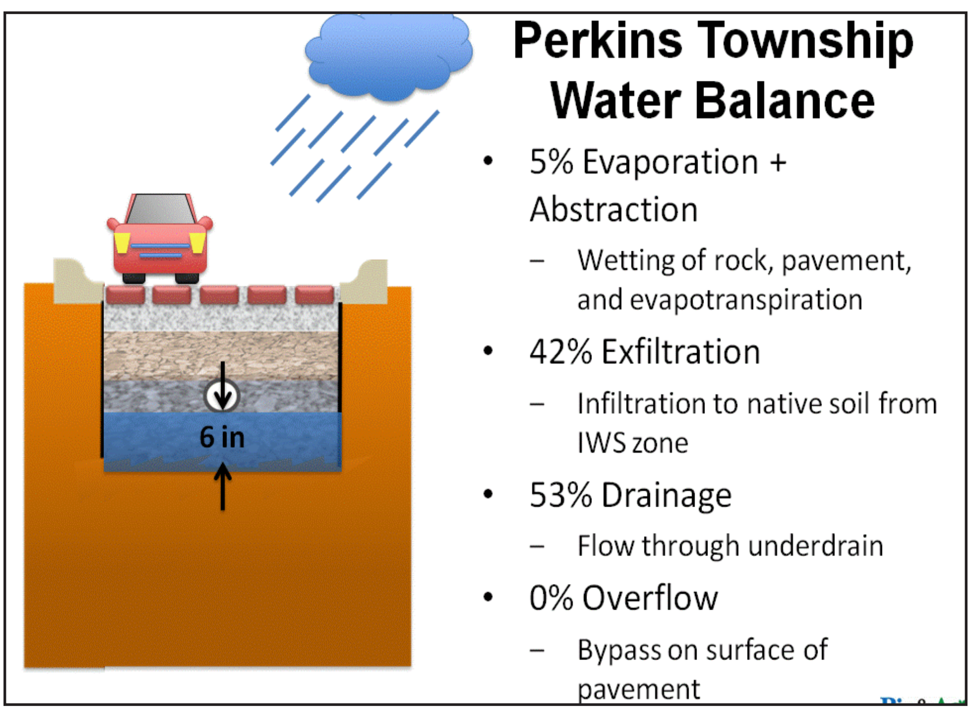
Site stabilization was another challenge. Some clogging occurred on a small section of pervious concrete that received stormwater runoff from an unstabilized adjacent area. Proper timing and sequencing of site stabilization during construction can avoid such problems.

Monitoring

A V-notch weir box instrumented with a pressure transducer measured outflow from the underdrain in the western pervious concrete application. The project team also deployed equipment to measure outflow from the eastern pervious concrete application, but backwater effects resulted in unreliable data from that location. A water table well was installed in the west application to measure water levels in the subbase. An on-site tipping bucket rain gauge measured rainfall. Pavement maintenance needs were assessed by measuring surface infiltration every 3 months using ASTM C1701 and a simple infiltration test developed by NCSU.

Results

Runoff from the western pervious concrete system reduced stormwater outlow by 47% through exfiltration, evaporation, and abstraction. All of the stormwater infiltrated the pavement surface, meaning that the remaining 53% of the flow exited the system as drainage from the underdrain. Of the 89 rain events recorded, 19% were completely captured, including events up to 0.5 inches. Peak flows of storms with peak intensity greater than the 1 year, 5-minute storm were reduced by 84 - 98% through restriction by the 4 inch diameter underdrain. Surface infiltration tests indicated that vacuuming was not yet needed 2 years after installation, with most testing locations having a surface infiltration rate that was still greater than 800 in/hr. Other stormwater engineers may want to use this design with minimal run-on from adjacent pavement and roof water directed into the subgrade on other sites to minimize maintenance needs while maximizing stormwater treatment.



Orange Village

Quick Facts

Installed SCMs with Area
PICP Drive- 9,490 ft²
Bioretention- 919 ft²

Catchment Area & Loading Ratio
PICP Drive- Direct Rainfall Only (1:1)
Bioretention- 20,740 ft²

Installation Costs
PICP Drive- $18.53 ft²
Bioretention- $17.84 ft²

Installation Dates
PICP Drive & Bioretention filter media - October 2013
Bioretention planted- May 2014

Monitoring Period
September 2013 - November 2014

About this Project

The Stormwater Solutions for Ohio project evaluated bioretention and permeable pavement performance on poorly draining soils at 6 sites. The permeable pavement and bioretention cell at the Orange Village annex building were among the stormwater control measures (SCMs) monitored. The information gathered through this project is being used to improve design guidance and stormwater policies at the state and local level.

In 2009, Orange Village purchased a property adjacent to their Village Hall and Fire Department. The existing buildings were renovated for use as offices for the service department, a community room, and a transfer facility for electronic and hazardous household waste. This site drains to Willey Creek, a coldwater habitat tributary to the Chagrin River. The cul-de-sac style driveway was built of permeable interlocking concrete pavers (PICP), and a small swale and a pipe conveys roof runoff from the building's roof to a bioretention cell. The project team monitored the hydrologic performance of the PICP installation and the bioretention cell.

Site Evaluation

The existing conditions were typical of other redevelopment properties in northern Ohio with highly disturbed soils, primarily consisting of fill from prior construction activity onsite mixed with or covering the native Wadsworth Silt Loam soil. This made evaluation of drainage and infiltrative capacity difficult. The first series of soil infiltration tests yielded very poor results (0.01, 0.00, 0.01 in/hr). Standing water in two deeper test pits likely reflected a significant amount of rainfall (> 5 inches) in the week prior to testing. A second series of tests performed during excavation for the permeable pavement system in July (about 7 months later) produced highly variable results ranging from 0.01 to 1.54 in/hr, and no standing water was present in the test pits. The stark contrast between testing results indicated that the fill material and native soils have different infiltration rates and that preferential pathways for drainage are likely.

Design

Because of concerns about the high water table present during the first round of infiltration tests, two 6 inch diameter curtain drains were installed beneath the SCMs to dewater the groundwater table at the site. The final design included a large permeable paver cul-de-sac and driveway and a bioretention cell. The site required substantial regrading to deliver water to the bioretention cell.

The PICP system included a minimum of 23 inches of aggregate. The cross-section was underlain by a geogrid at the interface with the in situ soils, which was covered by 2 inches of sand. On top of the sand was 15 – 21 inches of #1 and #2 stone, with 6 inches of #57 stone forming the next level, and 2 inches of #8 stone forming the bedding course for the pavers. The designer incorporated a 6 inch sump (internal water storage [IWS] zone) by raising the 6 inch diameter underdrain above the bottom of the subgrade. The subgrade of this system was sloped slightly away from the buildings to prevent seepage toward the foundations.

The design engineer included a 6 inch ponding depth in the bioretention cell. From the surface, the bioretention cell cross-section consisted of 3 inches of double shredded hardwood mulch, 30 inches of bioretention soil media, 3 inches of #8 limestone, and 12 inches of #57 stone. An upturned elbow in the underdrain provided a 3 inch IWS zone.

All underdrains and the curtain drains tied into one large precast circular vault accessible by a single manhole.

Construction

A general contractor coordinated and completed most of the construction, but the permeable paver and curb installations were performed by specialist subcontractors. The paving installer was ICPI (Interlocking Concrete Pavement Institute) certified and experienced with installing pavers. The first tasks were to demolish the existing pavement, and excavate soil where the PICP, bioretention area, and swale were installed. An abandoned septic tank was discovered under the PICP cul-de-sac that was not recorded on any site documentation. The tank was first examined to make sure that it was not in use, and then it was pumped dry and removed.

Although the construction plans specified “double washed angular stone,” unwashed stone was delivered and accepted for construction. In addition to being covered in stone dust (which could reduce the infiltration rate of the native soil), the #57 stone was river run gravel, which could lead to differential settling, rutting, or other long term performance issues. Angular aggregate should always be utilized in permeable pavement construction to ensure proper stone-to-stone contact. Additionally, the #57 stone was initially installed before curb installation, but was subsequently removed, temporarily stored nearby, and washed before being reinstalled after curb installation. The concrete curbs were installed along the driveway by a subcontractor while a separate crew continued to work on construction of the bioretention cell. To prepare for paver installation, a bedding course of #8 limestone aggregate was spread and graded. Next, Eco-Optiloc pavers were installed using a Probst VM-series “PaverMAX” mechanical paver installation system. The machine was used to install the vast majority of the parking lot, but pavers abutting curbs needed to be manually cut to size. The cul-de-sac design was aesthetically pleasing, but required a lot of manual work for contractors since nearly every paver next to a curb had to be cut with a saw. The increased labor associated with such designs will likely increase construction costs.

