Step-tiered bioretention bed design: monitoring performance for stormwater quality enhancement

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Highlights

- Enhanced conductivity reduction in stormwater runoff in successive steps
- Identified seasonal conductivity patterns: highest in winter, lowest in summer, intermediate in spring and fall
- Observed decreased porewater cation concentrations in subsequent steps

Introduction:

Untreated stormwater runoff can significantly impair rivers and streams by introducing pollutants that harm aquatic life and the associated ecosystems. To mitigate these adverse impacts, it is crucial to decrease stormwater runoff and intercept pollutants to safeguard ecosystems. Urban stormwater management systems widely incorporate bioretention beds to achieve these objectives. In the United States, urban stormwater infrastructures received a grade of D on a scale from A to F (Infrastructure Report CARD, 2021). The report also highlighted that from 2010 to 2018, the extent of impaired watersheds expanded from 424,000 miles to 588,000 miles due to stormwater. One of the innovative stormwater management designs is the step-tiered bioretention bed. The objective of this design feature is to improve water infiltration and reduce peak runoff (Chen & Chui, 2022). However, the effectiveness of this design feature for intercepting pollutants has not previously been investigated. This research focuses on the effectiveness of this bioretention system to reduce stormwater-derived pollutants. To achieve this objective, a key parameter for understanding pollution loads, conductivity, was monitored.

Methodology:

Conductivity monitoring:

Conductivity was monitored using HOBO U24 conductivity loggers (Onset Computer Corporation, Massachusetts, United States), which were deployed in each step, and near the outlet, designated as I-Step-1, I-Step-2, I-Step-3, and I-outlet (Figure 1). Data was offloaded approximately monthly. With each data transfer, three conductivity standards (0, 100, and 1000 µS/cm; Oakton conductivity standard, Cole-Parmer, Illinois, United States) were measured by each conductivity sensor to check the accuracy and stability across the sensors.

Lysimeter monitoring:

Suction lysimeters (SoilMoisture Equipment Corp, California, United States) were installed in the same locations as the conductivity sensors to collect porewater to evaluate concentrations of major cations (Na, Mg, K, and Ca) and changes in conductivity. Lysimeters were installed at 15 and 30 cm depths. Storm-associated lysimeter samples were collected monthly.

Figure 1: Deployed conductivity sensors in a step-tired bioretention bed. The yellow icon shows the approximate location of sensors.

Key findings:

Stormwater derived conductivity values were lower in each subsequent step. Data from approximately 13 months of monitoring revealed that average stormwater conductivity at each step were as follows: Step 1 (150 µS/cm) > Step 2 (126 µS/cm) > Step 3 (80 µS/cm). Seasonal variations were observed with an overall higher conductivity during winter, followed by spring and fall, and the lowest in summer. Analysis of lysimeter samples from August to December of 2023 showed a similar decreasing trend in cation concentrations across the steps. Among these cations, the order of average concentrations is as follows: Na (103 mg/L) > Ca (78.6 mg/L) > Mg (15.9 mg/L) > K (13.1 mg/L).

Recommendations

These findings demonstrate that the step-tiered bioretention bed effectively attenuated stormwater pollutant concentrations, with the initial step playing a critical role in pollutant interception. Our study supports the implementation of step-tiered bioretention beds as an optimized option for stormwater management systems pollutant management, thereby offering a promising strategy for protecting aquatic and associated ecosystems from stormwater-derived pollutants. This study is ongoing and additional monitoring efforts include collection of surface runoff and porewater to analyze above mentioned cations and anion, such as chloride, along with sensor observations to have comprehensive understanding of inorganic ion fate and transport in step-tiered bioretention bed.

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Providing Access for the Future of SCMs

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Highlights

- SCMs are increasingly viewed as a critical asset for those responsible for owning and maintaining them.
- Access for SCM maintenance is critical to SCM functionality and longevity of these assets.
- Maintenance access needs should be considered and incorporated into the SCM design process.
- Evaluate SCMs types and equipment needed to perform maintenance when designing access.

Introduction

Stormwater Control Measures (SCMs) play a crucial role in managing stormwater runoff and improving water quality for all proposed development whether it be urban or rural areas. An often-overlooked aspect of SCM design is providing adequate access for maintenance. Proper maintenance is essential to ensure that all SCMs continue to function as designed. Poor or limited access can hinder the inspection and maintenance processes that are required to keep the SCM operating properly.

