Implementing Credits and Incentives for Innovative Stormwater Management

A Final Report Submitted to the

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1. Abstract

This project promoted the implementation of low impact development (LID) stormwater control measures (SCMs) to reduce the impacts of stormwater runoff on Ohio's coastal communities and worked to improve state and local stormwater policies. The project team included the Chagrin River Watershed Partners, Inc. (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). A Collaborative Learning Group (CLG) of local and state stormwater regulators and consulting engineers provided iterative guidance and feedback to the project team.

Our team assessed the hydrologic performance of bioretention and permeable pavement on poorly draining soils by collecting and analyzing data from three bioretention cells, four permeable pavement applications, and a permeable pavement-cistern treatment train. All monitoring sites were located within Ohio's Lake Erie Basin and were within the Pipe Creek, Old Woman Creek, or Chagrin River watersheds. All stormwater controls were located over clayey soils. The bioretention cells we monitored reduced outflow by 36 - 60% through exfiltration and evapotranspiration. The monitored permeable pavement applications reduced outflow by 16 - 99%. The permeable pavement application with the smallest reduction in outflow drained an impervious area much larger than what is recommended by Ohio's stormwater manual, *Rainwater and Land Development*. The permeable pavement application with the greatest reduction in outflow had no run-on from impervious surfaces, areas of well draining fill within the subgrade soil beneath the permeable pavement, and a subdrain beneath the permeable pavement system designed to dewater the groundwater table. SWMM and DRAINMOD modeling allowed for further assessment of the impact of design choices on SCM performance.

This project resulted in updates to the bioretention design specification in *Rainwater and Land Development* and laid the technical foundation for a runoff reduction crediting mechanism to be added to *Rainwater and Land Development*. The runoff reduction guidance will provide a pathway to meet the state's NPDES water quality volume (WQv) requirement through runoff reduction, as well as a mechanism for crediting the runoff reduction benefits of LID SCMs toward meeting local peak discharge requirements. ODNR-DSWR's goal is to develop draft estimates, tools, and guidance, and subject them to industry and community review, by the end of 2015. This project also informed updates to CRWP's model comprehensive stormwater management code. Additionally, project team members provided technical assistance and training to many engineers and local government staff members over the course of the project to increase their capacity to implement LID.

Challenges encountered during the project included: difficulty finding SCMs suitable for monitoring, changes in project team staffing, the extended geographic reach of the project that resulted in some CLG members not attending CLG meetings further from their workplaces, and difficulty finding effective modeling contractors. Additionally, future climate datasets were difficult to procure.

2. Management problems and context

Stormwater runoff causes severe impacts throughout coastal Ohio through channel instability, severe streambank erosion, sedimentation, and habitat degradation (Ohio EPA, 2008). The traditional methods of managing stormwater are significant contributors to this problem (Konrad and Booth, 2005; USEPA, 2007; NRC, 2008). These impacts and recommendations for preventing degradation of coastal resources are detailed in the Ohio Coastal Management Program (CMP) policies on water quality and nonpoint source pollution. The CMP document includes Coastal Nonpoint Source Management Measures to decrease the erosive potential of increased runoff volumes and velocities associated with development-induced changes in hydrology, remove suspended solids and associated pollutants that result from development activities, maintain predevelopment hydrologic conditions, and preserve natural systems including in-stream habitat (NOAA Office of Ocean and Coastal Resource Management and ODNR Office of Coastal Management, 2007).

New development in Ohio is subject to both a state-level post-construction water quality requirement and local peak discharge requirements. Ohio EPA stormwater management regulations require the first 0.75" of rain, referred to as the Water Quality Volume (WQv), be captured and treated prior to discharge. Detaining this WQv is intended to reduce 80% of the total suspended solids in stormwater runoff (USEPA, 1993, 2005). Most local jurisdictions have stormwater peak discharge requirements, targeted at flood control, typically with some combination of the post-development 1-yr, 24-hr through 100-yr, 24-hr storms being released at or below pre-development flow rates. The Critical Storm Method (CSM) for determining post-development peak discharge requirements has been promoted by the Ohio Department of Natural Resources since 1980 to address stream stability and flood control goals (ODNR, 1980). The CSM requires that the peak rate of runoff from the "critical storm" and all more frequent storms must not exceed the peak rate of runoff from the 1-yr, 24-hr storm occurring on the same area under pre-development conditions. Storms of less frequent occurrence than the critical storm, up to the 100-yr storm, must have peak runoff rates no greater than the peak runoff rates from equivalent size storms under pre-development conditions. The "critical storm" is determined by the increase in the total volume of the 1-year, 24 hour storm caused by development (Table 1). The CSM has been adopted as the peak discharge standard by dozens of local jurisdictions (counties, townships and municipalities) in Ohio, estimated at roughly 50% of statewide MS4s.

Based on current regulations, large end-of-the-pipe stormwater detention ponds are the path of least resistance for most developments. They are familiar, easy to design and review, have the clearest guidance in regulations and specifications, and seem to be cost effective. However, large detention basins replace few of the landscape functions and services provided by soils, wetlands, and natural riparian areas lost during the development process.

