018530 - SWITCH

Sustainable Water Management in the City of the Future

Integrated Project
Global Change and Ecosystems

Deliverable D2.3.4 Training and Dissemination (Green and Brown Roofs)

Due date of deliverable: January 2011
Actual submission date: April 2011

Start date of project: 1 February 2006 Duration: 60 months

University of Birmingham

Draft Final

Project co-funded by the European Commission within the Sixth Framework Programme (2002-2006)		
Dissemination Level		
PU	Public	x
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

Contents

1 Introduction

Dissemination and Training has been undertaken on Green and Brown roofs regularly throughout the project period, with highest intensity in the first three years of the project 2009, when staff worked full time.

The dissemination can be separated into three parts, (1) dissemination related to the Demonstration Brown roofs in Birmingham, (2) dissemination and training related to the Birmingham Learning Alliance and stakeholder and stakeholder organisations within the United Kingdom and (3) dissemination at the Scientific meetings of the SWITCH project, including the demonstrations to a wider international audience through the Global Cities Workshop held in Delft in 2010.

This report presents an illustration of the activities that have been carried out to publicise the concepts and ideas underpinning the implementation of Brown roofs as both Ecological and Hydrological tools for improving biodiversity and surface water management within a City.

The report does not describe the research publications that have arisen from the programme. These are expanded under the science based deliverables that are outputs from the SWITCH supported green and brown research.

Much of the report draws on the information presented on the SWITCH Birmingham Learning Alliance Website - http://switchbirmingham.wordpress.com/ . This same material is also reported through the Deliverable D2.3.1e that describes the Demonstrations developed with the support of Birmingham City Council and other partners as part of the SWITCH programme.

Two illustrations of the style of presentations given to different audiences are included in Appendix A.

2 Illustration of Dissemination activities

The following dissemination activities are presented in reverse chronological order

2.1 Green Infrastructure – Assets and Benefits – 8/1/09

A poster was presented by Dr Adam Bates that looked at the way that green roofs can help to mitigate the effects of climate change. The day of seminars was organised by Natural England and was held at the BVSC; it included a wide variety of talks on the future of sustainable infrastructure construction.

2.2 RIBA/RICS green roof presentations and tour of the Fort Dunlop green roof – 8/10/08

A presentation was given by Dr Adam Bates that introduced green roofs, aimed to justify the installation of green roofs and discussed the trade-offs associated with different types of green roofs. This was followed by a presentation by Liam Foster of Hyder Consulting that discussed the various environmental advantages associated with green roofs. There then followed a tour of the Fort Dunlop *Sedum* mat green roof. The event was organised by the RIBA and the RICS, and well attended by around 20 architects and chartered surveyors.

2.3 Birmingham Climate Change Festival green roof tours – 3&4/6/08

Two lunch time green roof tours were put on for the nine-day Birmingham Climate Change Festival. The first (rainy) tour (3/6/08) was organised by CABE and RIBA West Midlands, led by Dr Adam Bates and comprised visits to: an intensive green roof at The University oBirmingham, the university brown roof research facility, and the BVSC brown roof. Twenty people, who were mainly architects, from the following companies came on the tour: Friends of Cannon Hill Park, Arthur Amos Associates, Yapp Design, John Dutton Architects, University of Birmingham, SVSMO Sustainable Moseley, Peter Poon Architects, CABE, RIBA West Midlands, and Birmingham City Council.

The second tour (4/6/08) was organised by CABE and RIBA West Midlands, was led by Dr Adam Bates and Dr Stefan Bodnar (Birmingham City Council) and comprised visits to: a combined acid heathland/S*edum* matt green roof at the Alexander Stadium's new Gymnastics and Martial Arts Centre and the Fort Dunlop *Sedum* matt green roof. Twenty five people, from the following companies came on the tour: Atkins, Lloyds TSB GPM, Exeter City Council, Birmingham City University, Birmingham City Council, DTZ, CABE and RIBA West Midlands.


The festival also included a display showing a photograph of the BVSC brown roof.

2.4 Midlands Environmental Business Company (MEBC) green roof tour – 23/4/08

Organised by the MEBC and Dr Adam Bates of the University of Birmingham, led by Adam Bates and sponsored by Alistair Moseley from the WSP Group.

The day included an introductory talk on green roofs, a visit to the Fort Dunlop *Sedum* matt green roof, a visit to the University of Birmingham's brown roof research facility, and a visit to the Birmingham Voluntary Service Council's (BVSC) brown roof. Attendees ranged widely and included aggregate suppliers, planners, environmental consultants, engineering consultants and representatives from industry. Overall, twenty four people attended the tour from the following twenty one companies: Alfa Aggregates Products, Birmingham City Council, Warwickshire County Council, Sustainable Procurement Ltd., Jaguar Cars Ltd, Globally Local, Environment Agency, WSP Buildings, WSP Environment & Energy, WSP Group, Stuart Guy Consulting, EBC Ltd., Arcadis AYH, Lister Associates, Wardell Armstrong LLP, Marley Eternit, MEBC, Land Rover, Arup, BCC, and BBEM.

2.5 Tour of the University of Birmingham brown roof research facility - 7/8/07

This was part of a tour organised by Rosemary Coyne (then of the Eastside Sustainability Advisory Group) that aimed to make architects aware of the advantages of using green roofs. The University of Birmingham sub-section of the tour consisted of a quick look at an old turf intensive green roof on campus, followed by a tour of the University of Birmingham brown roof research facility.

2.6 Actions to combat climate change and benefit biodiversity in an urban environment – 25/7/07

Organised by Land Care Associates, the University of Birmingham, Birmingham and Black Country Biodiversity Action Plan, The Wildlife Trusts (WT), and Natural England, and held at the University of Birmingham.

This was a one day seminar that included tours of the Fort Dunlop *Sedum* matt green roof and the University of Birmingham brown roof research facility. A wide range of speakers gave presentations on green roofs and the wider urban environment, particularly focusing on their role in combating climate change. The speakers were: Dr Stefan Bodnar (Birmingham City Council), Dr Jon Sadler (University of Birmingham), Dr Nigel Dunnett (The Green Roof Centre, Sheffield) and Dr Rossa Donovan (then with the University of Birmingham,

now at White Young Green Consultants). Attendees included landscape architects, planners, environmental consultants and ecologists.

2.7 Tour of the University of Birmingham brown roof research facility as part of 'What makes green roof affordable' – 20/3/07

This was part of a two-day workshop organised by Rosemary Coyne (then of the Eastside Sustainability Advisory Group) in partnership with Hyder Consulting, The green roof consultancy and LivingRoofs that made the business case for green roofs. The University of Birmingham sub-section of the tour consisted of a short introductory talk by Dr Adam Bates, a quick look at an old turf intensive green roof on campus, followed by a tour of the University of Birmingham brown roof research facility.

2.8 Green Roofs and Biodiversity Seminar – 15/11/06

Organised by Land Care Associates and the University of Birmingham and held at the University of Birmingham.

This one day seminar mainly focused on the role of green roofs in biodiversity conservation but also analysed the wider benefits of their installation. The seminar was mainly targetted at members of the Wildlife Trust (WT) and the Association of Wildlife Trust Consultancy (AWTC) members. There were talks from speakers with wide-ranging expertise, namely: Dr Rossa Donovan (then with the University of Birmingham, now at White Young Green Consultants), Dr Jon Sadler (University of Birmingham), Dusty Gedge (Livingroofs.org), Dr Adam Bates (University of Birmingham), and Tim Moughtin (Land Care Associates).

2.9 Using green roofs as a teaching resource at the University of Birmingham

The University of Birmingham brown roof research facility is currently used as a teaching resource for the third year Geography course GGM312 – Landscape and Urban Ecology that includes Geography, Environmental Science and Environmental Management students.

Appendix 1 Sample presentations used for dissemination.

The three presentations included in this appendix are designed to illustrate the different dissemination objectives and the range of audiences that listened to the presentations.

Presentation 1 was given at the SUDS Training Event in 2008 and encompasses the water management contributions that can be made using green roofs.

Presentation 2 was given to the UK Chartered Institute of Surveyors and explores the benefits and concerns that arise with the implementation of extensive green roofs for biodiversity and urban water management.

Presentation 3 was given to the Birmingham Learning Alliance as an introduction to Extensive green roofs and the potential tradeoffs that can arise when designing an extensive green roof and the rationale behind the SWITCH research.

THE STORM WATER EXPERTS
INGENIEURGESELLSCHAFT
PROF. DR. SIEKER MBH

SWITCH
SUDS training event
Birmingham
14 October 2008

SUDS/Green roofs/Rainwater Harvesting, Experiences and recent development in Germany

Dr. Heiko Sieker, IPS, Berlin, Germany

SUDS Training event, Birmingham

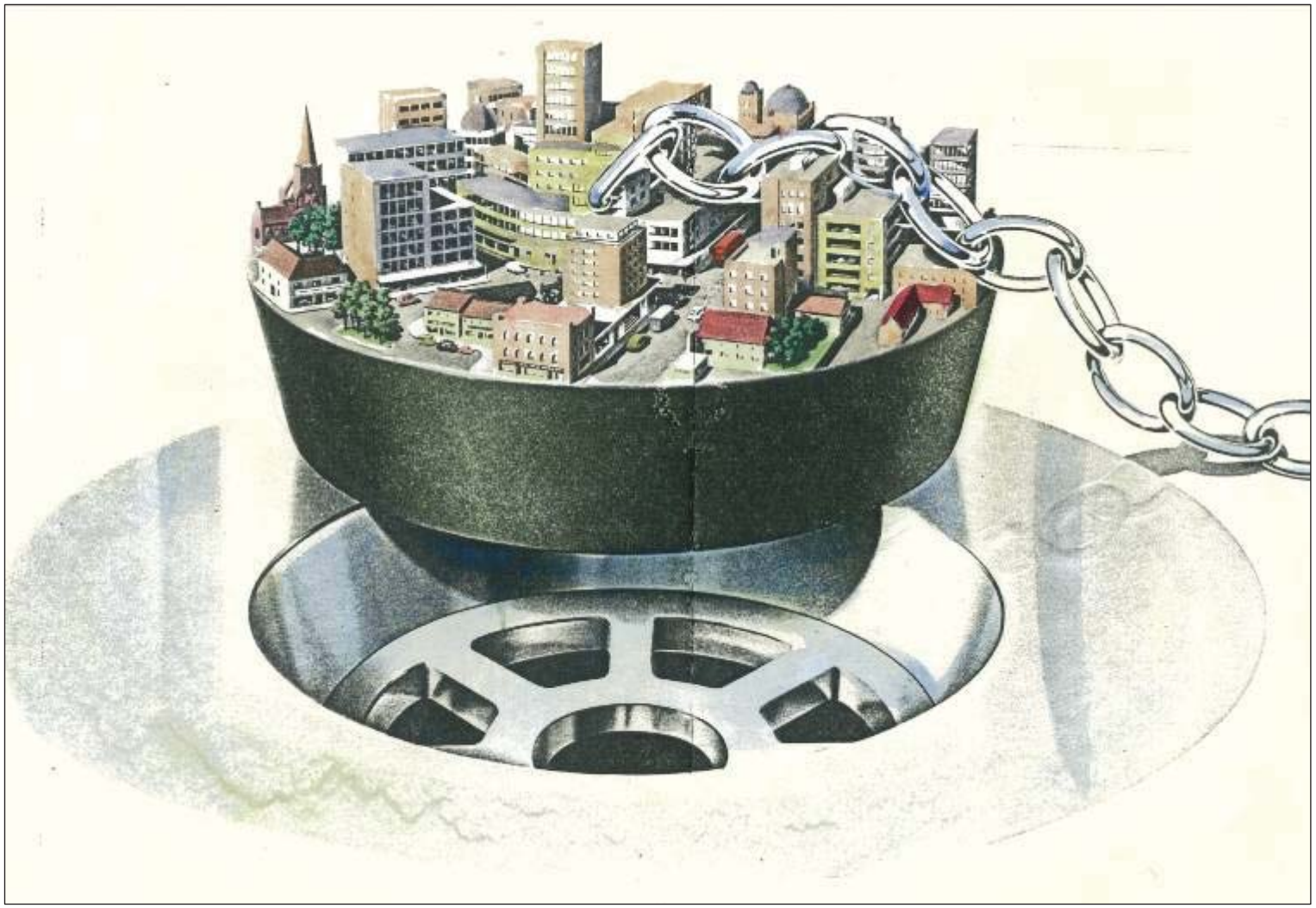
October 14th 2008

Sixth Framework Programme

Paradigm Shift in Stormwater Management

- Conventional Drainage
  - Separate or combined systems
  - Terms: Drainage, Disposal
  - “Getting rid of stormwater as quick as possible”

Paradigm Shift in Stormwater Management



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Paradigm Shift in Stormwater Management

- Conventional Drainage
  - Separate or combined systems
  - Terms: Drainage, Disposal
  - “Getting rid of stormwater as quick as possible”
- Modern approach
  - Infiltration, Mulden-Rigolen-System, Green roofs Rainwater harvesting, Wetlands, Throttled discharge
  - Terms:
    - Best Management Practices (BMPs),
    - Sustainable Urban Drainage (SUDs),
    - Water Sensitive Urban Design (WSUD)
  - “Manage stormwater near source”

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Conventional Drainage

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Conventional Drainage

Quelle: Chemnitzer Verkehrsbau GmbH

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Modern approach

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Modern approach

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Paradigm Shift in Stormwater Management

- Conventional Drainage
  - Separate or combined systems
  - Terms: Drainage, Disposal
  - “Getting rid of stormwater as quick as possible”
- Modern approach
  - Infiltration, Mulden-Rigolen-System, Green roofs Rainwater harvesting, Wetlands, Throttled discharge
  - Terms: BMPs, SUDs, WSUD
  - “Manage stormwater near source”
- Reasons for Paradigm Shift?
  - Environmental Awareness
  - Disadvantages of Conventional Drainage

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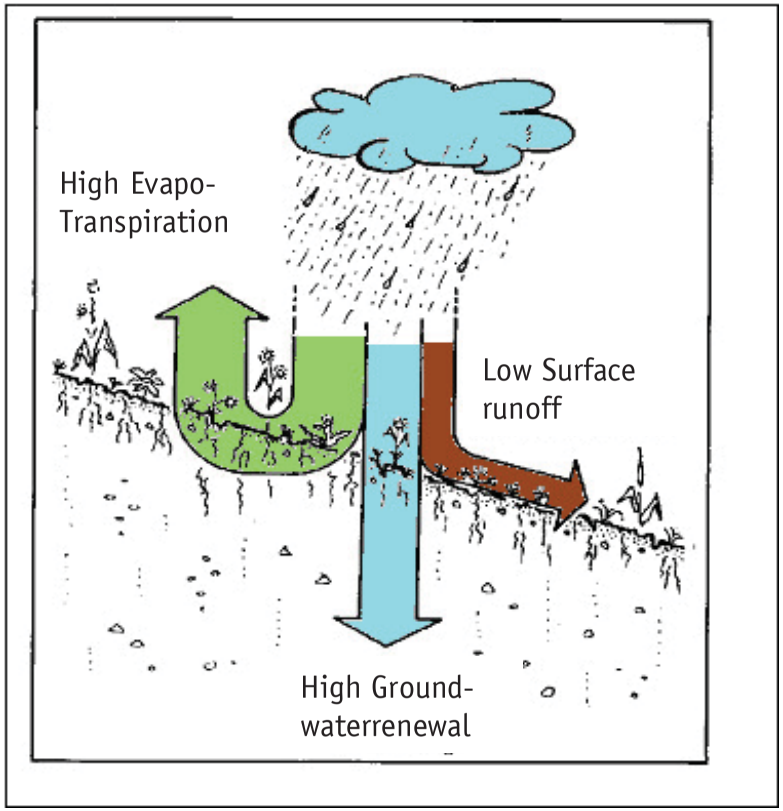
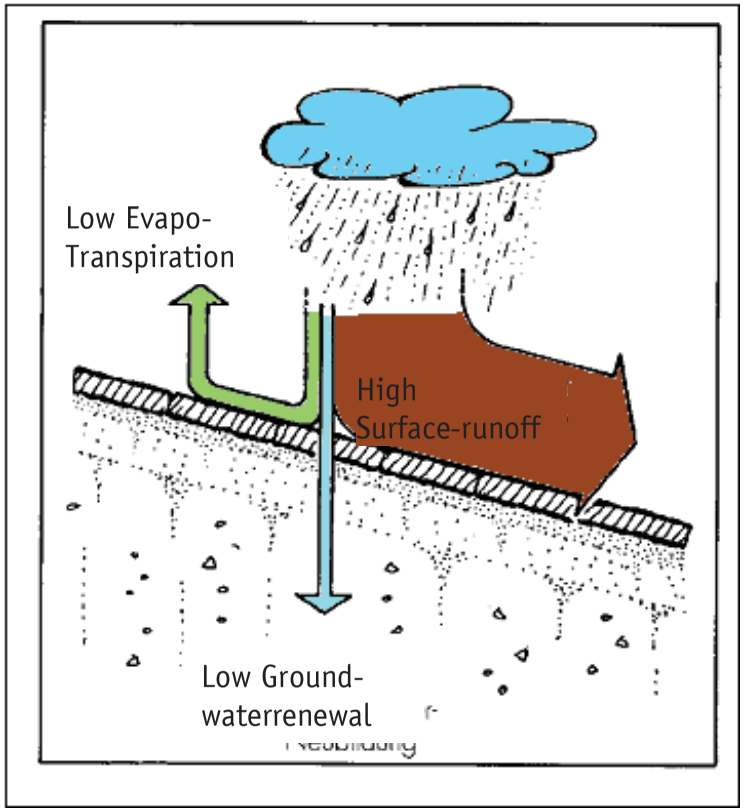
Impact of Surface Sealing on the Water Cycle