Designing SCM Maintenance Access

SCMs that are accessible will facilitate routine inspections and maintenance that are critical to the successful long-term performance of the SCM. Timely maintenance not only extends the lifespan of SCMs but also enhances the ability to treat stormwater runoff efficiently and as designed. During the design process, access for maintenance should be given the same level of design consideration as the rest of the SCM. SCM access has not historically been prioritized in the design process and is often an afterthought. The future of stormwater management will require access to become an integral part of the design process.

There are several factors to consider when designing maintenance access for SCMs. The access design should be site specific to each SCM. A "one size fits all" approach is not acceptable. Critical components of the SCM (e.g. outlet structure, forebay, cleanouts, etc.) also need to be accessible in addition to the general SCM location. It is not as simple as providing access for a vehicle next to the SCM. The type of maintenance equipment required for the SCM and how it will be brought to the site will affect the access design. Other considerations include, but are not limited to, maximum longitudinal slopes, turning radius, cross slopes, turnarounds, surface treatment, and various safety considerations.

The importance of SCM maintenance access cannot be overstated. Performing SCM maintenance will ensure that the as-designed functionality will continue to be achieved. Embracing a proactive approach to maintenance access design is essential to the long-term operation and maintenance of the SCM.

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Pump It Up- Designing SEPTA's resilient transit infrastructure!

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Highlights

- A detailed analysis of the contributing factors flooding SEPTA's critical trolley infrastructure.
- Developing a cost-effective and constructable design to address the problem.
- Delivering a design-build project through the pandemic, combatting unprecedented material and labor shortages.

Introduction

The Sharon Hill Flood Mitigation project was initiated as part of the Southeastern Pennsylvania Transportation Authority's (SEPTA) Infrastructure Resilience Program to improve the transit system's resilience against flooding. JMT's holistic and sustainable design approach provided a stormwater pump station and flood storage basin. The presentation will focus on the design solution, permitting approach, and constructability.

Background (for case study)

This $9.5M design build project was completed for SEPTA by Walsh Construction with JMT as the lead engineer.

Pre-construction conditions included a low point for a 48 acre drainage area exists along the SEPTA right-of-way, approximately 750 feet north of the Sharon Hill Trolley Station, where SEPTA tracks pass underneath CSX railroad. During storm events, runoff from the surrounding neighborhoods in Collingdale and Sharon Hill Boroughs discharges onto the SEPTA right-of-way and was conveyed through drainage channels along SEPTA tracks to a 30-inch gravity main that ultimately outfalls to Hermesprota Creek. This system resulted in the frequent inundation of the Route 102 tracks during storm events and renders the line non-operational, forcing major impacts to SEPTA service. The project's objective was to improve drainage systems to facilitate the efficient removal of stormwater runoff from the track right-of-way to a proposed flood storage basin which ultimately discharges to Hermesprota Creek, and to avoid the fouling and/or inundation of track. The design level of service is the 25-year, 24-hour rainfall event.

The proposed design solution was to construct a stormwater pump station with maximum capacity of 88 MGD. The runoff from the 48-acre drainage area is conveyed using precast U-shaped channels to the pump station inflow. The pump station consists of three 150 horsepower pumps and one sump pump, the system was designed with pumping capacity redundancy to ensure functionality. The electrical equipment is located on the roof of the pump station in a prefabricated building, the roof/equipment elevation corresponds to computed storm event water surface elevation that will allow the system to avoid impacts during major storm events. Since the pump station was located on a steep embankment, the back wall of the pump house acted as the retaining wall at 30" thick. The pump house required a generator pad which was built adjacent to the pump house on an elevated pad matching the pump house roof elevation, this elevation will keep the generator above computed storm event water surface elevation to maintain functionality during large storm events.

The pump raises the stormwater over 11 feet where it is then discharge to a 54" IPS HDPE forcemain. The forcemain is roughly 400 linear feet in length and outfalls to the flood storage basin. The flood storage basin provides over 300,000 cubic feet of storage volume. The design is intended to discharge to Hermasporta Creek to meet the existing flow rates established by the existing 30" discharge pipe. The proposed basin outlet structure is an open 24" pipe. An emergency structure is also provided to manage the larger storm events. These structures are connected through a truckline that extend over 600 ft to discharge to the creek. JMT's design approach was to minimize environmental impacts and permitting which impacts the design and construction schedule. Therefore, the discharge pipe was designed to be 36" diameter to minimize the permitting requirements and impacts to the waterbody.