Table 1: Determination of the Critical Storm

If the percent increase in runoff volume for the 1-year, 24-hour storm is:		The Critical Storm for peak rate control is:
equal to or greater than	and less than	
-	10	1-year
10	20	2-year
20	50	5-year
50	100	10-year
100	250	25-year
250	500	50-year
500	-	100-year

Many low impact development (LID) stormwater control measures (SCMs) provide effective water quality treatment, and can be designed to manage runoff volumes and maintain pre-development hydrology (CWP, 1998; Prince George's County, 1999a, 1999b; Coffman; USEPA. 2005a; Bitting and Kloss, 2008; MDE, 2008). LID approaches protect, enhance or mimic natural processes to maximize stormwater management functions and services provided by the landscape (Wulliman and Thomas, 2005). Two publications (Belan and Otto, 2004; DePhilip et al., 2006) promote this approach for Great Lakes watersheds. Research also suggests LID is a cost effective climate change adaptation strategy (Roseen, 2011).

In a 2008 Ohio Coastal Training Program (CTP) assessment of local official training needs, 85% of respondents and 100% of city and village engineers indicated they were interested in training and technical assistance on stormwater management (Elmer, 2008). Stormwater professionals identified a need for dialogue among local and state governments, design guidance and training for stormwater professionals and decision-makers, and quantitative data on innovative SCMs. Workshop participants requested design manuals and training or a certification program including research results, case studies, cost analysis, site visits, and consistent state guidance. Prior to this project, end users identified the following barriers to LID:

- Uncertainty about how LID SCMs perform in Ohio's poorly draining soils and cold winters
- Current regulations are focused on peak discharge control instead of runoff volume
- Zoning requirements impede low impact development designs
- Lack of credit toward meeting local peak discharge requirements
- A pipe-and-pond culture among designers and reviewers

Our team partnered with intended users in a collaborative process to evaluate SCM performance and address these barriers to LID. This project sought to address the following objectives:

- *Objective 1:* Engage stormwater professionals in a collaborative process to identify and remove regulatory and technical barriers to implementation of LID in Ohio. This collaborative learning group (CLG) included the project team, representatives from Ohio EPA, local government stormwater plan reviewers and program administrators, consulting engineers, and a sewer district addressing combined sewer overflows using grey and green infrastructure.
- *Objective 2:* Quantify SCM specific and site level hydrology for local soil and climate characteristics. This objective included design of at least two SCMs and monitoring of a total of six SCMs to track hydrologic performance.
- *Objective 3:* Simultaneously model treatment of water quality and quantity volumes to meet local and state requirements.
- *Objective 4:* Adapt models to include rainfall runoff scenarios anticipated as a result of climate change and characterize climate change adaptation functions of LID SCMs.
- *Objective 5:* Develop and provide training and technical assistance materials to build capacity of stormwater professionals and communities to implement LID approaches.

3. Outcomes, methods, and data

This project increased implementation of LID in northern Ohio through technical assistance, training, improvement of local regulations and state SCM design guidance, and assessing bioretention and permeable pavement performance under local conditions. Collaboration occurred among the project team and the Collaborative Learning Group (CLG). The project team included representatives from the Old Woman Creek National Estuarine Research Reserve (OWC NERR), Chagrin River Watershed Partners, Inc. (CRWP), the Ohio Department of Natural Resources (ODNR), North Carolina State University (NCSU), the Consensus Building Institute (CBI), and the Erie Soil and Water Conservation District (SWCD). The project team talked as a group at least once a month and met several times a year in person. They tracked all project progress, oversaw all aspects of the initiative, and planned and led the Collaborative Learning Group. Project team members built very strong relationships, and learned a lot about how to work together productively. Project team work was very respectful, despite some challenging periods and subjects. The group became effective communicators, with everyone working hard to err on the side of more communication and clarifications on team calls, in emails, and in individual calls or meetings. Having two primary facilitators kept discussions on track because of their diplomacy and willingness to push gently on topics that were difficult. Note-taking at all meetings helped keep the group on track and remind project team members what they had discussed and decided.

Our team assessed the performance of bioretention and permeable pavement on poorly draining soils by collecting and analyzing hydrologic data from 3 bioretention cells, 4 permeable pavement applications, and a permeable pavement-cistern treatment train to determine runoff reduction by these SCMs. All monitoring sites were located within Ohio's Lake Erie Basin and were within the Pipe Creek, Old Woman Creek, or Chagrin River watersheds (Figure 1). Furthermore, the underlying soils of all monitored SCMs were mapped as poorly draining (Hydrologic Soil Group D) or somewhat poorly draining (Hydrologic Soil Group C). We used weirs and pressure transducers to measure outflow from the SCMs, water table wells and pressure transducers to measure exfiltration, and weather stations, rain gauges, and standard engineering methods to estimate inflow to and evapotranspiration from the SCMs. We also collected and analyzed water quality data from 1 bioretention cell, 2 permeable pavement applications, and 1 permeable pavement-cistern treatment train to assess water quality performance of these SCMs. Automated samplers collected flow paced composite samples, and staff from the Northeast Ohio Regional Sewer District and Old Woman Creek NERR analyzed the samples according to best methods (APHA et al., 2012 or USEPA, 1983). NCSU conducted quarterly surface infiltration tests on permeable pavement on 3 sites in Ohio to evaluate permeable pavement maintenance needs.

