**Monday Program**

**13:00 - 13:20 | Welcome, Introduction, and UWRRC Award**

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|  | * Scott Struck, EWRI President * Dwane Jones, Conference Co-Chair * Meghan Hazer, Conference Co-Chair * Neil Weinstein, Conference Technical Program Chair * Brian Parsons, Director, EWRI |

**13:20 - 14:40 | Opening Plenary - Past, Present, and Future of LID**

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|  | **Larry Coffman**,  Past Deputy Director, Prince George's County Department of Environment (retired) |
|  | **Mami Hara**, Director of Seattle Public Utilities |
|  | **George S. Hawkins**, Esq., Founder and CEO, Moonshot LLC and Moonshot Missions |

**14:50 - 15:00 | Welcome & Introduction to Session 1-1 and 1-2**

**15:00 - 16:10 | Sessions 1-1 & 1-2**

**Session 1-1**

**The Green Revitalization of East Baltimore: Broadway East Greenprint Project**

* Kelly Lindow, CityScape Engineering
* Doris Minor-Terrell, New Broadway East Community Association
* Audrey Seiz, American Communities Trust, Inc.
* China Boak-Terrell, American Communities Trust, Inc.
* Scott Goldman, The 6th Branch

Baltimore’s Broadway East neighborhood covers approximately 220 acres in the Baltimore Inner Harbor watershed. Approximately 80 acres of land in the neighborhood is vacant -- the result of a half century of disinvestment, suburban flight, abandonment, and urban blight that compounded upon itself. An Amtrak rail line that runs along the neighborhood’s southern boundary has formed a barrier to the neighborhood, isolating wealth and investment to the south and poverty to the north. Despite the high proportion of vacant land, the neighborhood has a lack of greenspace. Studies have recorded temperatures in Broadway East and similarly disinvested neighborhoods nearly 6-degrees hotter in the summertime than the City-wide average temperature, which can be directly correlated to a lack of tree canopy and excessive amounts of impermeable pavement. Recently; however, there has been a resurgence of development interest in the Broadway East neighborhood. This includes renovations of the historic landmark American Brewery Building, Hoen Lithograph Building, Baltimore Pumphouse and several housing redevelopment projects.  
  
The extent of vacant land presents a unique opportunity for urban green infrastructure to support future redevelopment projects in Broadway East. The 6th Branch, a Baltimore-based non-profit organization that works to transform vacant lots into community green spaces, is working in partnership with The New Broadway East Community Association, Inc. (NBECA) and American Communities Trust, Inc. (ACT) to develop a Greenprint Master Plan for the neighborhood. Vacant lots will be mapped, assessed, and evaluated for greening and development opportunities. Opportunities for green-streetscape improvements and connections will also be considered. Priority project sites will be identified based on critical neighborhood hot spots for stormwater management and input from community residents regarding their priorities for creating open space. Four (4) greening project prototypes will be developed for streamlined implementation at the priority sites. Developing the Greenprint will also provide the community, developers and non-profit organizations with a shared guide for open space redevelopment within the entire Broadway East neighborhood.  
  
Concurrently, NBECA and ACT are developing an urban ecological and public art trail that integrates streetscape and open space planning along the Amtrak rail line to transform dark, unwelcoming overpasses into vibrant, green links that connect Broadway East and its neighbor to the south through artistic lighting, artwork, and greenery.  
  
These community-centered and community-led planning and design efforts serve to fuel future projects that add value to neighborhood open spaces; spur economic development; support watershed and bay protection efforts; connect neighboring communities; and beautify a neighborhood. The overarching goal is to create a comprehensive, community-driven approach for environmental improvement and sustainable stewardship, while promoting viable redevelopment and investment in the historic Broadway East neighborhood.

**Leveraging Watershed Planning for Health and Equity in Baltimore**

* Meghan Hazer, Baltimore City Department of Public Works
* Mark Cameron, Baltimore City Department of Public Works

Watershed Assessments performed to satisfy the requirements of Municipal Separate Storm Sewer Systems (MS4) permits typically focus on an analysis of the physical conditions within watersheds. These assessments represent a critical step in the planning process, as the types of data included ultimately will be used to inform decisions that shape the built environment for years after.  
  
Research has demonstrated that the built environment is a critical factor affecting human health outcomes. Public health practitioners working to address health disparities recognize the significance of this research, but do not have the ability to directly modify the built environment. The field of public health has formally recognized the value of collaborating with design and planning professionals, who are able to implement projects that modify the built environment, in order to add a health and equity lens to planned work.  
  
The mandated nature of watershed restoration activities creates an opportunity to leverage existing planning processes to support human health alongside environmental quality initiatives. This is particularly important in densely populated, highly urbanized watersheds.  
  
In the City of Baltimore, historical inequities drive systems of risk that contribute to and exacerbate broad human health disparities across small geographic areas. In 2019, Watershed assessments for the City of Baltimore took a unique approach. Data on health-supporting environmental factors relevant to watershed restoration activities and socio-economic and racial equity factors were integrated into a multitiered analysis in addition to the physical watershed characteristics typically considered. This analysis was used to generate a series of prioritization maps, which will be used in the planning of future watershed restoration work.  
  
This presentation will describe the methods and rationale for identifying relevant data, the process for integrating this data into the analysis of watershed conditions and opportunities, and how the results will be used to guide future watershed restoration work and engage non-traditional partners. Examples will be provided for how this process might be adapted and utilized for other planning initiatives. Critical gaps and opportunities for future work will be identified.

**Sligo Park Hills Neighborhood Retrofit Project - Ups and Downs in Retrofitting and Older Suburb with Hilly Terrain**

* Pamela Rowe, Montgomery County, MD DEP
* Daniel Sheridan, Montgomery County, MD DOT
* Kit Gage, Friends of Sligo Creek

Authors: Pamela Rowe (Montgomery County, MD DEP), Daniel Sheridan (Montgomery County, MD DOT), Donna Evans (Montgomery County, MD DEP), Kit Gage (Sligo Park Hills) Pamela.Rowe@montgomerycountymd.gov 240-876-2994  
  
The Sligo Park Hills neighborhood of Montgomery County, MD is an inner ring suburb of Washington DC, developed during the late 1920’s through the 1940’s. The hilly neighborhood has an extensive tree canopy, and contained very little drainage infrastructure. The streets were scheduled for repaving, with DOT plans on the table to install a traditional storm drain system as part of the roadwork. The neighborhood has direct connections to Sligo Creek, an urban watershed with a long history of stewardship and restoration activities, and a very active watershed group, with prominent members residing in the community. The community successfully advocated for taking an approach to the road project in keeping with local and State stormwater retrofit goals of implementing Environmental Site Design to the Maximum Extent Practicable, known locally as ESD to the MEP. If it could be done here in a very challenging topographic area with numerous space constraints in the ROW, then it could be done anywhere (perhaps?).  
  
The Upside: An ambitious effort and partnership between the Montgomery County Department of Environmental Protection (DEP) and Dept. of Transportation (DOT) was undertaken to try to squeeze in as many retrofits as possible in order to test the concept and retrofit approach for ESD to the MEP in the public street ROW, while attempting to meet the community’s desire to avoid extensive delays to the road project. Close work with community members, a flexible design and construction process, and an adaptive approach led to project success. The creative retrofitting of the neighborhood achieved multiple goals, with many co-benefits including aesthetic and practical enhancements to the streetscape. The project achieved its entire WQv treatment volume goal, and over 60% of the ESDv (CPv) goal, despite ROW utility, tree and slope constraints. Working with property owners to implement RainScapes projects on private residential lots provided a stormwater knowledge base and positive relationships in the community that contributed to project success and can provide a blueprint for success in other communities.  
  
A total of 77 ESD BMPs were installed throughout the street ROW in the community, treating 47 acres of DA, including 16 acres of impervious area. Treatment practices include Filterra tree boxes, PaveDrain Permeable Paver parking pads (with and without RainStore), Stepped Bioretention, FocalPoint Gabion storage, and Rain Gardens.  
  
The Downside (though with some tangible benefits): We all know maintenance matters, and maintaining the numerous ESD practices throughout the neighborhood, several of them utilizing retrofit practices/products new to the County at the time, has provided “lessons learned” for DEP and contributed to developing adaptive management strategies and new ESD BMP maintenance operation approaches, including PaveDrain maintenance approaches, and a new look at planting strategies.  
  
This paper will include before and after drainage area treatment and BMP analysis, cost data, and a report of numerous lessons learned from the County team and community perspectives.  
  
**Green-Grey Infrastructure-based Water Security Framework: A Socio-Ecological Equity Model for the City of Baltimore**

* Kazi Tamaddun, University of Virginia
* Lawrence Band, University of Virginia
* Garrick Louis, University of Virginia
* Charles Vörösmarty, City University of New York

The successful management of a sustained and resilient urban water system largely depends on how the surrounding eco-hydrological processes are managed and how the patterns of socio-economic and political development shape each other in a dynamic context. Urban water systems have been primarily designed to divert and store surface and groundwater to meet the demand for drinking water, treat wastewater, and to manage the flow of stormwater and other forms of runoff in order to minimize their adverse impacts on the built and natural environment. These services have historically been provided independently of each other by brick-and-mortar ‘grey’ infrastructure, which is highly capital intensive and exerts a sizeable footprint on the urban landscape. However, water resources also provide a wide variety of complementary ecosystem services as well as having intrinsic value to local, diverse populations. Such dimensions of water resources are seldom examined and often ignored within the scope of water resources policy, planning, and management. This contributes to missed opportunities to leverage complementary ecosystem services, or so-called, ‘green infrastructure,’ in the management of water resources. It also creates unnecessary social inequities through the marginalization of the value placed on water resources by certain socio-economic and cultural groups. Hence, there is a need for tools and frameworks that enable and promote interdisciplinary collaboration to develop resilient water systems that are not only reliable and productive in future uncertain climate conditions but are also capable of minimizing risks to the people and their surrounding environment, while conserving and restoring ecosystem functions in a manner that is equitable to all users in society. This work presents a unified framework for designing a coupled green-grey infrastructure (GGI)-based water management system that contributes to water security (by protecting source water and treating and recycling waste- and stormwater), sustains associated ecosystem services, and promotes socio-economic equity within different public policy contexts. The key features of the framework include a system with a scalable spatial boundary with causal connections, trade-offs, and feedback loops that can help a system to adapt to a wide range of socio-economic and hydro-climatic uncertainties. As a case study, the proposed GGI-based framework is demonstrated for the city of Baltimore to illustrate the dynamic interactions among the different sectors of the water resources management framework during a simulated period spanning from 2020 to 2099.

**Early Treatment of pervious concrete with carbonate laden waters**

* Nara Almeida, Lamar University
* Liv Haselbach, Lamar University

The use of magnesium chloride deicer on pervious concrete may be harmful to its mechanical properties. However, carbonation of the cementitious materials might increase its resistance to MgCl2 attack. Previous studies evaluated the efficacy of using carbonate laden water, specifically sodium bicarbonate solution treatments on pervious concrete, to accelerate the carbonation process and perhaps increase the material’s resistance to MgCl2 impacts. In this paper, 43 pervious concrete cylindrical specimens were subjected to 2 5-day treatments with either a 3.3% concentrated NaHCO3 solution or tap water, as a control. After treatment the compressive strength, elastic modulus and ductility, were tested. For half the specimens these mechanical property tests were tested a few days after treatment, and for the other half the tests were conducted two months later. Therefore age after treatment became an additional independent variable. The NaHCO3 treatment seemed to decrease the early tested specimens’ compressive strength, but the same type of treatment appears to increase the material’s compressive strength values, if tested 2 months later. No statistically significant changes in elastic moduli or ductility were noted. These results might imply that the sodium bicarbonate treatment may need to be combined with a natural carbonation or aging process, even after the treatment application, in order to be effective in terms of gain in compressive strength, but more research is needed, especially in order to verify the effectiveness of the treatment with respect to the resistance to MgCl2 deicer attacks.

**Session 1-2**

**When Maintenance Drives Design - Collaboration in Philadelphia and NYC**

* Robert Woodman, ACF Environmental

Over a period of 25 years, the City of Philadelphia "Green City-Clean Waters" program is seeking to manage 10,000 acres of impervious area including 2,500 miles of streets through the implementation of a variety of low impact development and green infrastructure BMPs.  
  
The City of Philadelphia has emerged as a national leader in the implementation of urban green infrastructure. What makes this program unique and what drives the success of the program is two fold: effective collaboration and the voice of maintenance has a seat at the table and helps drives design.  
  
Since the beginning of the program, not only have the capital costs of GI been understood but an awareness of the long term cost of ownership has also been evolving. From weighing sediment to timing rates at which BMPs take to clean and the frequency of cleaning - Philadelphia have a long term plan for the Green City - Clean Waters.  
  
This presentation will highlight the Philadelphia program and the presence of collaboration, but will also provide an overview of recent updates to the "green inlet filter" BMPs that ACF developed in collaboration with the Philadelphia Water Department. While the products will be shown, the focus of the message is that "without the voice of maintenance at the table, no one in design would have ever known that improvements were needed to these filters". The safety of maintenance personnel during maintenance and the effectiveness of maintenance were brought forward to design and the BMP designs were modified and upgraded to address these concerns.  
  
The upgrades create improved performance and longevity of the filters themselves, but improve safety of crew, simplify the maintenance process, and create overall savings in the cost of owning these simple green inlet filter BMPs.  
  
Beyond Philly, this presentation will highlight some more recent collaborative work in NYC DEP GI program and a variety of challenges that are being researched to improve the performance and ease of maintenance of ROW bioswales and infiltration basins.

**Field Studies on Innovative Urban Retrofit Stormwater Control Measures**

* Blake Guangyi Wang, University of Maryland
* Hamidreza Rezaei, University of Maryland
* Allen Davis, University of Maryland

Stormwater Control Measures (SCMs) are an integral part of the solution to reducing urban nitrogen (N) and phosphorus (P) discharges from stormwater. Two field projects in Maryland have been recently installed with media and design conditions optimized for enhanced N and P removal.  
  
The Davis Avenue Outfall Stabilization project is located in a residential community with an overall drainage area of 2.9 hectares. A water quality plunge pool is used with a high flow treatment media. The media was synthesized using 10% (by volume) water treatment residual s (WTR) and sand to provide enhanced phosphorus removal. Two facilities at Fairland Regional Park are treating impervious parking lots. Bioretention designs consist of three layers. The first layer is installed for vegetation establishment and growth. The second layer is an enhanced P removal layer employing a mixture of sand, WTR, limestone and added aluminum chlorohydrate solution. The bottom layer includes an internal water storage (IWS) zone for denitrification.  
  
Inflow and outflow stormwater runoff and water quality at both research sites are monitored using automated samplers, a rain gauge, and Thel-Mar volumetric and/or vee-notch weirs. Work at Davis Avenue began January 2019; that at Fairland Park, December 2019.  
  
The overall goal of the projects is to evaluate the performance of the designed SCMs under field conditions. Influent and effluent samples are monitored for pH, total suspended solids, total phosphorus, total dissolved phosphorus, total nitrogen, ammonium, nitrate, and total and dissolved Al, Cu, Fe, Pb, and Zn. In both projects, the SCMs show promise for phosphorus and phosphorus species removal. Nitrogen removal appears to vary between the SCMs, likely due to the different designs.