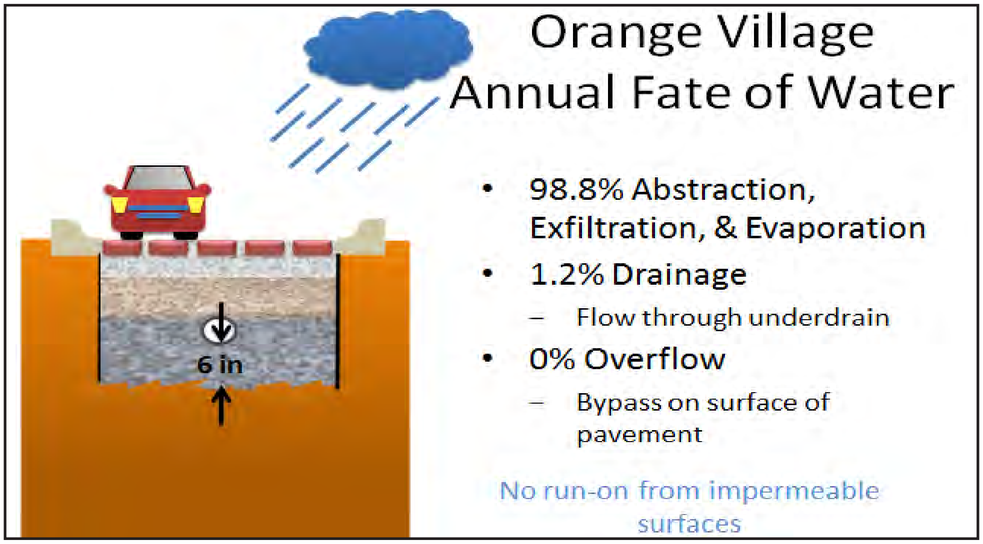
The bioretention soil was mixed onsite. It consisted of 60% sand, 40% topsoil, 8% clay/silt, and 2% organics. The design plans simply stated “bioretention soil mix,” which is not enough detail to ensure that soil media matches the *Ohio Rainwater and Land Development Manual* specifications. Following installation of the bioretention cell, a silt fence was erected to help protect the practice from sediment from the cut slopes. The silt fence used to protect the bioretention cell failed, and a 3 inch layer of sediment settled on the surface of the bioretention media. This was corrected by removing the sediment and regrading the bioretention area. Mulch was then placed on top of the media. Observations of drawdown after storm events showed that drawdown of the bowl of the bioretention cell was occurring within 12 hours (as required by the *Ohio Rainwater and Land Development Manual*), meaning that the removal of the clogging layer was successful.

Monitoring

North Carolina State University (NCSU) installed three v-notch weirs in the precast concrete vault to monitor outflow from the permeable pavement, bioretention cell, and curtain drains. Weirs were constructed so that they could be installed on the curved walls of the vault. In addition, long PVC pipes and rope were used to develop a means for calibrating and deploying water level loggers without requiring confined space entry into the deep manhole each time the data were downloaded. Another v-notch weir was used to measure outflow from the drainage swale, which was co-located at the inlet to the bioretention cell. Due to a construction mistake, water table monitoring wells were not installed at this site. This prevented the use of the data for monitoring simulations in SWMM and DRAINMOD. NCSU measured surface infiltration rates of the PICP every 3 months at five established locations: in a parking stall, under a tree, two locations near the entry drive, and a location in the cul-de-sac. Surface infiltration rates were measured over the first 1.5 years of the pavement life.

Because the curtain drains dewatered a larger area than the SCMs, it was difficult to calculate the total water balance for the SCMs. Since the curtain drains lie beneath the PICP and the bioretention cell, exfiltration from these practices may be routed to the curtain drains during or after the storm. Given this caveat, over 98% of the inflow left the permeable pavement system as exfiltration or evaporation. No runoff was observed during the monitoring period, suggesting that surface infiltration rates were still quite high after one year of operation. Tests indicated that surface infiltration rates were at least 400 in/hr after 1.5 years of operation, indicating that the pavement was still functioning as designed. No surface defects or structural problems were observed after this period, including after two winters of plowing after snowfall.

All rainfall received at minimum filtration, providing reduction of sediment to Willey Creek. The longer flow path for water to reach the storm sewer, as well as interactions with the aggregate and the soil beneath the pavement resulted in temperature reduction as the water passed through the pavement. This, combined with exfiltration observed from the PICP, resulted in major reductions in thermal load.



Willoughby Hills

Quick Facts

Installed BMPs with Area
PICP Large Bay- 4,420 ft²
PICP Small Bay- 480 ft²

Catchment Area & Loading Ratio
Large Bay Catchment- 0.22 acres
Small Bay Catchment- 0.08 acres

Installation Costs
Permeable Paver Retrofit- $13.05/ ft²

Installation Date
Fall 2013

Monitoring Period
September 2013 - November 2014

Monitoring Period
79 Storm events
Rainfall range: 0.1 in. -3.42in.

About this Project

The Stormwater Solutions for Ohio project evaluated bioretention and permeable pavement performance on poorly draining soils at 6 sites. The two bays of permeable interlocking concrete pavement (PICP) at Willoughby Hills Community Center were among the stormwater control measures monitored. The information gathered through this project is being used to improve design guidance and stormwater policies at the state and local level.

In 2013, the City of Willoughby Hills replaced a portion of an existing impervious asphalt parking lot at its Community Center with two permeable interlocking concrete pavement (PICP) applications. This parking lot discharges stormwater runoff into an unnamed tributary of Gully Brook, which flows into the Chagrin River. The small bay of PICP application has a much higher hydraulic loading ratio than that recommended in the Ohio Rainwater and Land Development Manual. The small bay drains an area of impervious asphalt that is 7.2 times larger than the PICP area. For the large bay, the ratio of impervious asphalt drainage area to the area of PICP receiving that drainage (2.2:1) is only slightly higher than the state's recommendation of 2:1, but parking lot islands upslope of the PICP installation are concentrating flow and sending disproportionate amounts of runoff to some areas within the PICP bay.

Site Evaluation

The soil survey identifies the soils on-site as Mahoning Silt Loam (HSG D). ODNR conducted infiltration testing during construction to measure the infiltration rates of the PICP system subgrade in each parking area. Infiltration rates varied from 0.00-0.06 in/hr, and soils appeared to be compacted fill.

Design

The total aggregate depth was 19.5 inches, with 1.5 inches of #8 bedding stone immediately below the pavers, 6 inches of #57 aggregate beneath that, and 12 inches of #1/#2 aggregate serving as a base course. An upturned elbow on the 6 inch PVC underdrain created a 6 inch sump to

promote exfiltration into the subgrade.

A design challenge at this site was that the west side of the large permeable paver bay was higher than the east side. In order to promote infiltration, the subgrade at the interface of the aggregate and the soil needs to be level. To minimize excavation costs while still promoting infiltration, the engineers chose to create 4 terraces in the subgrade. Plastic wrapped soil baffles pond water on each terrace.

Construction

Construction was performed by a single contractor. During excavation, heavy machinery traffic over the PICP system subgrade compacted the soil. In an attempt to correct this, the operator scarified the underlying soil using the teeth of the excavator bucket to loosen the soil. Next, the underdrains were installed and connected to the existing catch basins. A Tensar BX1200 Geogrid was laid down on subgrade, the water table wells were installed, and the excavated area was filled with a mixture of clean #1 and #2 limestone as the subbase. This layer was graded and a plate compactor was used to interlock the stone. Installation of the concrete curbs followed and was performed by hand to ensure that

the curbs were formed correctly and dimensions were in accordance with the design. A 27 foot section of curb had to be replaced because it dried too rapidly during the initial curing process and cracked as a result. The failed section of curb was poured on a day that exceeded 100°F. After curb installation, a layer of #57 angular limestone was installed and topped with a layer of #8 limestone. The last phase of the construction was to install the PICP using a Probst VM-series “PaverMAX” installation machine. Areas adjacent to curbs had to be cut by hand and manually fit into place. A layer of #8 stone was swept onto the paving surface to fill the interstitial spaces between the pavers and prevent any movement of the pavers. After PICP construction was complete, the site was stabilized and the parking stalls were striped.

Monitoring

Pressure transducers and weirs were used to monitor outflow from the PICP underdrains, and water table wells recorded the rate at which water exfiltrated into the subgrade. An onsite tipping bucket rain gauge measured rainfall. Autosamplers took flow-proportional composite samples for water quality analysis from the underdrains of both PICP applications and control samples from a catch basin draining the asphalt portion of the parking lot. The Northeast Ohio Regional Sewer District provided lab analysis of the samples.

