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A META-ANALYSIS OF EXPERIMENTS ON HYDRAULIC PROPERTIES OF POROUS PAVEMENTS

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ABSTRACT

A meta-analysis of studies evaluating the effect of porous pavements on surface hydrology. The analysis investigated experiments on infiltration rate and consequent runoff coefficient of porous pavements. Reviewed literature provided extensive indications on the benefits of porous pavements in mitigating hydrology in the built environment. It was demonstrated that previous pavements improved the hydrological properties of engineered surfaces including mitigating runoff and checking to flood. Accordingly, it was hypothesised that the mean effect among the selected studies is zero. A meta-analysis of selected experiments on porous pavements experiments established that the mean effect among the selected studies was zero. While the study adopted a methodology that included similar studies in terms of method, further study is recommended to control for the various factors that influence hydraulic properties of porous pavers mentioned in the conclusion of this study.

Keywords: porous pavement, meta-analysis, run-off, permeability/infiltration.

INTRODUCTION

The built environment has been associated with considerable adverse environmental impacts associated with interference with natural surfaces. Various studies have demonstrated the potential environmental impacts, including effects on hydrology that can be associated with urban development. Hydrological impacts have especially raised sustainability concerns. Accordingly, there has been a broad consensus on the need to advance sustainable hydrological systems (Arahuetes & Cantos, 2019; Dietz, 2007; Monrose & Tota-Maharaj, 2016). Several interventions have been adopted to facilitate more sustainable development in the urban spaces ranging from green design to address urban heat islands to water sensitive urban design. The current study is concerned with urban hydrology and experiments around porous pavements.

The adoption and use of pervious surfaces, including pavements, to mitigate urbanization impacts on hydrology have a longstanding history (ASCE, 1969; Beecham & Myers, 2010; Smith, 1984; Thelen, *et al.*, 1972). For instance, Thelen *et al*., (1972) reported that there was considerable attention on pervious surfaces by 1970. Notably, the adoption of porous pavements, also referred to as pervious pavements, was an attempt to mitigate the hydrological impacts of urbanizations that was characterized by extensive paving (e.g., Cahill, Godwin, & Tilt, 2018; Donofrio, Kuhn, McWalter, & Winsor, 2009; Dietz, 2007).

Sustainable urban design, as advanced under such approaches as sustainable Urban Drainage Systems (SUDS), Low Impact Development (LID), and Water Sensitive Urban Design (WSUD), extensively mentions the use of porous pavements alongside other strategies intended to mitigate excessive urban runoff and reduced surface infiltration rates (Imran, Akib, & Karim, 2013). Fundamentally, considerable studies have observed that pervious (porous) pavements have succeeded to a significant degree to provide the necessary structural requirements of pavements while allowing for comparatively better hydrology in the urban spaces. That is; they have facilitated reduced run-off coefficient and facilitated better surface infiltration rates through paved surfaces (e.g.; Monrose & Tota-Maharaj, 2016; Ball & Rankin, 2010; El-Hassana & Kianmehrb, 2016).

Currently, there is extensive literature on porous pavements. Many of these studies have been advanced to evaluate the performance of porous pavements and how they contribute to sustainable urban development (e.g., Huang, *et al*, 2016; Bean, Hunt, & Bidelspach, 2007). Also, since permeable pavements are presented in urban design as alternatives to impervious pavements, other studies have provided comparative analyses on hydrological performance, and cost-benefits (Marchioni & Becciu, 2015; Selbig & Buer, 2018; Selbig & Buer, 2018). Also, considerable experiments have been done to demonstrate the performance properties of pavement development over time (e.g., Alsubih, Arthur, Wright, & Allen, 2012; Novo, Bayon, Castro-Fresno, & Rodriguez-Hernandez, 2013).

Essentially, the highlighted interest in porous pavement arose from its supposed hydrological benefits in the context of the increasing need for sustainable development approaches. Such benefits have been extensively studied under the mentioned concepts of WSUD, LID, and SUDS. Accordingly, porous pavements provide a lesser footprint on the hydrological cycle while allowing development as opposed to conventional pavements, which are mostly impervious (with surface runoff coefficient ranging 0.9 and 1 according to Marchioni & Becciu (2015)). The increasing use of pervious concrete as sustainable and environment-friendly paving materials is primarily owed to its ability to reduce pavement runoff among other environmental benefits (El-Hassana & Kianmehrb, 2016). For instance, studies have shown that soil water infiltration influences groundwater

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recharge and potential topsoil loss by erosion (Ilstedt, Malmer, Verbeeten, & Murdiyarso, 2007).

