PERMEABLE PAVEMENTS AS LOW IMPACT DEVELOPMENT PRACTICES FOR URBAN RUNOFF MITIGATION AND SUSTAINABLE STORMWATER MANAGEMENT WITHIN THE BUILT ENVIRONMENT FOR THE CARIBBEAN

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PRESENTATION LAYOUT

- INTRODUCTION
- PERMEABLE PAVEMENT ENGINEERING (PPE)
- RESEARCH GAPS
- CONCLUSION AND OUTLOOK

INTRODUCTION

The Problem

Source: The author, 2016

- Conventional drainage systems do not adapt to future climatic variability and urbanization
- Poor land use practices
- Improper utilization of drainage infrastructure (littering)
- Faulty designs
- Lack of maintenance
- Conventional drainage systems focus solely on stormwater quantity control; no focus on the environment in terms of water quality, visual amenity, biodiversity and ecological protection

INTRODUCTION

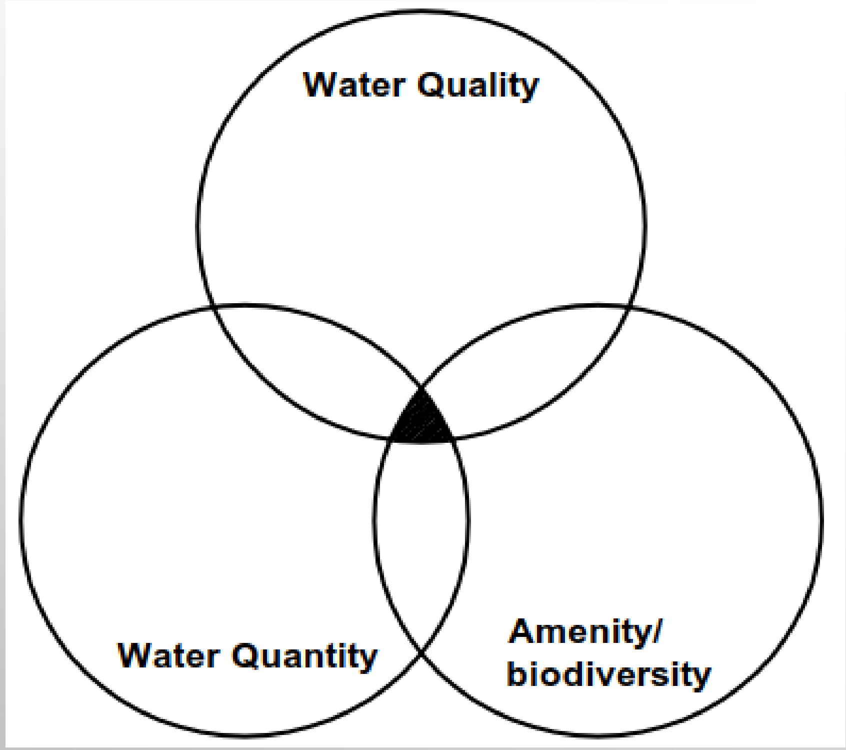
The Problem

Source: Trinidad Express Newspaper, 2016

Source: The author, 2016

INTRODUCTION

Low Impact Development (LID)

