Drones: Applications and Limits for SCM Inspections

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Highlights

- UAS inspection requires a trained pilot, trained data processing and a trained SCM inspector.
- UAS may be suitable for visual inspections in areas with minimal vegetation and obstacles.
- UAS is not well suited in dense vegetation or where detailed inspection is required.

Introduction

Stormwater Control Measures (SCM) require inspections during construction and throughout service life to meet permit requirements and ensure function. Costs associated with the inspections are difficult to secure, leading owners to seek alternatives. Unmanned Aerial Systems (UAS), more commonly known as drones, are being explored for many applications. While there are many beneficial uses, often the expectation of grand cost savings is misleading and inaccurate. Making the most informed decisions requires thorough understanding of both the intended use and the UAS capabilities. To assess the viability of UAS use in SCM inspections, a literature review and a mock SCM inspection were performed.

Background

UAS Flight Requirements

In the United States, drone flight is governed by the Federal Aviation Administration (FAA). The FAA stipulates all flights must be conducted by a pilot who has successfully passed a knowledge test and acquired a UAS pilot certificate under Code of Federal regulations (CFR) Title 14, Part 107 (Part 107). Under Part 107, pilots must maintain visual line of sight with the drone under operation at all times, either themselves or through the use of helpers called visual observers.

UAS Data Types

The most commonly used type of drone is called a multi-rotor drone. These units may be equipped with various types of cameras, scanners and imaging devices to collect the desired information. Data types relative to the subject of SCMs includes photographs, video, photogrammetry and LiDAR. These data types align with traditional inspection and survey information acquired via manned aircraft or ground observation methods.

SCM Inspection Types and Requirements

Stormwater Inspections covers a broad range of individual inspection types. This review is limited to UAS use in:

- During Construction Erosion and Sediment Control Inspections;
- During Construction PCSM SCM Critical Stage Inspections;
- Post-Construction SCM Service Life Inspections.

Key Findings

For each inspection type, permitting agency and SCM owner impacts the information collected which ultimately impacts the viability of drone use. This is based on general terms applicable to the most common inspection approaches. Every inspection type discussed requires data entry into a prescribed form either in paper, pdf or electronic App format. In all cases, the step of UAS data collection to the required documentation formation will require manual human data interpretation and effort. This effort must be accounted for on a case-by-case basis to assess efficiency of UAS use.

<u>During Construction Erosion and Sediment Control Inspections</u> (E&S Inspections) using traditional methods typically involve visual observations over the entire active construction site. Sites generally have low to no vegetation and other ground obstructions around. Physical measurements requiring human presence are minimal. The limited physical measurements, low vegetation and large connected area typically associated with active construction sites offers significant UAS use potential using photographic and video data collection. Use may be restricted on linear roadway projects adjacent to live traffic where FAA regulations and safety limit feasibility of image collection.

During Construction PCSM SCM Critical Stage Inspections (Critical Stage Inspection) traditionally involve visual and physical measurement comparisons to PCSM Plan information. Critical stages also involve observing work activities over extended periods of time to confirm proper construction techniques. Physical dimensions of work may be confirmed during some critical stages using hand measurements or survey data including length, depth, relative distances and elevations. UAS cannot easily replace in-person observations of construction technique confirmation or observations inside outlet structures and pipe connections which are required to confirm construction accuracy. However, UAS offers beneficial support of in-person activities including photographic documentation and, with more advanced equipment/post-processing, LiDAR or photogrammetry data acquisition to develop surface topography mapping.

Post-Construction SCM Service Life Inspections (Post-Construction Inspections) also traditionally involve visual and physical measurement comparisons to PCSM Plan information. SCM vegetation growth often fully or partially obstructs the view of deficiencies such as erosion, animal damage and inflow/outflow structural decline. Field inspections require measurement of pipes, components inside inlet/manhole boxes and other hands-on activities such as soil probing to check soil layers. The majority of SCM designs include satisfactory access for in-person hands on inspection access. In the very limited instances where physical access into the SCM is unsafe, UAS images offer an alternative, visual-only limited inspection. Due to the needed measurements and physical testing observations required for Post-Construction Inspection, the mass majority of locations offer limited benefit of UAS use over traditional methods.