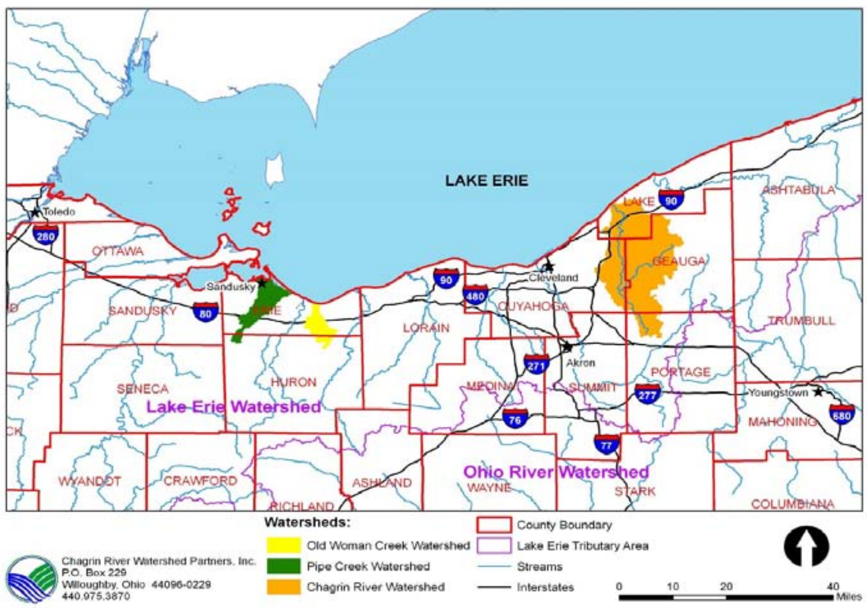

Figure 1: Monitoring sites were located within 3 watersheds within Ohio's Lake Erie Basin: Pipe Creek, Old Woman Creek, and Chagrin River.

The bioretention cells reduced outflow by 36 - 60% through exfiltration and evapotranspiration (Table 2 and Appendix A). Two of the monitored bioretention cells completely captured storms up to 0.25 inches without producing outflow, and the other bioretention cell completely captured storms up to 0.63 inches of rainfall without producing outflow (Figure 3). The monitored permeable pavement applications reduced outflow by 16 - 99% (Table 3 and Appendix A). The permeable pavement application with the smallest reduction in outflow drained an impervious area 7 times its surface area, much larger than what is recommended by Ohio's stormwater manual, *Rainwater and Land Development*. The permeable pavement application with the greatest reduction in outflow had no run-on from impervious surfaces, areas of well draining fill within the subgrade soil beneath the permeable pavement, and a subdrain beneath the permeable pavement designed to dewater the groundwater table. Because the subdrain dewatered a larger area than the permeable pavement installation, it was not possible to determine the amount of exfiltration from the permeable pavement system routed to the subdrain at this site. The monitored permeable pavement applications ranged in the size of storms they could typically capture without producing outflow from 0.11 inches to 0.99 inches (Figure 4). All monitored

SCMs included an internal water storage zone (IWS) to promote exfiltration achieved with either an upturned elbow at the outlet or elevating the underdrain above the subgrade (Figures 5 and 6).

Table 2: Water balance for bioretention cells over the monitoring period

Site Name	Cell Name	Total Inflow (ft^3)	Drainage (ft^3)	Overflow (ft^3)	Exfiltration + ET (ft^3)	Drainage (%)	Overflow (%)	Runoff Reduction (%)
Ursuline College	-	100700	28300	12500	61700	28.1	12.4	59.5
Holden Arboretum	South	35100	17900	2400	12900	51.1	6.8	42.1
	North	50300	28800	3500	18100	57.2	6.9	36.0

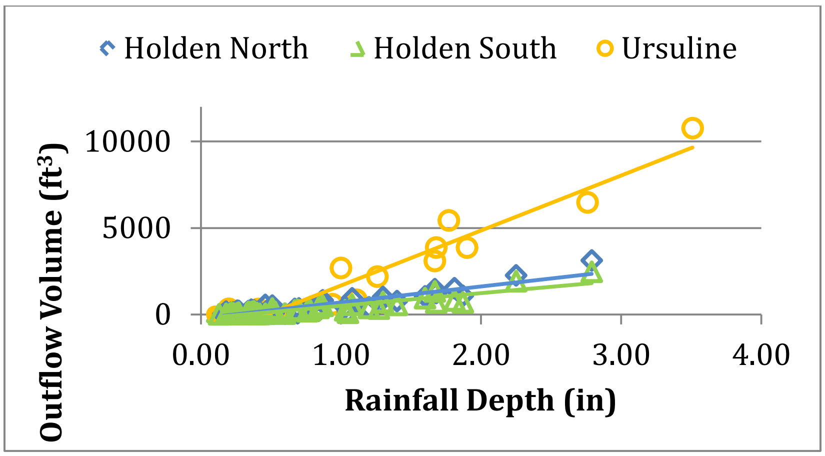

Figure 3: Segmented linear regression was used to determine the discharge threshold of each bioretention cell. For Ursuline College, rainfall depths less than 0.63 inches were typically completely captured. For Holden North, the discharge threshold was 0.25 inches, and it was 0.32 inches for Holden South.

