



**HAL**  
open science

# Mitigating impervious surface hydrology at a large commercial store using green infrastructure retrofits

Andrew Tirpak, Ryan Winston, Ian Simpson, Don Carpenter

## ► To cite this version:

Andrew Tirpak, Ryan Winston, Ian Simpson, Don Carpenter. Mitigating impervious surface hydrology at a large commercial store using green infrastructure retrofits. Novatech 2023, Graie, Jul 2023, Lyon, France. hal-04186323

**HAL Id: hal-04186323**

**<https://hal.science/hal-04186323>**

Submitted on 8 Sep 2023

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

## Mitigating impervious surface hydrology at a large commercial store using green infrastructure retrofits

### Atténuation de l'hydrologie de surface imperméable dans un grand magasin commercial à l'aide de rénovations d'infrastructures vertes

Andrew Tirpak<sup>1</sup>, Ryan Winston<sup>2</sup>, Ian Simpson<sup>3</sup>, Don Carpenter<sup>4</sup>

<sup>1</sup>The Ohio State University, Columbus, OH, USA. [tirpak.5@osu.edu](mailto:tirpak.5@osu.edu)

<sup>2</sup>The Ohio State University, Columbus, OH, USA. [winston.201@osu.edu](mailto:winston.201@osu.edu)

<sup>3</sup>University of Tennessee, Knoxville, TN, USA. [isimpson@utk.edu](mailto:isimpson@utk.edu)

<sup>4</sup>Drummond Carpenter, PLLC, Orlando, FL, USA. [dcarpenter@drummondcarpenter.com](mailto:dcarpenter@drummondcarpenter.com)

#### RÉSUMÉ

Les grandes aires de stationnement imperméables directement connectées sont une caractéristique commune des développements commerciaux. Malgré leur prévalence aux États-Unis et au-delà, des recherches limitées ont étudié le potentiel des mesures vertes de contrôle des eaux pluviales (SCM) pour atténuer le ruissellement de ces zones. Pour combler cette lacune dans les connaissances, une étude de bassins versants jumelés a été réalisée pour évaluer les impacts des rénovations SCM dans un parc de stationnement commercial à Reynoldsburg, Ohio, États-Unis. Les réponses hydrologiques du stationnement existant ont été étudiées pendant une période de surveillance de 12 mois. Suite à cela, une cellule de biorétention et une chaussée perméable ont été installées et ont reçu les eaux de ruissellement de 0,60 ha et 0,42 ha de l'aire de stationnement, respectivement ; les SCM ont été surveillés pendant 20 mois supplémentaires après la construction. Malgré une faible infiltration des sols sous-jacents, la cellule de biorétention a fourni des réductions substantielles du volume de ruissellement (de 83 %) et des débits de pointe (de 86 %). L'analyse des taux de rabattement a révélé l'influence des caractéristiques karstiques urbaines, car l'infrastructure souterraine (c'est-à-dire une tranchée de gravier autour d'un tuyau d'égout à proximité) a fourni des voies préférentielles pour l'exfiltration de la cellule. La chaussée perméable n'a fourni aucun avantage hydrologique, principalement en raison du colmatage important qui s'est produit rapidement après la construction. Il a été conclu que le rapport de chargement (27,6:1) de la chaussée perméable était beaucoup trop important et devrait être évité dans les futurs efforts de rénovation. Dans l'ensemble, les systèmes ont entraîné une atténuation significative du ruissellement sur le site, démontrant l'efficacité de la GCA dans des bassins versants commerciaux hautement connectés et hautement imperméables.

#### ABSTRACT

Large directly connected impervious parking areas are a common feature of commercial developments. Despite their prevalence in the United States and beyond, limited research has investigated the potential for green stormwater control measures (SCMs) to mitigate runoff from these areas. To address this knowledge gap, a paired watershed study was performed to evaluate the impacts of SCM retrofits in a commercial parking lot in Reynoldsburg, Ohio, USA. Hydrological responses of the existing parking lot were studied during a 12-month monitoring period. Following this, a bioretention cell and permeable pavement were installed and received runoff from 0.60 ha and 0.42 ha of the parking area, respectively; the SCMs were monitored for an additional 20 months post-construction. Despite poorly infiltrating underlying soils, the bioretention cell provided substantial reductions in runoff volume (by 83%) and peak flow rates (by 86%). Analysis of drawdown rates revealed the influence of urban karst features, as subsurface infrastructure (i.e., a gravel trench around a nearby sewer pipe) provided preferential pathways for exfiltration from the cell. The permeable pavement provided no hydrologic benefits, primarily due to extensive clogging which occurred rapidly after construction. It was concluded that the loading ratio (27.6:1) of the permeable pavement was much too large and should be avoided in future retrofit efforts. Overall, the systems resulted in significant runoff mitigation at the site, demonstrating SCM effectiveness in highly connected, highly impervious commercial catchments.