The basin is located on the PECO property and the adjacent PECO substation is intended for future expansion. SEPTA and PECO developed an agreement to permit the SEPTA flood control basin on their property. The basin area was limited, and the design needed to maximize its volume capacity. To do so, the basin is designed with 2:1 side slopes and a 150'+ long retaining wall along the western edge of the basin. The project design criteria was for the 25 year storm event, when that elevation is reached in the basin there is a floatable level sensor which transmits to the pump station to shut off the pumps, when the pumps shut off a scenario similar to existing conditions occurs where the low point along the SEPTA tracks becomes inundated. This will only occur for storm events which exceed the 25 year storm event and once the water surface elevation in the basin draws down by draining thru the proposed 24" pipe the sensor will reactivate the pump station.

JMT's innovative design relieves SEPTA's acute vulnerability to flooding at a critical trolley station in Delaware County, PA. Additionally, JMT and the contractor have worked together to find alternate design solutions, materials, and vendors to maintain the proposed construction schedule throughout the COVID pandemic and during industrywide supply chain issues. This collaboration was critical due to the number of site constraints which impacted constructability.

Key Findings

1- Discuss the impacts of unmanaged stormwater which creates significant flooding on SEPTA tracks.
2- Explain the design approach for providing a comprehensive solution including an 88MGD pump station with a 300,000 CF detention basin.
3- Constructability challenges (1) working in limited spaces and access due to proximity to existing infrastructure owners and (2) revising design to accommodate material availability.

Recommendations

SEPTA's Sharon Hill Rt 102 station is vulnerable to flooding, often displacing customers and impacting business operations. Resilient solutions need to be devised to protect assets. Often these solutions are complex and challenging to construct. Through the design-build process, JMT and Walsh were able to deliver a resilient solution through the delivery of the Sharon Hill Pump Station.

Introducing the iNode:
An Intelligent IoT Node for Low-Cost Remote Data Acquisition, Sensing and Actuation

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Highlights

- Transmits data over the Cellular Network, (or wifi, Bluetooth, USB). IoT / Cloud-enabled.
- Stores up to 2MB data locally for off-network locations, backup, or communication outages.
- Multiple sensor interfaces / types: (analog, digital, SDI-12, RS 485, Serial, I2C, 4-20mA pulse)
- Low power consumption from 12V or 5V supply with ESD and current overload protection.
- Also provides remote actuation capability (eg. for motors, servos, valves etc)

Introduction

On-site sensing and data acquisition is complicated by issues of connectivity and power. Typically, mains power is not available so the system must operate on solar or battery power with a very limited power budget. Likewise, wired connections for monitoring live data are not available, so either the data must be stored locally and/or it must be transmitted wirelessly using wifi (short range), LoRa (Long Range radio), cellular (long range), or satellite (very long range) communication. Furthermore, the data acquisition / telemetry system must be able to interface to a variety of different sensors (eg. for measuring soil moisture, water depth, conductivity, pH, temperature, air temperature and pressure, rain etc), each of which may use a different protocol or standard. To address these needs, several suppliers, including notably (Campbell Scientific 2024), (InSitu 2024), (Solinst 2024) have developed proprietary turnkey solutions. While these systems are robust and reliable, they are also relatively high-cost and typically require users to subscribe to a proprietary 'back-end' in order to access the data which is stored in a cloud repository. These costs are prohibitive to many NGO aid organizations working in water supply and management in low-income countries. The aim of this project was therefore to develop a low-cost system, with similar or potentially enhanced functionality relative to that of existing commercial systems. The system builds on the recent advent of highly-capable low-cost microprocessors specifically designed for Internet of Things (IoT) applications. In addition to data logging, storage, and telemetry, the system also offers remote output / actuation possibilities, for activating other devices, motors or valves etc.

Methodology and Background

System Architecture

Remote monitoring and acquisition systems typically comprise a sensing unit (measuring water depth for example), a telemetry unit (for transmitting this data), a cloud-based data repository, and a user interface for accessing the results as illustrated in Fig. 1. The long-term goal is to develop low-cost replacements for each of these subsystems. Initial discussions with end-users suggested that the ongoing/recurring costs associated with back-end data management were actually more limiting than initial hardware costs. The first phase of this work therefore developed a new back-end system (Silk 2023) which automatically pipes data from existing commercial sensing/telemetry hardware into a 'VC4HE' (Villanova Center for Humanitarian Engineering) database hosted at Villanova University. The database is non-proprietary and conforms to the Observations Data Model (ODM) that was developed by the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI) to provide a standard format for storing hydrologic observations in a relational database (Horsburgh 2008). The present work is now focused on the second phase, namely the design and implementation of a new telemetry gateway system called the iNode (intelligent Node).