Improvements in pavement design have been achieved over time. The case can be demonstrated by the various porous pavement designs such as permeable interlocking concrete pavers (PICP), porous concrete (PC), concrete blocks (CB), pervious asphalt (PA), concrete grids (GRIDS), aggregates, grass, plastic grids, granular materials, and loose decks, among other designs. Accordingly, various studies have evaluated these different designs (e.g., Cahill, Godwin, & Tilt, 2018; Imran, Akib, & Karim, 2013). Imran, *et al* (2013), for instance, defined porous pavements as pavements designed by omitting the fine aggregate from the concrete mix which makes the resulting pavement have characteristics more pores. Different designs or pavement layouts have been proposed and demonstrated different characteristics with regards to permeability and consequent infiltration rates (Cahill, Godwin, & Tilt, 2018; Imran, Akib, & Karim, 2013).

The illustration in Figure-1 presents a typical porous pavement design as suggested by Boogaard, *et al*. (2014). Similar designs have been provided by Arahuetes and Cantos (2019) and others. However, it is possible to note minor differences in the concepts presented. Mainly, and as suggested in the definition of porous pavement, different designs will present varying hydrological properties. For example, in an assessment of the hydrological performance of the porous pavements, Brown and Borst (2014) observed varying infiltration rates across different pavement designs. That is; infiltration rates were significantly different for each pavement type.

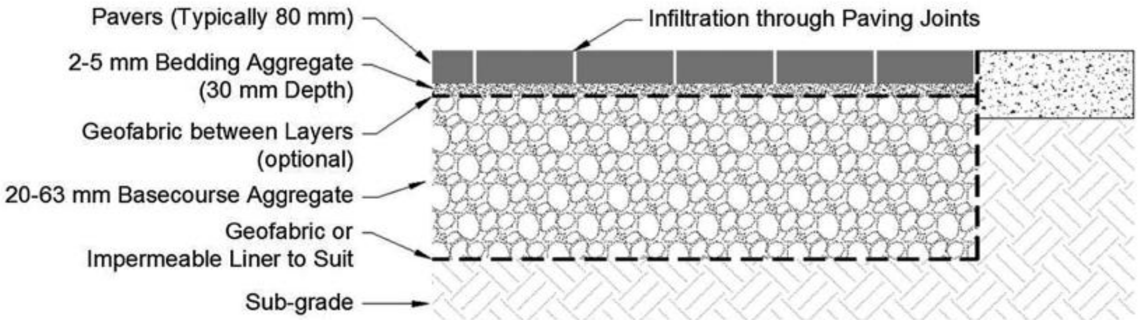

Figure-1. Typical permeable pavement structure. (Boogaard, *et al*., 2014).

However, the study highlighted the possible influence of clogging, nature of the underlying soils/base. For instance, the study further indicated that the infiltration rate was comparatively higher when the underlying soils were disturbed. In their study Huang, (2016) attributed the high initial Surface Infiltration Rate (SIR) of PC to its relatively high design porosity in the surface layer. The study, which compared the performance of three porous pavement designs noted that Porous Asphalt and PCIPs had lower design porosities. Other factors have also been associated with the performance of pavements. Boogaard, *et al*. (2014) discussed the effect of aging and, or lack of maintenance on the permeability and consequent hydraulic conductivity of the pavement.

Noting these many factors that influence infiltration and consequent surface run-off, it is possible to appreciate the complexity of performance testing for porous concrete. Also, the differences observed tended to indicate the importance of assessing the common indicator of the hydrological performance of porous pavements. There is an overwhelming indication that urbanization will persist. Ideally, the case means that more paving will occur. Consistently, there is a need to further the understanding of porous pavements to advance sustainable hydrological designs.

Past Meta-Analyses on Porous Pavements

Currently, there is a lack of Meta-analyses on hydrological performance. More so, the literature search failed to find considerable consolidated literature on the performance of porous pavements. While the foregoing review has demonstrated considerable scholarship in the field, there is a need to harmonize the findings to inform policy. Notably, the various studies highlighted in this paper have been observed as extensively fragmented. It is prudent that an attempt is made to provide an assessment of porous pavements in a more standardized manner. The current meta-analysis seeks to review existing literature on the performance of porous pavements as reported in various experiments and establish a common statistical viewpoint on the performance of porous pavements. While commenting on the use of Meta-analyses,for example, Rosenthal and DiMatteo (2001) noted that a meta-analysis avoids some of the limitations of the standard literature review and isolated studies. That it improves researchers' ability to statistically combine the results of many studies as well as reconcile conflicting findings through the examination of moderators and mediators.