Natural water cycle



Urban water cycle



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Urban Flooding

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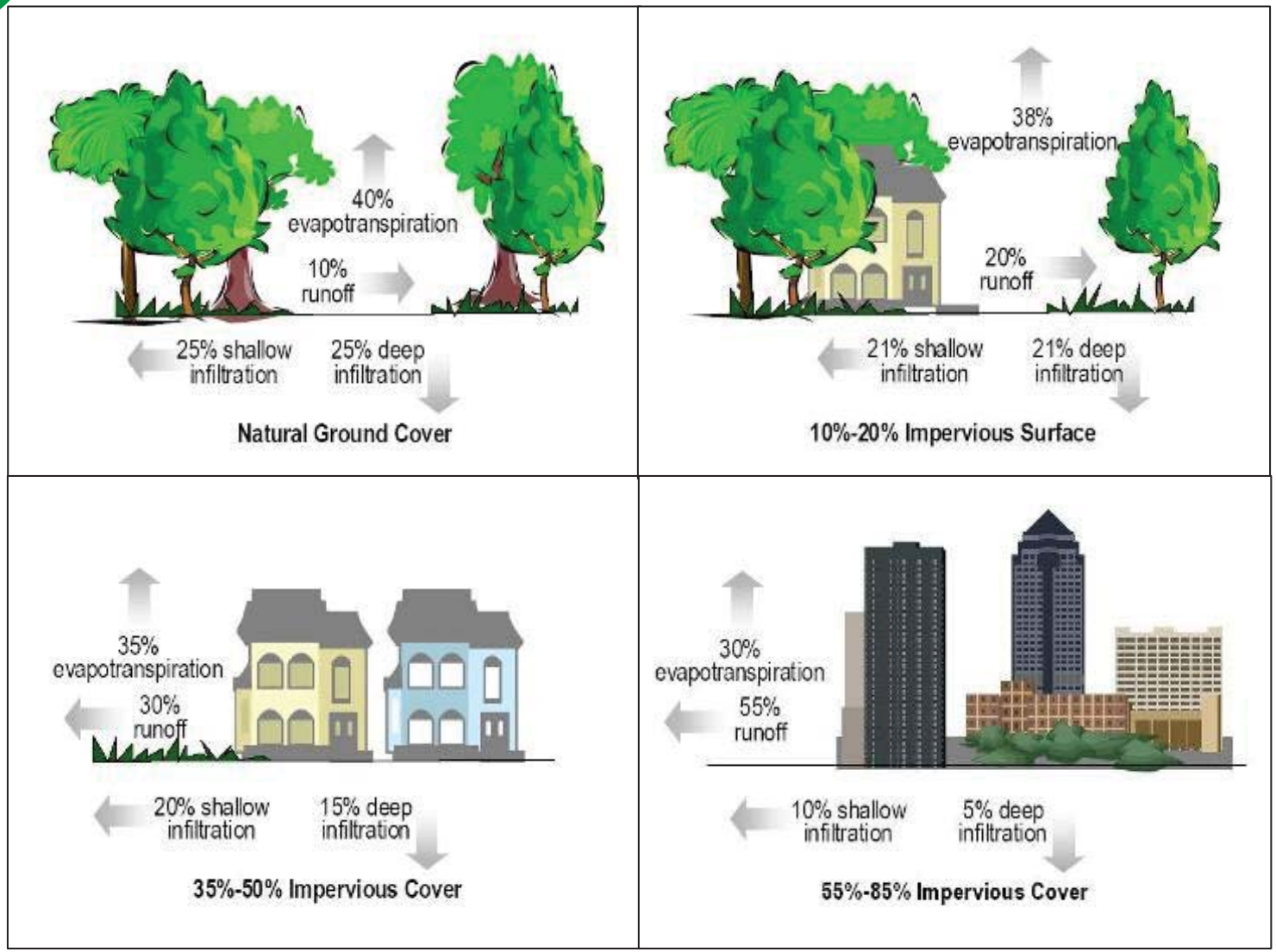
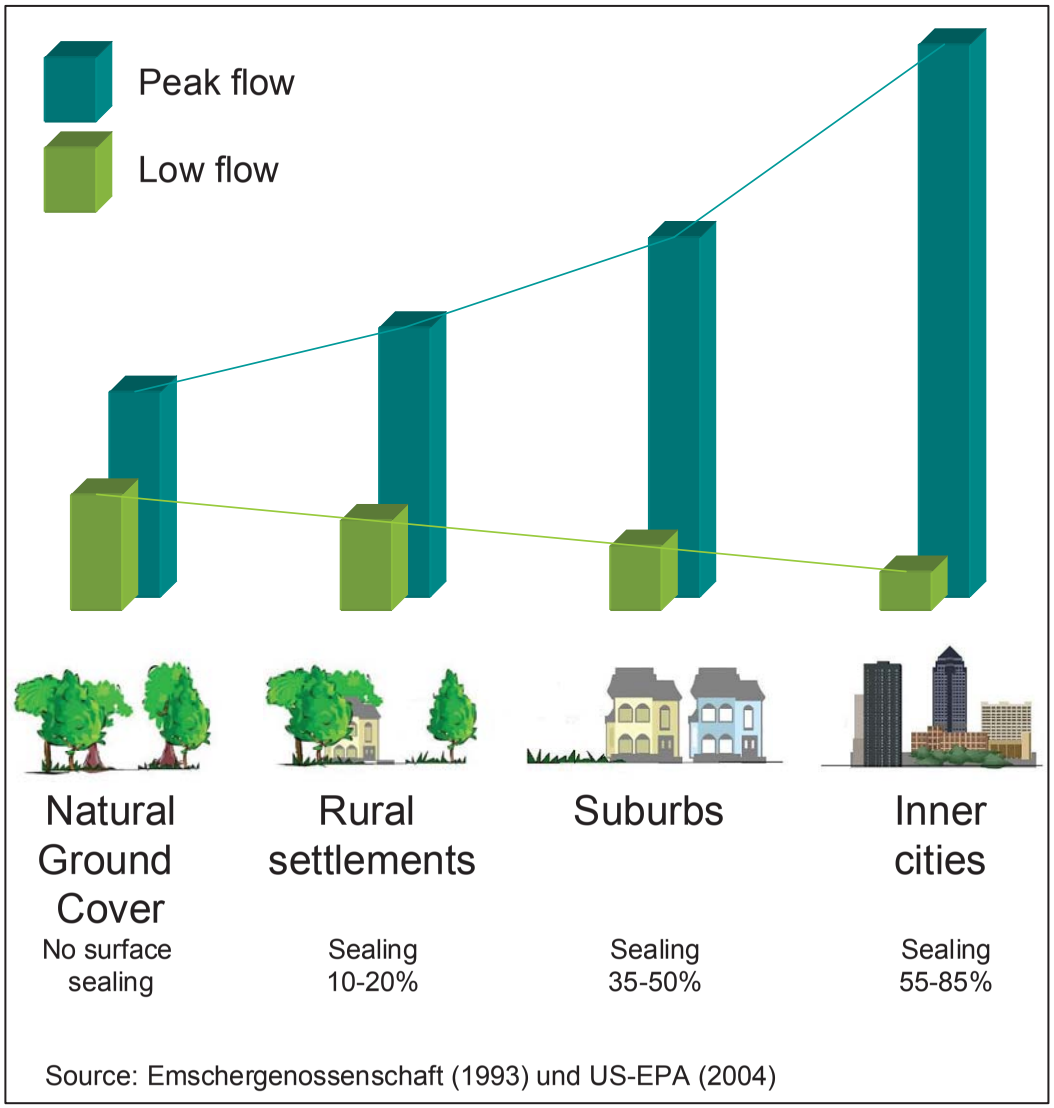
Disturbance of the Water Cycle



Quelle: US-EPA, 2004 (angepasst)

Disturbance of the Water Cycle



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Morphological Degradation

Morphological Degradation

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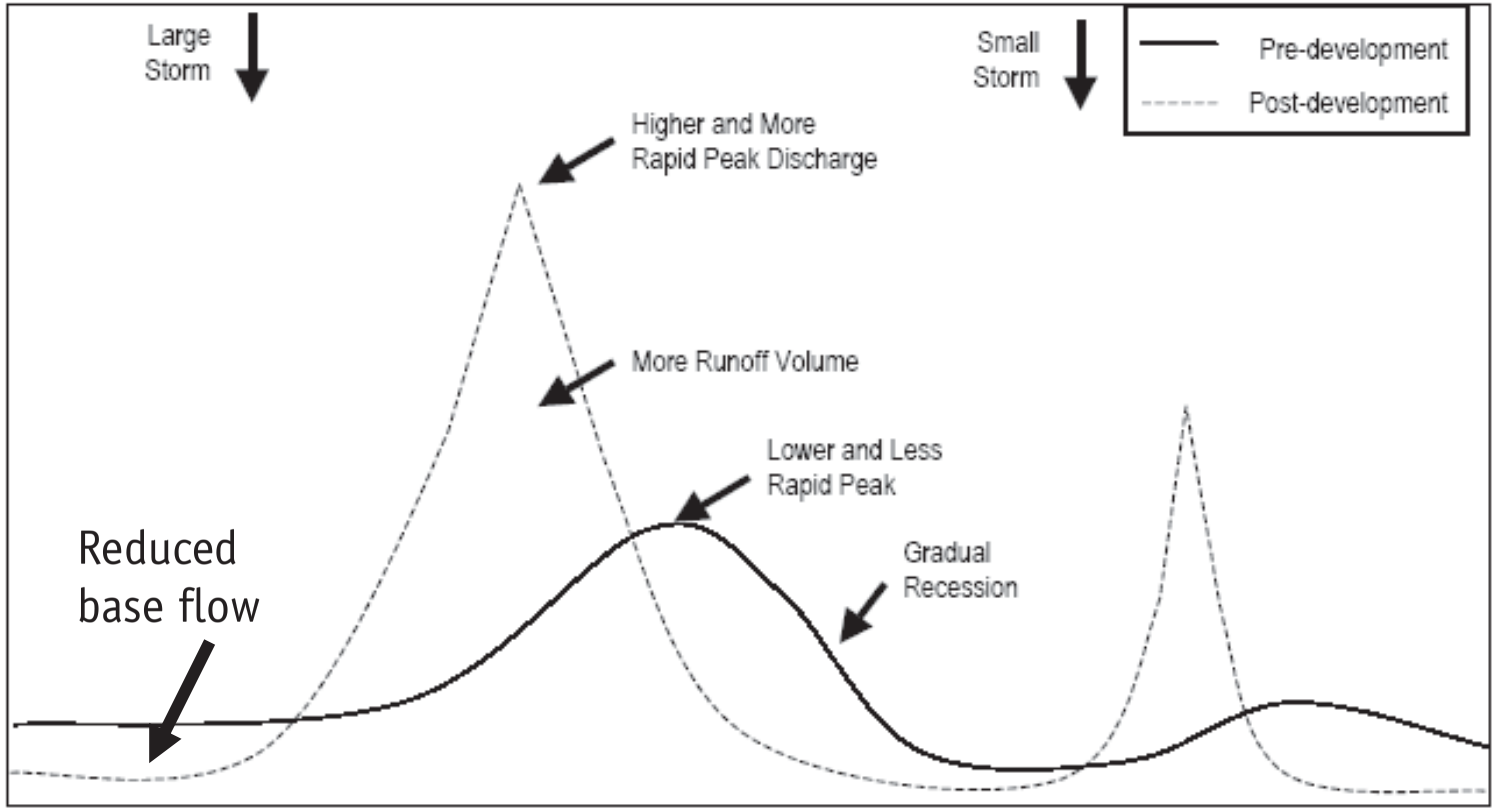
Reduction of baseflow



Quelle: US-EPA, 2004

Reduction of baseflow

Impact on water quality

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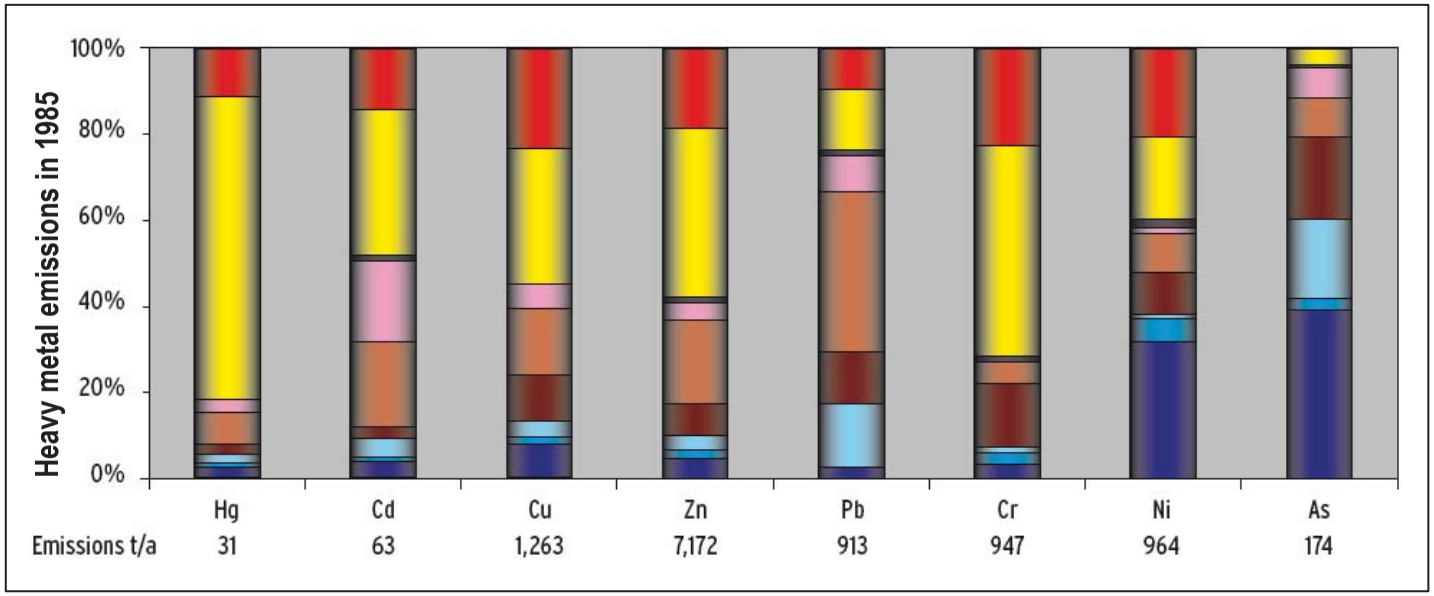
Pollution from Stormwater



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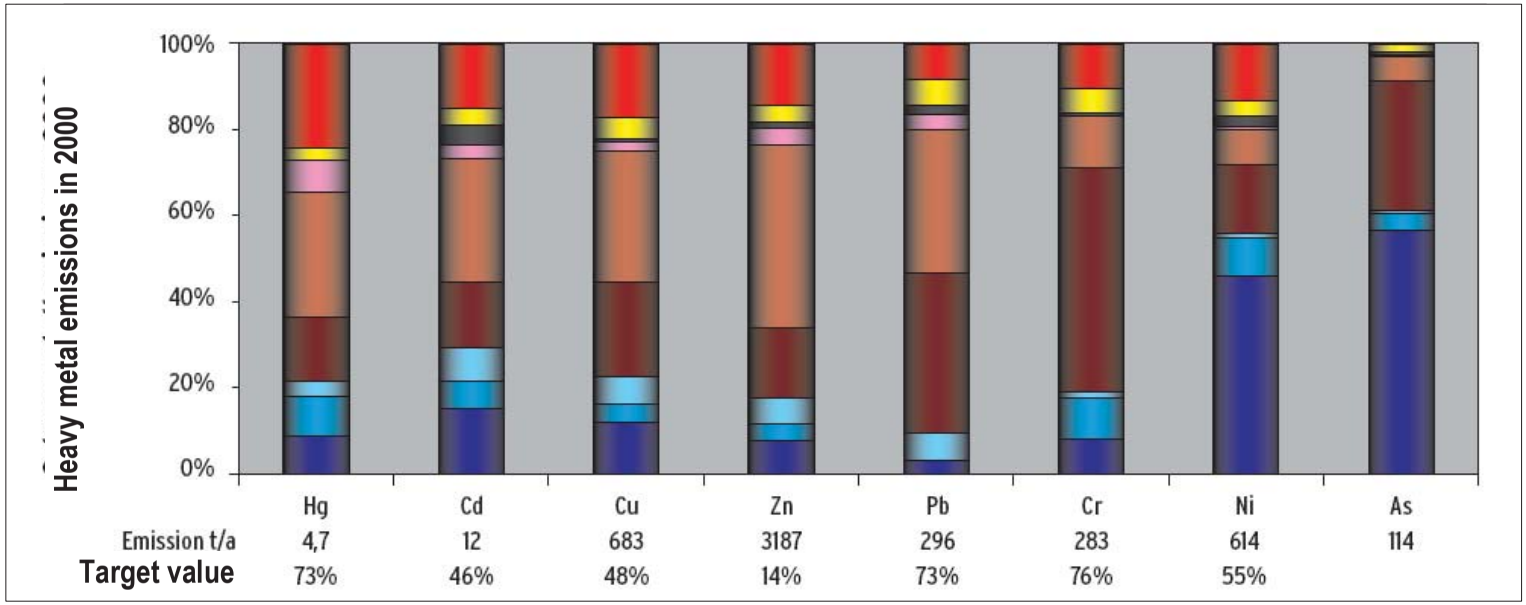
Pollution from Stormwater



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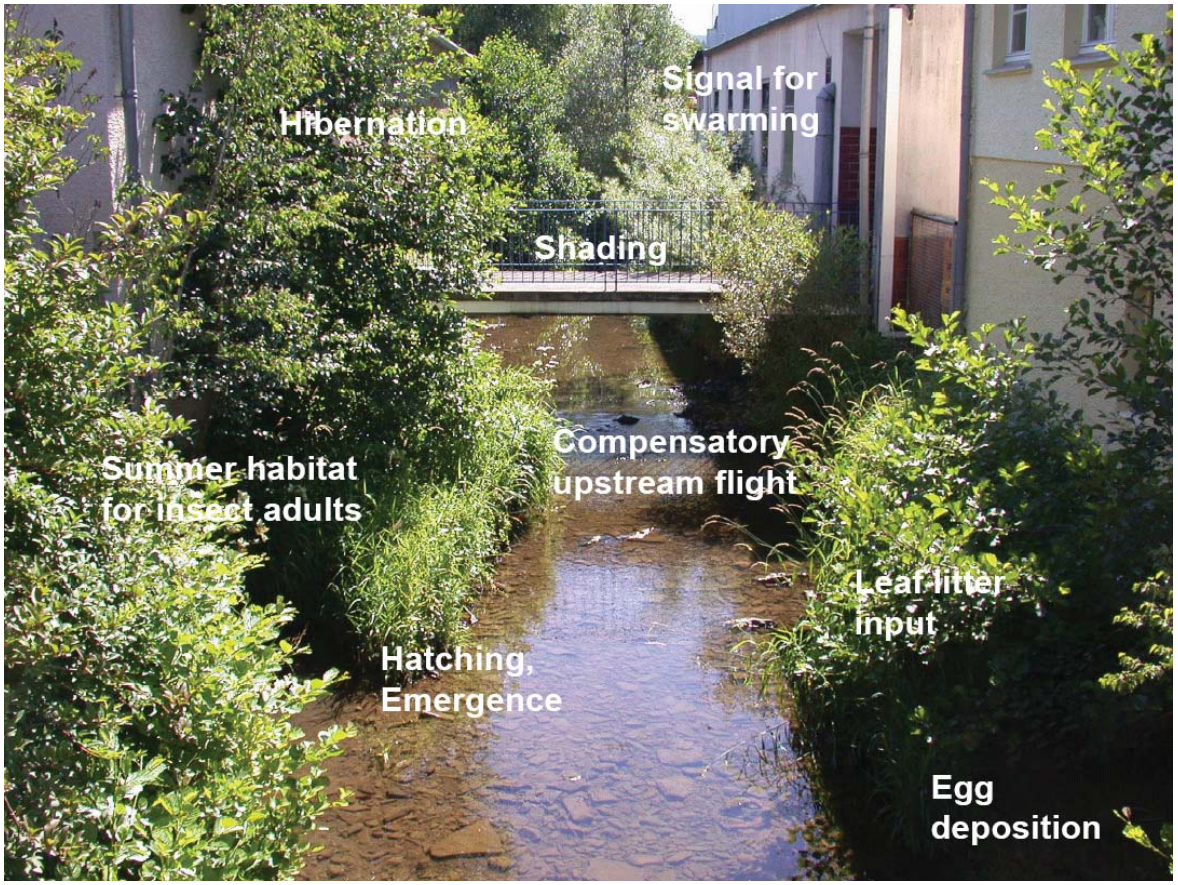
Hydraulic Stress

