# Comparing Conventional and Water Sensitive Urban Designs for a South African Greenfield township development

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## Highlights

- A 31.10% reduction (from 43.58 to 30.03 $m^3/s$) in peak runoff was achieved by implementing WSUD Scenario 3.
- Implementation of rainwater harvesting reduced potable water demand by ~35% in 40 years.
- Although WSUD may cost more than the conventional design, BCR analysis showed that WSUD is more attractive.

## Introduction

Greenfields within rapidly urbanizing areas present unique opportunities to implement alternative approaches to Conventional Stormwater Management Systems (CSMS). Water Sensitive Urban Design (WSUD) is an alternative and an integrated systems approach that is loosely described as 'urban design', which is done in a 'water sensitive' manner with the final goal being the holistic management of the urban water cycle to concurrently achieve desired economic, environmental and social targets and benefits (Armitage et al., 2014). WSUDs, also termed Best Management Practices and Low Impact Developments, include erosion and sediment control, rainwater harvesting and bio-retention cells. This study compares the CSMS design and WSUD in a South African Greenfield township development. In the study, the designs, benefits and costs of both are assessed. For the CSMS design, runoff generated within the development is conveyed and discharged into the nearby stormwater system. Based on the unique characteristics of the site, WSUD incorporated the above CSMS design and the following: (i) bio retention systems to improve runoff quality and to protect instream eco-systems from the effects of increased runoff (ii) detention storage to stabilize receiving stormwaters and to reduce erosion, and (iii) rainwater harvesting (RWH) tanks to augment non-potable water demand.

## Methodology and Key Findings

**The Greenfield township development**

The Greenfield development is located in the City of Ekurhuleni, Gauteng Province, South Africa. The development, which is mostly veld grassland, occupies an area of ~75 Ha and is to accommodate 1574 mixed-use erven.

**Pre-development and post- development runoff**

Using PCSWMM, pre-development and post-development (conventional and WSUD) runoff were modelled. Rainfall data for a 12 year period, at 5-minute intervals, was obtained from the South African Weather Services. The designs were undertaken using extreme event-based rainfall modelling. The development was simulated using design storms of various Recurrence Intervals. Rainfall depths and Recurrence Intervals were obtained for an SCS Type 3 Storm (Smithers and Schulze, 2012), and peak runoffs were calculated. The Recurrence Interval eventually selected was the 10-year design storm (DHS and CSIR, 2019) (Table 1).

**Table 1.** Pre- and conventional post- development runoff

| Recurrence Interval (years) | Probability of occurrence in one year (%) | Rainfall (mm) | Pre-development peak runoff ($m^3/s$) | Conventional post-development peak runoff ($m^3/s$) |
|---|---|---|---|---|
| 10 | 10 | 94.70 | 5.59 | 43.58 |

The flow-duration curve is a cumulative frequency curve that shows the percentage of time specified discharges were equaled or exceeded during a given period. The cumulative duration for which individual discharge rates were exceeded for pre- and post-development conditions are compared in Figure 1. For the WSUDs, 3 scenarios (listed below) were modelled.

***WSUD Scenario 1 – Post-development (with RWH)*:** Mpofu's (2019) model was used to determine the optimal RWH tank size (based on supply reliability, catchment characteristics, available tank sizes, rainfall characteristics and non-potable water demand) for each land use category. Implementing RWH reduced peak runoff (by 26.85% to 31.88 $m^3/s$).

***WSUD Scenario 2 – Post-development (with RWH, bio-retention cells and vegetated swales)*:** In Scenario 2, in addition to RWH, bio-retention cells and vegetated swales were implemented at strategic locations to intercept and convey runoff to an exit point and to permit infiltration. In this scenario, peak runoff further reduced by 3.70%.

***WSUD Scenario 3 – Post-development (with RWH, bio-retention cells, vegetated swales and detention pond)*:** In Scenario 3, a detention pond was added and sized to provide the volume required to meet pre-development peak runoff conditions after implementation of WSUD systems. An outflow of 5.39 $m^3/s$ from the pond met the pre-development runoff of 5.59 $m^3/s$. In this scenario, peak runoff was further reduced by 2.18%.

In total, a 31.10% reduction in the peak runoff was achieved (from 43.58 $m^3/s$ to 30.03 $m^3/s$ in Scenario 3).

