Redefining Water in the City[1]

A National Assessment of Rainwater Harvesting: Challenges, Needs, and Recommendations

Demonstration and Monitoring of Rainwater Harvesting Technology in North Carolina
K. M. DeBusk, J. D. Wright, and W. F. Hunt

ABSTRACT: Water conservation has grown in importance across North Carolina, as much of the state has recently suffered moderate to severe drought conditions. In addition to meeting water conservation needs, rainwater harvesting systems (cisterns) have an important application in low impact development (LID) as innovative stormwater management practices. A total of three cisterns were installed in each of the main physiographic regions of North Carolina: Craven County (coastal plain), Guilford County (piedmont), and Watauga County (mountain). These systems demonstrate above ground and partially buried applications. Uses for the captured stormwater include irrigating landscapes and gardens, washing vehicles, an additive for brine applied to icy streets and flushing kennels at an animal shelter. Each site is being monitored for water quantity and usage, and one system is monitored for water quality. Results will help establish the water quantity and quality benefits of rainwater harvesting systems and will influence design recommendations to be **incorporated in the State of North Carolina's new Stormwater BMP Design Manual.** (001)

Do Rainwater Harvesting Objectives of Water Supply and Stormwater Management Conflict?
Mark A. Jensen, Jennifer Steffen, Steven J. Burian, and Christine Pomeroy

ABSTRACT: Harvesting rainfall has been practiced since ancient times around the world, and remains common in many countries today. The concept is recently gaining new interest in urban areas in the United States (U.S.) because of its potential to meet multiple sustainability objectives including reduced water demand and managing stormwater runoff. However, the new applications are challenged by a range of different urban characteristics, competing sustainability objectives, and an uncertainty of the relative impact of municipal-scale implementation in terms of water supply and stormwater management. This paper presents preliminary results from a study of the relative benefits of rainwater harvesting in urban areas for water supply and stormwater management. An analysis was conducted for more than 20 cities in the U.S. using long-term rainfall records, historical water use data, and a rainwater harvesting analysis tool. Performance of the rainwater harvesting systems for a set of hypothetical applications in each city was quantified in terms of water demand supplied by harvested rainfall and stormwater runoff captured. For this paper, four cities are selected to highlight the general conclusions of the study. In general, the study illustrates the importance of the precipitation and water demand patterns in concert rather than climate alone in determining potential benefits. This study showed water supply and stormwater management are not competing objectives, but different cistern sizes are needed to realize the optimal benefits for each. In general, the cistern size must be greater for the optimal level of stormwater management benefits to be achieved. (002)

Rainwater Harvesting from Roofs for Non-Potable Reuse
Natasha Nicholson, Shirley E. Clark, Brett V. Long, Christina Y. S. Siu, Julia Spicher, and Kelly A. Steele

ABSTRACT: The use of harvested rainwater is one approach for freeing up potable water for more essential applications such as drinking water. Roofs are a readily available surface area that can easily be adapted for rainwater collection; however, some surface materials are not benign and may be more likely to leach contaminants than others. For this study, several commonly available roofing materials were evaluated for runoff water quality for approximately a year and a half. The runoff samples were analyzed for zinc, copper, pH, total phosphorus, total nitrogen, and conductivity. Data from this study showed that traditional roofing materials such as uncoated galvanized metal and treated woods are more likely to leach heavy metals, nitrates, and ammonia than other materials such as green roofs and coated metal roofs. Currently, the water quality data is being compared to recorded storm data and inter-event times to determine what factors affect the quality of the runoff. (003)

Advances in LID BMP Design Methods—Lessons Learned

A Methodology for Using Rainwater Harvesting as a Stormwater Management BMP
J. Alex Forasté and David Hirschman

ABSTRACT: Rainwater harvesting is a dynamic stormwater management tool that can be used to address multiple objectives and provide several stormwater, water and energy conservation and financial benefits. However,

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it is currently underutilized as a stormwater BMP. In many cases, rainwater harvesting systems are designed in isolation, instead of being incorporated as an integral component of a site's stormwater design. One major reason for this is that there is not a consistent means to account for the water quantity and quality benefits provided by rainwater harvesting. As a result, local plan reviewers and design consultants do not have a "common language" when it comes to compliance calculations and design features. This paper presents a rainwater harvesting specification developed to account for the water quantity and quality standards in Virginia's new stormwater program. The specification provides design guidance and a spreadsheet to model various system and demand scenarios to assess system performance. These tools provide designers with a unified method to size rainwater harvesting systems to meet stormwater management requirements and plan reviewers with a consistent set of guidelines with which to assess compliance. The objective of the spreadsheet is to put rainwater harvesting on a level playing field with other stormwater BMPs so that its use can become more widespread. By creating a common statewide specification, the multiple benefits of rainwater harvesting can become realized on a broader scale. (004)

ASCE-EWRI Permeable Pavement Technical Committee—Introduction of Committee Goals and Chapter 1 of Guidelines Design Considerations Common to All Permeable Pavements
Bethany E. Eisenberg

ABSTRACT: The growing trend towards low impact development (LID), with distinct goals to increase infiltration, protect water quality and reduce costs for stormwater management, has resulted in a rapid increase in the use of permeable pavements across the country. In addition to the more commonly specified porous asphalt and pervious concrete materials, new products continue to emerge in the marketplace. These new products are made with materials ranging from recycled tires to ceramics. Engineers, designers, regulators and/or planners are interested in using permeable products in place of standard impervious surfaces, but there are gaps in the technical data and historical performance data to support an open endorsement of the newer products. Standardized specifications are not available for many of these products and up-to-date technical information in a format useful for promoting, designing and implementing LID is needed. The ASCE Permeable Pavement Technical Committee is comprised of individuals from the academic and scientific communities, engineering and planning professions, the regulatory community and industry technical representatives with expertise in permeable pavements. This paper will discuss the status of the Committee's goal to provide a guidance document for the use of permeable pavements. This paper has been prepared with material for the opening presentation to a mini-symposium on permeable pavement and also discusses the outline for Chapter 1 of the Committee Report to date. Chapter 1 discusses design considerations common to all types of permeable pavements including the need to identify site conditions; pollutant concerns; and installation, inspection and maintenance requirements. (005)

Best Practices for Maximum Beneficial Use of Rainwater
Bobby Markowitz

INTRODUCTION: Our work with rainwater management systems (RMSs) has taught us to view rainwater as a critical resource. Well-designed and properly calibrated rainwater management systems have numerous benefits. They avoid or mitigate stormwater impacts, minimize infrastructure demand, filter pollutants on site, provide for site amenities, and more. By capturing, filtering, storing, and cycling rainwater to appropriate, exterior and interior uses, these systems achieve multiple design objectives, including Low Impact Development (LID) goals and Environmental Protection Agency (EPA) mandates. (006)

Considerations in Selecting a (Bio)filtration Media to Optimize Lifespan and Pollutant Removal
Shirley E. Clark and Robert Pitt

ABSTRACT: Many research studies have been published regarding the treatment efficiency of bioretention for a wide variety of pollutants found in urban stormwater runoff. However, limited information is available on predicting the treatability of these pollutants between media and between sites. Predicting the treatment ability of bioretention/infiltration/filtration media is a function of both soil and water chemistry. This paper begins that meta-analysis of pollutant removal as a function of chemistry. The results presented here are from a single project evaluating candidate bioretention media to meet numeric effluent limits and are based on a limited number of samples. As additional data becomes available in the spring, the analysis will be expanded. The preliminary results indicate that the media that appear to have the best removal ability for a wide range of metallic pollutants are those that have both cation exchange ability and comparatively high organic matter content. For metals, this also may require a lower media pH because of the generally increased solubility of metals at lower pHs. Lower pHs and higher organic matter contents, however, must be evaluated further if phosphorus removal is also desired since phosphorus is removed better at higher pHs and lower organic matter contents. These results also highlight the trade-offs in pollutant capture versus export when using ion-exchange media. (007)

Estimation of Green Roof Evapotranspiration—Experimental Results
Meghan Feller, Robert Traver, and Bridget Wadzuk

ABSTRACT: The purpose of this research is to quantify the evapotranspiration portion of the water budget for a green roof, located on the campus of Villanova University, and determine if current predictive equations for evapotranspiration are applicable in stormwater best management practice (BMP) design. The study design and preliminary results are presented (Feller 2010). (008)

Impact of Maintenance and (Im)Properly Sizing Bioretention on Hydrologic and Water Quality Performance
Robert A. Brown and William F. Hunt

ABSTRACT: Bioretention is one of the most common low impact development (LID) stormwater practices. Two sets of bioretention cells of varying media depths (0.6-m and 0.9-m) will have been monitored for two, 12-month periods, in Nashville, NC. They treat runoff from an impervious asphalt parking lot. During the first monitoring period, the bioretention cells were clogged with sediment from construction and were severely undersized. Complete drawdown of the surface storage took approximately 48 hours or more, as compared to the recommended 12 hours. Initially, the surface storage volumes for the 0.6-m and 0.9-m media depth cells were 36 percent and 46 percent of the design storage volume, respectively. The bioretention cells were designed to treat the 2.5-cm event, but the system became overwhelmed and overflow occurred for events as small as 0.8 cm. Overflow was occurring three times more frequently than intended. In March 2009, a contractor removed the fines layer that was present in the top 7.6- cm. Through removal of this layer and expanding the surface area, the surface storage volume was increased by 89 percent for both cells. With the increase in surface storage volume, more runoff has been treated, and the system was overwhelmed less frequently. The volume of overflow has been reduced to approximately one-third of the volume, as compared to the first monitoring period. Moreover, removing the fines layer has increased surface drawdown rate by at least 10 times. This site was also monitored for water quality. Nitrogen and phosphorus species and total suspended solids were measured. The results of this study show the importance of properly constructing and maintaining bioretention cells. Undersizing a bioretention cell as a result of a small construction error in setting the base elevation for the bottom of the bowl or the emergency overflow structure will result in a reduction in performance. (009)

In Situ Bioretention Design Concept
Michael Clar

ABSTRACT: Since its initial development and application in 1993, the bioretention system also referred to as “rain gardens” has rapidly become one of the most versatile and widely used BMPs throughout the US and many parts of the world. It has recently become identified as a preferred site practice for green building design and LEEDS certification. The current practice in bioretention design largely follows the initial guidance developed by the author in 1993 (Clar, et al, 19993) and consists of excavating existing soils and replacing with either or natural or artificial “soil media”. While this approach may still be necessary in some instances, there are many situations where the existing soils may not need to be totally removed but instead can be augmented in-situ to provide a more sustainable and low cost approach to bioretention design. This paper describes the procedure which is being developed in New Castle County, DE to facilitate the use of in-situ bioretention design. The design procedure is described and the benefits of this design approach are identified. (010)

Introduction to Permeable Friction Course (PFC) Asphalt
A. Braga and C. Connolly

ABSTRACT: The source of pollutants on roadways and parking lots can come from various sources, including the exhaust and fluid leakage from vehicles, abrasion from the friction between tires and roads, deicing activities, atmospheric deposition, and pavement itself. Permeable friction course (PFC) paving approach incorporates a pervious top course over a standard impermeable paving base. Studies in highway applications have shown that PFC overlays can provide stormwater runoff mitigation as well by significantly reducing the amount of pollutants discharged from paved areas; however, the performance of the material has not been extensively studied relative to water quality performance and volume retention in low-volume roads and parking areas. This presentation discusses PFC specifications and installation criteria and provides a comparison of PFC versus permeable pavement applications and provides case studies of projects where PFC has been installed. (011)

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Maintenance and Repair Options for Pervious Concrete
John Kevern

ABSTRACT: While permeable pavements have been applied in limited use in the southeastern United States since the 1970's, only recently have they become a more wide-spread technology for stormwater management. Various industry groups have done well promoting the benefits of permeable pavements, however maintenance issues are rarely discussed in-depth. Maintenance of permeable pavements involves cleaning to restore permeability and the repair of structural and non-structural deficiencies. This paper discusses common causes and identification of common and not so common pavement distresses. Methods to assess surface condition and permeability are presented along with suggestions for cleaning and surface repair. This paper is designed to assist with selection of appropriate remediation techniques for individual levels of pervious concrete distresses. (012)

Measure Twice, Build Once: Bench-Scale Testing to Evaluate Bioretention Media Design
Emilie K. Stander, Michael Borst, Thomas P. O'Connor, and Amy A. Rowe

ABSTRACT: Rain garden design manuals and guidelines typically recommend using native soils or engineered media that meet specifications for soil and organic matter properties. However, constructed rain gardens often deviate from these recommendations. Planned pilot-scale research at EPA's Urban Watershed Research Facility proposed using a locally-available engineered media with a higher silt and clay content than typically recommended and adding layers of shredded newspaper as a carbon amendment to promote nitrate removal. A bench-scale experiment was conducted to test the drainage capability of the chosen media containing shredded newspaper layers. Surface ponding in all three treatments and grain size and clay mineralogy analyses demonstrated that finer particles had migrated into the deeper soils, which could have inhibited drainage. As a result of these findings, an alternate media containing less than five percent silt and clay was obtained for the pilot-scale study. The results of these studies underscore the importance of conducting bench-scale testing of bioretention media before installation in full-scale, working rain gardens, particularly when media characteristics differ from recommendations or when modified to promote stressor removal. (013)

Permeable Pavement Demonstration at the Edison Environmental Center
Amy A. Rowe, Michael Borst, Thomas P. O'Connor, and Emilie K. Stander

ABSTRACT: There are few studies of full-scale, outdoor, replicated, functioning pervious pavement systems. More studies of pervious pavement operating in its intended use (parking lot, roadway, etc.) during a range of climatic events, daily usage conditions, and maintenance regimes are necessary in order to properly evaluate these systems. In accordance with this research need, the EPA's Urban Watershed Management Branch has installed an instrumented, working full-scale 110-space pervious pavement parking lot in Edison, NJ. EPA plans to monitor several environmental stressors in effluent and runoff. This parking lot demonstration site investigates differences among side-by-side pervious asphalt, pervious concrete, and permeable interlocking concrete paver systems. The parking lot consists of three sets of parking rows, each one surfaced with a different pervious pavement type, and driving lanes surfaced with conventional asphalt. The pervious pavement parking areas contain replicated subsections to collect the infiltrating water as well as sections that allow the filtered effluent to infiltrate into the underlying soil. The replication allows for statistical analyses of collected data. Investigated parameters include: volume, temperature, solids, indicator organisms, nutrients, metals, and semi-volatile organic compounds. (014)

Permeable Pavement Performance over 3 Years of Monitoring
Elizabeth A. Fassman and Sam Blackbourn

ABSTRACT: A 200 m2 permeable pavement test site was installed along Birkdale Road on Auckland's North Shore. Data from the permeable pavement section and an adjacent conventional asphalt section were collected concurrently in 2006 and 2008. Despite installation on an atypical high slope (6.5-6.8%), relatively impermeable subsoils, and active roadway, overall system performance was exceptional. For the 81 complete storms monitored for hydrology, peak flow, runoff timing and volume compared well to predevelopment conditions. A catchment designed on an LID-basis of controlling frequently occurring events would be well served using permeable pavement. Additional hydrologic control may be needed for design storms greater than 5-yr ARI. Water quality characterization for 4-17 storms (depending on pollutant type) was comparable to or better than typical end-of-pipe devices for TSS, PSD, total and recoverable Cu and Zn, and dissolved Cu and Zn. The permeable pavement discharge water quality had consistent event mean concentrations which were statistically lower than the conventional asphalt. Pollutant removal efficiencies are presented. A properly designed permeable pavement section would likely provide adequate treatment for an expanded source area. Permeable pavements should be given strong consideration as an LID at-source control. (015)

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Pervious Asphalt Roads and Parking Lots: Stormwater Design Considerations
A. L. Broadsword and C. A. Rhinehart

ABSTRACT: Use of pervious asphalt requires creative stormwater design using available and adapted hydrologic and hydraulic modeling tools, highly integrated site design, and a coordinated design process. This is demonstrated by two very different Puget Sound area installations: Brickyard Park and Ride Lot Expansion, and Snoqualmie Point Community Park. Brickyard Park and Ride is an overcrowded park-and-ride lot on a constrained site requiring 200 additional spaces within a limited, suitable footprint. Snoqualmie Point Community Park is a new city park with an access road, turn-around, and parking for 23 vehicles on a sloped, wooded site. Conventional stormwater facilities (traditional pavement with underground vault) were considered for Brickyard Park and Ride Lot and found to be more expensive than pervious pavement with detention storage in the pavement section. At Snoqualmie Point Park, utilization of an integrated low-impact stormwater approach was a primary design goal, in keeping with the natural character of the surrounding area and park design. This paper presents the stormwater design considerations for both projects. (016)

Pervious Concrete Testing Methods
Liv Haselbach

ABSTRACT: Pervious concrete is a unique construction material that serves simultaneously as a structural surface and a stormwater best management practice. Due to its void structure that allows for water and air to flow through the pavement, there are many existing concrete testing methods that may not be readily adapted to account for these differences, and simultaneously there are many procedures for porous material testing that may not be easily adapted to its solid structure. Testing methods for this novel material are needed for many reasons, from research consistency to material acceptance during placement and for determining long-term maintenance needs. This paper will review some of the testing methods currently under development for pervious concrete and summarize research methodologies which are being explored. (017)

Pervious Pavement Systems in Florida—Research Results
Manoj B. Chopra, Erik Stuart, and Martin P. Wanielista

ABSTRACT: Pervious pavement systems are being studied for stormwater quality and quantity control and as a major component of low impact development (LID). To assess the potential of several types of pervious pavement systems, the Stormwater Management Academy at the University of Central Florida is studying the behavior of these systems at its field laboratory. These pervious pavements are also considered as part of the new Stormwater Rule in the state of Florida. Research is being conducted on five types of pervious pavements, namely pervious concrete, FlexipaveTM, porous asphalt, and two types of brick pavers. One more pavement system called FilterpaveTM has recently been installed and is currently undergoing testing. This paper will present the results of the infiltration testing on these systems. Keeping in mind the long-term performance and maintenance requirements, these pavements are intentionally being loaded with sediment (sand and fine grained crushed limerock) to simulate clogging as indicated by significant reduction in their infiltration capacity. The pavements are then subjected to a rejuvenation technique using a vacuum sweeper truck. This paper will also present the results of these rejuvenation techniques on the performance of the pavements. This paper aims to update the water resources community on the new developments with these types of pavements. (018)

Replacing Incised Headwater Channels and Failing Stormwater Infrastructure with Regenerative Stormwater Conveyance
Ted Brown, Joe Berg, and Keith Underwood

ABSTRACT: Drainage infrastructure, whether it be simply conveyance based or intended for other stormwater management criteria (e.g., detention, channel protection), typically results in the concentration of flows at discrete outfall points. Standard energy dissipation in the form of flared end sections with rip rap or engineered stilling basins frequently prove to be inadequate to protect against outfall erosion and related receiving stream degradation. The result seen throughout urbanizing watersheds is impaired habitat, excessive erosion and transport of sediment and nutrients to downstream sinks (e.g., ponds, lakes, estuaries, etc.), and compromised infrastructure. Based on an inventory of stormwater outfalls, Anne Arundel County, Maryland has concluded that the majority of pipe outfalls, rip-rap and gabion level spreaders and energy dissipation devices used to convey stormwater have failed and resulted in more than $600 million in damage to streams, adjacent wetlands, and steep slopes. A more thoughtful, cost-effective, and restorative approach to handling urban stormwater flows was clearly needed, and leaders in the County Department of Public Works decided to pursue design solutions that provide a full range of benefits including improved water quality, stable conveyance, increased groundwater recharge, floodplain reconnection, and wetland creation. The new preferred approach is often referred to as regenerative stormwater conveyance (RSC). Regenerative stormwater conveyance (RSC) systems are open-channel, sand seepage filtering systems that utilize a series of shallow aquatic pools, riffle weir grade controls, native vegetation, and underlying sand channel to treat and

safely detain and convey storm flow, and convert stormwater to groundwater through infiltration. RSC systems combine features and treatment benefits of swales, infiltration, filtering, and wetland practices. RSC is applicable in new development, retrofit, and restoration scenarios and is fully consistent with and even expands upon the principles of low impact development, environmental site design and sustainable green infrastructure. (019)

The Urban Green BioFilter: An Innovative Tree Box Application
James H. Lenhart, Scott A. deRidder, and Vaikko Allen

ABSTRACT: The UrbanGreen BioFilter™ is a new Proprietary and Enterprise Technology which serves as a tree box filter combined with the well known Stormwater Management StormFilter® (StormFilter) technology. The unit is constructed in a curb inlet or area drain configuration and designed to treat runoff from roadways, parking lots, roof tops, and other runoff generating surfaces. The system utilizes a variety of complex treatment processes including physical, chemical, and biological activities which occur as stormwater infiltrates through a 91 cm (36 in) bed of engineered soil mixture and interfaces with the root system of a tree or other vegetation within a bioretention bay with a flow control orifice located at the outlet. The specific components of the engineered soil mixture were selected to provide high pollutant removal and permeability while maintaining sufficient moisture content for plant growth. After infiltrating through the engineered soil mixture stormwater exits the bioretention bay via the bioretention bay under drain which directs the treated stormwater to the outlet chamber. The UrbanGreen BioFilter employs two distinct treatment components. The first is the bioretention component as described above. The second is a media filtration component. When the bioretention bay reaches its treatment capacity, runoff begins to flow over a weir into a secondary chamber containing a set of Stormwater Management StormFilter® (StormFilter) media cartridges which then treat additional flow prior to discharging into the outlet. StormFilter media cartridges are among the most highly tested and proven stormwater treatment devices and can be designed with a variety of media types including CSF leaf compost, Perlite, and ZPG (a blend of Zeolite, Perlite, and Granular Activated Carbon) to target the specific pollutants of concern. The entire unit is also designed with a high flow bypass separated from the treatment areas to prevent bed scour and maintain conveyance for extremal events. This combination adds a robust feature to allow for the treatment and storage of smaller storms via bioinfiltration while allow more robust treatment by the StormFilters for higher flows. Data from flow testing, laboratory performance testing are presented. (20)

Case Studies

Case Study of LID Application and Design Method—Rain Harvesting for Waterscape and Water Balance Analysis
Wei Feng, Wu Che, Jianlong Wang, and Junqi Li

ABSTRACT: There were many waterscapes in urban residential areas, new development district and gardens of China. Under the situation of prevalent urban water crisis and strict water saving regulations, rainwater harvest is not only very important to build and run waterscapes but also it is imperative. It is an economical and reasonable idea and method to building waterscape making use of ideas and technology of Low Impact Development (LID). The operating experience of some implemented projects based the design of low-impact waterscape has shown that it is higher economic and environmental benefit. In design of low-impact waterscape, water balance analysis is very simple and important method which can achieve the suitable scale of waterscape, high efficient utilization of water resource, saving of the capital cost and operation cost. This paper briefly introduces the technical approach of building low-impact waterscapes with rainwater harvest and water balance analysis. In addition, a practical case of low-impact waterscape in a large residential area was introduced too. (021)