Foto: Podraza

Hydraulic Stress



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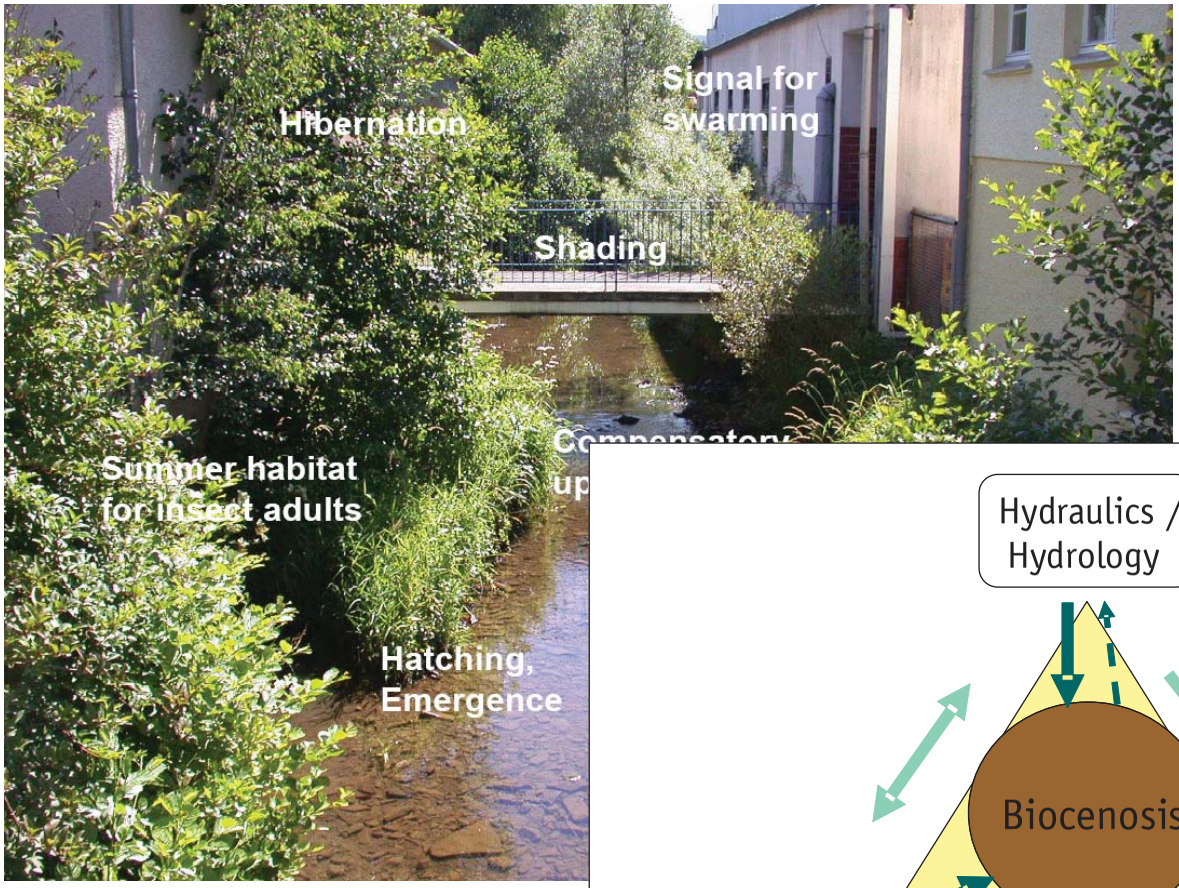
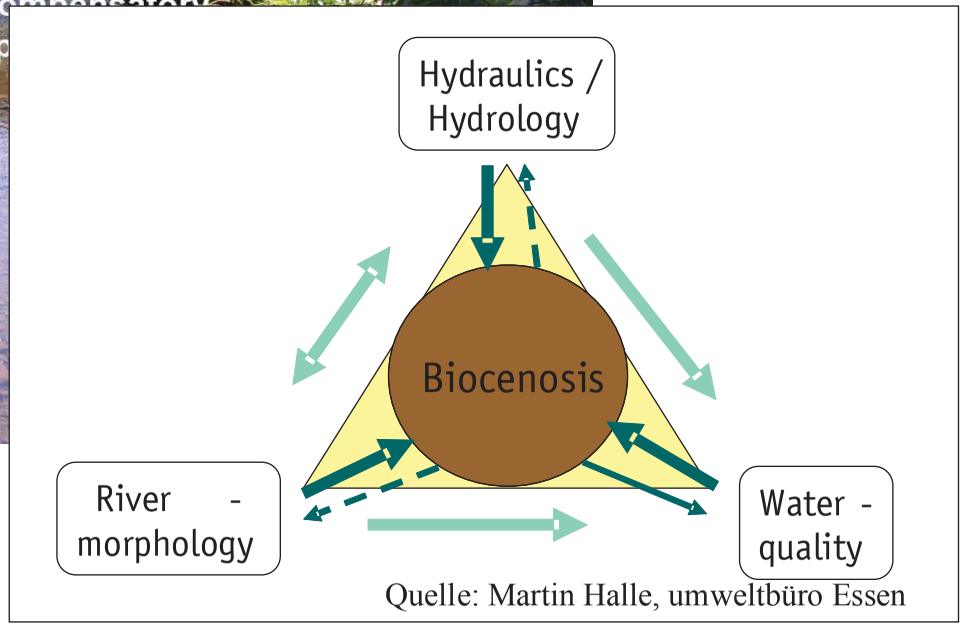
Hydraulic Stress





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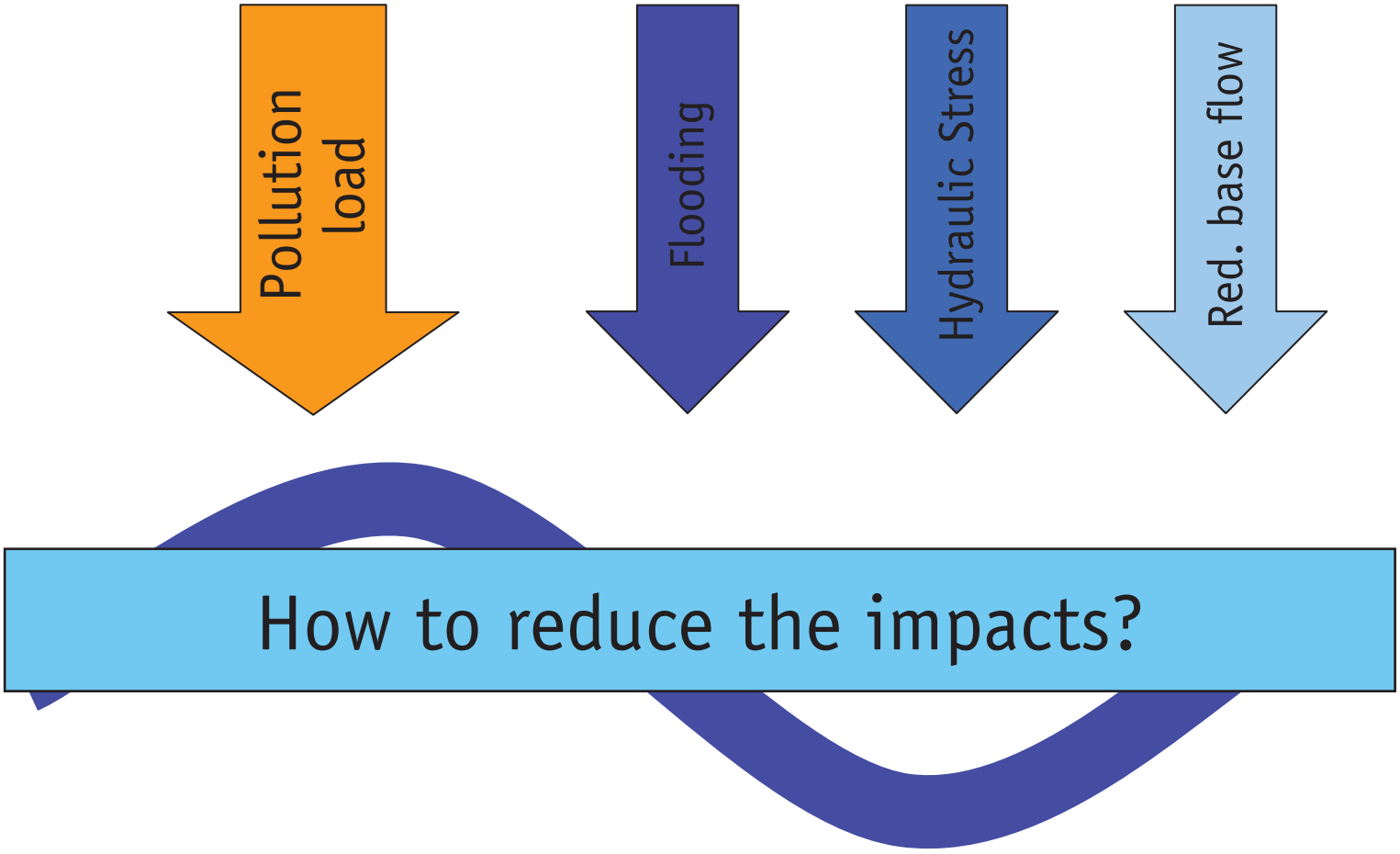
Water quality impacts from stormwater discharges



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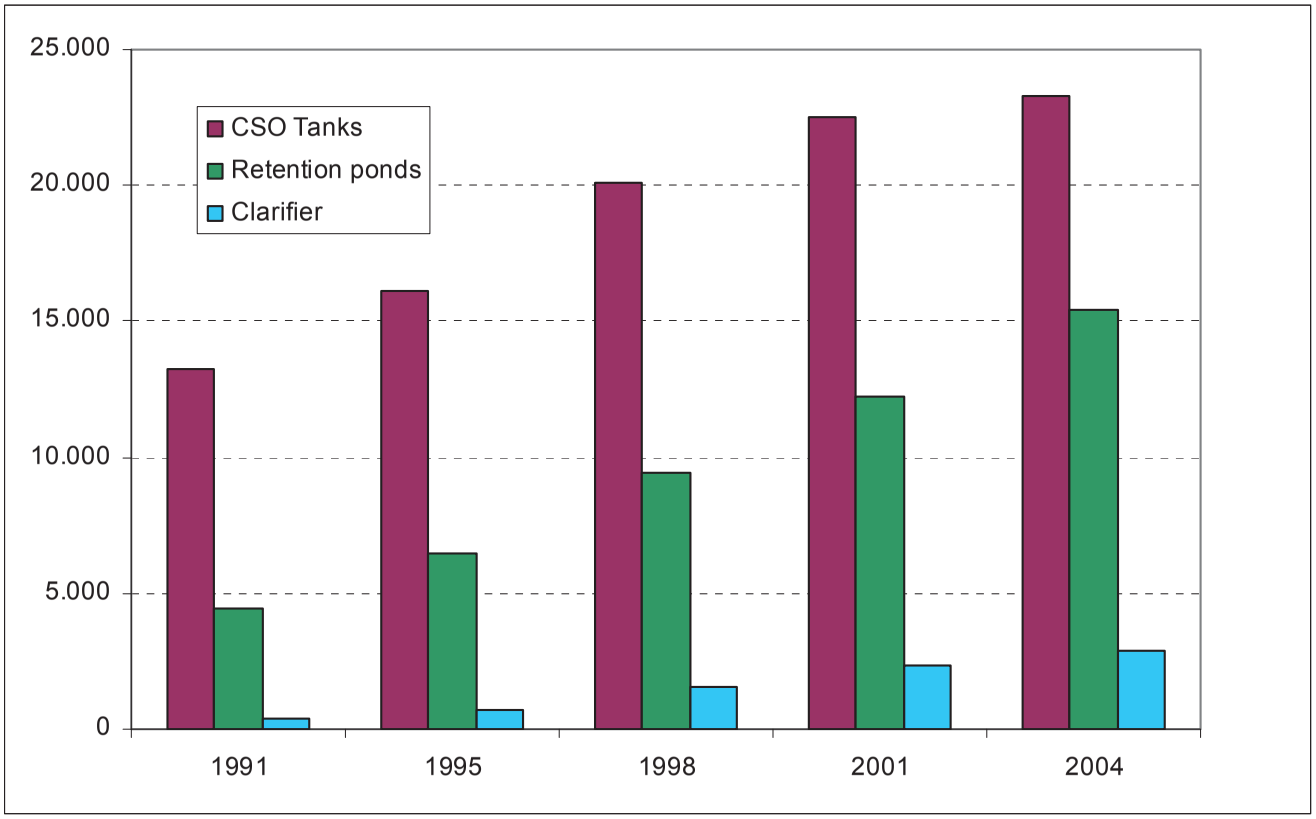
End-of-pipe-treatment

- End-of-Pipe-Treatment
  - Retention ponds
  - CSO tanks
  - Sedimentation tanks (clarifier)
  - Soil filter retention ponds
- Disadvantages
  - Not very efficient (clarifier)
  - Area demand up to 1-2% of the catchment (soil filter)
  - Often pumping in necessary
  - High cost

End-of-pipe-treatment



Cost of Stormwater Drainage

- Germany: most municipalities have a stormwater fee
- Cost for stormwater drainage is not included in fees for drinking water and waste water
- Base for stormwater fee: area connected to sewer
- Typical fee (Berlin): 1,50 €/m²/year
- Examples for fees
  - Private house (150 m² connected) 225 €/year
  - Supermarket (10.000 ² connected) 15.000 €/year
  - Supermarket (disconnected, infiltration) 0 €/year

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Paradigm Shift

- Development of new strategies in last 10-15 years
- New technical rules
  - ATV A138, DIN 1989
  - BWK-M3, ATV M153
- New legal regulations :
  - Regulation for infiltration in regional water laws
  - New “stormwater act” is under development (until 2008)

New Term:
Stormwater Management

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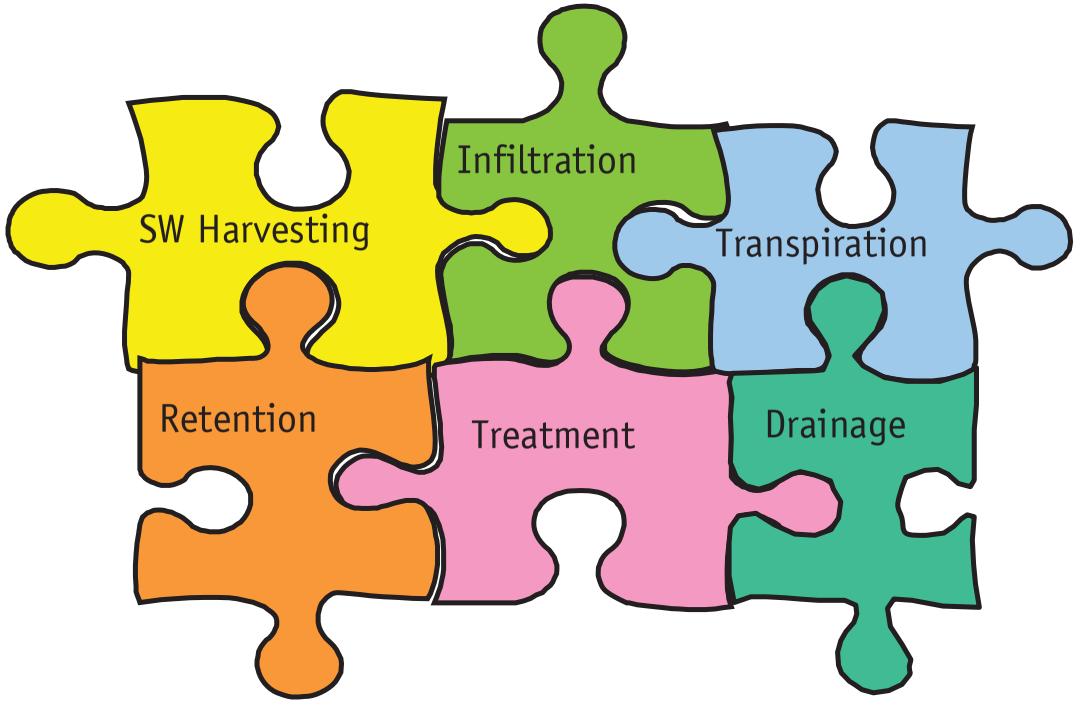
Stormwater Management