Recommendations

UAS use for SCM inspection must be assessed on a case-by-case basis. In some cases, drones offer cost effective, reliable inspection information to replace or support traditional in-person activities. In other cases, UAS use results in a higher cost and/or inaccurate inspections potentially missing critical issues.

Site locations with limited obstructions with no physical testing needs are the most viable. Construction E&S inspections where areas are generally denude of vegetation offer the most likely effect use of UAS services. Critical Stage Inspections may be augmented with UAS topographic survey data acquisition, but will not replace the majority of the in-person inspection needs. Post Construction Inspections will likely have minimal benefit from UAS imaging due to the visibility and flight obstruction presented by mature vegetation. Without proper planning, the use of an UAS can result in more expensive inspections, factoring in the cost of the drone pilot, the data processing/storage and the cost of the trained subject matter inspector interpreting and entering the data into required inspections formats.

References

Pennsylvania Department of Transportation (2021). Stormwater Control Measure Maintenance Manual, Publication 888, November 2021.

National Academies of Sciences, Engineering, and Medicine. 2023. Use of Unmanned Aerial Systems for Inspection of Stormwater Best Management Practices. Washington, DC: The National Academies Press. https://doi.org/10.17226/27139.

Code of Federal Regulation (CFR) 14, Part 107; https://www.ecfr.gov/current/title-14/chapter-I/subchapter-F/part-107 (accessed 2024-03-11)

Data-Driven Approach to Enhance Green Stormwater Infrastructure (GSI) Performance

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Abstract

Quantification of green stormwater infrastructure (GSI) performance/assessing its effectiveness is important to ensure it functions as intended, maintenance requirements, future planning guidance etc. to achieve sustainable urban stormwater management. GSI, such as rain garden performance can be measured through identifying trends of recession of ponded water through surface infiltration and evapotranspiration. Over time the function of these highly dynamic systems can impact the performance GSI. Hydrological modelling is a common practice to design and identify maximum performances of these GSIs. Advancement of technology coupled with advancements in observational data have created an opportunity to advance prediction of GSI preform overtime under a diverse change of conditions. Data-driven machine learning algorithms help to understand relationships or correlations between variables in a dataset to gain knowledge about GSI dynamics. Along with these data directly observed at a GSI location (e.g., precipitation, ponding depth, temperature, etc.), derived features can also be incorporated (e.g., storm intensity, storm volume, storm duration, previous dry days, etc.) and spatial features (e.g., sediment generation, liter indices, population density, etc.) to increase the model's ability to capture complex relationships between GSI and their environment. Long-term or specific rainfall events performance prediction of GSI systems is important to know to make well-informed decisions for GSI projects and create data-driven maintenance plans. This investigation seeks to identify important features/factors and length of data requirement to predict individual GSI performance to help maximum performance and ultimately sustainability of these systems.

Keywords: Green Stormwater Infrastructure (GSI), Performance, Recession, Observational Data, Machine Learning Algorithm

Historical Storm Events as an Alternative to Design Storms

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Highlights

- SCMs using historical storm event to meet peak rate design storm based regulatory standards.
- Using historic events for peak flow embraces green practices and reduces detention footprint.
- Flow duration curves from historical event design demonstrate geomorphologic protection.

Introduction

In the United States, most Stormwater Control Measures (SCM) regulations are based on a central-peaking synthetic design storm developed from extreme event hydrology statistics that were originally intended for structures whose failures would be catastrophic (Yen and Ang 1971). In Pennsylvania (PA), stormwater designers are required to manage the peak rate of the pre vs. post development from the 2-, 10-, 25-[1], 50-, and 100-yr/24-hr events. In addition, water quality and volume control are necessary for the 2-yr/24-hr storm (PADEP 2006).

The term "X-yr/24-hr storm" is featured throughout the regulations (PA Code 2023), leading to analysis using overly conservative design storm-based methodologies for stormwater management, that heavily weight the intensities in the center of the storm. Counterintuitively, the use of this conserve methodology does not necessarily result in a more conserve design. The pattern from actual rainfall events, which SCMs are intended to manage, tend to have periods of light rain and rarely, if ever, have high intensities in one centered period (Figure 1). The design storm preconstruction scenario often results in overly high peak flows from the conservatively extreme event, which is then the 'goal' to be met in the postconstruction design. This can also reduce the protection of protection from low, frequent storms.

