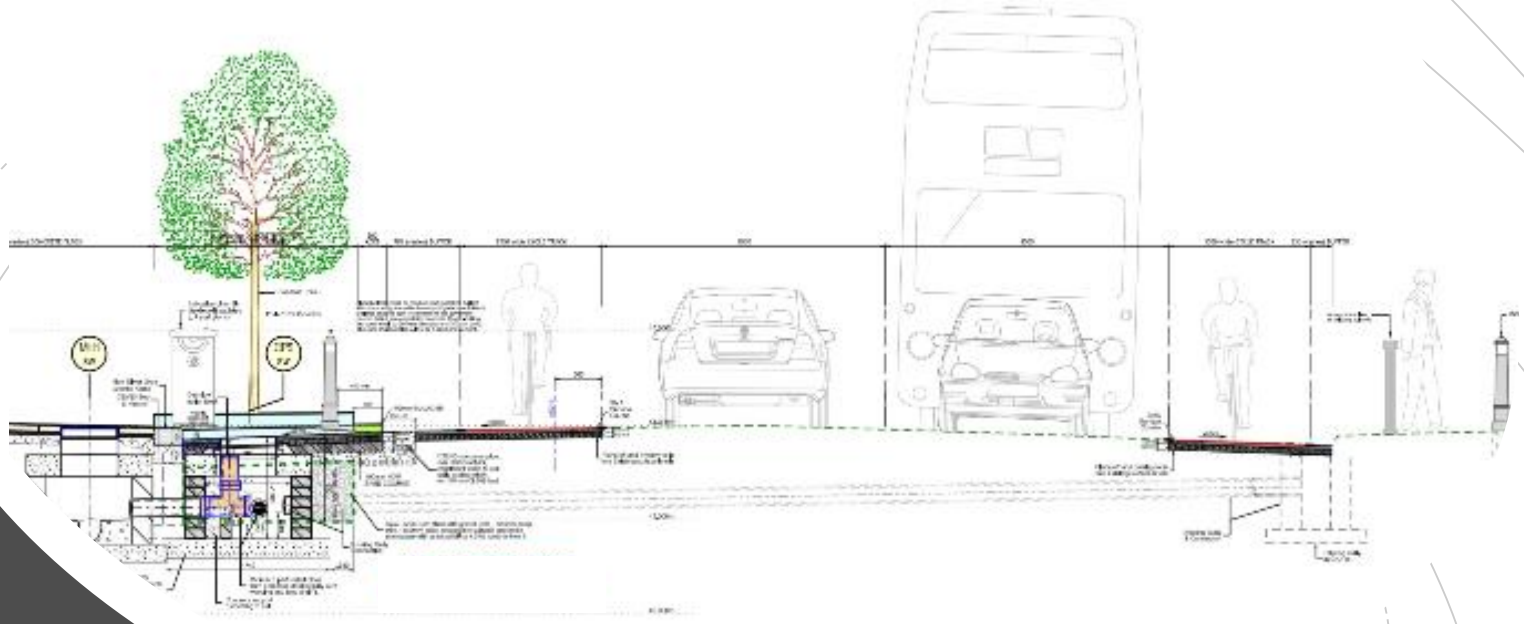


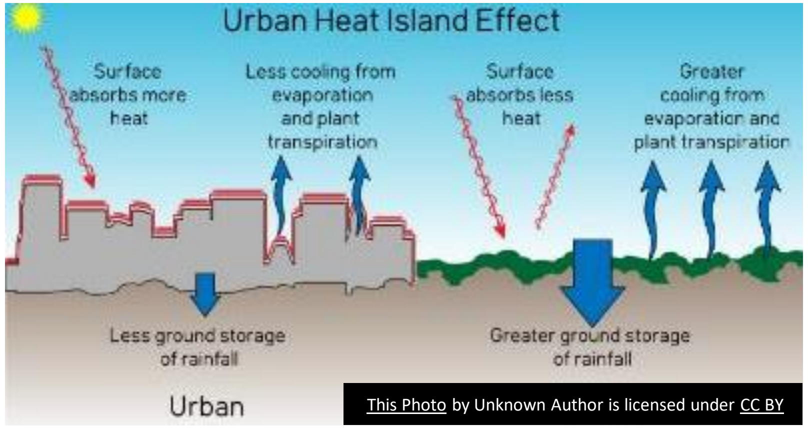
SUDS Techniques: what they are, and the multiple benefits they deliver

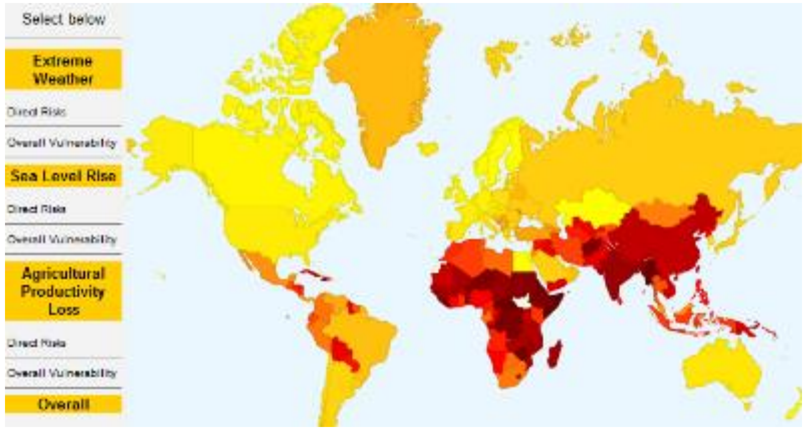
John Stack, Dublin City Council

Comhairle Cathrach
Bhaile Átha Cliath
Dublin City Council

Agenda

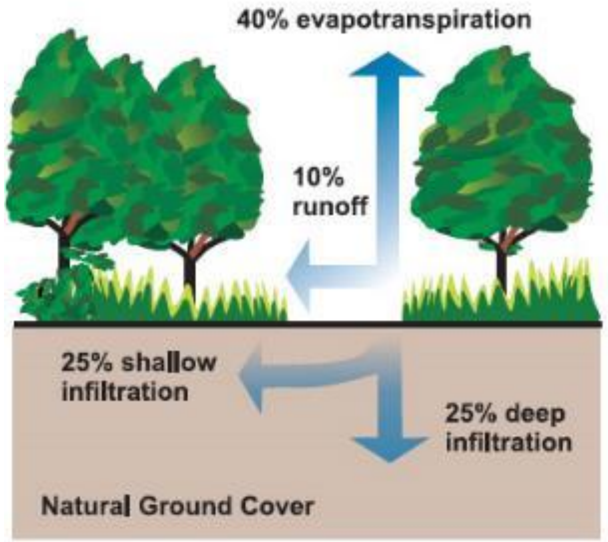
- What are the issues?
- Effects of Urbanisation
- Sustainable approach to stormwater management
- NWRM Examples
- Design Considerations
- Summary

