EA Project Summaries and Findings Report Project

Project 9 – Demonstrating the Environmental Benefits of Permeable Paved Surfaces over the Edwards Aquifer

Project Summary

Author: UTSA

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Funding Amount

$1,035,761

Stated objectives of the study - *This University of Texas at San Antonio project will demonstrate how permeable pavement designs can mitigate the water quality and amount of stormwater runoff associated with impermeable pavement surfaces over the Edwards Aquifer Recharge Zone and examine whether these alternative permeable pavement designs reduce pavement surface temperatures and water runoff temperatures, thus contributing to mitigating urban heat island effects.*

Justification for the study – *In urban areas, replacing the natural land cover with impervious surfaces, including parking lots, increases pollutant concentration in runoff (Tong et al. 2009). Furthermore, urban drainage infrastructure removes excess runoff from the surface, which results in concentrated runoff volumes and faster and higher peak flows, which can cause downstream flooding, property damage and loss of life (Sharif et al. 2014, Fang et al., 2014). Conventional paved surfaces (e.g., roadways, walkways and parking areas) comprise a large fraction of the impermeable ground cover in Bexar County, which is estimated to be about 14.1% of its total area. The goal of this project is to demonstrate how four alternative permeable pavement designs mitigate stormwater runoff water quality and quantity compared to impermeable pavement surfaces over the Edwards Aquifer recharge zone. In addition, it will examine whether these alternative designs reduce pavement surface and water runoff temperatures and thus contribute in mitigating urban heat island (UHI) effects.*

1 Summary

This project assessed the impacts of permeable pavement on water quality, stormwater runoff volume, and both pavement and runoff temperatures. The project team installed four types of permeable pavement and conventional asphalt in adjacent test lots, each with room for eight passenger cars, in a new parking area of Classen-Steubing Ranch Park. The pavement types included:

- Aggregate-Filled Plastic Grid (PGr)
- Permeable Portland Concrete (PC)
- Permeable Asphalt Concrete (PA)
- Permeable Interlocking Concrete Pavers (PICP)
- Conventional Pavement (CP)

The conventional pavement lot, constructed of a traditional impermeable asphalt concrete material, was included as a control to compare against the permeable pavement monitoring results. Each permeable pavement system was designed with the following components: 12-inch-thick base layer to provide storage, perforated pipes, and an impermeable liner on the bottom. The liners are required by state regulation to prevent the collected stormwater runoff from infiltrating directly into the Edwards Aquifer. The report provides thorough descriptions of the installation and design of the systems, as well as construction costs.

After installation, the project team conducted continuous monitoring of the five parking lots including sampling 11 rainfall events between August 2023 and May 2024. The researchers aimed to determine if the different structures and materials included in the permeable pavement lots were effective in reducing pollutant levels in roadway runoff, slowing and reducing the volume of runoff from a rain event, and the impact of the different materials on pavement and runoff temperatures. In addition,

infiltration tests were performed throughout the study to ensure permeability did not significantly change. By evaluating the systems' performance, costs, and infiltration rates over time, the researchers provided supporting evidence to address common implementation barriers and develop recommendations to facilitate more wide-spread installation.

1.1 Methods

The project included continuous monitoring of various characteristics, including discharge water quality and quantity, rainfall amounts, outflow and pavement temperatures, and visitor parking preferences. Equipment included ISCO water samplers and flow meters installed in monitoring boxes adjacent to the parking lots, temperature sensors installed within the pavement surface, and two rain gauges on either side of the study area. Collector pipes from permeable pavement system underdrains and from a grate inlet within the conventional pavement lot fed into manholes where additional monitoring equipment was installed, such as pressure transducers to monitor outflow water temperatures, and intake tubing for the water samplers.

Figure 1 – Location of permeable pavement lots and monitoring parameters.

The monitoring equipment collected samples from 11 rain events between August 2023 and May 2024. Samplers collected water from the first flush, triggered when the underdrain water level was greater than ¼ inch for 30 seconds, and then for two additional flow-based triggers with a total of 12 sample bottles available to capture larger rain events. The project team also developed real-time monitoring software which transmitted data, including pavement temperatures and rainfall measurements, to a dashboard enabling immediate data visualization. Cameras were equipped with custom software and a vehicle detection algorithm to monitor pavement usage for each parking lot type. These were supplemented with an 11-day field survey to validate and calibrate the algorithm's performance.