Table 2: Water Balance for Permeable Pavement Systems Over Monitoring Period

Site	Evaporation + Abstraction	Exfiltration	Drainage	Overflow
Perkins Township	5%	42%	53%	0%
Willoughby Hills Small	13.2%	3.5%	75.3%	8%
Willoughby Hills Large	10.5%	21.5%	44%	24%
Orange Village	98.8%		1.2%	0%

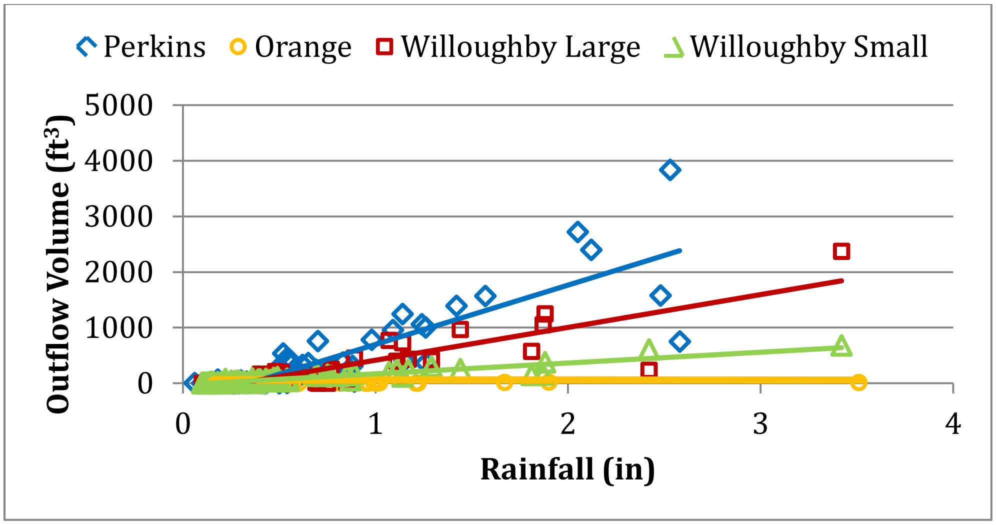

Figure 4: Segmented linear regression was used to determine the discharge threshold of each permeable pavement application. For Perkins Township, rainfall depths less than 0.35 inches were typically completely captured. Discharge thresholds for the other applications were as follows: Orange Village - 0.99 inches, Willoughby Hills Large - 0.31 inches, Willoughby Hills Small - 0.11 inches.

Figure 5: The underdrain with an upturned elbow provides an internal water storage (IWS) zone within the bioretention cell at Holden Arboretum.

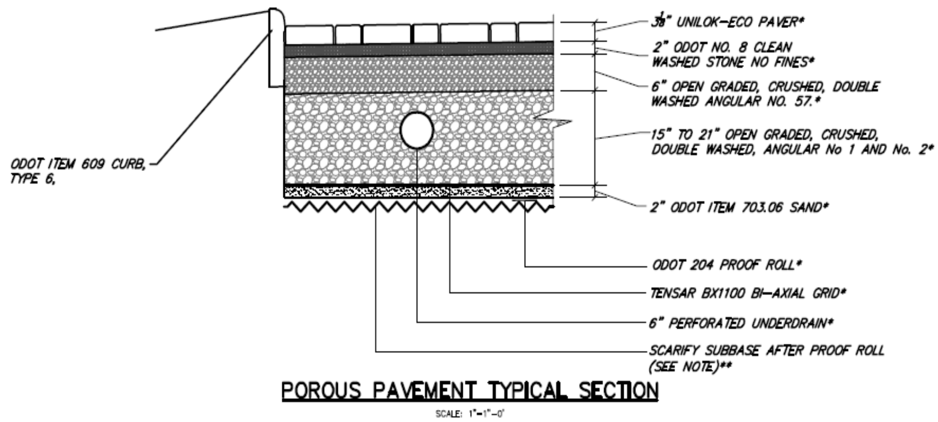

Figure 6: Elevating the underdrain above the subgrade is another means of providing an internal water storage (IWS) zone. This design was used for the permeable pavement installation at Orange Village.

The permeable pavement applications at Willoughby Hills reduced total phosphorus, soluble reactive phosphorus, total nitrogen, zinc, and copper loads leaving the site. In contrast to the literature on permeable pavement performance, the effluent concentrations of total suspended solids were higher than the influent concentrations at Willoughby Hills. The number of water quality samples for Old Woman Creek NERR and Ursuline College were smaller, so water quality results from those sites should be interpreted with caution. However, the limited data available indicated the permeable pavement-cistern treatment train at Old Woman Creek NERR reduced aluminum, copper, iron, manganese, lead, zinc, suspended solids, nitrogen, and phosphorus concentrations. The data from the limited sampling of the bioretention cell at Ursuline College suggested the cell reduced suspended solids, aluminum, lead, and zinc loads. More information about water quality performance of monitored sites is available in Appendix A.