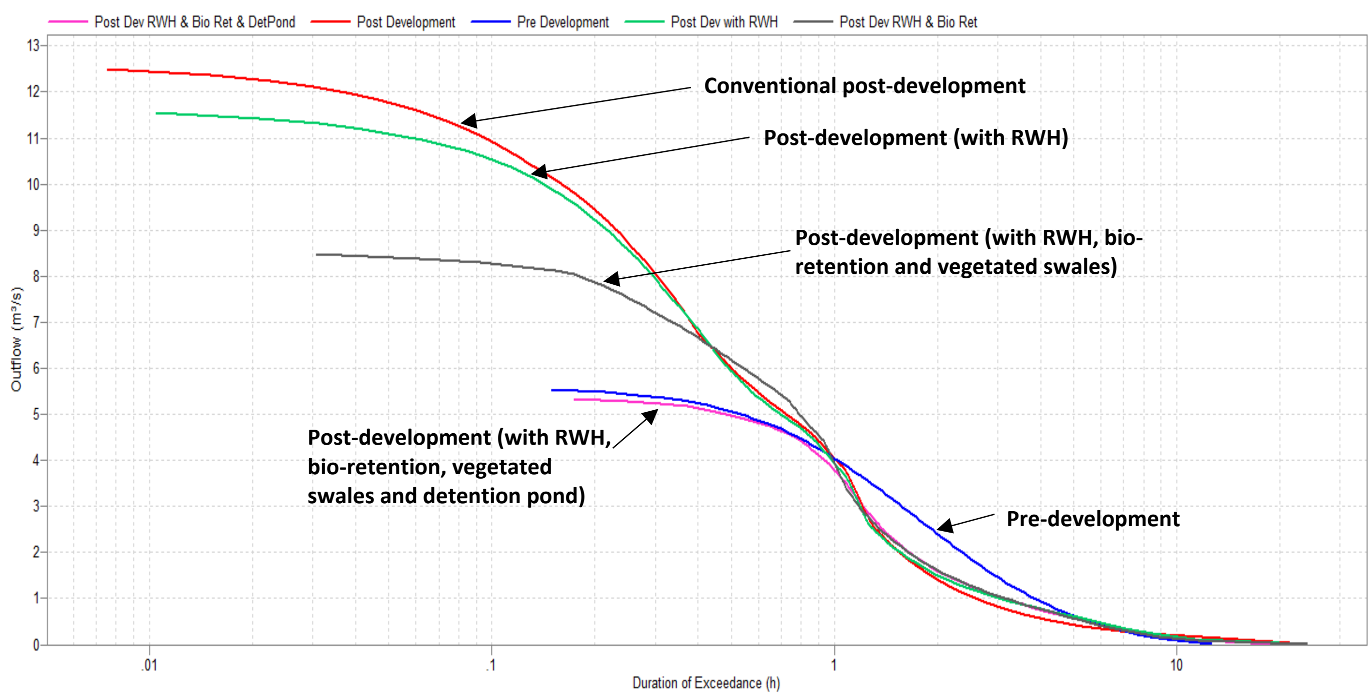


**Figure 1. Pre- and post-development outflow-duration curves**

## Project Costs and Benefits

The prevailing tariff was used to calculate potable water savings (benefit) due to implementing RWH. RWH can potentially save a total of R 131,974,530.89 ($ 7,331,918*) over 40 years (~35% savings in potable water demand). Capital and recurrent costs for the 4 options are shown in Table 2. A Benefit Cost Ratio (BCR) of 1.07 indicated that the WSUD Scenario 3 (best of the 4 options) was financially more desirable than the conventional design. WSUD Scenarios 1 and 2 produced BCRs of 1.34 and 1.16 respectively.

**Table 2.** Capital and recurrent costs of conventional and WSUD post-development infrastructure

| | | |
|---|---|---|
| Conventional post-development | ZAR 89,177,777.15 | $ 4,954,321 |
| WSUD Scenario 1 – Post-development (with RWH) | ZAR 98,600,490.73 | $ 5,477,808 |
| WSUD Scenario 2 – Post-development (with RWH, bio-retention cells and vegetated swales) | ZAR 114,202,133.14 | $ 6,344,563 |
| WSUD Scenario 3 – Post-development (with RWH, bio-retention, vegetated swales, detention pond | ZAR 123,591,890.65 | $ 6,866,216 |

**1 USD was equivalent to 18 ZAR as at June 2020*

# Recommendations

The implementation of WSUD resulted in the reduction of stormwater run-off generation and potable water demand. Although the WSUD implementation costs were higher than the conventional design, the BCR analysis showed that WSUD is financially more attractive than the conventional design alternative.