The study hypothesized that porous pavements facilitated increased surface infiltration and reduced surface runoff. That is, the infiltration rates of surfaces paved by porous/previous materials have a significantly higher infiltration rate resulting in a significantly lower runoff coefficient (C).

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METHODS

Study Design

The current study is intended to establish the effect size based on the mean values of infiltration rate and surface runoff coefficient as investigated in the selected studies. Following that the selected studies tended to have varying study designs, the use of mean values eliminated the question of different study designs, as a possible effect on the statistics does not arise. That is, as explained by Borenstein, *et al* (2009), from a statistical perspective the effect size (D) has the same meaning regardless of the study design.

Literature Search

The search of the literature was confined to articles published in the English language on the topics of hydrology, hydraulic conductivity, infiltration, or permeability. The literature search was conducted using the *EBSCO host Library,* Google Scholar, and freely available online libraries and the internet. The following search was conducted;

Topic= (Permeable pavement | Porous pavement | Pervious pavement * Infiltration rate | Permeability | Runoff coefficient
| Surface runoff (Simulation | Experiment | Field measurements))

From the search, a further search was conducted by selecting relevant referenced articles on similar topics.

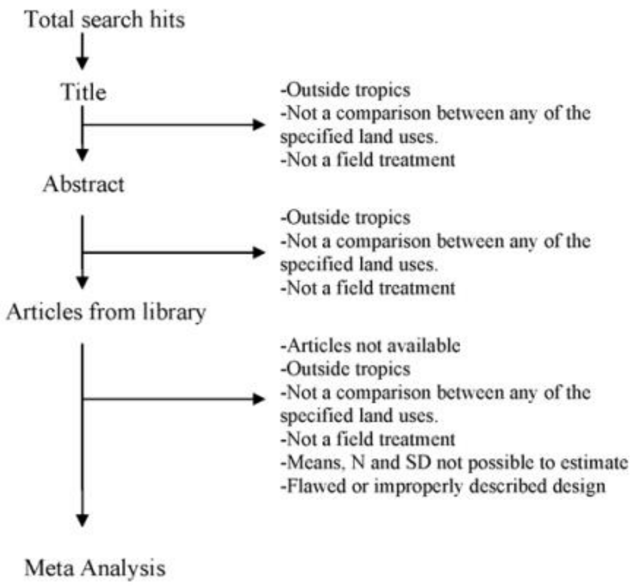

Figure-2. Search Criteria. Source: adapted from Ilstedt, *et al*. (2007).

Data Collection and Variables Considered

We used the criteria highlighted in Figure-2 to select studies for inclusion in the meta-analysis.

Analyses of Effect Sizes

The selected studies were analyzed using the statistical software OpenMetaAnalyst (Wallace, *et al*., 2012; Viechtbauer, 2010).

The meta-analysis hypothesized that porous pavements facilitated increased surface infiltration and reduced surface runoff. That surface with porous pavements had a significantly lower runoff coefficient (C). Since the hypothesis was derived from a literature review that indicated a consensus in the performance of porous pavements, the current analysis supposed that the mean effect among the selected studies is zero (Rosenthal & DiMatteo, 2001).

Further, following the variability in settings of the selected experiments, and the fact that the study adopted articles based on field data, laboratory experiments, and simulated results, a Random-effects measure was adopted. The use of random effects ensured that the study considered that effect sizes varied from one study to another. Accordingly, small studies were not discounted and it ensured that all studies were assigned appropriate weights. This approach is consistent with similar studies (e.g., Ilstedt, *et al*., 2007).

Reference Parameters

American Society of Civil Engineers (ASCE1969) suggested values for runoff coefficients (C) for various surfaces depending on site-specific characteristics. In the categories, previous surfaces had coefficient values ranging from 5 to 35% while impervious surfaces had coefficients ranging between 70 and 90%.

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The basis of this model is the assumption that all of the rainfall that lands on the effective impervious areas of a catchment surface will run off (ASCE, 1969).