#### KEYWORDS

Bioretention, permeable interlocking concrete pavement, low impact development, permeable pavement, paired watershed study

---

## 1 INTRODUCTION

Research has tied the deleterious impacts of urban development on receiving water resources for several decades. Impervious surfaces, such as roads, parking areas, sidewalks, and rooftops, diminish the infiltration capacity of a landscape, resulting in increased volumes and peak flow rates of surface runoff and reduced groundwater recharge. The degree of connection of impervious surfaces to the storm sewer network is critical to determine potential downstream hydrologic impacts. Streams in catchments with greater directly connected impervious areas (DCIA) (e.g., curb and gutter along roadways, parking lots drained by storm sewers, etc.) often experience greater impacts from stormwater runoff, resulting in degraded receiving streams. Commercial developments, such as large shopping centers, grocery stores, etc., represent an urban land use where large areas of directly connected imperviousness are particularly prevalent, wherein large parking areas designed to provide space for infrequent peak usage. Storm sewers are typically installed to drain these areas, contributing to the increased impacts of commercial runoff relative to other land uses (Pitt et al. 2004). Though some commercial developments implement traditional stormwater infrastructure (e.g., ponds) to lessen runoff related impacts, the efficacy of green infrastructure stormwater control measures (SCMs) in these settings is not well understood.

Bioretention cells and permeable pavements are two examples of green infrastructure SCMs which are increasingly implemented to mitigate stormwater runoff worldwide. Bioretention cells are excavated landscape depressions backfilled with an engineered sandy soil media and topped with turf grass or various plant species. Permeable pavements are paved surfaces (such as the permeable interlocking concrete pavements (PICP) used in this study) which simultaneously permit stormwater infiltration and support pedestrian and vehicular traffic. Both bioretention cells and permeable pavements can be distributed throughout urban areas to mitigate the effects of urban stormwater runoff. Despite a growing body of research on the benefits of these SCMs, few studies have investigated the performance of these technologies in commercial catchments.

To address this knowledge gap, a paired watershed study was conducted to evaluate the hydrologic impacts to a commercial parking area retrofitted with a bioretention cell and permeable pavement. The objective of the study was to compare the performance of the retrofits to a nearby, traditionally-drained (i.e., no SCMs) parking area to demonstrate their efficacy in commercial catchments and promote the use of green infrastructure technologies in settings which are becoming increasingly prevalent in urban areas worldwide.

## 2 METHODOLOGY

### 2.1 Study Description

This study focused on the hydrology of two adjacent parking areas serving a regional commercial grocery store and nearby restaurant in Reynoldsburg, Ohio, USA, between October 2016 and December 2019. Two adjacent catch basins draining a combined 1.02 ha section of the parking lot (i.e., predominantly DCIA) were selected for SCM retrofits, while the 0.60 ha parking lot of the restaurant served as a control for the study (i.e., no SCMs). Soil borings collected at the site indicated poorly draining silt loam soils (Hydrologic Soils Group C/D); the water table elevation was estimated to be approximately 1.5 m below ground surface. The bioretention cell and permeable pavement were retrofitted into the parking lot in November 2017 following a 12-month monitoring period (« calibration ») which aimed to characterize existing hydrology at the site. Both SCMs featured a 10 cm diameter underdrain and an internal water storage (IWS) zone to promote exfiltration and denitrification between rain events. Design elements of the SCMs are presented in Table 1.

Table 1: Design features of bioretention cell and permeable pavement installations.