To study maintenance needs, North Carolina State University (NCSU) researchers measured surface infiltration rates every 3 months and after the lot was vacuumed using ASTM C1781 and a simple infiltration test developed by NCSU. To conduct the simple infiltration test, cut a piece of 2’ x 4’ lumber into 4 equal lengths, screw them together into a square, seal the wood frame to the PICP surface with plumber’s putty, pour 4.75 gallons of water into the sealed frame, and record the time it takes to drain.

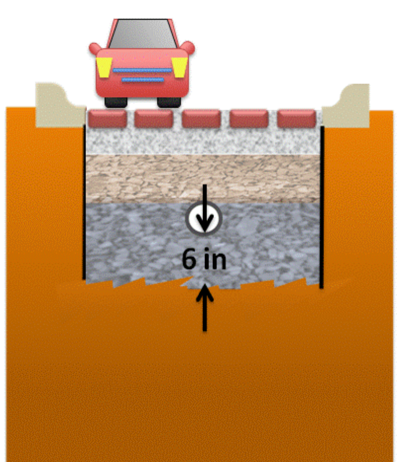
Results

The large bay reduced runoff by 32% and the small bay reduced runoff by 17%. Thirty of the 77 rain events recorded, including events up to 0.34 inches, were completely captured by the large bay. Only 4 storms produced no outflow from the small bay. PICP installations reductions reduced curve numbers for thier drainage areas from 98 to 94 for the small bay and 93.3 for the large bay. For storms with peak intensity greater than the one year, 5 minute storm (the most intense storms), the large bay reduced peak flows by 17-36%, and the small bay reduced peak flows by 27-61%. Peak flow reductions were lower for the large bay due to greater clogging of the pavement surface, resulting in more surface bypass. Additionally, since the peak flow rates for the large bay were higher than the small bay, engineers concerned with the peak flow attenuation may want to use a flat subgrade design instead of a stepped subgrade design.

The PICP applications reduced the amount of nutrient and metal pollutants leaving the site. The small application reduced total phosphorus loads by 30% and soluble reactive phosphorus loads by 41%. The large bay reduced both total phosphorus and soluble reactive phosphorus loads by 39%. Total nitrogen loads were reduced by 28% for the small bay and 53% for the large bay. The small bay reduced zinc loads by 42% and copper loads by 25%, and the large bay reduced zinc loads by 37% and copper loads 34%. Generally, nutrients and metal loads were reduced to a greater extent by the large bay, due to greater exfiltration and evaporation when compared to the small bay.

In July 2014, runoff was observed traveling over the top of the PICP during a light rain, and the surface infiltration tests also indicated reduced infiltration. Lake County vacuumed the lot and the City replaced the #8 aggregate. This maintenance restored the infiltration function of the permeable pavement. However, due to the high loading ratio and the up-slope parking lot islands of this site flow becomes concentrated before reaching the PICP, which will result in required maintenance 3 times a year to maintain the designed stormwater function. Loading from impermeable pavement should be minimized as much as possible to reduce log-term maintenance burden.

Hydrologic Loading Ratios:
Small Bay: 8.2:1
Large Bay: 3.1:1



Willoughby Hills Water Balance

Fate of Water	Small Bay	Large Bay
Evaporation & Abstraction	13.2%	10.5%
Exfiltration	3.5%	21.5%
Drainage	75.3%	44%
Surface Runoff	8%	24%

Measured Drawdown Rates:
Small Bay: 0.01 in/hr
Large Bay: 0.01-0.03 in/hr

Holden Arboretum

Quick Facts

Installed SCMs with Area
Bioretention Cell 1 (North)- 850 ft²
Bioretention Cell 2 (South)- 614 ft²

Catchment Area & Loading Ratio
North Catchment: 0.67 Acres
South Catchment: 0.48 Acres

Impervious Area & Percent Cover
North Catchment: .39 Acres (58%)
South Catchment: .28 Acres (59%)

Installation Date
Fall 2013

Period Monitored
October 2013 - November 2014

Precipitation Observations
90 Storm events
Rainfall range: 0.1 in. -2.8 in.

About This Project

The Stormwater Solutions for Ohio project evaluated bioretention and permeable pavement performance on poorly draining soils at six sites. The two bioretention cells in the Holden Arboretum parking lot were among the stormwater control measures monitored. The information gathered through this project is being used to improve design guidance and stormwater policies at the state and local level.

Holden Arboretum staff and project team members designed and constructed two bioretention cells to treat stormwater runoff from the Visitor Center parking lot. This site drains to Pierson Creek, a coldwater habitat tributary to the East Branch of the Chagrin River. The cells receive parking lot runoff from similarly sized watersheds, allowing direct performance comparison between the two cells. The partnership with the Holden Arboretum staff expanded the scope of the research project to explore how different plant communities impact bioretention performance and aesthetics. Both cells were installed in publicly visible parking lot islands located in the main parking area for the visitor center.

Site Evaluation

Test pits for each planned bioretention installation were excavated to a depth of approximately 4 feet to measure the infiltration rate at the proposed excavation depth of the bioretention practices. Two tests in the north pit yielded readings of 0.02 in/hr; whereas, two tests in the south pit yielded readings of 0.02 and 0.08 in/hr. The soil the north cell was installed on was mapped as Platea, and the south cell was mapped as Pierpont. These readings were similar to the 0.02 in/hr infiltration rate predicted by the Soil Water Characteristics Calculator (K.E. Saxton et al., 1986). The site was also surveyed to determine catchment boundaries, slope, and percentage of impervious cover.

Design

Project team engineers from NCSU and ODNR-DSWR worked collaboratively with Holden Arboretum staff on the design. The surface area of each bioretention cell was sized at 5% of the contributing impervious area to meet the Ohio Rainwater and Land Development Manual specification. The design incorporated the existing catch basins and storm sewer and accommodated hydrologic monitoring in both catch basins. An upturned elbow was attached to the underdrain in each cell to create an 18” internal water storage layer (or sump) in the north cell and an 15” in the south cell to improve hydrologic performance. The final design focused on enhancing stormwater treatment by increasing retention capacity, reducing peak flows, removing pollutants, and promoting infiltration and denitrification.

Holden Arboretum staff contributed their horticultural expertise to the landscaping design of each bioretention cell. Plantings had to be aesthetically pleasing, tolerant of a broad range of weather conditions, commercially available to landscapers, and small enough so as to not interfere with visual clearance. Aesthetic considerations that factor into planting selection include: timing and length of bloom, winter appearance, seasonal coloration, and spatial arrangement. Additional considerations about root type and length were also factors in the landscape design process. Holden Arboretum selected plants that use different rooting zones to lessen direct competition and increase water uptake and transpiration.

Construction

Each bioretention cell was excavated using a small track hoe. During excavation, the team encountered unmarked utilities. They cracked the outlet pipe leading to one of the catch basins, and repaired it with hydraulic cement. An electrical conduit for a lamppost was also damaged but was repaired as well.

A skid steer delivered layers of gravel and sand. Each layer was spread out and leveled by hand using rakes and shovels. The bottom layer consisted of 12 inches of washed #57 angular gravel to provide drainage and bedding for the underdrain. Installation of the underdrains required modification of the catch basins. Holden Arboretum staff drilled new outlet holes, installed PVC pipe outlets, and then sealed each outlet with hydraulic cement. Next, a filter layer was installed that consisted of 3 inches of medium concrete sand on top of 3 inches of #78 gravel. The final layer consisted of 36 inches of bioretention soil mix. Due to a miscommunication, the height of the catch basins were raised to a height of 15 inches above the filter beds instead of the 12 inch design specified. However, since these sites were closely monitored, it was decided to leave the overflows at the higher elevation to see how the systems perform with the deeper surface ponding.

A few issues with material sourcing occurred during construction. Much too large a quantity of #57 gravel was delivered, highlighting the importance of double-checking material quantities. Also, the first delivery of filter sand had to be rejected because it was fill sand instead of concrete sand. Additionally, the first delivery of planting soil media was not well screened, and there were big chunks of compost in the mix. The construction crew broke up these clumps manually, and they requested that the second delivery be better screened. This demonstrates the importance of clear communication with suppliers to ensure the accuracy of orders and the importance of inspecting materials upon delivery to make sure they comply with design specifications. All the materials installed at Holden Arboretum were high quality, but it took some onsite management to ensure this was the case.