- Lot of different solutions are possible



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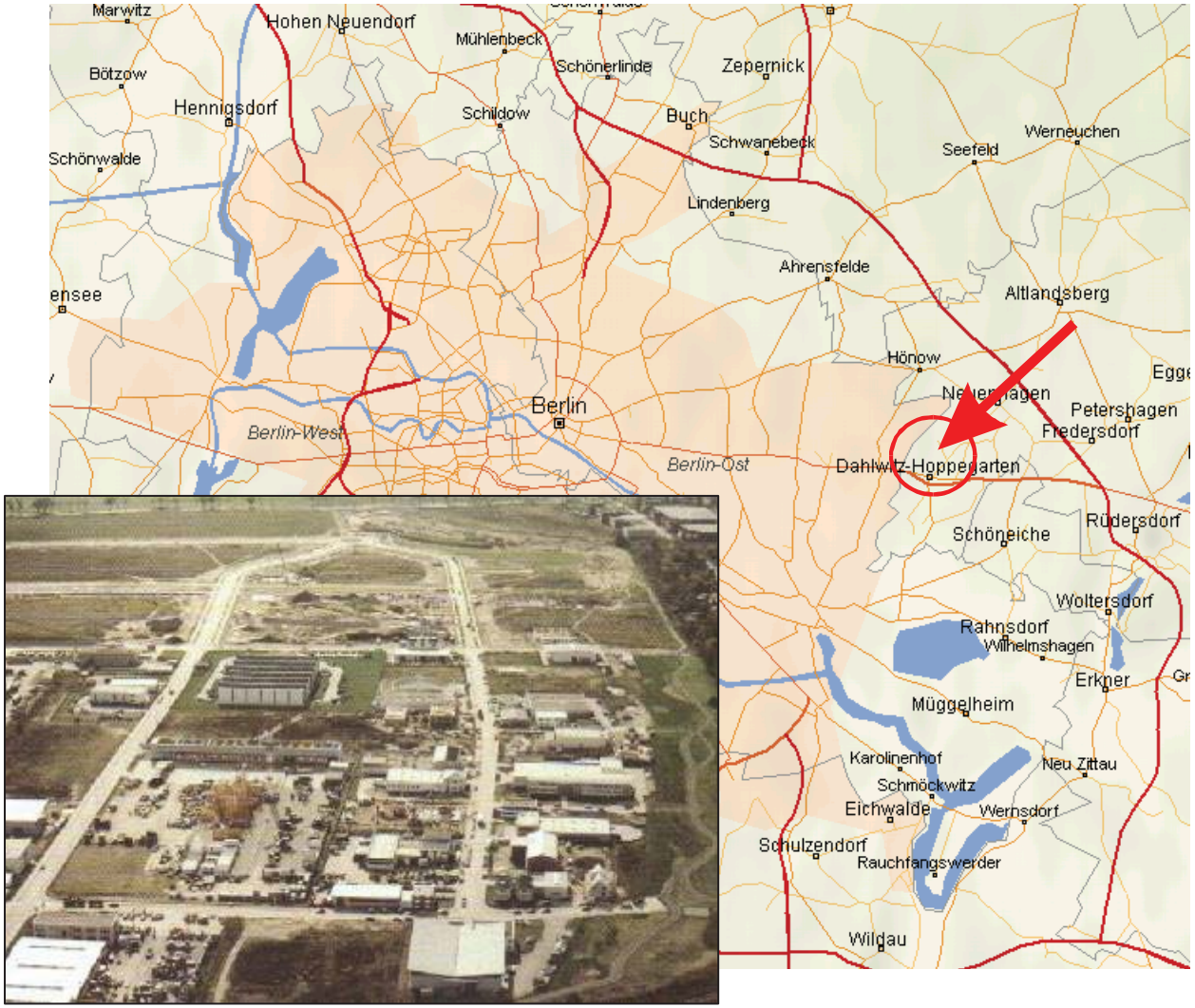
Example: Hoppegarten



Example: Hoppegarten

- Hydrological conditions
  - Poor hydraulic capacity
  - Max. discharge: 40 l/s
    (for 100 hectare new development!)
  - Runoff at heavy rainfall: 10 m^3/s
  - Extensive retention necessary
- Geological conditions
  - Glacial history
  - Loamy soil (Mergel):
    k_f-Wert: 10^{-7} m/s
  - “high groundwater tables"
  - Pure infiltration not possible

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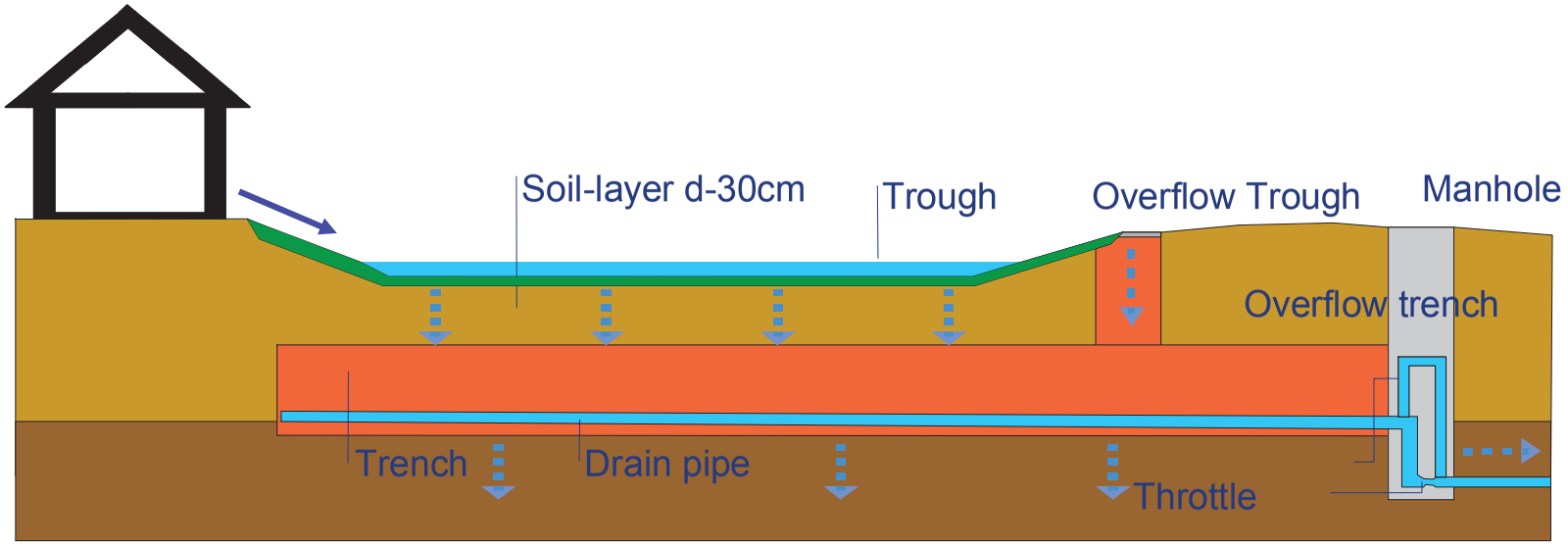
Swale-Trench-System



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Example : Hoppegarten

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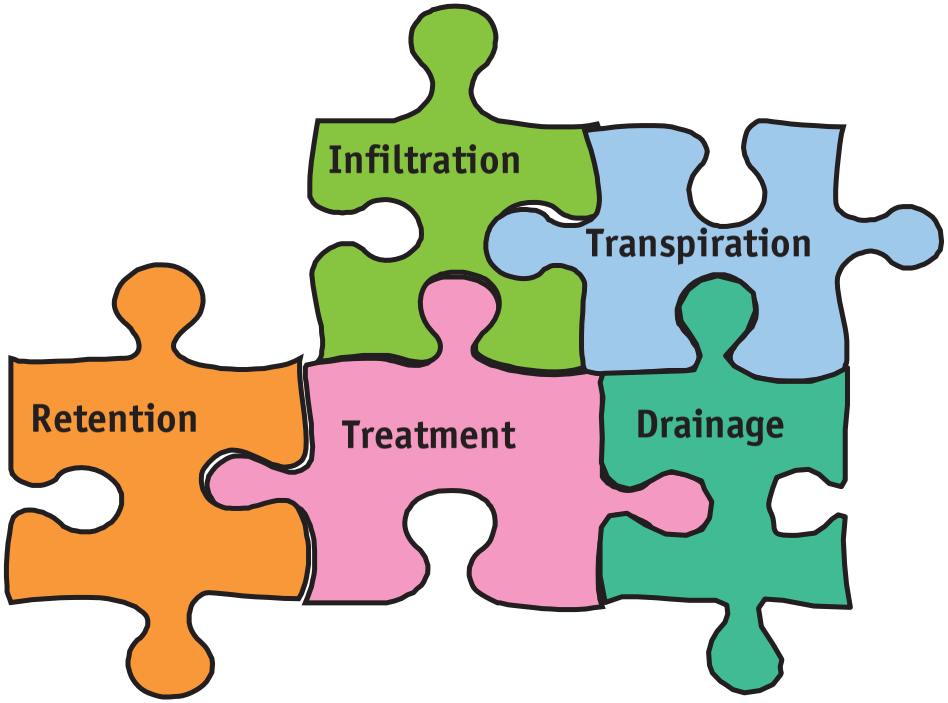
Stormwater Management

- Swale-Trench-System



SWITCH

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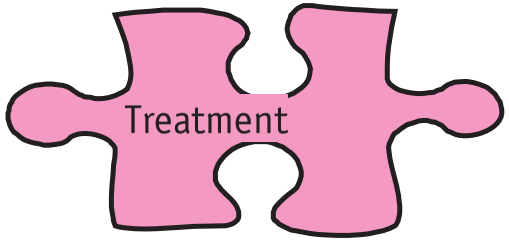
Stormwater Treatment

- Large variety of technical solutions



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Sixth Framework Programme

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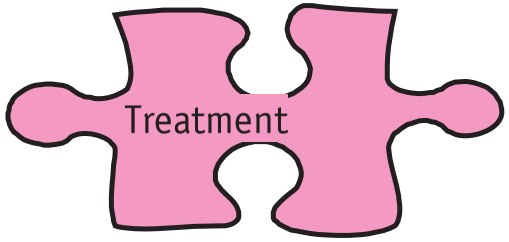

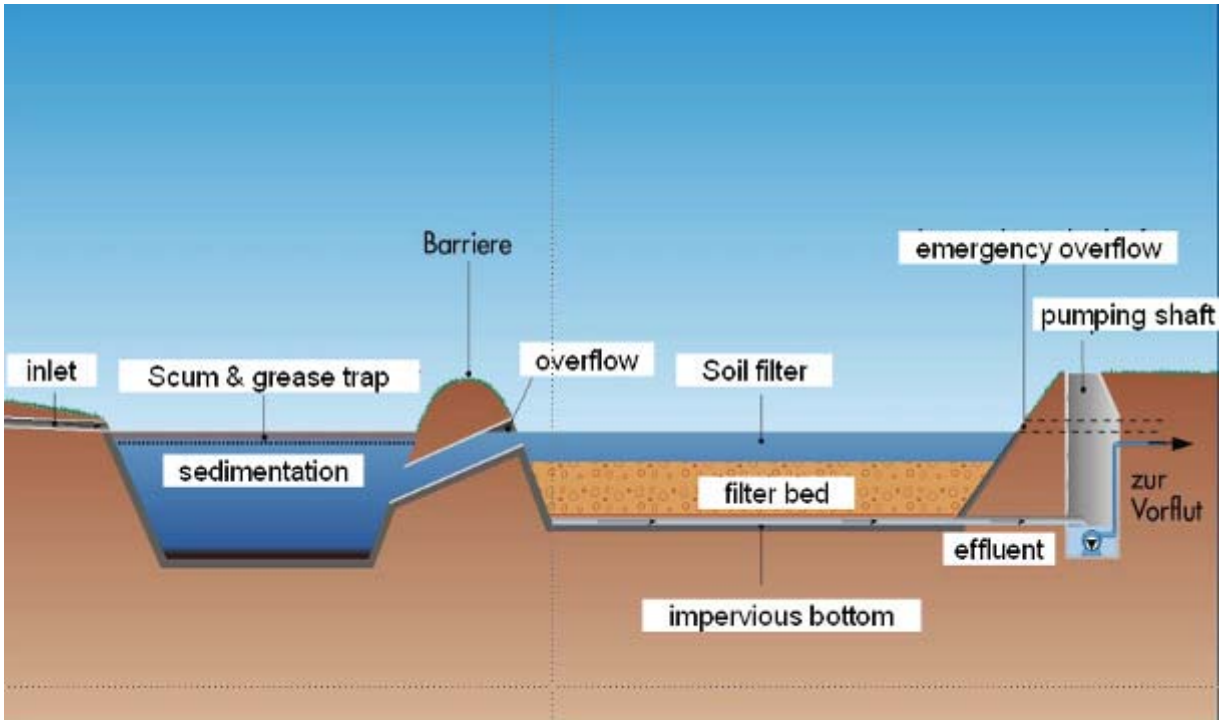

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Sixth Framework Programme

Stormwater Treatment

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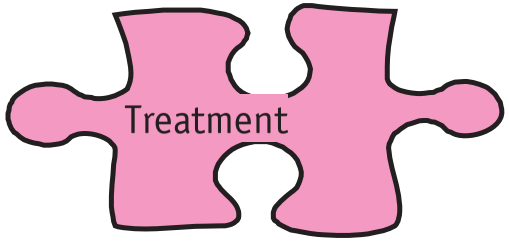

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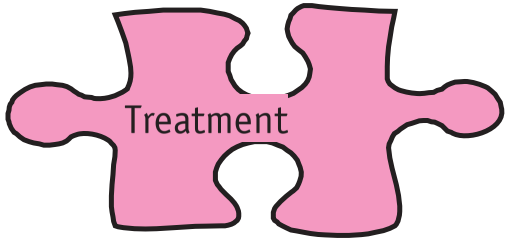

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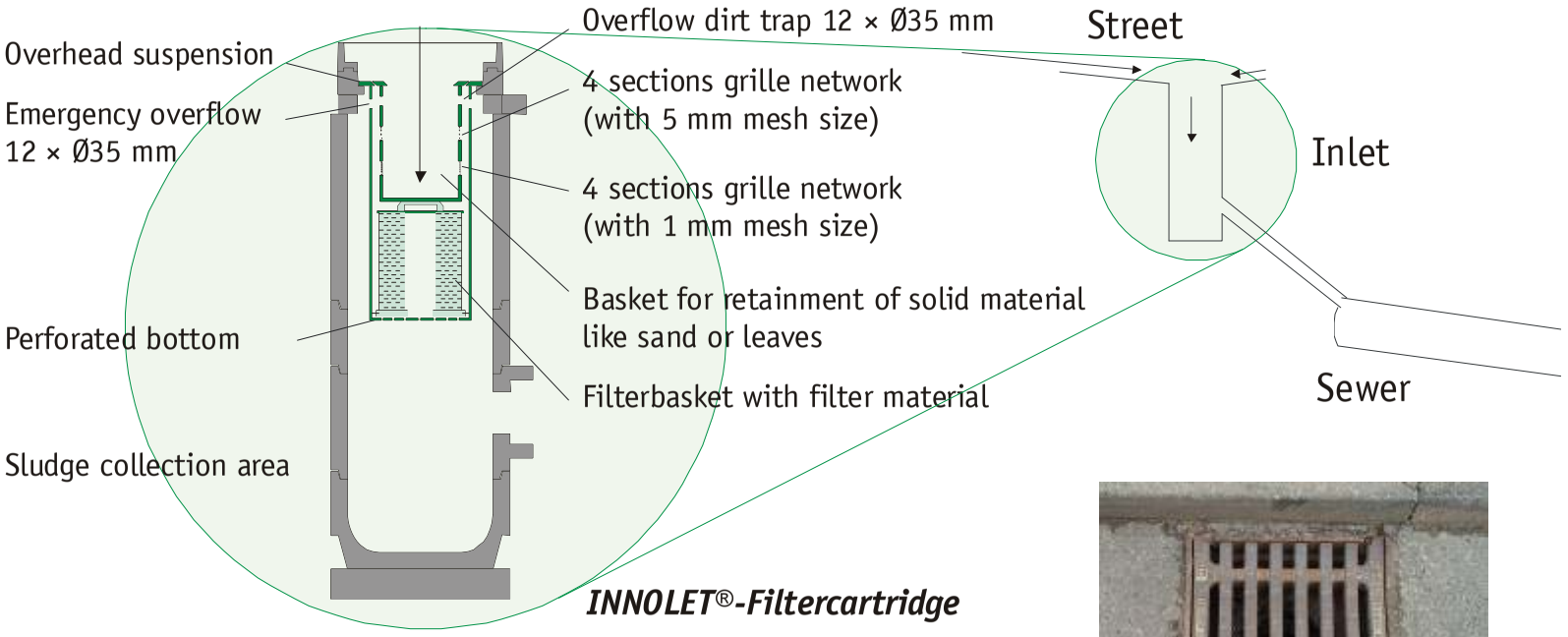
Innolet®

- Idea: Clean road runoff at the source



Rainwater harvesting in Germany

- Rainwater harvesting for non-potable use is quite common in Germany
  - In private households for garden watering, toilet flushing, washing
  - Also in public buildings
  - For commercial purposes
- The use of rainwater as drinking water is not allowed in Germany

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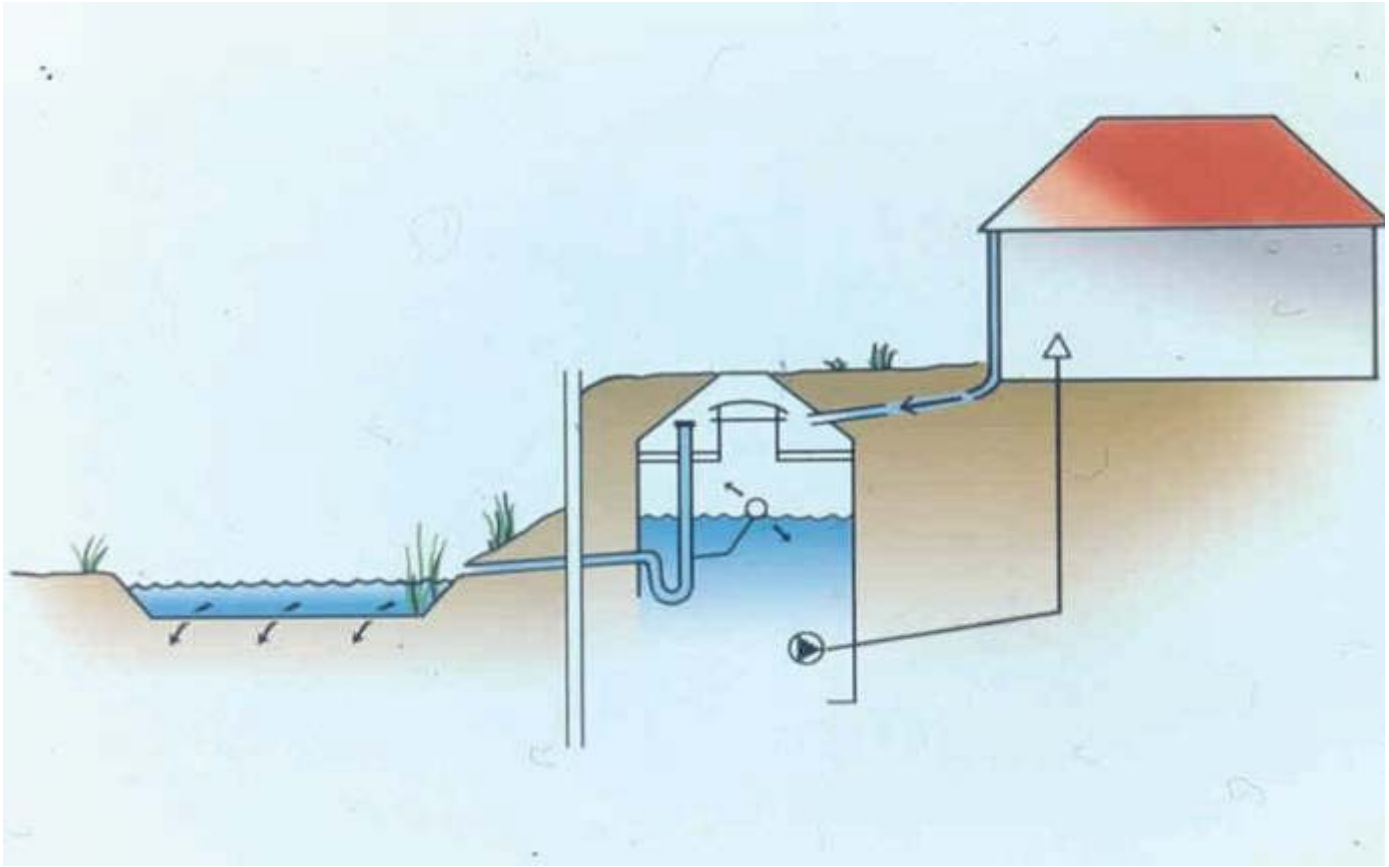
Harvesting on Household Level