# References

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# Plants in a pickle? Plant responses to deicing salt in highway-adjacent bioinfiltration basins

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## Highlights

- Stormwater runoff from highways in winter can be more saline than seawater, leaving soils with elevated salt well into the growing season.
- In basins along I-95, plant survival varied according to salt exposure and salt tolerance.
- In GSI with high salt loads, plant palettes should focus predominantly on highly salt tolerant taxa.

## Introduction

In regions with cold winters, bioinfiltration basins adjacent to highways can receive extremely saline stormwater runoff in winter. The sodium introduced in such runoff can persist in basin soil media for several months after winter ends, remaining elevated into summer in some years and locations (Caplan et al. 2024, Shetty et al. 2020). The vegetation planted in basins adjacent to highways may therefore be exposed to toxic levels of sodium and chloride, potentially necessitating a more salt-tolerant plant palette than is typically used in urban GSI.

We conducted two evaluations of bioinfiltration plantings in basins adjacent to I-95, one with a typical plant palette (i.e., with most taxa having little to no salt tolerance) and the other focusing on moderately to highly salt tolerant plants. We sought to characterize levels of mortality and determine how it varied with stormwater exposure. We expected mortality to be greater in plants with greater exposure to stormwater, but we expected the effect to be muted in plants with greater salt tolerance.

## Methodology

All of the plantings we evaluated were in basins that receive stormwater from I-95 in northern Philadelphia. We focused on 9 plant taxa in the study of basins with typical plant palettes (with inventories spanning three years) and on 13 taxa in the study with predominantly salt tolerant taxa (with inventories in two years). In both cases, mortality was assessed by counting living plants, though establishment success was lower in the newer basins, so we focused on the change in survival through the year beginning six months after installation. We also measured growth (leaf area and crown volume), tissue chemical composition, and physiological rates but we do not present those data here. To characterize stormwater exposure, we either measured soil electrical conductivity or moisture, or estimated exposure based on plants' topographic positions.

**Figure 1.** A basin along I-95 whose plant palette was not salt tolerant. Images were taken in 2017 (left) and 2020 (right).

## Key Findings

In the basins with a typical plant palette, mortality three years after installation ranged from 14-90% for herbaceous taxa and 0-30% for woody taxa. For herbaceous taxa, mortality ranks in the final year corresponded closely to salt tolerance levels. Woody taxa likely had lower mortality because they had greater carbohydrate stores.

In the basins with plants more tolerant of salt, mortality ranged from 0-78%. Three taxa experienced almost no mortality (<3%): seaside goldenrod, common rush, and feather reed grass. Exposure to higher salt levels was associated with greater likelihood of mortality in some of the other taxa. However, exposure to dry soil during the summer was also associated with elevated mortality in several taxa.

## Recommendations

In bioinfiltration basins and other vegetated GSI that receive runoff from highways or other heavily-salted roadways, the plants used along and adjacent to stormwater pathways should be highly salt tolerant, in addition to flooding and drought tolerant. Alternatively, these areas could be left unvegetated. However, because plant lists often report salt tolerance as binary, landscape designers should seek additional information on the performance of candidate taxa in highly saline soils (e.g., Deeter 2012). Finally, because highly salt tolerant taxa may not be readily available from suppliers, arrangements should be made to obtain the numbers of plants needed well ahead of installation.

## References


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Deeter L.M. (2002). Sodium chloride tolerance of selected herbaceous perennials and the effects of sodium chloride on osmotic adjustment and ionic uptake in three species of herbaceous perennials. PhD Dissertation, Ohio State University.

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# Still working after 22 years: Monitoring an Early Modular Stormwater Infiltration System at the Washington National Cathedral

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## Highlights

- In 2002, a large Rainstore infiltration system was constructed at the Washington National Cathedral.
- The bed was designed to intercept runoff from a six-acre drainage area that is 65% impervious.
- For over six months in 2023, Meliora and Andropogon monitored the system which continues to infiltrate.