Surface infiltration tests indicated only one permeable pavement site required vacuuming during the monitoring period, which ended between one and two years after the permeable pavements were installed. This site treated run-on from impermeable surfaces well in excess of recommended run-on ratios, and therefore clogging was not unexpected. Areas near the transition between impermeable and permeable pavement, under trees, and those receiving concentrated flow were most prone to clogging. Vacuum sweeping was often effective for restoring the function of clogged permeable pavement (Appendix A).

We assessed the impact of design variables on SCM performance and potential impacts of climate change on SCM performance. ODNR-DSWR and NCSU used calibrated and validated SWMM and DRAINMOD models to explore the impact of bioretention and permeable pavement design variables on hydrologic performance through a sensitivity analysis. They found the most influential parameters were the conductivity of the underlying soil and the inclusion of an IWS zone. The DRAINMOD model predicted that bioretention on soil that infiltrates 0.5 in/hr would exfiltrate 70-80% of the inflow volume, while bioretention on soil that infiltrates 0.02 in/hr would only exfiltrate 15-30% of the inflow volume, depending on design characteristics

(Appendix B). Similarly, the DRAINMOD model predicted that typical Ohio permeable pavement designs on soil that infiltrates 0.5 in/hr would exfiltrate about 80% of the inflow volume, while permeable pavement on soil that infiltrates 0.02 in/hr would only exfiltrate 35-40% of the inflow volume. Depth of the internal water storage zone also had substantial impact on the water balance, with more exfiltration occurring at greater internal water storage depths for both bioretention and permeable pavement (Figure 7 and Figure 8). The ratio of watershed area to SCM surface area (i.e. the hydrologic loading ratio) also impacted the performance of bioretention and permeable pavement.

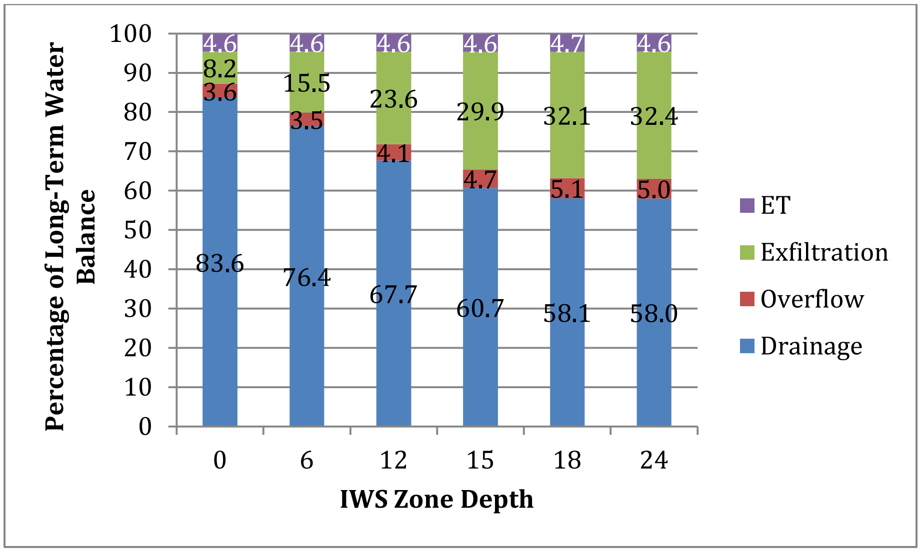

Figure 7: The impact of internal water storage depth on the water balance of bioretention cells on poorly draining soils (0.02 in/hr) as determined by a sensitivity analysis with calibrated DRAINMOD models.

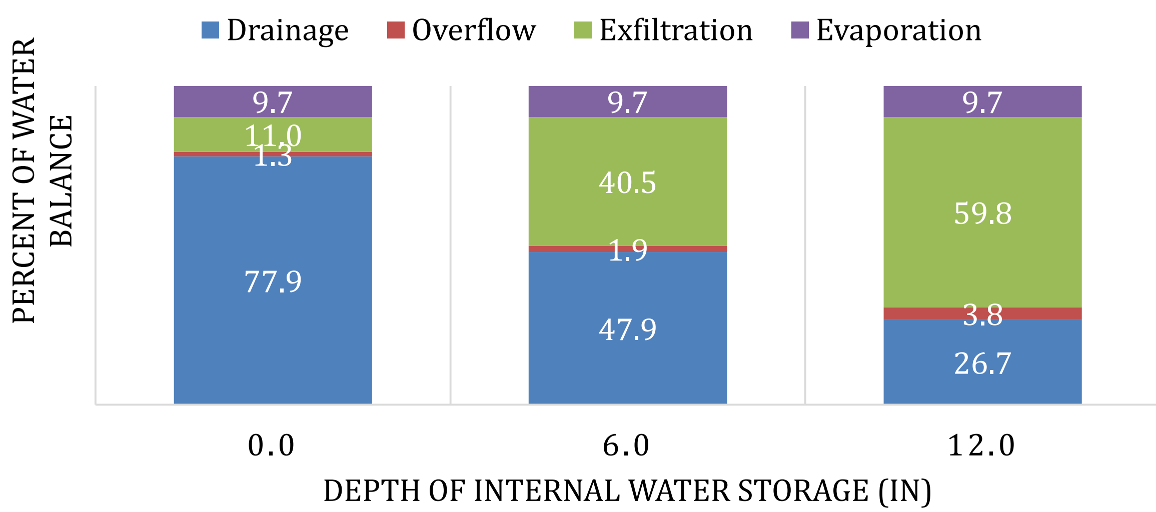

Figure 8: The impact of internal water storage depth on the water balance of permeable pavement on poorly draining soils (0.02 in/hr) as determined by a sensitivity analysis with calibrated DRAINMOD models.