The results of the real time monitoring were used to evaluate three water quantity metrics at each of the five test lots:

1. peak reduction (for the difference between a permeable pavement's highest flow compared to the CP's highest flow measured at the outfall during the rain event);
2. peak delay (the time between a permeable pavement's peak flow and the conventional pavements peak flow);
3. and storage (the volume of rainfall that did not drain out of the pavement during the monitored period).

Table 1 – Water quality monitoring parameters.

Parameters
pH
Hardness
Conductivity
Total Suspended Solids (TSS)
Volatile Suspended Solids (VSS)
Fecal and Non-Fecal Bacteria (Total Coliform)
Metals (Zinc, Copper, Lead)
Hydrocarbons (PAHs and TPHs)

The stormwater samples were analyzed for ten water quality parameters in either the UTSA Environmental Lab facility or a commercial facility (Table 1). The researchers then calculated the event mean concentration (EMC) and total load for each pollutant. The EMC is a weighted average based on flow during the entire storm event that allows comparison between storm events of different sizes. The total load is the amount of a pollutant transported by the runoff during an event. Surface temperatures and stormwater temperatures at the discharge location were compared to determine which pavement was cooler and did not significantly increase the temperature of runoff. In addition, the project team performed correlation analysis between the water quality parameters and water quantity indicators.

1.2 Findings

The results of the monitoring and statistical analysis for water quantity, quality, and additional characteristics, were interpreted to directly compare the performance of four permeable pavement types against conventional asphalt concrete pavement. Highlights are listed in Table 2.

All four permeable pavement systems were found to outperform conventional pavement when both reducing runoff volumes and delaying the peak flow. Average peak flow reductions ranged from 85% for PC to 95% for PGr when compared against conventional pavement. The average peak flow delays ranged from 16 to 33 minutes, although there was variability potentially due to changes in performance during different sized storm events. The average reductions of the permeable pavements' runoff volumes as a result of the systems' storage and performance were between 64% for PA and 86% for PGr. These results suggest that while all four permeable pavement types are successful at reducing water quantity of stormwater runoff, the aggregate-filled plastic grid system provides the best overall hydrologic improvements.

For water quality indicators, lower levels of TSS and VSS were also detected at all four permeable pavements. Fecal and non-fecal coliform bacteria analysis did not show substantial difference in performance between the permeable pavements or conventional pavement and displayed high variability between rain events. The project team attributed this to random contamination from external sources such as wildlife or domesticated animals.

Another important water characteristic, hardness, is a measure of dissolved minerals such as calcium and magnesium and can negatively impact aquatic life at high levels. The hardness levels within runoff samples varied, and the researchers theorized that the pavement materials contribute to the dissolved mineral content in runoff. Permeable asphalt had the higher mean EMC and total load, while the permeable concrete and plastic grid systems had the lowest hardness values. The runoff from permeable concrete was found to be significantly more alkaline than all the other pavements, which could contribute to the precipitation of metals thus reducing their bioavailability. However, it could also have a negative impact on nearby aquatic environments. All permeable pavements showed higher conductivity than conventional pavement. Of the four, permeable concrete was found to have the highest mean conductivity, and it is thought to release more dissolved ions into runoff due to its alkaline nature and material composition.

Table 2 – Comparison of permeable pavement analysis key results.

Permeable Pavement Types & Key Results	Aggregate-Filled Plastic Grid	Permeable Interlocking Concrete Pavers	Permeable Asphalt Concrete	Permeable Portland Concrete
Water Quantity Improvements	✓	✓	✓	✓
Water Quality Improvements (Pollutants)	✓	✓	✓	✓
Water Quality Improvements (Characteristics)		✓		
Temperature Mitigation	✓			✓
Improved Infiltration Rates	✓	✓	✓	✓

Very few samples detected metals and none detected lead. The project team theorized that void structure and material surface chemistry has an impact on metal retention through processes such as filtration or adsorption. Similar to metals, hydrocarbons were not detected at high levels in this study and when present, results were variable.

Permeable pavements were typically observed to be more desirable for thermal performance. For example, the surface of permeable concrete and permeable interlocking pavers consistently maintained lower temperatures than conventional pavement. However, permeable asphalt showed high levels of daily temperature fluctuations, with recorded values significantly higher than conventional pavement. The plastic grid system consistently exhibited the lowest average water temperature at the discharge point.

The researchers also tested the infiltration rates of the permeable pavement systems seven times throughout the monitoring period. They were unable to test the plastic grid system due to difficulties creating a proper seal on the material. Permeable interlocking concrete pavers were found to have the lowest infiltration rate. Permeable concrete has the highest infiltration rate, although it was also variable due to non-uniform compaction during installation.