Harvesting on Household Level

In Public Buildings

Potsdamer Platz, Berlin

Fotos: Klaus König, Überlingen

In Public Buildings

Salem College, Überlingen

Fotos: Klaus König, Überlingen

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In Public Buildings

Fotos: Klaus König, Überlingen

For Commercial Purposes

- Toilet flushing

Airport Frankfurt, Terminal 2

Constructed 1995

3 Cisterns, 200 m³ each

Fotos: Klaus König, Überlingen

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For Commercial Purposes

- Toilet flushing
- Cooling

Fotos: Klaus König, Überlingen

For Commercial Purposes

- Toilet flushing
- Cooling
- Cleaning processes

Fotos: Klaus König, Überlingen

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National Standards & Regulation

- Drinking water ordinance explicitly allows stormwater harvesting for
  - Garden watering
  - Toilet flushing
  - Washing (with exceptions e.g. for hospitals)
- DIN 1989 (German Institute for Standardization)
  - Notification of drinking water supply company
  - Refilling of cisterns with drinking water
  - Labeling of pipes

DIN 1989 is available in English and French

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Rainwater-Harvesting as a market

- Storage tanks
- Filter, pumping stations, ...
- Software for dimensioning

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Rainwater-Harvesting as a market

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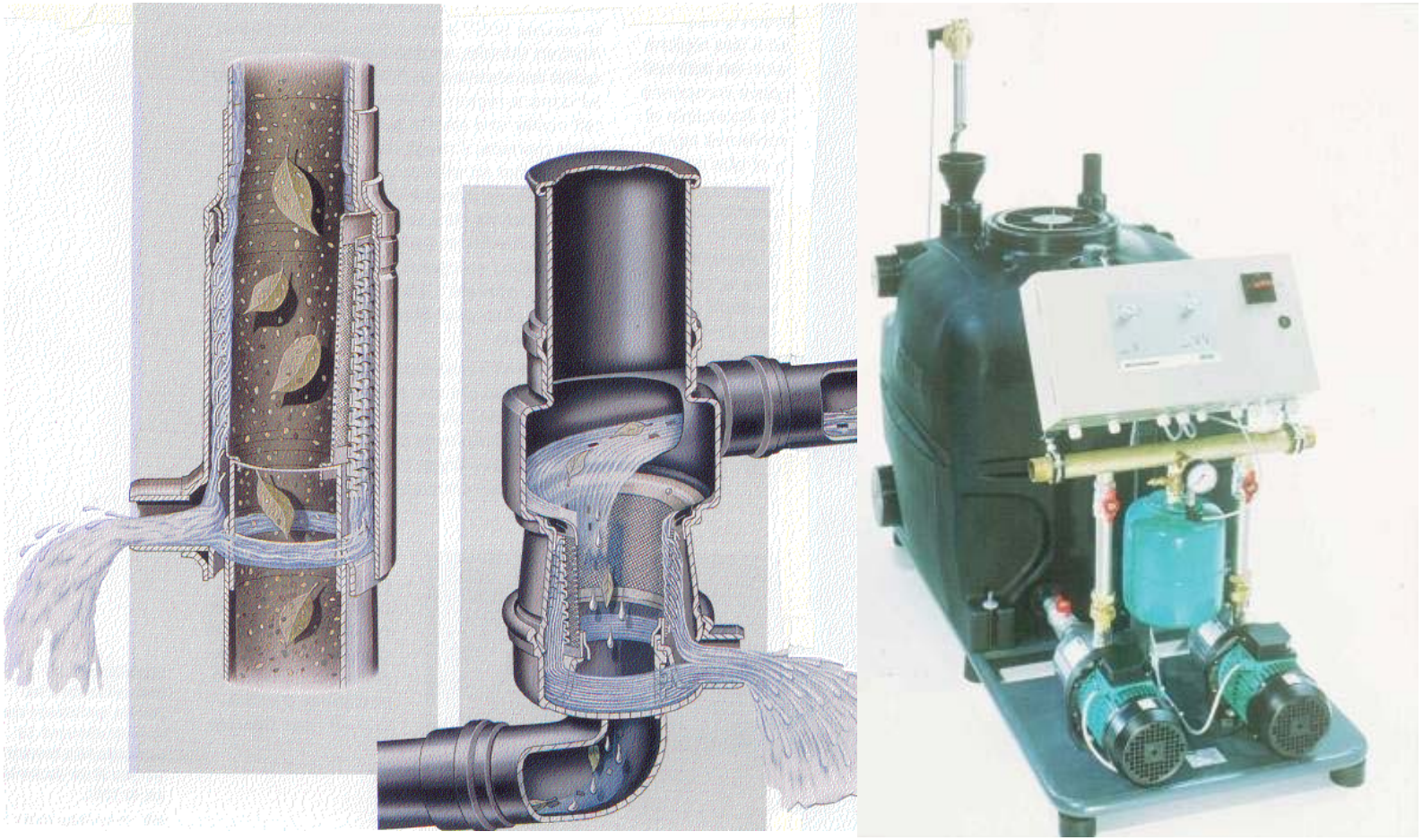
Rainwater-Harvesting as a market



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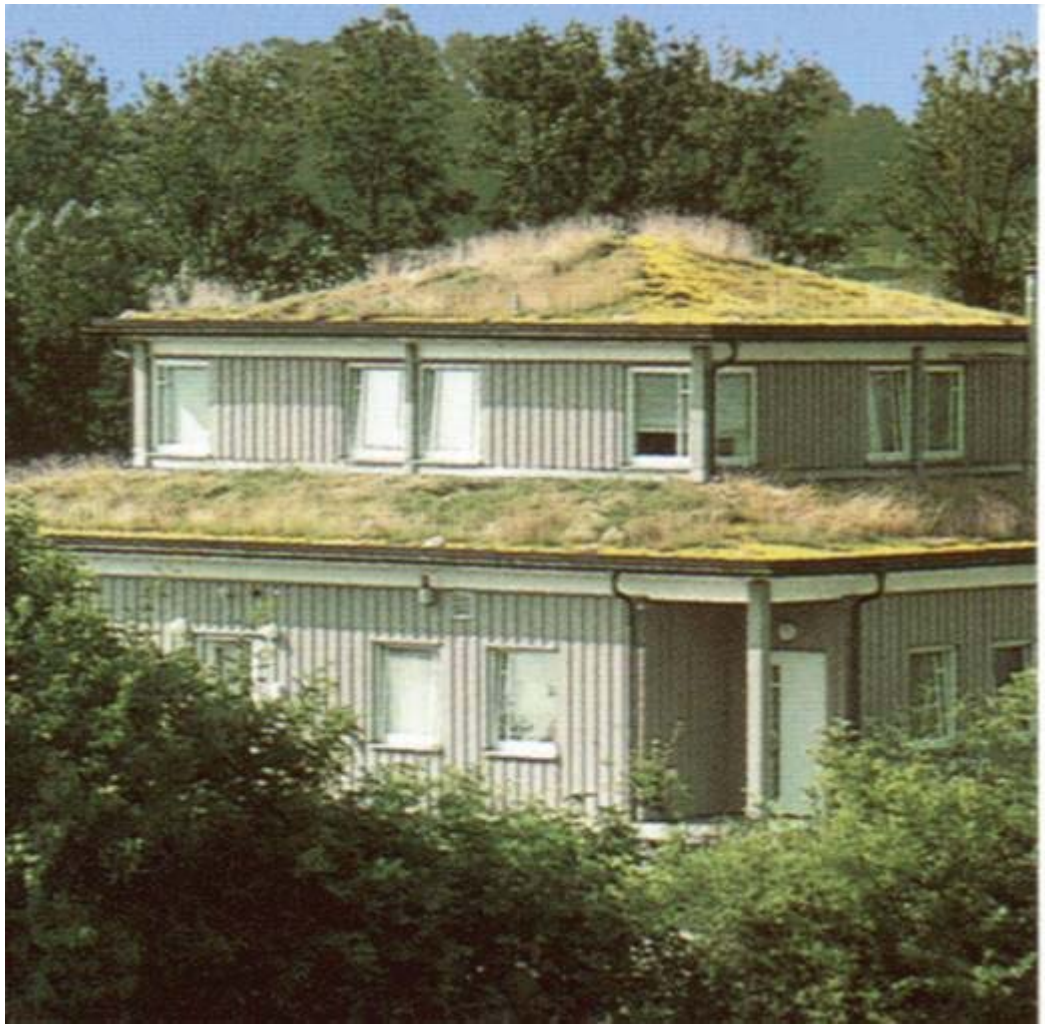
Statistics

• Number of cisterns in Germany	1,5 Mill.
• New systems per year	80.000
• Annual turnover	340 Mill.
• Number of jobs	~ 4.000 – 5.000
• Drinking water saved	75 Mill. m³

Rainwater Harvesting
is well established in Germany

Source: Mall, 2005

Green roofs



Green roofs

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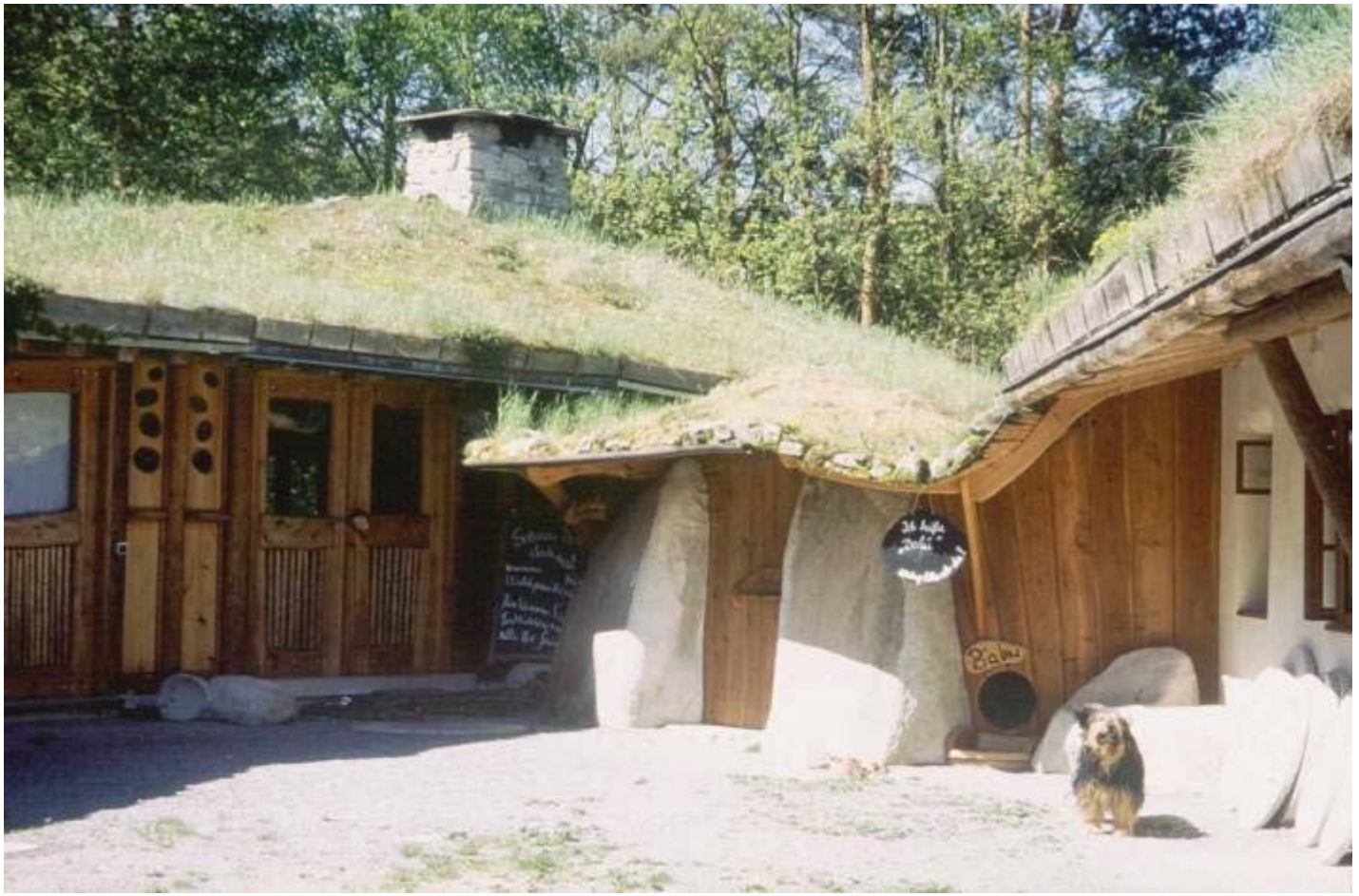
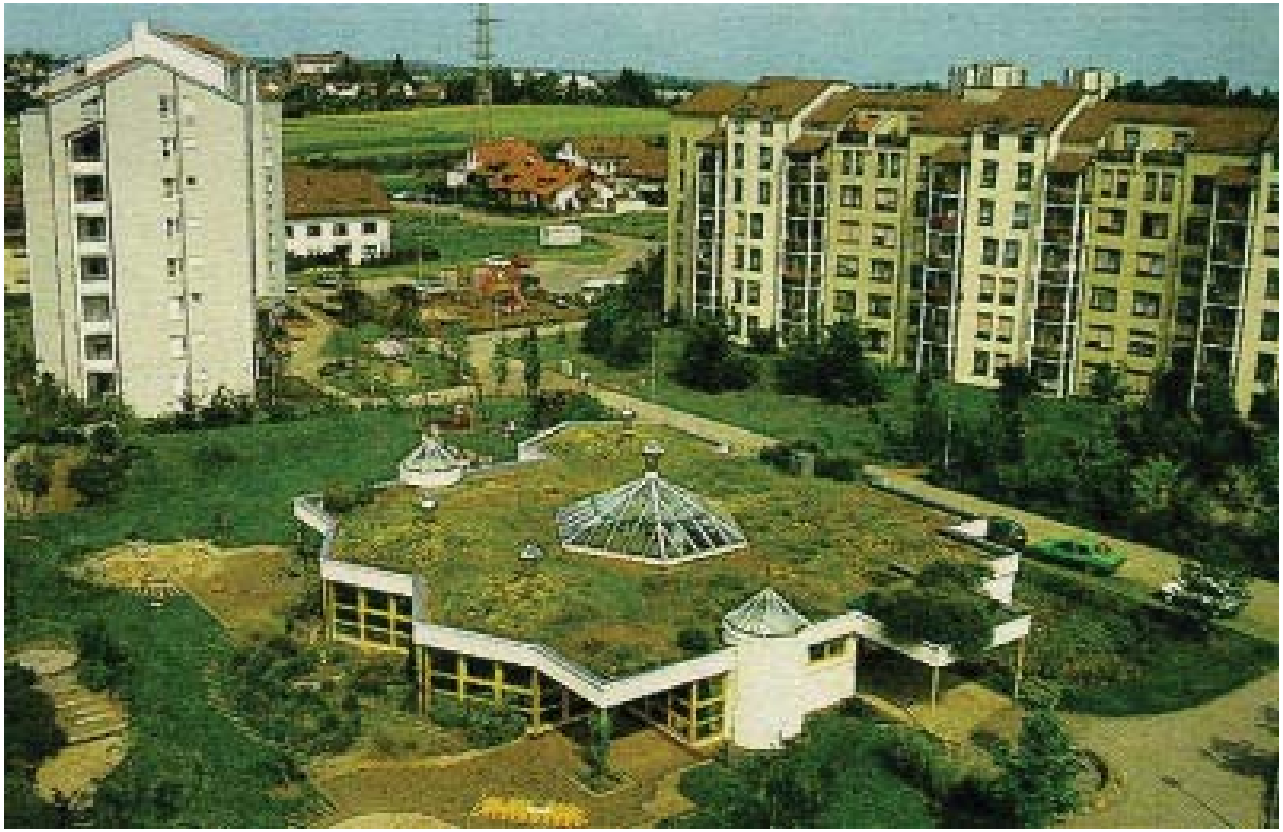
Green roofs

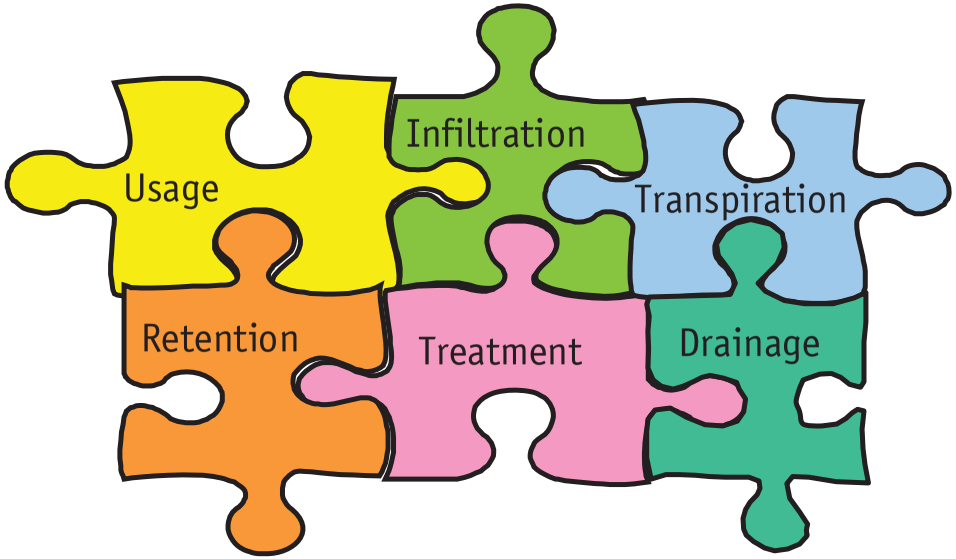


Green roofs



Conclusion

- Lot of technical solutions for SWM are available



- Optimal solutions usually are combinations
- SWM means looking for adapted solutions
- Challenge for the engineer!