Cardno JFNew, a subcontractor to this project, evaluated the impact of design choices on the performance of bioretention, permeable pavement, underground storage, dry detention, infiltration trenches, grass swales, vegetated filter strips, soil renovation, and green roofs using uncalibrated SWMM models (Appendix C). ODNR-DSWR is using the runoff reduction estimates for the 2" rainfall depth event from this modeling work as a surrogate for the 1-yr, 24-hr event to aid in the development of runoff reduction credits for SCMs. These sensitivity analyses supplement information derived from the research literature.

NCSU assessed the expected performance of bioretention and permeable pavement under future climate conditions by entering dynamically downscaled rainfall and temperature data for moderate (RCP 4.5) and severe (RCP 8.5) climate data projections for mid-twenty-first-century. This research was supported by data from the University of Tennessee and Oak Ridge National Laboratory (Gao et al., 2012). It was inputted into calibrated and validated DRAINMOD bioretention and permeable pavement models. Generally, future climate scenarios suggested lower annual average rainfall depths, longer dry periods, and hotter temperatures for northern Ohio. The climate model indicated some of the monitoring sites will experience increases in the rainfall depth of the extreme storms, while other sites will experience decreases in extreme storm depth; results were highly spatially variable. Sites forecasted to experience larger extreme storms had up to 66% (for bioretention) and 352% (for permeable pavement) increases in the volume of bypass. The models predicted increases in the proportion of water that evaporates from bioretention and permeable pavement applications in the future due to higher daily temperatures and longer dry periods (Appendix B).

Our project has resulted in updates to *Rainwater and Land Development* (ODNR, 2006), and has provided information for additional updates. ODNR-DSWR updated the bioretention specification in the manual during the project. The hydrologic performance information generated and gathered by the *"Implementing Credits and Incentives for Innovative Stormwater Management"* project will serve as the technical foundation for a runoff reduction crediting mechanism to be added to *Rainwater and Land Development*. The runoff reduction guidance will provide a pathway to meet the state's National Pollutant Discharge Elimination System (NPDES) water quality volume (WQv) requirement through runoff reduction, as well as a mechanism for crediting the runoff reduction benefits of LID SCMs toward meeting local peak discharge requirements. ODNR-DSWR's goal is to develop draft estimates, tools and guidance, and subject them to industry and community review by the end of 2015. ODNR-DSWR has made substantial progress towards developing the peak discharge crediting framework for the Critical Storm Method including developing draft spreadsheet tools and calibration of SWMM models for bioretention and permeable pavement. Modeling bioretention and permeable pavement practices with 100-yr events (with SCS Type II distribution) occurring on back-to-back days indicated the peak discharge attenuation function of the SCMs were largely intact, so ODNR-DSWR chose a 48-hr period for recovery of full runoff reduction capacity for the crediting system. ODNR-DSWR will require that bioretention is designed with an internal water storage (IWS) zone of 18"-24" for HSG-A, B, and C soils and 3"-18" for HSG-D soils to receive runoff reduction credit.

During this project, CRWP updated its model comprehensive stormwater, erosion and sediment control, and parking codes. Updates to the comprehensive stormwater and erosion and sediment control codes included incorporation of lessons learned from this project. Additionally, changes were made to ensure compliance with Ohio EPA's Small Municipal Separate Storm Sewer Systems (Permit Number OHQ000003) and the General Construction (Permit Number OHC000004) NPDES Permits. CRWP's updated model stormwater code is currently in review by Ohio EPA. The draft code includes language for crediting the volume reduction provided by LID SCMs towards meeting peak discharge requirements, lowering the threshold for land disturbance for which post-construction stormwater management is required, incentivizing reduction of impervious surface area and infiltration for redevelopment sites, requiring post-construction soil restoration for areas that must be disturbed during construction, and requiring that sites in coldwater habitat watersheds use SCMs that reduce runoff temperature (Appendix D). Since local governments in Ohio set peak discharge requirements for urban flood control, CRWP's model code and guidance from ODNR provide important tools for communities to change policies that are barriers to the use of LID SCMs. CRWP updated its model parking code in December 2013. This code includes parking maximums, bicycle parking, shared parking, compact car parking, and land banking provisions to discourage excessive impervious cover. CRWP provides model zoning codes to its member communities and works with them to adopt and implement best local land use practices. All of CRWP's model codes are available at www.crwp.org.