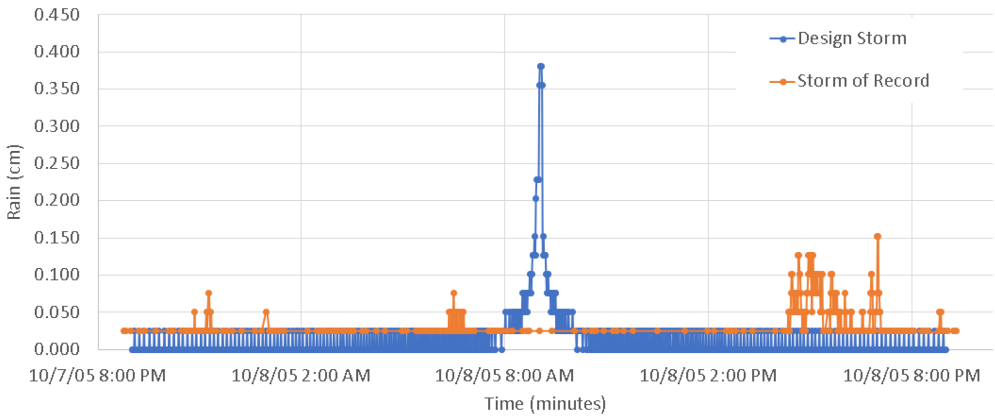

Figure 1. Comparison of a 25-yr/24-hr in Philadelphia (14.8 cm) to a storm event occurring on 10/7/2005 date with 15 cm over 24 hrs.

With the wealth of readily available 1 minute rainfall data, this work explores the option of using historical rain events (termed "storm of record approach") of similar total volume and duration as the required peak rate management. Additionally, a 15-year continuous simulation with a record of rainfall that contains all required peak flow storm events was performed to determine the flow duration of the design of an SCM system (rain garden and detention basin) based off the proposed method and design storm approach.

[1]Not a PA SCM requirement but included as it is a storm sewer requirement.

Methodology

Proof of Concept Modelling

This study uses the USEPA Stormwater Management Software (SWMM) to model a 0.405-hectare conceptual site of meadow in preconstruction converted to 100% impervious area controlled by a rain garden and downstream detention basin (Figure 2). The rain garden is designed to target volume control and water quality for storms up to and including the 2-yr/24-hr storm) and has been designed to do so using the 15-year continuous simulation. The detention basin is designed to mitigate peak rate effects for the 2-100-yr/24-hr storm events.

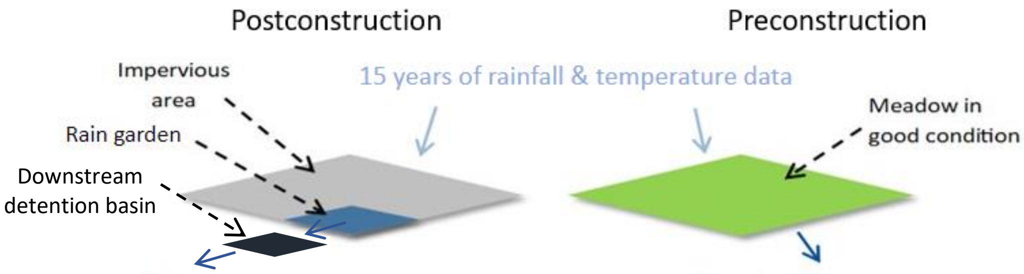

Figure 2. Conceptual schematic of pre- and post-construction SWMM model and inputs.

Rain Garden Design

Fifteen years (2005-2020) of 1 minute precipitation and daily temperature records from the Philadelphia International Airport station were obtained. Evapotranspiration was modelled via Hargreaves equation based on daily minimum and maximum temperature. Infiltration was modelled using Green and Ampt equation with a saturated hydraulic conductivity of 12.2 cm/d and a suction of 351 cm of water. The resulting design of the rain garden (Figure 3, left) manages the 2-yr/24-hr event (or 50% exceedance using partial duration statistics; Figure 3, right).