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Sixth Framework Programme

Thank you for your attention

Ingenieurgesellschaft Prof. Sieker mbH
Hoppegarten, Germany
www.sieker.de

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New stormwater regulation

- Change of the constitution in 2006: Regulation for water treatment is not any longer federal but national task
- Ministry of the Environment wants to define the Best available technology (BAT) for stormwater management until 2009
- Status quo of discussion
  - Definition of BAT only for new developments
  - Objectives instead of measures
  - Main criteria
    - Suspended solids
    - TOC, N, P , petroleum-derived hydrocarbon
  - Treatment schemes based on land-use
  - Infiltration if possible/Water balance approach

Water balance approach

- Alternative to the demand for infiltration
- Principle: „objectives instead of measures“
- Objective: Keeping up the natural water balance
- Suggested procedure (for new developments)
  - Calculate natural water balance
  - Calculate post-development natural water balance
  - Criteria:
    - Difference of infiltration +- 10%
    - Difference of runoff +- 10%
    - Difference of evapotranspiration +- 20%

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Green roofs: a frank summary

Adam Bates,
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& Rossa Donovan*

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What are green roofs?

Green roof is a general term for any roof covered with a growth substrate with plants growing on it

Large array of terms: biodiversity roofs, eco-roofs, living roofs, brown roofs, rooftop gardens, roof gardens → all types of **green roof**

- Intensive
  - Parks and gardens (lawns, trees & water features) usually accessible
  - Expensive → roof reinforcement & considerable maintenance
- Extensive
  - Thinner substrate, very low maintenance, often not accessible

Intensive green roofs

Cannon Street Station, London

Photograph livingroofs.org

Intensive green roofs

Photograph livingroofs.org

Extensive green roofs

Photograph livingroofs.org

Extensive green roofs

Photograph livingroofs.org

Extensive green roofs

Photograph livingroofs.org

Extensive green roofs

Photograph Rossa Donovan

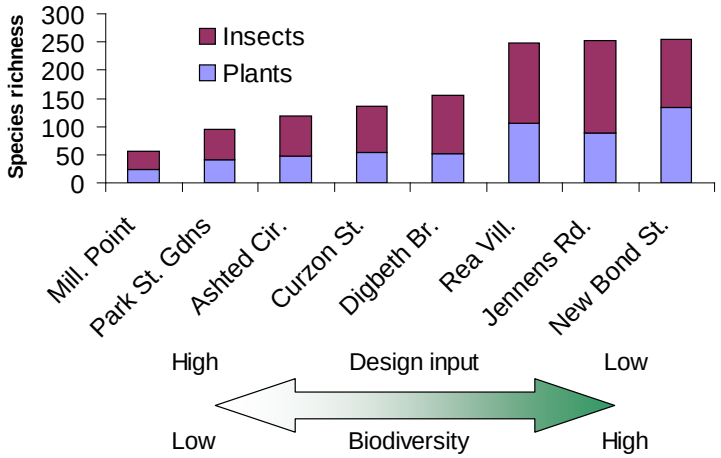
Extensive green roofs

Sedum roofs e.g. Fort Dunlop

- Most common & most research focus
- 'Off the shelf' solution provides consistent outcomes

Roofs designed for biodiversity

- Many possibilities e.g. flower meadow & heath
- Most focus on brownfield type habitats → brown roofs
  - Habitat of the black redstart
  - Very diverse habitats
  - Mitigation for habitat lost during construction



Donovan *et al.* (2005)

Perceived disadvantages of green roofs

Key issue of cost

- Costs vary greatly, especially on 'non-standard' projects (e.g. biodiversity roofs)
- Prices over-inflated at present due to unfamiliarity & poor economies of scale, will fall as become more mainstream
- Wong et al. (2003) in a study of extensive green roofs in Singapore suggest investment is paid back after ~10 years → increased roof longevity & insulation, after which money is saved
- Pay for an improved environmental image & aesthetics

Photograph livingroofs.org

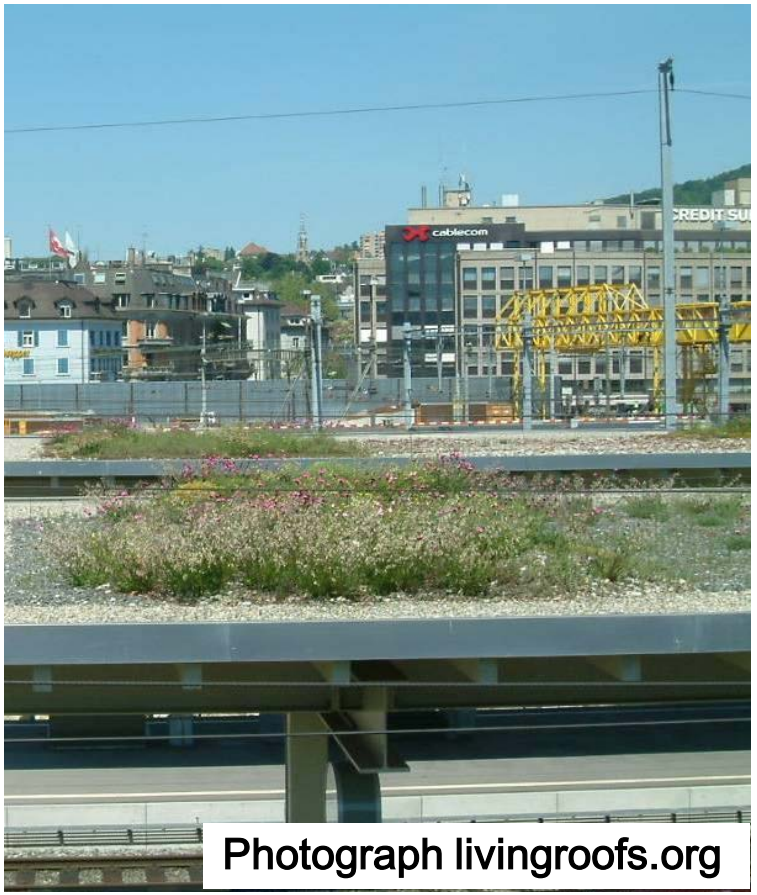
Perceived disadvantages of green roofs

Cost of increased loading

- Extra roof reinforcement sometimes needed
- Extensive green roofs typically 80-170kg/m^2
- Intensive 300-1000kg/m^2

But…

- Often aiming to hold the roof down, not up!
  - Gravel surface 90-150kg/m^2
  - Paving slabs 160-220kg/m^2
- Can work *with* the buildings structure



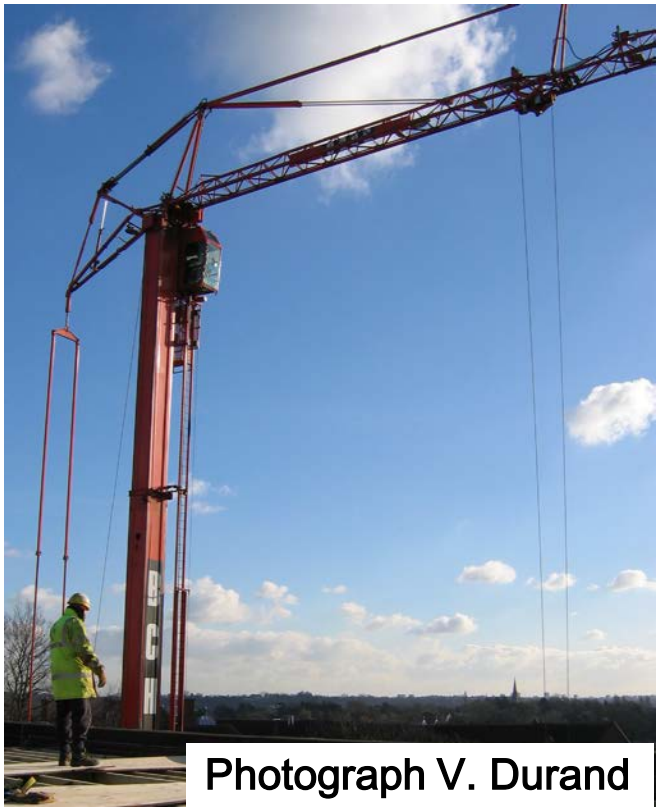
Photograph livingroofs.org

Perceived disadvantages of green roofs

- Maintenance
  - Intensive roofs require as much maintenance as a normal park or garden
  - Extensive roofs only require slightly more maintenance than a normal roof once established
    - ~2 times per year to clear drains & remove problem species
- Roof leaks
  - Green roofs require an additional roof protection layer to prevent damage to the roof by plant roots
  - It is badly installed roof water-proofing that leaks, not green roofs
  - Most green roof companies will guarantee the roof

Advantages of green roofs

- Insulation: reducing heating & cooling costs
  - New builds have good insulation anyway → minimal effect
  - Retro-fits will benefit most, but depends on roof structure
- Urban cooling – combating the heat island effect
  - Reflects much more short-wave radiation back into the atmosphere → can paint a roof white or silver for similar effect
  - Increased evaporative cooling → requires roof to be wet



Photograph V. Durand

Advantages of green roofs

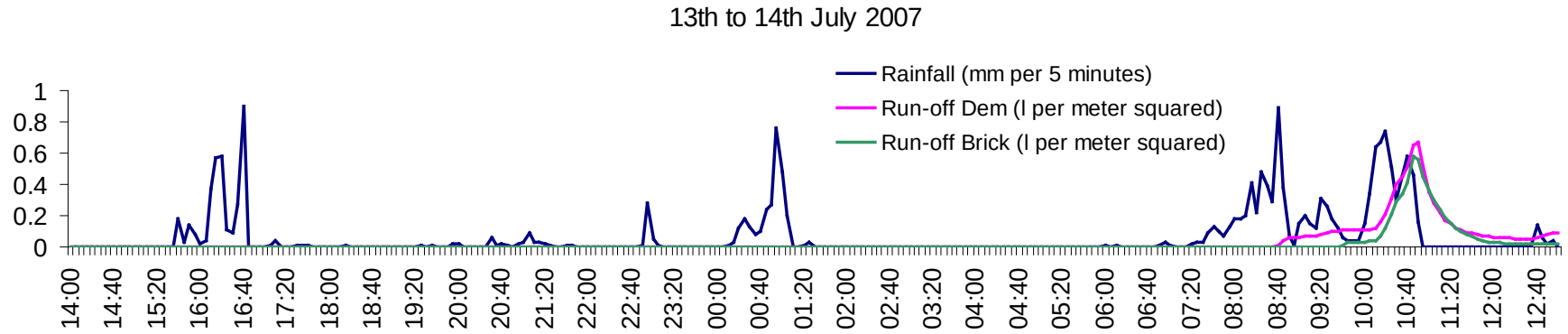
- Protection of roof membrane
  - Much lower temperature range → less cracking due to expansion & contraction
  - Protection from UV radiation
  - Protection from mechanical damage e.g. hail, walking
- Therefore increased roof longevity
  - But for how long?
  - This is the main way that green roof investment is recovered
- Aesthetic & amenity value

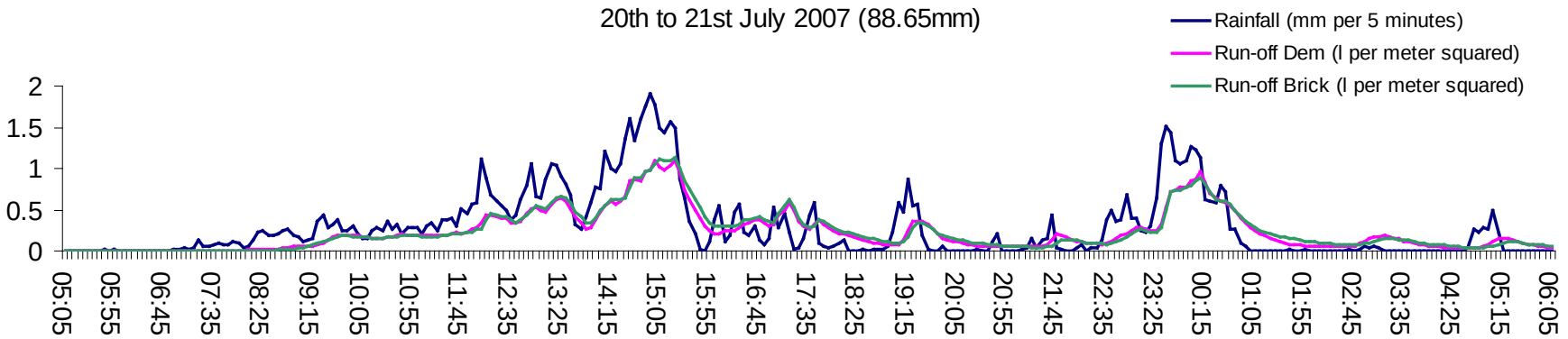
Photograph livingroofs.org

Advantages of green roofs

- Reduce urban run-off
  - Green roof field (water) capacity is controlled by soil depth & porosity → water **removed** from run-off
    - Field capacity recharged by evapotranspiration → controlled by temperature, wind speed, solar radiation & plant demand (therefore less capacity in the winter)
  - Once field capacity is reached, run-off is **delayed** as it takes time to move through the soil
- Green roofs can potentially be used to reduce local flooding & reduce infrastructure requirements for surface water drainage & storage (potential big savings in infrastructure costs(?))

Green roof hydrology





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Advantages of green roofs

- Habitat creation
  - Work in Switzerland by Stephan Brenneisen has shown that green roofs can act as habitat for a broad range, of often rare, species
- But how close can they be to the natural habitat?
  - Can species colonise?
  - What is the effect of altered microclimate?

Photograph Stephan Brenneisen

A solution to multiple problems?

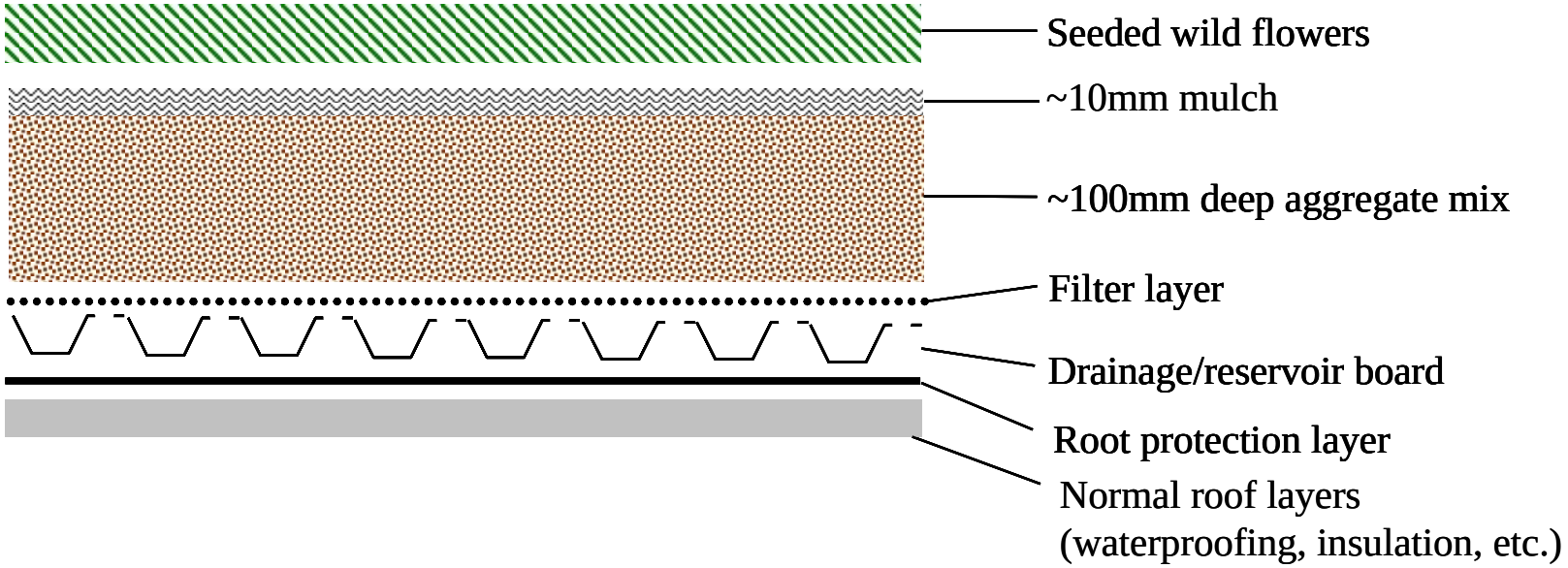
- Most of the advantages associated with green roofs have provisos → lots of research needed to maximise their benefits
- Maximising one benefit, will often trade-off against another → need to be clear about what the main aim is
- Generally lots of small environmental benefits that add up to a large benefit → green roofs are a great idea