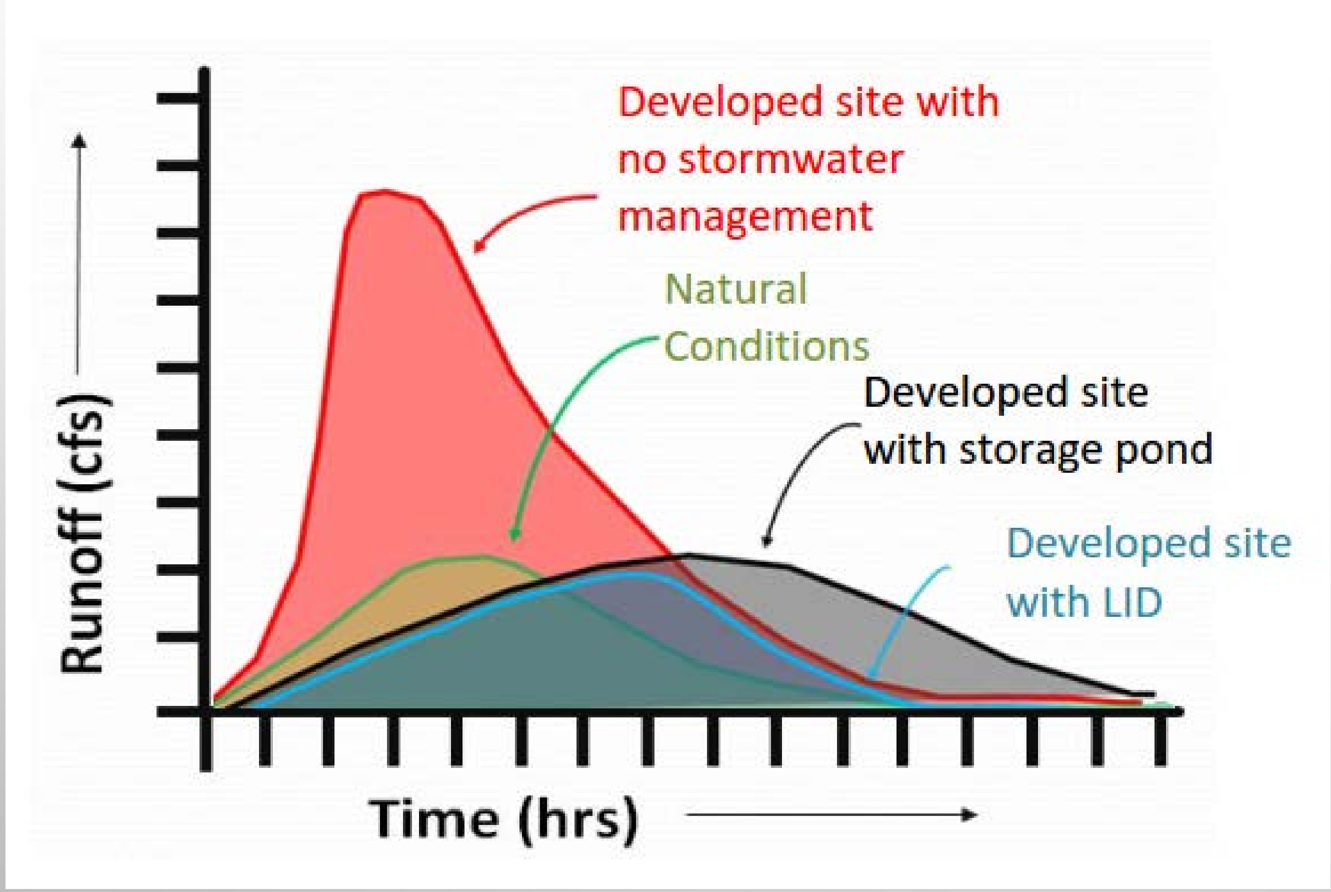


Source: SUDS Manual, 2015

- An approach which aims at achieving stormwater management controls by fundamentally changing conventional site design to create an environmentally functional landscape that mimics natural watershed hydrologic functions.
- Similar concepts used is different parts of the world include:
  - ✓ Sustainable urban drainage systems (SUDS)
  - ✓ Best Management Practices (BMP)
  - ✓ Water sensitive urban design (WSUD)

INTRODUCTION

Low Impact Development (LID)



Source: Horsley Witten Group and Center for Watershed Protection, 2014

- Comparison between runoff volumes and times to peak for various development conditions

PERMEABLE PAVEMENT ENGINEERING (PPE)