**Cloudburst Green Infrastructure for Resiliency in New York City**

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| * Pinar Balci, New York City Department of Environmental Protection * Alan Cohn, New York City Department of Environmental Protection * Paul Wojtal, New York City Department of Environmental Protection | * Dahlia Thompson, Hazen and Sawyer * Liza Faber, Hazen and Sawyer * Patrick DeLong, Hazen and Sawyer * John Brock, New York City Department of Environmental Protection |

The New York City Department of Environmental Protection (DEP) owns and operates one of the largest wastewater and stormwater collection systems in the world which include a combined sewer system and a separate sewer system; of which both contribute to the water quality of surrounding waterbodies. The performance of DEP’s programs and critical infrastructure is affected by prevailing weather patterns (e.g., rainfall, temperatures, extreme storms, tidal elevations, etc.) and after Superstorm Sandy, resiliency has been at the forefront of innovation, restoration, and future planning in New York City’s ultra-urban environment.  
  
In addition to other standard programs to combat climate change and increase resiliency, DEP initiated a study of infrastructure to address intense rainfall management, called the Cloudburst Resiliency Planning Study. The Cloudburst Resiliency Planning study analyzed data related to rainfall and made recommendations to incorporate the analysis into future climate change resiliency planning initiatives in a focus area of Southeast Queens. The City has embarked on a multi-billion dollar investment to construct a comprehensive storm sewer system for the area and pilot programs to improve resiliency by optimizing green and gray infrastructure to handle cloudburst events that provide solutions to local flooding issues.  
  
Cloudburst green and gray infrastructure uses innovative and proven technologies to manage stormwater runoff during high intensity rainfall events. It is supplemental to the existing storm sewer systems and focuses temporary storage of storm water to intended locations where it has minimal impact to the community. The cloudburst pilots aim to provide an increased level of service and provide relief to the sewer system during periods of stress and compounded downstream issues.  
  
New York City has chosen pilot project locations that focus on retrofits of public right-of-way and city-owned property to increase storage for runoff and provide community co-benefits. The approach to the design of the cloudburst infrastructure is two pronged: identify and pilot solutions and technologies proven internationally but uncommon to NYC, and modify standard NYC solutions to be optimized for high intensity rainfall events. One of the pilot projects is located on South Jamaica Houses, a New York City Housing Authority (NYCHA) campus comprised of eight city blocks (9 acres) and housing approximately 3,000 residents. The process to identify the chosen infrastructure included design charrettes with NYCHA residents, community leaders, city agencies, and other stakeholders, and extensive community outreach and coordination. The result of this effort was to identify features and solutions that incorporated community desired spaces and uses while also serving as public education on the impacts the infrastructure and construction might have.  
  
The design of the infrastructure includes surface and subsurface features that will keep runoff in smaller storm events underground and out of the way of the community, but will provide resiliency in larger, more intense events. The cloudburst pilot at South Jamaica Houses has the ability to be expanded to other areas on the NYCHA campus and within the community if successful.

**valuating pollutant concentrations in urban streams for watershed-wide green stormwater infrastructure improvement**

* Manish Venugopal, University of North Carolina at Charlotte
* Nicole Barclay, University of North Carolina at Charlotte

The increase in impervious surfaces accompanying urban development in the recent decade has resulted in greater volumes of stormwater runoff and pollutant loads flowing downstream to receiving waters. In response, green stormwater infrastructure (GSI) practices in urban areas have become recognized solutions. Now, there is a continual need to assess the impact and performance of these GSI practices on a watershed level. These assessments will aid in decision-making for improved efficiency and for strategic placement of future GSI measures. This work contributes to addressing the assessment need by evaluating the pollutant concentrations and loads in receiving streams within the urbanized watersheds of Charlotte, North Carolina. Temporal and spatial relationships are explored with several variables; time, precipitation, impervious cover throughout watersheds, and GSI distribution and characteristics. Exploring and analyzing these relationships help in understanding the variations in the pollutant concentration in streams with respect to the impervious cover and GSI cover in watersheds. Overall, this work contributes to the growing need for improving efficiencies in design and maintenance of stormwater systems.

**LID in a Desert City: Design experiment of hydro-ecological performance evaluation for biodetention details in Phoenix, Arizona**

* Chingwen Cheng, Arizona State University
* Paul Coseo, Arizona State University
* Amanda Trakas, Arizona State University
* Kristian Kelley, Arizona State University

Green infrastructure (GI) design used for stormwater control has been widely studied in temperate and wet climate in cities such as Seattle for decades yet little research has been done in hot and arid environment (Sanchez 2019). Cities in the Phoenix metro area in recent years have recognized the potential multiple benefits of GI and developed design guidelines. However, one of the challenges for implementation is due to a lack of supporting evidence for alternative practices (McPhilips and Matsler 2018). To understand GI’s hydrological performance and landscape design applications, the Hydro-GI Lab at The Design School collaborated with Flood Control District of Maricopa County (FCD) and conducted a field design experiment on FCD’s Durango Campus. We aim to answer two key questions: 1) how effective does GI biodetention design control stormwater flow infiltration in hot and arid environment? 2) how do native plants perform within GI stormwater design in Phoenix metro area? Three repeated samples of three different stormwater biodetention basin design details with identical planting design were installed and examined with three details: 1) Standard Basin with no soil amendment, 2) Water Harvesting Basin with 4 inches of mulch, and 3) Biodetention Basin with 16 inches of amended soils. Monthly experiments to measure infiltration rates and canopy volume were performed from June to December 2019. The preliminary results show promising trends of increased infiltration rates and stormwater holding capacity with additional soil amendment. Since native soil in the valley is clay-rich and not well drained, adding sand and organic matters can improve its infiltration and increased soil water capacity. This pilot GI stormwater design experiment demonstrated the positive effects of using landscape design strategies in managing stormwater onsite. The findings can help to inform urban design and GI policy-making to allow alternative stormwater design using nature-based solutions in hot arid regions.

**16:10 - 16:15 | Welcome and Introduction to Session 1-3 and 1-4**

**16:15 - 16:45 | Sessions 1-3 & 1-4**

**Session 1-3**

**Detroit’s Learning Curve with New Stormwater City Ordinance**

* Palencia Mobley, PE, Detroit Water and Sewerage Department
* Lisa Wallick, PE, Detroit Water and Sewerage Department
* Sarah Stoolmiller, Detroit Water and Sewerage Department

As part of compliance with the Detroit Water and Sewerage Department’s (DWSD) National Pollutant Discharge Elimination System (NPDES) Permit, the City of Detroit passed its first Post-Construction Stormwater Management Ordinance (PCSWMO) in November 2018. Up until the passage of this ordinance, developers in Detroit had no obligation to manage stormwater and instead directed runoff into the combined sewer system. Shifting developers focus to now include dedicated space to manage stormwater has allowed the opportunity for designers, developers, and DWSD engineers to work together and identify if there is room for innovative, low impact design alternatives based upon existing site conditions. Analyzing trends from the first year of the PCSWMO being active, DWSD is now better aware of designers’ level of understanding regarding the use of required design standards. DWSD has also determined that the ordinance would be more effective if performance standards and alternative compliance were defined outside of the ordinance itself in order to allow updates that will maximize economic viability of a project and stormwater management on each individual development site.  
  
To aid local developers and engineers in complying with the new regulations, DWSD published a Stormwater Management Design Manual. The design manual outlines design standards that must be used, such as NOAA Atlas 14 rainfall data, a 5-minute time of concentration, and hydrograph routing to find required storage volumes. These standards were uncommonly used practices by many local designers, creating a learning curve both for DWSD to understand designer needs and for designers to begin implementing these standards. Compounding the issue of understanding the design standards, much of Detroit is covered in clay soils. As such, city engineers and local designers have to work closely together to find functional and economical ways to meet the new retention standards. In the first 12 months of Detroit’s PCSWMO coming into effect, it became apparent that the performance standards and alternative compliance methods needed to be revised.  
  
When the stormwater ordinance was first introduced to the City Council, performance standards and alternative methods of compliance were outlined specifically in the ordinance language. Many municipalities do not use this approach and instead reserve the local ordinance to state the stormwater regulations and outline the performance standards in editable documents, avoiding the need to amend the ordinance when standards need editing. Based on developers’ feedback, DWSD realized that there were performance standards, which were unnecessarily hard to meet for some developments. Complicating this, the ordinance language did not allow enough flexibility for additional creative alternative compliance methods that could alleviate these performance hurdles without sacrificing the intent of the ordinance. One obstacle found with the PCSWMO included the definition of the regulated area held to the compliance standards. In the first year of the ordinance, regardless of the size of the new or redeveloped area, the entire site had to be managed for the flood control standards. This meant any site above 5 acres had to manage the 100-year 24-hour storm for the entire development site, regardless of what impervious area was on the site prior to the ordinance enactment. This can create unrealistic and unattainable scenarios when constructing or adding to a facility, such as on a college campus site. One application included a 1-acre improvement project on a 78-acre college campus, which would require the entire 78-acres provide flood control for the 100-year 24-hour storm. Meeting the retention of the 90th percentile storm requirement has posed another obstacle for developers, specifically when contamination is present in soils, which is very common in the City of Detroit. Under the original version of the PSCWMO, the only two options for site’s in this situation would be 1) to pay an In-Lieu fee or 2) manage an equivalent volume of stormwater on another site within the city limits. This is cost prohibitive for many projects. To allow for an on-site management option, DWSD is working towards allowing an extended detention in lieu of the retention requirement. With this option, the 2-year 24-hour storm is required to be detained for 48 hours, as opposed to 24 hours.  
  
As of January 2020, the City of Detroit has made some needed edits to the PCSWMO and is awaiting the City Council’s review and approval. DWSD has proposed ordinance updates that will remove performance standards from the ordinance and incorporate them more fittingly into the Design Manual. With this, DWSD will have the capability to amend performance standards when other local and/or state laws change, the City of Detroit’s NPDES and MS4 permits are updated, and as climate change affects parameters such as rainfall frequency and intensity. With the passage of the PCSWMO in Detroit, it was made very clear how important it is to create laws with a triple bottom line approach. While the City is working on eliminating combined sewer overflows, DWSD does not want the stormwater regulations to be unattainable or discourage local businesses from pursuing redevelopment or expansion projects.

**Evaluating co-benefits at the planning level using the four C’s: Community, context, connectivity and canopy**

* Katie Spahr, Colorado School of Mines
* Elizabeth Gallo, Colorado School of Mines
* John McCray, Colorado School of Mines
* Terri Hogue, Colorado School of Mines

Co-benefits, or ancillary positive outcomes related to the installation of stormwater control measures (SCMs), provide practitioners with an additional selling point for green stormwater infrastructure programs (GSI). Leveraging the broad-ranging impacts of co-benefits can help garner pubic support and open up inter-department funding opportunities for GSI programs. From the practitioner perspective, the more co-benefits identified and linked to SCMs the better. To investigate which co-benefits can be attributed to which SCMs we performed a critical review of the literature. Co-benefits were divided into two categories: decentralized hydrologic process benefits and vegetation-based benefits. Hydrologic-based benefits were found to be easier to quantify and optimize using stormwater modeling approaches. Vegetation-based benefits were found to be dependent on the four C’s (community, context, connectivity, and canopy) of a design sewershed. Using an example in the Berkeley neighborhood of Denver, CO, this study shows how spatial analysis of the larger urban green infrastructure (UGI) in a neighborhood can affect which co-benefits are accrued. Initial results find that, by area, GSI contributes approximately 15% of UGI in the Berkeley neighborhood. To leverage and enhance existing vegetated systems, we advocate that cities include an assessment of the four C’s in their GSI planning process to maximize benefit outcomes.

**Analysis of Green Infrastructure Practices on Urban Runoff and Groundwater Storage Enhancement using HSPF**

* Keyvan Asghari, Utah State Univ. (visiting scholar) and Isfahan Univ. of Technology
* Iman Setayeshfard, Isfahan University of Technology
* Richard Peralta, Utah State University

Careful management and distribution of runoff aids sustainable urban development. Conventional runoff management generally employs grey infrastructure and sewers to convey the stormwater quickly to safe places. Such practices often increase peak runoff, reduce infiltration and percolation to groundwater storage, and degrade the environment. As a low impact development (LID) alternative, Green Infrastructure (GI) can provide better environmental, social, and economic consequences. After validating an existing calibrated Hydrologic Simulation Program-FORTRAN (HSPF), we predict hydrologic consequences of implementing GI practices in Salt Lake County, Utah. For this intermountain valley urban watershed, we compare predicted groundwater recharge, runoff and stream flow for current and alternative GI land uses. Results will aid decision makers in policy deliberations.

**Session 1-4**

**Highway Stormwater Management Using Vegetated Compost Blankets: Preliminary Results and Future Work**

* Erica Forgione, University of Maryland
* Allen Davis, University of Maryland
* Ahmet Aydilek, University of Maryland
* Gar Felton, University of Maryland

In an attempt to address more stringent regulations for the hydrologic and water quality impacts of highway stormwater runoff, the National Cooperative Highway Research Program (NCHRP) is seeking novel ways to mediate stormwater issues. One new potential Stormwater Control Measure (SCM), a Vegetated Compost Blanket (VCB) is a loose layer of seeded compost placed on an established slope. VCBs could be a sustainable and affordable way to manage stormwater runoff on highways, made of a renewable resource and requiring no construction. While compost blankets have been used effectively as an erosion control method in steep areas prone to stormwater erosion (such as highways) and compost has been used as an amendment in various stormwater SCMs, the effectiveness of VCBs as a primary SCM has not been fully evaluated. The goal of this study is to document the effectiveness of VCBs as a stormwater treatment and to develop design suggestions for future use in highway applications in regions across the country.  
  
In determining the VCB’s effectiveness, runoff volume reduction and water quality improvement constitute the focus of an in-depth VCB study including complimentary greenhouse and field experiments. Contaminants of concern monitored in this study include Total Suspended Solids, nutrients (N and P), and heavy metals, which may be removed or released via various processes through the VCB. Experimental design parameters include variable slopes, drainage areas (runoff flow rates), underlying soil types, compost depths, blanket lengths, and pollutant concentrations.  
  
All compost treatments were observed to leach very high concentrations of nutrients immediately after placement in both the greenhouse and field studies, making the nutrient mass balance a critical focus. Data from greenhouse studies show the potential for TSS and heavy metal removal. Field and laboratory experimental water quantity and quality data will be presented, as well as differences observed between the greenhouse and field experiments. Future work on the issue of nutrient leaching, as well as modeling challenges, will be discussed.

**Complete Parks – Green Infrastructure in San Francisco Parks**

* Jessica Wala, Lotus Water

San Francisco is in the process of constructing green infrastructure stormwater management systems in public parks to reduce flooding, adapt and plan for climate change, reduce combined sewer discharges to the Bay and the Pacific, and improve the public realm. The Baker Beach Green Infrastructure project is part of a multi-billion-dollar citywide investment required to upgrade our aging sewer system. The neighborhood scale Project creates two green streets with rain gardens and permeable concrete, which will manage around 2.5 million gallons of stormwater each year. Prior to this project, the neighboring Baker Beach was experiencing combined sewer discharges (CSD) onto the beach an average of three times per typical year during major rainstorm events. This Project will reduce the CSD volume by around 90% and the number of annual CSD occurrences to only a single event per year. Along with managing stormwater through low impact development, the Project will also create new urban habitats, improve bicycle and pedestrian safety and calm traffic, and will inform future GI project designs through post-construction performance monitoring. The Bayfront Park is a privately funded site-scale integrated LID application project. The Park creates a flexible public space connecting the waterfront to the City through active and passive uses, emphasizing Bay views and the site’s industrial history. The Park design cost-effectively integrates passive stormwater management systems into the site design, illustrates the connection of the urban runoff to the San Francisco Bay, and addresses future sea level rise and storm surges.