The project team used a collaborative learning approach to engage a group of interested experts throughout the duration of the project. The CLG consisted of the project team and representatives from Ohio EPA, local government stormwater plan reviewers and program administrators, consulting engineers, and a sewer district addressing combined sewer overflows using grey and green infrastructure. The CLG provided iterative guidance and feedback to the project team on SCM site designs, the research goals and findings, and proposed methods for communicating project results. 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.

We used multiple approaches to assess the success of the collaborative process and the needs of the end users. CBI completed an initial needs assessment of stormwater professionals in Ohio in February 2012 (Appendix E). CLG members had opportunities to share feedback at each CLG meeting and through biannual online surveys. Summaries of every CLG meeting are available on the project's website (http://www.crwp.org/index.php/projects/research-projects/nerrs-science-collaborative). Finally, CBI reviewed meeting summaries, online survey results, and interviewed CLG and project team members and produced a final assessment of the project's collaborative process (Appendix F).

CLG members reported on surveys that the project was a good use of their time. In interviews at the end of the project, most participants said they enjoyed the CLG meetings and appreciated the variety of meeting components (including presentations, discussions, and site visits). They thought the frequency of the meetings was appropriate because it gave them the opportunity to track the research as it progressed. They felt the presentations and discussions at the meeting were lively and informative. CLG members also identified the structured discussion, time keeping, and organizational benefits of having a facilitator manage the meetings. Participants noted CLG members learned from each other and from project team presentations, and relationships among participants were created or strengthened. Many CLG members expressed pride in the work the CLG and project team members did and appreciation for the project team acting on input from the CLG. CLG members who began the project expressing skepticism about the efficacy of LID SCMs under Ohio's soil and weather conditions ended the project by affirming the data indicate these LID SCMs are effective in northern Ohio and expressing a need to conduct similar research for other SCMs.

CLG members also identified challenges associated with the project. People mentioned the extended geographic reach of the project resulted in long drive times for some participants (although meeting locations alternated between the different regions) and participants were less likely to attend meetings farther from their homes or workplaces. Some CLG members mentioned the sessions of CLG meetings dedicated to the modeling effort were sometimes difficult to participate in or seemed repetitive. At the end of the project, participants offered the following suggestions for improving CLG meetings: more small group work to enable quiet people or people who were nervous about speaking up to participate more actively, reduction in the amount of material for some meetings to allow for a more relaxed pace of presentation and discussion, and reducing the travel burden by having smaller groups meet regionally or allowing participation via webinar or conference call.

Project team members have provided training and technical assistance to stormwater professionals and local governments throughout the project. Project team members shared information from this project at the 2013 National Nonpoint Source Monitoring Conference, the 2014 and 2015 Ohio Stormwater Conferences, the 2015 American Society of Civil Engineers Environment and Water Resources Institute Conference, and the 2015 International Low Impact Development Conference. Project team members led a stormwater construction site training in October 2012 and assisted with SCM maintenance training in July 2013, October 2013, and October 2014. ODNR-DSWR presented updated bioretention design and maintenance guidance to over 400 attendees at five regional trainings between February and November 2014, and bioretention construction and oversight training in September 2014. NSCU presented project results at an Ohio Department of Transportation sponsored permeable pavement training in April 2015. Project team members led two offerings of a training presenting information on bioretention and permeable pavement performance on poorly draining soils in Ohio and suggested policy changes to 119 engineers, landscape architects, local government employees, state agency staff members, and soil and water conservation districts in June 2015. Erie SWCD assisted the City of Sandusky and Erie County with adopting comprehensive stormwater and erosion and sediment control regulations. CRWP assisted Mayfield Village with adopting a riparian setback ordinance and Mentor with updating its parking code. In addition to the monitoring sites, CRWP assisted Mayfield Village, Woodmere, Bainbridge, Pepper Pike, and Mentor with planning LID SCM installations, and Erie SWCD assisted the City of Sandusky and the City of Vermillion with planning LID SCM installations. NCSU added Ohio weather, evapotranspiration rates, and cost data into its rainwater harvesting model to make this tool more useful to coastal Ohio communities.

Project team members have also shared findings from this project within the NERRS. Our team presented posters at the 2013 and 2014 NERRS/NERRA Annual Meetings and co-led a professional sharing session on stormwater at the 2014 NERRS/NERRA. Additionally, our team hosted a transfer workshop with Great Bay, North Inlet-Winyah, and ACE Bain NERRs to share the results of NERRS Science Collaborative projects focused on stormwater management. Project results also were shared with Lake Superior NERR through a transfer workshop.

Project team and CLG members have identified several topics on which more research is needed. These include gathering performance data on different types of SCMs including swales, filter strips, and dry detention basins and learning more about how to maintain and restore soil health to reduce runoff from compacted soil. Some CLG and project team members see a need for better guidance on navigating rainwater and stormwater permitting hurdles in Ohio, so water from systems like the cistern in the OWC NERR visitor center parking lot can be used indoors. Many people have noted cisterns do not provide water quality benefits if the water is not used between storms since there is then no capacity to store the water from the next storm, and increasing the number of permitted uses should increase the odds of the water being used between storms. Some CLG members also requested more data on permeable pavement and bioretention including long-term performance evaluation, additional monitoring sites, large commercial sites, and more water quality monitoring. Another identified need was identifying and implementing effective construction methods for installation of LID SCMs.