Overview

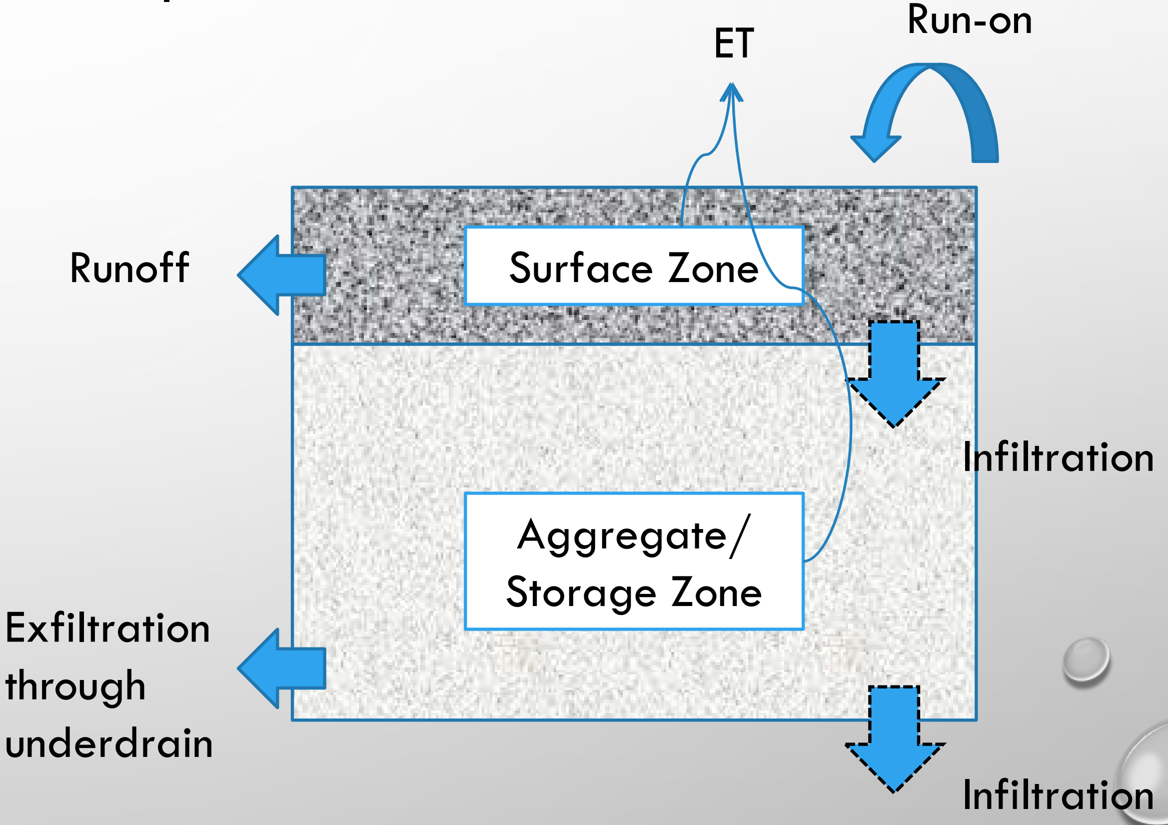
- Dates back to the early 1970s
- Involves a simple and effective method of providing structural pavements, whilst allowing runoff to infiltrate freely through the pavement surface and into a base/subbase reservoir
- Mimics the natural soil environment

PERMEABLE PAVEMENT SYSTEMS (PPS)