**Field evaluation of the performance of multiple bioretention systems in reducing phosphorus loading in urban stormwater**

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| * Yi Liu, Western University * Nick Mocan, Crozier & Associates Consulting Engineers * Katherine O'Hearn, Crozier & Associates Consulting Engineers * Jaeleah Goor, Western University | * Amanda Pinto, Crozier & Associates Consulting Engineers * Luke Parsons, Crozier & Associates Consulting Engineers * Clare Robinson, Western University |

Bioretention systems are an increasingly popular low impact development storm water management technology. In Southern Ontario, Canada, guidelines recommend that the engineered soil media should be a mixture of sand, soil, and organics but the performance of the media composition in removing pollutants including phosphorus (P) from the infiltrating stormwater is not well established. While prior studies focus on input-output water quantity and quality monitoring only, here we monitored six bioretention systems of different ages and with different engineered media composition to identify and compare the mechanisms governing P removal and release in the systems. Porewater samples were collected from the bioretention systems and analyzed for soluble reactive phosphorus (SRP) and other chemical species related to SRP mobility to investigate the biogeochemical evolution during storm water infiltration. In addition, sediment cores were analyzed to identify the major mechanisms controlling partitioning of P between the infiltrating water and solid phases within the bioretention systems. Results show widely varying performance of the bioretention systems with respect to SRP removal, although individual systems performed consistently over multiple rain events. For systems that showed a net release of SRP, SRP was mainly derived from P associated with primary minerals and adsorbed onto metal (Al- and Fe-) oxides. The porewater pH was found to be a major control on SRP release from the media to the infiltrating water with the bioretention system with porewater pH > 8 found to have the highest porewater SRP concentrations (>3 mg/L). This is thought to be due to SRP desorption from adsorbed mineral phases under high pH conditions. This study provides important new insights into the geochemical conditions that govern P release and attenuation in bioretention systems as needed to improve the composition of the engineering media used, and thus the water quality benefits of these systems.

**16:45 - 17:30 | Virtual Happy Hour**

**Tuesday Program**

**8:00 - 13:00 | Videos On-Demand**

**13:00 - 13:10 | Welcome and Introduction to Session 2-1 and 2-2**

**13:10 - 14:20 | Sessions 2-1 & 2-2**

**Session 2-1**

**RainScapes – Incentives matter and other Lessons learned 10 years of Voluntary retrofits on Private Property**

* Ann English, Montgomery County MD Dept. of Environmental Protection
* Daniel Somers, Montgomery County MD Dept. of Environmental Protection

It is not easy to implement the LID/GSI decentralized approach to stormwater management in an already developed landscape that is predominantly held in small lots and private hands. The RainScapes program of the Montgomery County, MD Department of Environmental Protection has developed and deployed a cost-effective and flexible set of tools in the toolbox of BMPs used to meet the County MS4 permit goals. Several steps were taken both organizationally and technically, including program revisions, that have resulted in a flourishing voluntary, private property retrofit program in the County based on this cost-share approach. The portfolio of projects types offered synthesize best practices from landscape architecture, horticulture, engineering, and community outreach to provide a solution-oriented suite of site level GSI practices to property owners. RainScapes Rewards incentives are offered to those who will voluntarily install low impact development projects, called RainScapes. Once installed, participants in the program can then apply for a maintenance incentive, the Water Quality Protection Charge Credit, which reduces their charge in exchange for verification of maintenance every three years.  
  
The RainScapes program approach of development and publication of practical and accessible design standards, professional training courses, consumer education, and cash incentives has worked to accelerate this form of on-lot retrofits. In the past decade, with a small staff, the program has overseen the addition of nearly 18 Acres of rain gardens, green roofs, permeable paver retrofits, conservation landscapes, and pavement removal projects which are adding runoff control to the landscape every time it rains. The advantage of decentralized BMPs is that they can be squeezed into smaller spaces and restores some of the processes of pre-development hydrology. But the fiscal promise of LID to be a cheaper than conventional means to manage stormwater and provide co-benefits such as aesthetic enhancement, habitat creation, natural system connectivity and improved local ecosystem health can be difficult to realize. RainScapes projects solve site level stormwater problems, disconnect rooftops and driveways from the stormdrain system while providing a host of co-benefits and providing owners with relief from increased lot to lot drainage in developed landscapes at a cost that the County can afford.

**Green Infrastructure in Parks: Practice & Policy to Promote Health, Equity and Resilience**

* Wende David, National Recreation and Park Association
* Jenny Cox, National Recreation and Park Association

Over the past decade, green infrastructure (GI) has become an increasingly popular tool to manage stormwater and localized flooding through enhanced environmental functionality while simultaneously providing additional social, economic and health benefits. Today, we have an opportunity to strategically integrate these practices into municipal park planning and programming.  
  
The National Recreation and Park Association (NRPA), the leading nonprofit dedicated to the advancement of public parks in the United States, is working to advance multi-benefit GI practices and policies within community parks. NRPA has been developing resources, tools, trainings and policy actions to integrate GI into the planning, programming and operations of public parks to improve environmental and social outcomes especially in underserved communities.  
  
This session will utilize GI research findings and park project case studies to illustrate how NRPA is positioning municipal park agencies to help their communities address social, environmental and health challenges through advocacy, evaluation and best practices. Key session topics include: •Policy action recommendations that identify policy and funding opportunities at the federal, state and local level to promote health-driven green infrastructure projects in parks. •Key themes and findings of a literature review that identifies evidence linking green infrastructure in parks to improved community well-being. •Evaluation tools and metrics designed specifically for park professionals to help them measure the many diverse benefits of green infrastructure park projects. •Communications and advocacy tools aimed at supporting park staff and advocates, decision makers, planners and other municipal agencies in promoting GI park practices and policies.

**Trends in Incorporating GSI into Suburban Land Development in Chester County, PA**

* Molly Deger, Chester County Conservation District

The objective of this presentation will be to provide some background on Chester County, PA and discuss some of the trends in the County with incorporating more GSI type principles into otherwise traditional land development projects. Chester County, a western suburb of Philadelphia and home to part of the “Main Line”, is the wealthiest county in PA by per capita income. There are 146,000 new residents projected between 2015 and 2045, business growth has been strong and is trending to remain so, yet over 30% of the County is preserved open space. Chester County is home to incredible natural and cultural resources, scenic rural landscapes, historic and booming towns, and suburban sprawl. Over 50% of the county is in a special protection (HQ or EV) watershed, but over 1/3 of the nearly 2,400 stream miles are considered impaired. With over 120 NPDES for Stormwater Discharges permits issued/authorized in 2018, the Chester County Conservation District continues to be one of the top 5 in the state for number of these permits issued. Chester County is also fortunate to have a strong presence of environmental groups and watershed associations (i.e. Valley Forge Trout Unlimited, Green Valleys Association, Brandywine Red Clay Alliance) who stay up to date with planned development projects and their associated impacts. Through the lens of the Chester County District Engineer responsible for providing Engineering Post Construction Stormwater Management (PCSM) Reviews for all Individual NPDES Permits and for a portion of the General Permits, this presentation will highlight positive and negative trends with design engineers incorporating GSI into traditional land development projects. Through regulation and policy updates (i.e. Chapter 102, Act 167, Act 162, MS4, PAG-02, PA DEP E&S FAQ Documents), the regulated community (including builders and developers) have for the most part acknowledged that LID and GSI are not just popular acronyms that stormwater-savvy neighbors want to hear at Planning Commission meetings, but are acknowledging that stormwater management needs to be accounted for up front in the land development process. There are more rain gardens, porous pavement, and water quality BMP technologies being utilized, and a scattering of green streets and green alleys implementations in more of the urban centers. There are; however, plenty of late adopters as well as more traditional BMP designs that are simply called rain gardens – these challenges and BMP failures will be highlighted as well.

**How long will they last? Performance Assessment of Mature Bioretention Systems in Ontario, Canada**

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| * Sylvie Spraakman, University of Toronto | * Jennifer Drake, University of Toronto |

Though research on bioretention has been steadily growing, studies are still predominantly on completed new bioretention systems that are less than 3 years old. It is unknown whether bioretention cells’ engineered media continues to detain and infiltrate intended runoff volumes as systems age. Bioretention media can become clogged with sediment, or the media can compact as it settles, reducing hydrologic performance over time. In this study, we survey and sample 21 Ontario bioretention cells that have been operational for at least 3 years. We measured soil properties such as hydraulic conductivity and field capacity, surveyed the cells to determine their volumetric capacity, and visually observed presence of clogging, plant die-off and saturated conditions. Measured soil parameters were then compared to the original design parameters and to initial conditions to determine if the bioretention media has degraded over time. All of the mature bioretention cells had infiltration rates above the recommended minimum (25 mm/hour). Infiltration rates remained unchanged at most sites but 1/3 had notable increases ranging from 20 -50%. The sand content across all sites was between 70 and 90%, which is consistent with Ontario guidelines for bioretention media. Overall, most bioretention cells continue to perform well from a hydrologic perspective, and infiltration capacity is maintained.

**Analyzing the performance of a rain garden over 15 years**

* Achira Amur, Villanova University
* Bridget Wadzuk, Villanova University
* Robert Traver, Villanova University

The Bioinfiltration Traffic Island (BTI) is a bioinfiltration rain garden that was retrofitted off an existing traffic island in 2001. Having been monitored since 2003, the BTI has quantitative hydrological data collected for the past 15 years, making it a very valuable dataset for an in-depth analysis of the performance of the site.  
  
The initial analysis comprises of a high-resolution analysis of rainfall event frequency along with resulting performance at the bioinfiltration rain garden. All rainfall events within the 15 years of collected data was discretized in to 2.5 mm, 2-hour bins. The binned rain events were then analyzed using a mass balance approach to understand how the different hydrological elements contribute to the ability of the site to treat incoming stormwater runoff. Each component of the hydrological cycle within the BTI will be studied in detail and over different types of rain events. The second part of the analysis focuses on assessing the intensities of each of the recorded storms to understand its influence on the performance of the rain garden.  
  
Preliminary results show that between 2003 and 2018, there were 1202 recorded events, and 82% of them were less than 25 mm. Approximately 16% of all observed events resulted in substantial overflow. The overall analysis provides lessons into system components and aims to understand the interaction of the different hydrological elements within the rain garden. The objective is to use the findings in designing Green Infrastructure systems that can be optimized in their ability to manage and treat incoming stormwater.

**Session 2-2**

**Biochar-augmented biofilters to improve pollutant removal from stormwater – Can they improve receiving water quality?**

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| * Alexandria Boehm, Stanford University * Colin Bell, Colorado School of Mines * Nicole Fitzgerald, Colorado School of Mines * Elizabeth Gallo, Colorado School of Mines * Christopher Higgins, Colorado School of Mines | * Terri Hogue, Colorado School of Mines * Richard Luthy, Stanford University * Andrea Portmann, Colorado School of Mines * Bridget Ulrich, University of Minnesota Duluth * Jordyn Wolfand, Colorado School of Mines |

Stormwater biofilters are being implemented widely in urban environments to provide green space, alleviate flooding, and improve stormwater quality. However, biofilters with convention media (sand, soil, and/or mulch or compost) do not reliably remove contaminants from stormwater. Research suggests addition of biochar to the biofilter media can improve the pollutant removal capacity of biofilters. In the current work, we present a systematic review of laboratory and mesocosm studies of biochar-augmented biofilters and an assessment of watershed-scale implementation of biofilters on local water quality. A full text review of 84 papers was conducted; of these, data were extracted from the 14 that met our inclusion criteria. Log10 removal of microbial pollutants and trace organic contaminants (TOrCs) by biochar-augmented media is generally greater than those of the controls containing just sand, soil, and/or compost. Log10 removal of nitrogen, phosphorous, total organic carbon, and total suspended solids in biochar-augmented biofilters is not clearly higher than those of control experiments. A supplemental analysis for four studies reporting breakthrough data revealed that TOrC removal effectiveness varies substantially among high temperature wood-based biochars, and that operational lifetimes of full-scale systems constrained by TOrC sorption capacity could range from five months to over seven years depending on the selected biochar. At the watershed-scale, biochar-augmented biofilters can provide enhanced treatment of runoff, resulting in the need for fewer treatment units or a smaller volume of watershed runoff treated to meet water quality criteria compared to their conventional counterparts. While their installation can reduce the load of pollutants to receiving waters, achieving concentration-based water quality targets may prove difficult even with when pollutant removal capacity is high. This work highlights the importance of a systems approach to studying how biofilter installation affects water quality within a watershed. We identify several topical areas where further research is needed, especially as installation of biofilters and other stormwater control measures gains popularity in highly urbanized watersheds.

**Microplastic removal in a bioretention cell**

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| * Kelsey Smyth, University of Toronto * Jennifer Drake, University of Toronto | * Chelsea Rochman, University of Toronto * Elodie Passeport, University of Toronto |

Although increasing microplastics research exists in various aquatic settings, little focus has been paid to upstream sources specifically stormwater. Moreover, there is almost no data about the efficiency of bioretention cells for microplastic removal from urban stormwater runoff. In this study, we quantified microplastic concentration and polymer type at the inlet and outlet of a bioretention cell at the Toronto Region Conservation Authority (TRCA) Kortright Centre in Vaughan, Ontario, Canada. Samples were size fractioned, density separated and visually counted before identification with Raman spectroscopy. In total, 23 rain events were sampled over the Summer and Fall of 2018 and 2019 from which 12 paired inlet and outlet samples were collected. The concentration of microplastics increased as the size range decreased from > 1mm, 500 µm – 1 mm, 300 µm – 500 µm, to 106 µm – 300 µm. Statistically significant decreases in microplastic concentration and loads were observed between the inlet and outlet of the bioretention cell, from a range of 28 to 704 at the inlet to a range of 22 to 134 particles/L at the outlet. Samples were primarily composed of microfibers as well as rubber at the bioretention inlet. Methods were validated by preparing artificial spiked samples and measuring their recoveries as well as with field and lab blanks. Overall, the results showed that bioretention cells worked to efficiently remove microplastics from stormwater.

**The Role of Estimated Soil Parameters on Bioretention Modeling: A Sensitivity Study**

* Whitney Lisenbee, University of Tennessee
* Jon Hathaway, University of Tennessee

Many hydrologic models have developed tools for modeling bioretention. Yet, many lack specific features designated for advanced bioretention cell modeling like underdrains, internal water storage (IWS) zones, soil-moisture accounting, and evapotranspiration calculations. One model that addresses many of these features is DRAINMOD-Urban which uses the soil-water characteristic curve (SWCC) to consider the effect of soil moisture in the bioretention cell profile between storm events. This is also one of few models with the capability to model the IWS zone applied in some bioretention cells. Due to the constant changes in water table depth and soil moisture within bioretention cells, soil properties play an important role model performance. Yet, these soil characteristics are not easily measured in the field or laboratory, so many models use estimations and simplifications often based on soil texture. Pedotransfer functions have also been used in modeling efforts to gain required soil inputs from easily measured soil properties. In this study, the sensitivity of DRAINMOD-Urban was examined through variation of calibration parameters and special attention was given to the sensitivity of the soil parameters. Then, pedotransfer functions were used to derive the required soil parameters for DRAINMOD-Urban. Simulations with measured soil parameters were compared to those calculated by pedotransfer functions to understand the level of detail required for adequate simulation of flow through a bioretention system. This study will provide valuable information on the importance soil parameters play in modeling of bioretention cells and if pedotransfer functions can be used to reduce soil input complexity without hindering model performance.