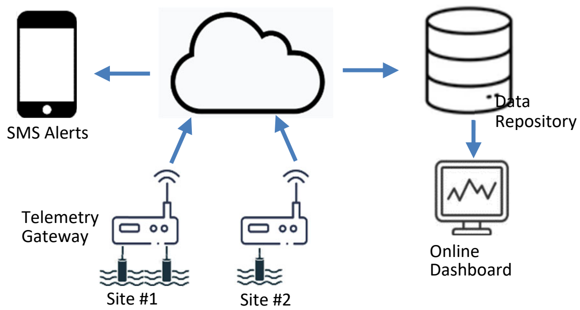

Figure 1. System architecture

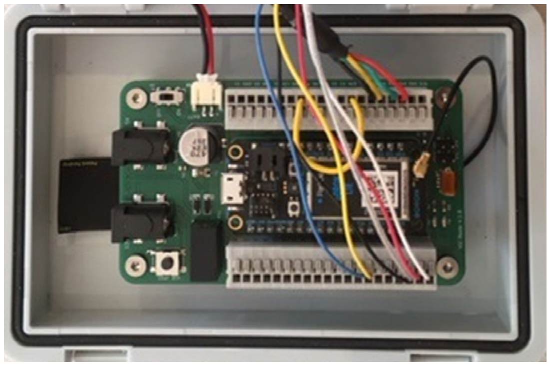

Figure 1. The iNode PCB

iNode Design and Specification

The iNode is designed around a family of 32-bit ARM processor devices marketed for IoT applications (Particle.io 2024). A cellular-enabled Particle Boron sits on a custom 'iNode' Printed Circuit Board (PCB) as shown in Fig. 2. Edge connectors provide easy interfacing to a variety of different sensors / actuators. The system has the following features:

Onboard features

- 32-bit ARM processor with onboard Cellular (Boron) or Wifi (Argon/Photon2) communications.
- LiPo battery and management/charging system to ensure continued processor operation during power outages
- 2MB onboard file system for data storage and backup when cloud communications are offline.
- 5 channel analog input + 4 channels digital IO including 2 channels high current drive for motors / relays / servos
- Clock for sampling control
- Pulse input (eg. for rain sensor)
- onboard temperature and baro pressure sensor

Cloud Control*:* A Graphical User Interface built on Google Sheets provides:

- Remote control of sampling period, reporting period, sleep mode, actuator outputs, and firmware update.
- Cloud storage of data. The data is also automatically piped to desired repository endpoints, eg. VC4HE.

Serial Communications*:* for local communication with other digital devices and sensors

- USB (virtual COM port) to PC host
- RS 485 half-duplex transceiver
- I2C (for 3rd party 3.3V sensors)
- On-board UART: (shared with RS 485 and SDI-12)
- SDI-12 half-duplex transceiver
- Bluetooth

Power*:*

- The system is powered from either 12V or 5V power. A LiPo battery ensures the processor is always powered.
- 12V, 5V and 3.3V Sensor power is controlled by the iNode and is generally disabled except during the sampling process. When 'sleeping' between samples with the cellular radio off the system consumes less than 1 mA.
- iNode-controlled sensor power outputs are ESD and over-current (short-circuit) protected.

Conclusions

The iNode is a new IoT-enabled intelligent data logging, storage and telemetry system providing remote configuration/programming, data streaming and actuator outputs at a cost of less than $150 (without enclosure).

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Stop the Leaks! Exploring Repair Techniques to Seal GSI Outlet Structures

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Abstract

As part of PWD's continued monitoring efforts of publicly owned green stormwater infrastructure (GSI), over 150 GSI systems have been identified with unsealed outlet structures (known as green-grey inlets) allowing stormwater to leak out of the GSI system and into the sewer system, effectively dampening the performance of the GSI system. As the structures age and the materials degrade, these leaks can become quite significant. Patch repairs using mortar have been ineffective and entirely replacing the structure is expensive and could damage adjacent GSI infrastructure. To minimize leakage and extend the lives of these structures, PWD has experimented with an injectable foam and full lining the structures with hydraulic cement. Testing is ongoing to assess the leakage from the structures before and after repair work. To date, over 35 structures have been tested with another 15 scheduled. While the work is still ongoing, PWD believes that these repair methods and testing efforts could improve existing GSI performance and provide valuable guidance to GSI design and maintenance activities.