Table-1. Standard runoff coefficients.

Surface Type	Runoff coefficient	Source
Pervious surface	5 to 35%	ASCE (1969) Ball & Rankin (2010)
Impervious Surface	70% to 90 %	ASCE (1969) Ball & Rankin (2010)
Traditional Pavements	0.90-1.00	Marchioni & Becciu (2015)

RESULTS

Search Results and Included Studies

The study retrieved a total of 33 articles and other publications, including conference papers, based on the search criteria outlined in the method. Using the inclusion-exclusion criteria, the study isolated 6 articles for the meta-analysis. The selected articles entailed 3 comparative studies that compared the infiltration rates of various types of porous pavements, and 3 studies that measured the hydrological performance of specific pervious pavements in different environments (See Table-2).

Table-2. Studies included in the meta-analysis.

No.	Author	Study Design	Hydraulic Parameter	Other Parameters Tested	Setting	Pavement type	Location
1	Pagotto, *et al* (2000)	With Comparison	Surface Runoff	Runoff water quality	Field measurement	Porous asphalt (PA)	Paris, France
2	Pratt, *et al.* (1995)	Without Comparison	Surface Runoff	Runoff water quality	Field measurement	Permeable. concrete block paving (PICP)	Nottingham, UK
3	Jefferies & Schluter (2002)	Without Comparison	Surface Runoff, Infiltration rate	---	Field measurement	Porous Paving (Type not mentioned)	Scotland
4	Smith (1984)	Without Comparison	Runoff coefficient	Runoff quality, pollutant loadings	Field measurement	Grid PICP	United States
5	Brattebo & Booth (2003)	With Comparison	Runoff	Runoff quality	Field measurement	Grid PICP	Washington, USA
6	Dreelina, *et al* (2006)	With Comparison	Runoff coefficient	Runoff quality	Field measurement	PA	Athens, Georgia, USA

Result of the Meta-Analysis

Overall results of the meta-analysis (Figure-2). From the studies and 6 experiments, it was established that there was a significant reduction in the runoff coefficient with a comparatively lower mean based on the Continuous Random-Effects Model indicated no effect size (Estimate = 0.357; 95%CI = -0.090–0.623; df = 5) (see Figure-3). This indicated that the supposed mean effect among the selected studies is zero.

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Summary

Continuous Random-Effects Model

Metric:

Model Results

Estimate	Lower bound	Upper bound	Std. error	p-Value
0.357	0.090	0.623	0.136	0.009

Heterogeneity

tau^2	Q(df=5)	Het. p-Value	I^2
0.109	391.695	< 0.001	98.723

Figure-3. Model summary.

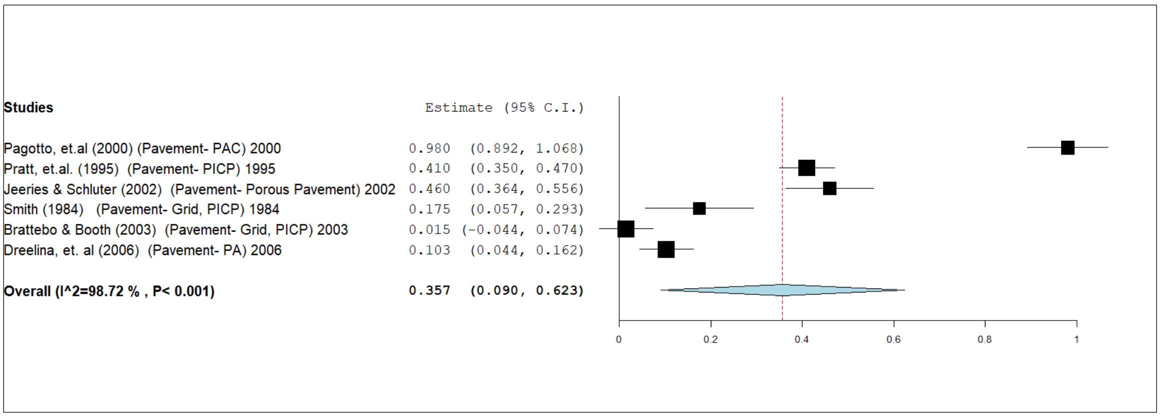

Figure-4. Leave one forest plot for mean difference.