## Introduction

The Washington National Cathedral was completed in 1990 in Olmsted Woods, the last vestige of what was once an extensive oak and beech forest. Frederick Law Olmsted, Jr, in 1917, spoke of “the great charm of approaching the Cathedral through and up a wooded hillside, leaving the city far behind and below”. However, by 2000, the Cathedral was facing the significant loss of large trees and forest areas due to erosion from the impervious surfaces and a lack of soil moisture in the forest soils. In 2002, a large Rainstore modular stormwater storage and infiltration system was constructed to restore the hydrologic balance to Olmsted Woods, an important contemplative experience at the Cathedral grounds. Excessive erosion from impervious area runoff was adversely impacting the health of the forest. The 1,400 square foot infiltration bed was designed to intercept runoff from a six-acre drainage area that is 65% impervious, including road, parking, and Cathedral roof areas.

## Background - Existing facility

The large infiltration bed is one of a number of stormwater measures constructed to reduce erosion and restore hydrologic health to the forest. In 2023, Meliora and the landscape architects at Andropogon Associates installed a water level monitor in the stormwater bed to evaluate the infiltration performance. The results show that the facility continues to infiltrate significant volumes of runoff.

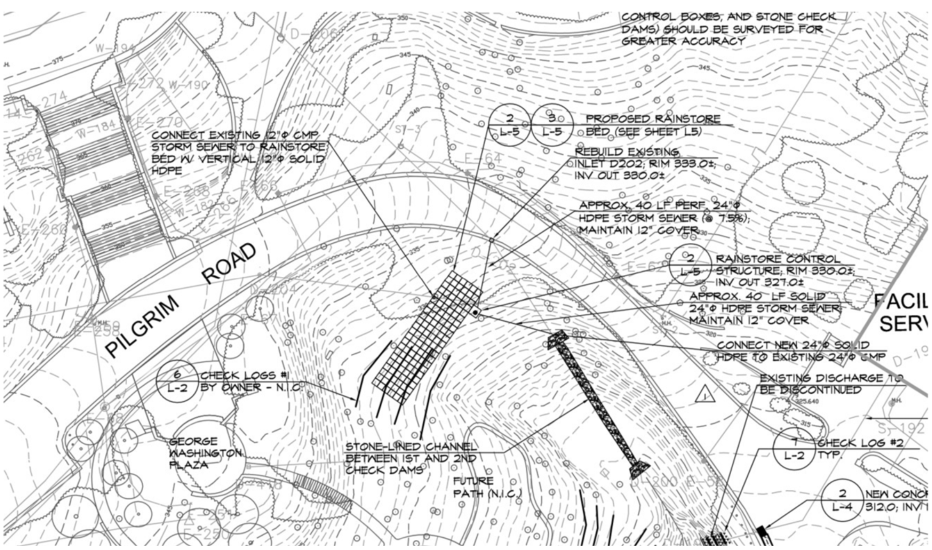


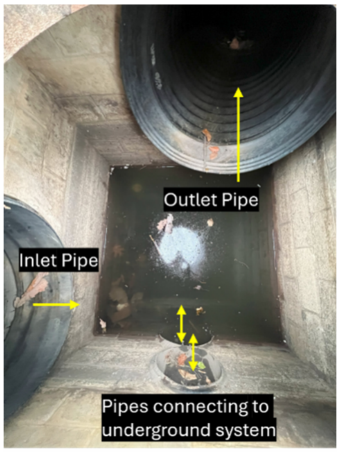

**Figure 1** – Plan View of Rainstore System

**Figure 2** – Construction Photo of Rainstore System

# Methodology

An HOBO water level logger was installed in the Rainstore Outlet Control Structure in order to record the rising and falling water level inside of the Rainstore system. The 73' long by 20' wide by 3.3' tall underground modular storage system was constructed "on-line" to intercept runoff in the existing storm sewer system. The bed receives runoff from road and parking areas and is wrapped in non-woven geotextile. Rainfall records from the nearest continuously recording rainfall gage were compared to the rising and falling water levels to assess the performance of the system. The HOBO sensor also records water temperature.

# Key Findings




The outlet pipe from the stormwater bed is located 2.25 feet above the bottom of the bed and sensor. Until the water level reaches 2.25 feet, no water is discharged downstream and all water entering the system infiltrates into the underlying forest soils.

Six months of monitoring confirmed that the bed continues to infiltrate and that most small frequent rainfalls are captured entirely, correcting portions of the hydrologic imbalance created by the impervious surfaces. The data also reflects the temperatures spikes of runoff from impervious surfaces. This paper will also address the technical and equipment challenges of this monitoring effort. It should be noted that there are no known records of maintenance on this facility, and as far as records show it has never been flushed or vacuumed. This infiltration bed has remained effective for over 20 years.