Creating a LID Environment in an Ultra Urban Setting
Larry John Matel

ABSTRACT: The City of Bremerton, Washington, with its 40,000 residents, is typical of a mature medium-sized Puget Sound city. Its older central business district is served by a stormwater system that is over 60 years old. Stormwater is currently routed, untreated, through a conventional storm drain system directly into Puget Sound. The City is going through significant revitalization efforts and employing Low Impact Development (LID) in an aggressive manner. This paper is a follow-up to one presented at the 2008 LID Conference in Seattle and presents additional examples of the use of LID in addressing the stormwater issues associated with major public infrastructure/transportation projects. Case studies of implementation of LID into significant transportation projects are presented, including a major 1,600 foot long urban bridge structure, an “economic stimulus” project involving a mile long roadway project in a commercial industrial area, and the introduction of pervious asphalt paving in a combined sewer overflow reduction project. A discussion of how engineering culture barriers were overcome to open the door for the introduction of LID into urban transportation projects is presented. (022)

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Effects of Minimum-Intervention-Design to Urban Waterfront Park in China: An Application of POE
Dihua Li, Jing Zhao, Jiewu Liu, Donghan Zhao, and Yanling Xu

ABSTRACT: POE (Post-Occupancy Evaluation) Methodology is an effective tool to find users' evaluation to built projects and help improve design. In this paper three ALSA prized projects in China as cases are explored, with some common characters of Minimum-Intervention-Design (MID) and have built as urban waterfront park, designed by the same office. The present study was performed to evaluate users' satisfaction and understanding rates to the three parks and their concepts basing on the POE method. Interesting results are: 1) Users' satisfaction rates are high in all of three parks. 2) MID creates diverse familiar spaces and opportunities for people to think of wildness and learn native plants resulting in high recognition. 3) Users' understanding and acceptation of the park have positive correlation with explanation system. 4) Post built maintenance influences the users' altitudes and turns to be a very important factor for more application of MID. (023)

Green Infrastructure for CSO Control in Kansas City, Missouri
S. D. Struck, R. I. Field, R. Pitt, D. O'Bannon, E. Schmitz, M. A. Ports, T. Jacobs, and G. Moore

ABSTRACT: Advanced design concepts such as Low Impact Development (LID) and Green Solutions (or upland runoff control techniques) are currently being encouraged by the U.S.EPA (EPA) as a management practice to contain and control stormwater at the lot or upland residential parcel level. These controls have shown that when implemented and maintained properly, they can increase retention at the runoff source – decreasing the runoff volume entering the drainage system and the demand on a drainage system. Both developed storm and combined sewersheds can benefit from the added storage from areas retrofitted with bioretention cells or rain gardens and other management, e.g., inlet retrofits or curb-cuts with tree plantings. This paper documents an effort by the U.S. EPA to demonstrate the efficacy of implementing integrated, green infrastructure-based solutions to support control of wet-weather flow pollution problems in an urban core neighborhood within a combined sewer system. This pilot project is part of a larger adaptive management approach to incorporate Green Solutions into the Kansas City long term control plan. The project involves local and regional efforts to provide the "basis-for-success" of the implementation of Green Solution infrastructure and stormwater management at the neighborhood, watershed, and regional levels. The project demonstrates the strategy and methodology, including model support, for identifying where and how Green Solutions will be implemented within Kansas City, Missouri. (024)

Implementing Low Impact Development for Sustainable Transportation Infrastructure in King County, Washington
J. F. Sussex

ABSTRACT: This paper presents a case study of an LID pilot project that was built by the King County Road Services Division as part of an arterial intersection improvement project in 2007. The initial LID features of the project included pervious concrete sidewalks and a linear bioretention facility. Due to various problems that were encountered regarding the design, construction, and monitoring of the linear bioretention facility, however, the LID pilot project was substantially revised during the spring of 2009. Redesigning the LID pilot project was possible because of the flexibility and financial support from the Washington State Department of Ecology through their Low Impact Development Stormwater Grant Program. The reconfigured rain garden feature and simplified monitoring approach that emerged from that process are part of an ongoing learning process for implementing LID more effectively. The purpose of this paper is to share the lessons learned from this LID pilot project experience, particularly in terms of how LID can more effectively contribute to sustainable transportation infrastructure. (025)

Integrated Stormwater Facility Design to Address Hydromodification on a College Campus, Livermore, California
Lucas Paz, William Beaman, and Hans Kramer

ABSTRACT: LFR provided civil engineering services to the Chabot-Las Positas Community College District ("the District") to support the proposed Las Positas College Facilities Master Plan ("the Master Plan") development with respect to the design and integration of campus-wide low impact development (LID) stormwater management and drainage improvements. Activities included technical studies, the preparation of civil improvement plans, and technical services needed to support the detailed engineering design of the proposed watershed drainage improvements and associated tasks as required by local, state, and federal regulatory agencies (USACE, USFWS, CDFG, Alameda County, City of Livermore, etc.). The work included the development of conceptual design options for new stormwater management facilities required to satisfy Alameda County's hydromodification and water quality treatment standards. The proposed stormwater facilities consisted of an integrated suite of measures including landscape based bioretention cells, vegetated swales, flow duration control basins, and subsurface storage elements. The Bay Area Hydrology Model (BAHM) was utilized to address hydromodification management goals and to determine sizing and design for each of the distributed, stormwater storage and treatment facilities. Following initial BAHM modeling, LFR developed a detailed Hydrology and Drainage Study ("the Study") to support the conceptual

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design by characterizing existing hydrology and to model proposed conditions using the BAHM continuous simulation approach. (026)

Brickyard Park and Ride Case Study: Pervious Asphalt and Integrated Site Stormwater Design
C. A. Rhinehart and A. L. Broadsword

ABSTRACT: The Brickyard Park and Ride project demonstrates the usefulness of pervious asphalt pavement to maximize onsite stormwater management despite potential obstacles of underlying soils, slopes, sensitive areas, and groundwater levels. This project indicates there is broader potential application and suitability of pervious asphalt pavement to a wider range of sites than one might initially assume. A key to broader use of porous asphalt is early and ongoing interdisciplinary coordination with the geotechnical engineer, landscape architect, and others to resolve potential design obstacles. The integrated stormwater detention and asphalt pavement design became a cost saving as well as a hydraulic and habitat benefit to the adjacent wetland area. (027)

Roadside Stormwater Master Plan Using Low Impact Development (LID)
J. L. Wang, W. Che, W. Zhang, J. Q. Li, and H. X. Yi

ABSTRACT: An innovative roadside stormwater master plan (located in the east part of core area in Ningbo east new city, China) on the basis of low impact development (LID) was proposed. The plan strategy employed a unique and unconventional approach for improving the health of local watersheds. LID techniques such as bioretention facilities, permeable paving, storm wetland, and ponds were utilized to reduce the runoff from roadways. Minimizing the stormwater flows from impervious surfaces and the potential pollutant load associated with the runoff will both improve the health of the watershed. Through full implementation of this plan, the developing area could realize reduction of runoff pollution loads (computed as COD), post-development general runoff coefficient was almost equal to the pre-development, significantly reducing stormwater runoff leaving the developing site. The plan included detailed descriptions of each stormwater management technology with a project summary, example photographs and a preliminary cost estimate on a single sheet for quick reference and comparison. LID techniques recommended by this plan are desire to advance to the forefront of sustainability and green infrastructure. This project provides an alternative to traditional methods of managing stormwater through the creative implementation of LID, and is a demonstration for other developing area and cities to follow. (028)

Using Landscape Plants for Phytoremediation
Mindy Ruby and Bonnie Appleton

ABSTRACT: Phytoremediation is an emerging technology that uses plants to degrade, extract, contain, or immobilize contaminants such as metals, pesticides, explosives, oil, excess nutrients, and pathogens from soil and water. Phytoremediation has been identified as a more cost effective, noninvasive, and publicly acceptable method of removing environmental contaminants than most chemical and physical methods. Two nutrients commonly found in stormwater runoff are nitrogen (N) and phosphorus (P). Both of these pollutants are also macronutrients needed for agronomic and horticultural plant growth, and are components of all complete fertilizers. Fertilizer application to residential, commercial, and municipal lawns and landscapes is a major non-point source of pollution with potential for reduction via phytoremediation. The majority of plants currently used in phytoremediation applications, including stormwater ponds (BMPs), riparian buffers, rain gardens, green roofs, constructed wetlands, etc., are herbaceous or non-woody. New stormwater runoff systems, that incorporate woody landscape plants into the systems, are being designed for streetscapes and landscapes. Two research projects are currently being conducted at Virginia Tech to identify woody landscape plants with nutrient and heavy metal hyperaccumulation or phytoremediation potential. One project involves a nutrient uptake screening protocol for landscape trees and shrubs. The other project involves screening landscape plants in situ and in Filterra stormwater management units to compare nutrient and heavy metal accumulation from landscape soil vs. the Filterra unit substrate. Results from both projects are beginning to identify both native and non-native landscape plants that are hyperaccumulators with phytoremediation potential. (029)

Management, Design, and Development of Irrigation System in Desert Regions Case Study:*Bagh-E-Shazdeh (Prince Garden)*
A.K. Hosseini Vahdat

ABSTRACT: This article tries to investigate the hydraulic and architectural dimensions of vernacular sustainable architecture design with focus on qanat system and irrigation order in *Prince Garden*. Surveying the system of irrigation in *Prince Garden* shows that the qanat system was an efficient technique for irrigation and water supply to manage stormwater, wastewater, watershed, and also ground and underground waters in the most efficient ways. Furthermore, in a mutual relationship, this system has affected on the irrigation order of the *Prince Garden* which has shaped vegetation, spatial, and functional orders of the garden, where as can consider variety of channels and fountains in three features of utilization of water includes fluent water, stagnant water, and waterfall. (030)

Coast to Coast, Integration of Stormwater Management with the Urban Landscape/Impacts on Organizational Culture

Green Streets in Southern California: Transformation of Basic Street Infrastructure to a Conversation of Beauty and Environmental Enhancements

Ken J. Susilo and Calvin Abe

ABSTRACT: The greening of streets in Southern California communities are increasingly resulting in both the beautification of public roadway infrastructure and direct improvements to (and within) the built environment. Regional and watershed-based water quality management plans that address existing infrastructure and water quality needs have specifically identified green streets as a key opportunity (and Low Impact Development Best Management Practice) that can provide significant environmental benefit in a widely distributed manner. Benefits of distributed green street BMPs include the ability to provide wide coverage within virtually all land use types (a significant benefit in older, built-out urbanized areas). A second benefit is the ability to mitigate stormwater pollutants near the sources. Other environmental benefits include the addressing of heat island effects, restoration of water balance elements, aesthetic enhancement, habitat creation, and building a sense of neighborhood and community through environmental stewardship, social engagement, economic growth, and the experience of beauty. Development of green streets projects in Semi-Arid and Mediterranean environments with impaired water quality, however, provide a number of challenges. These challenges include engineering constraints (particularly geotechnical and geological constraints), more extreme hydrology, erosion potential, pollutant loading and accumulation, vegetation-specific requirements and tolerances, and local aesthetics. This paper/presentation describes green street design elements, with particular emphasis on those elements that are unique to Southern California environments. Examples of successes and challenges will also be provided. (031)

Computational Methods

A Non-Dimensional Modeling Approach for Evaluation of Low Impact Development from Water Quality to Flood Control

T. Andrew Earles, James Guo, Ken MacKenzie, Jane Clary, and Shannon Tillack

ABSTRACT: Regulations in the United States establish water quality protection requirements that typically are targeted at relatively small, frequent events, comprising the bulk of non-point source pollutant loading to receiving waters. Although water quality requirements vary from municipality to municipality, typical requirements include promoting infiltration to reduce runoff volume and peak flows, storage and release of runoff or some combination of infiltration and storage/release. Examples of such requirements include ordinances requiring development to maintain runoff rates and, in some cases, volumes at pre-development levels for up to a specified design event and/or requirements to capture, store and release runoff from frequent events. Complying with these types of water quality requirements can be expensive, so it is understandable to question what benefit these requirements have for flood control. Flood control benefits of water quality facilities typically can be quantified using hydrologic and hydraulic calculations; however, there are important considerations that belie the simplicity of calculations, including ownership, operation and maintenance of facilities. These issues are especially important for on-site water quality facilities and "distributed" controls, which generally are not publicly owned and maintained. This paper presents hydrologic and hydraulic modeling to explore water quality and flood control benefits of water quality facilities, especially infiltration-based Low Impact Development (LID) practices. The paper presents a method for calculating an Imperviousness Reduction Factor (IRF) that can be used to calculate effective imperviousness based on total site imperviousness. This paper demonstrates that while water quality facilities are important for smaller, more frequently occurring events and play a role in water quality and stream channel protection when it comes to larger flooding events, hydrologic benefits diminish and must be complemented with sound detention, conveyance and floodplain management policies and practices. Failure to recognize and plan for this fact will inevitably subject properties to higher than appropriate flood risk. (032)

A Simplified Sizing Tool for LID Practices in Western Washington

A. Lancaster

ABSTRACT: As a part of the new NDPES permit requirements, the Washington State Department of Ecology has introduced flow duration standards for creek protection that require the use of continuous simulation hydrologic modeling. The new permit also requires the use of low impact development (LID) best management practices (BMPs) to the maximum extent feasible. To address these complex regulations, a tool was developed to simplify the sizing of pre-designed LID BMPs for jurisdictions in western Washington. This tool allows the designer to size BMPs without extensive calculations or continuous modeling, and can streamline agency review of design submittals by providing "rule of thumb" sizing equations. By providing pre-designed and pre-sized LID BMPs, this tool helps reduce barriers to LID implementation in western Washington. This paper presents the modeling methods and resulting LID BMP sizing tool for Kitsap County, Washington. Similar methods will be used in 2010 and 2011 for a grant-funded effort to develop a regional tool for all lowland areas in western Washington. (033)

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An Innovative Decision Support System for Quantifying and Optimizing Benefits of Decentralized BMPs for Los Angeles County
Youn Sim, Stephen Carter, John Riverson, and Jenny Zhen

ABSTRACT: The Los Angeles County Flood Control District (LACFCD) is currently developing a decision support system to evaluate the most cost-effective combination of distributed and entralized BMPs to support water quality improvement planning of the County's watersheds, including the evaluation of the benefits of decentralized BMPs and potential savings in terms of alternative stormwater infrastructure improvements. Building on an extensive body of relevant studies in the Los Angeles region, including monitoring, model development, and regional model parameterization efforts, this study is designed to develop and apply a comprehensive modeling framework for the evaluation of alternative stormwater BMPs and Low Impact Development (LID) methods. This decision support system allows managers to evaluate the ability of various BMP scenarios to provide necessary flow volume and pollutant load reductions and optimizes the scenarios based on benefits and costs. In addition to overall stormwater quality management, results of this study will support numerous initiatives including TMDL implementation planning, investigation of a water quality design storm to assist in BMP design, development of BMP/LID design/sizing criteria, and financial assessment of capital projects. This study has resulted from a collaboration of LACFCD and the U.S. Environmental Protection Agency, Region 9, with a focus on developing an approach to water quality improvement planning and TMDL implementation that considers practicable application of BMPs that considers costs and effectiveness. Once completed, the decision support system will be available to the public to support their individual planning needs involving water quality improvement. (034)

Comparison of BMP Infiltration Simulation Methods
Jenny Zhen, Mow-Soung Cheng, John Riverson, Khalid Alvi, and Tham Saravanapavan

ABSTRACT: Prince George's County has developed a Best Management Practices Decision Support System (BMPDSS) to assist in assessing the effectiveness of Low Impact Development (LID) technologies. This module uses process-based algorithms to simulate BMP function and removal efficiency. The processes include weir and orifice outflow, flow and pollutant routing, evapotranspiration, infiltration, and a general loss/decay representation for a pollutant. Among these processes, infiltration is a key mechanism that controls the effectiveness of LID types of BMPs on both flow reduction and water quality improvement. Therefore, an accurate representation of the infiltration process is the basis of a successful BMP simulation module. The current version of BMPDSS employs the empirical Holtan-Lopez model. With the U. S. Environmental Protection Agency's support, the model is currently being enhanced to include a layered infiltration scheme using the process-based Green-Ampt method. This paper compares the performance of these two different approaches for simulating the infiltration process occurring in LID types of BMPs like bioretention, vegetated buffer strip, and bio-swales. The pros and cons of each method are discussed in this paper. (035)

Curve Numbers and Urban Runoff Modeling—Application Limitations
Robert N. Eli and Samuel J. Lamont

ABSTRACT: The U.S.D.A. SCS (now the NRCS) Curve Number method has been in continuous use for about 50 years. As originally developed, the method yields a direct runoff depth from the accumulated 24 hour rainfall depth as function of the curve number CN. The method has since been extended to hydrograph generation and is found in commonly used hydrologic models applied to urban drainage design (e.g., WinTR55, SWMM and HEC-HMS). A number of recently published studies, including Curve Number Hydrology - State of the Practice, by the ASCE/EWRI Curve Number Hydrology Task Committee, have warned that it is inappropriate to use the method to generate runoff hydrographs, yet the practice continues with little awareness of this limitation by most users. A common misconception is that the CN method is an infiltration model, which can lead to significant errors in peak discharge predictions. CN values can be converted into equivalent physically based infiltration model parameters used in the Green-Ampt method in SWMM (or HEC-HMS), or in the infiltration component used in the PERLND module of EPA's HSPF model, each of which can produce a more acceptable hydrograph that matches CN method direct runoff depth. (036)

Effectiveness Site Design and Low-Impact Development on Stormwater Runoff Patterns at Partridgeberry Place LID Subdivision
Renee Fitsik

ABSTRACT: Partridgeberry Place Subdivision (LID Subdivision) located in Ipswich, Massachusetts incorporates an environmentally sensitive site design by using a variety of Low-Impact Development (LID) storm water management techniques and Open Space Residential Design (ORSD). The LID Subdivision is a compact site design, clustering 20 single family homes on residential lots less than 0.20-acres in size, preserving 74% (28-acres) of the 38-acre site as undeveloped open space. LID techniques used in the subdivision include dry wells, vegetated swales, bioretention, and reduced impervious area. Using an ORSD approach, the amount of open space was maximized and the amount of impervious area was reduced. The study compared the hydrology of the LID Subdivision, as built, and

developed three theoretical model alternatives: 1) a subdivision that is clustered but that contains no additional LID storm water features (Cluster Only), 2) a conventionally developed subdivision (Conventional Subdivision), and 3) the pre-development (forested) condition (Pre-development Watershed). To understand the storm water runoff dynamics at the LID Subdivision, storm water runoff volumes from the developed portion of the site were monitored. During this time, forty-four (44) storm events (ranging from 0.01 to 2.45 inches) were collected, totaling approximately twenty (20) inches of precipitation. The monitoring data were used to calibrate storm water models to predict the hydrologic responses of both the LID Subdivision and the Pre-Development Watershed for a range of design storms. The LID, Cluster Only, Conventional, and Pre-development Watershed models were used to predict and compare storm water runoff dynamics over the entire 38-acre parcel for a variety of design storm events (2-year, 10-year, 25-year, 50-year, and 100-year, 24-hour). Based on the model results, the LID Subdivision generates the smallest volume of storm water runoff among the three development scenarios. For the 2-year design storm, the Cluster Only Subdivision reduced runoff volume relative to the Conventional scenario by 35 percent. The LID Subdivision reduced runoff volume relative to the Conventional scenario by an additional 3 percent, for a total 38 percent reduction. A comparison of the of three development scenarios to the Pre-development Watershed showed that runoff volumes from the LID Subdivision most closely resembled those of the pre-development condition. For the 2-year design storm, the LID Subdivision generated 11 percent more runoff volume than the Pre-development Watershed, while the Cluster Only generated 16 percent more, and the Conventional Subdivision generated 45 percent more. (037)

ESD in Practice: Comparison of Environmental Site Design Regulations Using Example Application
T. A. Suehr and J. R. Reiderman

ABSTRACT: Stormwater authorities are revising their regulations to allow and require the use of Low Impact Development (LID) design techniques. The slow transition to regulations that encourage environmental site design has challenged designers endeavoring to create more sustainable sites. Maryland and Virginia are two states that have recently undertaken the arduous process of revising their stormwater regulations to encourage the use of LID. Although these states are contiguous and have similar climate, geography, and development conditions, they have each enacted very different regulations. Maryland's new regulations are based on the theory of Environmental Site Design (ESD) and using LID practices to the Maximum Extent Practical (MEP). Virginia's regulations use the Runoff Reduction Method to advance the use of design techniques that promote stormwater infiltration. Although Maryland and Virginia's systems have similar theories and goals, the practical application varies significantly. Using a single site, this paper will compare and contrast the requirements of two different stormwater regulation systems. Two different stormwater solutions will be created for the site. One to meet the requirements of Maryland's stormwater regulations; the second will comply with the proposed stormwater regulations of Virginia. The new regulations' affect on the design process will be analyzed to determine the advantages and challenges of each system. Environmental site design techniques challenge design engineers to alter their design methods and techniques. Lessons will be investigated to assist engineers in identifying the best solutions to meet the needs of their client while complying with the new regulations in each state. (038)

Modeling Bioretention Hydrology with DRAINMOD
Robert A. Brown, William F. Hunt, and R. Wayne Skaggs

ABSTRACT: It has been documented that bioretention cells are an effective low impact development (LID) stormwater practice to remove nitrogen, phosphorus, and other pollutants at high rates, as well as to restore a site's pre-developed hydrology. However, hydrologic performance has varied greatly in past field studies because of the impact of underlying soils, physiographic regions, drainage configuration, and media depth. Development of a long-term hydrologic model that generates an annual water balance is needed to more accurately describe hydrologic performance to predict pollutant loads and to determine whether a site meets LID hydrology criteria. The only models available are either unable to run continuous simulations or do not accurately model underdrain flow for typical designs of bioretention cells. DRAINMOD, a widely accepted long-term agricultural drainage model, is being used to predict bioretention hydrology. The concepts of water movement in bioretention cells are very similar to agricultural fields with drainage pipes, so many bioretention design specifications correspond directly to DRAINMOD inputs. As a result, calibration of DRAINMOD to model bioretention hydrology is currently underway. Detailed hydrologic data have been specifically collected from two field sites over the past 24 months to calibrate the model. Additional hydrology data are available from at least 10 other bioretention cells across NC to validate the model. DRAINMOD is also unique from other bioretention models in that it accounts for evapotranspiration (ET), and the controlling factor in DRAINMOD is the drainage configuration which employs the Richards Equation. The model can be used on an hour-by-hour basis for long periods of climatological records (e.g. 50 years). Hydrologic outputs from the model include: volume of runoff, overflow, drainage, exfiltration, and ET. These outputs will allow users to examine the water balance to discern a most suitable design based on varying design configurations. (039)

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Moving Beyond the Percent Removal Paradigm: Using Lower Limit Effluent Concentrations in Design Guidance and Evaluation
Scott Job and Jonathan T. Smith

ABSTRACT: A modeling application, called the Site Evaluation Tool (SET) was developed to test site designs with stormwater BMPs and verify compliance with pollutant loading rate standards in a water supply watershed. Traditionally BMP performance is assessed using average or median percent removals of pollutant mass based on monitoring studies. However, researchers have recognized for some time that removal is strongly related to pollutant influent concentration, and using mass removal efficiencies alone is likely to overestimate gross pollutant removal when influent concentrations are relatively low. The SET uses median percent removal to assess BMP performance, but with removal capped by lower-limit effluent concentration. This paper focuses primarily on research to support development of the lower limit effluent concentrations, and the application of the SET to development site performance assessment. (040)

Use of Stormwater Capture Curve for Sizing Storage-Based LID Facilities in Korea
Sangdan Kim, Chihyeon Choi, Seongcheol Seo, Doo Kee Kang, and Hyunsuk Shin