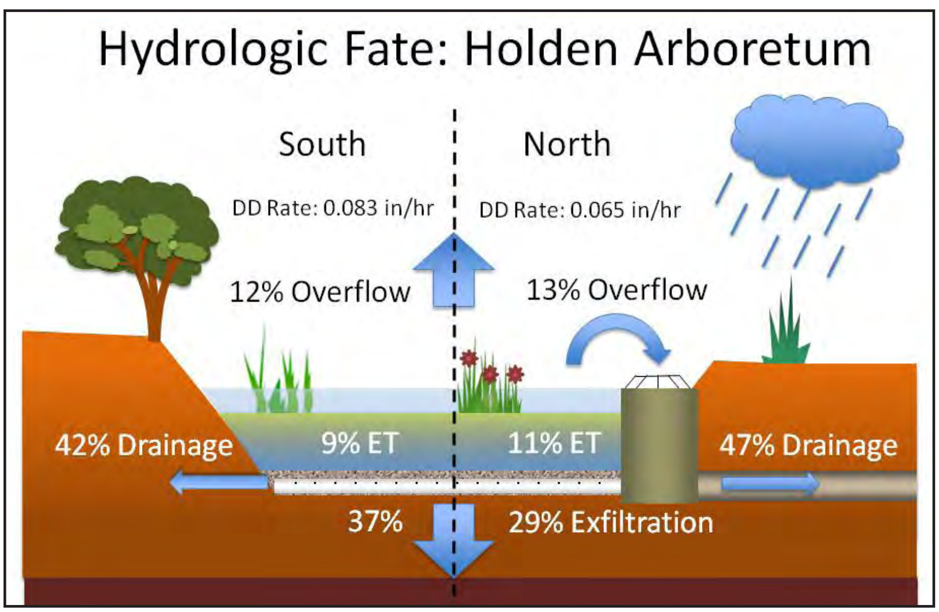
After a heavy storm shortly after construction before the cells were planted, some minor erosion occurred. This demonstrates the importance of site stabilization during or immediately following construction. Use of grass sod on side slopes and on pretreatment filter strips can help to combat erosion in areas with concentrated flow.

Monitoring

NCSU stormwater engineers used weirs and water level loggers to measure outflow from underdrains and water table wells to monitor exfiltration. Conductivity was also measured with a separate logger. Soil moisture and temperature arrays were installed in the planting soil layer (at depths of 6", 1 ft, 2 ft, and 3 ft below the media surface) to monitor soil conditions for bioretention cells. Water table wells were incorporated to measure water level within the profile of each bioretention cell.

Results

The south cell reduced runoff by 46%, and the north cell reduced runoff by 40%. Of the 90 rain events monitored, the south cell completely captured 41 events and the north cell completely captured 28 events. The maximum rainfall depth that was completely captured by each cell was a 0.5 inch storm. The drainage area for both cells had a curve number of 90.5 without the bioretention. After the installation of the bioretention cells, the curve number for the north cell decreased to 83.5, and the curve number for the south cell decreased to 85.



Old Woman Creek NERR

Quick Facts

Installed SCMs with Area
Permeable Pavement Surface Area: 2,900 ft^2
Rainwater Harvesting Cisterns: 420 ft^3

Installation Date
July 2014

Catchment Size
Permeable Pavement & Cistern: 5,014 ft^2

Monitoring Period
August-December 2014

Precipitation Observations
22 Storm events
Rainfall range 0.1-1.5 inches

About this Project

Until June 2014, the parking lot area of Old Woman Creek National Estuarine Research Reserve (OWC NERR) consisted of approximately 16,200 ft^2 of impervious asphalt and approximately 2,900 ft^2 of pervious grass pave system containing 13 parking stalls installed in 2001. The grass pave system stopped functioning properly due to poor water infiltration likely caused by compaction of the underlying soil or gravel. Parking lot runoff contributed to slope erosion near one of the trails and excess sediment loading into the estuary. OWC NERR was chosen as one of the project sites of this NERRS Science Collaborative project for several reasons: it is a high profile location with frequent visitors, staff were interested in replacing their failed grass pave system, additional Stormwater Control Measures (SCMs) were desired to treat stormwater on site, and because OWC NERR has the capacity and interest to monitor treatment SCMs over the long-term.

Site Evaluation

Soil profiles taken with an auger determined the top 24 inches were Del Rey silt loam soil; somewhat poorly draining. Four single-ring infiltration tests revealed OWC NERR had extremely low infiltration rates of <0.005 in/hr.

Initial Design

Initial design plans for the site, developed in 2012, consisted of replacing the grass pave system with porous asphalt pavement. The grass pave area was located between the traditional asphalt parking lot and shallow swale adjacent to the prairie. The plans went through three revisions incorporating feedback from the project team, Collaborative Learning Group (CLG) of stormwater professionals, and the project team.

Along the way, the design team experienced several challenges designing and bidding the porous asphalt parking area. Porous asphalt mix includes specialized binders and fibers. These serve as a surrogate for the sand portion of an asphalt mix not used in manufacturing porous asphalt. In addition to the cost of these modifiers, the special asphalt mix requires the asphalt supplier to dedicate the asphalt plant solely to the production of porous asphalt. This process would be more manageable if the asphalt supplier had a batch plant designated to handle smaller asphalt jobs. Most asphalt suppliers in Ohio have switched solely to using drum mixers making it uneconomical for the suppliers to handle smaller quantities like that needed for the Old Woman Creek project. These challenges resulted in a bid cost of $43 per square foot for the porous asphalt, well over the budgeted cost.

Final Design

In 2013, a professional engineer on the project team redesigned the permeable pavement using Permeable Interlocking Concrete Pavement (PICP) instead of porous asphalt. From the bottom to the top of the cross-section, the permeable pavement aggregate layers include 18-22 inches of #2 stone, 4 inches of #57 stone, and 2 inches #78 stone. The 6 inch underdrain was raised 3 inches off the subgrade to provide an internal water storage zone and promote exfiltration. The final design also incorporated a rainwater harvesting system consisting of two concrete cisterns, each 3' x 8' x 16' and hydraulically connected with three booted 4 inch PVC pipes. These cisterns were placed within the footprint of the PICP system, reducing the effective soil area beneath the PICP that could exfiltrate stormwater to 2,646 ft^2. The cisterns have concrete tops and eccentric cone manways to allow access from the surface for maintenance purposes. The cisterns were covered with 1.5 ft of heavy clay soil compacted to 95% Proctor density. The aggregate layers for the PICP extend across the top of this compacted clay. The system was designed so that PICP underdrain flow would be conveyed to a nearby catch basin, then to the cisterns. When the cisterns were full, overflow was expected to be channeled through a pipe into a rock lined outlet located in a nearby forest.

Construction

Construction began on June 24, 2014. A single contractor was responsible for the excavation, construction, and installation of the PICP and rainwater harvesting system. First, the existing grass pave system was removed, the practice was excavated to finished grade, and the subgrade soil scarified with the excavator bucket to remove smearing. OWC NERR staff knew about a set of unmarked underground electrical and data lines but not their location. Upon digging the overflow pipe trench, contractors discovered these unmarked lines crossing underneath the adjacent swale and took caution during construction to avoid damaging them. Next, the #1 and #2 limestone aggregate and underdrain were installed.

The weight of the cisterns (18,100 lbs) exceeded the 10K limit of an excavator, which required a crane for installation. Crane rental increased the total project cost more than if an excavator was used. If cisterns made from lighter weight material are available, they may be able to be installed with a track hoe saving the cost of crane rental; however, a lighter cistern could float in areas with high water tables. After cistern installation, a fork lift lowered the catch basin into place followed by the pouring and forming of the concrete curbing. Next, a #57 limestone layer and a screeded layer of #78 limestone were installed. Each limestone layer was compacted in 6 inch lifts using a 10 ton roller.

Grey pavers were placed using a robotic paver laying machine. Pavers placed near curbing were adjusted and strategically cut with a saw to ensure correct interlocking alignment. Lines of grey PICP were removed and replaced with red pavers to delineate parking stalls. Next, a brush tool attachment for the robotic paver laying machine was used to sweep #78 limestone into PICP joints. This brush tool also could be used to sweep #78 limestone back into paver joints during maintenance. Additionally, the swale was slightly rerouted, re-graded for positive flow, seeded with an Ohio Department of Transportation seed mix and covered with straw mulch to prevent erosion.

The design engineer provided essential on-site oversight during construction. This led to in-field changes being made efficiently during the construction process which included:

- Adding a six inch curb reveal to separate surface flow in the swale to prevent clogging with the on-site clay soils.
- Increasing the elevation of the outlet pipe grade due to a utility line conflict.
- Ordering and installing a different water pump than what was specified in the plans due to the difficulty of locating and ordering specific parts.

Monitoring

The OWC NERR project site was monitored for hydrology, water quality, and weather conditions. The reserve has an onsite water chemistry lab, which enabled OWC NERR personnel to complete most of the water quality analyses. Water samples could be collected quickly after a rain event by reserve staff, making this project site a prime location for potential long-term monitoring.