Definitions

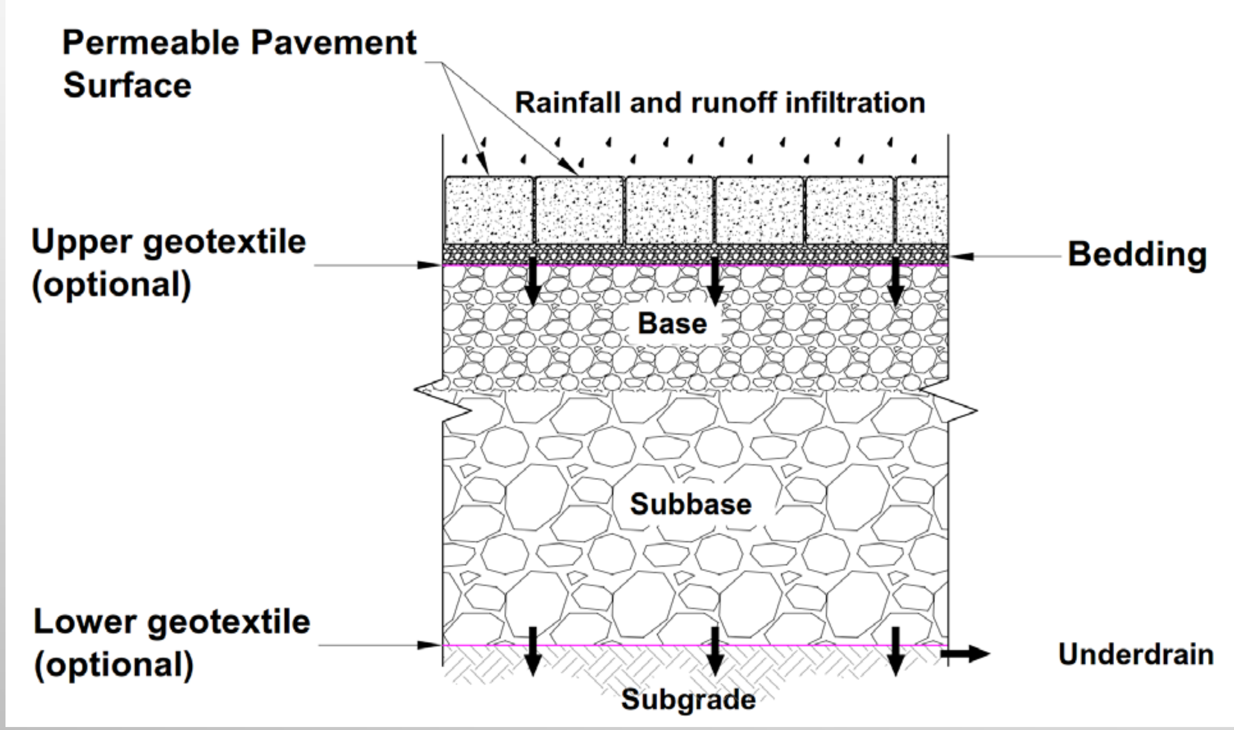
- Permeable pavement: pavement that allows water to pass through the joints between paver units
- Permeable pavement is often used interchangeably with pervious or porous pavement
  - Pervious pavement: pavement that allows infiltration of water
  - Porous pavement: pavement that allows water through the pores in the pavement

Conceptual Model



PERMEABLE PAVEMENT SYSTEMS (PPS)