4. Retrospective

Participants in this project made some unexpected discoveries during their work. Several project team and CLG members were surprised at how well the various stakeholders were able to work together to provide valuable input into the project. Additionally, participants learned more lessons about design, construction, and maintenance challenges through experience with the monitoring sites than initially anticipated. ODNR-DSWR incorporated some of these lessons learned into the updated bioretention specification in *Rainwater and Land Development*.

Our project team experienced several staffing changes throughout the course of the project. In the summer of 2014, the initial project lead left CRWP. Another CRWP staff member who had been the project team liaison for multiple monitoring sites took over as the project lead for the remainder of the project. One of our original collaboration leads left her job, luckily moving from one organization involved in the project to another, so she remained on the project team, but changed roles from collaboration lead to intended user of project results. Another staff member from Old Woman Creek took over her role as collaboration lead. Several project team members took leaves of absences over the course of the project, shifting significant workload to other team members. The team is proud of and a bit surprised at how well they weathered these changes. Redundancy or duplication of skill on the project team made a huge difference and allowed the project team and project work to be resilient to staff changes and other challenges.

Collaboration with end users informed several aspects of our team's applied science approach. CLG feedback influenced the project team's choice of SCMs to monitor. At the request of the CLG, we attempted to monitor SCMs during the winter and added water quality monitoring to some sites. Equipment failure, error due to sub-freezing temperatures, and snowplowing practices changing watershed areas made most of the data collected during the winter unusable, but water table well data collected in the winter were usable. The temperature data collected by the loggers in the water table well indicated temperatures within the aggregate beneath the permeable pavement never reached freezing temperatures, which helped address some stormwater professionals' concerns about how these systems perform in the winter. CLG feedback also resulted in a change to the bioretention inlet design at Ursuline College. Furthermore, the CLG offered extensive feedback on how to effectively translate results to end users. This input resulted in changes to CRWP model code language and presentation of material at conferences and trainings.

Our team ended up with the necessary expertise to complete the project, but some essential expertise was added to the team while the project was in progress. Initially, our team lacked monitoring expertise, but through a Request for Qualifications process, NCSU joined the team to provide that skill set. Some team members thought inviting contractors to participate in the CLG would have offered useful insight, while others thought contractors would not have gotten enough out of meetings to be worth their time to attend. Project team members did gain some information from conversations with contractors during the construction of the SCMs we monitored.

Resources could have been used more efficiently for the modeling component of the project. We had initially intended that ODNR would hire an employee to complete the modeling work, but the agency had a hiring freeze at the start of the project. We subcontracted the modeling component, but we had difficulty with contractors completing work in a timely fashion. This problem was exacerbated by having a modeling contractor expend its budget before the work was completed. After the problems with the initial modeling contracts, we contracted with NCSU to calibrate and validate DRAINMOD models and perform a sensitivity analysis. This approach worked better. For future collaborative projects receiving feedback from end users, it may be useful to partner with universities because this approach may allow teams to access added expertise and flexibility. Additional SWMM modeling work was completed by ODNR-DSWR.

Our project also tried to use modeling to look at how well bioretention and permeable pavements are expected to perform under predicted future climate scenarios. In order to do this, we needed a dataset that forecasted precipitation for our sites. We thought a cost effective way to do this would be to use a future climate dataset that had been developed for the eastern U.S. The modeled data showed little change in extreme precipitation events for coastal Ohio, which is different than what Pryor et al. (2014) forecast. Because of this, it would have been useful to have a future climate dataset specifically developed for our area of interest to increase our confidence in this assessment, but our grant budget for this project did not allow for this.

5. Sharing your work with Reserves and NOAA

Other Reserves and NOAA may find our project's products interesting. *Innovative Stormwater Solutions for Ohio: Case Studies of LID Implementation and Performance 2015* includes brief descriptions of each site and monitoring results (Appendix G). *Monitoring the Performance of Bioretention and Permeable Pavement Stormwater Controls in Northern Ohio: Hydrology, Water Quality, and Maintenance Needs* (Appendix A) shares in-depth monitoring results regarding runoff reduction and peak discharge mitigation for bioretention and permeable pavement on poorly draining soils, water quality monitoring results, and results of surface infiltration testing of permeable pavement. *Modeling the Hydrologic Performance of*

Bioretention and Permeable Pavement Stormwater Controls in Northern Ohio using DRAINMOD: Calibration, Validation, Sensitivity Analysis, and Future Climate Scenarios reports results from DRAINMOD modeling of monitored bioretention and permeable pavement applications (Appendix B). *Assessment of Collaboration in the Stormwater Incentives in Lake Erie Basin Project* contains feedback and reflections on the collaborative component of the project (Appendix F). Additionally, the project team hosted 2 trainings to share project results with 119 stormwater professionals on June 9 and 10, 2015. This project also allowed for updates to NCSU's rainwater harvesting model to include Ohio data. All reports are available on the project website (http://www.crwp.org/index.php/projects/research-projects/nerrs-science-collaborative).

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