ABSTRACT: Most of the related literatures of designing storage-based LID facilities assume that precipitation event-depths follow the 1-parameter exponential probability density function in order to reduce the mathematical complexity of the derivation process. However, how to express the precipitation is the most important factor for analyzing stormwater, and thus, a better mathematical expression that represents the probability distribution of precipitation depths is suggested in this study. Also, the rainfall-runoff calculation procedure required for when deriving a stormwater capture curve is altered by the NRCS (U.S. National Resources Conservation Service) runoff curve number method to consider the nonlinearity of the rainfall-runoff relation, and at the same time, to obtain a more verifiable and representative curve for design when applying it to urban drainage areas with very complicated land-use characteristics such as occurs in Korea. The result of developing the stormwater capture curve from the rainfall data in Seoul, Korea confirms that the methodology suggested in this study provides a better solution than the pre-existing one. (041)

Normalized Runoff Capture Volumes for Low Impact Designs
James Guo and Shou-Ching "Eric" Hsu

ABSTRACT: The latest stormwater low impact developments encourage on-site treatment and stormwater disposal, including retentions, vegetal beds, wet lands, porous detentions, and sidewalk landscape. All of these efforts are to aim more at frequent rainfall events rather than the extreme events. In practice, a 2-yr event is considered too large for sizing on-site stormwater quality control systems. Without using the flood return period as an index, determining the design volume for a water quality control system has been a major challenge. Over the years, the concept of runoff capture volume has been derived from the analyses of tens of hundreds of individual storm events delimited from a continuous record. Rainfall event separation process can be subjective, depending on how the minimum interevent (no rain) time is chosen. In general, the longer the rainfall event separation time is, the higher the average rainfall event depth will be. To improve the consistency among the rainfall databases, this paper presents a mathematical model by which a continuous rainfall record can be directly converted into stormwater runoff capture curves. Applying the exponential distribution to a complete rainfall data series, the normalized runoff capture curve was derived in this study to describe the non-exceedance probability distribution of runoff volume population. This curve provides necessary and important design information by which the stormwater basins can be sized on a consistent basis of overflow risk. (042)

Web-Based Low Impact Development Decision Support Tool for Watershed Planning
James G. Hunter, Bernard A. Engel, and Joseph E. Quansah

ABSTRACT: Low Impact Development (LID) practices reduce pollution and hydrologic instability from stormwater arising from increases in impervious surfaces and land development practices. In response to increasing demands for information and tools to quickly and easily assess LID practices in comparison to conventional development practices, an easy to use web-based LID decision support and screening tool, L-THIA/LID, has been developed to evaluate the benefits of LID practices. The Long-Term Hydrologic Impact Assessment (L-THIA) web application is a decision support system based on the integration of web-based programs, geographic information system (GIS) capabilities, and databases. It provides information for decision makers on the impacts of water quantity and quality resulting from land use change. The web-based L-THIA/LID tool, which builds on L-THIA capabilities, will enable various stakeholders to quickly evaluate: (1) the impact of urban development on average annual runoff volume; and (2) the potential stormwater and pollutant reduction of proposed LID practices. Runoff quantity and water quality impacts of proposed land use change are displayed in tables, bar charts, and pie charts. The tool's aim is to enable decision makers the ability to evaluate and understand the effects of LID practices and thus support effective watershed planning to achieve desired stormwater management goals. (043)

Why Single-Event Modeling Doesn't Work for LIDs
Douglas C. Beyerlein

ABSTRACT: LID practices reduce stormwater runoff by temporarily storing water on site and then slowly releasing the water as either infiltration to the soil or evapotranspiration to the atmosphere. What happens between storm events is just as important in LID modeling as what happens during storm events. Accurate stormwater modeling of the effectiveness of different LID practices requires the ability to accurately model the long-term, between-storm changes in soil moisture due to infiltration and evapotranspiration. Single-event hydrologic modeling cannot accurately simulate these dry-period hydrologic changes. This is why single-event hydrologic modeling doesn't work for LIDs. (044)

Constructing LID Facilities

Application of a Structured Infiltration System for Stormwater Management in Campus
Marla C. Maniquiz, Jiyeon Choi, Jeongyong Lee, Byung-Sik Lee, and Lee-Hyung Kim

ABSTRACT: Through the grant of the Ministry of Environment (MOE) in Korea, the Eco- Bio Filter (EBF) test bed, a type of a structured infiltration system was developed and constructed at the Kongju National University campus. It was the first pilot project established inside the university campus that serves as a research tool and designed to provide demonstration opportunities to study the low impact development hydrologic and water quality performance. The monitoring of rain events was performed subsequent to the completion of its construction in May, 2009. This paper presents the results of the preliminary monitoring assessment on the EBF built to treat stormwater runoff from road. It includes the development of design, the lessons learned from the post-construction testing and the improvements in the renovation made. After a series of monitoring, the MOE will use the results to apply the design to other areas in the country. (045)

Enhanced Biofilter Treatment of Stormwater by Optimizing the Residence Time
Redahegn Sileshi, Robert Pitt, and Shirley Clark

ABSTRACT: The treatment of stormwater by biofilters is dependent on the hydraulic residence time in the device for some critical pollutants. The effective use of biofilters for the control of stormwater in combined sewered areas is also related to residence time, as it is desired to retain the water before discharge to the drainage system in order to reduce the peak flows to the treatment plant. This paper will describe the initial results from a series of tests being conducted to determine the hydraulic characteristics of sand-based filter media (having a variety of particles sizes representing a range of median particle sizes and uniformity coefficients) during pilot-scale trench tests. The drainage rate in biofiltration devices is usually controlled using an underdrain that is restricted with a small orifice or other flow-moderating component. These frequently fail as the orifices are usually very small (<10 mm) and are prone to clogging. A series of tests are also being conducted using a newly developed foundation drain material (SmartDrainTM) that offers promise as a low flow control device with minimal clogging potential. A pilot-scale biofilter using a trough 3m long and 0.6 x 0.6m in cross section is being used to test the variables affecting the drainage characteristics of the underdrain material (such as length, slope, hydraulic head, and type of sand media). Current tests are also being conducted to test the clogging potential of this drainage material. This paper describes the initial tests that have investigated the basic hydraulic properties and the clogging potential of this drain material. (046)

Evaluation of the Contaminant Removal Potential of Biofiltration Media
Robert Pitt, Shirley Clark, and Brandon Steets

ABSTRACT: This paper describes the detailed laboratory tests of biofiltration media that are being considered for use in engineered stormwater treatment systems recently proposed for a large field site in the southwestern United States. These stormwater treatment systems were designed to treat 90% of the long-term runoff volume from drainage areas ranging from 5 to 60 acres at the site. The main pollutants of interest for the project include cadmium, copper, lead, and dioxins, and the effluent concentrations had to meet design criteria that are based on numeric effluent limits that are applied to stormwater discharges through the site's NPDES permit. An additional feature of the project is that existing runoff concentrations for the pollutants of interest are generally below levels typically seen in urban and industrial stormwater runoff, therefore the tests needed to simulate site-specific conditions by adjusting raw influent samples to representative levels, where possible. The purpose of this study is to determine optimal biofiltration media combinations and contact times (based on achievement of permit limits in treated effluent), hydraulic properties, and clogging/breakthrough frequency for design purposes and maintenance planning. (047)

Costs of LID

Planning-Level Cost Estimates for Green Stormwater Infrastructure in Urban Watersheds
M. J. Vanaskie, R. D. Myers, and J. T. Smullen

ABSTRACT: The use of green stormwater infrastructure as an effective stormwater management technique has great potential in urban watersheds, and the development of accurate construction cost estimates is critical for achieving the desired results. This study evaluates a variety of factors that influence the development of construction cost estimates for implementing green stormwater infrastructure technologies, and provides the basis for unit-area planning level costs for use in largescale urban watershed planning. Green stormwater infrastructure costs depend on land cover, development density, the specific technology, size of the controlled area, and the level of stormwater management planning. The authors of this study developed cost estimates for implementing various green stormwater infrastructure techniques within several land use types. For the purposes of this study, a minimum level of control (infiltration or slow release of the first 1.0 inch of runoff) was used and normalized to the directly connected impervious tributary area at each site. For each stormwater management plan, construction costs were estimated for two cases: (1) a redevelopment construction cost, and (2) a full retrofit construction cost. Green stormwater infrastructure construction costs depend on a variety of factors, but for planning level costs for large-scale urban watershed planning, these factors can be normalized to the directly connected impervious tributary area. (048)

Western Case Studies and Cost Analysis of Xeripave
Deen Gill

ABSTRACT: The information contained in "Western Case Studies and Cost Analysis of Xeripave" is intended to help designers, architects, engineers and landscapers understand the cost efficiencies of the Xeripave pervious paver. Six different treatments are outlined, with a cost analysis on each, followed by a summation at the end.

Education, Training, Outreach

Certifying the Landscape Community in Rain Garden Installation: The North Carolina Experience
Ryan J. Winston, William F. Hunt, Kathy M. DeBusk, Mitchell D. Woodward, and Wendi W. Hartup

ABSTRACT: Low Impact Development (LID) stormwater practices are being utilized to a greater extent in new construction to mitigate pollutant loads and hydrologic impacts associated with development. However, many cities are trying to find ways to improve water quality from existing non-LID developments. As a result, retrofit programs are becoming more common. Homeowners are often interested in improving water quality in their neighborhood, and backyard rain gardens are a practice that has become popular in North Carolina. Few homeowners have the technical expertise to size and construct a rain garden; therefore, they often hire a landscaper to complete these tasks. Faculty at N.C. State University and extension agents of N.C. Cooperative Extension have developed a 1.5-day certification course that offers landscapers a detailed understanding of how to properly site, design, install, and maintain a residential rain garden. Attendees listen to six hours of presentations and participate in in-class exercises on rain gardens, and then take a two hour tour of local rain gardens that have previously been installed. On the second day of the workshop, attendees take both an in-class and a field exam. Four workshops were delivered from March to November 2009, with a total of 73 people certified. The certification passing rate is approximately 80%. Some of the certified landscapers are actively advertising their certification. Similar programs could easily translate to other communities throughout the country. Rain gardens help to control runoff at its source, and may make meeting watershed-wide LID hydrology goals easier to obtain. (050)

Lakewood RainCatchers: Lessons Learned in Recruiting for Residential Rain Garden and Cistern Installations
Bob Spencer

ABSTRACT: Seattle Public Utilities (SPU) received a grant from the United States Environmental Protection Agency (EPA) to evaluate the use of decentralized green stormwater infrastructure through the private property installation of rain gardens and cisterns in a combined sewer overflow basin. Over a 2 year period, residents were educated and recruited to participate in the program. A variety of methods were used to educate and recruit participants, and lessons learned along the way have influenced the strategies the city will implement as it pursues additional installation of green stormwater infrastructure on private properties as part of SPU's Residential RainWise program in target combined sewer overflow (CSO) basins. (051)

LID Design Education for Undergraduate and Graduate Engineering Students
Andrea Bradford and Jennifer Drake

ABSTRACT: At the University of Guelph, in Ontario, LID has been a substantial component of both the senior undergraduate *Urban Water Systems Design* and graduate *Urban Stormwater Management* courses since 2002. Key

challenges in delivering these courses include the large amount of course content for the undergraduates, the diverse backgrounds of graduate students, and increasing class sizes. To address these challenges and further highlight the important role of LID in achieving better environmental outcomes in urban areas, the course content, its delivery and student assessment methods were updated in 2009. A new design project, involving an LID retrofit for the University of Guelph Campus, is a central component of both courses. Each undergraduate team of 4 students designs an LID retrofit for one block consisting mainly of buildings and parking areas, and each graduate student team designs a green street for the campus. Designs are completed and shared with other groups by week 9 of the 12 week semester, with the final weeks devoted to modeling and evaluating the collective system. Both courses were offered during Fall 2009 and the changes are being evaluated based on observations, student feedback and the results of student assessment relative to learning objectives. Reorganization of the course content in the undergraduate class was effective; although a greater effort is needed to make time for guest lectures by design professionals, municipal staff and faculty from Landscape Architecture, who can offer diverse perspectives on LID. Some students, both undergraduate and graduate, require a more structured introduction to the modeling software. The design project proved to be an exceptional learning experience for most students. Challenges with group dynamics negatively affected the experience for a few groups, particularly in the graduate class. The diverse background of graduate students continues to present challenges. Student assessment methods offer many benefits for the students, but will likely become unmanageable if class sizes continue to increase. (052)

LID Education and Installation in Mixed Income and Ethnically Diverse Areas of Milwaukee, Wisconsin
Gary J. Belan and Cheryl Nenn

ABSTRACT: From 2005 to the present, American Rivers and the Milwaukee Riverkeeper have been involved in the installation of a variety of LID practices in the Johnson's Park neighborhood of Milwaukee. During that time, the two organizations worked to educate homeowners and cultivate interest in a grant program to design and install rain gardens, rain barrels, and downspout disconnects to volunteers within the neighborhood. The goal was to reduce stormwater pollution in an urban area and to explore the basic social and economic factors that might affect the installation. Rain barrels were installed at four houses and bioretention cells were installed at seven houses. While the installations themselves were successful at mitigating stormwater challenges arose with homeowner/non-profit communications and expectations. Some participants were unhappy with the natural landscaping of the rain gardens and replaced native plants with turf grass. The modified soil that was applied during the garden construction phase is the primary medium in infiltrating water, and the cells have turned out to be very effective even with turf grass. We concluded that homeowners should be given a choice of designs and rooted plants should be used as opposed to plant seeding. Minimizing the different varieties of plants would also be helpful in more clear identification of weeds during maintenance. Additionally, turf grass should be considered an option as an infiltration cover medium for residential projects. (053)

Stormwater BMP Inspection and Maintenance Program in North Carolina—A 3 Year Update
William G. Lord and William F. Hunt

ABSTRACT: Stormwater BMPs are being installed across the United States and studies show they are not being properly inspected and maintained. If not properly maintained, stormwater BMPs will not perform as intended or fail, but little guidance or training on maintenance and inspection procedures is available. The North Carolina State University Cooperative Extension Service developed a 1.5 day Stormwater BMP Inspection and Maintenance program in 2007 that has trained and certified more than 1250 local government officials, design professionals, and landscape maintenance practitioners from across the United States. The course consists of 12 modules that range from stormwater regulations to parking lot BMPs. A learner feedback loop has been incorporated into ongoing development of the course and information is being gathered about whom does maintenance, how it is done, and how often it is performed. Upon passing an exam, the Extension Service certifies an individual for 3 years, when a 4 hour recertification class is being offered. To date, approximately 10 cities and counties in North Carolina are requiring certification for anyone who inspects or maintains stormwater BMPs. (054)

Water Quality in Municipal Stormwater Management: Recognizing State of the Practice Tools Available to Missouri Communities
Sheila Shockey, Jeff Henson, and Ruth Wallace

ABSTRACT: The Missouri Department of Natural Resources is developing a stormwater program guidance document to guide communities in using low impact development (LID) and green infrastructure as a way to protect their community resources, meet regulations and develop a superior program. A comprehensive stormwater guide can be a critical tool in helping communities to manage stormwater quality and quantity. The document speaks to multiple audiences and "sells" state-of-the-practice benefits that line up with community vision and goals. While regulations are at the core of any official municipal program, real change takes more than rules. The document guides communities through processes and tools to help them meet their needs and living preferences. Stormwater management practices that protect streams often go together with other desirable characteristics like trails, trees,

green spaces, lakes and streams. These features help treat both water quality and quantity, and also make the area a desirable place to live. (055)

Green Streets in Harsh Climates (Invited Presentations)

Green Street Retrofits in the Northeast: Design and Acceptance Challenges for Stormwater Management Retrofits
Kathleen M. Ogden, Michael J. Seluga, and Bethany E. Eisenberg

ABSTRACT: While green street retrofits for stormwater management are increasing nationally, especially in Northwest cities such as Portland, Oregon, and Seattle, Washington there are limited examples in urbanized areas in the Northeast. The idea for green street retrofits in the Northeast are typically openly accepted in concept for the many values they provide in addition to stormwater management that often align with other urban revitalization goals such as pedestrian safety, traffic calming and aesthetics, however the concerns relative to their detailed designs and maintenance requirements is often a hurdle. An additional hurdle that is resulting in slow incorporation of this concept in the Northeast is the more familiar struggle of promoting a "new" design concept that does not rely on standardized details with a given track record in the region. Another concern is the winter performance and operation of green street retrofits designed to manage stormwater. The Northeast experiences an ongoing struggle to balance the need for vehicular and human safety with environmental concerns relative to the use of sand and/or salt for deicing. It is necessary in the Northeast to design effectively for the potential sand and salt loads that are used along urban roadways, as well as evaluate how the system will work under winter conditions when snow banks along roadways can be of significant width, height and duration. Further, concerns relative to frozen ground/infiltration media must be considered. This paper discusses two urban case studies in the Northeast: one in a downtown setting and one in a residential setting. Both cases involved the design of a green street technology for stormwater management as a retrofit into existing roadways and required a detailed process for the concept acceptance. The design process had unique challenges including the winter weather operational issues, the hurdles associated with engineering a new design technique, and the process of gaining stakeholder support to accept and further concepts into actual projects. (056)

Ultra Urban Green Street Design Criteria
I. D. Turney and B. Neilson

ABSTRACT: The City of Columbus, Ohio, is implementing ultra urban revitalization in their recently separated Combined Sewer Overflow Service area. The City is looking to provide a leadership role in showcasing the use of green streets for stormwater volume and water quality treatment. During the process of green street design, the City realized a tier of unique design and construction criteria required for successful ultra urban implementation. The authors highlight the planning tools, analytical techniques and results from the City's Green infrastructure integration into their RiverSouth Urban Revitalization project. The planning tools include a design matrix process, incorporating the technical design criteria for green street construction with design liability issues specific to urban inner city conditions. The analytical techniques are for the areas serviced by the green streets, to ensure all stormwater volume and quality requirements are met. The results are the process of short and long term construction, operation and maintenance insights from the implementation and integration into the ultra urban environment. (057)

Incentives for Using LID

Alternative Site-Assessment Hydrologic Metrics for Urban Development
K. M. DeBusk and W. F. Hunt

ABSTRACT: While LID techniques are becoming more commonplace across the United States, there is no universally-accepted method for evaluating how well a site adheres to LID principles; namely, how closely the post-development hydrology mimics predevelopment (or target) hydrology. As part of the Sustainable Sites Initiative™ (www.sustainablesites.org) a method was developed to assess the pre- and post development hydrology of a site and provide a means for a currently built upon site (a greyfield) to receive credit for partial restoration of hydrology. The Stormwater Management Model (SWMM) was used to model runoff at five locations across the U.S. for 10 years, with varying degrees of urbanization represented by a range of curve numbers. Based on natural soil type and vegetative cover, a target curve number was assigned to each location. A watershed's runoff flow volume and rates were calculated for each curve number and the change in flow volumes were then calculated relative to the target curve number. The percent decrease was then assigned a point value which a developer could potentially use for credit, similar to the U.S. Green Building Council's LEED® program. Graphical representations of hydrologic conditions and corresponding point values were developed. This method provides developers and regulators with a tangible, numeric goal for post development hydrology when retrofitting developed sites while allowing flexibility in how that goal is achieved. The analysis of additional locations could provide the means for this approach to become the primary method across the country to evaluate a site's adherence to LID hydrologic principles. (058)

Incorporating LID into New Developments

A Solution to Requiring LID in Stockton Urbanized Area: A Volume Runoff Reduction Approach
Rebecca Winer-Skonovd

ABSTRACT: The Stockton Urbanized Area's Phase I MS4 permit requires that new development and redevelopment integrate Low Impact Development (LID) principles into project design. Stockton's permit does not prescribe how LID should be required; instead, Stockton was able to explore a variety of options for meeting this requirement. This allowed several options to be vetted through a stakeholder process and considered within the context of Stockton-area conditions and characteristics. Permittees and stakeholders reviewed the pros and cons of a variety of LID standards, including effective impervious area limits, flow control requirements, and volume reduction standards. Ultimately, stakeholders and permittees alike opted for a volume reduction approach. The Volume Reduction Requirement was developed to provide a design criterion for achievement of LID at proposed development projects. The Volume Reduction Requirement is defined as the post-project runoff volume minus pre-project runoff volume for the area's 85th percentile, 24-hour storm depth (0.51-inches).