**Figure 3.** Photo of outlet control structure

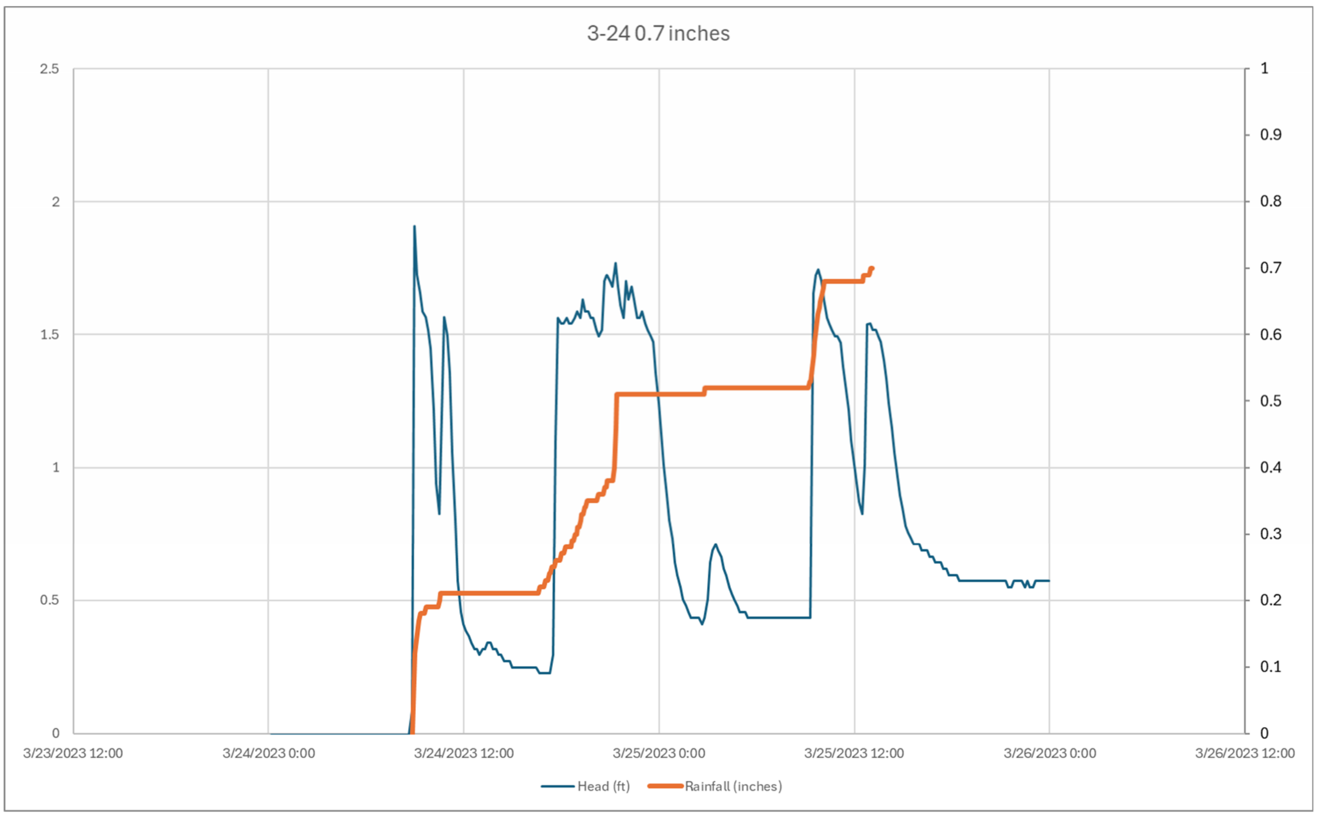



**Figure 4.** Comparison of Water Level and Cumulative Rainfall Depth

# Recommendations

Modular stormwater systems, such as this Rainstore system, have become effective ways to provide stormwater management in urban areas. Continued monitoring of the constructed examples should be undertaken to understand the long term effectiveness and to learn lessons about how to most effectively design and install these systems.

# Radnor Township Municipal Projects for Climate Resiliency

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# Highlights

- Radnor Township has experienced significant flooding issues due to its urbanized hydrology and proximity to streams.
- Flooding events are occurring during the increasing high intensity storms that match the ten-year one-hour design storms.
- Meliora Design has incorporated Township needs into stormwater management solutions that are designed for the ten-year one-hour design storm.