Pavement Structure of PPS

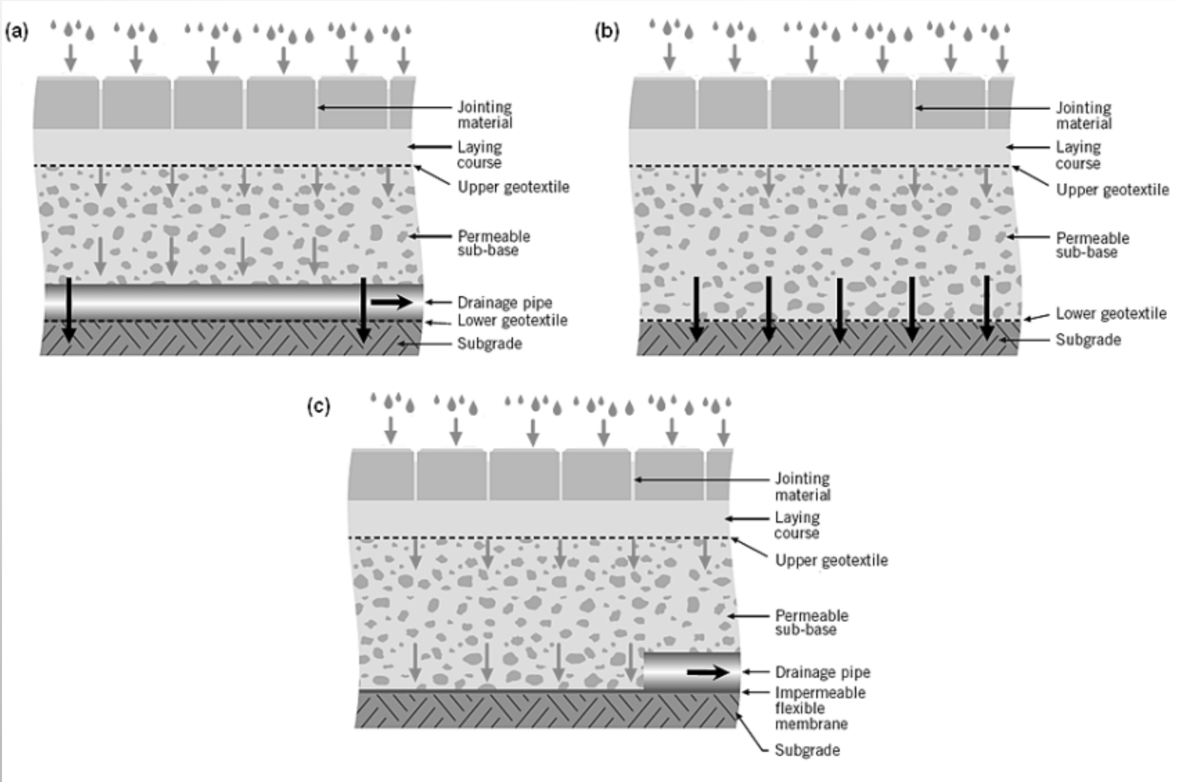


Adapted from: Tota-Maharaj et al., 2012

- Subgrade – natural or existing soil
- Subbase – Typically crushed aggregates of ASTM No. 2 gradation classification (19 to 63 mm). Depth dependent on structural and/or storage requirements
- Base – Typically crushed aggregates of ASTM No. 57 gradation classification (5 to 25 mm). Depth dependent on structural and/or storage requirements
- Bedding – Typically 30-50mm deep comprising ASTM No. 8 aggregate with gradation ranging from 2 to 5 mm.
- Pavement surface – typically used to describe the type of PPS

PERMEABLE PAVEMENT SYSTEMS (PPS)

Infiltration Boundary Conditions



Source: Interpave, 2010

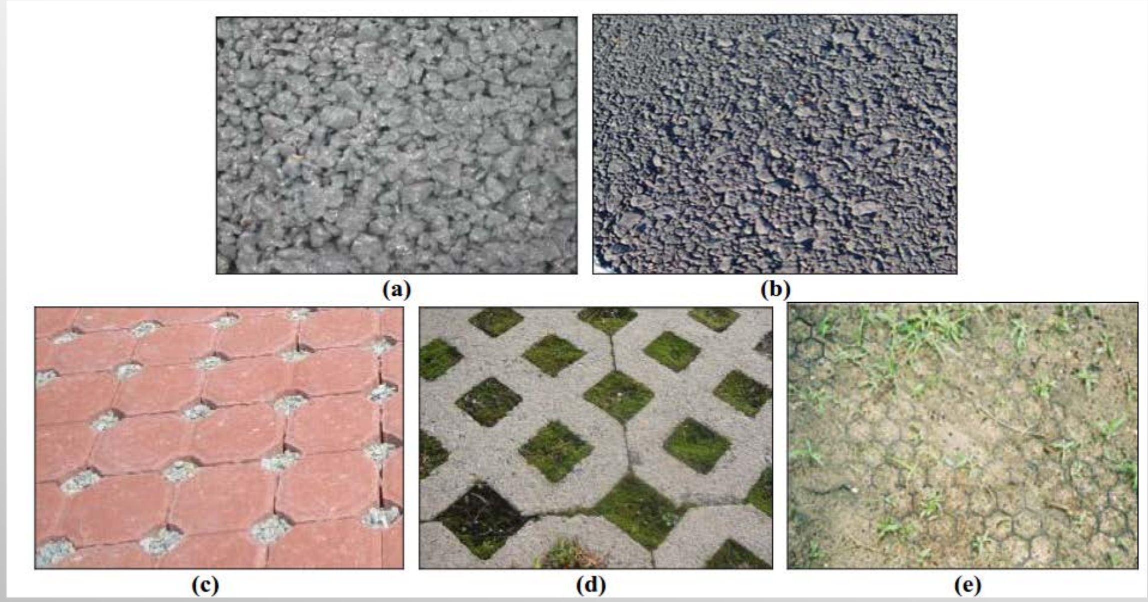
(a) - No infiltration – no desire for infiltration into the native soil. Soil type possibly clay with low permeability.

(b) – Full infiltration – Native soil permits infiltration in addition to infiltration being desired.