Moderator Variables

Moderator variables included the type of pavement, location, and surface characteristics. The current analysis was able to assess the effect of the type of pavement. The effect of adjusting for pavement design type was notable (Figure-5). That is, it returned a significant effect size for selected articles that tested for PICP pavement; 0.200 (-0.074, 0.475).

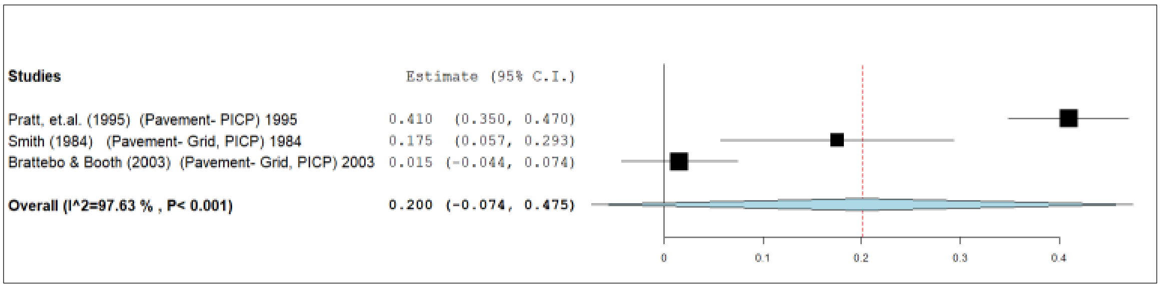

Figure-5. Sensitivity analysis controlling for pavement type.

In Figure-5, only Grid type pavements were used and returned a significant effect size. The case indicated that the study was sensitive to grid type. This observation was consistent with literature values that indicated extensive variation in hydrological properties across different pavement types.

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DISCUSSIONS

The current meta-analysis recognizes other factors that could affect the variable considered in this analysis. Typically, the Hydraulic conductivity of materials depends not only on surface conditions but the prevailing slope that often influences retention time. Also, an ideal case could entail almost identical cases albeit from different settings. Recognizing these factors, and others, the current discussion presents a comprehensive overview of the established results and attempts to place them in context. As noted before, the study was based on selected studies (see Table-2) that were accessible during the period of the study.

The observed effect of porous pavements is subject to many other factors beyond the ones considered in this meta-analysis. Inherently, the current study focused on infiltration rate and runoff coefficient. However, studies have explored a range of covariates including specific location characteristics of test sites, pavement design, and other factors. For instance, in an experiment on infiltration rates, Bean, (2007) noted that those rates were influenced by the location of the permeable membrane and whether such pavements had been well maintained. Also, Huang, *et al*, 2016) observed that the condition of the subsurface soils can significantly influence the infiltration rate. That is, the study observed that infiltration into the subgrade for groundwater recharge was negligible as the soils were impermeable (Huang, Valeo, He, & Chu, 2016). In a similar case, an experiment by (Marchioni & Becciu, Experimental results on permeable pavements in Urban areas: A synthetic review, 2015) observed that pervious asphalt installed over an impervious surface did not yield the benefits of fully permeable pavement. Consequently, Runoff from the previous asphalt was significantly higher than the conventional value confirming the importance of a fully permeable base to reduce runoff.

The case highlights the need to consider subsurface characteristics before evaluating the effect of permeable membranes.

The effect of subsurface hydraulic conductivity can be addressed by establishing the natural in-situ infiltration and comparing it with both permeable and impermeable pavements. While such a proposition may seem ideal, the current study failed to find studies that included such data. Nonetheless, the provided methodology used in this meta-analysis adopted inclusion criteria that controlled for the various factors observed.

The current analysis sought to investigate already published data on porous pavements experiments that measured in the field or in the laboratory, or simulated. It has been demonstrated in the literature that types of pavement and laid extensions, hydrological and permeability parameters (such as rainfall intensity, sub-surface outflow, runoff volume coefficient, infiltration rate) affect the performance of pavements. It was also noted that porous pavement showed considerable improvement in runoff quality and pollutant. However, the efficacy of the pavements was influenced by base material, soil type, saturation of the soil and other prevailing conditions. Also, the type of pavement, which mostly dictated the porosity and consequent hydraulic properties of pavements, was a key factor. Accordingly, it is possible to appreciate the complexity of the hydrological phenomena and perhaps challenging to completely account for each variable. Nonetheless, the foregoing experiments mostly used comparisons to assess hydrological behavior based on specific settings. That way, it was possible to assume that most of the underlying factors remained extensively constant.