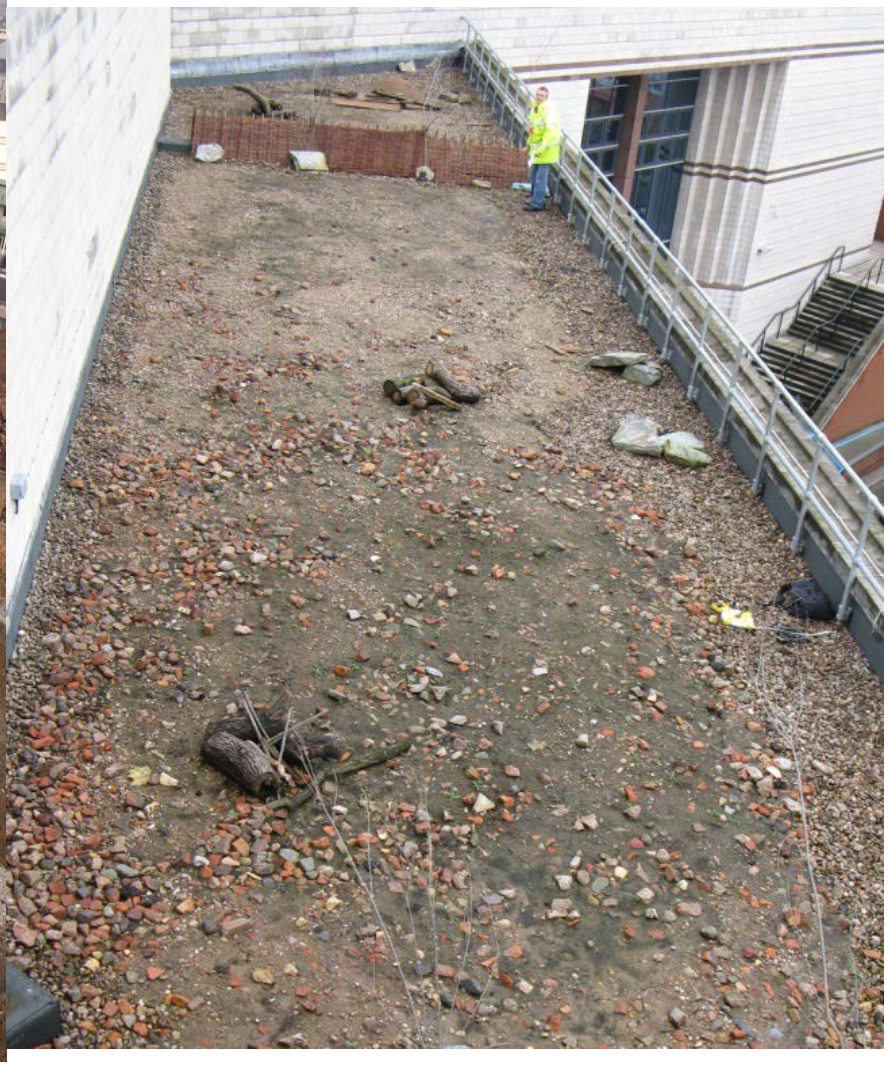
How to design a brown roof

- Need to include a brown roof at the concept design stage, difficult to bolt-on afterwards
  - Possibility of using aggregate already on site with its seed bank
  - Possible structural implications
- Low nutrient, mainly coarse substrates used → have to discard inherited horticultural wisdom
- As a rule of thumb, the greater range of microhabitats, the greater the diversity of species supported
- Need deeper, more fertile areas for species to retreat to during droughts & to hibernate in
- Carefully designed wild seed mixes

Basic design

- Many possibilities, but the below is typical





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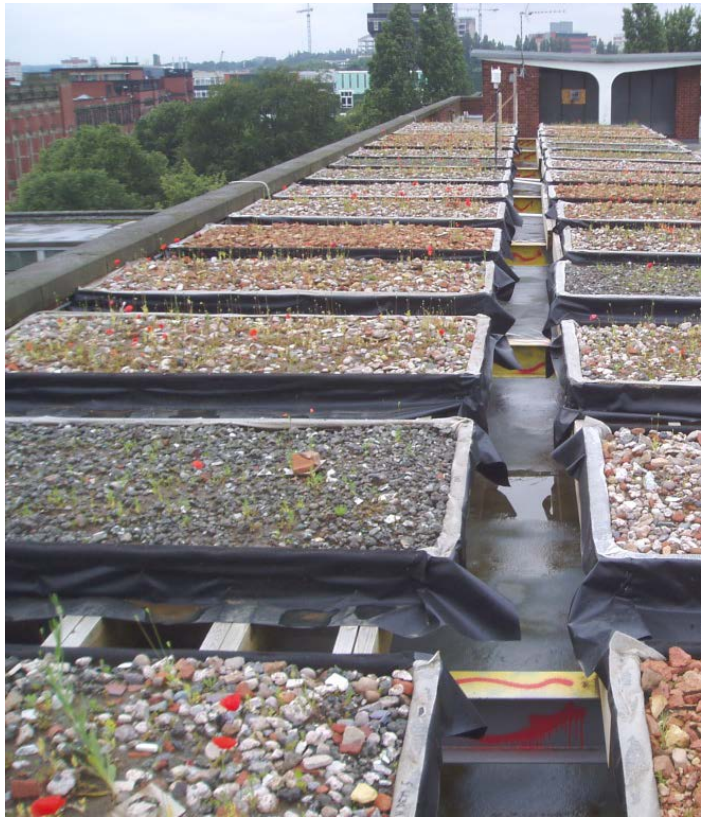
Brown roof disadvantages

- Not to everyone's aesthetic taste
  - Need for bare ground and dead stems
  - Peak summer and winter die-back
- Recycled aggregates (e.g. crushed brick, cursched concrete)
  - Heavy
  - Low water holding capacity → contrasted to e.g. pumice, expanded clay



Funding sources

- University of Birmingham research funded by SWITCH:

  http://www.switchurbanwater.eu/

- SWITCH Birmingham Alliance:

  http://switchbirmingham.wordpress.com/

- BVSC (Birmingham Volunteer Service Council) roof funded by SITA Trust from Landfill Communities Fund & SWITCH

  http://www.sitatrust.org.uk/

World Green Roof Congress 2008 - London

- 17-18th September 2008
- Conference, workshops & tours of some London green roofs
- Organised by CIRIA & LivingRoofs
- http://www.worldgreenroofcongress.com/

Acknowledgements

- The EU, UNESCO, and SITA Trust for funding this research
- Dusty Gedge & www.livingroofs.org for permission to use many photographs and information
- IKO/Permanite for initial advice on green roof construction
- The initial work by numerous people that this presentation draw upon

Integrating the multiple benefits of green roofs

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Sixth Framework Programme (2002-2006)

Preamble

- Green roofs offer multiple environmental benefits within urban systems
- They can potentially play a key role in SUDS (BMP's), but this function cannot be examined independently of other associated benefits due to green roof design trade-offs
- This talk will therefore also examine the other main environmental benefits of green roofs
- The development of sustainable water management systems will have to integrate with holistic sustainable management of ecological, climatological, built & human systems

Presentation outline

1. Introduction to green roofs
   - What are green roofs?
   - Intensive & extensive
   - Basic structure of green roofs
2. Design issues / green roof myths
   - Maintenance & leaks
   - Loading
   - Aesthetics
3. Advantages of green roofs
   - Private advantages
   - Whole life costs analysis – justifying the spend
   - Public/environmental advantages
4. Green roof use in SUDS (stormwater BMP's)
5. Design trade-offs of green roofs
6. Summary & Conclusions

What are green roofs?

Green roof is a general term for any roof covered with a growth substrate with plants growing on it

Large array of terms: biodiversity roofs, eco-roofs, living roofs, brown roofs, rooftop gardens, roof gardens → all types of **green roof**

- Different terms developed because of wide range of roof types and large number of green roof researchers
- Intensive
  - Parks and gardens (lawns, trees & water features) usually accessible, require structural support & expensive
- Extensive
  - Thinner substrate often not accessible, more potential for widespread use

Intensive green roofs

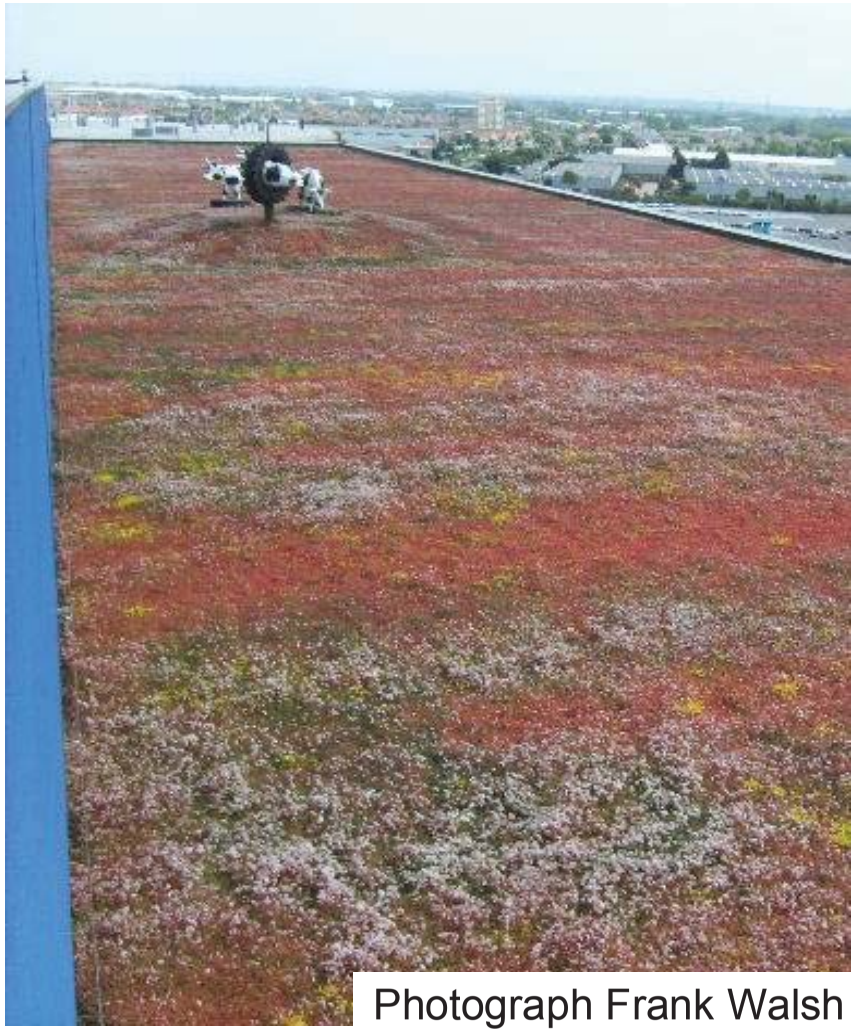
Cannon Street Station, London

Photograph livingroofs.org

Intensive green roofs

Photograph livingroofs.org

Extensive green roofs



Photograph Frank Walsh

Extensive green roofs

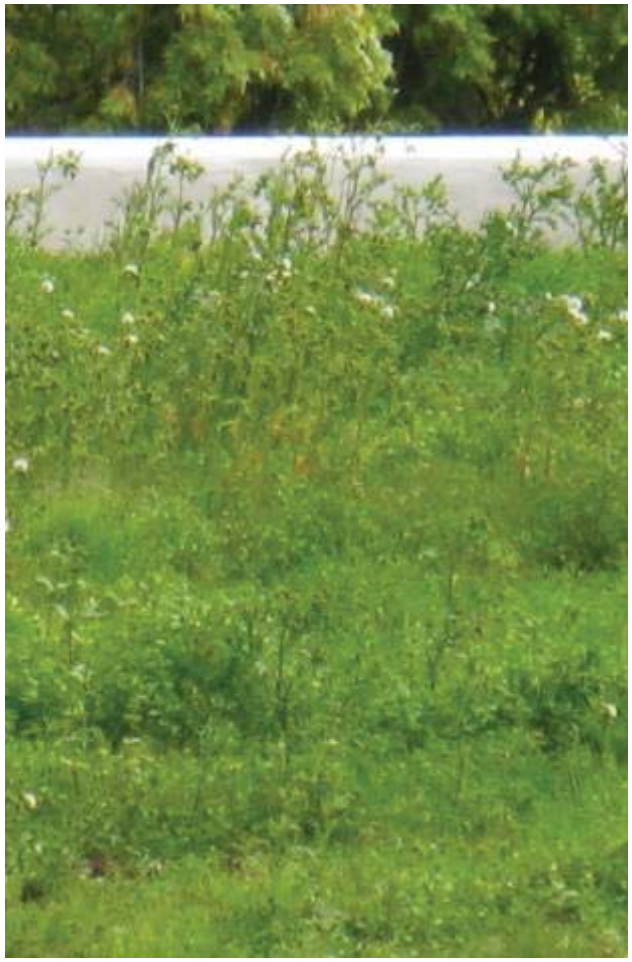
Photograph livingroofs.org

Extensive green roofs

Extensive green roofs

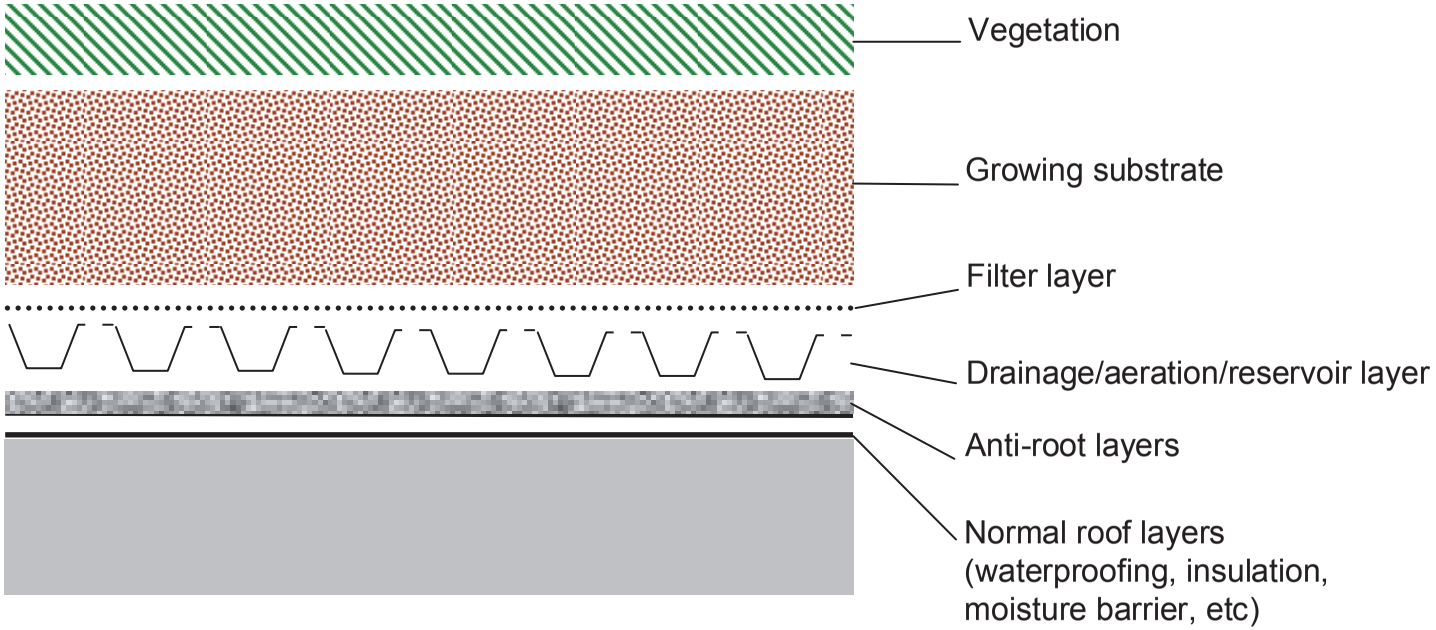
Photograph Rossa Donovan

Extensive green roofs



Basic structure of green roofs

- Whatever the type of green roof, the basic components of its structure are the same



Maintenance & leaks

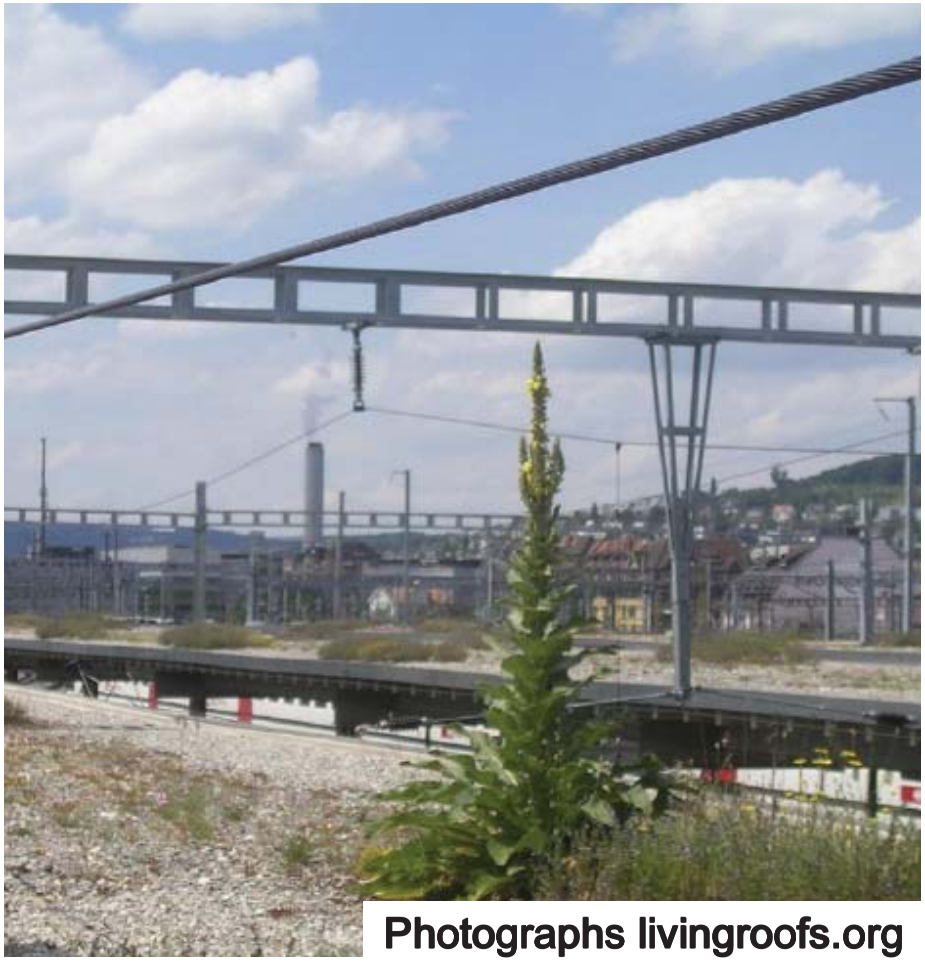
- Maintenance
  - Intensive roofs require as much maintenance as a normal park or garden
  - Differences of opinion but extensive roofs require the same, or slightly more maintenance than a normal flat roof
    - Annual to biannual visits after the first year to clear drains and remove problem plant species (mainly *Budleja*)
    - Grass meadow green roofs will require annual to biannual mowing
- Roof leaks
  - Green roofs require an additional roof protection layer to prevent damage to the roof by plant roots
  - It is badly installed roof water-proofing that leaks, not green roofs
  - Green roof companies guarantee the water-proofing & will guarantee the plant survivability in standard systems