Two v-notch weirs were installed inside the catch basin to monitor underdrain flow and overflow. Pressure transducers and bubblers were also used to calculate flow rates. Water quality sampling occurred at three locations on site: a sampling trough at the edge of the asphalt parking lot, the PICP underdrain, and the cistern's spigot (i.e. point of use). Control samples from the asphalt were rainfall paced composite, underdrain samples were flow paced composite, and spigot samples were grab sample. Two water table wells were installed to monitor the height of water within the infiltration layers and sump.

Results

During the four month monitoring in 2014, a total of twenty-two rainfall events occurred. Due to leaks between manway and cistern lid joints, only one rainfall event had outflow from the underdrain. Water was transmitted from the aggregate beneath the pavers, through the backfilled soil on top of the cisterns, and into the cisterns without first draining through the underdrain. Throughout the monitoring period, the cisterns remained full because of a lack of use of the stormwater for irrigation and vehicle washing. In spite of this, a slow drawdown in water level following each storm event was observed, indicating that water leaked through the cistern joints into the surrounding soil, resulting in an overall volume reduction of 16.9% for the system. The median drawdown rate from the cistern (0.068 in/hr) was higher than the drawdown rates from the two wells in the permeable pavement aggregate (0.002 in/hr), suggesting that a more permeable lens in the soil exists at deeper depths at the Old Woman Creek site.

Seven rainfall events were sampled for water quality. Al, Ca, Cu, Fe, Mn, Pb, Zn, nitrogen, total phosphorus, and sediment concentrations were lower at the spigot than from the parking lot. Most of the heavy metals were effectively retained with the system. This treatment train reduced sediment, nutrient, Al, Cu, Fe, Mn, Pb, and Zn loads; however, Ca, Mg, and Cl concentrations were higher. The Ca and Mg could be leaching into the system from the limestone aggregate. The Cl is most likely a result of salt run-off.

Ursuline College

Quick Facts

Installed SCMs with Area
Bioretention cell- 1,960 ft^2

Installation Costs
Bioretention cell: \$33.16/ft^2

Installation Date
Construction: April-May 2014

Monitoring Period
May-December 2014

Precipitation Observations
50 Storm events
Rainfall range 0.1-3.51 inches

About this Project

Ursuline College is located in the City of Pepper Pike within the Pepper Creek subwatershed, a tributary to the Chagrin River. A stream restoration was planned on campus to restore part of a headwater tributary of Pepper Creek. Since Ursuline College was interested in innovative stormwater management, a 1,960 ft^2 bioretention cell was added to the construction plans. The bioretention cell is located between an existing 0.69 acre parking lot and the stream.

Design

The bioretention cell (henceforth, cell) treats all stormwater runoff from the adjacent parking lot. In order to channel runoff into the cell, the original design called for 12 curb cuts. However, this was changed to a single 3 foot wide flush curb cut and a rock forebay because of feedback from the Collaborative Learning Group (CLG). The forebay acts as a pretreatment for runoff by reducing the velocity of inflow allowing sediment and trash to settle out before they enter the cell.

The top 24 inches of the cell are composed of bioretention media followed by 18 inches of aggregate below. The bioretention media (Kurtz Brothers Hydro Clear Bioretention Soil) is an engineered soil that is "loamy sand" texture with less than 5% clay, and does not contain particles larger than 0.04 inches. The Ursuline College bioretention cell contains Osorb (supplied by ABSMaterials, Inc.) which is not a normal component of Kurtz Brothers Hydro Clear Bioretention Soil. Osorb is an organically modified silica based absorbent material which helps absorb contaminates such as pesticides, hydrocarbons, pharmaceuticals, and other dissolved organic molecules.

To create the soil layer, 9 inches of bioretention media was placed, then a 6 inch layer of mixed bioretention media and Osorb, followed by 9 inches of the non-Osorb mixed bioretention media to backfill on top. The aggregate layers below consists of: 3 inches of washed medium concrete sand, 3 inches of #78 washed pea gravel, and a 12 inch layer of #57 washed gravel.

A network of underdrain pipes span the length of the cell and were plumbed into a concrete catch basin located in the center of the cell. An upturned elbow connected to a 12 inch perforated PVC pipe allowed water drainage from the catch basin into the outflow pipe and out to the stream. This design included a 24 inch internal water storage (IWS) zone, of which 6 inches was within the bioretention cell media. Two overflow devices were used in this system: (1) a 3 ft by 3 ft concrete catch basin into which the underdrains were routed, and (2) a broad crested weir in the berm of the cell that acts as an emergency overflow. Vegetation for the site consists of low-mow grass on the side slopes and over 1,400 plant plugs of native grass, sedge, and forb species within the filter bed.

Site Evaluation

Project team members augured 3-4 feet below the excavated bottom of the bioretention cell to generate a soil profile. The soil profile revealed the underlying soil had 95-120 inches of uncompacted fill composed of silt-loam placed on top of native soil, unexpected to the contractor. The fill was most likely brought in from another area on campus. Project team members conducted three single-ring infiltrometer tests which revealed infiltration rates of 0.02, 0.02, and 0.03 in/hr. During infiltration testing, the project team observed water infiltrating much quicker from the other end of the cell. An additional infiltration test was attempted in this quick draining area but was unsuccessful.

Construction

Construction took place in April and May 2014. One contractor was responsible for planting, mulching, and watering vegetation, and a subcontractor managed excavation and construction.

Before excavation began, a dandy bag (or silt bag) was placed over the existing storm sewer pipe to prevent construction sediment from entering the stream. The bottom of the cell was excavated 18 inches below the existing storm sewer pipe and was scarified 4-6 inches to allow for better stormwater infiltration. Some ponding occured in one area of the excavation and the construction contractor re-scarified the bottom to roughen it and relieve compaction. Construction machinery was not driven inside the cell to avoid compacting the subgrade.

Next, the catch basin and the underdrain piping were installed. Aggregate was mechanically placed into the cell then manually spread and raked to final grade. An excavator backfilled bioretention media with the Osorb mix layer around the catch basin and over the aggregate layers. Next, native plant plugs were placed inside the cell and three inches of coarse aged shredded hardwood mulch was spread around the plants. Using an excavator,

the side slopes were cut at a 2:1 slope back toward the parking lot. A low-mow seed mix and straw was placed on the side slopes to help prevent erosion and increase side slope stability. Lastly, sod and scour-stop matting was lain at the emergency spillway area. Due to incorrect interpretation of the engineering plans, the construction contractors cut into the existing storm sewer pipe, thinking the plan was to tie the new outflow pipe into the existing storm sewer. The monitoring contractor patched the cut to make sure flow did not short-circuit into the storm sewer.

After construction was completed, a large sink hole formed over the new outlet pipe within bioretention cell. Formation of the sink hole was caused by material settling. The sink hole was addressed by the primary contractor who filled it in. Careful observation of the cell after construction allowed corrective actions to take place

and remedy the situation.
A one-year warranty was established with the primary contractor involving: a care plan for plant replacement, post-installation care service, and watering during inadequate rainfall. Having a plant warranty ensured adequate and long-term establishment and survivability of the vegetation.

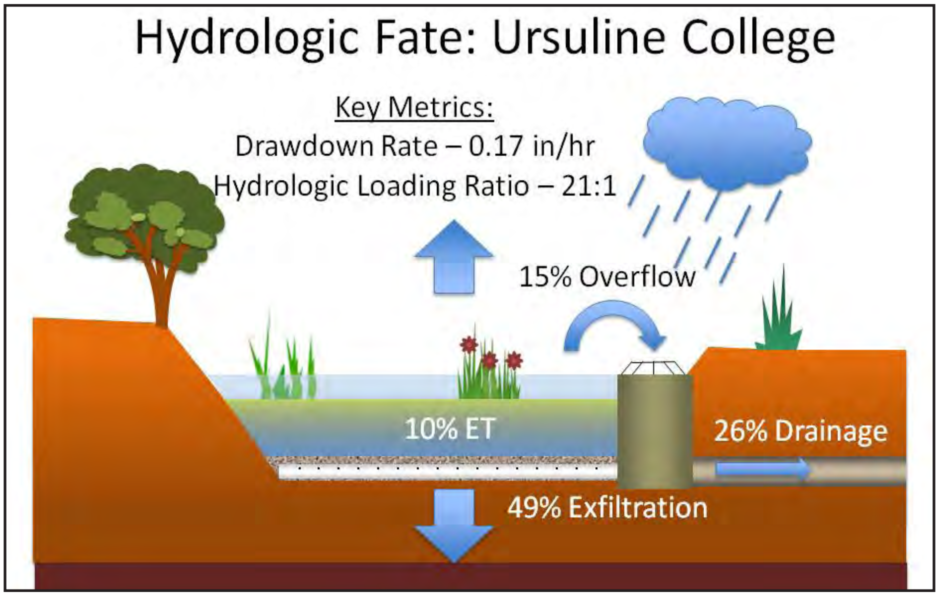
During construction, slumping of the side slopes occurred multiple times. The construction contractor mechanically pulled slumped soil out of the cell and mounded it on both sides. Despite efforts to address slumping, it still occurred, creating very rough side slopes. This made it difficult for grass to establish. A few months after the project was completed, the side slopes were smoothed and the low-mow grass seed replaced.