Future Research

While permeable pavements have been demonstrated as having a significant effect on the infiltration rate/hydraulic conductivity, the current study was limited by several factors. The reviewed literature is mostly comprised of fragmented literature of experiments and simulations across the world. In many cases, it was not possible to provide details that could inform on the possible confounding effects. Accordingly, and following that the current meta-analysis did not consider possible covariates, a more detailed study is needed to isolate the various factors noted in the study. For example, Boogaard, *et al*. (2014) discussed the effect of aging and, or lack of maintenance on the permeability and consequent hydraulic conductivity of the pavement. Others, such as Alsubih, *et al* (2012) and Gomez, *et al* (2001). also, mentioned the effects of the subbase, soil types, types of porous pavers, and similar differences. Regarding the mentioned factors, it is possible to suggest that the current meta-analysis succeeded in assessing the effect size among the selected studies. Accordingly, it is possible to suggest that the positive effect of porous pavements advanced in the studies can be generalised.

Nonetheless, the generalisation of such findings needs to consider that the tested pavements broadly follow a hypothetical decay curve of infiltration rate with the age of pavement (Boogaard, Lucke, & Beecham, 2014). Also, the foregoing paragraphs have mentioned other factors such as clogging and the importance of maintenance in maintaining the performance of porous pavements.

CONCLUSIONS

A meta-analysis of studies evaluating the effect of porous pavements on surface hydrology. Specifically, the analysis investigated experiments on infiltration rate and runoff coefficient properties of porous pavements. Reviewed literature provided extensive indications on the benefits of porous pavements in mitigating hydrology in the built environment set up. It was demonstrated that pervious pavements improved the hydrological properties of engineered surfaces including mitigating runoff and checking to flood. A meta-analysis of already published data on porous pavements experiments (measured in the field or the laboratory, or simulated): types of pavement and laid extensions, hydrological and permeability parameters (rainfall intensity, sub-surface outflow, runoff volume coefficient, infiltration rate), others (i.e.: runoff quality, pollutant loadings, etc.) established a statistically significant effect of porous pavements on runoff coefficient and infiltration rates for the reviewed cases. While the study adopted a methodology that included similar studies in terms of method, further study is recommended to control for the various factors that influence hydraulic properties of porous pavers mentioned in the conclusion of this study.

REFERENCES

Alsubih M., Arthur S., Wright G. & Allen D. 2012. Experimental study on the Hydrological Performance of a Permeable Pavement. Institute for Infrastructure and Environment.

Amos C. B., Audet P., Hammond W. C., Bürgmann R., Johanson I. A. & Blewitt G. 2014. Uplift and seismicity driven by groundwater depletion in central California. Nature, 509(7501): 483-486. doi:10.1038/nature13275

Arahuetes A. & Cantos J. O. 2019. The potential of sustainable urban drainage systems (SuDS) as an adaptive strategy to climate change in the Spanish Mediterranean. International Journal of Environmental Studies. 1-16.

ASCE. 1969. Design and Construction of Sanitary and Storm Sewers. New York, NY: American Society of Civil Engineers.

Ball J. E. & Rankin K. 2010. The hydrological performance of a permeable pavement. Urban Water Journal. 7(2): 79-90.

Bean E. Z., Hunt W. F. & Bidelspach D. A. 2007. Field Survey of Permeable Pavement Surface Infiltration Rates. Journal of Irrigation and Drainage Engineering. 133(3): 249-255.

Beecham S. & Myers B. 2010. Designing Porous and Permeable Pavements for Stormwater Harvesting and Reuse.

Befani A. 2009. Basic Principles of the Theory of Processes of Surface and Underground Runoff. Hydrological Sciences Journal, 6(3): 18-31. doi: 10.1080/02626666109493225

Boogaard F., Lucke T. & Beecham S. 2014. Effect of Age of Permeable Pavements on Their Infiltration Function. CLEAN - Soil, Air, Water. 146-152.

Borenstein M., Hedges L. V., Higgins J. P. & Rothstein H. R. 2009. Introduction to Meta-Analysis. Chichester, West Sussex: John Wiley and Sons, Ltd.

Brattebo B. O. & Booth D. B. 2003. Long-term stormwater quantity and quality performance of permeable pavement systems. Water Research. 37, 4369-4376.