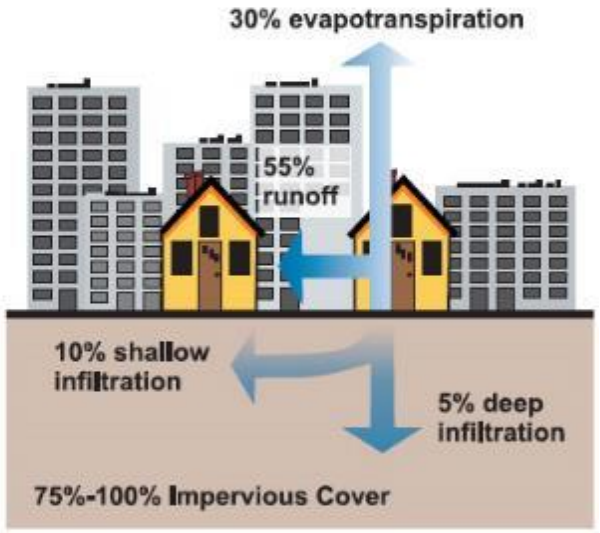




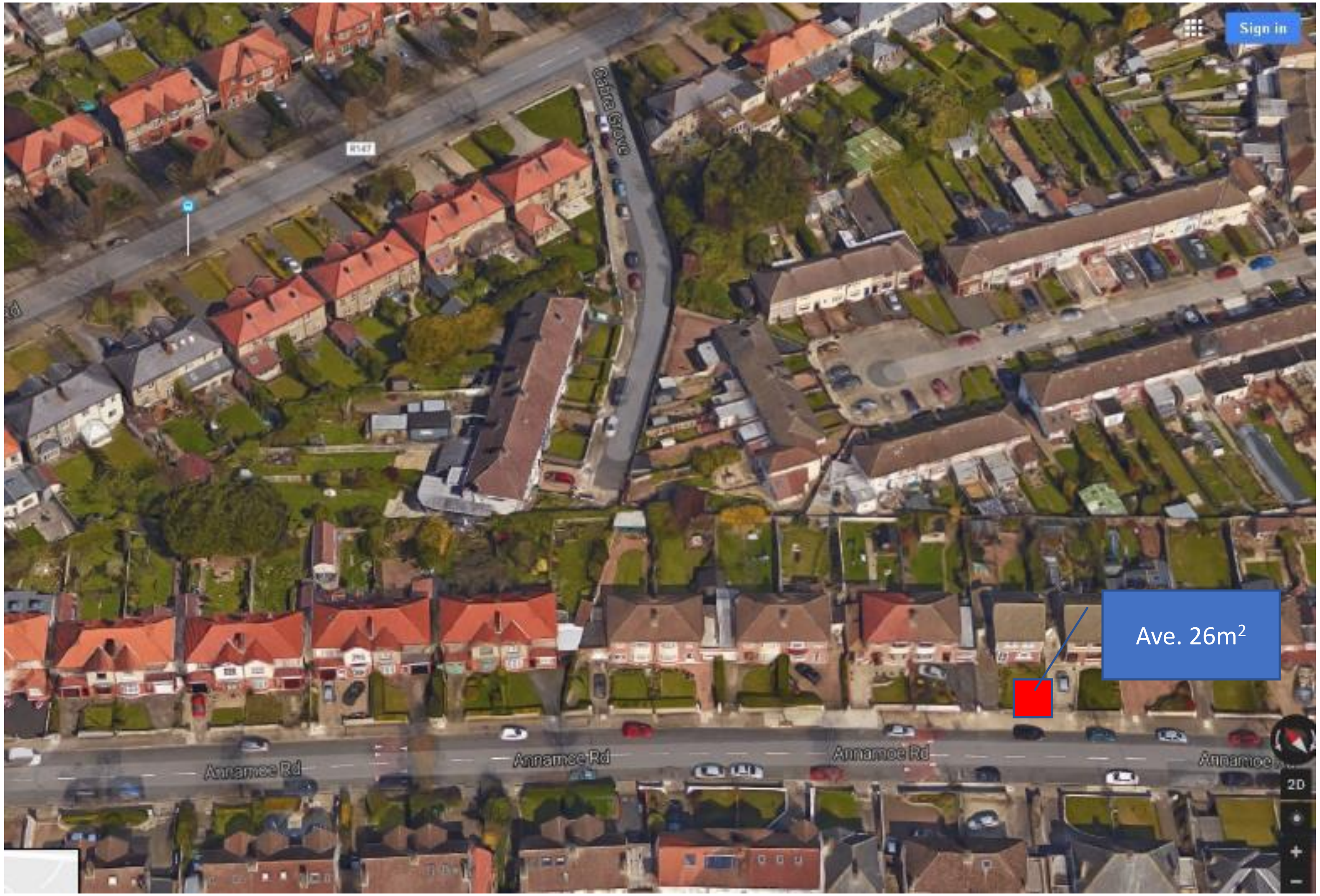
What are the issues?

Urbanisation





‘Urbanisation is NOT just the outward expansion of the city



Internal Urban Creep:

- Developing existing green sites within the urban area
- Paving front/back gardens, extensions, adding garden sheds, etc.

Paving front gardens:
c. 132,000 houses in Dublin
AAF = 750 mm/yr

If 20% of these pave their front garden, that’s 686,400 m^2 new impervious area
x
2.54 cm (1”) of rainfall
=
approx. 17,500 m^3 additional runoff

(it’s over 87,000 m^3 if they all do it)

Pluvial Flooding, River Santry, Dublin

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Urban Runoff & Water Quality

- Le Fevre et al, 2015
  - “wide variety of pollutants”
  - ….at levels high enough to have a deleterious effect….”
  - Toxic metals, suspended solids, pathogens, nutrients, hydrocarbons frequently found at elevated levels
- McGrane, 2014
  - Emerging priority pollutants
- Flint and Davis, 2007
  - Most of the load is delivered in the 1st flush
- McGrane, 2016
  - Mobilisation of contaminants expedited through increased surface runoff and hydraulic efficiency

Habitat and Biodiversity Loss

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Impact of urbanisation on habitat loss

- McKinney, 2002
  - Urban development has a major impact on habitat, ecology and biodiversity
  - Persistent and likely to expand into other local ecosystems

- Seto et al, 2015
  - Complex relationship between urbanisation and biodiversity
  - Landcover change is the biggest direct impact
  - Indirect impacts