**The Gwynns Falls Integrated Restoration Program**

* Nick Lindow, CityScape Engineering, LLC
* Bonnie Sorak, Interfaith Partners for the Chesapeake
* Jessie Hillman, Blue Water Baltimore

The Gwynns Falls Integrated Restoration Program (Gwynns Falls IRP) is a joint effort between non-profits, municipal governments, community groups, religious organizations, and technical consultants to engage residents on local environmental issues, implement high-value restoration opportunities, reduce flooding and improve water quality in the watershed. The Gwynns Falls IRP has two key objectives: (1) implementing widespread green infrastructure practices, planting new trees and installing stormwater retrofits treating acres of legacy impervious surfaces; (2) evaluating the impact of restoration activities on long-term water quality monitoring data; and (3) promoting environmental education and raising public awareness of the current state of the streams and rivers in their neighborhoods. Supporting the Gwynns Falls IRP are Blue Water Baltimore, the Interfaith Partners for the Chesapeake, and CityScape Engineering. The Gwynns Falls watershed encompasses the southwest sides of Baltimore City and County. Covering 66 square miles, the watershed makes up 24 percent of Baltimore City and 7 percent of Baltimore County, contributing 25 percent of the containment load to the Baltimore Inner Harbor (MDE, 2010; USGS, 2018). The Gwynns Falls Watershed has been the subject of decades of research through the Baltimore Ecosystem Study (BES), one of 26 research programs established by the National Science Foundation to study ecological systems over long term periods. The upper sub-watersheds are a mixture of lower density residential areas with agricultural and forested land use. Further downstream, the sub-watersheds transition to middle and high density residential mixed with commercial and industrial land use. The land use change from 2001 to 2011 was minimal (approx. 2%). In 2018, Blue Water Baltimore, the United States Geological Society, and the Carey Institute published a groundbreaking multi-decade study of the watershed. The study indicated that the Gwynns Falls is a favorable location to study the effect of Best Management Practices (BMPs). Using a long-term data set of water quality, the research was able to show a significant improvement in total phosphorus and phosphate loading in the Gwynns Falls due to the implementation of stormwater BMPs. Our presentation will provide an overview of the on-going water quality monitoring in the watershed, the outreach and education measures undertaken to encourage voluntary restoration, and our work to map, assess, and implement opportunities for new green infrastructure on privately owned lands throughout the watershed. Upland restoration strategies include both engineered stormwater facilities (LID practices and structural BMPs) and actions in partnership with local watershed associations, citizen awareness campaigns, and volunteer activities, such as reforestation and impervious removal. Results of the study will aid contractors and watershed managers to re-imagine the future of LID in historically urban areas.

**Green Infrastructure Monitoring and Rehabilitation**

* Brad Udvardy, LimnoTech
* Volker Janssen, LimnoTech
* Lukas Vander Linden, LimnoTech
* James Woodworth, DC Department of Energy and Environment

Green Infrastructure performance can be difficult to quantify even for newly-installed practices. This challenge is particularly acute for practices that have not consistently demonstrated a stormwater volume-reduction benefit, and that have had maintenance deferred for significant periods. This phase of DOEE’s RiverSmart project will quantify green infrastructure practice performance both before and after rehabilitation and maintenance activities, to help determine the extent to which performance may be recovered by those activities. Secondary but closely-related, the project will determine whether practice-level monitoring is effective in quantifying GI performance, and in differentiating between performance of different practice types.  
  
The RiverSmart Washington Green Infrastructure (GI) demonstration sites were constructed in 2014 to quantify stormwater volume reductions from green infrastructure. The GI practices at two sites consisted of a mixture of curb-side bioretention cells and permeable street parking and alley surfaces of various types (permeable pavers, porous concrete, and porous asphalt). City-wide and site-specific modeling in support of GI design efforts predicted a significant reduction in stormwater runoff volume and combined sewer overflows through widespread implementation of GI, and the demonstration sites provided an opportunity to assess the real-world performance of GI. Both pre- and post-construction shed-wide sewer monitoring were conducted in 2010 and 2015-2016, respectively. The subsequent data analysis was inconclusive, in that no statistically significant benefit could be determined after GI implementation. In response, DOEE initiated another phase of RiverSmart that would both add individual GI practice-level data collection, and seek to examine whether practice rehabilitation and maintenance could restore GI performance.

**14:40 - 16:00 | Plenary Session- Green Infrastructure Innovation and Co-Benefits in the Anacostia Watershed**

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|  | **Tommy Wells**, Director, DC Department of Energy and Environment |
|  | **Adam Ortiz**, Director, Department of the Environment, Montgomery County, MD |
|  | **Joe Gill**, Director, Department of the Environment, Prince Georges County, MD |

**16:00 - 17:20 | Panel Discussion: Washington DC's Award Winning Approach to Watershed Restoration**

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| * Cecilia Lane, DOEE * Bryan Arvai, Biohabitats, Inc * Ted Brown, Biohabitats, Inc | * Josh Burch, DOEE * Nick Bartolomeo, National Park Service |

**Wednesday Program**

**8:00 - 15:45 | Videos On-Demand**

**14:45 - 15:35 | Sligo Park Hills and Prince Georges County Technical Tour**

Sligo Park Hills Neighborhood Retrofit and Prince George’s County Innovative LID Projects. This virtual tour covers a variety of projects notable for partnership approaches among communities, schools, funders, and a variety of local government agencies to find innovative ways to implement a diverse set of stormwater management approaches. The Sligo Park Hills Neighborhood in Montgomery County features Green Streets projects implemented in challenging terrain with the intent to pilot ESD to the MEP. Techniques include rain gardens, linear bioretention, RainStore, PaveDrain, FocalPoint, and Filterra tree boxes. The retrofit approach involved close partnership with the residents of the community, the Department of Environmental Protection, the Department of Transportation, and outreach and education efforts through the RainScapes program.

Four sites in Prince George’s County include:

* Eleanor Roosevelt High School is a Clean Water Partnership School Retrofit Project. The CWP has completed over 50 school retrofit projects. Many of these are integrated into the school’s STEM curriculum. This is a parking lot reduction and a surface sand filter that treats over 3 acres of impervious surface.
* Fordham Road is a recent stream restoration project that is a partnership between the Prince George’s County Department of Environment Storm Water Management Division and the Maryland‐National Capitol Park and Planning Commission.
* Town of Edmonston Green Street and Anacostia River Trail. This was the first Green Street in the region. It was designed by the Low Impact Development Center. The project was one of the first featuring co‐benefits.
* University of Maryland College Park Public Health Garden. This is an experimental project led by the University of Maryland through various grant programs. It looks at innovative solutions to siting of facilities and features water reuse, urban agriculture, and advanced treatment of stormwater.

**15:45 - 17:00 | Panel Discussion: DC Water’s Practicability Assessment of Green Infrastructure in the Combined Sewer Area**

* Seth Charde, DC Water
* Amanda Zander, Delon Hampton & Associates Chartered
* Eric Lienhard, PE; Hazen and Sawyer

**15:45 - 17:00 | Panel Discussion: Exploring Green Stormwater Infrastructure as an Integrated Tool to Improve Resiliency**

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| * Saleem Chapman, Deputy Director, Philadelphia Office of Sustainability * Jordan Fischbach, Co-Director, RAND Climate Resilience Center * Carrie Grassi, Deputy Director for Planning, NYC Mayor’s Office of Resiliency | * John Miller, Mitigation Liaison to NJ Office of Emergency Management, FEMA * Shandor Szalay, Senior Vice President, AKRF, Inc. |

**17:00 - 17:10 | Welcome and Introduction to Session 3-1 and 3-2**

**17:10 - 18:20 | Sessions 3-1 & 3-2**

**Session 3-1**

**Trained Landscape Professionals Help City of Lancaster Meet Stormwater Goals**

* Beth Ginter, Chesapeake Conservation Landscaping Council
* Kate Austin, City of Lancaster, PA
* Becky Grubb, City of Lancaster, PA

The Chesapeake Bay Landscape Professional (CBLP) certification program is a collaborative effort which provides consistent, high-quality training across the Bay watershed for professionals who design, install, and maintain stormwater best management (BMP) practices and conservation landscapes. The goal of the program is to support partners in local governments, watershed groups, academic institutions, and other organizations in meeting their Bay restoration goals, and to help ensure that green infrastructure projects are implemented and managed to maximize long-term effectiveness. In 2017, CBLP began a collaboration with the City of Lancaster, Pennsylvania, where we have since collaboratively held Level 1 classes for more than 70 individuals, including City staff, as well as landscape architects & designers, engineers, horticulturists, arborists, installation/maintenance contractors and other related professionals from the surrounding community. City staff help lead the field maintenance practicum component of Level 1 training, sharing experience and lessons learned from several years of managing BMPs in the City. City staff who have completed CBLP certification not only further develop their careers by completing training, but they are apply newly-learned skills and knowledge to ensure proper function of urban BMPs and conservation practices such as riparian buffers. Additional partnerships with academia, watershed groups, and private businesses have strengthened this collaboration, and several new efforts are planned to expand the positive impact of our work. As a result of the collaboration, there is a larger pool of qualified professionals available in the Lancaster workforce to successfully implement BMPs on both public and private land in the City.

**Entry-Level Training for Green Infrastructure and Sustainable Landscaping**

* David Hirschman, Hirschman Water & Environment, LLC
* Beth Ginter, Chesapeake Conservation Landscaping Council
* Lori Lilly, Howard EcoWorks

Antonia Bookbinder, The Maryland-National Capital Park and Planning Commission, Department of Parks and Recreation, Prince George’s County (M-NCPPC)

In 2018, the Chesapeake Bay Landscape Professional (CBLP) certification program, Hirschman Water & Environment, and Howard EcoWorks in Howard County, MD, piloted a new training program for individuals entering the workforce. CBLP-A (Associate) is a certificate course designed to generate interest among people of various ages in green infrastructure and sustainable landscaping careers. The program provides high quality training to entry level workers, develops appropriate materials and programming to complement the work of existing programs (e.g., summer jobs programs, workforce development, schools), and creates mentoring opportunities to connect CBLP-A candidates with certified CBLP professionals. CBLP-A has been adopted by Howard EcoWorks and its job training programs. In 2019, a new collaboration with Maryland National Capital Park and Planning Commission (M-NCPPC) in Prince George’s County, MD added CBLP-A to a summer youth employment program for high school students. CBLP-trained partner staff serve as instructors for the CBLP-A training in the summer programs, workforce development efforts, and in several high school environmental science programs. Our collaboration uses CBLP core standards and materials to advance knowledge of Bay restoration and develop skills across diverse groups. Mentoring is beneficial not only for youth entering the workforce, but also provides a recruitment pipeline for landscape contractors and local governments that need trained workers to successfully install and maintain stormwater best management practices and conservation landscapes. Several CBLP-A participants from the initial cohort are now employed in the DC region and several others have completed CBLP’s Level 1 professional certification. Additional CBLP-A partnerships will bring this program to Pennsylvania and Virginia in 2020-21.

**How to keep a good thing going: adaptations to implement standard GI in challenging spaces**

* Kate Mennemeyer, Hazen and Sawyer
* John Brennan, Hazen and Sawyer

As green infrastructure (GI) implementation efforts advance, public urban areas are an increasingly challenging space to retrofit with cost-effective GI due to the exhaustion of minimally constrained opportunities. In public ROW spaces, topography, sidewalk curbs and ramps, utility infrastructure, and mature landscaping are common constraints. For public on-site areas, installing GI around existing infrastructure or retrofitting conveyance utilities can also present challenges. In an ideal scenario, GI can be sited while maintaining preferred offsets and clearances from these existing constraints, but what happens when those preferences can’t be achieved? Additionally, how can standard designs be implemented while accommodating highly variable site conditions? Optimizing designs to avoid or overcome site specific constraints can provide new opportunities in areas where GI would otherwise be considered infeasible. This adaptation is especially critical when applying standard designs or best practices to a non-standard landscape where existing site conditions or design requirements can limit opportunities to implement GI or impact GI performance once constructed. While adopting some degree standardization is beneficial for widespread implementation of GI, it is important to understand that the landscape is not standard. This presentation will identify common urban environmental variabilities and provide examples of how to be flexible with GI design to accommodate the available space as well as critical design aspects necessary to maintain the integrity of GI function and performance. For example, designing of GI in the right-of-way where there is also excessive cross slope in the sidewalk may require changes to a standardized grading plan, curb construction, or tree fence detail. Curb and gutter systems with insufficient curb reveal similarly may require raising the existing curb and adjusting the adjacent sidewalk’s cross slope or adapting a standard inlet detail to allow for sufficient inlet capacity. These and other examples of potential siting constraints and design adaptations will be discussed to highlight the importance of thinking through standard design and construction at the start of a program as well as adapting more complex GI design later on in a program.

**No Outlet, No Problem- Infiltrate!**

* Jennifer Young, Stantec Consulting

With 42 acres of land and no drainage outlet, RBJ Schlegel Park needed a drainage design that was cost effective, aesthetically pleasing, and could manage the regional storm (Hurricane Hazel)for the site. The park uses LID and infiltration exclusively for the stormwater management The City of Kitchener is leading the pack among Ontario municipalities handling stormwater runoff. The goal with the RBJ Schlegel Park project is to maintain the existing gravel infiltration conditions, support the City’s Low Impact Development (LID) policy, and ensure that the stormwater runoff design allowed for free play within the park. The main obstacle to overcome with this project is to ensure the site, and its grading, can handle a large storm event; provide water quality, have the storage volume to ensure infiltration, and with smaller storm events, the surface infiltration designs did not impact enjoyment of the park. The design process had many challenges and unique solutions, with refinement in the design occurring though out the design, tender, and early construction processes. An engaged, committed client and proactive contractor have led to an innovative, usable design that will serve city residents for decades to come.

**Water Sensitive Design as an Ecologically Based Urban Design Approach to Facilitate Stormwater Resilience for Industrial Areas in Auckland**

* Yuliang Wang, The University of Auckland
* Marjorie van Roon, The University of Auckland

Rapid urban sprawl leads to tremendous changes to land surface characteristics and various urban environment problems that become visible, such as urban flooding, catchment pollution and receiving waterbody damage caused by increasing urban stormwater runoff. Compared to residential areas, industrial areas have more stormwater problems due to higher proportions of impervious area and industrial pollution. This paper draws on a catchment in Auckland, New Zealand, which contains a developing industrial area. This is a case study example to demonstrate the development of a Water Sensitive Design (WSD) approach that provides a stormwater resilient environment for industrial areas. To identify WSD physical characteristics, possibilities and constraints, document data and digital data from publicly available government databases, were obtained and analysed. Natural urban green and blue spaces, and artificial open spaces, play important roles for applying WSD and they provide potential opportunities for Industrial Water Sensitive Development (IWSD). The assessment of urban landscape characteristics evidently identifies the potentials and barriers for IWSD in the case study area. The study demonstrated that combining the WSD approach into the urban design stage is essential to deal with urban stormwater issues in a flexible and sustainable way when integrating WSD practices into the natural hydrological water cycle in an industrial catchment. The research proves that the reasonable synergy of urban green space and natural water cycle play an important role in IWSD success. This approach offers industrial development a new concept for achieving a stormwater resilient industrial catchment and finally leads to a sustainable water environment.

**Session 3-2**

**Optimizing Resilience to Respond to the Challenge of Sea Level Rise**

* Breanna Gribble, STV, Inc.

Cities must respond to chronic stresses like sea level rise by establishing and utilizing resilience capacity building frameworks to promote strategic thinking. This research includes a literary survey of resilience building frameworks to understand whether the existing frameworks encourage strategic thinking at all phases of strategy development: conceptual, analytical, and at the implementation phase. The presumption being that these three phases in iteration promote strategic thinking. In this context, strategic thinking is an optimization mechanism for resilience capacity building. Critical analysis of a select framework (100 Resilient Cities) through the lens of the New York City case study, facilitate a qualitative assessment about whether resilience frameworks are adequately giving cities the tools to plan for future conditions.  
  