Monitoring

Monitoring equipment was installed both during and post–construction. The monitoring contractor installed an automated rain gauge and two auto-samplers. One autosampler collected stormwater runoff samples as water entered the bioretention cell. The second collected combined drainage and overflow to allow for direct comparison of inlet and outlet water quality. Inflow hydrology from the parking lot was estimated using the curve number and rational methods. The drainage system was kept separate from the existing storm sewer to isolate flows for monitoring purposes. Within the catch basin, a weir and baffle system was installed to collect hydrologic data from combined drainage and overflow. The cell was monitored for hydrology and water quality. A temperature sensor nest and a water table well were installed within the cell to measure drawdown rates between rain events.

Results

During the seven month monitoring period, a total of fifty rainfall events occurred. Out of those rainfall events, 33 had no outflow due to the relatively high average exfiltration rate (0.17 in/hr) and deep IWS zone (24 inches). The cell reduced runoff by 59%. Partially because of the effectiveness of the cell at reducing runoff, the team was unable to get enough samples at this site to evaluate water quality performance.



Lessons Learned

Overall

The following are some key insights from the design and construction of LID stormwater practices in northern Ohio during the first two years of the project. Feedback from project team members, collaborative learning group members, and interviewees was used to synthesize these lessons learned.

The following key insights are organized by project phase.

Pre-Design

- Establish goals in advance of the design process and provide opportunities for relevant stakeholders to provide feedback in a timely and coordinated manner to minimize redesign costs.

- Engineers and landscape architects should visit project sites before attempting to create site designs, because a wide range of factors need to be considered at each site that may not be apparent from surveys or aerial photographs.

- Involve people on site visits who know where infrastructure is located and/or have experience with developing conceptual plans for LID systems.

- Conduct site investigations during site evaluations and identify offsite drainage. It is helpful to determine the historical context of the site (i.e. soil grading or filling from pervious development), since this can affect results of soil investigations.

- Infiltration testing is critical for determining design parameters for LID SCMs.

- In greenfield development situations, the Soil Water Characteristics Calculator can be used to estimate infiltration rates and select appropriate LID approaches.

Design

- Aesthetics are important when designing SCMs because they are often constructed at publicly visible locations. Implementation will be much more widespread if projects are visually appealing.

- Design SCMs with a level subgrade to allow for even ponding that will promote exfiltration.

- For retrofits, consider SCM drainage area topography when designing SCM inlets

- Realize that features such as parking lot islands and speed bumps upslope of permeable pavements can cause flow to concentrate and disproportionately hit some areas of the permeable pavement surface, which can reduce the potential effectiveness of the system and increase maintenance needs.

- Consider SCM maintenance needs during design. Permeable pavement draining larger sections of impervious surfaces will need maintenance more frequently, and so will permeable pavements under trees.

- Design SCM underdrain systems with ample cleanouts to facilitate maintenance and prevent the build-up of sediment in drainage pipes.

- Specify appropriate materials for each type of SCM to make sure they will perform as intended.

- Landscaping of bioretention cells is very important and requires careful consideration. Select plantings that tolerate a range of soil moisture conditions, avoid visual clearance issues, minimize routine maintenance, provide year-round aesthetic appeal, and are commercially available to landscapers.

- Consider adding a suggested construction sequence to plans.

Pre-Construction

- Educate site owners, designers, inspectors, contractors, and others about purpose and function of LID SCMs to minimize problems during construction.
- Communicate with design engineers, site inspectors, and construction contractors about the importance of using appropriate materials, and provide potential bidders with supporting information about required materials, sequencing, and construction techniques.
- Ensure site inspectors are experienced and knowledgeable about constructing LID SCMs.
- Use specific language to describe LID SCMs when advertising projects. Use key words that differentiate the project from other types of construction and avoid vague terms like “restoration” and “retrofit” unless appropriate qualifiers are used.
- Hire certified and experienced contractors whenever possible. The ability to recognize the need for, and make adjustments during construction is a critical skill refined with experience. Provide site specific or SCM specific guidance and education as needed.
- Preconstruction meetings should be used to review plans with designers, owners, contractors and inspectors. Review the following key items: 1) construction sequencing and practices, 2) avoiding compaction of subgrade and scarification of underlying soils, 3) monitoring well installation (if applicable), 4) erosion control and site stabilization to prevent clogging, 5) protection of underdrains before and during construction, 6) material specifications, and 7) design engineer verification of critical installation points.

Construction

- Permeable paver systems with curved designs are more expensive to install because of the added labor costs associated with making additional curb cuts. Designs requiring fewer curb cuts can drastically reduce overall costs.
- Mechanical installation of permeable pavers and bedding significantly reduces installation costs.
- Permeable pavers can be installed late in the construction season (early winter) provided that the ground is not frozen. Mechanical paving equipment can be outfitted with heaters to ensure that pavers and aggregate bedding do not freeze and bind together.
- Pervious concrete needs to be carefully protected with plastic sheeting during the initial seven day curing period. Ensure that sheeting is properly secured.
- Wetting the subgrade of pervious concrete installations prior to pouring concrete may improve the appearance of final product and reduce surface raveling.
- Use the correct materials and avoid compacting the subgrade soil when constructing LID SCMs. Educate excavators and contractors on how to avoid soil compaction and scarify the subgrade soils beneath LID installations to promote exfiltration.
- Critical points of installation and materials inspection need to be verified (preferably by the design engineer) even with the best contractors.
- Construction sequencing is important for preventing errors and ensuring SCMs are functional once installed.
- Site stabilization during and after construction is critical for preventing clogging of newly installed SCMs.

Permeable Pavements

Pervious Concrete, Porous Asphalt, & Permeable Pavers

• Power wash pervious concrete (at a shallow angle) after a 10 day curing period following construction to remove any remaining loose gravel and debris.

• Maintenance needs can be determined by visual inspection and infiltration testing. Inspect system during and after rain events to determine need for maintenance.

• Clean permeable pavements with a vacuum sweeper truck or industrial outdoor vacuum at least once per year, preferably during late spring or early summer to prevent clogging. The frequency of vacuuming depends upon the area draining to the SCM and the proximity of adjacent trees to the SCM. Additionally, areas receiving concentrated flow will clog quickly.

• After sweeping permeable pavers, it is necessary to sweep #78 stone across the pavers to fill any voids between pavers.

• Never dump mulch, leaves, soil, or any other fine materials on the pavement surface that could cause clogging.

• Snow removal can be performed using the same methods used for impervious surfaces. Use of a steel, plastic, or hard rubber edged plow, or a snow blower, is acceptable.

• Limited salt or deicing products should be used on the pervious concrete for a year following construction because they interfere with the long-term curing process and could damage the pavement. If possible, do not use any salt products during the first year following installation.

Vacuum sweeper trucks can be used for permeable pavements

Bioretention

Bioretention cells require routine landscaping maintenance to ensure they are working properly and aesthetically pleasing.

Plant Selection

• Careful selection of plantings can minimize erosion, enhance aesthetics, and reduce overall maintenance and maintenance costs.

• In Ohio, the aesthetics of plantings during the winter months need to be considered.

• Consider space constraints, visual clearance, arrangement, and rooting zones of plantings.

Maintenance

• Diseased vegetation should be treated and dead vegetation should be removed.

• Mowing or pruning may be needed depending upon the types of plantings and the desired amount of visual clearance.

• If a bioretention cell is receiving a heavy sediment load from the watershed, it is necessary to periodically remove accumulated sediment to prevent clogging.

• The procedures used for maintaining bioretention cells are very similar to those used on most commercial and municipal landscapes. Hiring an experienced landscaper educated on the purpose and function of bioretention cells is a simple and cost effective way to ensure routine maintenance is being performed properly.

• If the bioretention cell is ponded for more than 12 hours after a rain event, the maintenance personnel should check the cell for a clogging layer near the surface of the media.

•Avoid over applying mulch to maintain that the ponding depth the designer intended.

•Periodically check inlets and outlets to make sure that they are structurally sound and are not blocked. Address any areas of concern.

•If the bioretention cell is ponded for more than 12 hours after a rain event, the maintenance personnel should check the cell for a clogging layer near the surface of the media.

Why use a collaborative learning approach?