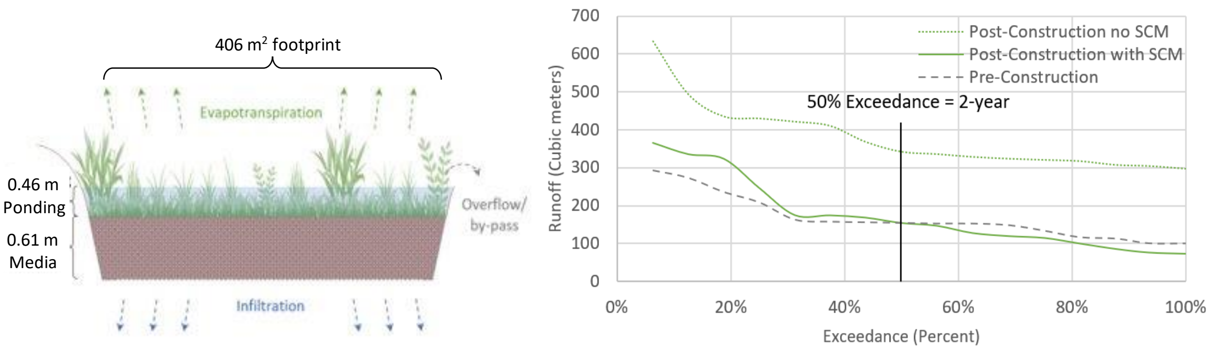

Figure 3. (left) Schematic of rain garden design and (right) continuous simulation result to design for 2-yr/24-hr volume (50% exceedance) requirement. The “post-construction with SCM” is only referring to the management of flow that leave the rain garden.

Detention Basin Design

The detention basin located downstream of the system was modelled with a static 0.91 m depth with straight sides and the footprint size and outlet box design that is optimized for two methods of peak rate management: storm of record and design storm approach.

The selection of the storms of records to represent the 2-,5-, 10-, 25-, 50-, and 100-yr/24-hr storms were based on total volume of the storm event between NOAA 14 median depth and upper 90% confidence interval depth and occurred within a 24-hour period. Shorter duration storms (as short as 11 hours) that met depth were considered as well since they are more conservate and enabled this method to be used for infrequent storm events. Storm events that occurred between 2005-2020 where prioritized. If multiple storms of record could meet the criteria, the one with the highest 5- and 10-min peak intensity and the longest duration, not exceeding 24 hours, was used (Table 1). However, for the 50-year return period a different approach was taken. The only storm of record available, that met the above criteria, in recent time occurred in September of 1999, which was recorded in hourly data. To assimilate this data, the program NetStorm was used to disaggregate the hourly data to one minute rainfall data (Heineman, 2004). The one-minute data for the 1999 storm was added to 2012, the lowest annual rainfall volume that occurred in 2005-2020.

Table 1. Design storm total depth, 5- and 10-minute intensity for the return interval and historical storm of record that correlated to the design storm based on selection criteria.

Design storm (24-hour duration)				Historical Storms of Record				
Return Interval	Depth (cm)	Peak intensity (cm/hr)		**Date**	Depth (cm)	Duration (hr)	Peak intensity (cm/hr)	
		5-min	10-min				5-min	10-min
2-yr	8.92	1.04	1.65	**6/6/2013**	8.43	24	0.30	0.61
5-yr	10.36	1.22	1.93	**9/30/2010**	10.82	19	0.38	0.69
10-yr	12.19	1.42	2.29	**9/10/2015**	12.17	24	0.56	1.02
25-yr	14.86	1.73	2.77	**10/7/2005**	14.99	24	0.56	1.04
50-yr	17.12	2.01	3.20	**9/16/1999***	18.59	15	0.64	0.79
100-yr	19.56	2.29	3.66	**7/28/2013**	20.98	11	1.91	2.92

* Note this storm is out of the 2005-2020 range and thus added to 2012

The outlet box in the detention basin design was based on a T-shaped weir with a low flow orifice, however many more variety of designs could have been employed. The detention basin height was kept at 0.91 ft in depth for both designs. First, the detention outlet weirs and orifice were designed to manage the peak flows in postconstruction (as close to the preconstruction rates) using the design storm approach for all return intervals listed in Table 1. The resulting footprint of 93 m^2 was found to work well for the design storm approach. Next, a different outlet weirs and orifice design was developed using the storm of record approach for all storms listed in Table 1. The footprint size of this design was reduced to try to maintain similar maximum depths that were seen in the design storm approach. The full 15-year simulation (including the 1999 storm) was run through both designs to obtain flow duration curves.