Unique aspects of the Volume Reduction Requirement include:

- New development and redevelopment projects must apply a combination of Volume Reduction Controls (e.g., rain barrels, interception trees) and LID Treatment Controls (e.g., bioretention, stormwater planters).
- Volume reduction credits are provided for each Volume Reduction Control and LID Treatment Control. These credits are used towards compliance with the Volume Reduction Requirement.
- The benefits of Volume Reduction Measures are also recognized in the form of impervious area reduction credits. Impervious area reduction credits will reduce the effective design area for LID Treatment Controls, resulting in smaller-sized LID Treatment Controls.
- Redevelopment projects must also comply with the Volume Reduction Requirement; however, depending on the type of redevelopment (e.g., high density, transit-oriented) reductions may be applied to lower the Volume Reduction Requirement. (059)

Calculation of LID Benefits in Meeting New Development Standards
Richard A. Wagner

ABSTRACT: The Beaufort County, South Carolina Stormwater Best Management Practices (BMP) Manual provides guidance regarding the selection and design of BMPs necessary to protect the high-quality waters within the county. Estimated stormwater pollution loads from various land use categories and estimated pollution removal efficiencies of structural BMPs form the basis for an antidegradation water quality goal established for new development. Further concern regarding discharge of freshwater to the tidal rivers led to additional evaluation of low-impact development (LID) features as volume control BMPs. Considerations included capture of residential rooftop runoff and reuse for lawn/landscape irrigation; capture of flat-roof runoff in commercial areas and recycling flow back to roof to enhance evaporation; and more common practices, such as rain gardens and swales. This paper focuses on the calculations performed as the basis for developing charts and worksheets to assess the effective impervious area. Developers will ultimately use these results to evaluate the benefits of the proposed LID site features, as part of the overall BMP plan. (060)

Comparison of Low Impact Development Treatment, Traditional Stormwater Treatment, and No Stormwater Treatment for Commercial Shopping Centers in North Carolina
Robert A. Brown, Daniel E. Line, William F. Hunt, and William G. Lord

ABSTRACT: Low impact development (LID) stormwater practices are becoming more popular because of their ability to improve water quality and recharge groundwater. New regulations require water quality treatment of stormwater runoff in addition to reducing peak flows, especially in nutrient sensitive watersheds. Previously, the main focus of traditional stormwater practices had been on mitigating flooding and reducing peak flows; whereas, newer LID practices improve water quality and attempt to restore a site's natural or pre-developed hydrology. This is accomplished by promoting more evapotranspiration and infiltration. Three commercial shopping centers have been monitored from April 2008 to September 2009 to measure the performance of using LID stormwater treatment, traditional stormwater treatment, or no stormwater treatment. All three sites were monitored for water quality and hydrology, and they were located within 70-km of each other. The site with no stormwater treatment and the site with traditional stormwater treatment were located in Raleigh, NC, and the site with LID treatment was located in Nashville, NC. Since the sites did not receive the same precipitation depths for each storm, the hydrology data were normalized per area treated. The LID practices were designed to treat the first flush of runoff or water quality event. The LID site incorporated the use of bioretention, permeable concrete, and constructed wetlands. Seven bioretention cells of varying media depths (0.6-m and 0.9-m) treated the front asphalt parking lot, and permeable concrete treated the rear parking lot. Storage was added beneath the permeable concrete to completely capture a 2.5-cm event. The

constructed wetlands treated rooftop runoff, miscellaneous paved areas, and outparcel lots. Each LID practice was monitored as a separate unit and the site was monitored as a whole system. Effluent was monitored from the retention basin at the site with traditional stormwater treatment. A mixture of parking lot and rooftop runoff was monitored at the site with no stormwater controls. In addition to the water quality and hydrology results, much was learned about the construction and implementation of multiple and large scale LID practices at one site. LID practices are typically more sensitive practices, so proper construction oversight, installation, and maintenance are vital to adequate functioning of these stormwater treatment devices. Errors at this site included: undersized bioretention cells, clogged bioretention cells, a continuously flowing bioretention cell due to interception of the water table, and constructed wetlands that remained flooded, resulting in vegetation die off. (061)

Control Effects Comparison of Three Kinds of Typical LID Infiltration and Emission Reduction Measures: Beijing Case Study
J. Q. Li, W. L. Wang, W. W. Zhao, and H. Y. Li

ABSTRACT: Low impact development (LID) stormwater management system emphasizes source control using structural and non-structural measures to achieve the objective of runoff emission reduction. Three typical LID technical measures, permeable pavement, sunken greenbelt and rain garden are evaluated on design methods, application conditions and key parameters of them. All of them are very effective for runoff volume reducing, peak rate and pollution control. Combining with the typical practices and key design parameters of three measures, hydrologic quantitative reductions evaluation including the reductions calculation in runoff volume, peak rate and the total pollutants were given, and then the cost-effectiveness assessment through the investment analysis were carried out, the control effects of them were compared through a sample project. The conclusions are valuable for urban stormwater management in Beijing and other cities in China. (062)

Development and Application of Modular LID Site Planning Tool
Vaikko Allen, Tory Walker, and Tyler Schemper

INTRODUCTION: The push for low impact development (LID) by the EPA, State and local stormwater regulators has increased emphasis on pollution source reduction and site design elements of stormwater management planning. Emerging regulations and project review priorities encourage project designs that minimize the impact to the predevelopment hydrologic balance by reducing the amount of imperviousness created, and by integrating small-scale, distributed retention and treatment facilities into the landscape. This LID based approach stands in contrast to more conventional approaches, which generally seek to efficiently convey runoff to central detention and treatment facilities. Successful projects will require developers or their representatives to coordinate the efforts of planners, architects, civil engineers, landscape architects and geotechnical engineers around a development plan that includes specific stormwater runoff reduction and treatment recommendations. In order to establish the feasibility of a proposed development project, it is necessary to estimate the land requirements, capital costs and ongoing operation and maintenance costs for potential stormwater management measures. However, BMP design criteria and associated cost information are highly variable. To add to the uncertainty, a developer's proposal of a suite of BMPs that constitute treatment to the "maximum extent practicable" (MEP) may be rejected by plan reviewers. As stormwater regulations evolve, developers may find themselves facing delays and cost overruns as they are forced to redesign their sites to fit those regulations late in the project development process. Avoiding this costly situation requires early consideration of stormwater management elements and a detailed understanding of local regulatory requirements, site constraints and BMP design requirements. CONTECH has developed the LID Site Planner, a modular planning tool that incorporates this information into a preliminary stormwater mitigation plan. The plan provides a list of BMPs that are expected to satisfy the MEP criteria for a specific proposed development and their approximate sizes and costs. (063)

LID in Minnesota State Statute: Minimal Impact Design Standards
J. Westerlund and J. Riggs

ABSTRACT: To better protect the State's water resources, the Governor of Minnesota signed Low Impact Development into law in the spring of 2009. Statute now reads: "The [state] shall develop performance standards, design standards, or other tools to enable and promote the implementation of low impact development and other storm water management techniques. For the purposes of this section, 'low impact development' means an approach to storm water management that mimics a site's natural hydrology as the landscape is developed. Using the low impact development approach, storm water is managed on site and the rate and volume of predevelopment storm water reaching receiving waters is unchanged. The calculation of predevelopment hydrology is based on native soil and vegetation." MN is currently developing the performance standards, design standards, and tools to enable and promote the implementation of LID to protect and restore predevelopment hydrology. The process and package is called Minimum Impact Design Standards (MIDS). By creating consistent performance standards and calculation methodologies, as well as zoning (064)

LID in New Schools: The LAUSD Example
Alla Anchipolovsky, Talal Balaa, Ying Wang, Lisa Austin, and Kelly Havens

ABSTRACT: The Los Angeles Unified School District (LAUSD) is committed to providing better learning environments for its students. Green, high performance designs have a substantial impact on the environment and public health and contribute to a more effective learning environment. LAUSD was the first school district to adopt the sustainability standards of the Collaborative for High Performance Schools (CHPS). This point-based system defines a high performance school as site, energy, material, and water efficient, as well as healthy, comfortable, and easy to maintain and operate. In 2001, the LAUSD Board of Education passed a resolution adopting CHPS as a guideline for building sustainable schools, and, in 2003, the Board made CHPS official policy. By 2012, CHPS criteria will have been applied to the planning and design of 130 new schools and 15 existing schools. This paper explores the use of Low Impact Development (LID) techniques in LAUSD new school projects. School districts face many difficult challenges in designing and implementing LID at new schools. Design considerations include safety concerns, accessibility requirements, fire codes and fire lanes, real estate limitations, and the cost of maintenance. Just as the stormwater facilities must achieve water quality goals, they must also maintain a safe environment, be aesthetically pleasing to staff and students, and comply with the Americans with Disabilities Act requirements. This paper presents a number of case studies for new school designs that incorporate LID techniques, as well as Leadership in Energy and Environmental Design (LEED) Gold certification. The case studies highlight the special considerations that accompany LID implementation for new school projects within the District and include techniques such as infiltration, biofiltration, use of site-specific native plants, green roofs, and community-based wetlands. The case studies showcase projects that have addressed the special school design considerations and achieved the green goals established by the School Board. (065)

Soil Amendments for Mitigation of Compacted Soils
E. Z. Bean and M. D. Dukes

ABSTRACT: Traffic during construction has been shown to compact soils, resulting in reduced porosity and infiltration rates and increased runoff. In agricultural settings soil amendments have been found to counter-act compaction effects. This study is evaluating two soil amendments (compost and fly ash) to mitigate compacted soils. Results from a column study and the compaction phase of this study are presented. Forty-two lysimeters were filled with two soils (Orangeburg Sandy Loam and Arredondo Fine Sand) overlaying a drainage layer of quartz stone. Runoff was directed into collection tanks and volumes were recorded from eight rainfall events. The soils were compacted to levels representative of observed levels found in North Central Florida based on bulk densities, and infiltration rates. As a predecessor, a column study was performed to identify where the two amendments were incorporated into the two soils with increasing amendment fractions (0, 0.05, 0.10, 0.30, and 1.0). Results were analyzed to determine which analytes to include in runoff and leachate water quantify analysis and potential water quality results for amendments. (066)

LID and Reimagining Cities

Creating Better Communities with LID
S. Sutton

ABSTRACT: Many communities, both new and longstanding, are applying Low Impact Development (LID) principles to address stormwater management. However, balancing improved runoff capture with attention to neighborhood aesthetics, and community character has proven a challenge. Successful LID solutions must embrace a multi-objective approach, by which urban and suburban landscapes both define visual context as well as combat global warming, biodiversity loss, limited water supplies and poor waste management. This paper explores many examples, from communities across the country, of stateof- the-art LID approaches and aesthetically-adventurous solutions to capturing and treating stormwater at the neighborhood and community scales. It also examines many visually unappealing, even truly ugly solutions that have been installed, and suggests possible alternatives. Comprehensive stormwater management has traditionally been the domain of the engineering field. However, recent LID practice has shown that engaging a qualified, integrated design team, including a landscape architect well-versed in stormwater and sustainable design practices, will better ensure that a given project contributes to aesthetically-pleasing and inviting neighborhood character. (067)

LID and Sustainable Natural Resource Management in the Urban Environment: The Unique Case of New York City
B. Gunther, M. G. Larson, and F. Watt

ABSTRACT: New York City's Sustainable Stormwater Management Plan (SSMP) was issued in 2008 as part of PlaNYC 2030, an unprecedented, sweeping guide to sustainable development and the enhancement of NYC's urban environment. The SSMP reflects a new willingness to look at source control of stormwater, and was made possible by high-level political commitment, regulatory requirements, championship by technical experts, and years of community

and environmental advocacy. With this guiding document complete, the road to implementation remains perhaps one of the most challenging in the country, given NYC's size, density, degree of urbanization, physical and political complexity and age of infrastructure. A multitude of efforts are currently underway in NYC to better manage stormwater, with particular focus on reducing combined stormwater sewer overflows. Parks' Greenstreets program, for example, has spearheaded efforts to treat stormwater as a resource to be managed at its source and will soon expand its stormwater capture greenstreets program thanks to federal stimulus funds. This will allow the testing and monitoring of a wider range of designs and provide opportunity for continued collaboration with academic research partners. Parks' academic, non-profit and outside agency partners have initiated a variety of stormwater capture projects with support from Parks, including stormwater capture in tree pits, and raingardens that capture road runoff. One of Parks most expansive efforts, a ca. 16,000 sf (1490 m2) green roof complex of 16 different greenroof systems, has become a site for numerous research studies, including monitoring of the ecological as well as stormwater capture impacts of greenroofs. Parks is also implementing a massive urban tree planting campaign which will increase the canopy cover of NYC by 2030. Under PlaNYC, Parks is also working with NYC Dept of Environmental Protection to implement several pilot projects aimed testing performance standards, and working through issues of interagency coordination related to regulations, codes, specifications, permitting, maintenance, and sometimes conflicting mandates. Each of the above efforts has a unique genesis and suggests different environmental benefit goals and different opportunities for replication and expansion across New York City. (068)

LID Helps Define North Bethany as a Community of Distinction in Suburban Oregon
Kevin Timmins, Carrie Pak, and Andrea Vannelli

ABSTRACT: For nearly 40 years, Oregon has enacted land use laws to control urban sprawl and protect agricultural land. Washington County envisioned the recent 800 acre expanded urban growth boundary in North Bethany as a "Community of Distinction" and wanted to raise the bar for community planning in Oregon. Among the goals adopted by project stakeholders was one stating a variety of parks, protected open spaces, and water quality facilities will result in a designed and coordinated system integrated within the urban fabric. As the project stakeholder responsible for stormwater management and in the North Bethany Study area, Clean Water Services saw a unique opportunity to come up with a drainage master plan for a large, undeveloped area that considered what works and improve upon what is not working. The resulting strategy takes a comprehensive approach to incorporating stormwater management into the landscape of North Bethany by protecting natural resource areas, utilizing Low Impact Development (LID), and discouraging small, isolated facilities hidden in fenced corners. Clean Water Services will continue to require riparian buffers on all jurisdictional waters. Regional facilities will be located adjacent to natural resource areas, outside of regulatory buffers, and integrated with the park system as a linear feature with the trail system, or as a multi-purpose facility within a community park. Washington County and Clean Water Services have already begun to address the challenges associated with implementing LID, including revisions to design and construction standards, maintenance agreements, modifications to street standards, creation of a LID Handbook, and public education. Coordination will be on-going. (069)

LID, LEED, and Alternative Rating Systems—Integrating Low Impact Development Techniques with Green Building Design
Laura Prickett and Jill Bicknell

ABSTRACT: The demand for developments that achieve green rating criteria continues to be strong despite the weakened economy. Many municipalities throughout the U.S. are adopting green development ordinances or policies with various environmental goals, often with an emphasis on addressing global climate change. At the same time, environmental advocates and state and federal stormwater regulators are increasingly emphasizing low impact development (LID) design techniques to reduce long-term water quality impacts from new development and significant redevelopment projects, replenish groundwater resources, and provide for rainwater capture and reuse. This paper explores opportunities for harnessing some of the momentum of the green building movement to further the implementation of LID strategies in new development and redevelopment projects. We examine the extent to which LID designs can earn green building credits under Leadership in Energy and Environmental Design (LEED) rating systems for new construction (LEED-NC) and neighborhood development (LEED-ND), as well as alternative rating systems such as the Sustainable Sites Initiative (led by the American Society of Landscape Architects, Ladybird Johnson Wildflower Center, and U.S. Botanic Society), and GreenPoint Rated (a program of Build It Green, a California non-profit organization). The paper features the results of a comparison of green building criteria in LEED and alternative rating systems with LID techniques that may earn green development credits. Gaps in credit availability for specific LID techniques are identified, along with opportunities to further integrate the LID approach and green building initiatives. (070)

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Low Impact Development: The Saviour of the 21st Century City or a 20th Century Suburban Irrelevance?
J. Blanksby, R. M. Ashley, J. R. Hogg, and A. F. Poole

ABSTRACT: A common perception of low impact development is that they are only applicable in areas of low density development. However the drivers and pressures acting on 21st Century cities may often result in densification of the existing urban areas rather than expansion into the surrounding countryside. Using the City of Bradford in the UK as and example, the paper concludes that many surface water management measures which can be classed as low impact development are appropriate to the needs of the modern city. However, the way in which they are presented needs to change in order to make them appear relevant to those striving to reshape our cities to meet the demands of climate and demographic changes whilst shielding valuable historic urban and rural landscapes from damage. (071)

The Application of Form-Based Zoning and Low Impact Development for the Revitalization of the Town Center of Simsbury, Connecticut
Steven D. Trinkaus

ABSTRACT: Simsbury is one of the oldest communities in Connecticut. It was incorporated in 1670 and contain approximately 34.5 square miles. State Route 10 (Hopmeadow Street), a major north/south arterial road bisects the Town Center, and while there is commercial development on both sides of Hopmeadow Street, the majority of the commercial development is found on the east side of Hopmeadow Street. The current zoning regulations are prescriptive in nature and are "highly restrictive, but to provide the opportunity for creative architectural design and south inter-relationships of buildings to open spaces, pedestrian and automotive circulation…" The entire town center area drains to the east, through a large wetland system and ultimately into the Farmington River. An aerial view of the area shows that the automobile and not pedestrians are the dominant component of the existing development. The town desired to create a vibrant town center that would encourage people to live, work and socialize within the center area. In order to accomplish this goal, the town plans to create zoning regulations utilizing Form-Based Zoning for new and redevelopment projects. Along with the Form-Based Zoning, Low Impact Development storm water strategies are to be applied to collect, treat and infiltrate runoff from the town center area so as to not adversely affect the water quality in the Farmington River. (72)

The Integration of Low Impact Development to Enhance the Application of Smart Code Zoning to Create a Gateway District to the Historic Town Center of Tolland, Connecticut
Steven D. Trinkaus

ABSTRACT: This paper will discuss the how the recently adopted Low Impact Development storm water strategies and performance standards for the Town of Tolland were enhanced and integrated to address storm water issues in the newly proposed Tolland Village Area for the Town. The paper will also address modifications to the LID Design Manual which will specifically apply to the Tolland Village Area. Like many other colonial era towns in Connecticut, the center of the community was a "town green" along the main road in the community. The historic town green is located approximately 1 mile north from Interstate I-84 along Route 195. The existing strip commercial development along Route 195 does not provide an aesthetically pleasing gateway to the historic town center area and consists of a hodge podge of commercial uses. These uses include gas stations, convenience stores, small retail stores and fast food restaurants. Minimal storm water treatment is provided by the conventional curb/gutter drainage system. The Town is using the Smart Code to implement transect based zones for the creation of a Traditional New England Village as an entrance to the historic town green. The desired goal is to create village area, which will focus on mixed use development, including diverse housing stock which incorporates "workforce housing". While the density of development in this area will increase, specific LID strategies will be implemented to protect the natural resources, such as the Tolland Marsh from the adverse impacts of non-point source runoff. (073)

LID and Sustainability

National Assessment of Rainwater Harvesting as a Stormwater Best Management Practice: Challenges, Needs, and Recommendations
Steven J. Burian and Dwane Jones

ABSTRACT: Rainwater harvesting has emerged as a sustainable technological solution to address multiple urban water management goals. Recognizing that current technical knowledge and guidance with respect to the benefits of the technology for use as a stormwater management best management practice (BMP) is limited, the Rainwater Harvesting Task Committee (RWHtc) was formed under the Low Impact Development Committee and the Urban Water Resources Research Council of the Environmental and Water Resources Institute (EWRI) of the American Society of Civil Engineers (ASCE). The objectives of the RWHtc were to (1) compile the literature and summarize technical information on rainwater harvesting as a stormwater best management practice (BMP) and (2) develop

preliminary national guidelines for the use of rainwater harvesting technology as a stormwater BMP. The RWHtc has prepared a report summarizing key technical issues, challenges to and incentives for implementation, and general guidance for design methods, costs, and research and education needs for use of rainwater harvesting as a stormwater BMP. This paper summarizes the preliminary report. (074)

Alternative Futures: Economic and Water Resource Analysis of Traditional vs. Low Impact Redevelopment
L. M. Adams, S. Schulte, M. Rivarola, C. McDonald, and J. K. Ruhl

ABSTRACT: Stormwater management is an important issue for communities across the nation. The National Pollutant Discharge Elimination System (NPDES) and its mandatory compliance programs, aging infrastructure, streambank erosion and flooding, and increased citizen interest in improving water quality and promoting sustainable landscapes is driving cities to prioritize capitol expenditures, develop monitoring and educational programs and adopt new design standards. Innovative low-impact development (LID) techniques allow stormwater to be managed in a manner that retains predevelopment hydrologic and ecological functions, while addressing major NPDES compliance requirements. Communities and developers, however, continue to debate the economic benefits and impacts of LID. This paper was developed to fulfill the following three goals: 1) Compare the lifecycle cost and benefit of LID and traditional redevelopment and infill development in the Midwest, 2) Analyze the developer's potential return on investment for LID and traditional redevelopment, and 3) Inform policy and ordinance recommendations for the City of Mission, Kansas. The authors compared life cycle costs and water quality benefits of LID scenarios with traditional development scenarios to help evaluate the cost-effectiveness of LID approaches and to inform future policies and design criteria. An economic analysis and water quality modeling were performed at the site level. To evaluate a variety of redevelopment opportunities, the authors selected three distinctive sites. These sites represent a mixed use commercial redevelopment, a multi-family development, and a typical single family residence. To actualize the potential benefits of LID development, the paper provides recommendations to update codes and ordinances. The City plans to use this study as a foundation moving forward and implement substantial changes to the Municipal Code in order to not only allow but require improved stormwater and environmental management strategies. (075)

Appropriate Drainage Systems for a Changing Climate in the Water Sensitive City
R. M. Ashley, M. G. Faram, P. R. Chatfield, B. Gersonius, and R. Y. G. Andoh

ABSTRACT: With increasing uncertainty and demands on drainage systems in future the question of what type of system is most appropriate is an important one. Future drainage systems need to be: integrated into the water cycle and into other urban services; multi-functional providing not only wastewater management but also reductions in urban heat island effects; ecosystem and water quality benefits as well as amenity opportunities. Normative systems using pipes and large underground facilities have worked well in the past, but only to preserve public safety; not to provide the other benefits now expected. Indeed normative drainage systems have contributed to the climate changes now being seen by careless energy and resource use. The need for future drainage systems to provide a resilience function is illustrated in this paper and the use of LIDs, SUDS and BMPs is shown to be a significant potential contributor to these needs for the future. (076)

Cation Exchange Capacity of Inorganic Green Roof Substrates Prevents the Negative Effect of Available Zinc on *Sedum* Species
S. Lorelly Solano, Andrew G. Ristvey, John D. Lea-Cox, and Steven M. Cohan

ABSTRACT: Crumb rubber, a recycled tire product, is a potential substrate amendment for green roofs, and is currently available in large quantities throughout North America. Crumb rubber's low bulk density may reduce substrate loads, resulting in decreased engineering costs for buildings and may improve porosity and longevity of green roof substrates, reducing maintenance and renovation costs. As with other recycled products, its use is appreciated for reducing environmental impacts with respect to extraction and production of new materials. However, it is known that crumb rubber can release 99.5 µg Zn per gram when saturated with RO water during 16 days. Hydroponic studies comparing three different zinc levels demonstrated that Sedum kamtschaticum completely collapses at concentrations higher than 80 ppm when grown in glass beads after three months of weekly fertigation. However, the plants exhibited a great tolerance to the same levels when grown in an inorganic substrate. The results are consistent with previous findings, showing that substrates derived from expanded shales, slates and clays can adsorb almost 100 times the available zinc released in a mix of 30% crumb rubber and 70% roofliteTM. Proportions of crumb rubber added to a green roof substrate did not interfere with establishment and growth quality index of three *Sedum* species (*S. kamtschaticum, S. album,* and *S. reflexum*). The cation exchange capacity of inorganic substrates prevents available zinc to become toxic to plants and reduces the chances for zinc to become an environmental pollutant when leached from crumb rubber-amended green roofs. (077)

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Effects of Crumb Rubber Amendments on the Porosity, Water Holding Capacity, and Bulk Density of Three Green Roof Substrates
Andrew G. Ristvey, Lorelly Solano, Kimberly Wharton, Steven M. Cohan, and John D. Lea-Cox

ABSTRACT: Extensive green roof systems are becoming increasingly popular with urban Low Impact Design (LID), having a number of tangible benefits, not the least of which is storm water mitigation, ameliorating urban storm water discharge from impervious surfaces while reducing high-flow periods which cause stream-bed erosion and carry pollutants to local waterways. The most important factor of storm water amelioration is the substrate or media, which are mineral-based manufactured aggregates, blended with specific granulometric distributions based on design intent or regional rainfall patterns, better optimizing water holding capacity while still providing enough airfilled porosity for healthy plant roots. Crumb rubber, a recycled tire product, is a potential green roof substrate amendment, and is currently available in large quantities throughout North America. Crumb rubber offers many potential benefits, including improvements in substrate air-filled porosity while reducing the weight of the green roof substrate for increasing the potential retrofit of older buildings. Three typical green roof substrates were amended with 8-12 sieve-mesh crumb rubber in increments of 0, 6, 12, 18, 24, and 30% by volume, and were analyzed for air-filled porosity and water holding capacity with the North Carolina State University Porometer system. Higher proportions of crumb rubber significantly reduced total porosity and water holding capacity, yet increased air-filled porosity compared to unamended control in one substrate and decreased bulk density in all substrates. This study was developed to determine the effect of crumb rubber amendments on the porosity and bulk density of green roof substrates to balance water holding performance yet, retain a root friendly environment, and increase the potential for green roof retrofit onto buildings with limited structural capacity. (078)

Modeling Impervious Area Disconnection with SWMM
William C. Lucas

ABSTRACT: Given careful design and measures to improve soil infiltration, remarkable results can be obtained from disconnecting runoff, even with relatively small receiving areas. Improving soil infiltration with deep tillage and incorporation of compost is well documented in the agricultural literature. The combination of disconnection with improved soils has considerable promise as an effective Green Infrastructure control. The effects of impervious area disconnection were modeled on an office/commercial complex with 67% impervious cover. The perimeter of the site is graded as a gently sloping biofiltration swale. Flush curbs and bumper blocks provide sheet flow conditions to the shallow sides of the swales Runoff from office building roofs sheet flow toward shallow lawn inlets. These inlets discharge directly into the bottom of the swales, as does the runoff from the commercial building roof. Given shallow side slopes and flat bottoms, nearly the entire area of the swales is wetted, providing as much wetted area as possible. PCSWMM was used to compare three different scenarios: Full Disconnection at 1.0 in/hr. Ksat, compared to Full Disconnection at 0.25 in/hr. Ksat and No Disconnection at 1.0 in/hr. Ksat. The 1.0 in/hr. Ksat represents improved soils, while 0.25 in/hr. Ksat represents typical soils with turf management. The No Disconnection Alternative represents the typical direct manifold of roof leaders and storm drains. The swales were modeled as trapezoidal conduits placed inside the swale subcatchments to represent the time lag that occurs at low flow depths in biofiltration swales.