The research suggests that resilience frameworks rate high on the promotion of conceptual and analytical strategic thinking, but the implementation phase needs improvement. In the conceptual phase: frameworks accentuate the importance of early and iterative stakeholder engagement, active stewardship, and outline good process for resilience planning. At the analytical phase, cities are excelling at the analytics of resilience. Comprehensive resilience indicators give cities the tools to assess and profile their resilience which bolsters the business case. Innovative spatial mapping technologies enables decision-makers to make informed policy and investment decisions. Projects at the implementation-phase suffer from a lack of strategic thinking post-procurement. Strategic thinking is focused at the project-level instead of strategy being born out of the development of frameworks.

**Watershed-scale, cost-benefit optimization of stormwater infrastructure**

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| * John Riverson, Paradigm Environmental * David Rosa, Paradigm Environmental * Steve Auger, Lake Simcoe Region Conservation Authority * Dustin Bambic, Paradigm Environmental | * Ben Longstaff, Lake Simcoe Region Conservation Authority * Tracy Patterson, Freeman Associates Ltd * Mike Fortin, M. Fortin, Consulting Economist |

Stormwater management (SWM) is an increasingly complex challenge for all municipalities across North America. Major challenges relate to insufficient resources, aging infrastructure, areas lacking stormwater infrastructure, poor planning and an ever-increasing toolbox of LID/GI approaches to utilize. Combined with urbanization and climate change, we are witnessing an unprecedented increase in issues such as flooding, erosion and water quality impairment.  
  
There is growing consensus that significant and broad sweeping changes to stormwater management are needed to address the stormwater deficit. Critical to the required paradigm shift in stormwater management is ensuring stormwater is managed at a watershed scale and optimized for the greatest environmental outcomes at the greatest cost efficiency using combination of grey and green infrastructure. Optimization can be achieved through the economic concepts of scale, aggregation, integration and equitable responsibility.  
  
A pilot project within the East Holland River, Ontario, Canada applied a continuous simulation model (LSPC) integrated with the US EPA model SUSTAIN. Using LSPC-SUSTAIN, literally thousands of stormwater management scenarios are modelled to assess the economic concepts under different development, climate and planning scenarios.  
  
These findings will be used to secure policy shifts in support of whole system, nature-based/LID, integrative and transformative planning and design of SWM infrastructure. The presentation will provide an overview of the study methods, results, implications and next steps.

**Performance of urban green stormwater infrastructures in central Pennsylvania in stormwater metals accumulation**

* Bishwodeep Adhikari, The Pennsylvania State University
* Jeffrey Zaengle, The Pennsylvania State University
* Lauren McPhillips, The Pennsylvania State University

Urbanization has led to an increase in impervious surfaces across the globe causing severe flooding due to runoff generation during the period of heavy rainfall events. This threatens the water quality of nearby streams receiving stormwater since the water may carry metals from impervious surfaces. Green stormwater infrastructures (GSIs) are being adopted to reduce this impact of stormwater and are emerging as one of the best management practices nowadays. Here we focus on metals accumulation performance of GSIs in the State College region of central Pennsylvania. We hypothesize that metals will have higher concentrations near the inlet and pool of the GSI basins compared to adjacent reference soils that are not receiving stormwater. The performance of GSIs based on characteristics such as type, size, age, soil composition, and type of surface draining to the GSIs (e.g. roof and parking lot) are also considered for this research. Fifteen soil samples were collected from each site- 5 as reference samples at the location in the site where stormwater does not have much influence, 5 at the inlet of the basin through which runoff enters, and 5 in the pool of the GSI basins where runoff is detained and infiltrated. Soils are digested and analyzed for the concentration of 12 metals (Ca, Cd, Cr, Cu, Fe, K, Mg, Na, Ni, P, Pb, and Zn). Preliminary results show that certain metals (e.g. Cd) have undetectable concentrations for all the samples at all sites. The accumulation of metals at inlet and pool differs based on sites. Some sites showed accumulation of metals near inlet and pools while some had metals leached out; we are performing statistical analyses to discern drivers of these differences (or lack of differences). Copper (Cu) is the one metal to show consistently higher accumulation near the inlet and pool compared to the reference at all sites analyzed thus far. This research will help us understand design and environmental factors that influence metals accumulation performance of GSI.

**Thermal Gradient Dynamics within Rainwater Harvesting Systems Across the Eastern U.S.**

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| * Kathy Gee, Longwood University * Ryan Winston, Ohio State University | * Eban Bean, University of Florida * Chris McNabb, Ohio State University |

Rainwater harvesting (RWH) systems are valuable water conservation and stormwater management practices. Rainwater harvesting systems have an important application in low impact development (LID) as they have been shown to significantly mitigate stormwater runoff rates and volumes, as well as nitrogen, phosphorus, and sediment concentrations in harvested rainwater. One issue that has not been addressed to date is runoff thermal pollution contributed by RWH systems. It is well documented that elevated temperatures of urban stormwater runoff can serve as a source of thermal pollution in receiving water bodies, negatively impacting biological communities, reducing cold-water habitat, and altering aquatic chemistry. When designed correctly, filtration-based and underground stormwater control measures (SCMs) have been shown to mitigate the effects of this thermal pollution, including bioretention, permeable pavement, vegetated filter strips, and underground detention. This is the first study to document the contribution of RWH systems to, or mitigation of, thermal pollution via stormwater runoff and aims to fill this knowledge gap by evaluating the temperature dynamics within 7 RWH systems (3 underground, 4 above-ground) in Ohio, Virginia, North Carolina, and Florida. For each system, water level sensors were installed at the bottom of the storage tank to monitor water level fluctuations over time. Temperature probes were installed at the bottom of the storage tank, as well as at the 25%, 50%, 75%, and 100% of the depth of the tank. Water temperatures were recorded at each depth at 10-15 minute intervals for 12-30 months. Data analyses are ongoing, and preliminary results are expected by early summer 2020. It is anticipated that these results will allow an accurate assessment of RWH systems’ mitigation of (or contribution to) thermal pollution based on a range of geographic and climatic settings, as well as for above- and below-ground configurations. Additionally, results will be used to generate recommendations regarding system design to maximize the thermal load mitigation provided by these SCMs.

**Microburst Storm Flooding, Buried Streams and Available Storage in an Older, Small Urban Watershed**

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| * Shirley Clark, Penn State Harrisburg * Jacob Hoffman, Penn State Harrisburg | * Benjamin Clemmer, Penn State Harrisburg * Christopher Homer, Tsinghua University |

On July 23, 2017, a microburst storm dropped 4.7 inches of rainfall on the watershed in 83 minutes, resulting in substantial flash flooding in non-FEMA-floodplain areas. While developing a PCSWMM-based model of the watershed, it was noted that the flood locations generally followed what appeared to be the stormwater main pipes in the system. For both trunk lines, based on small sections of daylighted stream, it also was apparent that the pipes did not contain just stormwater, but also a baseflow component from these continuously-flowing, spring-fed streams. This was confirmed using historical maps of the town dating from the mid-1800s and from sewer discharge permits from the 1910s. However, flooding in a third area of town did not follow either of the two main trunk sewers. Further review of the permits and maps available at the PA State Archives revealed that there was a third stream buried sometime during the town’s buildout in the early 1900s. Crull’s Run has been a source of complaints to the borough regarding soggy soils and flooding basements. Monitoring started in early 2020 to measure flow during both wet and dry conditions in order to calibrate the model and understand the importance of baseflow contributions during heavier rainfall conditions. This will be combined with satellite measurements of soil moisture since this older system leaks due to cracks in manholes and inlet boxes. The inflow and infiltration contribution in these older systems is poorly documented. Once the flow contributions are better understood, the undergraduate capstone class will be able to determine how to optimize existing storage, where the “best” places to install green infrastructure are, and to determine, using SWMM modeling, the optimal size to reduce flooding during most storms.

**18:30 - 18:40 | Welcome and Introduction to Session 3-3 and 3-4**

**18:40 - 19:50 | Sessions 3-3 & 3-4**

**Session 3-3**

**Buffalo Sewer Authority Raincheck 2.0 – City-wide Green Infrastructure**

* David Barnes, Arcadis
* Kevin Meindl, Buffalo Sewer Authority

Officially launched by the BSA in 2015, the Rain Check GI program has involved local, state and national water protection partners to plan and implement GI to reduce the frequency and impact of sewer overflows into local waterways.  
  
Rain Check 1.0 was the first generation of GI implementation in the City of Buffalo. This initiative included green street construction along key transportation corridors and successful implementation of a rain barrel and downspout disconnection program.  
  
Rain Check 2.0 is a comprehensive, strategic plan that will deliver green infrastructure projects within six priority sewer basins to reduce the stormwater runoff from approximately 500 acres of impervious surfaces. Community education and engagement is critical to the success of the program. The project includes the following major tasks: • Benchmark Report for Raincheck 1.0 GI Implementation. • Communication and Education efforts including a new website, online tour and engagement materials for Raincheck 2.0. • A Technical Advisory Committee (TAC) consisting of local and national GI practitioners to provide input and guidance on technical and implementation challenges. • Local Government Engagement Meetings to identify opportunities for collaboration. • Private Engagement Meetings to identify partnerships for implementing GI projects. • A Stormwater Tree Analysis and TAC to identify planting opportunities and crediting. • Retrofit Reconnaissance Investigations (RRI) including a desktop Screening Analysis to identify possible sites. Field Investigations were then performed to determine feasible sites.  
  
The Raincheck 2.0 Final Opportunity Report identifies key partners and locations for the next level of GI in the City of Buffalo.

**City of Mount Rainier Climate Change Adaptation Plan**

* Emily Clifton, Low Impact Development Center
* Neil Weinstein, Low Impact Development Center

Smaller communities in urban areas are faced with the challenge of addressing climate change and resiliency planning with limited resources and an aging and often inadequate infrastructure. This paper will present the challenges and solutions to meeting these requirements through green infrastructure and other funding programs to address flooding and water quality while providing co-benefits that create momentum and community engagement and support. The City of Mount Rainier, MD, is a 0.64 square mile urban suburb in very close proximity to Washington, DC. Existing grey stormwater infrastructure is limited, and localized flooding is common. During periods of heavy rain or rapid snow melt, many private and public properties and roads experience localized flooding.  
  
This presentation will provide an overview of the stormwater infrastructure system capacity analysis and vulnerability assessment techniques utilized. The presenters will also discuss how this information is being used to inform community discussions on the impacts and value of potential improvements for affected properties and a climate change adaption plan for the City. This project was funded by a grant from the Maryland Department of Natural Resources.

**Understanding the Performance and Applicability of Low Impact Development Structures under Varying Infiltration Rates**

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| * Heidi Guerra, Hanseo University | * Youngchul Kim, Hanseo University |

With the increasing effect of urbanization becoming more apparent through flooding and decline in downstream water quality especially from heavy rainfalls, stormwater runoff management solutions have focused on runoff volume reduction and treatment through infiltration. However, there are areas with low infiltration soils or are experiencing more dry days and even drought. In this study, a laboratory-scale infiltration system was used to compare the applicability of two types of soil as a base layer in gravel-filled infiltration systems with an emphasis on runoff capture and suspended solids removal. The two types of soils used were sandy soil representing a high infiltration system and clayey soil representing a low infiltration system. Findings showed that infiltration rates increased with the water depth above the gravel-soil interface indicating that the available depth for water storage affects this parameter. Runoff capture in the high infiltration system is more affected by rainfall depth and inflow rates as compared to that in the low infiltration system. Based on runoff capture and pollutant removal analysis, a media depth of at least 0.4 m for high infiltration systems and 1 m for low infiltration systems is required to capture and treat a 10-mm rainfall in Korea. A maximum infiltration rate of 200 mm/h was also found to be ideal to provide enough retention time for pollutant removal. Moreover, it was revealed that low infiltration systems are more susceptible to horizontal flow and that the length of the structure may be more critical than depth in this condition.

**Hope for the Future: Using Envision to Improve Sustainability**

* John Phillips, Parametrix

Infrastructure is at the heart of addressing this key challenge of the 21st century, and the standards and methods of the past will not be adequate to meet the needs of the future. A new paradigm is required.  
  
But how do infrastructure developers know whether their decisions are contributing to sustainability or not? How do they bring attention to the need for more sustainable infrastructure? How do they communicate around a shared understanding of what sustainability means? Envision provides a consistent, consensus-based framework for assessing sustainability and resilience in infrastructure. Envision:  
  
•Sets the standard for what constitutes sustainable infrastructure; • Incentivizes higher performance goals beyond minimum requirements; • Gives recognition to projects that make significant contributions to sustainability; and • Provides a common language for collaboration and clear communication both internally and externally.  
  
Envision is a framework that includes 64 sustainability and resilience indicators, called ‘credits’, organized around five categories: Quality of Life, Leadership, Resource Allocation, Natural World, and Climate and Resilience. These collectively address areas of human wellbeing, mobility, community development, collaboration, planning, economy, materials, energy, water, sitting, conservation, ecology, emissions, and resilience. These indicators collectively become the foundation of what constitutes sustainability in infrastructure.  
  
Each of the 64 credits has multiple levels of achievement representing the spectrum of possible performance goals from slightly improving beyond conventional practice, to conserving and restoring communities and environments. By assessing achievement in each of the 64 credits, project teams establish how well the project addresses the full range of sustainability indicators and are challenged to pursue higher performance.  
  
In this talk, the use of a sustainability processes through Envision will be discussed and examples of how to improve the performance of GSI using Envision as a tool to enhance the benefits of using GSI using existing GSI installations in the Seattle area.

**Tactical Green Infrastructure: Implementing Simple, Low-Cost, and Fast-Paced Stormwater Projects**

* Kevin Perry, Urban Rain Design, Inc

While the use of green infrastructure is becoming more widely accepted, many communities continue to struggle to implement green infrastructure due to the complexity of the design and construction, the high cost of implementation, and the widespread concern about long-term maintenance. This presentation highlights a new design methodology, developed by the nationally recognized landscape architect Kevin Robert Perry, called “Tactical Green Infrastructure”, that helps strategically implement simple, low-cost, maintenance-friendly, and highly-effective stormwater projects in a short amount of time.  
  
The purpose of this presentation is to introduce the audience to the principles, process, and successful examples of Tactical Green Infrastructure. Specifically, the author will introduce a unique public-private-academic program of Tactical Green Infrastructure called the Student Leadership in Green Infrastructure. Formed in 2015 by Kevin Robert Perry, the Student Leadership in Green Infrastructure is a group of inter-disciplinary students who work alongside design professionals to design, build, research, and advocate for simple and cost-effective green infrastructure projects throughout California- starting with university campuses as a canvas. Several Tactical Green Infrastructure retrofit projects have been completed to date in Northern California and the rapid success and recognition of this program has led to potentially expanding Tactical Green Infrastructure throughout the West Coast and beyond. This presentation will showcase several Tactical Green Infrastructure projects, including those implemented by the Student Leadership in Green Infrastructure program in a visually-rich and interactive presentation format including the use of videos of these projects during stormwater events.