Results and discussion

The resulting configuration of the detention basin outlet (Figure 4) indicated that a smaller basin size was needed for the storm of record-based design (70 m^2 vs 93 m^2 for design storm) in addition to smaller maximum depth (0.56 m vs 0.76 m for design storm).

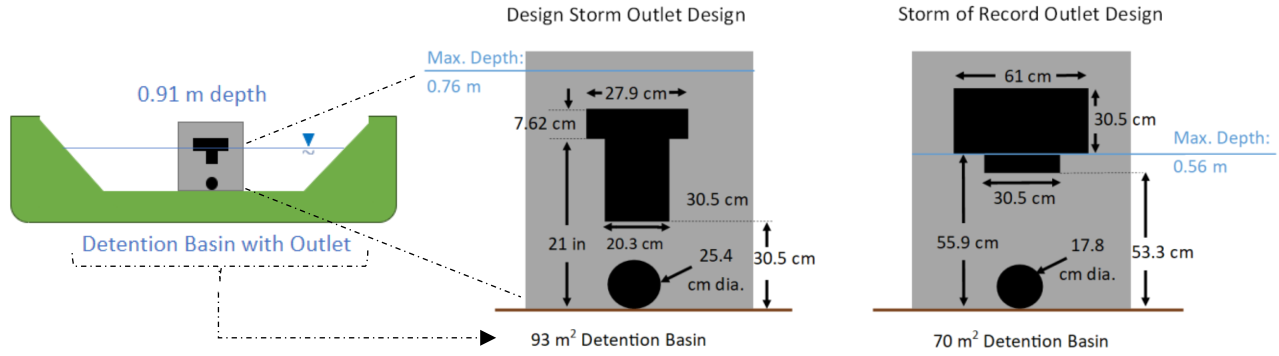

Figure 4. (left) schematic of the detention basin, (middle) design storm-based outlet box configuration and footprint size, and (right) storm of record outlet box configuration and footprint size.

Although reduction in facility size will likely enable more options for stormwater management, a more important finding is the range of flows that the detention facility is targeting in each design (Figure 5 left). For the design storm approach, the preconstruction range of flows for the 5-, 10-, 25-, 50-, and 100-yr/24-hr storms are approximately between 0.81 to 2.09 cms (grey shaded area in Figure 5 left), which indicates that the postconstruction peak flows can also be in this range. In this case, the postconstruction flows ranged from 0.012 to 2.09 cms and were not as high as the preconstruction for the smaller extreme events due to the rain garden treatment prior to the detention facility. It should be noted that the design of the rain garden is based on the 2-year/24-hr storm event which is quite high volume (about 5-8 cm) for volume and water quality control compared to other states (which typically range from 0.7 mm to 3.8 cm; USEPA

2016). For the storm of record approach, the range of flow is much smaller (0.035 to 1.38 cms; blue shaded area in Figure 5 left) for both pre and postconstruction.

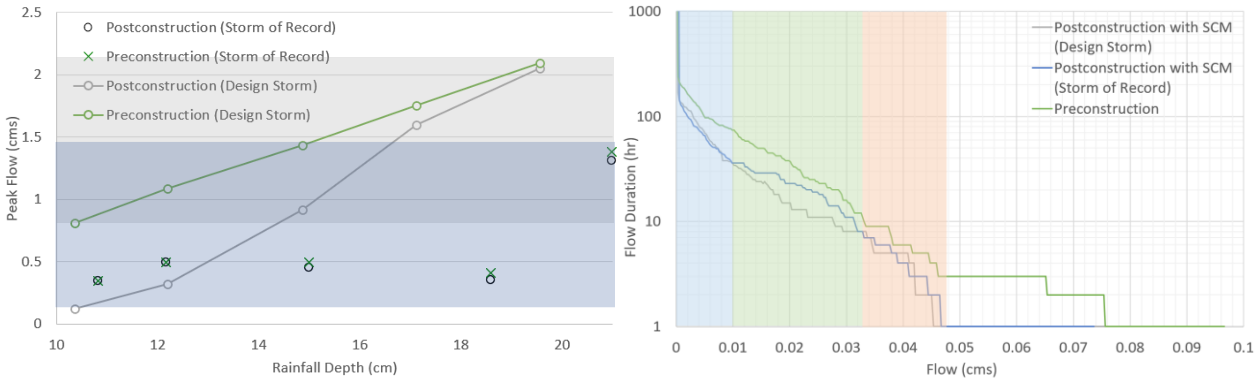

Figure 5. (left) Pre and postconstruction peak flows for both the design storm and the storm of record approaches to the detention facility and (right) flow duration curve (in hours) for preconstruction and postconstruction with SCMs (rain garden and detention basin) for design storm approach and storm of record approach for 15-year continuous simulation.