The following results were obtained for the 2005 design year:

Scenario:	None 1.0	Full 0.25	Full 1.0
Maximum Outflow (cfs):	10.72	8.342	6.089
Mean Outflow (cfs):	0.01391	0.005505	0.002007
Total Outflow (ft^3):	438,700	173,600	63,300

The effects of disconnection onto improved soils are considerable. Annual runoff volume is reduced by 86%, while the volume of exceedance over 0.05 cfs/acre is reduced by 81%. Both the number and duration of exceedances are reduced by 92%. It is also instructive to see how disconnection can perform in the unimproved soils. As may be expected, the results are worse, but still remarkable. The annual runoff volume is reduced by 60%, while the volume of exceedance over 0.05 cfs/acre is reduced by 50%. The number of exceedances is reduced by 77%, while the duration is reduced by 71%. (079)

Implementing Sustainable Green Streets and Parking Lots in San Mateo County, California
Matthew Fabry, Kevin Robert Perry, and Laura Prickett

ABSTRACT: Although sustainable green streets are becoming commonplace in pioneering cities, such as Portland, Oregon, and Seattle, Washington, it can be challenging to bring these designs into the mainstream. In 2007, the San Mateo Countywide Water Pollution Prevention Program (Countywide Program) initiated a Sustainable Green

Streets and Parking Lots Program to help municipalities in San Mateo County (immediately south of San Francisco) implement low impact development designs in transportation infrastructure, using funding from a countywide vehicle registration fee. A case study of this innovative program is presented, describing the results of its three initial components – an award-winning design guidebook, grant funding of demonstration projects, and municipal staff training – followed by a discussion of future plans and objectives. (080)

Integrating LID into Your Asset Management Program
Christine Spencer

ABSTRACT: The San Francisco Public Utilities Commission's (SFPUC's) Wastewater Enterprise (WWE) Division has developed and implemented a Storm Water Management Pilot Project (Sunset Swales) that utilizes vegetated swales and infiltration basins to capture and purify water that flows directly into Lake Merced. The life of this project can be made indefinite by conducting a combination of Preventive and Corrective Maintenance activities which are implemented, budgeted and tracked through utilization of the SFPUC Maintenance Management System. This presentation will demonstrate the:

- Steps required for developing the Sunset Swales (L.I.D) Maintenance Program.
- Comparison of conventional WWE Asset Data hierarchy for aiding in the formulation of a unique L.I.D Storm Water Management System (Sunset Swales Pilot Project).
- Advantages of leveraging Asset Data Hierarchies for optimizing Asset Management
- Maintenance Key Performance Indicators for the Sunset Swales Pilot Project. (081)

LID Meets Permaculture: Sustainable Stormwater Management in the Mountains of Western North Carolina
Timothy Ormond, Bailey Mundy, Mary Weber, and Zev Friedman

ABSTRACT: Inhabitants of the Southern Appalachian Mountain Range of Western North Carolina have a long tradition of living sustainably from the land. More recently, however, there has been a rapid increase in population from outside the region and corresponding development pressures that have resulted in degradation of numerous pristine mountain water resources. Nonpoint source pollution from stormwater runoff is the primary cause of degradation of many of these waters. There are numerous obstacles to protecting water resources in the region including lack of stormwater and steep slope development regulations, perceived conflicts with private property rights, and a general lack of awareness of both the causes and solutions of nonpoint source pollution. In an effort to advance stormwater management practices in the region, a group of stakeholders joined together in 2008 to implement a stormwater low impact development (LID) best management practice (BMP) demonstration project in Mars Hill, North Carolina. The goal of the project is to develop cost-effective, sustainable, stormwater practices, appropriate for the mountain region that will educate and inspire the regional community. A unique aspect of this project is the incorporation of permaculture design principles, which consider the often complex human interrelationships with landscapes and ecosystems. This paper provides an overview of the Mars Hill LID demonstration project and explores the benefits of incorporating permaculture design principles into LID projects. (082)

Maximizing Sustainable Water-Use for Low Impact Development
J. S. Leys and S. B. Sarté

ABSTRACT: The topic of water management has been elevated within and beyond the design community to levels never seen before. This awareness provides us all with a unique opportunity to make valuable and lasting change to the way we manage water. The visibility of this subject could not come at a better time. The looming variable impact of climate change on our water supplies, combined with the increasing pace of land development world wide, add to the importance of meeting this challenge immediately and directly. Low Impact Development (LID) design and successful implementation has come a long way in recent years. Although traditional water management is still standard practice, more and more municipalities are seeing the advantages of LID techniques and supporting its implementation. Recent work in this area has created the precedent necessary to elevate LID stormwater management to the level of standard practice. As LID has advanced it has become an essential part of engineer's toolkits – transforming how engineers approach and solve complex water resource management problems. This paper details how LID is being applied in a variety of ways to projects ranging from regional plans to neighborhood master plans to single sites. Using three projects as case studies, the interrelationship between LID and integrated water management is illustrated, and a successful approach is outlined. (083)

Modifications to Existing Codes and Ordinances: Bioassay of Microbial Diversity in Compost
Carole Ann Rollins and Jae Koenig

ABSTRACT: Application and use of compost in urban and agricultural landscapes has become a common practice for maintaining healthy soils and restoring ecological balance. While testing protocols have improved since

2006, many materials labeled as "compost" are only anaerobic decomposing organic matter due to both processing and packaging. This paper presents research indicating that aerobic compost, with confirmed active and diverse microbial populations, provides the environment necessary for proper nutrient cycling performed by the soil foodweb. This paper will propose a revision to the quality testing protocols specified by the U.S. Composting Council ("USCC"), the American Society for Testing and Materials ("ASTM") and the US EPA Report SW-846 to include biological assays to reflect the diversity of microbial populations in compost using expanded methods to include direct microscopy, updated molecular techniques, phospholipid fatty acid analysis, and plate counts using numerous agar food sources. Currently, a bioassay of compost analyzes only possible existence of pathogens, stability of compost by measuring oxygen consumption, or seed emergence and seedling vigor relative to positive controls. This paper proposes that compost, meeting this expanded testing requirement, will ensure nutrient and water retention in soils to maintain and improve health of stormwater runoff and related environmental impacts. (084)

Modular Wetland System: A History of Wetland Treatment and Case Study of an Advanced Subsurface Flow Wetland to Treat Stormwater and Continuous Nuisance Flows
Michael Alberson

ABSTRACT: Wetlands are nature's way of filtering polluted waters. They act as buffer zones between upland areas and water bodies, such as lakes and oceans. Various treatment technologies based upon wetlands have been applied in numerous applications relating to improvement of water quality. Over the past 30 years various types of wetland treatment systems have been used. One particular type, the subsurface flow wetland, has demonstrated exceptionally high performance given smaller footprints. Other advantages will be discussed in following sections. Currently, new generations of manufactured or modular subsurface flow wetland systems are being used to provide treatment of stormwater runoff and nuisance flows. This generation focuses on better engineered pretreatment systems and new wetland media mixes that increase performance and decrease maintenance costs. These systems are designed for use in very urbanized areas where no space exists for traditional wetland designs. Various case studies have been done showing the effectiveness of these systems. This paper outlines the history, advancement, and success of subsurface flow wetland technology, and the results of the latest case study done on an innovative design known as the Modular Wetland™ System – Linear. (085)

Rainwater Harvesting: Policies, Programs, and Practices for Water Supply Sustainability
Allison Gold, Robert Goo, Lisa Hair, and Nancy Arazan

ABSTRACT: Rainwater harvesting has the potential to supplement water supplies, manage stormwater and help mitigate combined sewer overflows (CSOs), decrease water withdrawals, reduce energy consumption and thereby reduce greenhouse gas emissions. This paper contains an analysis of the policies, programs, incentives, rules, regulations, impediments, and other voluntary and regulatory mechanisms that promote or require rainwater harvesting throughout the country at the municipal, state, and national levels. The paper also contains a summary of the benefits of rainwater harvesting. A section on programmatic tools that facilitate the assessment and evaluation of the municipal, state, and national policies also is included to provide insight into trends, future developments, and research gaps regarding the harvest and use of rainwater and snow melt. (086)

Same Old Drainage Problem, Different Solution
Thomas R. Ingram

INTRODUCTION: Take a drainage area on the edge of the Historic Central Section of "Town Z". Throw in the old drainage problem. The pipe under the highway is too small. It is making a bottleneck for the stormwater that needs to scurry further downstream. However, the area downstream of the highway cannot handle the stormwater it receives now, so sending additional stormwater under the highway will only add to the problem further downstream.

Stormwater Runoff Reduction Achieved by Green Roofs: Comparing SWMM Method to TR-55 Method
Daniel Roehr and Yuewei Kong

ABSTRACT: This research uses the EPA Storm Water Management Model (SWMM) to simulate runoff generated by impervious roofs and green roofs. Simulation results are compared with previous simulation results using Natural Resources Conservation Service Technical Release-55 (tr-55) and measurement by the British Columbia Institute of Technology (BCIT). Findings show that SWMM's Green-Ampt method can calculate more accurate runoff coefficients of impervious roofs than tr-55's Curve Number method. Annual runoff coefficients are 0.88 by SWMM, 0.6 by tr-55 and 0.93 by BCIT's measurement. However, using SWMM's Green-Ampt method alone does not accurately simulate green roof runoff. Green roof runoff is more accurately simulated by combining the Green-Ampt method with evapotranspiration of green roofs. According to BCIT's measurement, runoff reduction rates of

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monitored green roofs are 24% and 21%. As determined by combining the Green-Ampt method with evapotranspiration of green roofs, the potential runoff reduction achieved by green roofs is 20%. (088)

The Feasibility and Desirability of Stormwater Retention on Site in California and on the West Coast
Eric Strecker and Aaron Poresky

ABSTRACT: The retention of stormwater on-site with the goal of mimicking predevelopment hydrology is increasingly being required or encouraged for new and redevelopment projects. The recently adopted Ventura and Orange County Municipal Separate Storm Sewer System (MS4) NPDES permits require retention on site of runoff from storms up to the water quality design storm via infiltration, evapotranspiration and/or harvest and use. To date, the retention of stormwater on site has primarily been accomplished via infiltration and, to a much more limited extent, evapotranspiration. In only a few cases has rainwater harvesting and non-potable use been employed on a site scale; typically when it has been included it has been part of meeting LEED requirements. The feasibility and desirability of retaining stormwater on site up to a specific design storm has not been vetted technically on a national or regional scale. For example, there has been almost no consideration of the natural water balance in technical guidance. Often infiltrated volumes must be increased over natural conditions in order to match pre-development surface runoff volumes, yet there has been little consideration for whether increasing infiltration over natural conditions may be an issue. There has also been almost no assessment of the circumstances necessary for rainwater harvesting systems to work well for stormwater management. This paper presents some of the considerations for retaining on site and proposes conceptual criteria for determining whether it is feasible and/or desirable to do so. The paper reviews and discusses the general precipitation and runoff patterns for California and the west coast; the natural water balance and changes to that balance under developed and low-impact development conditions; under what conditions infiltration is feasible and desirable with examples of evaluations; what levels of evapotranspiration can be achieved; and finally presents some examples of the use of rainwater harvesting as a means to retain stormwater on site. Example modeling scenarios of rainwater harvesting for irrigation and toilet flushing are presented from Southern California and Portland, Oregon to highlight both the stormwater management results as well as impacts on potable water demand. Implications related to reclaimed water use will also be presented. (089)

Tricosan in Greywater: Implications for Reuse
K. H. Baker, D. I. Harrow, and B. A. Ritchey

ABSTRACT: Greywater is household wastewater containing all used water except sewage. In order to conserve water, it has been proposed to use greywater for irrigational purposes. If this was the case, greywater would travel straight from the house to outside for use, minimizing the need for installing pipelines and such to carry the water elsewhere. However the widespread use of a variety of antibacterial and there subsequent presence in greywater raises concerns regarding impact on environment and health. Our research looked at the possible modification of microbial communities within the soil due to the presence of a commonly used antibacterial agent, triclosan. Along with the community structure, we also looked at any antibiotic resistance due to the constant exposure to triclosan. This experiment involved of three groups: control, greywater only and greywater with triclosan. Each group consisted of four soil filled columns treated with their designated solutions on a weekly basis. The effluent was collected from each column and cultured onto plates. Isolates were then taken from the plates for further testing. Our findings show that under constant exposure, the community structure did, in fact, change showing two very distinct heterotrophic populations between those that were treated with triclosan and those that were not. It was also seen that due to the exposure to triclosan, resistance to the four tested antibiotics (ampicillin, chloramphenicol, streptomycin and tetracycline) increases. Our results indicate that triclosan in greywater can have significant impacts on soil microbes. The changing of the microbial community structure could lead to a change in available nutrients and the form those nutrients are found. While the antibacterial products may be present in very minute concentrations, their constant presence may be selecting for bacteria that are resistant to all types of antibiotics, thus making it harder to treat. It is possible that all this is avoidable by treating the greywater before using it or by removing antibacterial products. In congruence with our data, there is a need for further investigation. (090)

Urban LID Using Compost
P. Schultze-Allen

ABSTRACT: The City of Emeryville has required all new projects to use LID strategies and biofiltration of stormwater since 2005. Using its APA-award-winning "Stormwater Guidelines for Green, Dense Redevelopment" the City has worked with private developers in constructing five new projects in addition to one new City park that all use vegetated stormwater treatment systems and elements from the low impact development toolbox. Now the City is focusing on sustainable landscaping practices to augment the requirements and take the sustainability features of these new projects to the next level. A local agency has developed the program "Bay-Friendly Landscaping" which the City has adopted. One of the key concepts in BFL is using high quality locally produced compost sourced from nearby urban, suburban and rural feedstocks. The City is requiring that all new landscapes use compost according to City

standards as the soil amendment of choice in place of synthetic fertilizers and traditional forest products. The City of Emeryville may be the only city in the United States that currently has this requirement. The Bay Area is fortunate to have two composting facilities that produce certified organic compost products. Compost producers and laboratories in the Bay Area have also received certification under the US Composting Council's Seal of Testing Assurance Program (STA) which is a compost testing, labeling and information disclosure program designed to provide the information needed to get the maximum benefit from the use of compost. The STA certification is one factor in assuring the City and the purchaser that the compost product is high quality because the compost facility understands and employs composting practices and testing procedures in a consistent manner. The City of Emeryville requires that the compost product used in the new landscapes in the City is produced at least partially with feedstocks sourced from residents and/or businesses in the City, so the nutrient recycling loop is completed when the compost product comes back to the City. Leaves from a home or food scraps from a restaurant come back in the form of compost for a new landscape or garden which in turn produce plant trimmings or food scraps for collection again. The presentation will use photographs and case studies of the five private projects and one public project that have used biofiltration and LID strategies to treat stormwater and how compost was used in the landscaping. (091)

Using the Bay-Friendly Landscape Standards to Implement Low Impact Development in the San Francisco Bay Area
G. Wolff and S. Sutton

ABSTRACT: Bay-Friendly Landscaping integrates Low Impact Design (LID), into a holistic, sustainable, watershed approach to landscaping that addresses current environmental, economic, health, and safety issues, including stormwater management and protection of San Francisco Bay water quality. More than 30 new landscapes, including libraries, community centers, fire stations, community colleges, multifamily housing and streetscapes, have been designed and constructed to meet the Bay-Friendly Landscape standards, with many of these projects also meeting both LID and LEED™ goals. Project goals and features, including those to manage stormwater, are described for two Bay-Friendly Rated landscapes in the East Bay. Ohlone College's new campus in Newark, CA, for the Center of Health Sciences and Technology, designed to achieve the LEED™ Platinum and the Bay-Friendly Ratings, includes weather-based irrigation controllers, planting with low level water requirements, an integrated pest management policy, a Bay-Friendly maintenance program, and multiple strategies to collect and filter stormwater. Sara Conner Court is a community of 57 affordable rental homes in Hayward, CA. The site directs all stormwater runoff toward lawns, planting beds and bioswales, moderates building temperatures and reduces heat island effect with effectively placed trees. Parking areas without curbs and grass-porous pavement in courtyards increase the infiltration and filtration of stormwater. (092)

LID from Rules to Reality

LID from Rules to Reality—The Role of the Plan Reviewer
Hunter C. Freeman

INTRODUCTION: What is Low Impact Development? This deceptively simple question was presented to a group of stakeholders during the development of Low Impact Development (LID) stormwater programs in North Carolina in 2008, and today, we have yet to get past a draft definition. Although the objectives are apparent - that the built-upon environment should be planned, designed, and constructed to preserve the natural hydrologic qualities inherent to the pristine site - what makes a developed site capable of being called LID is more difficult to define in the context of achieving the requirements of any particular stormwater management ordinance. Is a project worthy of being labeled "Low Impact Development"? Has the designer done enough throughout the development planning, design and construction process to meet the intent of LID philosophy? While conventional and LID stormwater management examples on either extreme of the spectrum may be clear cut, the majority of projects incorporate a hybrid approach, combining conventional stormwater management practices with any number of LID techniques. With an infinite number of site specific variables involved, a standard evaluation method is necessary to objectively compare two sites with different natural and proposed characteristics. In the paper to follow, examples from coastal North Carolina permitting programs will be used to construct an example permitting system for sustainable stormwater management plan review. Because of a desire to highlight permitting programs, this paper uses new development permitting as its foundation, but the principles and concepts discussed could be used to objectively evaluate all kinds of stormwater infrastructure improvement projects. The permitting system proposed in this paper draws from real world examples, but is not an actual permitting program at this time. (093)

Long-Term Performance, Maintenance

Design, Construction, and Maintenance of LID Practices: Results from a Field Assessment in Virginia's James River Watershed
David J. Hirschman and Laurel Woodworth

ABSTRACT: In 2008, the Center for Watershed Protection, Inc. (CWP) and project partners conducted a field assessment of nearly two hundred stormwater management facilities, including selected LID practices, throughout

urban areas of Virginia's James River watershed. This assessment was conducted as part of CWP's *Extreme BMP Makeover* project, a three-year endeavor to aggressively improve the nutrient reduction achieved by stormwater best management practices (BMPs) within Virginia's James River watershed and the greater Chesapeake Bay region. The project is funded in part by the National Fish and Wildlife Foundation. The field assessment process documented indicators of BMP performance problems, such as signs of by-passing, proper functioning of inlets and outlets, adequate sizing, the integrity of filter media and vegetation, and key maintenance and longevity items. The purpose of this research was to attempt to isolate critical stormwater BMP design, construction, and maintenance factors that may contribute to enhanced treatment of runoff and longevity of BMPs. Although the sample set for this survey included the wide variety of facility types presently used in Virginia, this survey especially targeted several types of LID practices that are becoming increasingly popular and are likely to enjoy more widespread application in the next decade, including bioretention, permeable pavement, and infiltration. In general, the condition of BMPs and LID practices in Virginia's James River watershed can be illustrative of performance conditions of such practices throughout the country. Results from this field survey reveal a number of design and installation factors that can "make or break" the proper performance of practices, as well as a list of more subtle features and maintenance practices that could extend their functional life. (094)

Overcoming Institutional and Other Barriers to LID Implementation

An Assessment of Barriers to LID Implementation in the Pacific Northwest and Efforts to Remove Those Barriers
C. Doberstein, R. Kirschbaum, and A. Lancaster

ABSTRACT: Low impact development (LID)—design that strives to mimic natural hydrologic processes—continues to grow and evolve as a preferred method of stormwater management. Agencies and jurisdictions across the nation are working to facilitate and promote incorporation of LID approaches into surface water management programs. Key to these efforts is the need to identify and address barriers that impede LID implementation at the local and regional level. Stormwater practitioners in the Pacific Northwest have been at the forefront of technical and policy developments in LID, including direct efforts to identify and remove barriers to widespread implementation. This paper addresses key barriers identified in the state of Washington, their impact, and the steps being taken by local agencies, institutions, and professionals to remove them.