A Sustainable Approach

- Green Infrastructure
- Natural (Nature-Based) Water Retention Measures

Green Infrastructure

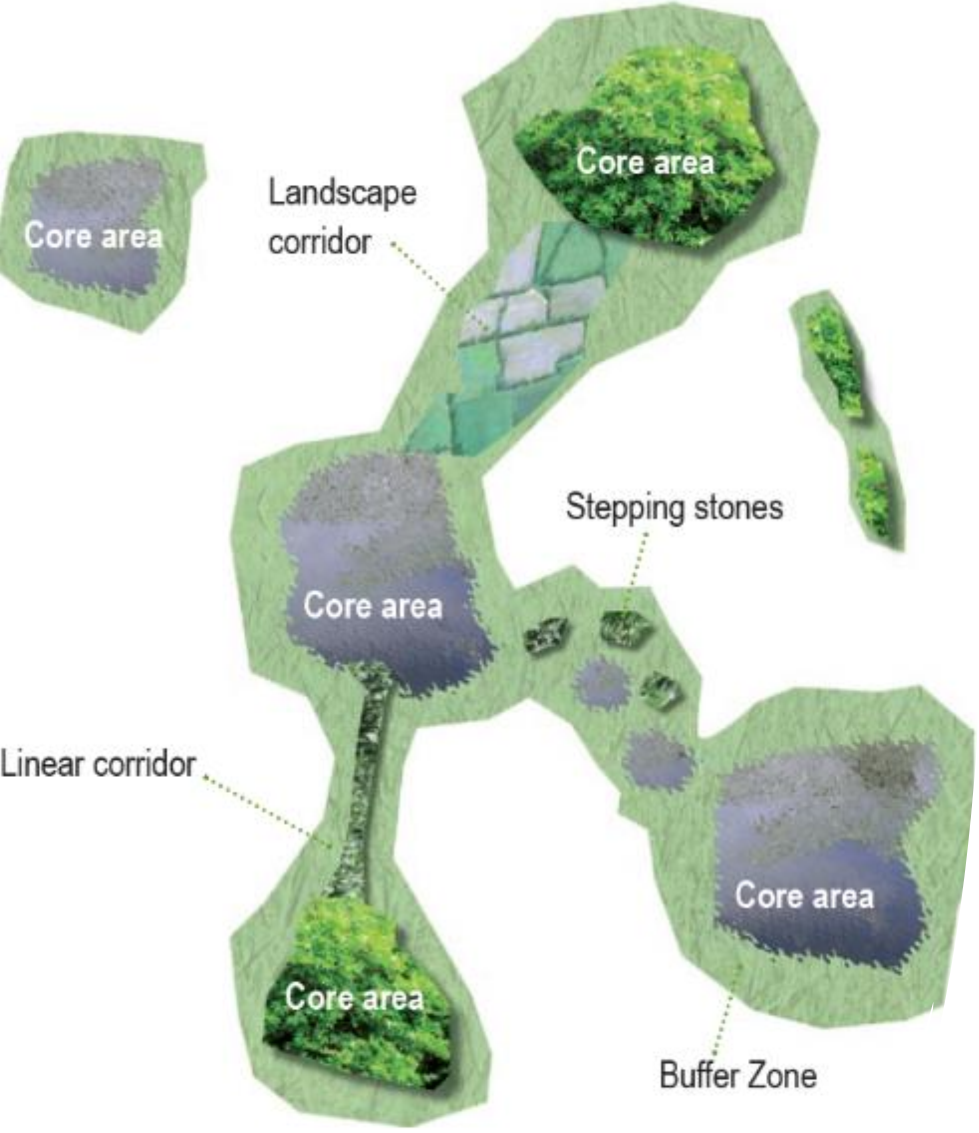


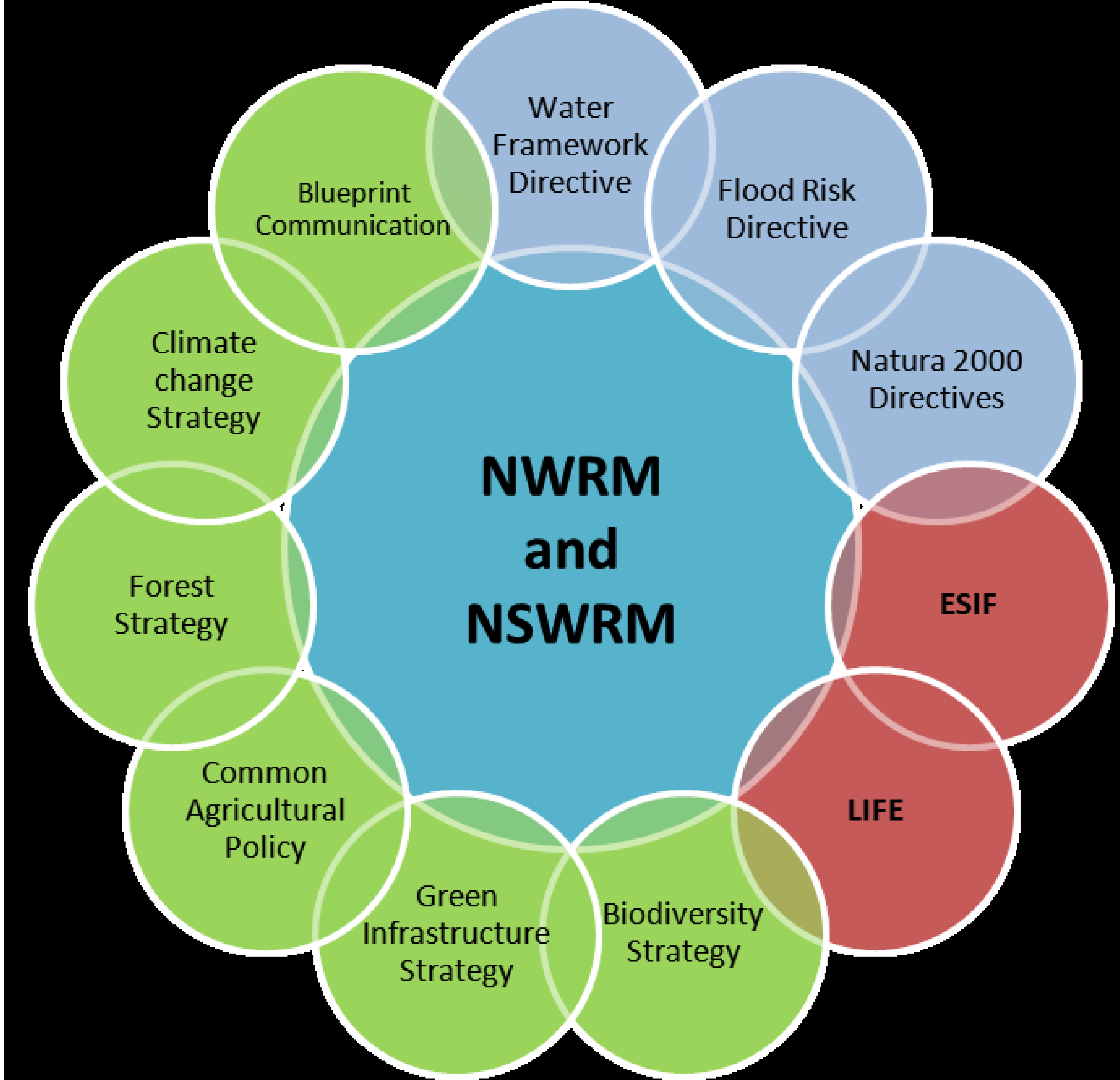
Image: Institute of Ecology and Environmental Management

- "An interconnected network of natural areas and other spaces that:
  - Conserves natural ecosystem values and functions
  - Sustains clean air and water
  - Provides a wide array of benefits to people and wildlife"

- *Benedict and McMahon, 2006*

Natural Water Retention Measures

- *"…multi-functional measures intended to protect and manage water resources using natural means and processes, therefore building up green infrastructure…."*
- *WFD CIS Working Group Programme of Measures, 2014*