The project's collaborative learning approach was designed to ensure that stormwater management needs in Ohio were effectively addressed using applied research methods.

Collaborative learning is a process that engages individuals in a group setting to foster creative thought, constructive debate, joint fact finding, and shared knowledge creation. The success of this process hinged upon the participation of collaborative learning group (CLG) members and the project team's technical and facilitation expertise.

Project site tour during September 2013 CLG meeting

Project site tour during July 2013 CLG meeting

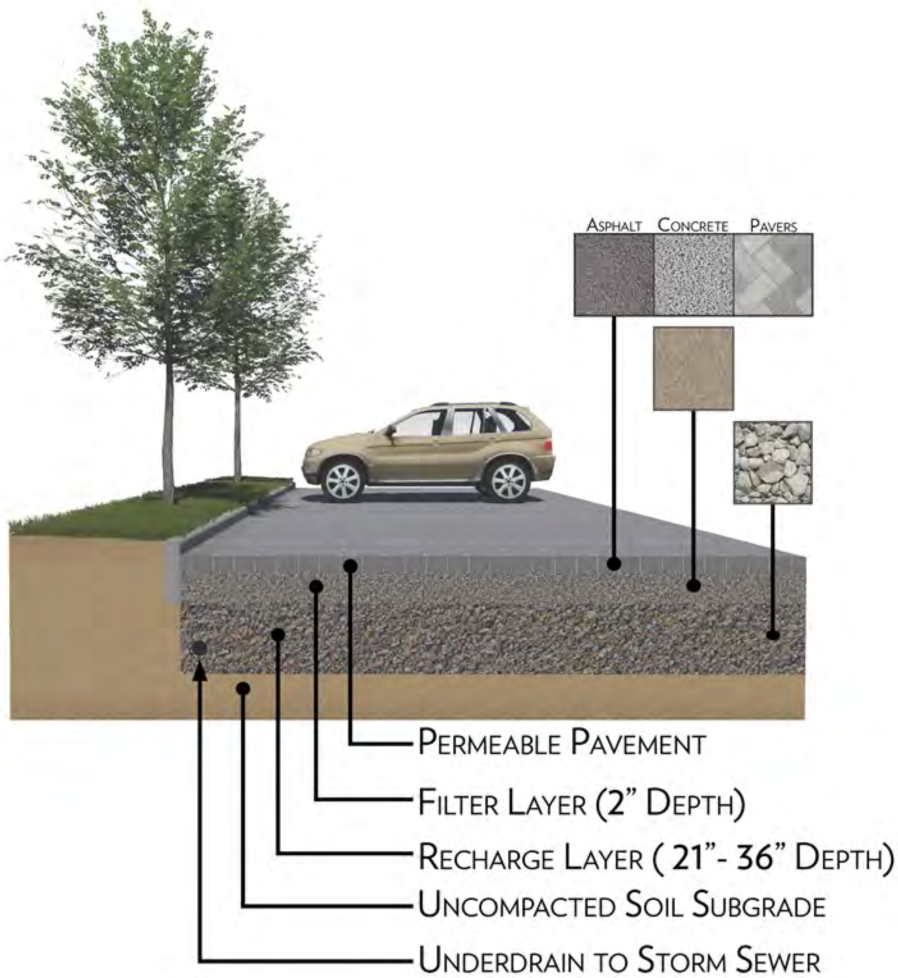
How has collaborative learning benefited the project?

The CLG provided input and guidance on research priorities, site selection, SCM design, construction, monitoring, and modeling. CLG members also provided feedback on training and tools to disseminate project results, including design guidance and model codes. The interdisciplinary nature of the group allowed the project to benefit from a range of different perspectives and suggestions that might have otherwise been overlooked. CLG input ensured this research is relevant to practitioners and helped the project team to hone the research approach.

How was collaborative learning used?

Team members from the Consensus Building Institute (CBI) and Old Woman Creek National Estuarine Research Reserve (OWC NERR) were the primary facilitators and collaboration leads. They engaged participants in the research effort and developed a shared learning environment that encouraged interaction and fostered creative problem solving. Facilitation ensured that all CLG members had an equal opportunity to participate and kept the group focused on productive discussion. The CLG was a voluntary group comprised of consulting and community engineers, regulators, stormwater utility managers, and watershed organizations. Meeting frequency was determined by the availability of new information and progress made toward project objectives. Meetings were held 2-3 times a year, which was frequent enough to keep participants engaged, but did not become a scheduling burden. Site tours and presentations from guest speakers were often featured to enhance the shared learning experience and promote constructive discussion. CLG members stated that these meeting elements were extremely valuable and greatly added to their learning experience. They also said that unstructured periods of the meetings were valuable for networking and informal discussion with other stormwater professionals. CLG members shared project information with others and some applied what they have learned in site planning and stormwater design.

Permeable Pavements



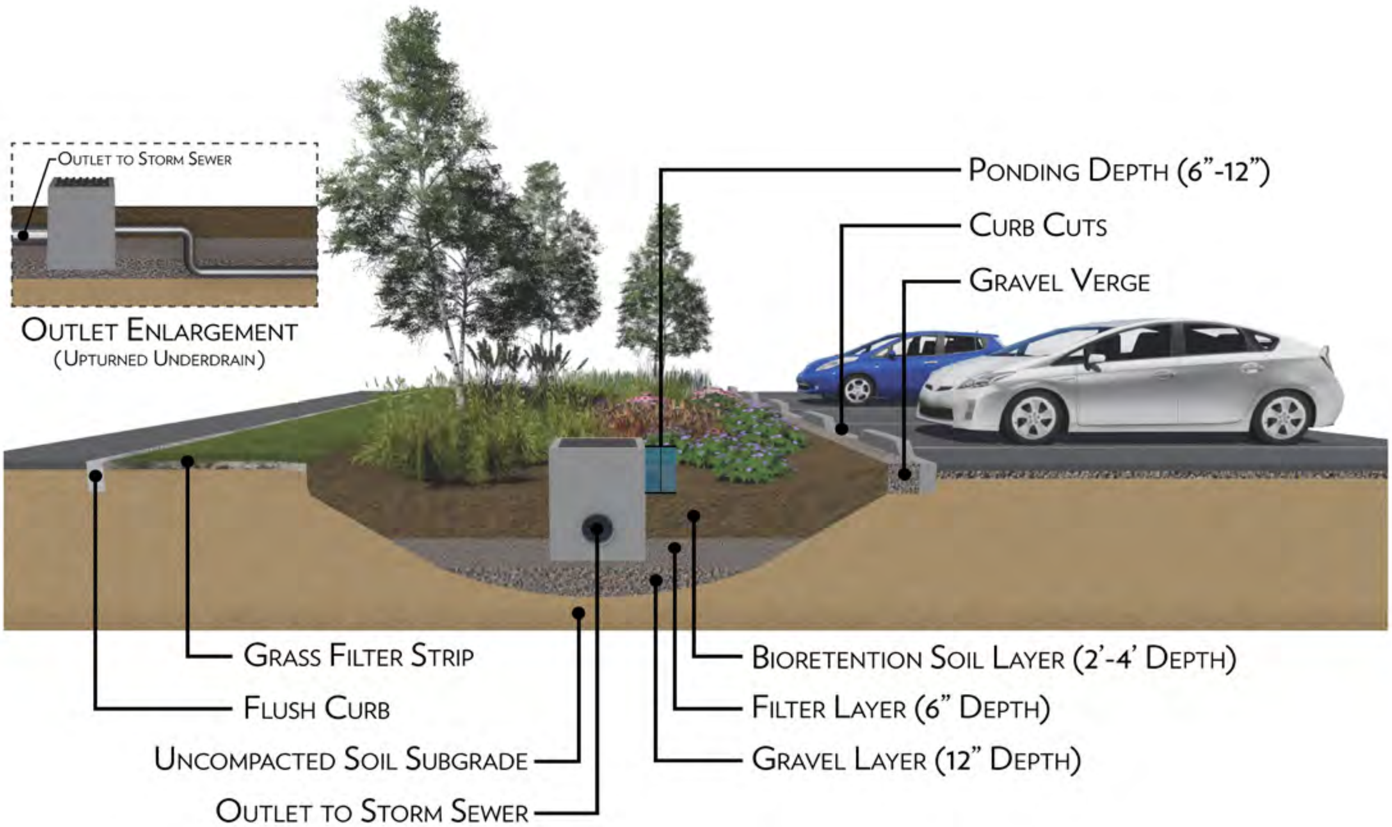
Permeable Pavements

Permeable pavement systems reduce stormwater volume and peak flow rates and reduce suspended solids, metals, petroleum hydrocarbons, and other pollutants in runoff. Stormwater runoff is captured either by infiltrating through a highly porous pavement surface (specially formulated asphalt or concrete with most fines removed from the mix design) or through gaps filled with highly permeable aggregate between pavers. Permeable pavement systems have one or more open-graded aggregate layers beneath the pavement surface to provide structural support and temporary storage of stormwater. The recharge layer is designed to be a structurally stable subbase for the pavement and is constructed using #1 or #2 interlocking stone. It is important to note that all aggregates used for these systems should be washed and contain very few fines. Additionally, all stone should be angular (not river run), so it will interlock for structural support of the pavement.