The barriers are:

1. Insufficient designer and policymaker familiarity with LID applications and limitations
2. Stormwater regulations lagging behind field performance data
3. Skepticism about LID facility performance and reliability
4. Technical complexity, particularly for parcel/SFR-scale applications
5. Homeowner acceptance, understanding, and willingness to maintain facilities
6. Water rights-related limitations. (095)

Assessing Stormwater Management in King County, Washington: An Evaluation of Pollution Mitigation Strategies
Erin Jo Churchill

ABSTRACT: With the projected increase of urban development in the Puget Sound region, a corresponding decrease in natural drainage will occur, leading to greater amounts of stormwater flowing into vital receiving waters. As a result, the Washington State Pollution Control Hearing Board (PCHB) has recently directed the Washington State Department of Ecology (DOE) to implement low impact development (LID) in its national pollution discharge elimination system (NPDES) permit requirements. This directive has created an opportunity for new policies and mitigation strategies to be developed within local jurisdictions. In order to identify potentially useful stormwater management strategies, this study examines mitigation plans being developed in four Washington State jurisdictions: Bellevue, King County, Renton, and Seattle. These four cases are presented to highlight the complicated issues behind developing and implementing stormwater strategies by exploring the relationships between the PCHB and the DOE and their influences on jurisdiction regulations. The PCHB ruling directs DOE to develop new requirements that call for Phase I jurisdictions to direct money and time into researching LID strategies and the corresponding adjustments that must be made in their building ordinances to adhere to permit requirements. These cases from King County, Washington highlight differences in expectations between jurisdictions, economic gaps, and general uncertainty involved in implementing new strategies with few experienced LID practitioners. (096)

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Forecasting Multiple Watershed-Level Benefits of Alternative Storm Water Management Approaches in the Semi-Arid Southwest: Required Tools for Investing Strategically

Rainer Hoenicke, Meredith Williams, Katherine Ridolfi, John Oram, Kathleen Van Velsor, Jennifer Krebs, and Samuel Ziegler

ABSTRACT: The menu of alternative storm water management approaches and best practices has grown considerably over the last few years – even for densely urbanized areas. At the same time, watersheds have gained recognition as planning templates. Municipalities, counties, special districts, and private developers are now required to mitigate unavoidable impacts on aquatic resources of new and re-development projects in a watershed context. However, public agencies currently have few tools available, are faced with sometimes conflicting public policies, and often have insufficient expertise to translate the overwhelming choices on the LID menu into implementation guidance, let alone determine how to predict the off-site impacts of a project on watershed functions and processes. The role of watershed position in determining the effects small-scale, site-specific LID practices remains largely unexamined and unknown. Nor are the cumulative beneficial outcomes and cost-effectiveness of LID applications across a watershed sufficiently understood. As a result, scarce resources directed at alternative storm water management approaches are rarely maximized, although local government can ill-afford non-strategic approaches to LID. California has unique public financing constraints for storm water management and other public benefit expenditures. Therefore, any public investments using non-traditional management approaches have to pass a fairly high documentation threshold of anticipated environmental and public health and safety benefits, regardless of whether new expenditure requests are placed in front of the voters, or existing funds are reprioritized. For these reasons, we propose that initial investments in forecasting tools capable of predicting the cumulative benefits of site-specific applications of appropriate bioengineering and design solutions are needed to guide implementation of appropriate mixes of runoff reduction, harvesting, re-use, and infiltration options in a climate with distinct dry and wet seasons. These up-front investments should include development and application of standardized monitoring infrastructure and protocols that are built into pilot LID designs to document environmental benefits and generate data for model calibration. Ultimately, the systematic application of forecasting tools, supported by performance monitoring data, will enable resource economists to compare the benefits of individual LID projects and their implementation and maintenance costs at a watershed scale with more traditional, centralized, and capitalintensive public infrastructure investments. We present examples that include interactive maps of existing natural and man-made runoff conveyance infrastructure, land use, land cover, and ownership, as well as other critical landscape characteristics at the appropriate resolution to model environmental outcomes prior to large-scale implementation. (097)

Integrating Valuation Methods to Recognize Green Infrastructure's Multiple Benefits

S. Wise, J. Braden, D. Ghalayini, J. Grant, C. Kloss, E. MacMullan, S. Morse, F. Montalto, D. Nees, D. Nowak, S. Peck, S. Shaikh, and C. Yu

INTRODUCTION: Reducing the negative impacts of storm water is gaining priority in United States communities' efforts to develop more sustainably and to comply with Clean Water Act requirements. Nationwide, communities may need to invest hundreds of billions of dollars in coming decades to meet clean water goals, assuming expansion and repair of conventional infrastructure (US EPA 2002). These projections include $54.8 billion for combined sewer overflow (CSO) control, and another nine billion dollars for storm water management programs (US EPA 2008a). The Clean Water Act's regulatory requirements, along with perennial budget struggles facing many municipalities, are driving cities and utilities to identify and choose the most costeffective approaches to storm water management. The parallel needs to improve water quality and prioritize cost-effective infrastructure investments have brought Green Infrastructure (GI) and Low Impact Development (LID) practices to the fore of cities' water infrastructure investment strategies. Several major metropolitan areas, including Portland, Seattle, Philadelphia, Kansas City, New York, Washington, Louisville, and others, have sought to integrate green infrastructure into their control plans for combined sewer overflows, and many more are or will be facing similar strategic investment choices soon. Green infrastructure and LID practices (we use these terms interchangeably) produce a range of economic and social benefits in conjunction with managing storm water. Incorporating the value of those benefits into investment decisions is essential in comparing GI and conventional infrastructure's costs and ecological, economic and social effectiveness. Natural drainage practices improve storm water management and water quality. Recent studies also indicate that GI storm water benefits are accompanied by capital and avoided cost savings compared to conventional infrastructure (EPA 2007b). Research has identified other economic impacts of LID, including impacts on energy consumption, property value, urban heat island effect, community health, and global climate change. Green infrastructure's benefits accrue across varied geographical scales. Previous studies have surveyed economic benefits literature (MacMullan and Reich, 2007). Numerous studies define benefits specific to particular practices or impacts. And others summarize benefits of one or several practices in a single locale (e.g., Stratus Consulting, 2009). The difficulty lies in integrating valuation of these multiple benefits, in quantifying benefits that may not be easily monetized, and in bringing recognition of these values into infrastructure investment decisions by developers, communities, and agencies. This paper reviews current methods, tools and case studies of valuation of the economic and social benefits produced by green infrastructure practices, particularly as they are applied in urban settings. It begins to define a framework for assessing the economic

benefits of LID practices on site and community scales. Analysis begins by defining benefits that accrue with a set of common GI practices: tree planting, infiltration practices, permeable pavement, water harvesting, and green roofs. Each practice suggests input units as the basis for benefit calculations, explores variables that affect the accumulation of benefits, and scales at which the benefit occurs. We explore the relationship between input units of green infrastructure practice with resource units representing the value of individual benefits. Finally, we discuss how calculation of site scale benefits can be aggregated at larger scales and between practices. Although some of the benefit calculations discussed vary according to regional or local cost factors and site-dependent impact measurements, the ultimate aim is to allow assessment of GI benefits that is flexible in accounting for such local and regional differences. We also recognize that cost-effective infrastructure decisions require comparing the benefits evaluated here with costs and performance related to both GI and conventional practices. GI practices could conceivably incur costs that do not occur with conventional practices, either in construction or maintenance. A full economic analysis including costs and benefits is beyond the scope of this paper, but the research presented here focuses on beginning to clarify the benefits side of the equation to improve future infrastructure investment decisions. (098)

Low Impact Development for the Empowered Homeowner: Incentive Programs for Single Family Residences
I. A. Meder and E. Kouma

ABSTRACT: In June 2007, the City of Lincoln initiated the Holmes Lake Watershed Improvement Program, a community-based program for public participation and water quality education. This first program focused on a pilot incentive to provide homeowners 90 percent off the cost of a rain garden, free rain barrels, and free nophosphorus fertilizer. Adding to this momentum, a second program began when the City was awarded a $145,000 grant in 2008 to expand the rain garden incentive program citywide. To strengthen the rain barrel promotion, the city began a third program, to offer grant funded Build-Your-Own Rain Barrel classes in 2008. These three incentive programs have created a citywide interest for individuals improving water quality in their own back yards. In 2007, only a few homeowners in our city had a rain garden or rain barrel. Now, 102 homeowners have a rain garden and over 1000 homeowners have a rain barrel. The numbers may seem small, but they amount to a great start in citywide awareness of stormwater quality. (099)

On the Physics of Low Impact Development—Pervious Pavement
Larry John Matel

ABSTRACT: Conventional wisdom in the low impact development (LID) community focuses on the fact that porous pavement structures function by allowing stormwater runoff to infiltrate vertically downward, or flow horizontally into the soil matrix, as primary mechanisms of stormwater disposal. Discussions of rain gardens qualitatively consider the role that evapotranspiration plays in stormwater disposal. Soil scientists look in much more detail at water movement through soil structures, both vegetated and not. However, the current popular LID literature surrounding porous pavement only seems to consider infiltration capacity of the underlying soils. Often times the potential benefits of porous pavement structures are discounted because of low permeability soils that are postulated to inhibit infiltration and, consequently, porous pavement feasibility. In reality, the mechanism of the removal of water from a porous pavement structure is much more complex involving such concepts as capillary action, diffusion, vapor pressure gradients, and heat/mass transfer. The magnitude of evaporation from porous pavement structures is potentially much greater than that predicted by pan evaporation data due to the increased surface area available for mass transfer when compared to the pavement "top" surface area. This paper presents a discussion of the broader considerations in explaining the workings of a porous pavement structure. A review of some of the current thinking related to the evaporation process is presented. Estimates of available surface area in a porous pavement structure available for evaporation are considered and an approach to estimating the magnitude of evaporation as a result of that consideration is discussed. (100)

Seattle's Implementation of Green Stormwater Infrastructure to the Maximum Extent Feasible
Tracy Tackett

ABSTRACT: Seattle is embracing sustainable building and green infrastructure stormwater management practices through numerous different programs and policies. The newest addition to Seattle's policies is the implementation of a stormwater code requiring the use of green stormwater infrastructure to the maximum extent feasible. This paper provides an overview of the tools in place for new and redevelopment and how Seattle is reviewing and enforcing the inclusion of green stormwater infrastructure. (101)

Strengthening Storm Water Management at Federal Facilities and on Federal Lands in Response to Presidential Executive Order 13508
D. J. Cotnoir and R. Goo

ABSTRACT: On May 12, 2009, President Obama signed Executive Order 13508, *Chesapeake Bay Restoration and Protection* to begin a new era of shared federal leadership for protecting and restoring the Chesapeake Bay. Section 202(c) of the order directed the Department of Defense to lead the development of a report making recommendations for strengthening strom water management practices at Federal facilities and on Federal Lands with the Chesapeake Bay watershed. Section 202(c) also directed the Environmental Protection Agency to lead the development of storm water best practices guidance. In addition, Section 502 of the order directed EPA to publish guidance for Federal land management in the Chesapeake Bay watershed. Highlights and status of the recommendations and guidance developed in response to these sections of the order are presented. (102)

Evolution of Low Impact Development in the Puget Sound Region
Bruce Wulkan

ABSTRACT: In 1999, few professionals in the Puget Sound region were familiar with low impact development (LID). Far fewer possessed the confidence and experience to assert that it should be required for new development and redevelopment projects. Yet research and on the ground projects suggested that LID showed great potential for improving how we develop land and manage stormwater. Based on this potential, the Puget Sound Action Team added LID to the state and federal plan to restore Puget Sound. The 2000 Puget Sound Water Quality Management Plan called on local governments in the basin to adopt ordinances to allow and encourage LID. This document, combined with the energy and expertise of many dynamic, forward-thinking professionals in the region, helped make Puget Sound a national leader in the voluntary implementation of LID. Fast forward to August 2008, and the success of this voluntary approach has proven so successful that the state Pollution Control Hearings Board ruled that LID should be required, where feasible, in the National Pollutant Discharge Elimination System (NPDES) Municipal Phase I Permit. In a follow up ruling on the NPDES Municipal Phase II Permit in February 2009, the board directed permittees to take steps to prepare for LID requirements in future permits. LID had shifted in the region, in less than ten years, from a voluntary approach to an NPDES permit requirement. Design and engineering practices typically evolve slowly. Why did this change occur? What factors led to this swift, significant and sweeping change? This presentation will explore the environmental, social and political factors behind this change. Presenting will be Bruce Wulkan, who authored the LID section of the 2000 Puget Sound Water Quality Management Plan; managed the first LID national conference in Seattle in 2001; and currently manages the state's LID program for Puget Sound. (103)

Recent Monitoring/Performance Findings

Bioretention Cell Efficacy in Cold Climates
U. T. Khan, C. Valeo, A. Chu, and B. van Duin

ABSTRACT: Bioretention cells are an emerging technology used to capture and treat urban stormwater runoff before it enters the drainage system. However, studies of bioretention cell use in cold climates have been very limited. To evaluate the efficacy of bioretention cells in cold climates, both field and laboratory experiments were conducted. Results from field experiments indicate a high rate of runoff volume capture (96.31%) and a high rate of contaminant mass capture (99% for solids, and more than 80% for nutrients, BOD-5 and chloride). Laboratory experiments show a high rate of nutrient leaching, decrease in saturated hydraulic conductivity and high capture rate of TSS. (104)

Bioretention Outflow: Does It Mimic Non-Urban Watershed Shallow Interflow?
K. M. DeBusk, W. F. Hunt, and D. E. Line

ABSTRACT: Bioretention, a key structural practice of Low Impact Development (LID), has been proven to decrease peak flow rates and volumes, promote infiltration and evapotranspiration and improve water quality. Exactly how well bioretention mimics pre-development (or "natural") hydrology is an important question that continues to be researched. Do bioretention outflow rates mirror shallow groundwater inter-event stream recharge flow associated with natural or non-urban watersheds? Streamflow from three small, non-urban watersheds, located in the piedmont of central North Carolina, was compared to bioretention outflow from four cells also in North Carolina's Piedmont region. Each benchmark watershed drained to a small stream, where flow rate was monitored for an extended period of time. After normalizing the flow rates and volumes by watershed size, data were combined to form two data sets: bioretention outflow and stream inter-event flow. Results indicate that there is no statistical difference between flow rates in streams draining undeveloped watersheds and bioretention outflow rates for the first 24 hours following the commencement of flow. Similarly, there is no statistical difference between the cumulative volumes released by the two systems during the 48 hours following the start of flow. These results indicate that bioretention cells behave comparably to watersheds in natural or

non-urban conditions with respect to both flow rates and flow volumes and that bioretention outflows somewhat mirror post storm event shallow groundwater recharge. Solely considering bioretention outflow as a conjugate to runoff may be a misinterpretation of a flowrate that actually resembles shallow interflow. (105)

Analysis of Bioretention Media Specifications and Relationships to Overall Performance
Sean W. O'Neill and Allen P. Davis

ABSTRACT: Column studies were undertaken to determine the media P adsorptive capacity for various bioretention mixtures. Media amendments included aluminum-based drinking water treatment residual (WTR), triple-shredded hardwood bark mulch (HBM), and washed quartz sand (LFBSM). Media oxalate extractions were analyzed for Al (Alox), Fe (Feox), and P (Pox) to determine the phosphorus saturation indices (PSI). Increasing media P adsorption was observed with increasing WTR content, HBM addition, (Alox+Feox):Pox ratio, and decreasing fines content. Media is expected to provide adequate stormwater P treatment with a (Alox+Feox):Pox ratio of 20 to 30 or more, or PSI of 0.035 to 0.055 or less. (106)

Ecoroof Performance Monitoring in Portland, Oregon
Tim Kurtz

ABSTRACT: Ecoroofs have become a primary option for reducing roof runoff into our sewers and streams. Because of city requirements to control runoff for new development and redevelopment projects, and builder incentives, the number of ecoroofs will continue to grow in coming years. Peak flow reduction, volume retention, and effluent water quality are all important aspects to maintaining sewer capacity and improving watershed health. Two Portland ecoroofs – the Hamilton Apartments and the Portland Building Ecoroof – are both within the downtown Portland area, and have unique designs in terms of soil media, thickness, and maintenance practices. The Hamilton Apartments Ecoroof was installed during the construction of the building in 1999. The west side of the ecoroof has been monitored continuously for 8 years and provides an excellent long-term data record. The average peak flow reduction has been consistently over 90% for the most intense storm events. Annual runoff retentions have varied between 41% and 63%. Average seasonal retentions have been 84% for summer (May – Oct) and 52% for winter (Nov – Apr). A comparison of the effluent water quality of the ecoroof with that of the building's conventional penthouse roof, shows higher levels of several constituents – in particular, copper and phosphorus. These constituents can be important for watershed health. The number of samples is small, but they suggest efforts should be made to minimize export through the selection of soil media with low copper and phosphorus levels, or the use of stabilization additives. The Portland Building was retrofitted with an ecoroof in November 2006, and a portion has been monitored for almost 3 years. The average peak flow reduction has been consistently over 90% for the most intense storm events. Annual runoff retention has been over 60%, and has been consistent each year. Average seasonal retentions have been 83% for summer (May – Oct) and 56% for winter (Nov – Apr). Effluent water quality has been similar to that of Hamilton despite different soil media composition. (107)

Effect of Soil Disturbance in Native and Engineered Soils Used in Stormwater Infiltration Systems
Daniel P. Treese, Shirley E. Clark, and Katherine H. Baker

ABSTRACT: Hydrologic cycle restoration is the primary objective of stormwater management. Infiltration and bioretention systems composed of engineered and/or native soils are preferred tools for achieving this objective while also providing pollutant removal. However the disturbance of native soils can cause releases of nutrients and suspended solids in the early life of these systems. To limit the potential of replacing one problem with another, a better understanding of the behavior of soil components as they contribute to water transport and pollutant treatment is needed. This project investigated the ability of the various soil horizons in a Wharton silt loam (Pennsylvania) to treat runoff from simulated storm events. The soil was collected intact, but had to be air-dried and the columns repacked when soil shrinkage caused bypassing of runoff along the walls of the laboratory columns. This process is similar to the disturbance of soil by bioretention construction and provided a unique opportunity to evaluate resulting nutrient releases. The effluent water from this reconstructed silt loam had elevated concentrations of total nitrogen (leaching > 100 mg/L of N initially from all soil horizons) and of total phosphorus from the organic horizon (~1.5 mg/L) during application of the first 0.6 m of stormwater runoff. A release of calcium (~500 mg/L) from all soil horizons also occurred, likely due to the destruction of cement bonds between soil aggregates. Potassium was also released from the O-horizon of the disturbed silt loam (~30 mg/L) but leveled off after 0.2 m of applied runoff. (108)

Evaluation of Roadside Filter Strips, Dry Swales, Wet Swales, and Porous Friction Course for Stormwater Treatment
R. J. Winston, W. F. Hunt, and J. D. Wright

ABSTRACT: Due to NPDES regulations, the North Carolina Department of Transportation (NC DOT) is required to treat stormwater from NC DOT facilities throughout North Carolina. There are hundreds of miles of existing right-of-

way swales and filter strips across North Carolina. Relatively few roadside swales and filter strips have been tested for water quantity and quality control. Also, no studies exist on swales with wetland characteristics. This paper presents an assessment of dry swale, wetland swale, and filter strip performance along an interstate highway in North Carolina. Four existing right-of-way linear swales along I-40 were monitored to determine their hydrologic and water quality effectiveness. Two different treatments were examined: one dry swale and one which was allowed to establish wetland vegetation and hydrology. This experimental design was replicated once. Also addressed was the impact of the vegetated filter strip between the shoulder and the edge of the swale. Samples have been collected from 17-21 events (depending on the site) and analyzed for TKN, NO2-3-N, TN, NH4-N, Organic-N, TP, and TSS. It should be noted that this section of highway had a porous friction course (PFC) applied, which had an impact on swale and filter strip performance. Mean effluent TN concentrations were lower for the swales with wetland characteristics than the non-wetland swales. No such difference was observed for TP effluent concentrations. TP concentrations measured at the edge-of-highway were low (mean <0.11 mg/L) at all four sites, resulting in poor reduction of TP EMCs by the swales and roadside filter strips. Due to the presence of a porous friction course on the highway, mean TSS concentrations from the roadway were below 32 mg/L at all four sites. Effluent concentrations of TSS from both the swales and filter strips were higher than edge-of-pavement concentrations. The swales and filter strips did not perform well using traditional concentration reduction metrics for TP and TSS; this was mainly due to the lower sediment-bound pollutant concentrations derived from the porous friction course overlay. (109)

Working with Regulators to Change Permeable Pavements Acceptance
William F. Hunt III

ABSTRACT: Starting in 1999, North Carolina State University faculty began research on permeable pavement used to infiltrate stormwater runoff, or permeable pavement. NC State conducted several studies from 1999 to 2005, all of which repeatedly showed positive performance for runoff reduction. Faculty at NC State cooperated with regulators at the North Carolina Department of Environment and Natural Resources (NC DENR) and eventually helped persuade the regulators to accept permeable pavement as a stormwater best management practice in 2006. Permeable pavement's initial "approval" was confined to the eastern, and sandier soil region, one-third of the state of North Carolina. Subsequent to the initial allowance, faculty at NC State further cooperated with staff of State Senator Marc Basnight who passed a law requiring the use of permeable pavement, or an acceptable alternative, in parking lots across the state of North Carolina. The NC Department of Transportation (DOT) has since been required to evaluate the use of permeable pavement for every sidewalk in NC DOT right-of-way statewide. This loosened the restriction for use of permeable pavement for only sandy in-situ soils. Due to the change in state policy, certain communities have embraced the use of permeable pavement, and the implementation of the product has increased substantially. One of the main reasons for this was the NC DENR's treating of permeable pavement as a mostly permeable (and partially impermeable) surface. The relationship of a university working hand-in-hand with regulators has proven very beneficial for the use of permeable pavement. (110)

Examinations of Pervious Concrete and Porous Asphalt Pavements Performance for Stormwater Management in Northern Climates
Kristopher M. Houle, Robert M. Roseen, Thomas P. Ballestero, Joshua F. Briggs, and James J. Houle

ABSTRACT: In northern climates, runoff from standard pavements has varying seasonal effects on the surrounding environment. Year-round runoff carries transportation associated contaminants into surface waters. During the winter and spring, deicing practices for pavements result in high levels of chloride-laden runoff that is both toxic to aquatic biota and degrades drinking water supplies. The use of pervious pavements for parking lots for new and redevelopment projects are one watershed-based strategy that can both mitigate impacts for new development and reverse impacts in areas with redevelopment. This study presents the findings from 2 pervious pavements, a pervious concrete and a porous asphalt parking lot, studied at the University of New Hampshire Stormwater Center. Winter in particular places great demands on pavements however it was observed that due to the well-drained nature of the reservoir base that freeze thaw was limited. Surface infiltration rates, frost penetration, degree of snow and ice cover, and surface friction were measured on a monthly basis to assess winter performance. Frost penetration was observed to reach depths of eighteen inches however, surface infiltration capacities remained in excess of 200-in/hr. Analysis of snow and ice cover and pavement skid resistance demonstrated that up to 75% less salt was needed for porous asphalt to maintain equivalent or better surface conditions as the reference dense mix asphalt lot. The annual median snow and ice surface cover for the porous asphalt lot was not significantly different than the reference lot with salt applications four times greater (p=0.749 @95% CI). The annual median weighted skid resistance for the porous asphalt lot was 12% greater than the reference lot with greater salt application (p=0.061 @95%CI). Pervious concrete did not demonstrate substantial salt reduction capabilities during storm events; however, 'black-ice' formation did not occur during freeze-thaw conditions indicating possible annual reductions. Pavement color and shading were found to be major factors influencing the amount and duration of snow and ice cover on the pervious concrete lot. (111)

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Expanding the International Stormwater BMP Database Reporting, Monitoring, and Performance Analysis Protocols to Include Low Impact Development (Part 1)
Jane Clary, Marcus Quigley, Andrew Earles, Jonathan Jones, Eric Strecker, and Aaron Poresky

ABSTRACT: Low Impact Development (LID) strategies are being encouraged throughout the country as an approach to reduce potential adverse impacts of development on receiving streams. Many questions exist regarding how well various LID strategies perform in different settings, just as similar questions have been raised regarding performance of traditional stormwater best management practices (BMPs). Over a decade ago, American Society of Civil Engineers (ASCE) Urban Water Resources Research Council (UWRRC) members worked to develop a set of standardized monitoring and reporting protocols for traditional BMPs and establish a master database for the purpose of evaluating BMP performance and the factors affecting performance. This effort culminated in the International Stormwater BMP Database (www.bmpdatabase.org), which contains data for approximately 360 BMPs and continues to operate as a clearinghouse for stormwater BMP data and performance analyses. During 2008-2009, the Stormwater BMP Database project expanded to better integrate LID into its monitoring, reporting and analysis protocols through the support of a coalition led by the Water Environment Research Foundation, the U.S. Environmental Protection Agency, the Environmental and Water Resources Institute of ASCE, the Federal Highway Administration, and the American Public Works Association.