(c) – Partial infiltration – soil permeability too low to allow for full infiltration

PERMEABLE PAVEMENT SYSTEMS (PPS)

Types of PPS



Source: Collins, 2007

Either monolithic, modular, or grid types

(a) – Porous Concrete (PC)

(b) – Porous Asphalt (PA)

(c) – Permeable interlocking concrete pavers (PICP)

(d) – Concrete grid pavers (CGP) with topsoil and grass infill

(e) – Plastic grid pavers (PC) with earth infill

PERMEABLE PAVEMENT SYSTEMS (PPS)

Porous Concrete (PC)

Source: Harrison, 2011

- Monolithic
- Traditional concrete with high porosity from the absence of fine aggregate
- Typical water-cement ratio ranges from 0.35 to 0.45 with void content from 15 to 25%
- High void content implies PC is lightweight with densities ranging from 1600 to 1900 kg/m^3
- Compressive strengths usually low ranging from 2.8 to 28 MPa

PERMEABLE PAVEMENT SYSTEMS (PPS)

Porous Asphalt (PA)

Source: flexiblepavements.org

- Monolithic
- Traditional hot mix asphalt with reduced fines content
- Voids of approx. 22% have been reported
- Voids reduce aquaplaning, increase skid resistance, reduce splash, noise, spray and light reflection

PERMEABLE PAVEMENT SYSTEMS (PPS)

Permeable interlocking concrete pavers (PICP)

Source: Horsley Witten Group and Center for Watershed Protection, 2014

- Manufactured modular units of various shapes and sizes
- Placed adjacent to each other in various patterns
- Drainage typically through small joints between the units (3 to 13 mm)
- Joints infilled with small aggregates (2 to 5 mm)
- Paver thickness – 60 or 80 mm with minimum compressive strength of 55 MPa

PERMEABLE PAVEMENT SYSTEMS (PPS)

Concrete grid pavers (CGP)

Source: lastormwater.org

- Max dimensions of 610 mm L x 610 mm W x 80mm H
- 20 to 50% void area consisting typically of topsoil and grass

PERMEABLE PAVEMENT SYSTEMS (PPS)

Plastic grid pavers (PC)

Source: Horsley Witten Group and Center for Watershed Protection, 2014

- Also referred to as geocells
- Made up of flexible plastic interlocking units that permit infiltration through wide gaps filled with clean gravel or topsoil with grass
- A sand bed and gravel base course in typically added to improve infiltration and storage

PERMEABLE PAVEMENT SYSTEMS (PPS)

Typical Applications of PPS

- Roadway shoulders
- Residential driveways
- Parking lots
- Pedestrian access
- Slope stabilization
- Erosion control

Source: The author, 2016

PERMEABLE PAVEMENT SYSTEMS (PPS)

Advantages of PPS

- Improve stormwater quality
- Recharge ground water
- Reduce flooding
- Reduce erosion
- Reduce Runoff
- Reduce urban heat island effect
- Meets LID for sustainable development
- Promote water harvesting and reuse for irrigation and/or grey water use
- Reduces amount of land space utilized for other stormwater management infrastructure such as detention ponds
- Overall cost reduction through less stormwater infrastructure (retention and detention ponds, storm sewers, etc.)

PERMEABLE PAVEMENT SYSTEMS (PPS)

Hydrologic Impact

- PPS hydraulic characteristics contribute to four areas of hydrologic control: peak flow, runoff volume, hydrograph timing, and duration
- Variables which influence hydrologic performance include:
  - Local climatic and geological conditions
  - Pavement structure design
  - Boundary conditions
  - Age of pavement
  - Magnitude, intensity and duration of rainfall events
  - Antecedent conditions

Study	Location	PP Type	Average Runoff Reduction(%)	Boundary Condition
Abbott and Comino-Mateos (2003)	U.K	PICP	78	Impermeable membrane
Collins et al. (2008	NC	PICP	99.3	Sandy loam to sandy clay
		PC	99.9	
		CGP	98.2	
Fassman and Blackbourn (2010)	New Zealand	PICP	52	Clay

PERMEABLE PAVEMENT SYSTEMS (PPS)