# Introduction

Meliora was asked to help Radnor Township develop stormwater management techniques to combat increasingly frequent severe flooding events. The flooding events were determined to occur during the high intensity rainfall events that are occurring more frequently with climate change. Meliora designed around the ten-year one-hour storm event and worked to incorporate stormwater solutions into other municipal needs to create designs that were both effective and immediately constructable.

# Methodology

## Modeling the Design Storm

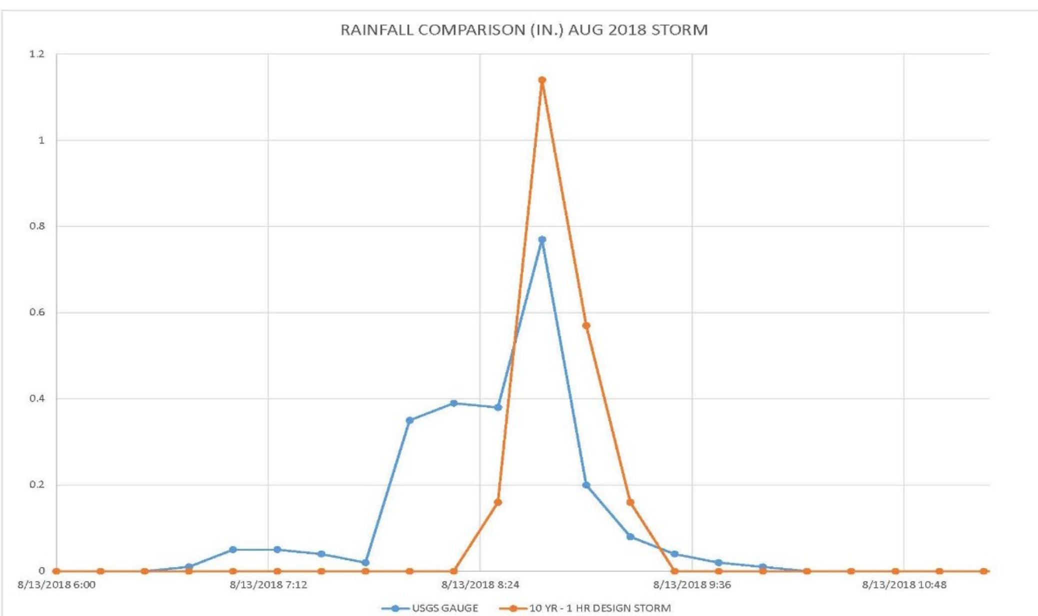


**Figure 1** – Comparison of August 2018 storm that caused severe flooding in Radnor to the design 10-yr 1-hr storm

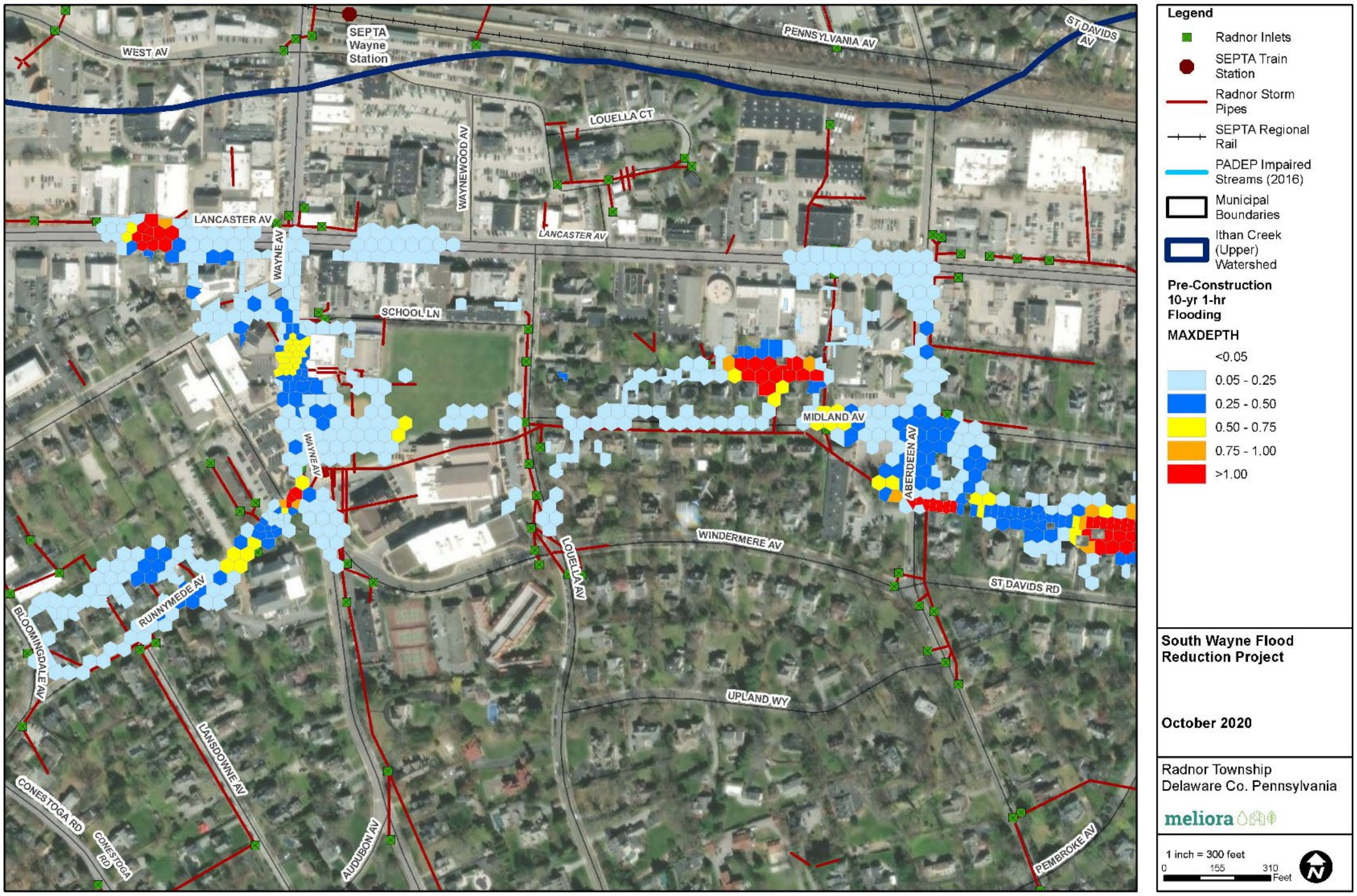


**Figure 2** – Modeled max flooding depths during the design 10-yr 1-hr storm in an area of Radnor that has experienced flooding issues

PCSWMM was used to model the 10-yr 1-hr storm in areas of Radnor that were prone to significant flooding. After confirming flooding issues in the model matched areas of concern, Meliora analyzed potential locations for stormwater interventions. Radnor emphasized that solutions needed to be effective and immediately constructable. Meliora therefore focused on areas that could contribute significant storage and also provide tangential benefits to the community.

# Key Findings

Two major construction projects have thus far materialized from the initial Radnor study. In November 2023, construction completed on a parking lot redesign that included 250,000 gallons of stormwater storage. The parking lot had previous design issues that led to safety issues and the lot being underutilized despite its close proximity to the Wayne Business District. By tying the stormwater solution to a tangible need for the community, Radnor was able to realize a tangible improvement in stormwater management that received community support. Another component of the project involved connecting stormwater inlets to an existing stormwater subsurface feature in the Radnor Middle School field. The connections were unable to be made during the original construction due to several utility conflicts. Meliora worked to relocate utilities and reroute stormwater connections to provide an additional 350,000 gallons of storage during the design storm.

**Figure 3.** Photo of constructed improved parking lot.

The second major project began construction in October 2023. The project includes a wooded wetlands restoration that will enhance habitat and meet water quality goals, receiving both Growing Greener and NFWF funding. Additional storage will be provided by subsurface stormwater systems in an adjacent dog park and parking lot. In total, the project will provide over 1 million gallons of additional stormwater storage during design 10-yr 1-hr storms. In addition to the significant storage provided, the enhanced wooded wetland habitat will provide the community with a more usable and educational environment, along with a high-functioning wetland habitat.

**Figure 4.** Photo of the West Wayne Preserve under construction. After the regrading work to provide additional storage, it will be filled with high quality wooded wetland vegetation.