SCM	Catchment area (ha)	DCIA (%)	SCM area (m <sup>2</sup> )	Loading Ratio (DCIA: SCM area)	IWS Zone Depth (cm)	Media/Aggregate Depth (cm)	Underdrain Diameter (cm)
Bioretention	0.60	74	100	44.4	30	76.2	10
Permeable Pavement	0.42	100	152	27.6	15	88	10

## 2.2 Data Collection and Analysis

Based on paired watershed study design, field monitoring included two periods of interest, calibration (i.e., prior to SCM retrofits; October 2016-October 2017) and treatment (i.e., after SCM retrofits were installed; December 2017-December 2019) (Clausen and Spooner 1993). Monitoring was discontinued during winter months (i.e., January-March) due to freezing temperatures. Data collected during both the calibration and treatment phases were used to establish linear relationships between runoff depths and peak flow rates for the control and treatment (i.e., bioretention and permeable pavement) catchments. Hydrologic monitoring was conducted using several V-notch weirs and HOBO U20 water level loggers installed in the receiving catch basins. Rainfall measurements were collected at two-minute intervals using a tipping bucket rain gauge. Internal stage in the SCMs was monitored using U20 loggers housed in perforated PVC wells. Linear relationships were established between log transformed hydrologic data collected from the control and treatment catchments. Analysis of covariance (ANCOVA) was then used to identify significant differences in slopes and intercepts of regression models between monitoring periods which could be attributed to the installation of the SCMs. Least squared means (LSM) analysis was used to quantify changes in hydrologic performance.

## 3 RESULTS AND DISCUSSION

Thirty three rain events totaling 424.4 mm were recorded during the 12 month calibration period, with rainfall depths ranging from 2.5-44.2 mm. Similarly, 76 events, ranging from 2.5-51.1 mm and totaling 810.8 mm of rainfall, were recorded during the treatment period. No significant differences in rainfall depth, peak and average rainfall intensity, and antecedent dry period between the monitoring periods were identified during statistical testing.

Results of ANCOVA analyses for the SCM retrofits are presented in Figure 1. While regression slopes remain unchanged between the calibration and treatment periods, significant changes in model intercepts highlighted the hydrologic impacts of the bioretention cell (as indicated by the vertical shifts between the regression models in Figure 1). LSM analyses revealed 86% and 83% reductions in runoff depth and peak flow rate, respectively, between the calibration and treatment periods. The runoff threshold, the rainfall depth at which incipient runoff is generated, decreased moderately between monitoring phases, likely due to the high proportion of DCIA in the bioretention catchment. However, the effects of the bioretention underdrain in moderating outflow rates were evident during larger storm events, resulting in substantially lower volumes for events greater than 5 mm compared to the calibration period.

Due to the paired watershed design of this study, these changes can be directly attributed to the installation of the bioretention cell. However, though some hydrologic benefits were expected following the bioretention retrofit, the magnitude of these benefits were surprising given the poorly drained *in situ* soils at the site and the amount of DCIA draining to the cell. Drawdown rates indicated the presence of alternative drainage pathways that bypassed the underdrain which may have contributed to the unexpected performance of the cell. Instead of receding to the level of the IWS zone (30 cm), water levels rapidly declined to 9 cm above the bottom of the cell at a rate (15 mm/hr) approximately ten times greater than the infiltration rate of the underlying soil (1.3 mm/hr). It was hypothesized that adjacent subsurface infrastructure, namely a gravel trench enveloping a nearby storm sewer pipe, served as a preferential pathway for water to exit the bioretention cell. These interactions are an example of urban karst, defined as disturbed areas of soil with high porosity and void spaces associated with pipe trenches, building foundations, and other subsurface features that impact near-surface groundwater flows and infiltration in urban areas (Bonneau et al. 2017). While the bioretention cell provided substantial hydrologic benefits, similar interactions with existing subsurface infrastructure may occur in bioretention cells installed in other commercial settings unless steps are taken to prevent these interactions in design and construction, such as wrapping cells with impermeable liners.

Unlike the bioretention cell, runoff depth and peak flow rates in the permeable pavement catchment were statistically unchanged between the calibration and treatment periods (Figure 1). Critically, this indicated that the functionality of the permeable pavement was not significantly different than the traditional asphalt parking surface it replaced. A series of surface infiltration rate (SIR) tests confirmed extensive clogging throughout the PICP surface layer; median SIR declined by 96% over 14 months following construction of the pavement. The most notable decreases in SIR occurred in points of lower elevation or areas where snow had been piled during winter months. Extensive sediment accumulation in these areas rapidly clogged the PICP joint spaces and prevented runoff from infiltrating into the

underlying aggregate layer. In addition to a lack of routine maintenance performed at the site, the decline in the function of the permeable pavement was attributed to its high loading ratio (i.e., ratio of drainage area to surface area; 27.6 :1). This was intentionally used in the design process to study the performance of the pavement in hydrologically taxed conditions. However, while increasing maintenance frequency and improving snow management activities at the facility may have extended the efficacy of the system, it was concluded that the permeable pavement was much too small relative to the size of the contributing catchment, rendering it ineffective at mitigating runoff from the parking lot.