Key point

Green Infrastructure is a FRAMEWORK

NWRM is a methodology

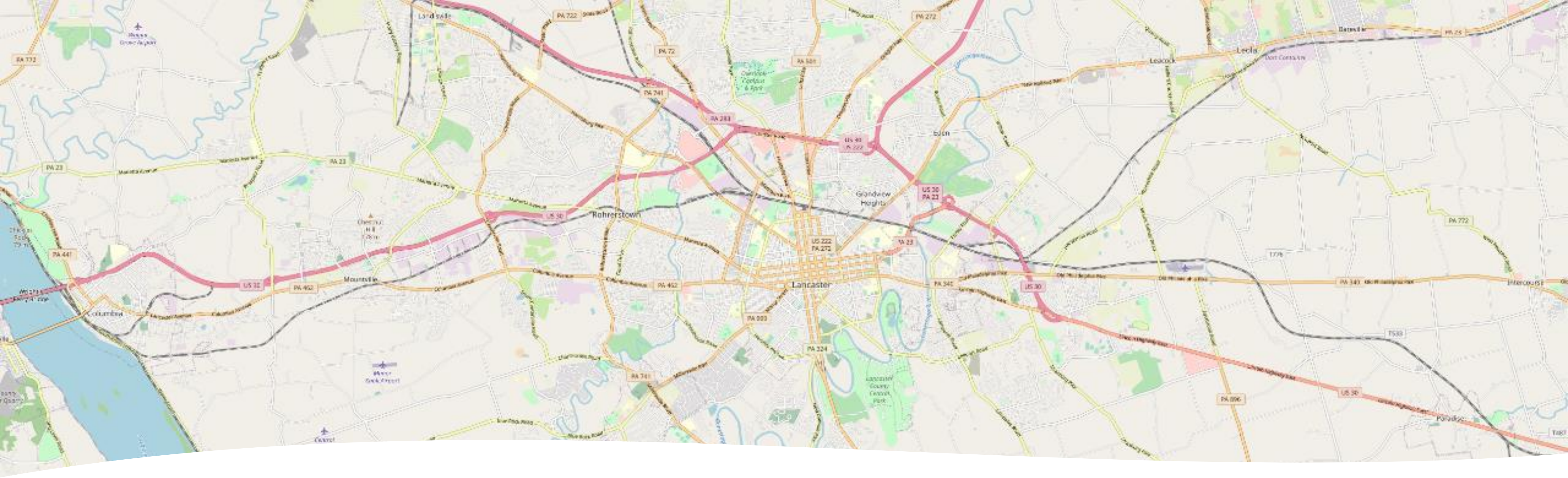
GI as a Framework

- Ellis, 2013
  - Need for development planning process to integrate SUDS drainage infrastructure within the context of a multi-purpose greenspace network
  - Consider infrastructure needs and provision as ***the first step*** in the spatial planning process.

- Therefore, neither GI nor NWRM can be an add-on

Multiple Benefits of GI/NWRM

	Benefit categories in 2019 version
Monetized benefits	Air quality
	Amenity
	Asset performance - Pumping wastewater and stormwater - Treating wastewater
	Biodiversity and ecology
	Building temperature
	Carbon reduction and sequestration
	Education
	Enabling development
	Flooding
	Quantity of water - Flow in waterbodies - Groundwater recharge - Rainwater harvesting
	Health and wellbeing
	Noise
	Recreation
	Traffic calming
	Water quality
Non-monetised	Crime
	Economic growth



Example: Lancaster, PA, USA

- GI plan would provide approx.
  - $4.2 m in energy, air quality and climate related benefits annually
- Un-costed, benefits
  - reduced urban heat island effect,
  - increased property value,
  - reduced noise pollution,
  - increased recreational value,
  - habitat improvement,
  - public education, and
  - community cohesion

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NRWM Examples

For Urban Areas

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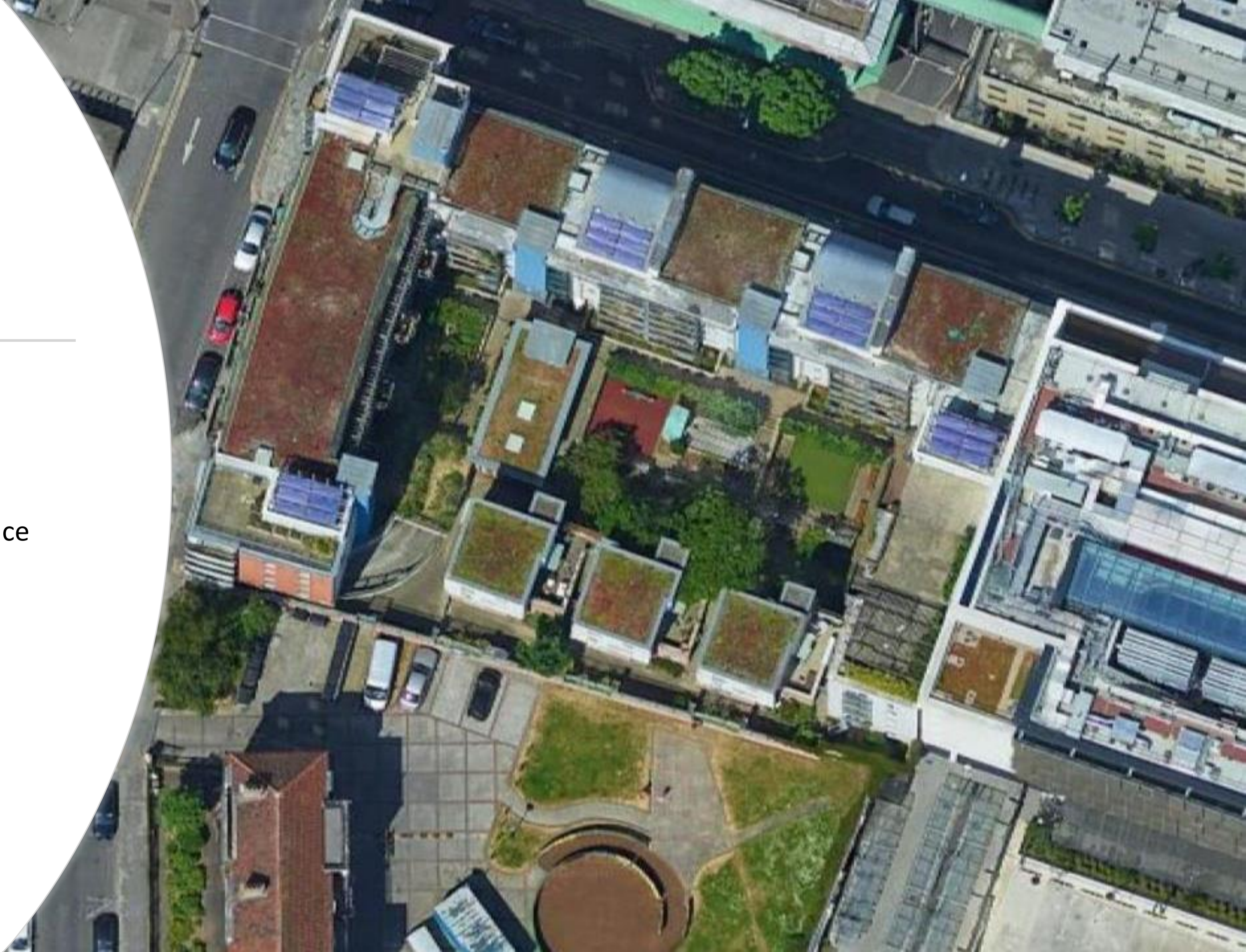
Green Roofs

- Roof/Roof Section that is vegetated
- Comprises several layers
- Require very little maintenance