**Session 3-4**

**A pilot water conservation site with LID and IoT monitoring design in Taipei city, Taiwan**

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| * Chi-Feng Chen, Chinese Culture University * Jen-Yang Lin, National Taipei University of Technology * Shyh-Fang Kang | * QingChi Cai * Liang-Hua Ko * Ching-Yu Wang |

Unban stormwater management is a key issue for a city which pursuing sustainability. Especially, under the challenge of climate change, unstable weather patterns and scarce water resource force people to upgrade drainage system and strengthen rainwater reuse simultaneously. Disperse onsite stormwater management with low impact development (LID) facilities is an optimal design to adapting the impacts from climate change. Taipei city is a basin surrounded with mountains, so that its drainage system is important and is designed with the highest standard in Taiwan. However, there are still flooding threats in some areas. A pilot water conservation site in BeiTou elementary school in Taipei city is designed to collect runoff from roofs and basketball court and the collected rainwater is then reused as irrigation water. The area of pilot site is around 200 m2. Two rain gardens and one underground rainwater storage are settled. The total surface of the pilot is permeable. In order to assess the performance of this site, 4 water level meters and 4 thermometers were placed and linked with IoT system to show the real time data on line. Moreover, the real time data are used to verify Storm Water Management Model (SWMM) and the model can be able to demonstrate the contribution of the pilot site on reducing the loadings of surrounding public drainage system. This pilot site was built in the summer in 2019 and stated to monitoring in September, 2019. The performance of the pilot site showed that the two raingardens and permeable pavements had at least 2oC temperature lower than the adjacent impermeable pavements and the highest difference was up to 7.64 oC. In a rainfall event with 56 hours and 165 mm, no runoff flew out from this site, meaning the runoff reduction was 100%. However, in the following typhoon event, the runoff reduction was only 16% because the volume of the underground storage was already occupied by the former rainfall event. We used SWMM model to simulate the performance of this pilot site under the designed rainfall events in Taipei city, which is 78.8 mm/hr. The simulations showed that the runoff reduction rate is 23%. With long-term monitoring data, the performance of the pilot site in water conservation, heat reduction, public education, and the related construction design and modelling applications are expected to be suggested to facilitate the adaptation capacity of a city.

**Urban-Rural Fring: A Perfect Place for Enhancing LID Infrastructure**

* Carol Wong, Center for Watershed Protection, Inc.
* Reid Christianson, University of Illinois at Urbana-Champaign

Due to proximity and lack of in-stream processing, nutrient losses from coastal land areas have a substantial impact on water quality in the Chesapeake Bay. This study evaluated the use of roadside ditch woodchip bioreactors to treat shallow groundwater as well as provide treatment and enhanced infiltration for storm flow. Three in-ditch bioreactors were monitored in Talbot County, Maryland in 2017 and 2018. Each bioreactor had three longitudinal (upstream to downstream) wells installed with pressure transducers to measure water depth. Weekly water samples were taken for analysis of nitrogen and phosphorus using HACH brand pocket ColorimeterTM II. High sediment concentrations were observed in many of the initial samples, which may have added to the variability of results. There was generally a slight decrease in total nitrogen concentrations between upstream and downstream, though no trend was seen in total phosphorus concentrations. Based on well water levels, substantial volumes of water infiltrated into these systems, which was an unexpected nutrient removal mechanism. Ultimately, implementing low impact development strategies in the urban-rural fringe, taking advantage of existing infrastructure, is a quick, inexpensive, and effective.

**Planting Strategies for Reducing Maintenance in Bioretention Facilities**

* Donna Evans, Montgomery County MD, Department of Environmental Protection

My current position managing the ESD/LID maintenance on public property for Montgomery County DEP has brought to the forefront a need to educate professional on correct horticultural practices and landscape design principles to reduce maintenance costs of bioretention facilities and improve aesthetics by using the correct plant for the space and understand how to arrange plants so they grow together in an attractive way. This process is multi stepped and one size does not fit all. I will be addressing how to make the proper plant selection based on specific site conditions, design/aesthetic, maintenance and plant cultural considerations and the process to decide on what kind of plant to use (tree, shrub, perennial, grass, ground cover) and how to arrange them based on facility size and aesthetic goals. Some case studies in the presentation include: • Replanting of green streets facilities in the Breewood community to improve aesthetics. • Replanting a medium sized facility at a local Senior Center to reduce maintenance costs and improve aesthetics using a more balanced planting plan approach. • Replanting of larger facilities that the public does not see regularly and is in a more natural setting for a once a year mow situation and pollinator benefits. Stressing plant size and spacing importance and a ground cover layer, testing different ground cover layers. • Cost comparison of all herbaceous plantings vs a balanced planting pallet of trees, shrubs, grasses, perennials and a ground cover layer of similar square foot coverage showing the reduced maintenance cost for the more balanced plan. Participants will benefit by having a template to work from for making more informed plant choices and plant arrangements for lowering maintenance costs and increasing public acceptance.

**NYC Rain Gardens' Effectiveness**

* Yara Elborolosy, NV5
* Joseph Cataldo, Cooper Union

The purpose of this paper would be to study both the cost and hydraulic effectiveness of the rain gardens in New York City. In 2015, New York City started to use rain gardens throughout the city as a cost effective method to reduce the water flowing into the sewer system. The rain gardens initially have a higher upfront cost, with some contracts averaging ,000 per rain garden, compared to the standard practice of piping or detention tanks but the maintenance cost will save in the long term. The current New York City sewer system also overflows during huge rain events so decreasing the amount of water or detaining some of it will help reduce the overflow and allow the system to last longer. Since 2015, there have been over thousands of rain gardens planted and still thousands more that will be constructed this upcoming spring. New York City Department of Environmental Protection has estimated that the first 90 rain gardens planted in Gowanus would be able to absorb over 8 million gallons of water each year. Over the last few years, there have been several design changes to help make them easier to construct and to allow for more stormwater collection. These changes, such as new types of rain gardens, allows the city to place rain gardens in more areas, reducing the amount of impervious area and replacing it with pervious area. The types of rain gardens that New York City currently uses are standard, green-strips, infiltration basins, and stormwater green strip (SGS) all differ by their dimensions, siting criteria, amount of filtration and detention rates. The green-strips are used for areas where there is limited room due to their reduced width. Infiltration basins are used for areas with lots of entrances because they can be designed with concrete tops for people to walk on. SGS are used in the streets where there is adequate space for them (very rare). The rain gardens not only help with increasing pervious area but they also help with water quality, helping remove nitrogen from the water before releasing it in to the sewer system. There have been several studies of areas with high chances of flooding due to the poor state of the sewer infrastructure with how much flooding they have. Recently, there have been rain gardens installed in these areas (such as Jamaica, Queens) and the amount of flooding will be measured to see how much the rain gardens have helped with the reduction of flooding. Knowing the amount of rainfall for each of the storms will also help in estimating the amount of inflow into the rain gardens. NYCDEP has several excel sheets available to calculate nitrogen removal and stormwater detention which can be compared to the experimental data from the field.

**INTEGRATING URBAN AGRICULTURE AND GREEN INFRASTRUCTURE IN WASHINGTON, DC**

* Harris Trobman, University of the District of Columbia, Center for Sustainable Development and Resilience
* Kamran Zendehdel, University of the District of Columbia, Center for Sustainable Development and Resilience
* Neil Weinstein, Low Impact Development Center

Urban Agriculture is a rapidly expanding movement that can provide multiple environmental, social, and economic benefits to the local community. Farms and gardens provide produce to the local community, beautify the city, improve air quality, moderate temperature, and provide critical social infrastructure. However, if improperly managed activities from urban farms can negatively affect water quality. Impacts from urban farming activities on water quality can be minimized by using adaptive best management practices (BMPs). Many practices can be devised to increase productivity, save urban farmer’s money, while improving water quality.  
  
The University of the District of Columbia (UDC) and the Low Impact Development Center (LIDC) have developed an innovative model that integrates urban agriculture into green infrastructure projects in Washington, DC. Prototype BMPs have been setup and are being monitored at three existing UDC CAUSES’ urban “Food Hubs” located in underserved areas of the District. This project focuses on using innovative, simple, and economically feasible methods to control stormwater at the community and household scale. At risk youth from the community were provided training and technical support to construct the projects. Community members are currently maintaining the projects utilizing through the technical support of UDC master gardeners. Additionally, a manual has been developed for community engagement and training urban farmers and gardeners on stormwater best management practices.  
  
This presentation will share transferable results and lessons learned from the pilot projects which includes monitoring of 3 BMPs, community outreach, workforce development training, and the development of a comprehensive manual to integrate green infrastructure best management practices into urban agriculture.

**Thursday Program**

**8:00 - 13:00 | Videos On-Demand**

**13:00 - 13:10 | Welcome and Introduction to Session 4-1 and 4-2**

**13:10 - 14:20 | Sessions 4-1 & 4-2**

**Session 4-1**

**Thoughtful Digital Evolution: Effective Green Infrastructure Asset Management**

* Ruth Hocker, City of Lancaster, Pennsylvania
* Marcus Quigley, EcoLucid
* Glen Recknagel, City of Lancaster, Pennsylvania

Although many municipalities have implemented some form of asset management and computerized maintenance management system (CMMS) for conventional assets, few have integrated green infrastructure into those systems effectively. The City of Lancaster Pennsylvania has undertaken an aggressive green infrastructure program as part of their clean water compliance efforts including a comprehensive GI inspection, monitoring and maintenance program. In order to manage the program efficiently and achieve compliance outcomes consistently, the City is implementing a fully digital green infrastructure asset management program and CMMS. This paper focuses on the development process and the implemented proposed solution and illustrates the thoughtful stakeholder engagement and tool development so critical for transitioning municipal manual processes to a fully digital system. The ultimate goal of these systems are to thoughtfully evolve and modernize City systems, reduce costs, gain insight into return on capital investments, maintain compliance, and protect the environment.

**Identifying priority sites for low impact development at a catchment scale based on the assessment of ecological risks induced by human activities**

* Qian Li, Tsinghua University
* Yang Yu, Tsinghua Shenzhen International Graduate School
* Haifeng Jia, Tsinghua University
* Yuntao Guan, Tsinghua Shenzhen International Graduate School

The pressure imposed by human activities is a leading cause of increased ecological risks to urban ecosystems. Low impact development (LID) has been progressively applied as a source and green solution to restore the hydrologic process of urban ecosystems and ultimately to mitigate risks. In order to identify the priority sites of LID solutions, it is essential to first understand the spatial features of ecological risks. We developed a framework for prioritizing LID sites based on an ecological risk assessment (ERA) and applied it to an environmentally sensitive catchment in Shenzhen, China. The ERA was implemented depending on a series of factors contributing to the spatial distribution of risks across the catchment, including topography, hydrology, vegetation coverage, human activities, and ecologically sensitive elements. We first employed the fuzzy analytic hierarchy process method to determine weights for these factors and then performed a multifactor-based spatial superposition analysis in the geographic information system to produce a risk map. The risk map was first validated to ensure the reliability of the ERA and then applied to establish the priority of LID solutions for the natural and built environment at the catchment scale. The map indicated that the area at extremely high risk accounts for 4.3% of the total catchment area, in which 60.4% of the area is built-up areas, mainly distributed in the area surrounded by the Dashanpo Reservoir, Chiao River, and Nanping expressway. These areas are considered priority sites for implementing LID solutions, which can restore ecosystem resilience of built-up areas by means of regulating rainfall-runoff process, reducing non-point source pollution at the source, and increasing rainwater reuse potential. It also showed that the natural environment with extremely high risk is mainly distributed around and within (21.8%) water-source reserves. LID solutions to prevent these ecologically sensitive elements from human activities should be considered on an urgent basis. The proposed framework of ERA-based LID site prioritization is conducive to develop effective LID implementation plans, which is also applicable to the sustainable urban development of other regions.

**Tracking Denitrification in Green Stormwater Infrastructure with Nitrogen and Oxygen Stable Isotopes**

* Charles Burgis, University of Virginia
* Gail Hayes, University of Virginia
* Wuhuan Zhang, University of Virginia
* James Smith, University of Virginia

Urbanization has made non-point source pollution a leading threat to aquatic ecosystems in developed landscapes. Sudden discharges of stormwater from paved surfaces results in flooding, erosion, sewer overflows, and pollution into receiving waters. One particularly important pollutant in the Chesapeake Bay Watershed is nitrogen. Green Infrastructure (GI) stormwater management practices mimic natural landscape hydrology by slowing, spreading, and infiltrating stormwater runoff before discharging it to receiving waters. GI is increasingly designed into urban landscapes to protect waterways from detrimental effects of urban stormwater, but it is still a young and developing technology with many performance knowledge gaps. GI has demonstrated ability to remove nitrogen from stormwater, but the removal mechanism is often unclear. Denitrification removes nitrate from water permanently, making it the most desirable removal mechanism. The extent of denitrification happening in GI is currently unknown, but a stormwater denitrification footprint can be observed by measuring shifts in nitrate stable isotope ratios. A roadside infiltration GI practice (bioretention basin) in Northern Virginia was monitored year-round to investigate its transport and removal of nitrogen. Stormwater runoff volumes, total nitrogen and nitrate concentrations, δ15N-nitrate, and δ18O-nitrate were measured at the inlet and outlet of the bioretention during 24 precipitation events over 14 months. Nitrate reductions displayed seasonal trends, with higher reductions happening in the summer and fall. Isotope results indicate that although bioretention has the potential for denitrification to occur, it is happening infrequently and other nitrogen removal mechanisms (e.g. infiltration and plant uptake) are primarily responsible for nitrogen reductions. Results are further used to show what conditions lead to denitrification how we can encourage it to happen more in our future stormwater management designs.

**Maximizing the Benefits of Standardized Green Infrastructure During and Post Construction**

* Eric Lienhard, Hazen and Sawyer
* Seth Charde, DC Water

In early 2017, DC Water, in collaboration with District agencies, developed a standard design process for permeable alleyways using GIS and standard construction details. Field tablets were used to quickly evaluate potential sites, where the efficiencies of a standardized approach would be realized. Working closely with permitting agencies, DC Water updated its design details to accommodate both a streamlined permitting process and the issuance of a blanket permit as well as creating a simplified design package for the Contractors to bid on. This process was further refined during the implementation of the Districts AlleyPalooza program.  
  
The partnership between DC Water and DDOT provided the opportunity to expand our standardization tool box to include simplified specifications, erosion and sediment control measures, MOT, and testing protocols. DC Water realized that implementing standard designs in a diverse, highly urbanized environment also comes with challenges and risks, and needed to remain nimble to account for these challenges, not just through the design process, but also during and after construction.  
  
The Potomac River-A and Rock Creek-A projects account for the first two of eight GI projects in the nation’s capital, part of its Long-Term Control Plan to reduce combined sewer overflows. Under DC Water’s consent decree, modified in 2016, the Authority will design and construct GI facilities to manage 1.2” of rainfall on 498 impervious acres between now and 2030.  
  
The Potomac River-A and Rock Creek-A GI projects highlight a myriad examples of variable physical site characteristics which the standard designs had to account for, such as unknown utilities, unclear property lines, buttressing tree roots, unusual street drainage, and degraded areas adjacent to proposed GI. Site verification, basic property line analysis, 360-degree imagery were critical tools for successful siting of standard designs during the design stage. However, DC Water was realistic and understood that undertaking construction of a standardized design in the built environment would require field adjustments to accommodate the unknowns when working in the urban landscape.  
  
During construction, the “one-size-fits-all” installation of a standard design proved to provide the construction efficiencies anticipated. Nonetheless, as green infrastructure was being constructed, performance due to site variabilities became apparent as well as the need for increased maintenance. For example, in finished alleys, the amount of sediment captured within the facility was due to the variability within the physical characteristics of the properties served by the alley. These characteristics included parking pad materials (concrete, stone, dirt), property interface with the alley (grass, landscape-wall with weep holes, bare dirt) and quantity of roof disconnections directed onto the alley. These elements are not always accounted for in developing a standard design but can cause performance and maintenance issues due to the fluctuation in sediment loading.  
  