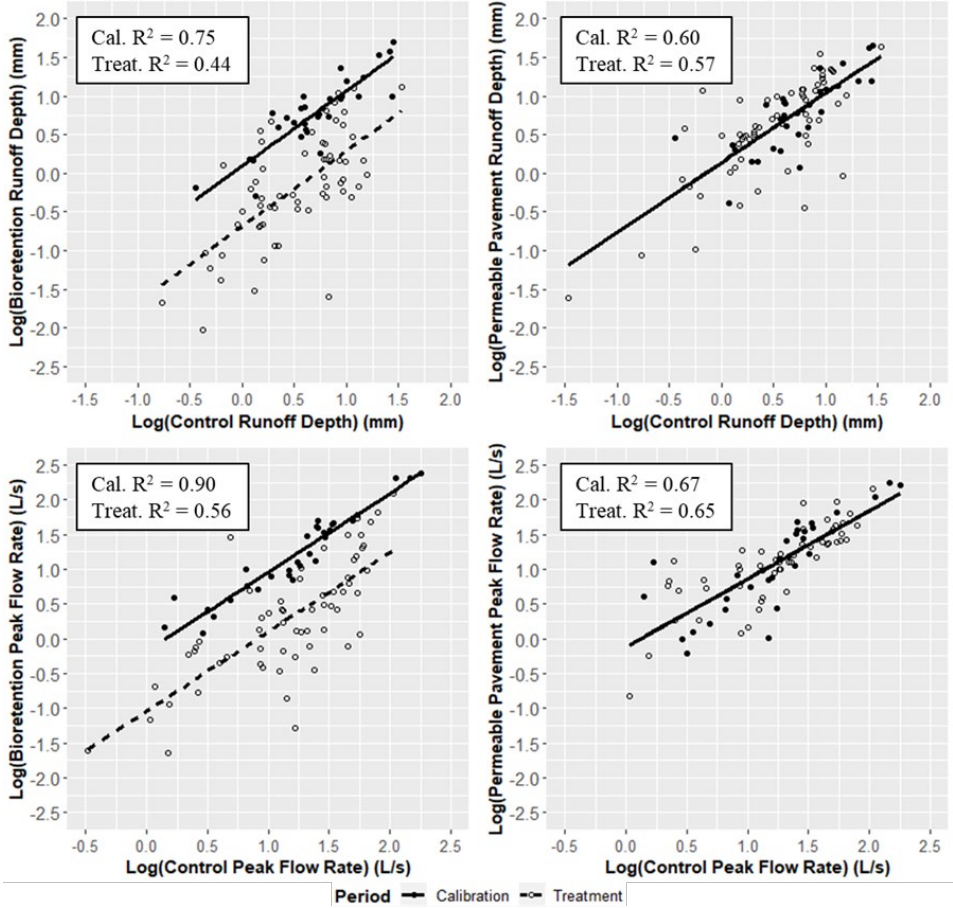


Figure 1 : ANCOVA models comparing runoff depth and peak flow rate from the bioretention and permeable pavement catchments to control catchment during calibration and treatment periods.

#### 4 CONCLUSIONS

The performance of bioretention cell and permeable pavement retrofits in a commercial parking area in Reynoldsburg, Ohio, USA, was studied during a two-year paired watershed study. Results indicated that the bioretention cell provided substantial reductions in runoff depths and peak flow rates, which were primarily attributed to interactions with adjacent urban karst features (i.e., gravel trenches surrounding sewer pipes) which provided preferential pathways for exfiltration from the cell. Conversely, the permeable pavement retrofit provided no significant hydrologic benefits to the parking lot due to its high loading ratio (27.6 :1), snow management practices, and a lack of maintenance performed during the monitoring period. Future studies should aim to quantify the water quality benefits of SCMs in commercial developments and characterize the subsurface interactions between these technologies and urban karst features in these settings.

#### LIST OF REFERENCES

Bonneau, J., Fletcher, T. D., Costelloe, J. F., and Burns, M. J. (2017). *Stormwater infiltration and the ‘urban karst’ – a review. J. of Hydrol. 552, 141-150.*

Clausen, J. C., and Spooner, J. (1993). *Paired watershed study design.* USEPA 841-F-93-009.

Pitt, R., Maestre, A., and Morquecho, R. (2004). *The National Stormwater Quality Database, version 1.1.* Univ of Alabama, Tuscaloosa, AL, USA.