The correlation analysis aimed to describe the influence of water quantity factors on pollutant behavior across the different pavement types. There were significant correlations found for conventional pavement between each of the pollutants measured and at least one water quantity indicator, implying that runoff quantity and duration have an impact on pollutant concentrations. For TSS, VSS, hardness, and conductivity, higher runoff volumes corresponded to decreased concentrations of pollutants, or dilution.

The permeable pavements had fewer consistent correlations with the antecedent dry period than the conventional pavement. Increased rainfall characteristics (including depth, duration, and intensity) and runoff volumes led to increases in water quality results. This indicates that larger storm events are capable of mobilizing the accumulated pollutants within the pavement structures. For example, increases in either rainfall depth or rainfall volume led to increases in TSS and VSS samples collected from the PICP and PGr systems. Rainfall depth was also found to have a positive correlation with fecal bacteria levels within runoff collected from the PGr and PA lots. Increases in peak flow were found to increase the pH of PC, and decrease the hardness level of PA. These results indicated that each material's surface characteristics, porosity, and infiltration capacity impacts pollutant retention, accumulation, and mobilization.

1.3 Challenges and Limitations

Although this study did not observe significant reductions in infiltration rate that would have led to required maintenance, it is important to routinely monitor and provide maintenance as needed on permeable pavement systems to facilitate their continued effectiveness. Pollutant removal varies based on the permeable pavement system being implemented, the pollutant loads in the system's drainage area, and local rainfall characteristics. Thus, evaluation for applicability is needed on a case-by-case basis.

Permeable pavement can incur additional costs when compared against conventional pavement due to the additional materials such as liners and underdrains. In this study, the researchers only compared the costs of the permeable pavements surface layers, including the contractor's markup and fees. Unit costs for permeable pavements ranged from $13 for PA to $22 for PC. A direct comparison is difficult to make between the PPs and the conventional pavement, since the latter was installed in a much larger quantity across all of the park's access roads. In addition to cost, permeable pavement systems require experienced installation teams in order to ensure the systems function as designed. Finally, it is challenging to sample sheet flow on a parking lot system which led to the experiment's design comparing the pollutant loads and concentrations in stormwater discharge against discharge from a control lot. There are limitations on the assumptions that can be made due to variability in how each lot might be used and the impact on the quality of the runoff entering each system.

2 Benefits

This study provides multiple benefits for our understanding of permeable pavement types and their performance compared with each other and against conventional pavement. The study also provides valuable data about pollutants and levels in discharge from parking lots.

The overall contributions of the study are as follows:

- The study found substantial evidence that all the permeable pavement types evaluated were more successful at reducing runoff volumes, delaying peak flows, and increasing water storage when compared against conventional pavement.
- The project serves as a local example to generate interest with other similar developments in the region. This could result in an increase of local adoption.
- The permeable pavement test lots are having a positive impact on the quality and quantity of runoff in Classen-Steubing Ranch Park.
- The project increased the understanding of permeable pavement installation and function, which will help break down implementation barriers such as actual construction and maintenance costs.
- The researchers expanded the local dataset of water quality and quantity parameter impacts of four types of permeable pavement.

- The project team's open-source approach to real-time monitoring serves as an example of how future studies can streamline stormwater data transmission and visualization while remaining cost-effective and easily implementable.

Project Deliverables:

Papagiannakis, A.T., Giacomoni, M.H., Johnson, D.W., Brasil, J. (2025). Demonstrating the benefits of permeable pavements over the Edwards Aquifer. The University of Texas at San Antonio.

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Project 9 – Demonstrating the Environmental Benefits of Permeable Paved Surfaces over the Edwards Aquifer

Fact Sheet

Project 9 – Demonstrating the Environmental Benefits of Permeable Paved Surfaces over the Edwards Aquifer

Investment

$1,035,761

Project Components

Stormwater Monitoring

Stormwater BMP Construction

Evaluating the Performance of Permeable Pavements

Source: UTSA Today

UTSA The University of Texas at San Antonio

Benefits

Improved Water Quality

Design

Watershed Management Recommendations

Outreach and Education Tools

Expanded Dataset

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Project 9 – Demonstrating the Environmental Benefits of Permeable Paved Surfaces over the Edwards Aquifer

Project Graphic

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Study to compare the effectiveness of several low impact development pavement types in reducing water quantity and pollutants in stormwater runoff.