Broadbent A. M., Coutts A. M., Tapper N. J., Demuzere M. & Beringer J. 2018. The microscale cooling effects of water sensitive urban design and irrigation in a suburban environment. Theoretical & Applied Climatology, 134(1-2): 1-23. doi:10.1007/s00704-017-2241-3

Brown B. & Borst M. 2014. Evaluation of Surface Infiltration Testing Procedures in Permeable Pavement Systems. Journal of Environmental Engineering. 140(3).

Buda A. R., Kleinman P. J., Srinivasan M. & Bryant R. B. 2009. Factors influencing surface runoff generation from two agricultural hillslopes in central Pennsylvania. Hydrological Processes, 23, 1295-1312. doi:10.1002/hyp.7237

Cahill M., Godwin D. C. & Tilt J. H. 2018. Low Impact Development Fact Sheet- Porous Pavement. Oregon: 2018 Oregon State University. Retrieved from https://catalog.extension.oregonstate.edu/sites/catalog/files/project/pdf/em9210.pdf

Chen, J.-S., Chen, S.-F., & Liao, M.-C. (2015). Laboratory and Field Evaluation of Porous Asphalt Concrete. Asian Transport Studies, 298-311.

Christensen D. & Schmidt A. R. 2008. An Approach to Analyze the Hydrologic Effects of Rain Gardens. Low Impact Development Conference. Seattle, Washington: American Society of Civil Engineers.

Dietz M. E. 2007. Low Impact Development Practices: A Review of Current Research and Recommendations for Future Directions. Water Air Soil Pollut. 186, 351-363.

Donofrio J., Kuhn Y., McWalter K. & Winsor M. 2009. Water-Sensitive Urban Design: An Emerging Model in Sustainable Design and Comprehensive Water-Cycle Management. Environmental Practice, 11(3): 179-189. doi:10.10170S1466046609990263

Dreelina E. A., Fowlerb L. & Carroll C. R. 2006. A test of porous pavement effectiveness on clay soils during natural storm events. Water Research. 799-805.

El-Hassana H. & Kianmehrb P. 2016. Pervious concrete pavement incorporating GGBS to alleviate pavement runoff and improve urban sustainability. Road Materials and Pavement Design. 1-16.

Fwa T., Tan S., Chuai C. & Guwe Y. 2001. Expedient Permeability Measurement for Porous. The International Journal of Pavement Engineering. 2(4): 259-270.

Gomez J., Nearing M., Giraldez E. & Alberts E. 2001. Analysis of Sources of Variability of runoff volume in a 40 plot experiment using a numerical model. Journal of Hydrology. 183-197.

Gu F., Ma W., West R. C. & Taylor A. J. 2019. Structural performance and sustainability assessment of cold centralplant and in-place recycled asphalt pavements: A case study. Journal of Cleaner Production. 1513-1523.

Hoban A. 2019. Water Sensitive Urban Design Approaches and Their Description. In Approaches to Water Sensitive Urban Design (pp. 25-35). Brisbane, Australia: Bligh Tanner P/L. doi:10.1016/B978-0-12-812843-5.00002-2

Huang J., Valeo C., He J. & Chu A. 2016. Three Types of Permeable Pavements in Cold Climates: Hydraulic and Environmental Performance. Journal of Environmental Engineering. 1-10.

Ilstedt U., Malmer A., Verbeeten E. & Murdiyarso D. 2007. The effect of afforestation on water infiltration in the tropics: A systematic review and meta-analysis. Forest Ecology and Management. 45-51.

Imran H., Akib S. & Karim M. R. 2013. Permeable pavement and stormwater management systems: a review. Environmental Technology, 34(18): 2649-2656. doi:10.1080/09593330.2013.782573

Jefferies C. & Schluter W. 2002. Modelling the outflow from a porous pavement. Urban Water. 4, 245-253.

Kale S. Y., Halwele A. P., Rathod K. & Jirapure M. A. 2017. Permeable Pavement a step towards Sustainable Urban Drainage System. International Advanced Research Journal in Science, Engineering and Technology, 4(3): 85-89. doi:10.17148/IARJSET

Lipsey M. & Wilson D. 2001. Practical Meta-Analysis. . Thousand Oaks, CA: Sage Publications.