Green Roof – peak flow reduction rates

Peak flow reduction 24 to 91%

Study	Location	Runoff reduction (%)	Peak Flow reduction (%) or Peak delay (min)
Kohler et al. (2002)	Germany	60-79	
Hutchinson et al. (2003)	Oregon, USA	69 (10-100)	up to 93% for single event
Moran et al. (2003)	North Carolina, USA	60 (10-100)	85%
Berndtsson et al. (2005)	Sweden	51 (30-80)	
VanWoert et al.(2005)	Michigan, USA	60.6 (52.4-96.2)	up to 100% for single event
VanWoert et al.(2005)	Michigan, USA	65.9-70.7 (59.5-97.1)	
Carter and Rasmussen (2006)	Georgia, USA (model)	50–90	18 min (compared to conventional roof)
Getter et al. (2007)	Michigan, USA	80.8 (57.1-95.5)	
Hathaway et al. (2008)	North Carolina, USA	64	>75% (average)
Bliss et al. (2009)	Pennsylvania, USA	5–6[illegible]	5–70% (compared to conventional roof)
Fioretti et al. (2010)	Italy	68 (5-100)	89% average (50-100% single events, compared to modeled conventional roof)
Voyd et al. (2010)	New Zealand	66	91% average 93% median (33-100% for single events)
Buccola and Spolek (2011)	Oregon, USA	20–65	4–8 min
Carpenter and Kaluvakolanu (2010)	Michigan, USA	68.25	88.86%
Qin et al. (2012)	Singapore	11.4	65%
Stovin et al. (2012)	Sheffield, UK	50.2 (0.0-100.0)	60% (20-100% for single events)
Carson (2013)	New York, USA	36-61	
Kok et al. (2013)	Kuala Lumpur, Malaysia		24%
Locatelli et al. (2014)	Denmark (model)	43–68	0–40 min
Wong and Jim (2014)	Hong Kong	38.9-45.3*	25-35 min, 40.6-56.3%
Lee et al. (2015)	South Korea	13.8-60.8	
Zhang et al. (2015)	China	68.0 (38.8-100)	

Green Roof – Pollutant Removal

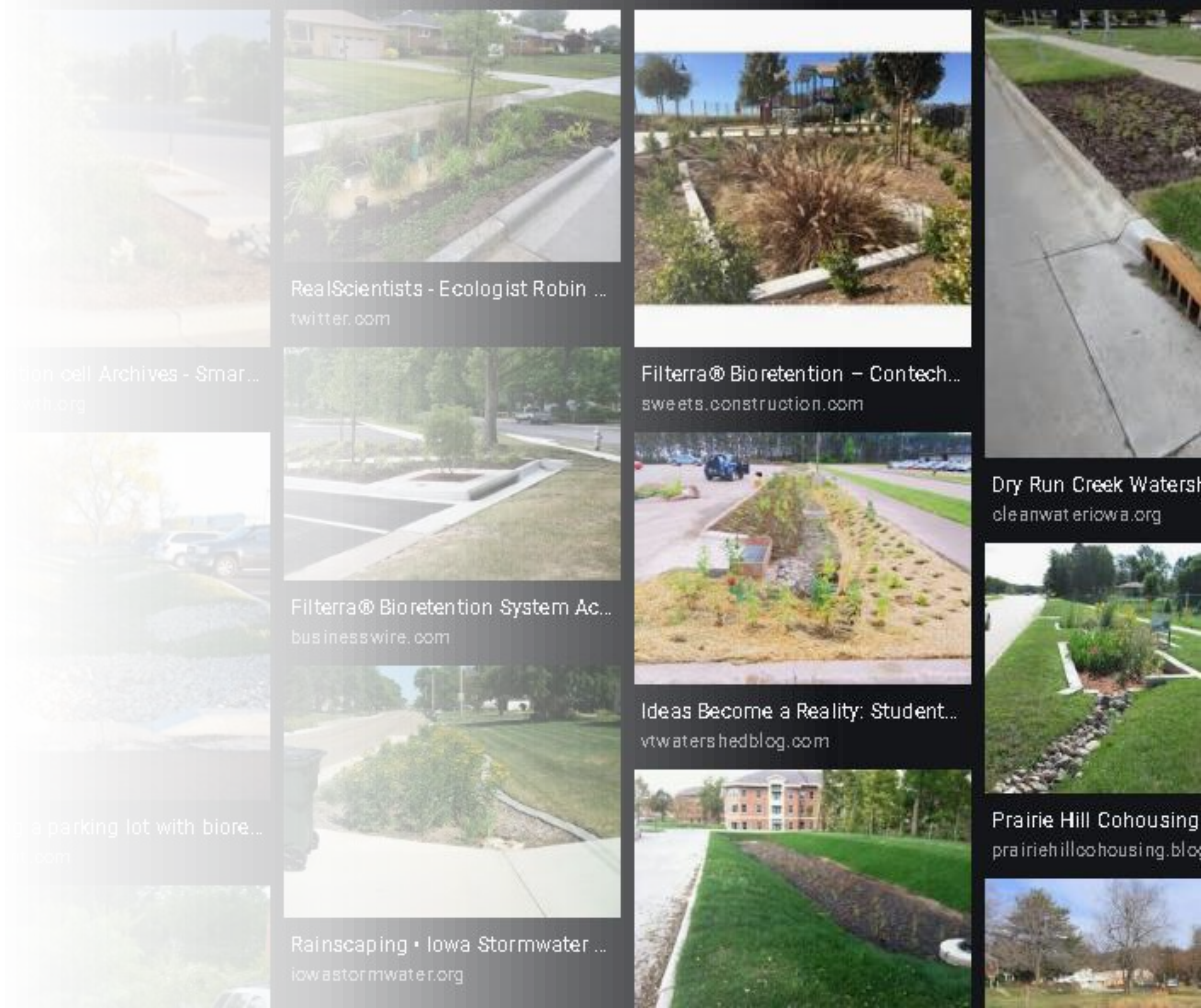
- Few studies with conflicting results
- Roof age, use of fertilizer, substrate type, vegetation type all impact effectiveness
- Temporary increase in nutrient runoff if new green roof is fertilised
- Can act as a protective layer on, e.g. metal roofs, decreasing pollution runoff from them
- Greatly extend the lifespan of existing roofs
- Several benefits for biodiversity if done right

Bioretention Cells/Rain Garden

- Area designed to collect runoff from impervious surfaces
- Site is graded to cause stormwater to flow into garden

Benefits

- Peak flow reduction > 80%
- Reduces pollutant load of intercepted runoff
- Small in size – approx. 150 m^2 for 0.25 ha surface area
- Evapotranspiration significant
- Aesthetic appearance



Bioretention Cells – Hydraulic Efficiency

			Bioretention Design				Catchment Characteristics		Hydrologic Performance	
Reference	Location	Description	Media Composition	Media Depth (cm)	Bioretention Surface Area (m^2)	IWS Depth (cm)	% Catchment Impervious	Catchment Surface Area (ha)	Peak Flow Reduction (%)	Runoff Volume Reduction (%)
Willard et al., 2017	Virginia, USA	Clay Liner	88% sand, 8% fines, 4% OM	180	35	150	96	0.16	82	84
Olszewiski and Davis., 2013	Maryland, USA		54% sand, 46% fines	65	102	none	**	0.37	83	79
Brown and Hunt, 2011	North Carolina, USA		96% sand, 4% fines	110	146	88	76	0.22	**	89
				110	146	58	76	0.22	**	93
				96	142	72	72	0.25	**	98
				96	142	42	72	0.25	**	100
Debusk and Wynn, 2011	Virginia, USA		88% sand, 8% fines, 4% OM	180	35	150	96	0.17	99	97
Hathaway et al., 2011	North Carolina, USA		87% sand, 4% silt, 4% clay	60	55	none	100	0.1	**	63
			88% sand, 5% silt, 5% clay	25	54	none	98	0.05	**	61
Davis, 2008	Maryland, USA	Lined Cell	50% sand, 30% topsoil, 20% OM	90	28	none	100	0.24	44	52
				120	28	90	100	0.24	63	65
Hunt et al., 2008	North Carolina, USA		Loamy sand, 6% fines	120	229	none	99	0.37	97	**
Hunt et al., 2006	North Carolina, USA		Organic sand	120	10	none	**	0.2	**	72