Post construction monitoring of the facilities began in March 2019 and it was quickly observed that the flow restriction device valves that were installed, began to leak around the seals. These valves were initially tested during the design stage to determine the allowable release of water through the underdrain system back to the combined sewer. Once constructed, functional testing of the facilities proved that the valves were properly sealed and provided the necessary control of water back into the system. However, over time, the valve performance dropped. DC Water reviewed and tested many alternative solutions, and replaced the valves using a plug with orifice. A custom designed installation system was developed to install the plugs in pipes 5’ below the surface.  
  
Additional lessons learned and innovative solutions will be presented in the final presentation

**Using a new integrated decision support tool (i-DST) to optimize the benefits and tradeoffs of greener to greyer stormwater infrastructure in three cities across the United States.**

* Elizabeth M. Gallo, Colorado School of Mines
* Katie M. Spahr, Colorado School of Mines
* Colin D. Bell, City and County of Denver
* Emily Grubert, Georgia Institute of Technology
* Terri S. Hogue, Colorado School of Mines

Millions of dollars are spent annually by municipalities implementing green and grey stormwater control measures (SCMs) to meet objectives such as flood control or water quality permit compliance. More recently, municipalities are also considering additional benefits to the environment and local communities that could be generated by SCMs. With so much capital at stake, accurate estimation of the performance and life cycle costs (LCC) of the potential SCM alternatives is important. This work gives an overview on an integrated decision support tool (i-DST) which evaluates the benefits and tradeoffs of green, grey, and hybrid SCMs. The i-DST watershed scale tool utilizes the EPA’s System for Urban Stormwater Treatment and Analysis Integration (SUSTAIN) to optimize the types and numbers of SCMs in order to minimize cost and maximize a user selected evaluation target. Prior work has shown that 1) the optimal stormwater management plan is unique for each watershed, 2) greyer SCMs offer benefits that should be considered, and 3) LCC and co-benefits may be the tipping point in choosing one SCM over another. Initial testing of the i-DST planning tool is being undertaken on three watersheds across the United States (Los Angeles, CA; Denver, CO; Charlotte, NC). The fully developed iDST tool includes a BMP pollutant decay rate calibration tool, improved list of evaluation targets, greyer underground detention/infiltration SCMs, a LCC estimation, and a community co-benefit quantification. Modeling results demonstrate how the tool takes into account the unique physical/hydrologic characteristics and the municipal needs of the watershed in order to assist stakeholders in making holistic decisions for the optimal stormwater management plan.

**LESSONS LEARNED: CONSTRUCTING GI WITH THREE CONTRACTING MECHANISMS**

* Patrick DiNicola, RK&K
* Laura Bendernagel, RK&K
* Seth Charde, DC Water

DC Water recently completed construction and one year of post-construction maintenance for approximately 120 green infrastructure (GI) facilities built as part of DC Water’s Long Term Control Plan to reduce combined sewer overflows to DC’s waterways. The GI facilities were built in three dense residential neighborhoods with high pedestrian and vehicular traffic, numerous adjacent existing structures, and substantial underground utility networks. Most notably, three different contracting mechanisms were used for three distinct GI project packages, including Design-Build (DB), Design-Bid-Build (DBB), and Indefinite-Delivery/Indefinite-Quantity (IDIQ). Most facilities within the DB package were constructed using detailed plans and profiles. All facilities within the DBB and IDIQ packages were constructed using standard details with streamlined plans or no distinct plan sets. Constructing, maintaining, and observing this many GI practices afforded DC Water an invaluable opportunity to evaluate the challenges and successes of constructing different GI facilities using these various delivery methods and in turn, identify critical ways to adapt the delivery of future GI projects. These observations may benefit other GI or stormwater programs, as they impact a wide range of facets of the projects, including: • Cost and schedule; • Ease of obtaining and closing permits; • Ease of site layout; • Management of field changes; • Level of oversight and quality of final installation; • Protection of unknown utilities and structures such as laterals, foundations and inlets; • Maintenance during construction; • Functional testing, performance, and acceptance of the facilities; and • Development of facility specific documentation, including redlines and as-builts. This presentation provides a comparative overview of how each project progressed and the challenges associated with each contracting mechanism, as well as an overview of lessons learned with the intent of sparking conversation and knowledge sharing between localities, agencies, consultants, and vendors contributing to future implementation of GI practices.

**Session 4-2**

**A Road Map for Permeable Pavements**

* John Harvey, Univ of California Pavement Research Center
* David Smith, Interlocking Concrete Pavement Institute

In early 2017, the University of California Pavement Research Center and the National Center for Sustainable Transportation, working with the Interlocking Concrete Pavement Institute, identified gaps in knowledge and other barriers to wider implementation that were perceived to be holding back the full potential for deployment of pavements that can simultaneously solve transportation, stormwater quality, and flood control problems. Further discussions were held with the National Ready Mixed Concrete Association, the National Asphalt Pavement Association, and the Tongji University Sponge City Project in Shanghai, China. A workshop was organized in November 2017 to identify knowledge, information, and communication barriers to adoption of permeable pavement of all types, and creation of a road map to help overcome them. The workshop brought together a diverse group of stakeholders from the planning, stormwater quality, flood control, and pavement spheres to listen to presentations, exchange and discuss unanswered questions identified by the group. The group also provided a framework for a road map to fill the gaps in knowledge, processes, and guidance. This presentation summarizes the workshop deliverables. These include the following map routes with detailed deliverables and funding: Route 1. Infrastructure management organizations that consider the full functionality of permeable pavements Route 2. Planning guidance that considers the multi-functionality of permeable pavements Route 3. Accurate life cycle cost analysis and environmental life cycle assessment tools Route 4. Reduction of target pollutants to meet water quality requirements Route 5. Reduction of urban flooding risks Route 6. Reliable pavement structural designs Route 7. Routine achievement of high-quality construction. Route 8. Maintenance and rehabilitation costs and methods Route 9. Incorporation of permeable pavements into asset management systems Route 10. Efficient and comprehensive access to the best information

**Combining Optimization Modeling and Triple Bottom Line Analyses: Planning Efficient Infrastructure and Making Decisions Easier**

* Scott Struck, Geosyntec Consultants

The traditional approach for evaluating capital improvement options within networked hydraulic systems typically considers few alternatives. These alternatives are often modeled to understand the benefits of each, estimate the planning-level costs for the most promising alternatives, and select the most cost-effective alternative for more detailed design. This approach works well if the assessed area is small or the number of potential alternatives is limited. However, as the scale of master planning increases to include larger systems, watersheds, and entire towns, the need to evaluate many controls and conveyance systems result in a vast number of alternatives. The required resources using more traditional manual methods is very challenging and often results in incomplete, partial, or no comparisons of alternatives, resulting in the selection of less cost-efficient projects. With advances in computing power and optimization algorithms, a more efficient and objective-based approach to assess hundreds of thousands of capital improvement alternatives is possible. Using the Renfrew case study in the City of Calgary, a demonstration of how optimization software, hydraulic performance, estimated costs, and consideration of environmental and social benefits (e.g., triple bottom line assessment) will be presented to demonstrate least-cost alternatives scenarios for improved stormwater and conveyance systems benefits and convincing metrics for political decision making and policy development.

**Learning from the present: Improving LID design by considering O&M challenges**

* Carmen Franks, Brown & Caldwell

Successful LID design practice takes into consideration lessons learned from operations and maintenance of LID already in the ground. Often LID designers are experienced in planning, design, and construction oversight, but removed from long-term operations and maintenance tasks. Strengthening connections between LID designers and O & M staff for LID facilities and understanding the level, frequency, and type of maintenance that will be provided for LID, during the design phase improves the likelihood that LID practices will function properly and meet community aesthetics for their intended lifespan. Often simply placing a maintenance task list and schedule in the designs or specifications is not enough to ensure that LID facilities will be maintained properly; an acknowledgement of the maintenance capabilities of the city, agency, or other LID owner is critical for proper LID design. Case studies from Northeast Ohio will be presented to demonstrate how designs influence the long-term performance of BMPs, specific attempts by an LID installer/owner to reduce maintenance costs through minor upgrades to existing structures, and how to plan for the realistic level of maintenance that a site will receive.

**Functions of Bioretention for Cold Climate in Large Storms**

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| * Tong Yu, University of Alberta * Yanru Wang, University of Alberta * Yiyu Lu, University of Alberta | * Jinhao Li, University of Alberta * Wenming Zhang, University of Alberta * Xiangfei Li, EPCOR Drainage Services |

In cold climate, when bioretention that is primarily designed for small storms encounters large storms, how will the bioretention function? This research aims at finding answer to the question. Bioretention in cold climate experiences freeze-and-thaw cycles, affecting its functions with low temperature. Changing climate pattern leads to increased frequency of large storms (e.g., 1-in-100 year storm re-occurs in few years). We need data on the roles bioretention can play in urban flood mitigation in cold climate.  
  
The laboratory bioretention systems we built have capacity to control temperature from plus 22 to minus 20 degree Celsius and to simulate storms at various intensities. The two media, loam and sandy loam, were primarily designed for 1-in-2 year storms and had previously experienced complete freeze-and-thaw cycle, including annual events in summer-autumn-winter and during spring snowmelt runoff. In this study, the bioretention systems were subject to two events of 1-in-5, 1-in-10, 1-in-25, 1-in-50 and 1-in-100 year Edmonton storms, respectively.  
  
The experimental results demonstrate: (1) The bioretention systems can function to certain degree during large storms. The sandy loam medium maintained hydraulic function without overflow up to 1-in-25 year storms. For the 1-in-100 year storms, at least 50% of inflow filtered through both media, with at least 80% peak reduction. (2) With pre-treatment, both media had at least 90% TSS removal. (3) Repeated large storms reduced Ksat value of the media, affecting negatively on lifetime of bioretention; however, the saturated zone (for nitrogen removal) seemed to be a potential counter-measure to this negative impact.

**Impact of Street Leaf Litter on Phosphorus in Urban Stormwater Runoff**

* Yi Wang, University of Wisconsin Madison
* Anita Thompson, University of Wisconsin Madison
* William Selbig, United States Geological Survey

Urban street trees are a key part of public green infrastructure in many cities. Leaf litter on streets is a critical biogenic source of phosphorus (P) in urban stormwater runoff. Stormwater extracts P from leaf litter and transports it directly to a receiving waterbody through storm sewer network. The goal of this study is to understand P leaching dynamics of two prevalent tree species (Norway Maple and Green Ash) and its impact on end-of-pipe P concentration (Pconc) and load (Pload) in stormwater runoff. Five urban residential basins in Wisconsin were monitored by the U.S. Geological Survey to evaluate the water-quality benefits of municipal leaf collection during Fall 2017 and 2018. Laboratory experiments showed that total P release from Norway maple (2.10 mg/g) was greater than from Green Ash (1.60 mg/g). Within the same species, increased fragmentation of leaves led to more rapid initial P release, but not greater total P release over a 48-hour period. Increased decomposition of leaves led to a notable decrease in total P release. Incubation temperature and volume of water in contact with leaves may not be critical factors affecting P leaching dynamics. Multiple linear regression analyses were used to relate Pconc and Pload to street leaf litter characteristics and storm event hydrologic variables. The key explanatory parameters that affect Pconc were street leaf litter mass (Mleaf) and antecedent dry days, while Mleaf and runoff volum explained Pload. Results from our study can be used to evaluate P reduction credits for leaf collection in regulated cities.

**14:30 - 14:40 | Welcome and Introduction to Session 4-3 and 4-4**

**14:40 - 15:50 | Session 4-3 & 4-4**

**4-3 Building Equitable Stormwater Infrastructure - A Panel Discussion**

* Jaqueline Goodall, Interim Executive Director, Maryland Black Mayors Inc., Former Mayor, Town of Forest Heights, Washington, DC metro area
* Rita Kampalath, Ph.D., P.E., Sustainability Program Director, Los Angeles County, Los Angeles, California
* Sara Meerow, Ph.D., Assistant Professor, School of Geographical Sciences and Urban Planning, Arizona State University, Tempe, Arizona
* Marccus Hendricks, Ph.D., Assistant Professor, Director at Stormwater Infrastructure Resilience and Justice (SIRJ) Lab, University of Maryland, College Park, Maryland

**Session 4-4**

**Moving SCM Design from Storm-Based to Continuous Simulation**

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| * Amanda Hess, Villanova University | * Robert Traver, Villanova University |

In Pennsylvania, stormwater designers must manage the net change in the pre- vs. post-development runoff volume from the 2-year/24-hour storm per § 102.8(g)(2) for volume and geomorphologic concerns. This statement lends itself to analysis using design storm or single storm-based methodologies. Design storms were developed with the best available data at the time, however with the development of computing power and availability of long-term rainfall records (i.e. 15-30 years), it is possible to design Stormwater Control Measures (SCMs) through continuous simulation. When approaching SCM design through continuous simulation, a challenge is to meet the intent of the regulatory requirements that were formed based on the design storm approach. The authors propose to use the same statistical basis to analyze the continuous simulation output that has been used to develop design storms. As PA’s volume requirement is based in the 2-year/24-hour storm event, the 50% exceedance probability This presentation includes examples that consider all aspects of a rain garden SCM design (using various infiltration rates) in comparison of the two approaches (i.e. design storm vs continuous simulation). Beside volume and peak flow associated with the 2-year/24-hour storm, one geomorphologic benefit to the continuous simulation approach is the ability to develop flow duration curves. The flow duration curves for these examples show that the receiving stream has reduced exposure to flows associated with the 2-year/24-hour storm and below. Continuous simulations use the EPA SWMM tool to model the interaction of the long-term rainfall patterns, climate, and soil physic processes to produce a more efficient and resilient SCM design. Results demonstrate the advantages of the continuous simulation approach, and its applicability to other green infrastructure SCM. As PAS's volume requirement is based in the 2-year/24-hour storm event, the 50% exceedance probability is used to meet volume requirements using continuous simulation.

**Green infrastructure right-of-way inlet type selection: Hydraulic, hydrologic, and siting factor considerations to optimize long-term design capture goals**

* Andrew Anderson, Hazen and Sawyer
* Kristin Connors, Hazen and Sawyer

Optimizing stormwater capture for urban green infrastructure is contingent on the placement and performance of inlets. It is crucial to thoroughly examine the benefits and drawbacks of each type when designing a reliable system, be they grate, curb opening, combination, or slotted drain inlet types. In ultra-urban environments, site constraints often control the selection and placement of inlets, introducing the complication that hydraulic preferences may not always be achievable. Careful optimization is needed to achieve stormwater capture goals while minimizing costs, considering maintenance efforts, and protecting public safety. Inlet and green infrastructure functionality will be discussed as a function of site factors and hydraulic factors, including through the lens of future climate and rainfall pattern variability. The presentation will provide a detailed analysis of these factors to ensure the appropriate inlet tributary to green infrastructure is installed at the optimum location, including placement at gutter sag points or upstream of sag locations (“on grade”) when future more intense rainfall patterns play a role. Implications of improperly-sized or sited inlets will be discussed, including localized ponding and idle green infrastructure systems. Hydraulic considerations that can be exacerbated by future climate hydrologic variability include debris clogging, slope, drainage area, and inlet geometry. The annual performance of green infrastructure under different rainfall intensity scenarios associated with climate uncertainty will be used to examine inlet configurations insofar as green infrastructure performance is concerned, while addressing these impacts on alleviating roadway drainage hazards.