Water Quality Impact

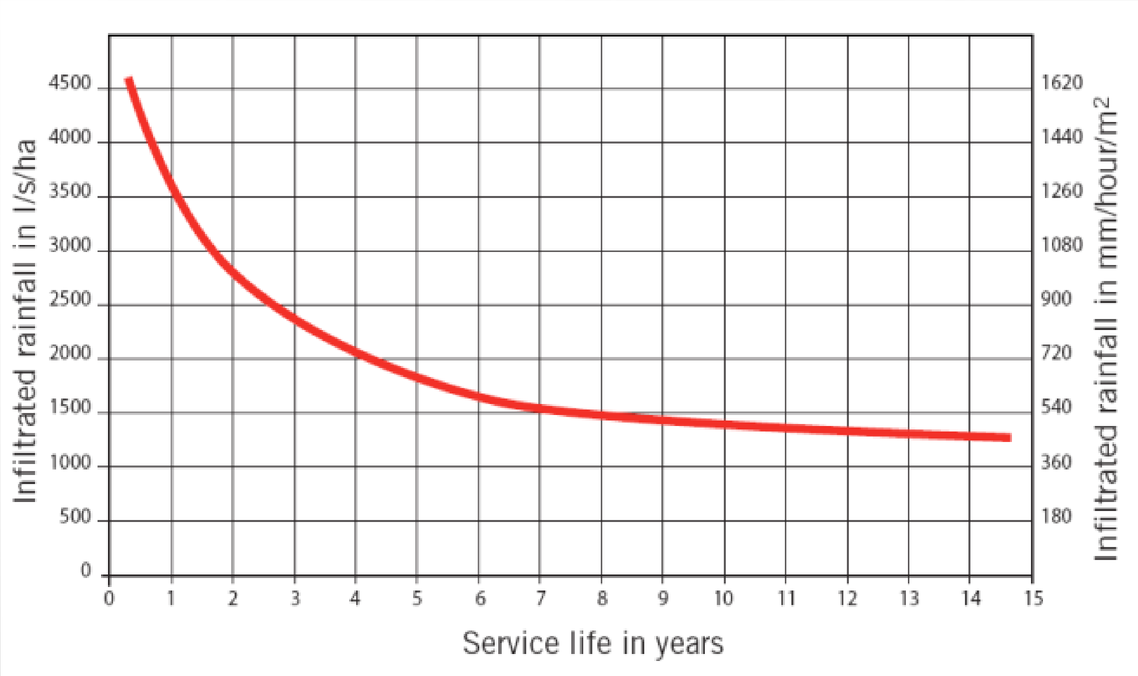
- Typical urban runoff pollutants include:
  - TSS
  - Heavy metals (Zn, Cu, Pb, etc.)
  - Pathogens (Faecal coliforms, E-Coli)
  - Nutrients (Phosphates, Nitrates)

Study	Study Type	PP Type	Pollutant Removal Rate (%)
(Pagotto et al., 2000)	Field-scale	PA	87% for TSS; 35% for Cu; 78% for Pb; 66% for Zn
(Bean et al., 2007)	Field-scale	PICP	75% for TSS; 43% for TN; 42% for TP; 88% for Zn; 62% for Cu
(Gilbert and Clausen, 2006)	Field-scale	PICP	> 80% for TSS; 66% for TP; 50% for TN; 65% for Cu; 67% for Pb; 79% for Zn
(Dreelin et al., 2006)	Field-scale	PICP	> 75% for TSS; 80% for TP; 43% for TN; >80% for Zn
(Brattebo and Booth, 2003)	Field-scale	PICP	89% for Cu; 69% for Zn
(Tota-Maharaj and Scholz, 2010)	Lab-scale	PICP	98-99% for Total Coliforms, E. Coli and Faecal Streptococci
(Legret and Colandini, 1999)	Field-scale	PA	59% for TSS; 84% for Pb; 0% for Cu; 77% for Cd; 73% for Zn

PERMEABLE PAVEMENT SYSTEMS (PPS)

Challenges with PPS

- Clogging and maintenance of infiltration capacity
  - Typical for sediments to capture near surface of PPS resulting in clogging
  - Numerous studies have shown an exponential decay of surface infiltration as a function of age of the permeable pavement
  - Periodic maintenance key to limit clogging
  - Examples of maintenance techniques include street sweeping, vacuuming and pressure washing



Source: Interpave, 2010

PERMEABLE PAVEMENT SYSTEMS (PPS)