Enhanced outlet designs create an area for internal water storage, promoting exfiltration and reducing the volume of stormwater entering the storm sewer through the underdrain (Mathews, 2006). The water storage capacity within the recharge layer is determined by the depth of the aggregate between the underdrain and the underlying soil. Exfiltration can be further enhanced by loosening, ripping, or trenching the soils beneath the aggregate subbase using the teeth of an excavator during construction (Tyner et al., 2010).

Many types of permeable pavements are commercially available, including permeable interlocking concrete pavers (PICP), pervious concrete (PC), and porous asphalt (Mathews, 2006). Each pavement surface material has different specifications and applications, but all permeable pavement systems have similar subgrade designs.

Bioretention



Bioretention

Bioretention systems are integrated into the landscape of small drainage areas and use soil media, sand, gravel, and plantings to remove pollutants. Research has shown that bioretention SCMs improve water quality by removing heavy metals, suspended solids, bacteria, nutrients, petroleum hydrocarbons, and organic compounds (Hunt et al., 2006). They are designed to promote a variety of different pollutant removal mechanisms including sedimentation, filtration, evapotranspiration, microbial breakdown, adsorption, and nutrient uptake by plants and microbes (Mathews, 2006; Hunt et al., 2006). Modification of outlet structures to include an upturned elbow on the underdrain creates an internal water storage layer in the practice that enhances denitrification, promotes exfiltration, reduces peak flow rates, and mitigates outflow temperatures (Hunt et al., 2006).

Bioretention systems capture stormwater runoff in a shallow surface depression (typically 9-12 inches deep) that allows the water to gradually percolate through the soil media. Stormwater is filtered as it moves through the soil media, filtration layer, and gravel layer. The soil media layer consists primarily of loam with no less than 80% sand and no greater than 10% clay mixed with 3-5% decomposed organic matter (Mathews, 2006). The filter layer is comprised of 3 inches of clean medium concrete sand over 3 inches of #8 stone or pea gravel. The gravel layer uses 12 inches of #57 stone to facilitate drainage, water storage, and protection of the underdrain system. Treated water exits the system by either exfiltrating into the ground, evaporating or transpiring into the atmosphere, or flowing into the storm sewer through the underdrain system. If runoff from a large storm event exceeds the surface ponding depth of a bioretention practice, then water overflows into the storm sewer bypassing treatment. Bioretention practices are typically sized to capture runoff from the first flush or water quality event (0.75"-1" of rain). Plantings should be aesthetically appealing year-round, commercially available to landscapers, and tolerant to salt and a broad range of soil moisture conditions.

Acknowledgements

Project Team Members

Project Coordinator and Fiscal Agent
• Keely Davidson-Bennett;
Chagrin River Watershed Partners, Inc.

Collaboration Leads
•Frank Lopez; Old Woman Creek National Estuarine Research Reserve

• Ona Ferguson; Consensus Building Institute providing technical assistance

Applied Science Investigator
• Jay D. Dorsey, Ph.D., P.E., ODNR, Division of Soil and Water Conservation

Additional project team members
• Heather Elmer and Kristen Buccier, Chagrin River Watershed Partners, Inc.

•Breann Hohman and Crystal Dymond, Erie Soil and Water Conservation District

• Ryan Winston, North Carolina State University

Collaborative Learning Group

- Dan Bogoevski, Ohio Environmental Protection Agency
- Jane Cullen, City of Sandusky
- Justin Czekaj, City of Aurora
- Eric Dodrill, Erie Soil and Water Conservation District
- Alexander Etchill, John Hancock & Associates
- John Farschmann, Erie County Engineer
- Ken Fortney, Erie County Engineer
- Lynette Hablitzel, Ohio EPA
- Clyde Hadden, CT Consultants, Inc.
- John Hancock, John Hancock & Associates, Inc.
- Philip Kiefer, City of Kirtland / CT Consultants
- Dave Ritter, Northeast Ohio Regional Sewer District
- William Sanderson, Forest City Land Group
- Leo Sferra, GPD Group
- Rachel Webb, Northeast Ohio Regional Sewer District
- Betsy Yingling, Northeast Ohio Regional Sewer District

Additional Resources

ODNR Division of Soil and Water Resources
Rainwater and Land Development Manual
soilandwater.ohiodnr.gov/water-conservation/stormwater-management#RAI

Erie Soil & Water Conservation District
eriesoilandwater.org

North Carolina State University
Stormwater Engineering Group
bae.ncsu.edu/stormwater

Old Woman Creek National Estuarine Research Reserve
wildlife.ohiodnr.gov/oldwomancreek

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http://www.nerrs.noaa.gov/ScienceCollaborative.aspx

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Collaborative Learning Group Meeting September 2013

Site Representatives, Design Engineers, and Contractors

Perkins Township

• Site Representative: Eric Dodrill, Erie Soil and Water Conservation District

• Engineer: Alexander Etchill, John Hancock & Associates

• Contractor(s): RMH and Star Building, Inc.

Orange Village

• Site Representative: Bob Zugan, Orange Village

• Design Engineer: Brian Mader, Orange Village Engineer and Stephen Hovancsek & Associates

• Contractor: Seitz Builders

City of Willoughby Hills

• Site Representative: Mayor Robert Weger, City of Willoughby Hills

• Design Engineer: John Topolski, CT Consultants

• Contractor: LCI Construction

Holden Arboretum

• Site Representative: Roger Gettig, Holden Arboretum

• Design Engineer: Jay Dorsey, Ohio Department of Natural Resources

• Landscape Plan Design: Roger Gettig, Holden Arboretum

• Contractors: Jay Dorsey, Ohio Department of Natural Resources, Holden Arboretum staff

Ursuline College

Site Representatives: June Gracyk, Ursuline College

• Design landscape Architects: Craig Cawrse and Richard Washington, Cawrse & Associates, Inc.

• Contractor: Marks Construction and Davey Resource Group

Old Woman Creek NERR

Site Representatives: Frank Lopez, Old Woman Creek NERR

• Design Engineer: Ryan Winston, North Carolina State University

• Contractor: LCI Construction

Monitoring Contractors

• William F. Hunt, North Carolina State University, Ph.D., P.E.

• Shawn Kennedy, North Carolina State University

• Ryan Winston, P.E., North Carolina State University

• Paul Kovalcik, Biohabitats

• Kevin Grieser, Biohabitats

Modeling Contractors

• Scott Dierks, Cardno JFNew

• William F. Hunt, Ph.D., P.E., North Carolina State University

• Ryan Winston, P.E., North Carolina State University

Alessa Smolek, North Carolina State University

Observers/Partners

• Carlo DeMarchi, Ph.D. Case Western Reserve University and Oberlin College

• Cyndee Gruden, Ph.D., University of Toledo

• Anne Jefferson, Ph.D., Kent State University

Interviewees

• Alex Etchill, John Hancock & Associates

• Nick Licursi and Anthony Licursi, LCI Construction

• Bob Zugan, Orange Village Service Department

• Eric Dodrill, Erie Soil and Water Conservation District

• Roger Gettig, Holden Arboretum

• Jay Dorsey, Ph.D., P.E., ODNR, Division of Soil and Water Conservation

• John Topolski, P.E., CT Consultants

• Betsy Yingling, Northeast Ohio Regional Sewer District

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Mathews, John. *Rainwater and Land Development: Ohio's Standards for Stormwater Management, Land Development and Urban Stream Protection.* 3rd ed. Ohio Department of Natural Resources, Division of Soil and Water Conservation. 2006. Web. http://www.dnr.state.oh.us/Portals/12/water/rainwater/8_30_2012RLDFiles/3-3-14RLD_All.pdf

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Additional Information

Please visit the Chagrin River Watershed Partners website (www.crwp.org) for progress reports, meeting summaries, project updates, presentations, and other project resources. Project information can be accessed by selecting *Research Projects* from the *Projects* menu and then clicking on *NERRS Science Collaborative*.

Direct Link:
http://crwp.org/index.php/projects/research-projects/nerrs-science-collaborative

For Questions, Please Contact:

Chagrin River Watershed Partners
www.crwp.org
(440) 975-3870

Old Woman Creek National Estuarine Research Reserve
http://wildlife.ohiodnr.gov/oldwomancreek
(419) 433-4601

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