This paper provides an overview and progress report on the LID-focused effort, including the following topics:

1. New monitoring guidance for LID studies.
2. An overview of recent changes to the stormwater BMP database to better accommodate LID studies, including LID studies at the site development level (multiple distributed controls) and individual LID techniques.
3. A summary of LID studies currently included in the database, including bioretention, green roofs, permeable pavement, biofilters and other practices. (112)

Flow Control and Water Quality Treatment Performance of a Residential Low Impact Development Pilot Project in Western Washington
Curtis Hinman

ABSTRACT: Washington State University and project partners implemented a flow monitoring project on a 3.35-hectare (8.27-acre) pilot project in western Washington (Meadow on the Hylebos) that incorporates low impact development (LID) stormwater management practices. LID practices used in the project design include bioretention swales, permeable concrete, compost amended soils, and surface flow dispersion. The primary goals of the monitoring effort are to evaluate the performance of individual LID practices and evaluate the effectiveness of integrating these practices into a stormwater management system. Continuous simulation modeling (Western Washington Hydrology Model) was used to assess peak flow and flow durations compared to stated flow control goals of the project. Flow rates for individual storms were assessed and water budgets developed that include surface and subsurface flow, infiltration and evapotranspiration in relation to precipitation inputs for bioretention swales and the project as a whole. Infiltration rates over time for the permeable concrete were also measured. (113)

Green Roof Hydrology: Results from a Small-Scale Lysimeter Setup (Bronx, NY)
Kimberly DiGiovanni, Stuart Gaffin, and Franco Montalto

ABSTRACT: A small scale lysimeter setup situated on the green roof of the Ethical Culture Fieldston School in the Bronx, NY has been the focus of ongoing monitoring initiated in June 2009. Data collected from the lysimeter setup and associated experimental equipment including a rain gage, soil moisture sensors and tipping bucket gage (for qualitative runoff monitoring) has provided the basis for the calculation of runoff and percent stormwater retention during storm events, as well as evapotranspiration (ET) during antecedent periods. Relationships between percent stormwater retention and governing factors such as total storm depth, antecedent period, storm duration etc. have been explored. Additionally, methods of estimating potential ET were compared to measurements of actual ET to examine the applicability of these approaches to green roofs. Results from the analysis of runoff and ET from the small scale lysimeter setup support the need for further research in estimating and evaluating water fluxes from green roofs as well as appropriate techniques for measuring and estimating these fluxes. (114)

Improved Standard Sumps as Best Management Practice for Stormwater Treatment
Adam Howard, Omid Mohseni, John Gulliver, and Heinz Stefan

ABSTRACT: There are many standard sumps that may also qualify as a best management practice to pre-treat stormwater runoff before it enters an LID practice by removing suspended sediment from the water column. However, no data on the effectiveness of sediment removal and maintenance schedule of the sumps exist. Such data

could justify providing pollution prevention credit for the use of standard sumps for transportation departments, municipalities, counties and other local governments. To determine whether they remove suspended sediment from stormwater runoff, two standard sumps of different size were tested in a laboratory setting. Removal efficiency under low flow conditions as well as resuspension rates under high flow conditions were determined. In the low flow removal efficiency tests sediments of known size distributions were fed at known rates into the influent pipe of a sump. At the conclusion of the test the sediments removed by the sump were collected, dried and weighed. In the high flow resuspension tests a commercially available sediment (e.g. F110 sand) was placed inside the sump, and the amount remaining after the sump had been flushed by high flows for a period of time was determined. The sumps did remove suspended sediment at low flows, but at high flows the scour was substantial. A porous baffle was designed and tested as a possible retrofit to the standard sump. Multiple configurations with varying percent open area and different angles of attack were evaluated in a scale model. An optimum configuration was then constructed at the prototype scale and evaluated for both sediment removal efficiency and sediment retention. Results indicate that, with the right baffle configuration, the scour of sediments accumulated in the sump can be nearly eliminated for flows up to the 10-year design storm runoff (as defined by an assumed watershed and slope), and removal efficiencies can be increased at Peclet numbers above 1.5. Removal efficiency functions have been developed for standard sumps and sumps retrofitted with the porous baffle. In addition, uncertainty analyses have been conducted as part of the data interpretation. The data collected show that standard sumps retrofitted with the porous baffle can be successfully used as pre-treatment for LID practices in a stormwater treatment train. (115)

Low Impact Development Benefits of Level Spreader—Vegetative Filter Strip Systems
Ryan J. Winston and William F. Hunt

ABSTRACT: Vegetative filter strips (VFS) have been employed to reduce pollutant export from agricultural watersheds for years. In order to enhance the effectiveness of VFSs, level spreaders have been employed to distribute flow evenly across the length of the upslope end of the buffer. During the past decade, level spreaders have been required in nutrient-sensitive watersheds in N.C. to reduce erosion in riparian buffers. An assessment of the performance of four level spreader – vegetative filter strip (LS-VFS) systems was conducted in the Piedmont of North Carolina. At each site, one 7.6 m (25 ft) wide grassed VFS and one 15.2 m (50 ft) wide, half grassed, half forested VFS drained highly impervious watersheds. Monitored parameters included rainfall, inflow to, and outflow from each LS-VFS system. The VFSs promoted infiltration, which resulted in a substantial decrease in flow volume and peak flow rate between the inlet and outlet of the system. To date, 58 storm events have been monitored for hydrology in Louisburg, NC. Mean flow volume was reduced by greater than 40% for both the 7.6 m and 15.2 m VFSs. Reconcentration of surface flow in the VFS was shown to substantially impair filter strip performance. These results show that a LS-VFS system can effectively reduce the hydrologic impacts of impervious surfaces. Twenty-one and twenty-two flow-proportional water quality samples were collected and analyzed for the Apex and Louisburg sites, respectively. Constituents monitored included TKN, NO3+NO2, TN, NH4, Org-N, TP, Ortho-P, PBP, and TSS. All LS-VFS systems studied significantly reduced mean TSS concentrations ($p<0.05$), with the 7.6 m buffers reducing TSS by at more than 50% and the 15.2 m buffers reducing TSS by more than 65%. Concentrations of TKN, TN, Org-N and NH4-N were significantly reduced ($p<0.05$) by both 15.2 m VFSs, while results were mixed for the 7.6 m VFSs. Significant pollutant mass reduction was observed ($p<0.05$) for all nine pollutant species analyzed at the Louisburg site due to infiltration in the VFSs. The effects of VFS length and/or vegetation type are very important for pollutant removal, as effluent pollutant concentrations were lower (with one exception) for the 15.2 m VFSs. Median effluent concentrations for TN and TP for the four LS-VFSs were better than fair water quality benchmarks for the Piedmont of North Carolina, but only met good water quality metrics in one-half of the studied storm events. (116)

Performance of Permeable Pavements in Cold Climate Environments
Jennifer Drake, Andrea Bradford, and Tim Van Seters

ABSTRACT: The University of Guelph and Toronto Region Conservation Authority have recently initiated a research collaboration to evaluate the performance of permeable pavement in cold climate environments. Permeable pavement offers a means to reduce runoff, improve water quality and minimize thermal impacts to receiving water systems. However, there is continuing concern and uncertainty regarding the long term performance of these systems. In particular the harsh winters, which occur throughout Ontario and the associated sanding and salting of roadways, have a detrimental effect on both infiltration performance and the quality of the infiltrated water. Sanding of parking facilities can clog the voids within the pavement and, in extreme circumstances, essentially render the pavement impermeable. Even if pavement facilities are not sanded or salted during winter months contaminants and fine particulate matter are still introduced through the day-to-day flow of vehicle traffic. The hydraulic performance of porous pavement can be improved and even restored if regular maintenance is performed and fines removed. Numerous permeable parking facilities, of varying ages, exist throughout Ontario but there are few comprehensive studies evaluating pavement performance within Ontario. In this paper performance issues associated with Ontario conditions will be explained and details of the collaborative permeable pavement research project will be presented. (117)

Quantification of Petroleum Hydrocarbon Residual and Biodegradation Functional Genes in Rain Garden Field Sites
Gregory H. LeFevre, Paige J. Novak, and Raymond M. Hozalski

ABSTRACT: Stormwater is known to convey oils, greases, and polycyclic aromatic hydrocarbons from impervious surfaces, and previous studies have indicated that bioretention is effective at removal of these pollutants. Concern has been expressed that such petrochemicals in stormwater could accumulate in the soil during infiltration and create "pollutant depots" in raingardens, resulting in environmental liability for the site owner. This research was performed to determine if petroleum hydrocarbon hotspots exist in bioretention areas, what factors influence petroleum hydrocarbon concentrations, and if bacteria capable of degrading petroleum hydrocarbons are present in raingardens. As a result, a field survey in the Minneapolis/St. Paul metropolitan area was conducted. Soil samples were collected from 56 raingardens and 4 upland locations and total petroleum hydrocarbons (TPH) and bacterial DNA were extracted and quantified. TPH was detected in many of the raingarden soil samples, but at low levels; upland samples were uniformly non-detect. TPH levels did not correlate to site characteristics such as catchment area or vegetation type. Functional genes levels in soil samples ranged from non-detect to 1010 copies/g soil. Overall, we observed that a substantial "toxic depot" effect did not occur, as TPH levels in raingardens were significantly below typical levels of concern. Furthermore, the ubiquity of genes indicative of petroleum hydrocarbon degradation capacity suggests that accumulation of TPH is not a major concern as petroleum hydrocarbons are likely to be biodegraded in raingardens. (118)

Site-Level LID Monitoring and Data Interpretation: New Guidance for International BMP Database Studies (Part 2)
Aaron Poresky, Marcus Quigley, Marc Leisenring, Eric Strecker, and Jane Clary

ABSTRACT: Low Impact Development (LID) performance monitoring and reporting is currently in its infancy and continues to evolve as LID practices and site designs are implemented in more communities. The majority of the currently completed or published LID studies focus on monitoring individual LID practices, such as a single bioretention cell or a single green roof. However, the primary goal of incorporating LID into developments is to affect the ways in which overall site design and implementation impact hydrology and water quality. It is this level of monitoring for which there is not currently adequate guidance or uniformity that would allow comparisons amongst LID sites. The 2009 version of the Urban Stormwater BMP Performance Monitoring Manual (Geosyntec Consultant and Wright Water Engineers for USEPA, WERF, FHA and EWRI/ASCE) has added chapters to focus on site level monitoring and to suggest approaches to assess the collective effects at this scale. The structure and functionality of the International BMP Database has also been revised to accept practice-level and site-level LID studies. LID site-level monitoring is differentiated from practice-level monitoring, and general site-level monitoring approaches are introduced with key considerations for designing a study to reach meaningful conclusions. Creative approaches to optimize study design are introduced that consider such factors as the length of monitoring period and intensity of instrumentation. Concepts in characterization of composite watershed attributes and site hydrologic characterization are introduced and discussed in the context of LID sites. Finally, methods of interpreting data to evaluate site-level performance and methods of comparing LID site performance between sites and to other BMPs are introduced. A case study is highlighted, demonstrating methods that have been employed for LID site monitoring and data interpretation. (119)

Storm Water Quality Control Volume for Southwest Region of USA
Shou-Ching "Eric" Hsu, James Guo, and Randy Fultz

ABSTRACT: The fast growth in the City of Las Vegas results in a need of innovative storm water management plans in order to comply with the National Pollutant Discharge Elimination System (NPDES) program established under the Clean Water Act. Since 2000, the EPA has recommended that all major stormwater discharges be released through water quality control facilities. This paper presents a numerical algorithm to derive the water quality capture volume (WQCV) for on-sites storm water detention designs. Tests conducted for the southwest arid climate region reveal that the WQCV curves normalized by the local average rainfall event depth may exhibit a regional similarity. (120)

Stormwater Mitigation by Living Roofs in Auckland, New Zealand
Emily Voyde, Elizabeth Fassman, and Robyn Simcock

ABSTRACT: Living roof technology is emerging as a low impact development method for stormwater management suitable for retrofit in densely developed urban centres. This paper presents results of field monitoring of a 235 m2 extensive living roof suitable for retrofit installation in Auckland, New Zealand (NZ), to quantify the extent of stormwater control. Comparison in stormwater control is made between living roofs with three different substrate types at two different depths in a side-by-side comparison. No statistically significant differences in runoff response were found between the three substrate types tested. There was no statistically significant additional stormwater benefit found when increasing plot depth from 50-70mm. The overall cumulative retention efficiency of the UoA living roof was 71.6% over the period of 23 October 2008 to 22 October 2009, where 1137.2 mm of rainfall was received. On an individual event basis, the living roof retained a median of 83.6% of rainfall received, with a

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median peak flow reduction per event of 93.2%. Living roof response cannot be linked to one factor alone; multiple parameters such as rain depth, rain intensity, climatic variables and antecedent dry days all play a role in influencing hydrologic response. (121)

Surface Temperature and Heat Exchange Differences between Pervious Concrete and Traditional Concrete and Asphalt Pavements
William Flower, Steven J. Burian, Christine A. Pomeroy, and Eric R. Pardyjak

ABSTRACT: Permeable pavement has been used successfully for many years to provide stormwater control and has recently become a common feature in low impact development (LID) projects. Recently, the potential benefits of pervious concrete over traditional impervious concrete and asphalt pavements for reducing surface temperatures, sequestering carbon, improving health of adjacent trees, and more have been identified. Isolated studies have quantified these benefits for a select few cases. Additional studies are needed to continue to expand the knowledge base of the benefits of pervious concrete beyond stomrwater management. This paper addresses this need by presenting results quantifying the impact of pervious concrete on surface temperatures in semi-arid urban environments. Surface and internal temperatures were monitored at a new pervious concrete site, an adjacent traditional concrete site, and a traditional asphalt pavement site. The results from the summer of 2009 showed a significant reduction of surface temperature at the pervious concrete site compared to the asphalt site. Interestingly, as the monitoring moved into June the traditional concrete site became shaded, providing a comparison between pervious concrete and shaded traditional concrete. The surface temperatures were very similar, leading to the conclusion that pervious concrete may serve as a UHI mitigation measure equivalent to shading of traditional concrete. The results of the surface and internal temperature monitoring of the pervious concrete were used to calibrate and validate a numerical heat flux model. The model was used to analyze the relative impact of pervious concrete aggregate selection and thermophysical properties on surface temperatures, heat exchange to the earth, and heat exchange with atmosphere. (122)

Site Design Considerations

Design of a Green Infrastructure "Retrofit" as an Alternative to Conventional Stormwater Management for a Residential Subdivision
K. E. Thomas and D. Wible

ABSTRACT: Following city approvals of a site plan and stormwater management plan for a thirty-four unit residential subdivision in Syracuse, New York, a "retrofit" of the plan was evaluated to incorporate green infrastructure (GI) instead of the conventional stormwater management (i.e. connected impervious areas and a stormwater pond) approved for the project. Based on an initial screening process, porous pavements and green roofs were identified as technically feasible GI techniques to potentially be incorporated at the project, given the dense nature of the proposed development and seasonally shallow depth to groundwater. Hydrologic simulation of the project with green roofs and porous pavements incorporated into the design indicates that the site will behave similar from a hydrologic standpoint under the developed and the existing conditions for the 1-yr 24-hr precipitation event. A constructed wetland, to be incorporated into the eastern portion of the site plan, will effectively detain more extreme events. Concerns often exist, however, with both the continued structural integrity of porous pavements in cold climates and the maintenance of surrounding groundwater quality where shallow depth to groundwater exists. Porous asphalt roads associated with the project will be constructed with a 30 in infiltration basin to provide protection of the frost-susceptible subgrade soils, and the porous bituminious top course and asphalt-treated permeable base will be elevated above the surrounding landscape to provide drainage and frost protection for these frost-susceptible courses. Porous drives and walks will be constructed with a geocell surface matrix that is less susceptible to frost damage. In combination with the dwelling green roofs, it is demonstrated that New York State water quality volume (WQv) treatment requirements and protection of surrounding groundwater quality will also be achieved. (123)

Lateral Seepage Flow between Low Impact Development Drainage Devices and the Underground Water Level
Yuan Cheng

ABSTRACT: For Low Impact Development (LID) sites, the seepage flow simulation between the underground storage devices and the groundwater level is based on potential flow equations and Darcy's law. This paper presents solutions and a computational example for the free surface of the seepage flow and for the flow rate using the Boundary Element method and the Finite Element method, respectively. The seepage flow zone and its lateral boundary can have a major impact on the adjacent properties of an LID site. The computed hydraulic head can be a factor in the embankment slope stability if the infiltration zone is under the embankment, such as an infiltration trench installed along the gutter line of the staggered bench of embankment. In addition to the computed hydraulic head, the computed infiltration rate can be beneficial to determine whether the LID devices are effectively discharging the required amount of the infiltration flow or not. (124)

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LID in Retrofitting an Ultra-Urban Transportation Infrastructure
Neal Shapiro

ABSTRACT: The City of Santa Monica's Watershed Management Program requires postconstruction Best Management Practices (BMPs) for all construction projects, both new development and redevelopment (retrofits), to reduce the amount of stormwater runoff and to improve runoff quality entering the Santa Monica Bay. While the city's watershed management program continues to promote Low Impact Development strategies for individual parcel projects, the transportation grid is a harder area to incorporate BMPs. Transportation infrastructure involves other complexities of development, such as underground utilities, changes in drainage grades, parkways, traffic flow and safety vehicle and pedestrian movement. To demonstrate the feasibility of incorporating the green transportation infrastructure with a BMP strategy in an ultra urban, built-out setting, the city obtained a state grant to retrofit a city residential street into a green street, the Bicknell Avenue Green Street Project. This Project demonstrates how an urban street can be retrofitted with a combination of BMPs. The result is an aesthetical, attractive, and more sustainable, vis-à-vis natural resources, street that can harvest up to 80% of wet weather flows. (125)

Overcoming Obstacles to LID Implementation—Tales from Silicon Valley
Mike Campbell

ABSTRACT: The San Francisco Bay Regional Water Quality Control Board's emphasis on LID has made the designing of drainage systems for new development projects considerably more challenging. Numerically-sized LID-based treatment controls require the maximum utilization of available landscaping and open space on a given development site. Site constraints, land planning, hydraulics, utilities and maintenance all come into play when designing NPDES-compliant drainage systems that incorporate LID-based treatment controls. The feasibility, and ultimately, the success of a particular treatment solution is dependent on these factors. This paper will examine the most challenging issues associated with the design and implementation of LID-based treatment, and how those issues have been addressed, using recent new development project examples from the Santa Clara Valley area. The projects include high density residential, single-family residential, big-box retail, auto dealership, recreational and community facility sites. The paper will focus on policy, design and construction issues, and will include a discussion of success stories and lessons learned from the various projects. (126)

Plant Selection for Bioretention in the Arid West
C. D. Houdeshel and C. A. Pomeroy

ABSTRACT: The Arid West is the fastest growing region of the country. Expanding development in this harsh environment brings new stormwater management challenges. Bioretention present unique engineering and ecological challenges different than more mesic regions of the country. To address these challenges, two bioretention cells are being constructed in Salt Lake City to test performance in an arid climate. Factors driving plant selection and design are expected delivery of annual precipitation as well as physiological traits of native plant species. First, expected precipitation amounts and pattern of delivery are reviewed for Salt Lake City. Second, physiological benefits and restraints of selected upland species from the area are explored to determine suitability for use in bioretention stormwater facilities. Traits examined include carbon to nitrogen ratios, rooting depth, salt tolerance, soil preferences and season of growth. This analysis is expands to evaluate precipitation patters and native plant physiology of the 4 largest population areas of the Arid West: the Great Basin (Boise, ID and Salt Lake City UT), the Colorado River Basin (Las Vegas, NV), the Salt River Basin (Phoenix, AZ), the Rio Grande Basin (El Paso, Texas), and Costal Southern California (Anaheim, CA). Timing of precipitation plays an important role in selecting vegetation in arid climates. Although annual precipitation is similar, each region experiences unique patterns of precipitation delivery and physiologically different native plants. Special consideration must be given to these local factors when planning sustainable Low Impact Development stormwater management in these harsh climates. Plant suggestions are listed for each urban center. (127)

Predicting the Feasibility of Wide-Scale LID Implementation—Accuracy of Reported Soil Characteristics in Urbanized Areas of Los Angeles County
Jason D. Wright and Stephen Carter

ABSTRACT: Most Low Impact Development (LID) style Best Management Practices (BMPs) are designed with the intention of restoring predevelopment infiltration rates to developed sites. In order for LID style BMPs to be effective underlying soils must have appropriate infiltration rates, typically greater than 0.5 in/hr. Designers tend to rely on U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) reported Hydrologic Soil Group (HSG) to estimate the infiltration capacity of the in situ soils. It is generally accepted in the design community that only HSG A and B soils are appropriate for infiltration. Infiltration rates were investigated at sites with varying land uses and impervious concentrations with HSG A, B, and C soils to support LID implementation. Surface infiltration rates were measured using the *Standard Test Method for Infiltration Rate in Field Soils Using Double-Ring*

Infiltrometer at thirty sites in Los Angeles County. Soils were also characterized in the field to a depth of ten feet and categorized by HSG. Each of the sites showed some variability in the measured surface infiltration rates due to the variation in surface conditions. Many of the sites had an urban complex or urban soils in the top 1 to 2 feet, which resulted in an infiltration rate higher than expected based on the HSG. Characteristic of many urban areas, most of the sites experienced major disturbances from construction related activities and continuing active recreation and management. Many sites had debris at the surface left over from construction causing higher than expected infiltration rates. Several sites experienced lower than expected infiltration rates due to high levels of surface compaction caused by maintenance activities, such mowing. Each of the sites had an infiltration rate greater than the typical recommended minimum infiltration rate of 0.5 in/hr. In general, areas with a less concentrated impervious configuration showed a greater likelihood that measured infiltration rates were consistent with the ranges reported by the NRCS for the respective HSGs. Many times the reported HSG in less concentrated areas were found a few feet below the surface. Areas with greater urban density were much more prone to extensive disturbance from construction. In general, the higher the level of disturbance, the more mixing of HSG's at the surface would occur. Many sites were suitable for infiltration BMPs while most would be appropriate with soil amendments near the surface including sites reported to have HSG C soils. (128)

Structural/Hydrologic Design and Maintenance of Permeable Interlocking Concrete Pavement
David R. Smith and William F. Hunt

ABSTRACT: Permeable interlocking concrete pavements (PICP) combine stormwater infiltration, detention and a riding surface for vehicles into one location. These pavements rely on an open-graded crushed stone base for storage, infiltration and vehicular support. Much research has been conducted on the hydrologic and water quality aspects. State and municipal BMP and LID manuals have incorporated design guidelines developed from university research, industry guidelines and experience by various agencies, project owners, civil engineers and contractors. This paper integrates hydrological and structural design for PICP for potential use in the emerging ASCE guidelines for permeable pavement. Hydrological analysis determines if the volume of water from user-selected rainfall events can be stored and released by the pavement base. Designer-selected parameters determine how much water infiltrates the soil subgrade and/or is carried away by subdrains. Structural capacity for vehicular loads is determined using PICP industry design charts or the American Association of State Highway and Transportation Officials (AASHTO) 1993 structural design method. This paper includes design examples using these methodologies with an example using design software. The paper includes input design considerations as well as outputs for stormwater drainage and pavement design. In addition, recent experience is summarized on surface cleaning and surface repair. (129)

Special LID Applications

Addressing an Impervious Cover TMDL through the Use of LID
Kelly Collins, Lori Lilly, and Deb Caraco

ABSTRACT: In 2006, the Connecticut Department of Environmental Protection issued an impervious cover Total Maximum Daily Load (TMDL) for the Eagleville Brook Watershed, located on the University of Connecticut (UConn) campus and the adjacent Town of Mansfield, CT. The TMDL, approved by the Environmental Protection Agency in February 2007, represents the first of its kind in the nation. While traditional TMDLs are typically target a specific pollutant, this one addresses the impacts of urban development directly by using impervious cover as the TMDL's metric. This approach was chosen because the Brook's biological impairment could not be attributed to any one pollutant. Since 5% of 303(d) listed waters in the nation are listed for "cause unknown – impaired biota," this project could set a national precedent for using impervious cover in a regulatory framework for implementing low-impact development (LID) practices at the watershed-scale. The project objective was to reduce the amount of *effective* IC in the watershed by either removing IC directly or by treating impervious cover using low impact development techniques. The project team conducted a stormwater retrofit inventory within the watershed, and identified 99 opportunities to treat or disconnect impervious cover on the UConn campus. Although IC is the "yardstick" to measure progress in this TMDL, the ultimate success will be the restoration of the biological communities in the Brook by improving the stream's habitat and water quality. (130)

Energy Independence and Security Act (EISA) of 2007: Advancing the Science and Use of Low Impact Development (LID)
N. Weinstein, S. D. Struck, and J. G. Lee

ABSTRACT: The implementation of EISA has broad and far reaching implications for advancing the science and use of LID. This paper will present the goals and objectives of this legislation and the guidelines for implementation. The discussion of implementation of the Act will provide perspectives and examples of how this will promote the use and understanding of LID by the engineering design and regulatory community. Case studies from the EISA Implementation Guidance (USEPA, 2009) will be presented in order to demonstrate the

key elements of the program and how it will promote the use of LID. The authors of the paper were both key contributors to the EPA team that developed this guidance. (131)