** no values given in study, OM = organic matter,

Bioswales

- Vegetated channels or trenches
- Designed to intercept overland sheet flow
- Very common in car parks
- Can be seen as linear bioretention cells

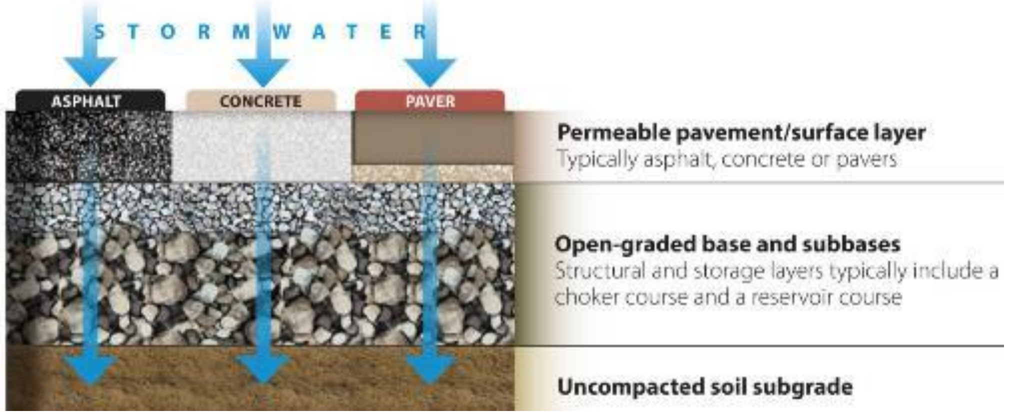
Bioswales – performance

- Davis et al (2012) – Hydraulic Performance
  - Run-off completely retained in smallest 40% of storms
  - Run-off reduced in the next 40% of storms
  - Conveyance and limited reduction in the largest 20% of storms
    - Due to soil saturation

- Pollutant Removal
  - High for TSS (up to 97%)
  - Moderate to high efficiency for TN and TP
  - Limited for metals removal
- Biodiversity
  - Increases urban biodiversity, even better than traditional urban gardens and parklands
  - Tree planting within bioswales further improves biodiversity

Pervious paving

- Specially designed pavement system that allows water to infiltrate through rather than becoming runoff
- Stone reservoir provides temporary storage to allow infiltration to subsoil
- Many different types
  - Porous asphalt
  - Interlocking pavers



Pervious Paving - Performance

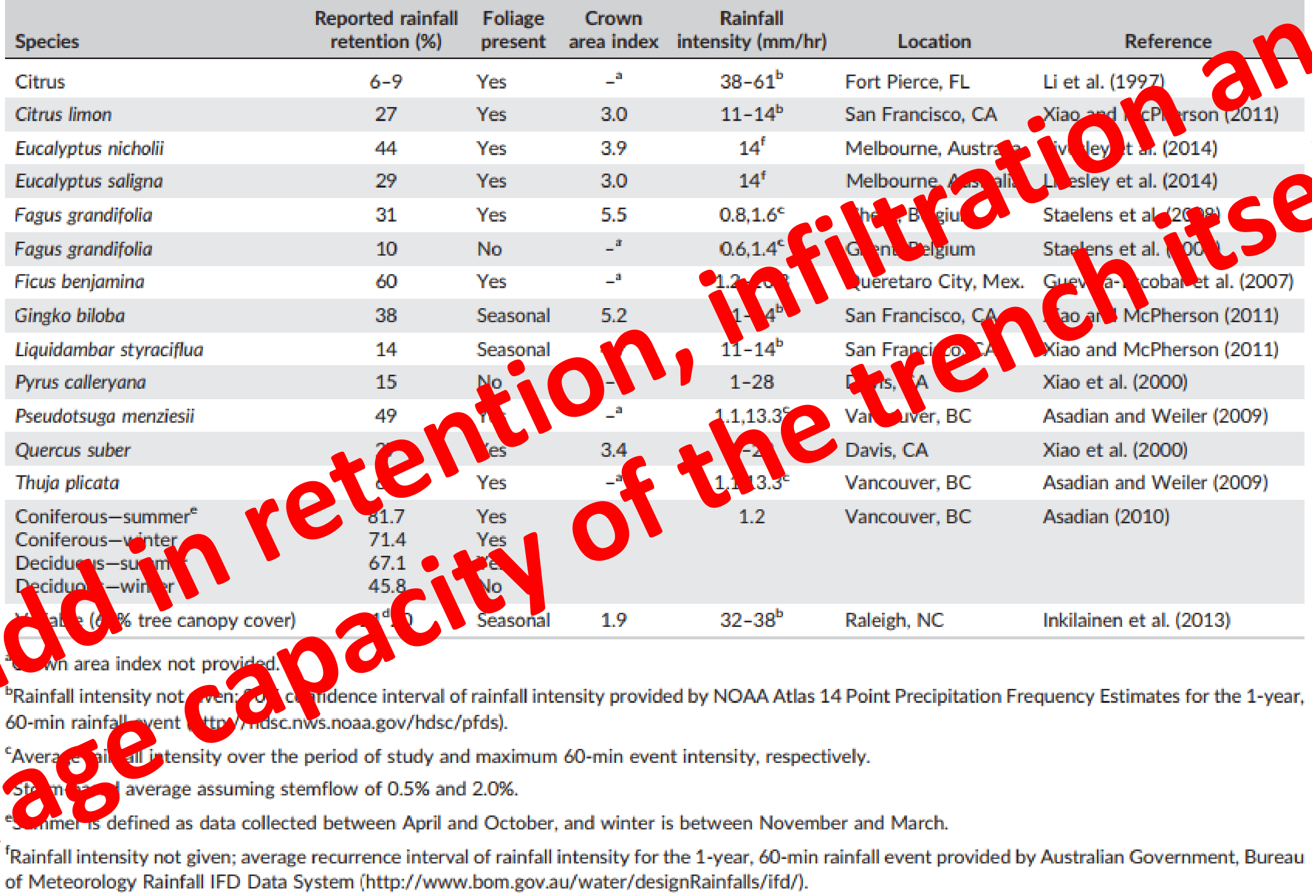
- Hydraulic performance varies substantially
- All can reduce peak flow to some degree
- Bean et al (2007)
  - 37 out of 40 sites had infiltration rates > 25 mm/hr
- Pollutant Removal
  - TSS – 80 – 90% removal rate
  - TP – varies, 20 – 78%, median 45.9%
  - TN – not so good, but….
  - Toxic metals – good removal rates, 65% - 84%
- Road Safety
  - Reduced noise (Golebiewski et al, 2003)
  - Enhanced tyre grip due to rougher macro-texture (Kudo and Ida, 2013)

Tree Trenches and Tree Pits

- Single tree or series of trees in a trench system connected by an underground filtration structure
- Often described as mini-bioretention cells
- Rain partially intercepted by tree canopy, surface runoff intercepted by roots and evapotranspirated, or infiltrated
- Can have overflow to drainage network