**Green Stormwater Infrastructure Buffers Surface Water from Deicing Salt Loading**

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| * Charles Burgis, University of Virginia * Gail Hayes, University of Virginia * Derek Henderson, University of Virginia | * Wuhuan Zhang, University of Virginia * James Smith, University of Virginia |

Winter deicing salt application has led to water quality impairment as stormwater carries salt ions (Na+ and Cl-) through watersheds. Green infrastructure (GI) is a promising urban stormwater management practice, but its efficacy in managing salt is unknown. GI is not yet designed to treat salt, but may have potential to mitigate its loading to surface waters. Two roadside infiltration GI practices in Northern Virginia (bioretention and bioswale) were monitored year-round over 28 precipitation events to investigate the transport of salt through modern stormwater infrastructure. Stormwater runoff volumes and concentrations of salt ions entering and exiting each GI were monitored to determine reductions of salt ions. Both the bioretention and bioswale significantly reduced loads of Cl- and Na+ (76% to 82%), displaying ability to temporarily retain and infiltrate salts and delay their release to surface waters. Changes in bioretention soil chemistry revealed a small percentage of Na+ was stored long-term by ion exchange, but no long-term Cl- storage was observed. Limited soil storage along with groundwater observations suggest the majority of salt removed from stormwater by the bioretention infiltrates into groundwater. Infiltration GI can buffer surface waters from salt, but are also an avenue for groundwater salt loading.

**Porous Concrete Panels in a NYC Street: From Design Through Post-Construction Monitoring**

* Anthony Falcone, HDR
* Meghan Broderick, HDR

As part of the New York City Department of Environmental Protection (DEP) Green Infrastructure Program, the Bureau of Environmental Planning and Analysis (BEPA) implemented a pilot project in Rego Park, Queens to install and test the performance of precast porous concrete panels in a typical NYC street. BEPA initiated this pilot project for a 27-acre contributing drainage area to achieve the green infrastructure related milestone requirements of DEP’s Combined Sewer Overflow (CSO) Consent Order. This pilot project also fulfills the requirements of Local Law 80 of 2013, which requires a study be conducted within streets and sidewalks to gather information on the design, construction, maintenance and performance of various porous paving materials. Construction of 6,270 linear feet of porous concrete panels was completed in January 2019. The panels extend from the curb line into the street at a width of four feet, bound by a flush curb on the street side. HDR oversaw field and geotechnical investigations, provided a preliminary design report, final construction documents, design services during construction, pre- and post-construction performance monitoring and maintenance studies to carry out the first large-scale pilot project of porous concrete in the City’s right-of-way. Siting and design were coordinated with NYCDOT, NYCDPR, and local utility agencies to accommodate varying field conditions and geotechnical criteria, adhere to design criteria, and address conflicts. This allowed us to implement stormwater retention in an area that prohibited other types of green infrastructure. Additionally, design services during construction were vitally important to address any challenges that arose during implementation. Performance monitoring will be conducted during 12 month pre- and post-construction periods. In addition to flow measurements, performance monitoring is comprised of visual observation, traffic analyses and controlled testing. Design, construction and post-construction monitoring phases have concluded. Lessons learned during design and construction, as well as data collection procedures and observations from monitoring will be shared during the presentation.

**Stressors, Ecosystem Services, and Restoration Strategies for a Central New Mexico Arroyo**

* Gerhard Schoener, SSCAFCA

Approximately 60% of all streams in the conterminous U.S. are ephemeral or intermittent. In the southwestern U.S., they make up more than 80% of all water courses. While dry during most of the year, ephemeral streams (also called arroyos) episodically convey runoff and sediment following intense summer storms. Arroyos provide a wide range of ecological functions such as habitat and hydrologic connectivity. Perhaps less notably, they also furnish ecosystem goods and services important for human well-being: groundwater recharge, water quality benefits and recreation, to name just a few examples. Despite their vast spatial extent, dryland watersheds and the arroyo systems they support have received less attention compared to their perennial counterparts. Under natural conditions, arroyos are in a state of dynamic equilibrium between sediment supply and transport. This equilibrium is disrupted by urbanization. In urban areas, impervious cover causes increased surface runoff. This, in turn, increases the magnitude and frequency of runoff events. At the same time, imperviousness prevents erosion, and runoff from municipal areas carries little sediment. Increased discharge and decreased sediment supply lead to channel degradation. In the past, runoff from urbanizing areas was often treated as a nuisance, and arroyos were seen as having one sole purpose: to get rid of stormwater as fast and efficiently as possible. This short-sighted view of ephemeral systems overlooks the multitude of ecosystem services they provide. Channel degradation has a profound negative impact on the welfare of dryland watersheds and the people that inhabit them. This study examines one arroyo in central New Mexico where urbanization-induced stressors have led to substantial degradation. Engineered elements designed to increase channel stability have had the opposite effect and exacerbate the problem. Important ecosystem services provided by the stream are identified, and possible restoration strategies are discussed. This example demonstrates that low impact development in a semi-arid setting requires rethinking of traditional engineering approaches.

**Evaluating a Permeable Gutter and Street Tree Treatment Train for Stormwater Management**

* Sarah Waickowski, NC State University
* Amethyst Kelly, NC State University
* William Hunt, NC State University

Previous research regarding street trees designed for stormwater management have demonstrated the ability to remove pollutants; however, bypass does occur during intense storm events. Research by North Carolina State University (NCSU) indicates a treatment train consisting of permeable pavement parking stalls and a street tree system located underneath the adjacent sidewalk can reduce bypass. However, this combination of stormwater control measures (SCMs) can be expensive and difficult to maintain. As a result, NCSU, the North Carolina Clean Water Management Trust Fund (CWMTF), and the City of Burlington have collaborated to design, construct, and monitor the state’s first permeable gutter and street tree treatment train. Inflow is estimated using an EPA Storm Water Management Model (SWMM) while water quality data is collected from a nearby catch basin using a paired watershed experimental design. Water quality samples are also collected from the gutter and street tree’s underdrain systems. Effluent hydrology and bypass are monitored at a catch basin located immediately downstream of the treatment train. Results from this study will include the system’s pollutant removal and hydrologic efficiencies as well as design and maintenance recommendations.

**15:50 - 17:05 | Expanded Session: Permeable Interlocking Concrete Pavement**

* David R. Smith, Technical Director, Interlocking Concrete Pavement Institute

Presentation Outline

* Introduction and site suitability evaluation methods and tool
* Municipal flood reduction examples and pollutant reduction performance
* Hydrologic design overview
* Structural design method developed from full-scale PICP load testing
* Construction do’s and don’ts
* Handling slopes and utilities
* Maintenance evaluation methods and recent developments in cleaning equipment

**15:50 - 16:35 | Technical Tour: Restoration of the Breewood Watershed and nearby locations using LID Tools**

The Breewood Watershed, located 5 miles north of the D.C. Capital Beltway, encompasses 64 acres of high-density suburban development that drains to the Breewood Tributary. Development in this watershed had occurred between 1950 and 1970. Land cover imperviousness went from almost zero to 42% during this twenty-year period. Restoration efforts in the Breewood Tributary were aimed at reversing impacts from 40 - 60 years of uncontrolled stormwater runoff on this small headwater stream.

In 2009 the Montgomery County Department of Environmental Protection identified the Breewood Tributary for a comprehensive watershed restoration effort as required in the County’s MS4 permit. Planning, design, and implementation of solutions in this watershed took over 10 years. The Breewood Watershed Restoration Project includes stream restoration , and a range of various LID practices on private and public property including, bioretention, raingardens, tree-boxes and pervious concrete. In total, these LID practices provide water quality treatment of stormwater runoff from 17.3 acres or 65% of the imperviousness in the Breewood Watershed.

One of the more significant challenges was securing landowner permission to construct LID projects on private property. A key aspect of receiving owner permission was the County’s ability to provide on-going maintenance of LID practices in perpetuity. The project was completed in 2018. Early monitoring results from biological and habitat sampling, as well as automated stream samplers will be reviewed.

Implementation of LID practices through the CIP process in Breewood was completed at four separate locations, 1) University Towers (Condominiums), 2) Northwood Presbyterian Church, 3) Breewood Manor Neighborhood streets and 4) Breewood Road bioretention. In addition, a few residential properties participated in the effort to restore the stream with rain garden projects. There were some unique design challenges and redesign efforts which have informed other projects, particularly in the area of rain garden planting design.

The Breewood project was part of a larger effort by the department to restore stream health in the Anacostia stream system. Many other retrofits were added nearby, but outside of the Breewood Watershed. These projects center around the Dennis Avenue corridor and include the first Green Street project in the county in Forest Estates, a Sinuous Swale at Lanark Way and a number of projects in the Dennis Ave corridor including Green Streets Gardens and Sligo Middle School CIP and RainScapes for Schools projects. This tour highlights the ways the department has found to retrofit stormwater management facilities that are both functional and beautiful. This tour will summarize lessons learned as DEP implemented an ambitious range of design, construction, community engagement and maintenance and monitoring of these projects

**Friday Program**

**8:00 - 13:00 | Videos On-Demand**

**13:00 - 13:20 | Introduction to the Closing Plenary on Bioretention**

* Scott Struck, EWRI President
* Bridget Wadzuk, Panel Moderator

**13:20 - 14:40 | Closing Plenary- Future Opportunities of the Value-Add of LID**

Lauren Smalls-Mantey- Lauren Smalls-Mantey, Ph.D is an Environmental Systems Analyst working at the New York City’s Department of Health and Mental Hygiene. Her research focuses on adaptation and mitigation measures that reduce the impacts of extreme heat. She is the lead research analyst for the Cool Neighborhoods NYC Initiative.

Carol Wong, Center for Watershed Protection- Carol Wong is a Professional Engineer with a Bachelor of Science in Mechanical Engineering from the University of Maryland College Park and a Master of Science in Environmental Engineering from Stanford University. Carol has worked at the Center for Watershed Protection for the past six years, with responsibilities including program management, workforce development training, BMP research and design, stormwater plan review, construction inspection, and water quality monitoring. Prior to joining the Center, Carol worked for the private sector as a consultant, managing environmental research and development projects for the Army.

Allen Davis, University of Maryland- Allen P. Davis, PhD, PE, F.ASCE, F.EWRI, D.WRE is Professor and Charles A. Irish Sr. Chair in Civil Engineering in the Department of Civil and Environmental Engineering and Affiliate Professor in Plant Science and Landscape Architecture at the University of Maryland.  For over two decades, he has been investigating sources and treatment of pollutants in urban stormwater runoff with a focus on nature-based practices, particularly bioretention. He is Editor-in-Chief of the ASCE Journal of Sustainable Water in the Built Environment.

Emily Clifton, LID Center- Emily Clifton is a Senior Environmental Planner and Scientist at the Low Impact Development Center. Emily has more than 18 years of experience in environmental planning, green infrastructure planning, natural resources management, and stormwater management. Emily has provided leadership on green street master plans and concept designs; LID design manuals; LID and stormwater pollution prevention trainings; plan development and review; and research related to green infrastructure and resiliency. Emily holds an M.S. in Environmental Science, a Master in Public Affairs, a B.A. in Business Administration, and a B.A in Philosophy.

Dwane Jones, UDC- Dwane Jones is currently the Acting Dean of the University of the District of Columbia's College of Agriculture, Urban Sustainability, and Environmental Sciences (CAUSES). He is a leader with over nearly 20 years of combined experience in leadership, green infrastructure programs, research, urban design, environmental planning and program management with government, academia, nonprofit and community based agencies and international governments and universities. Dwane uses design thinking to problem solve, innovate, prototype, execute, and research human-centered challenges while using sustainability as a lens to address these problems.

**15:00 - 17:00 | Integrated Decision Support (I-DST) Beta Testing for Stormwater Practitioners**

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| * Katie Spahr * Terri Hogue * Elizabeth Gallo * Mengistu Geza | * Ali Shojaeizadeh * Emily Grubert * Aysegul Petek Gursel * Arpad Horvath |

The i-DST is a planning-level stormwater decision support tool that helps practitioners select the most appropriate suites of green, grey, and/or hybrid infrastructure. The tool is modular and composed of site-scale and sewer-shed scale hydrologic modeling, life cycle cost and life cycle assessment, and a co-benefit analysis. The sewer-shed hydrologic model uses an updated version of the EPA’s SUSTAIN to optimize the types and numbers of varying stormwater infrastructure in order to determine the best-fit scenarios for decision makers. Updates to SUSTAIN for this tool include a new user friendly GUI (Qt) to read, write, and run SUSTAIN input files, an improved list of evaluation factors to optimize on, greyer underground detention/infiltration infrastructure, and a life cycle cost estimation tool that is integrated with the SUSTAIN optimization engine. The co-benefit analysis is utilized to evaluate the benefits and tradeoffs between greener and greyer stormwater infrastructure. The purpose of this workshop is to beta test the different modules of this tool and receive feedback from participants. The team running the workshop will provide a test case scenario, but participants are encouraged to bring their own data (i.e. modeled or observed flow/water quality times series, stormwater infrastructure design parameters) to be input into the tool.

**15:00 - 16:30 | Planting Strategies to Survive and Thrive: Keeping the Bio in Bioretention**

* Ann English, RainScapes Program Manager, Department of Environmental Protection, Montgomery County, MD
* Darlene Robbins, RainScapes Planner, Department of Environmental Protection, Montgomery County, MD
* Donna Evans, Program Manager, Stormwater BMP inspections & Maintenance, Department of Environmental Protection, Montgomery County, MD

Plants are a key part of LID/GSI bioretention systems. They provide functional value and multiple environmental, social, and community benefits. LID systems are touted as a visual amenity to communities through lush plantings and immersive landscapes. Achieving and maintaining LID as a community amenity takes work and practitioners have found it is more difficult than initially thought to bring the lush landscape to life. Plants need water and good soil conditions, competition with weeds needs to be controlled, and maintenance crews need to know what they are maintaining.

This workshop will give practical tips on how to create and maintain a planted landscape to survive and thrive. What are the best plant selections, what establishment regime is needed, and how little maintenance can be done? This interactive workshop will bring together landscape professionals and municipal program managers to give you the time tested and latest techniques to create bioretention landscapes to survive and thrive. Bring your planting challenges and share with the group while the experts provide strategies and solutions. Practical solutions will be discussed that you can incorporate into your planting designs and program.

**15:00 - 15:20 | Technical Tour: Alger Park Stream Restoration and LID Retrofit**

On this virtual tour, you will visit Alger Park in SE Washington, DC and see how a comprehensive subwatershed stormwater management approach was applied in tandem with stream restoration. The objective of this project was to restore about 1,500 feet of stream in a neighborhood parkland as part of a larger project to improve water quality, reduce stormwater volume, stabilize the stream, and improve habitat conditions. A highly incised and eroded stream gully was restored using regenerative stream design techniques, neighborhood streets were retrofitted with green infrastructure, and residents were engaged and offered incentives and rebates for the installation of lot-level green infrastructure, all as part of a comprehensive approach to watershed management.

**15:20 - 15:40 | Technical Tour: Carter Barron Stormwater Retrofit Project**

On this virtual tour, you will visit an 11-acre project area in Rock Creek Park that was retrofitted with a variety of innovative green infrastructure to restore natural hydrology, prevent erosion, reduce stormwater pollution, and protect and restore existing natural habitat for wildlife, including endangered species. The project was identified as a priority restoration area by the U.S. Fish and Wildlife Service, National Park Service, and the District Department of Energy & Environment due to the impacts of a highly impervious subwatershed on existing habitat along Rock Creek.

**15:40 - 16:00 | Technical Tour: Stormwater Retention Credits & Mount Olivet Cemetery Green Infrastructure**

On this virtual tour, you will be introduced to the District of Columbia’s first-of-its-kind Stormwater Retention Credit trading program. The presentation will provide key background on the credit trading program as well as the District’s innovative Stormwater Retention Credit Price Lock program. The tour includes a virtual visit to historic Mount Olivet Cemetery to highlight one of the success stories of these programs.

**16:00 - 16:20 | Q & A for Friday Technical Tours**