Green Infrastructure Optimization Analyses for Combined Sewer Overflow (CSO) Control
I. B. Neilson and D. Turney

ABSTRACT: The City of Indianapolis, IN is analyzing the means to effectively integrate green infrastructure Best Management Practices (BMPs) for multiple use urban revitalization and combined sewer overflow (CSO) management. Working independently within public right-of-way as well as leveraging multiple public-private relationships, the City looks to realize a variety of cost saving techniques that reduce the overall economic impact of the unfunded CSO reduction mandate. The authors highlight the planning tools, analytical techniques and results from the City's Green Infrastructure Optimization Analyses projects for both the Pleasant Run and the Lower Pogues Run Watersheds. The Pleasant Run watershed maintains a mixed use residential, commercial and light industrial land use base. The Lower Pogues Run Watershed is the downtown, ultra urban City center of Indianapolis. The planning tools include green infrastructure sizing studies; WinSLAMM (SCS based) modeling for green infrastructure sizing and water quality treatment; RECARGA (TR- 50 based) modeling for green infrastructure infiltrative design; maximizing public right-of-way for CSO abatement; Green Street-to-land use design optimization; and integrating economic revitalization, intermodal greenway linkage and CSO program requirements. The authors will highlight the use of compatible modeling platforms for the City's regulatory compliance based SWMM CSO model. The analytical techniques include the use of the planning tools to maximize green infrastructure abatement processes within land use categories for sub-basin or modeling catchment areas. Benefit-to-Cost (B/C) analyses are defined in the comparison to traditional store-pump-treat CSO abatement processes. The B/C analyses are utilized to define the maximum green infrastructure integrated into public right of way as well as participating private entities. The localized results are extrapolated across the each watershed sub-basin in order to determine the overall benefit for use of green infrastructure for the mix of land uses. Results from early pilot projects have set the basis for the City's long-termed planning process to maximize location, design and construction of cost effective multi-use green infrastructure corridors, including Green Street use optimization. The authors will utilize actual local stormwater, wastewater and CSO program management costs to illustrate cost effectiveness of green infrastructure technique (132)

Lakewood RainCatchers Pilot Project for Reducing Combined Sewer Overflows
R. Kirschbaum and B. Spencer

ABSTRACT: Like many cities in the United States, a large portion of Seattle's underground drainage pipe networks consist of combined stormwater/sewer systems that were designed to convey both sewage and rainfall runoff from paved surfaces, such as rooftops and roadways. These systems were not designed with adequate capacity for the demands placed on them today. With population and development in Seattle already beyond the designed system capacity in many areas, the combined sewer systems are frequently overwhelmed during large rain storms, resulting in combined sewer overflows (CSOs) into local lakes and Puget Sound. Seattle Public Utilities (SPU) is investigating various strategies for controlling these CSO events. Traditionally, large centralized detention facilities have been used to store high flow volumes during the peak of a storm, which are then released back to the system after the storm has subsided. Currently SPU is conducting a pilot project in the Lakewood neighborhood to evaluate the use of decentralized (customer-based) strategies for reducing CSOs to Lake Washington. These strategies include rain gardens and cisterns installed on single family residential sites to capture and control rainwater on-site. Hydrologic and hydraulic modeling performed for this project using InfoWorks Collection System (CS) and Western Washington Hydrology Model (WWHM) indicate that the pilot project alone would not achieve the regulatory goal of one CSO event per year in the basin. However, widespread use of cisterns and rain gardens by Lakewood residents could significantly reduce the required volume of other traditional CSO infrastructure by as much as 25 percent. This paper documents the development and evaluation of alternatives for decentralized strategy pilot studies in the Lakewood neighborhood of Seattle, Washington. To support alternative development, an array of decentralized strategies was evaluated for CSO reduction benefits, as well as potential water quality impacts to Lake Washington. (133)

Watershed Retrofit with LID

An Alternate Approach to Size Vegetative Filter Strips as Elements of a Highway LID Stormwater Management Strategy
P. L. S. Schooler

INTRODUCTION: This study aims to evaluate observed and modeled performance data to develop a design strategy to size LID vegetative filter strips for use as highway stormwater BMPs. Vegetative filter strips are uniformly graded and densely vegetated sections of open space, engineered to reduce and treat overland sheet flows primarily through infiltration. In green highway design and redevelopment, this LID technology (also classified as a structural BMP) creates functionally equivalent hydrologic landscapes. These BMPs are installed in highway right-of-way to maintain,

replicate or minimize the change in pre-development hydrologic regime and manage stormwater runoff on site therefore reducing the need for conventional drainage structures. All data in the study is measured by mass balance, a function of inflow and outflow, which are in turn functions of the drainage area, storm intensity, runoff volume, and VFS features. To this end, these factors influencing performance are further analyzed through an application of the scientific theories governing the measured parameters. Specifically, drainage area, and storm magnitude and duration, complied in design scenarios as the Water Quality Volume (acre-feet), *WQV*, are massed again to calculate the flow rate (cfs), *Q*, in an application of Darcy's Law that governs VFS mechanics and the mass balance. VFS sizing is then determined based infiltrating the *WQV*. Units are consistent with those from the collected data. (134)

Changing a Culture: Managing Stormwater Sustainably in the UK City of the Future—Learning from the USA and Australia
R. M. Ashley, R. Newman, L. Walker, and R. Nowell

ABSTRACT: In Australia, Water Sensitive Urban Design mirrors the practice of Low Impact Design in the USA and both are part of the global shift toward integrated water management. This approach has not become mainstream in the UK for complex reasons including: lack of experience of, and hence trust, in the approach; fragmented systems that prevent integrated approaches; short-termism by economic regulators; dislocations in the roles of major players; and fear of dealing more closely with the public to deliver these approaches. Three UK examples illustrate attempts manage surface water differently from traditional practice. None of the examples demonstrate any move toward fully developed LID or WSUD as a normative process, despite the three having distinctly different institutional and governance regimes. The change needed in the UK to manage water quantity and quality will require practices such as those being delivered in the USA and Australia to be implemented without prejudice. (135)

Evaluation of Low Impact Development Stormwater Technologies and Water Reuse Options for the Lake Simcoe Regions
James Li, Douglas Banting, Darko Joksimovic, and Mike Walters

ABSTRACT: In support of the efforts of the Lake Simcoe Region Conservation Authority (LSRCA) to meet its Vision for the Restoration and Protection of Lake Simcoe and its Watershed, Ryerson University conducted a study to evaluate the suitability and effect of implementation of non-conventional wastewater and stormwater control technologies, including low impact development technologies (LID) and water reuse options, within the pre-defined uncontrolled study area where conventional stormwater management practices were not feasible. The aims of the study project were to: identify opportunities for implementation of these technologies, quantify at a planning level the benefits that could be provided in terms of reduced nutrient loadings to Lake Simcoe, and ultimately provide guidance to municipalities within the watershed. Phase I compiled all the existing data and information, summarized the previous studies and projects that had been carried out to date deemed relevant to the project, and carried out a geographic information system analysis (GIS) of the opportunities for implementation of LID (based on suitability criteria such as land use and physical site requirements). Phase II carried out a more detailed study of the usage of LID identified in Phase 1 as being potentially suitable, evaluated the best combinations of LID (and their placement), quantified preliminary costs of their implementation and pollution reduction benefits such as annual nutrient loading reduction, and examined the opportunities for reclamation of wastewater and stormwater in the study area. Additionally, the effects of future development and climatic changes on the overall efficiency of promising solutions were evaluated. The modeling of the pollution reduction benefits was based on the development of hydrologic unit response functions (URF) for different land uses and LID combinations and the aggregation of these URF over the study area using GIS. The study findings indicate that the implementation of the feasible LID such as bioretention cell, rainwater harvesting, greenroof, and downspout disconnection could potentially reduce the nutrient loading from the uncontrolled study area by about 10 to 20%. (136)

From Art to Infrastructure: Designing Flow Control for Efficient LIDs
J. Fink and J. Mackinnon

ABSTRACT: Whether you call it Low Impact Development (LID), Sustainable Drainage Systems or Water Sensitive Urban Design, it's clear that stormwater management is undergoing a paradigm shift. The shift has been propelled by stakeholders who, by conventional practice, have not been heavily involved in site construction and stormwater management – architects and ecologists – leaving many consultants and engineers wondering what role their favorite reliable water management practices can and will play in stormwater management of the future. This paper is intended to help bridge the gap between some of the most celebrated, highconcept stormwater plans, and the conventional wisdom which engineers comfortably use every day. Using hydraulic modeling and real-world installation examples, this paper illustrates how the core concepts of decentralized storage and flow control employed in unique pilot demonstrations have also been used successfully in mainstream commercial, municipal and residential installations in the US and Europe. (137)

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Improving the Water Quality of Lake Tahoe One Development at a Time: Watershed LID Retrofits in the Tahoe Basin
S. L. Schuster

ABSTRACT: LID-based improvements to previously developed watersheds in the Lake Tahoe Basin are highly effective in protecting the lake's water quality. As in many places throughout the developed world, stormwater runoff in the Tahoe Basin has historically been treated as a waste stream to be conveyed, and discharged, to the lake as efficiently as possible. The pollutants, especially very fine sediment and nutrients, being washed into the lake have been largely blamed for causing a notable decrease in the clarity of Lake Tahoe's water. In 1997, the Lake Tahoe Restoration Act was passed by Congress, committing millions in federal funds to protect this national treasure. Actions taken include extensive erosion and sediment control and stormwater management projects aimed at reducing the volume, and improving the quality, of runoff reaching Lake Tahoe. The administration of this large number of similar type projects precipitated the development of standardized planning and design guidelines to help focus funding on those actions known to be most effective. Based on extensive research and experience, these guidelines are structured to provide a stakeholder-based process and the detailed evaluation of multiple project alternatives. The designs are developed by considering source controls as a top priority; followed by hydrologic controls; and finally, treatment controls. Soil and water are treated as valuable resources to be retained onsite, rather than as pollutants to be removed, bypassed, or disposed of from the system. The resulting low-impact design- (LID) based retrofit projects have shown success in improving water quality and overcoming some of the barriers to implementing LID. Examples of three LID-based retrofit projects in highly space-constrained "Old Tahoe" developments are presented to illustrate the application of Tahoe's water quality planning process and the lessons learned in implementing effective LID-based improvements. (138)

Integrated Modeling of Green Infrastructure Components in an Area Served by Combined Sewers
Robert Pitt and John Voorhees

ABSTRACT: The Kansas City demonstration project on the use of green infrastructure to minimize combined sewer overflows (funded by the US EPA and supported by a wide range of national and local agencies) will use a variety of integrated practices and modeling approaches. This extensive project will collect data before, during, and after implementation of a variety of control practices in a 100 acre test watershed, and in a parallel control site. The reduction of discharges to the drainage system during wet weather will be calculated using models and verified through field monitoring. The continuous models will determine the decreased amount of stormwater discharged for each event as the storage and infiltration facilities dynamically fill and drain over an extended period of time. (139)

LID in a Canadian Residential Brownfield Re-Development
K. Robinson, M. Poirer, A. Senevirathna, and C. Friesen

ABSTRACT: The release rates from the Currie Barracks Phase 1 re-development (brownfield site into a medium density residential site) in Calgary, Alberta are required to match pre-development flows. In order achieve these release rates AMEC developed a Low Impact Design (LID) approach to stormwater management. Some of the key issues that AMEC resolved throughout this process were the impacts of the unique climate dominated by freeze-thaw events during winter months and the impacts of freezing on infiltration facilities. The LID features used on the site use natural materials to improve water quality and attenuate stormwater flows. Engineered approaches to manage the full volumes in large rain events include rooftop rainwater harvesting for irrigation and catch basins with non-clogging weirs to facilitate distributed stormwater flow attenuation. In order to support the development application and demonstrate the performance of the stormwater design, AMEC conducted modeling using MS Excel, SWMHYMO, QHM, and PCSWMM. (140)

Low Impact Development (LID) Restoration Master Plan for Town of Centreville, MD
M. Clar, J. McCoy, and B. Stuller

ABSTRACT: This paper describes the development of a Low Impact Development (LID) Restoration Master Plan for the Town of Centerville.

The master plan is based on the results of a detailed feasibility study and addresses the following elements:

- Background
- Goals and objectives of the LID restoration master plan
- Problem identification
- Strategies and solutions
- Potential retrofit sites
- Benefits of master plan

This project is part of the overall Corsica River Watershed Restoration Action Strategy Plan which is focused on making the Corsica River the first watershed in Maryland to be removed from the Maryland List of Impaired Waters.

The goals and objectives of the LID restoration master plan, which are described in this document include:

- Use LID practices to restore hydrology:
  - restore the volume of runoff to predevelopment levels;
  - restore groundwater recharge,
  - eliminate flashy flows associated with impervious surfaces
  - reduce nuisance flooding from mid-size storms)
- Use LID practices to optimize pollutant removal from urban runoff
- Use LID practices to help reduce and/or eliminate sources of impairment coming from urban areas to Mill Stream, Gravel Run, Three Bridges Branch and Corsica river
- Specifically target improving the MBSS physical habitat index of biological integrity at the mouth of Gravel run from poor to fair or good (141)

Marketing for Behavior Change and Nutrient Reduction
J. Riggs, A. Hong, and J. Westerlund

ABSTRACT: Recent efforts in Minnesota have shown that targeted social marketing approaches result in broader implementation of behaviors that have measurable water quality benefits. We can take the lessons learned in successful water resource social marketing programs and apply them to broader audiences that will maximize the nutrient load reduction benefits. Social marketing science teaches that the barriers to change must be addressed before behaviors will be modified. Social norms, technical expertise, time, and financial limitations are the primary barriers for changing practices for water quality improvement. Voluntary implementation on a broad scale requires effective marketing to generate interest, increase demand, and change social norms. It is apparent that broad scale implementation will be necessary to achieve higher water quality standards and minimize impacts of runoff from urban, suburban, and rural areas. As comprehensive approaches to resource management are implemented, it is becoming apparent that intensive marketing is needed to drive demand for clean water. The Blue Thumb Program follows many social marketing strategies and helps the general public plant native gardens, raingardens and shoreline plantings. The goal of the Blue Thumb program is to address many of the barriers that currently prevent people from "planting for clean water." The message is carefully crafted to effectively reach its target audience. The program also leverages incentives to motivate people to act. Blue Thumb employs neighborhood parties as a strategy to change social norms. One party held in 2007 resulted in 22 raingardens. These twenty-two raingardens equates to approximately 11 pounds of Phosphorus reduction, which is directly attributed to the marketing, technical assistance, and incentives provided. Similar results were experienced in 2008 and 2009. Accordingly, we can document that effective marketing (when connected with a holistic incentive and technical assistance program) reduces pollutant loads. Today's presentation will discuss Social Marketing as a tool to promote LID retrofits for TMDL load reduction, review the Blue Thumb program as a model, and discuss the benefits of marketing for behavior change and load reduction on private lands. We show that effective water resource social marketing motivates and inspires landowners to implement nutrient reduction practices. (142)

Moving Green Stormwater Infrastructure into Seattle's CSO Control Program
Tracy Tackett and April Mills

ABSTRACT: Seattle is surrounded by Puget Sound, Lake Washington, and Lake Union all which receive wet-weather combined sewer overflows (CSOs). Seattle Public Utilities (SPU) has been working with King County for 40 years on a phased CSO reduction plan. To date, our efforts have resulted in a 93% reduction of CSO volume per year. However, we still have 90 SPU permitted CSO outfalls with 430 million gallons discharged annually. We are currently working to accomplish the goal of no more than one overflow per year for each uncontrolled CSO outfall. In the past, we have exclusively relied on intensive traditional approaches to manage these events, however for our CSO Plan update, we are incorporating green stormwater infrastructure (GSI) strategies as part of the toolbox to meet our goals. These efforts include: (1) comparing cost effectiveness of GSI alongside traditional strategies for our highest priority contributor basin; (2) rolling out a community-based incentive program for homeowners to install rain gardens and cisterns in CSO basins; (3) basin monitoring of parcel, right-of-way, and alley GSI projects to reduce sizing of traditional storage facilities; and (4) coordinating with King County to implement a pilot basin to maximize GSI for CSO control. (143)

Pierce County Paving the Way to a Greener Environment
Dawn Anderson and Al AmirZehni

ABSTRACT: The benefits of using Low Impact Development (LID) techniques to retrofit a developed site to improve instream water quality and recharge aquifers. This paper provides an overview on using Low Impact Development techniques to address these problems in a retrofit situation. (144)

Redeveloping Brownfields with LID Design
Tatiana H. Papakos, Mindy Gould, and Jack Brunner

ABSTRACT: In FY 2009, the U.S. Environmental Protection Agency (EPA) provided more than $500,000 in technical assistance for 16 Brownfields Sustainability Pilots that support activities such as the reuse and recycling of construction and demolition materials, green building and infrastructure design, energy efficiency, water conservation, renewable energy, and low-impact development (LID). Through the pilots, EPA directly assists communitities to incorporate sustainable redevelopment into the planning, design, and implementation of their brownfields projects. Three pilots that incorporate LID strategies to manage urban stormwater are discussed, including a mixed-use riverfront redevelopment in Allentown, PA; an affordable workforce housing redevelopment in Greenville, SC; and a LID parking lot for the planned Haynes Recreation Center in Laredo, TX. At the Waterfront Redevelopment in Allentown, PA, the proposed master plan includes approximately 1 million square feet (sf) of building area in an urban setting with residential, retail, and office space. LID practices incorporated at this 26-acre site include soil bioengineering techniques, naturalized detention areas with wetland vegetation, infiltration trenches with filter strips, pervious pavement, bioretention, green roofs, cisterns, and rain barrels. At the City of Greenville, a small-scale, affordable workforce housing redevelopment is planned with six detached, singlefamily houses. LID and sustainable features of the site plan include community gardens, a passive park with a plaza and native landscaping, rain gardens, bioswales, infiltration trenches, pervious paving, rain barrels, and solar panels. For the City of Laredo Haynes Recreation Center, LID practices incorporated in the design of one of the center's parking lots include pervious pavement, envirogrid geocells with flat curbs, bioretention, vegetated swales, and infiltration trenches. These projects exemplify how LID practices can be incorporated into brownfields redevelopment projects, while considering contaminated soil or groundwater constraints, to help restore urban watersheds. (145)

Reducing Phosphorus in Urban Stormwater Runoff with Low Impact Development
Jennifer Drake, Mark Randell, and Andrea Bradford

ABSTRACT: Stormwater runoff has been identified as a major source of water pollution within the Lake Simcoe Basin in Ontario, Canada. Stormwater is estimated to contribute approximately 1/3 of phosphorus (P) load within Lake Simcoe and its surrounding tributaries. The effects of stormwater on the water quality of Lake Simcoe are expected to become increasingly significant as urban development continues to expand. Traditional conveyance and end-of-pipe stormwater management is no longer achieving the desired standard of watershed management within this area. Low impact development (LID) is emerging as a possible alternative which may allow hydrologic and environmental objectives to be achieved. LID practices can greatly reduce urban runoff, restore more naturalized hydrographs, and delay costly replacements of aging infrastructure. However the effluent of some LID practices, such as bioretention or green roofs, may have higher concentrations of P. Even so the reduction in overall urban runoff rates due to LID infrastructure may result in a net-decrease P loading. A study to quantify the extent to which P loading may be reduced through the introduction of LID techniques in selected urban drainage areas within the Lake Simcoe Basin is currently underway at the University of Guelph. Urban catchments in the East Holland Subwatershed will be utilized for the investigation. Several LID scenarios comprising different combinations of LID practices (e.g. porous pavement, green roofs, bioretention) will be assessed. The analysis will be based on ranges of runoff volume reductions and effluent P concentrations attributed to various LID techniques in the literature. P loading reductions achievable with various combinations of LID practices will be quantified using water and mass balance approaches. This paper provides an outline of the preliminary methodology and will demonstrate an application of the mass-balance model. (146)

Thornton Creek Water Quality Channel: From Parking Lot to Channel Headwaters
Greg Giraldo, Melanie Davies, and Sarah Preisler

INTRODUCTION: The Thornton Creek Water Quality Channel project is part of a larger City of Seattle strategy for transforming an urban center's underutilized, auto-oriented office/retail area into a pedestrian-focused development with an emphasis of restoring a degraded surrounding environment. The project site was a 9-acre abandoned parking lot with a 60-inch underground drain pipe carrying base flow to Thornton Creek and conveying stormwater run-off from several commercial developments, city streets, and Interstate 5. Three separate issues were addressed by this project: Improving the stormwater quality to benefit downstream habitat; providing public open space and pedestrian connectivity to major transit hub; and, developing the project site in a way that promotes surrounding economic development. By partnering with private developers the City was able to move development forward using a smarter approach to growth and development. The project created a water-quality treatment channel within a three-acre parcel. The solution was to treat urban stormwater runoff on a scale not previously attempted, using basic treatment principles. The team of civil engineers and landscape architects, modified the traditional vegetation palette of grasses to assure biodiversity and high-performance pollutant capture while combining the hydraulics of a natural stream with the urban design elements focused on the pedestrian experience. (147)

Using the Hydrologic Footprint Residence to Evaluate Low Impact Development in Urban Areas
Chandana Damodaram, Marcio H. Giacomoni, and Emily M. Zechman

ABSTRACT: Urbanization adversely impacts the health of a watershed and the receiving water body, as increased runoff volumes, velocities, and peak flows cause erosion, flooding, and degradation of ecosystem habitats. Low Impact Development (LID) strategies are used to mitigate the impacts of urbanization by reducing the runoff at the source and restoring the natural hydrologic flow regime. Rainwater harvesting, permeable pavements and green roofs may be placed in urban areas to mitigate the runoff generated from rooftops and parking lots. This study simulates and evaluates the placement of these LID strategies for an urban watershed on the Texas A&M University campus. A conventional metric, the peak flow, is used to evaluate the hydrologic performance of LID, in addition to the Hydrologic Footprint Residence (HFR), which is a new metric that captures the inundated areas and duration of floods in downstream reaches. The results indicate that HFR can be used to evaluate the hydrologic performance of LID as it captures both changes in runoff volumes and the duration of flooding to represent the impacts of urbanization. (148)

Watershed Functions as the Basis for Selecting Low Impact Strategies Case Study: The Tryon Creek Headwaters Development
Tom Liptan, Amin Wahab, and Casey Cunningham

ABSTRACT: The Headwaters Development at Upper Tryon Creek Watershed transformed a derelict site, piped creek, brownfield, degraded wetland, and poor transit into a sustainable development that "gives back" to its neighborhood and watershed. The 2005 Fanno/Tryon Creek Watershed Plan calls for approaches that help return natural elements to the built environment. The Tryon Headwaters Project achieves watershed functions and economic development with creek and wetland restoration, restored habitat, improved creek hydrology and water quality, reduced urban heat island and energy consumption, increased property values, new market rate and affordable housing, property tax revenues, and improved transit for pedestrians, cars and bikes. The project design focused on the application of vegetative stormwater management strategies such as ecoroofs, stormwater planters, and raingardens to accomplish comprehensive stormwater management and other benefits. This project was a private/public partnership and included significant redevelopment and retrofitting on private property and public right-of-way. This presentation will cover planning, design, construction, monitoring and O&M of this project in the context of an urban watershed. (149)

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