Marchioni M. & Becciu G. 2014. Permeable pavement used on sustainable drainage systems (SUDs): a synthetic review of recent literature. Urban Water II 183. doi: 10.2495/UW140161

Marchioni M. & Becciu G. 2015. Experimental results on permeable pavements in Urban areas: A synthetic review. International Journal of Sustainable Development and Planning. 806-817.

Monberg R. J., Howe A. G., Ravn H. P. & Jensen M. B. 2018. Exploring structural habitat heterogeneity in sustainable urban drainage systems (SUDS) for urban biodiversity support. Urban Ecosystems, 8. doi:10.1007/s11252-018-0790-6

Monrose J. & Tota-Maharaj K. 2016. Permeable Pavements as Low Impact Development Practices for Urban Runoff Mitigation and Sustainable Stormwater Management within the Built Environment for the Caribbean. 25th Silver Anniversary Annual Caribbean Water and Wastewater Association (CWWA) Conference & Exhibition, 24-28. West Indies.

Montes F., Valavala S. & Haselbach L. M. 2005. A New Test Method for Porosity Measurements of Portland Cement Pervious Concrete. Journal of ASTM International. 2(1): 1-13.

Mulyono T. & Anisah. 2019. Laboratory Experiment: Pervious Concrete for Permeable Pavement, Focus in Compressive Strength and Permeability. IOP Conference Series: Earth and Environmental Science. 1-15.

Nassar U. A., Waseef A. & Elsamaty H. 2017. Water Sensitive Urban Design: A Sustainable Design Approach to Reform Open Spaces in Low-Income Residential Rehabilitation Projects in Egypt. UPLanD-Journal ofUrban Planning, Landscape & Environmental Design. 2(3): 123-148.

Novo A. V., Bayon J. R., Castro-Fresno D. & Rodriguez-Hernandez J. 2013. Temperature Performance of Different Pervious Pavements: Rainwater Harvesting for Energy Recovery Purposes. Water Resour Management, 27, 5003-5016. doi: 10.1007/s11269-013-0270-y

Pagotto C., Legret M. & LeCloirec P. 2000. Comparison of the Hydraulic Behaviour and the Quality of Highway Runoff Water According to the Type of Pavement. Wat. Res. 34(18): 4446- 4454.

Palhegyi G. E. 2010. Designing Storm-Water Controls to Promote Sustainable Ecosystems: Science and Application. Journal of Hydrologic Engineering, 16(6): 504-511. doi: 10.1061/(ASCE)HE.1943-5584.0000130

Pratt C. J., Mantle J. D. & Schofield P. A. 1995. UK research into the performance of permeable pavement, reservoir structures in controlling stormwater discharge quantity and quality. Water Science and Technology. 63-69.

Qin H.-p., Li Z.-x. & Fu G. 2013. The effects of low impact development on urban flooding under different rainfall characteristics. Journal of Environmental Management. 129, 577-585.

Rosenthal R. & DiMatteo M. 2001. Meta-analysis: recent developments in quantitative methods for literature reviews. Annual Review of Psychology. 52, 59-82.

Schluter Wolfram & Jefferies C. 2002. Modelling the outflow from a porous pavement. Urban Water, 245–253.

Seatle.gov. 2020. Tomorrow: Why Build a Rain Garden? Retrieved from Seatle.gov: https://atyourservice.seattle.gov/2013/09/25/tomorrow-why-build-a-rain-garden/

Selbig W. & Buer N. 2018. Hydraulic, water-quality, and temperature performance of three types of permeable pavement under high sediment loading conditions. Reston, VA: U.S. Geological Survey (USGS). doi: 10.3133/sir20185037.

Smith D. 1984. Evaluations of concrete grid pavements in the United States. Second International Conference on Concrete Block Paving. Delft.

Thelen E., Grover W. C., Hoiberg A. J. & Haigh T. I. 1972. Investigation of porous pavements for urban runoff control. Water Pollution Control Research Series. Washington, D.C.: U.S. Environmental Protection Agency.

Viechtbauer W. 2010. Conducting meta-analyses in R with the meta for package. Journal of Statistical Software. 36.

Wallace B. C., Trikalinos J. L., Paul T. & Schmid C. H. 2012. OpenMetaAnalyst: Closing the Gap between Methodologists and End-Users: R as a Computational Back-End. Journal of Statistical Software. 5.

Wong T. H. 2006. An Overview of Water Sensitive Urban Design Practices in Australia. Water Practice & Technology, 1(1). doi:10.2166/WPT.2006018.