The storm of record approach is targeting a comparably smaller range of flows than the design storm but is also providing more resiliently in the range of flows that can be expected to be experienced during the lifetime of the SCMs. Furthermore, when designing for the range of flows that design storm produces in preconstruction, a much larger amount of flow will be able to be released in postconstruction compared to real storm events. To ensure that the storm of record approach would not contribute negatively to downstream effects, a flow duration curve for a 15-year continuous simulation was developed for both methods (Figure 5 right). The blue shaded area is where the rain garden is controlling flows below 0.01 cms. The green shaded area (flows of 0.01-0.031 cms) is where the two methods are most different and the shaded orange area (flows of 0.031-0.05 cms) is where both methods are effectively behaving similarly. Both designs are effective at being lower than or equal to the preconstruction flow duration. However, the high end of extreme range of flows that the design storm designs for (0.014 to 0.20 cms) is rarely, if ever experienced the 15-year continuous simulation. Because the storm of record approach is focusing on management of a realistic range of extreme storm flows, it can still meet preconstruction conditions while also reducing the size of the detention facility.

Conclusions and future work

Main conclusions and key findings include:

- Storm of record approach resulted in smaller detention facility compared to design storm.
- Design storm peak flow analysis results in a less resilient SCM as it allows for more flow to be exported from using an extremely conservate method for the preconstruction condition.
- Flow duration curves indicate that the storm of record approach can manage flows more efficiently in a smaller facility and still meet or surpass preconstruction conditions.

Future works includes exploring this method in different areas across Pennsylvania that experience different rainfall patters and have different soil types.

References

Heineman, M. (2004). "NetSTORM - A Computer Program for Rainfall-Runoff Simulation and Precipitation Analysis," World Water and Environmental Resources Congress, American Society of Civil Engineers. 10.1061/40737(2004)395

Pennsylvania (PA) Code. (2023) Title 25 Chapter 102 § 102.8. PCSM requirements. https://www.pacodeandbulletin.gov/

Pennsylvania Department of Environmental Protection (PADEP). (2006). *Pennsylvania Stormwater Best Management Practices Manual.*

Pennsylvania Department of Environmental Protection (PADEP). (2023). *Pennsylvania Post-Construction Stormwater Management (PCSM) Manual*. Draft Version.

United States Environmental Protection Agency (USEPA). (2016). *Summary of State Post Construction Stormwater Standards.*

Yen, B.C. and A.H.S. Ang. (1971). 'Risk Analysis In Design of Hydraulic Projects,' Paper presented at 1st International Symposium on Stochastic Hydraulics, University of Pittsburgh, Pittsburgh, Pennsylvania.

Extended Abstract

A "CLOUD" SOLUTION TO CLIMATE RESILIENT STORMWATER INFRASTRUCURE

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Introduction: Exelon's Vintage Pond Gets Smart

The construction of Exelon's stormwater management pond dates back to 1981. The pond is located in the upper reaches of the Middle Gwynns Falls Watershed and was one of the earliest stormwater management ponds constructed in Baltimore County, Maryland. The pond was designed to function as a flood mitigation device, with no consideration given to achieving a water quality treatment function (the standard in this era). Having learned of a significant stormwater management advancement where artificial intelligence, cloud computing and real-time data could be leveraged to drastically improve stormwater management pond performance Exelon elected to retrofit their 43-year-old stormwater pond with a *Smart Stormwater Management System*.