# Resilient Green Infrastructure - Case Study Abstract

## Stormwater Management and Outfall Design for Extreme Precipitation Events

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## Highlights

- Case Study of new school complex design which integrated extreme runoff capture design and resilient outfall protection through a riparian buffer with use of green infrastructure in a high quality watershed. Hurricane Ida was a 1,000-year storm at location, with no issue.
- Second Case Study of Redevelopment site and retrofit of dry stormwater basin into constructed wetland with resilient outfall protection integrating green infrastructure in an exceptional value watershed. Hurricane Ida was a 750-year storm at location, with no issue.

## Introduction

Stable outfall design is a primary consideration for any project. It has been a legacy PADEP focus. Two case studies are presented which were located in Special Protection watersheds. Integration of Green Infrastructure, in particular at the outfalls to meet water quality requirements, were also designed for a 100-year event. These designs in fact proved to be completely resilient to the extreme flows caused by Hurricane Ida, that were respectfully 1,000- and 750-year events. Both projects both required PADEP Individual NPDES approvals.

## Background

### Design Considerations

The Northeast United States, including Pennsylvania, is projected to continue on a trend of experiencing increased heavy precipitation events. Management of large storm events, particularly outfall stability, has been an ongoing topic of focus for PADEP. Related design supplements since the 2006 Stormwater Management Manual include level spreader guidance, off-site discharge to non-surface water policy, and of course, the Managed Release Concept. Following all the design guidance for runoff volume management, water quality treatment and rate control may still result in an unstable outfall. In such scenarios, in a best case, nuisance scour regularly occurs, in the worst case, devastating levels of erosion persist. When coupled with a riparian buffer requirement of no disturbance within 150 feet of a special protection watercourse, a true design problem is presented. How can discharges from large storm events be conveyed to the stream, in a stable manner, without a rip-rap or other armored channel or storm sewer?

### Case Study #1 - Manavon School

The project was a redevelopment of an existing golf course in use since the 1920s, and before that a farm. Extensive site testing yielded adequate soil area viable for infiltration for “delta 2”. However, after exhausting options, the geology required that runoff capture for infiltration originate from offsite. Enhanced capture devices were designed and implemented to ensure conveyance of the offsite flow into the infiltration system. Additional water quality treatment was required for project discharges not subject to volume control. A high-quality stream was on-site as the primary discharge location. However, a 150 foot riparian buffer was required with no disturbance. The existing discharge regime was an 800 foot width of sheet flow through the buffer area. The proposed condition required a point source on the buffer edge. A level spreader, separation of small storm and large storm flows, green infrastructure and a non-disturbance stabilization method were utilized in conjunction to provide a distributed flow path. This design proved completely resilient to Hurricane Ida which was a 1,000-year storm at the project location and pushed the system performance to 150% of the design. There was no erosion at the outfall whatsoever.

**Case Study #2 - LCOR**

The prexisting site condition had included more impervious cover than the original design condition. An extended detention basin dated to the late 1980s was modeled to preform amazingly well per current standards, especially with the existing site with reduced impervious area. The existing basin discharge was used as the basis of design for the proposed site, as further reduced. Due to documented severe karst and active sinkholes, an infiltration design was not recommended. The Exceptional Value watershed required enhanced stormwater management design. The site topography and storm sewer network lent itself to ensured conveyance of flow to the basin area. The basin was retrofit to an enlarged constructed wetland that included a pre-MRC design. Draft MRC guidance in existence at the time was followed. The MRC design would help the retrofit maintain stream baseflow better than the existing basin. The existing outfall was an eroded splash pool split to two eroded channels through a lawn area. The outfall was redesigned into a level spreader that maintained the flow divergence. The eroded channels were converted to widened bio-swales with TRM-protected amended soils and naturalized plantings. Hurricane Ida at this location was a 750-year storm, far exceeding the 100-year storm design for the SCM. The combination of design elements proved to withstand the extreme precipitation.

## Key Findings

Use of Green Infrastructure was key in maintaining stability of outfalls during an extreme event, while meeting water quality requirements for design storms at both case studies.

**Figure 1. Existing Extended Detention Basin and Retrofitted Constructed Wetland**

**Figure 2. Existing Basin Outfall Scour and Restored Condition**

## Recommendations

Surface overflow for SCM capture must be a critical, integrated design element should storm sewer capture/conveyance be exceeded or compromised. At the outfall, physically separate constant/frequent low flow outfall from infrequent, high flow discharge. Integrate Green Infrastructure for stability and water quality – a vegetative matrix can outperform rip-rap for energy dissipation.

## References

Ranstead, Zachary H. (2012) Baseflow Replication (precursor to MRC) PA Stormwater Technical Workgroup