Tree Pits and Tree Trenches – Hydraulic Performance

Philadelphia– standard tree trench has capacity of 2,400 US Gallons



Species	Reported rainfall retention (%)	Foliage present	Crown area index	Rainfall intensity (mm/hr)	Location	Reference
Citrus	6–9	Yes	–[a]	38–61[b]	Fort Pierce, FL	Li et al. (1997)
Citrus limon	27	Yes	3.0	11–14[b]	San Francisco, CA	Xiao and McPherson (2011)
Eucalyptus nicholii	44	Yes	3.9	14[f]	Melbourne, Australia	Livesley et al. (2014)
Eucalyptus saligna	29	Yes	3.0	14[f]	Melbourne, Australia	Livesley et al. (2014)
Fagus grandifolia	31	Yes	5.5	0.8,1.6[c]	Ghent, Belgium	Staelens et al. (2008)
Fagus grandifolia	10	No	–[a]	0.6,1.4[c]	Ghent, Belgium	Staelens et al. (2008)
Ficus benjamina	60	Yes	–[a]	[illegible]	Queretaro City, Mex.	Guevara-Escobar et al. (2007)
Gingko biloba	38	Seasonal	5.2	11–14[b]	San Francisco, CA	Xiao and McPherson (2011)
Liquidambar styraciflua	14	Seasonal	[illegible]	11–14[b]	San Francisco, CA	Xiao and McPherson (2011)
Pyrus calleryana	15	No	[illegible]	1–28	Davis, CA	Xiao et al. (2000)
Pseudotsuga menziesii	49	Yes	–[a]	1.1,13.3[c]	Vancouver, BC	Asadian and Weiler (2009)
Quercus suber	[illegible]	Yes	3.4	[illegible]	Davis, CA	Xiao et al. (2000)
Thuja plicata	[illegible]	Yes	–[a]	1.1,13.3[c]	Vancouver, BC	Asadian and Weiler (2009)
Coniferous—summer[e] Coniferous—winter Deciduous—summer Deciduous—winter	81.7 71.4 67.1 45.8	Yes Yes Yes No		1.2	Vancouver, BC	Asadian (2010)
Variable ([illegible]% tree canopy cover)	[illegible]	Seasonal	1.9	32–38[b]	Raleigh, NC	Inkilainen et al. (2013)

[a] Crown area index not provided.

[b] Rainfall intensity not given; [illegible] confidence interval of rainfall intensity provided by NOAA Atlas 14 Point Precipitation Frequency Estimates for the 1-year, 60-min rainfall event ([illegible]hdsc.nws.noaa.gov/hdsc/pfds).

[c] Average rainfall intensity over the period of study and maximum 60-min event intensity, respectively.

[d] [illegible] average assuming stemflow of 0.5% and 2.0%.

[e] Summer is defined as data collected between April and October, and winter is between November and March.

[f] Rainfall intensity not given; average recurrence interval of rainfall intensity for the 1-year, 60-min rainfall event provided by Australian Government, Bureau of Meteorology Rainfall IFD Data System (http://www.bom.gov.au/water/designRainfalls/ifd/).

Then add in retention, infiltration and storage capacity of the trench itself

Tree Pits and Tree Trenches – Pollutant Removal

- Performance due to phytoremediation, media adsorption, absorption and filtration
- Varied performance depending on design, tree type used, substrate used, etc.
- TSS – 63.4 – 87.5%
- TP – 50 – 60%
- TN – 40 – 50%

Tree Pits and Tree Trenches – Secondary benefits

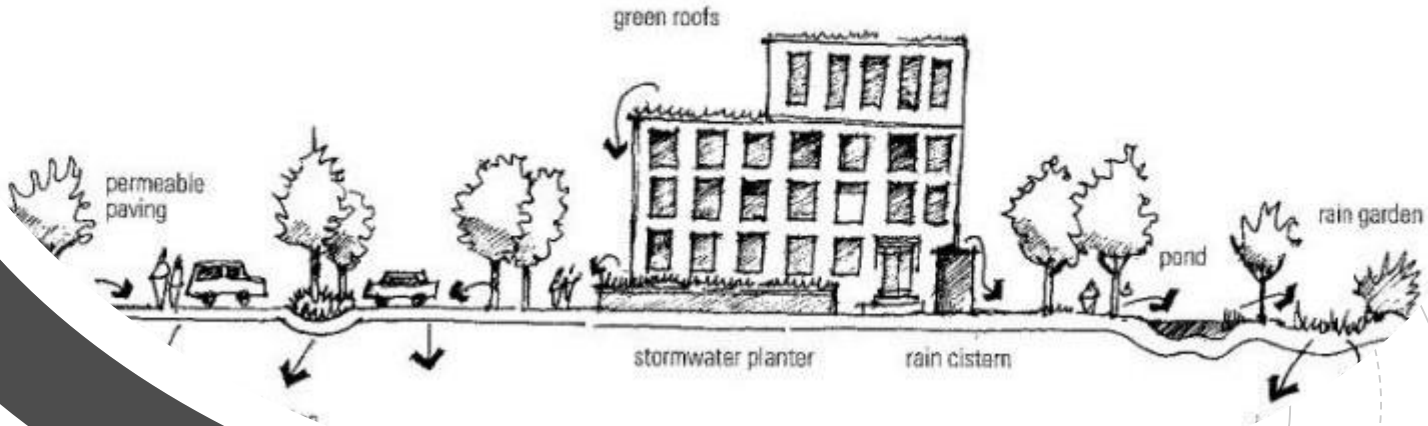
- Positive impact on property values
- People’s physical and mental health
- Biodiversity
- Contributes to reduced thermal/heat island effects