Methodology:

The state of wireless connectivity and microcomputer technology make it now practical to precisely control the timing, volume and rate of discharge from stormwater management facilities; thereby greatly enhancing their performance. Traditional Stormwater Management design techniques utilize static synthetic rainfall distributions that are often assumed to last exactly 24 hours. Smart Stormwater Management Systems utilize artificial intelligence to adapt stormwater management facility behavior to hyper-local precipitation forecasts; both precipitation quantity and temporal distribution. Smart Stormwater Management Systems react to this data in real time, even when the forecast updates. Likewise, Smart Stormwater Management Systems maximize the opportunity for runoff reduction by retaining the runoff volume for the entire period of time between storm events. In so doing Smart Stormwater Management Systems maximize the opportunity for pollutant reduction, aquifer recharge and/or stormwater reuse. This "technology driven" stormwater management technique produces unprecedented runoff reduction and flood mitigation; even when stormwater management facilities would otherwise have limited flood control capacity.

When Smart Stormwater Management Ponds release stored water, they do so in advance of the impending precipitation event and at the minimum discharge rate possible to minimize the erosive energy imposed upon the downstream channel/stream. The timing of releases from Smart Stormwater Management Systems are typically offset from that of other portions of the watershed; thereby further reducing both downstream erosion and flooding. Smart Stormwater Management Systems optimize the flood control capability of stormwater infrastructure by actively controlling discharge rates and volumes.

Highlights and Key Findings

Exelon's "Smart Pond" achieves unprecedented pollutant removal and flood control performance while also creating an attractive property amenity. Exelon's new Smart Pond is particularly significant since the Middle Gwynns Falls watershed is classified as a High Environmental Justice Concern Area by the

Baltimore County Department of Environmental Protection and Sustainability with very limited opportunities to install stormwater management practices. Kevin Hedge, senior environmental project manager at Baltimore Gas and Electric (BGE), estimated the stormwater credits generated by the pond modernization saved BGE approximately $450,000.

Recommendations

Smart stormwater management technology is still quite new and its capability varies by service provider. The stormwater management research, regulatory and consulting industries are only now starting to recognize the benefits derived from its use. Research on the technology's capabilities are limited. Exelon will be sharing its Smart Pond performance data with Dr. Claire Welty, Professor of Chemical, Biochemical, and Environmental Engineering and Director of the Center for Urban Environmental Research and Education at the University of Maryland, Baltimore County (UMBC) in support of the research she is performing for the Chesapeake Bay Trust Restoration Research Program.

References

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Re-"connecting" the Delaware River Basin with Smart BMPs

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Highlights

- Adaptive BMP Technology improves performance by 5-10X
- Multi-stakeholder collaboration leads to scalable and cost-effective stormwater management
- Innovation can meet and exceed NPDES MS4 standards

Summary

The William Penn Foundation, along with the Center for Watershed Protection and Lower Moreland Township, PA, are leading a pilot program in the Delaware River Basin to implement innovative and adaptive stormwater best management practice (BMP) technology. This cutting-edge approach aims to mitigate the effects of stormwater runoff. Studies have shown that this innovative method can enhance water quality by 30-50% and elevate wet weather capture to 90%, surpassing the performance of conventional passive BMPs.

Background

The Delaware River stands as a vital lifeline, supplying drinking water to over 15 million individuals and embodying a national treasure. However, its integrity faces threats from urbanization, climate change, and stormwater runoff, which precipitate flooding, habitat loss, and water quality degradation, significantly impacting communities.

Across the Delaware River Basin, collaborative efforts are underway to identify and implement cost-effective restoration practices to counter these impairments. The partnership between the William Penn Foundation, Center for Watershed Protection, and Lower Moreland Township, PA, recognized an innovative and adaptive BMP as an opportunity to bolster existing infrastructure and address various stormwater objectives, including quantity and quality.

Traditionally, passive BMPs were tailored to singular objectives, lacking adaptability to changing environments and comprehensive storage utilization. In contrast, innovative solutions integrate real-time data from field sensors and weather forecasts to monitor performance and autonomously adjust stormwater storage and flows. Studies have validated the efficacy of adaptive BMPs, showcasing a 30-50% improvement in water quality and a 90% increase in wet weather capture compared to passive BMPs.

This presentation will offer insights into the watershed drivers, funding mechanisms, project design incorporating adaptive BMPs, construction and implementation processes, regulatory compliance, pollutant reduction strategies, and delineate the subsequent steps required to advance smart, resilient stormwater management systems across the Delaware River Basin.