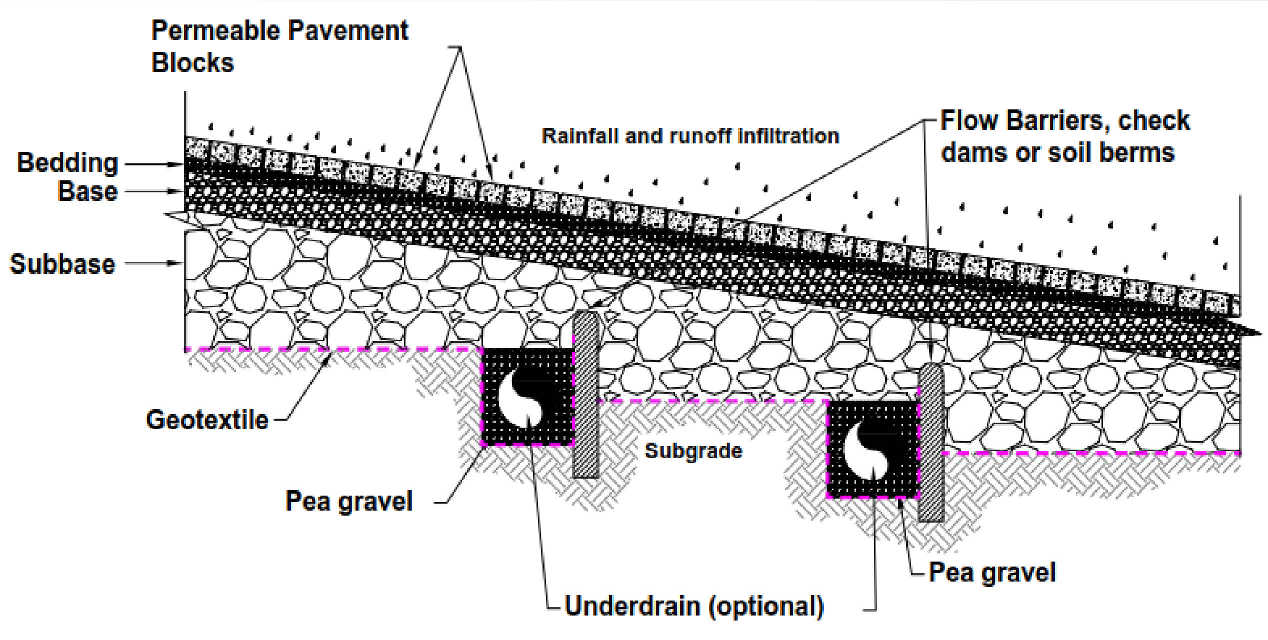
Challenges with PPS

- Cost
  - Initial costs typically higher than those of conventional pavements due to thicker aggregate layers
  - Savings and benefits realized from life cycle approach through reduced need for conventional stormwater infrastructure
- Groundwater contamination
  - Concerns minimized through use of an adequate impermeable geo-membrane over subgrade
  - Several studies have revealed low risks of subsoil pollutant accumulations and groundwater contamination (Legret and Colandini, 1999; Legret et al., 1999; Dierkes et al., 2002; Kwiatkowski et al., 2007)

PERMEABLE PAVEMENT SYSTEMS (PPS)

Challenges with PPS

- Sloping terrain
  - Typically installed over slopes up to 5%
  - Some laboratory studies have reported successful performances on slopes up to 10% (Castro *et al.*, 2007; Illgen *et al.*, 2007)



Adapted from: Kumar, 2014

RESEARCH GAPS

- Impact on recycled waste materials on the performance of PPS
  - Caribbean generates an average of 1.3 kg/capita/day of waste (Kinnaman, 2010)
  - Frees up on volume of material landfilled
  - Reduces rate of landfill space consumption
  - Reduction in carbon foot-print
  - Reduction in quarrying and the use of natural aggregates
- Life cycle cost analysis of PPS applicable to built up areas of with Caribbean SIDS

CONCLUSION AND OUTLOOK

- Numerous studies have reported successful applications of permeable pavements worldwide
- PPS improve stormwater runoff quality, provide vital reservoir storage for potential reuse and improve the hydrologic functions of numerous locations
- Technical uncertainty in performance, lack of data, social perceptions, clogging, maintenance and costs may invite reluctance to implementation of PPS in the Caribbean
- On-going research at the University of Greenwich, UTT, UWI and AECOM addresses timely and novel PPE, designs applicable to Caribbean SIDS

THANK YOU

Questions?