For the householder

- Water butts
- Rainwater planters
- Rain gardens
- Green Roofs



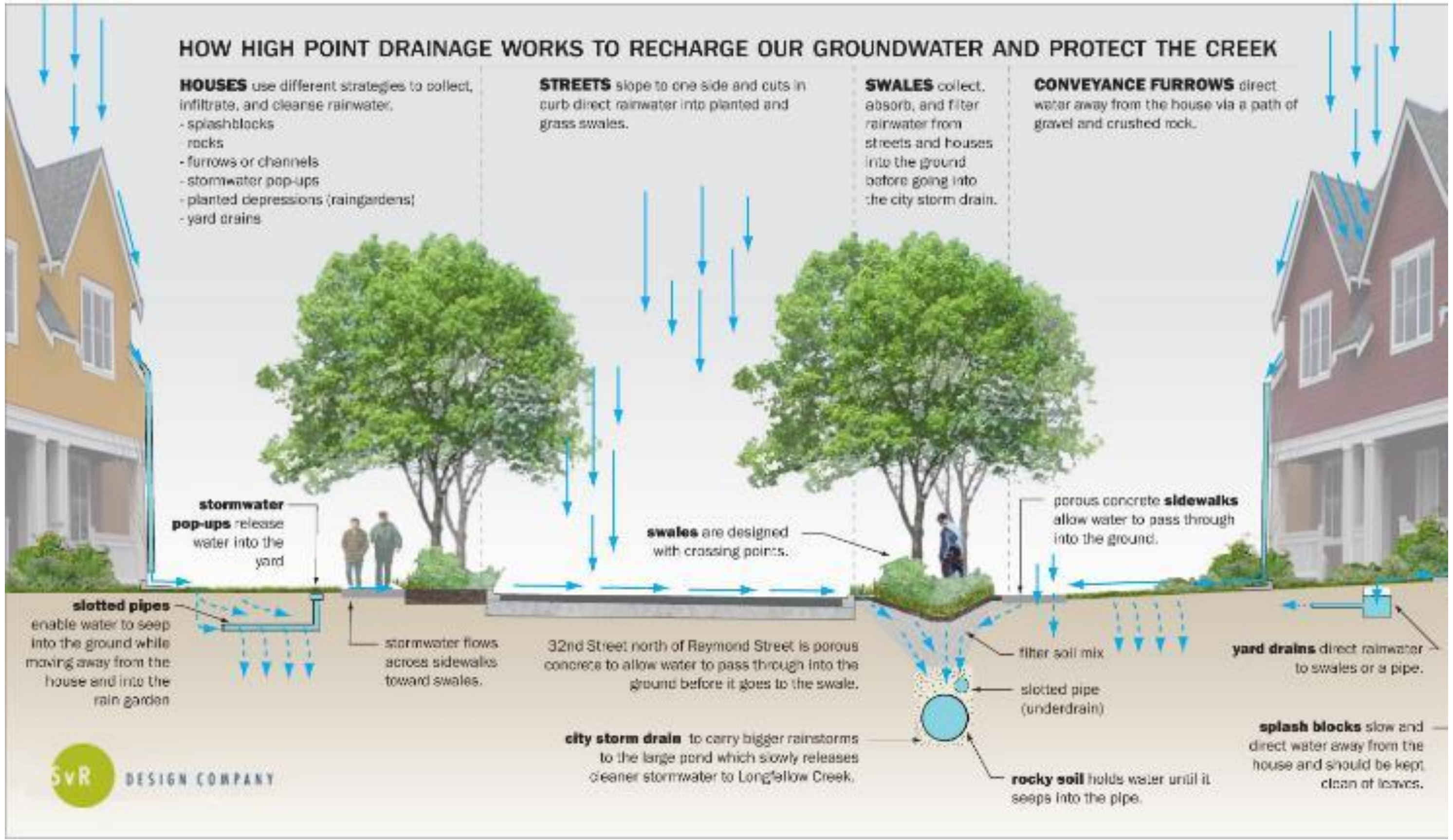




Design Considerations

Bioretention and The Stormwater Chain

Source: Rain Gardens, Nigel Dunnett and Andy Clayden



HOW HIGH POINT DRAINAGE WORKS TO RECHARGE OUR GROUNDWATER AND PROTECT THE CREEK

HOUSES use different strategies to collect, infiltrate, and cleanse rainwater.
- splashblocks
- rocks
- furrows or channels
- stormwater pop-ups
- planted depressions (raingardens)
- yard drains

STREETS slope to one side and cuts in curb direct rainwater into planted and grass swales.

SWALES collect, absorb, and filter rainwater from streets and houses into the ground before going into the city storm drain.

CONVEYANCE FURROWS direct water away from the house via a path of gravel and crushed rock.

stormwater pop-ups release water into the yard

slotted pipes enable water to seep into the ground while moving away from the house and into the rain garden

stormwater flows across sidewalks toward swales.

swales are designed with crossing points.

32nd Street north of Reymond Street is porous concrete to allow water to pass through into the ground before it goes to the swale.

city storm drain to carry bigger rainstorms to the large pond which slowly releases cleaner stormwater to Longfellow Creek.

porous concrete **sidewalks** allow water to pass through into the ground.

rocky soil holds water until it seeps into the pipe.

yard drains direct rainwater to swales or a pipe.

splash blocks slow and direct water away from the house and should be kept clean of leaves.

4 Elements of the Stormwater Chain

- Prevention of runoff
- Retention techniques
- Detention facililties
- Conveyance techniques

Objectives of Bioretention

REDUCE THE AMOUNT OF IMPERVIOUS SURFACES IN ORDER TO REDUCE RUNOFF

UTILISE THE LANDSCAPE AND SOILS TO NATURALLY MOVE, STORE AND FILTER STORMWATER RUNOFF BEFORE IT LEAVES A SITE

NWRM must be properly designed

water

MDPI

Article

When Green Infrastructure Turns Grey: Plant Water Stress as a Consequence of Overdesign in a Tree Trench System

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Abstract: Green infrastructure (GI) systems are often overdesigned. This may be a byproduct of static sizing (e.g., accounting for a design storm's runoff volume but not exfiltration rates) or may be deliberate (e.g., buffering against performance loss through time). In tree trenches and other GI systems that require stormwater to accumulate in an infiltration bed before it contacts the planting medium, overdesign could reduce plant water availability significantly. This study investigated the hydrological dynamics and water relations of an overdesigned tree trench system and identified factors contributing to, compounding, and mitigating the risk of plant stress. Water in the infiltration bed reached soil pits only once in three years, with that event occurring during a hydrant release. Moreover, minimal water was retained in soil pits during the event due to the hydraulic properties of the soil media. Through a growing season, one of the two tree types frequently experienced water stress, while the other did so only rarely. These contrasting responses can likely be attributed to roots being largely confined to the soil pits vs. reaching a deeper water source, respectively. Results of this study demonstrate that, in systems where soil pits are embedded in infiltration beds, overdesign can raise the storm size required for water to reach the soil media, reducing plant water availability between storms, and ultimately inducing physiological stress.

Keywords: evapotranspiration; green infrastructure; HYDRUS-2D; leaf water potential; low impact development; optimization; overdesign; stomatal conductance; simulated runoff test; static sizing; stormwater control measure; tree trench

1. Introduction

The use of green infrastructure (GI) to control non-point pollution associated with stormwater has been written into law by municipalities around the world [1–3]. Such laws protect surface water bodies in and adjacent to urban areas from contaminants transported by stormwater as well as those released during combined sewer overflow events [4]. By reducing the volume of stormwater entering combined sewer systems, GI lowers pollutant loading, runoff velocity, and peak flow rates [5]. Although GI systems need not be vegetated, plants and soils can contribute substantially to volume reduction, in particular by enhancing rates of evapotranspiration (ET), interception, and infiltration [6–9]. Evapotranspiration is arguably the most effective of these processes with respect to volume reduction; studies using weighing lysimeters have found that 50% of incident precipitation can be removed by

Water **2020**, *12*, 573; doi:10.3390/w12020573

- Under-design can cause plant stress and poor performance
- Overdesign can also cause plant stress due to drought conditions
- Size v Number consideration

Design Integration with landscape

"Don't worry, the ground water here is clean."

- Stormwater chain incorporated into the existing landscape
- Catchment scale
- Development site scale
- Single house scale

Maintenance

NWRM tend to require very little maintenance

Maintenance costs must be compared with the cost of managing traditional drainage infrastructure, roadways

Community engagement can also contribute, e.g. litter picking, vegetation management, etc.

Real issue with Maintenance – who’s budget?

Safety

- Same River Channel Pre- and Post-Restoration
- Which is easier to get out of?

Prior to works part of the channel through
Inch Park was brick lined – April 2006

© AECOM

The new course of the Braid Burn through Inch Park after two years. Marginal
vegetation has established well and natural processes have enhanced the

Role for Planners

- Planning is crucial to delivering SuDS
- Coordination Role - how to incorporate SuDS into the built environment
  - Housing density requirements
  - Human needs v Ecological/Natural needs
- Ensuring multiple benefits are realised
- Importantly, GI at the right scale and at the right time
  - GI planning must be planned strategically
    - Not at Planning Application scale

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Summary

- Must distinguish between GI and NWRM
- Achieving multiple benefits necessary to maximise the use of NWRM
- Whole range of NWRM elements that planner and developers can consider
- Working *with* the landscape is key to successful utilisation of NWRM
- Multi-disciplinary, systemic approach essential

Thank you.

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