Loading

	Dunnet & Kingsbury	FLL
Crushed brick (1cm depth)	18kg/m^2	10-13kg/m^2
Pumice (1cm depth)	6.5kg/m^2	11-12kg/m^2
Expanded clay (1cm depth)	3-4kg/m^2	5-8kg/m^2
Topsoil (1cm depth)	17-20kg/m^2	16-19kg/m^2
Compost (1cm depth)		10-13kg/m^2
Sand (1cm depth)	18-22kg/m^2	
Egg-box drainage board 4cm depth (entire course)		19-21kg/m^2
Fibre matting (entire course)		20-50kg/m^2
Extensive plant growth (total)		10kg/m^2

- Extensive green roofs typically 80-170kg/m^2, intensive 300-1000kg/m^2
- But… are often aiming to hold the roof down, not up!
  - Gravel surface 90-150kg/m^2
  - Paving slabs 160-220kg/m^2

Loading – working with the structure of the building



Photographs livingroofs.org

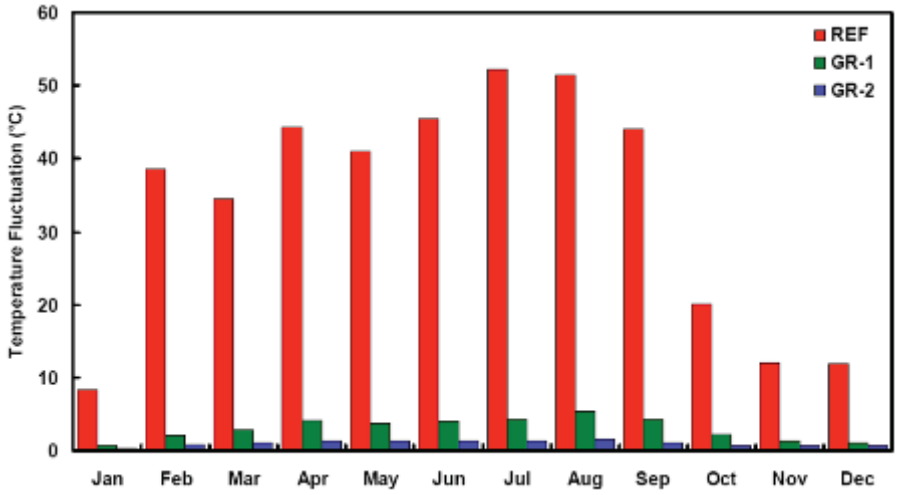
Aesthetics

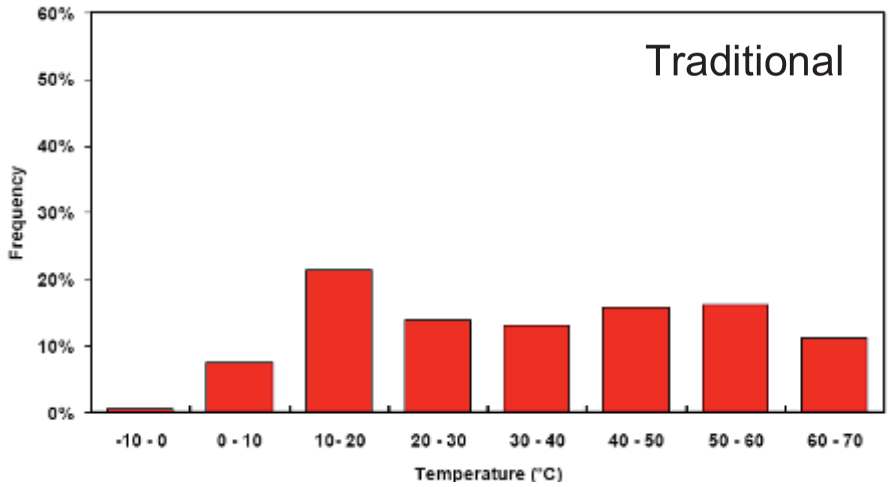
- Unrealistic expectations
  - Choice of nomenclature
    - Green roofs rarely green
    - Rooftop gardens rarely garden-like
  - Glossy summer photographs
    - Time to establish
    - Die-back during dry periods, after seeding & in the winter
- Only ‘off the shelf’ solutions likely to have a reasonably consistent outcome
- Biodiversity/brown roofs particularly variable

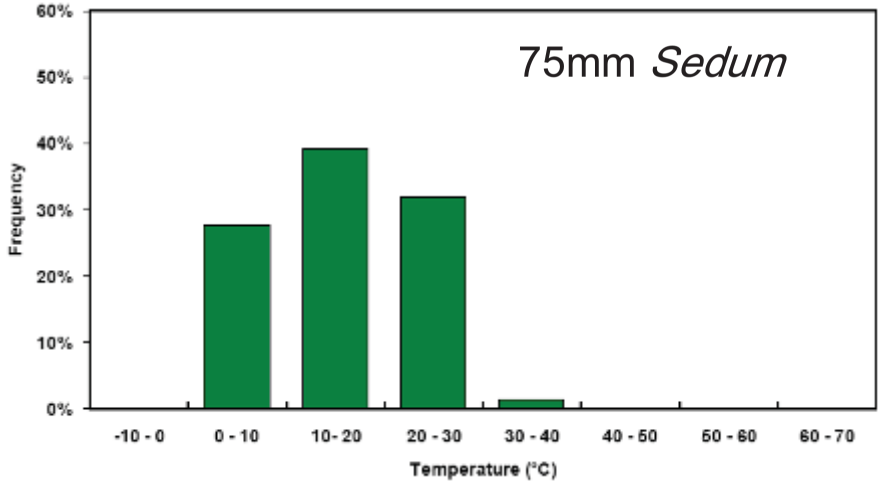
Private advantages of green roofs

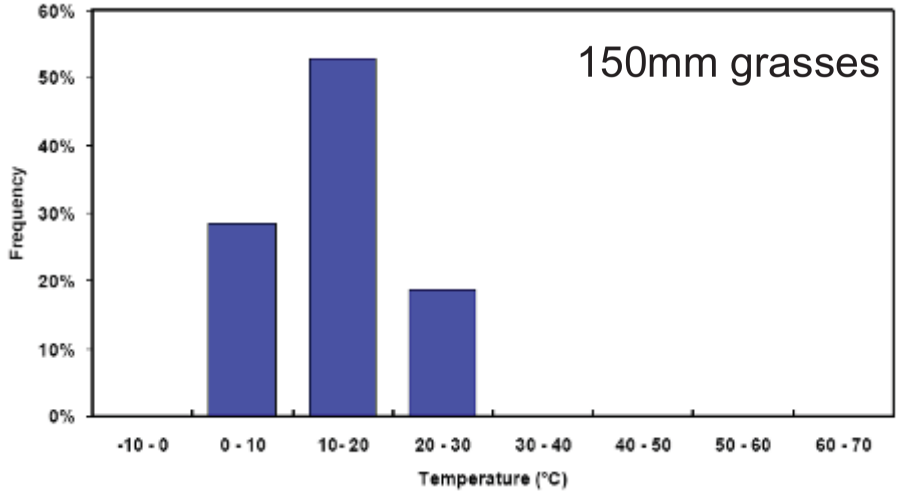
1. Enhanced longevity of roof water-proofing
   - Much lower temperature range under a green roof
     - Reduced expansion & contraction of water-proofing
     - Reduced out-gassing of roof volatiles
   - Protection from UV & mechanical damage (e.g. hail, walking)
   - A green roof is thought to at least double the longevity of roof water-proofing membranes
     - Guarantee of water-proofing is not extended
     - Will get similar benefits from an inverted warm-deck roof (where the insulation is on the outside)

Roof temperature fluctuations







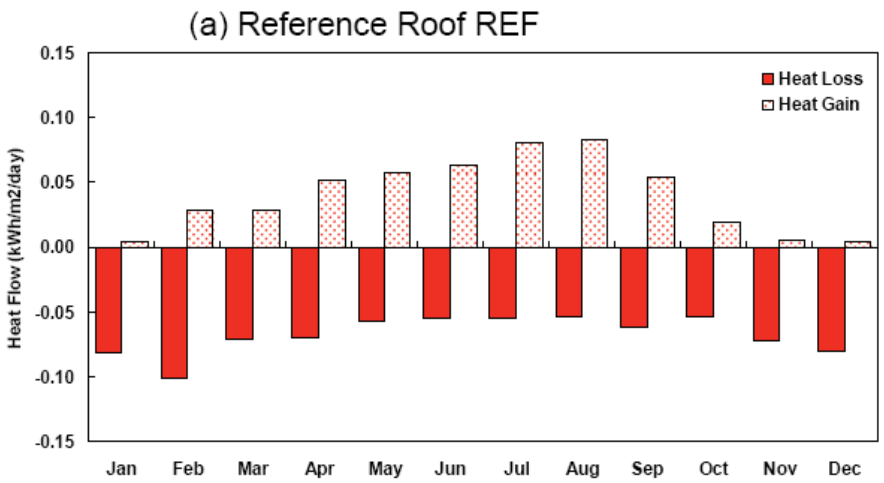


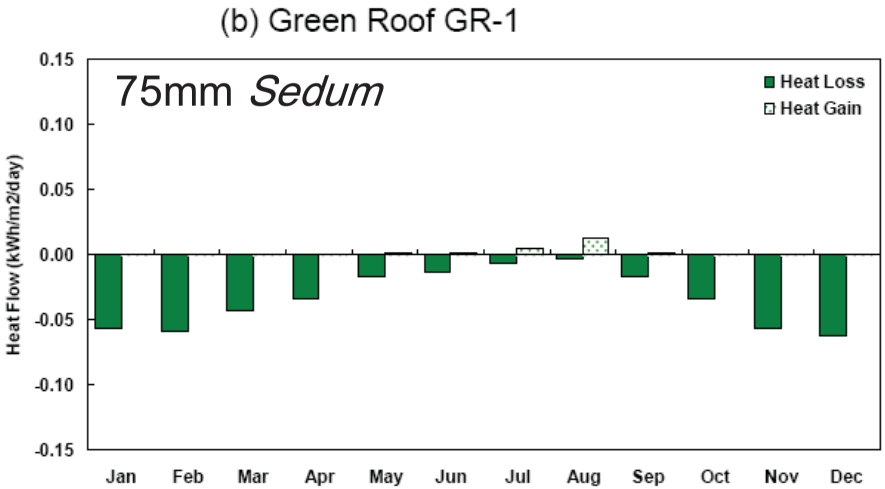
Connelly *et al.* (2006)

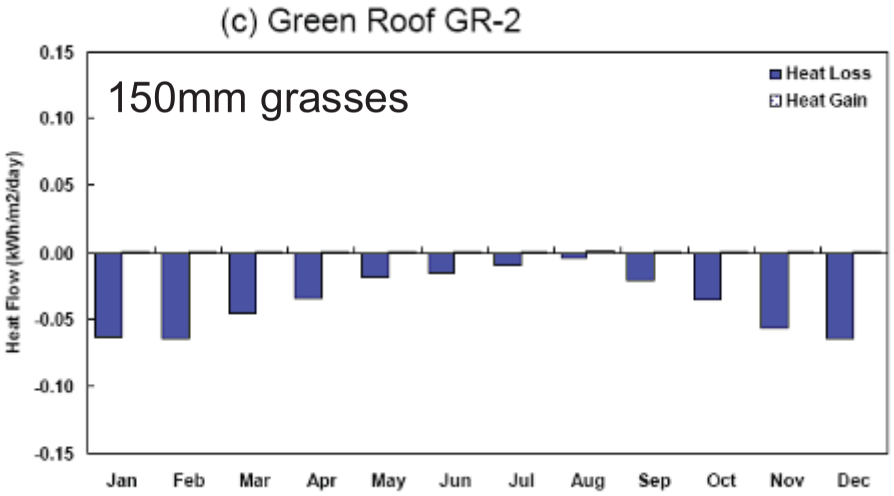
Private advantages of green roofs

1. Building insulation
   - Potential to keep buildings cool in summer & warm in winter
   - Function of amount & type of vegetation, substrate thickness & type, and substrate wetness → cannot subscribe simple R-values (or U)
   - Impact on well-insulated roofs is low
2. Improved environmental image (Ford, Barclays & GAP)
3. If roof accessible → improved psychological wellbeing of tenants/employees
4. Lower whole life costs compared to standard roofs
5. Hydrological
   - Reduction in necessary internal drainage capacity
   - Off-set below ground water storage costs?

Green roof insulation







Connelly *et al.* (2006)

Cost of green roofs

- Prices relatively over-inflated in the UK compared to Germany
  - Small economies of scale
  - Contractors unfamiliar with green roof installation, tend to err on the expensive side
  - Should fall as they become more mainstream
- Prices vary according to height, size of roof & if new build or retrofit

	Conventional (£/m^2)	Shingle (£/m^2)	Paved (£/m^2)	Self build (£/m^2)	Biodiverse (£/m^2)	Sedum blanket (£/m^2)	Sedum plug (£/m^2)
Warm roof	55	70	75	95	105	120	125
Extra expense (£)		+15	+20	+40	+50	+65	+70
Percentage increase		27	35	73	91	118	127

From Bamfield & Fox-Davies

Cost of green roofs

- Saleability & letability of buildings enhanced by green roofs → improved maintenance profile & user acceptability
- Reduction in the proportion of void periods
- Whole Life Cost of green roofs generally lower than 'standard roofs'
  - Carter & Keeler (2008) Journal of Environmental Management 87: 350-363
  - Wong et al. 2003 Building & Environment 38: 499-509
  - Clark et al. 2008 Environmental Sci. & Tech. 42: 2155-2161
- But… savings mainly based on the increased life expectancy of water-proofing membranes

Public advantages of green roofs

1. Urban cooling → combating the urban heat island effect (caution)
2. Habitat creation (caution)
3. Uptake of CO_2 → combating global warming
4. Lower release of CO_2 through reduced need for heating & cooling → combating global warming
5. Aesthetic value when roof over-looked
6. Removal of pollutants from rainfall (caution)
7. Removal of air pollutants

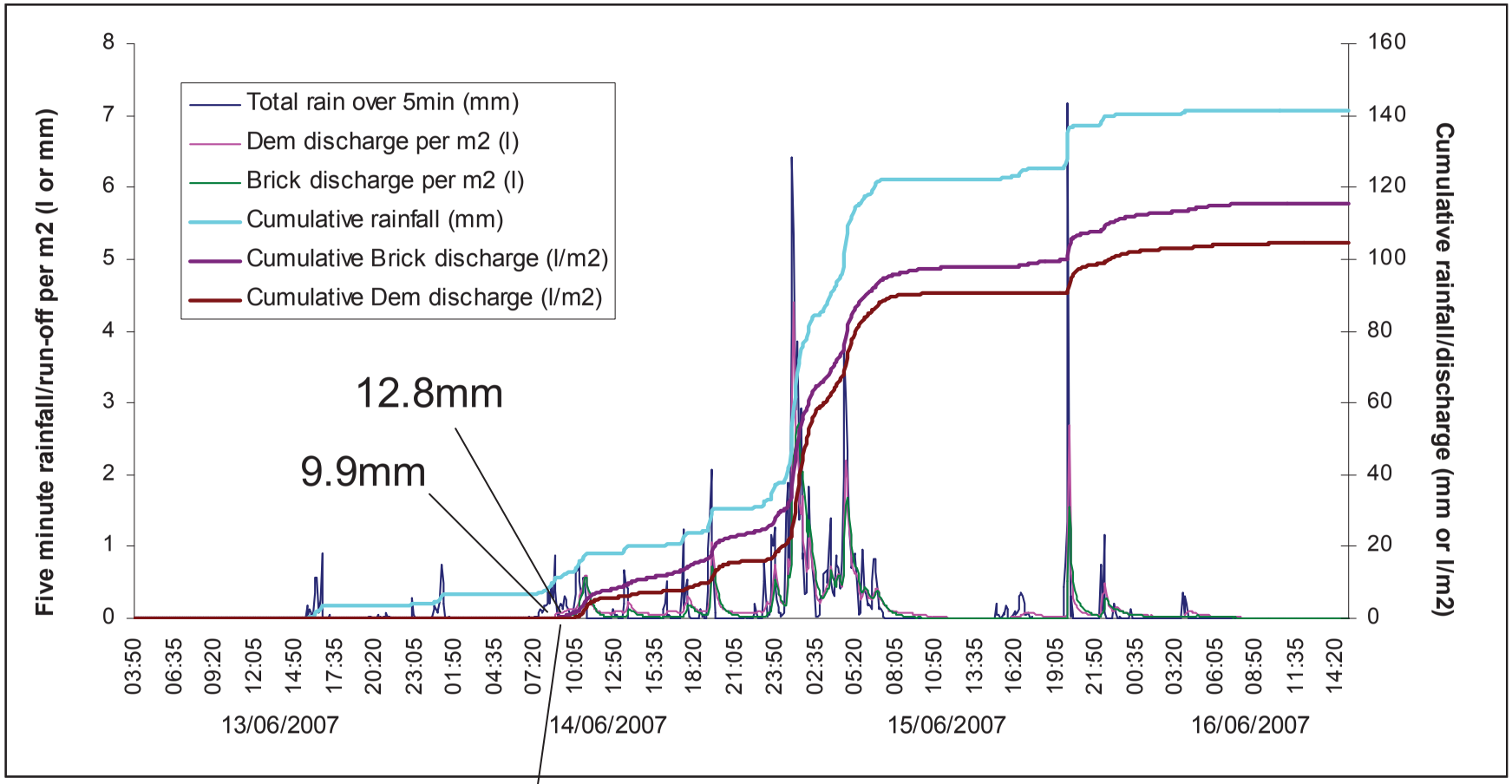
Public advantages of green roofs

- Green roofs associated with lots of small environmental benefits that are difficult to quantify holistically
- Comparative Life Cycle Assessment
  - Saiz et al. (2006) Environ. Sci. Tech. 40: 4312-4316
  - Kosareo & Ries (2007) Building & Environment 42: 2606-2613
- Main environmental gains are reduction in energy required to heat & cool buildings & increased life of membrane – counteract initial greater use of resources & energy associated with the green roof construction
- This could be that these are the best understood benefits of green roofs & the most easily quantified (some of the other assumptions are potentially dubious)

Hydrological function of green roofs

- Green roofs reduce roof run-off by:
    1. Delaying the initial time of run-off due to water absorption
    2. Reducing the total run-off by retaining part of the rainfall (amount retained a function of depth and water-filled porosity)
    3. Distributing the run-off over a longer time period due to temporary storage
- Capacity to retain rainfall is recharged by evapotranspiration from the green roof

Hydrological function of green roofs



Similar to a thin (~5cm deep) standard green roof

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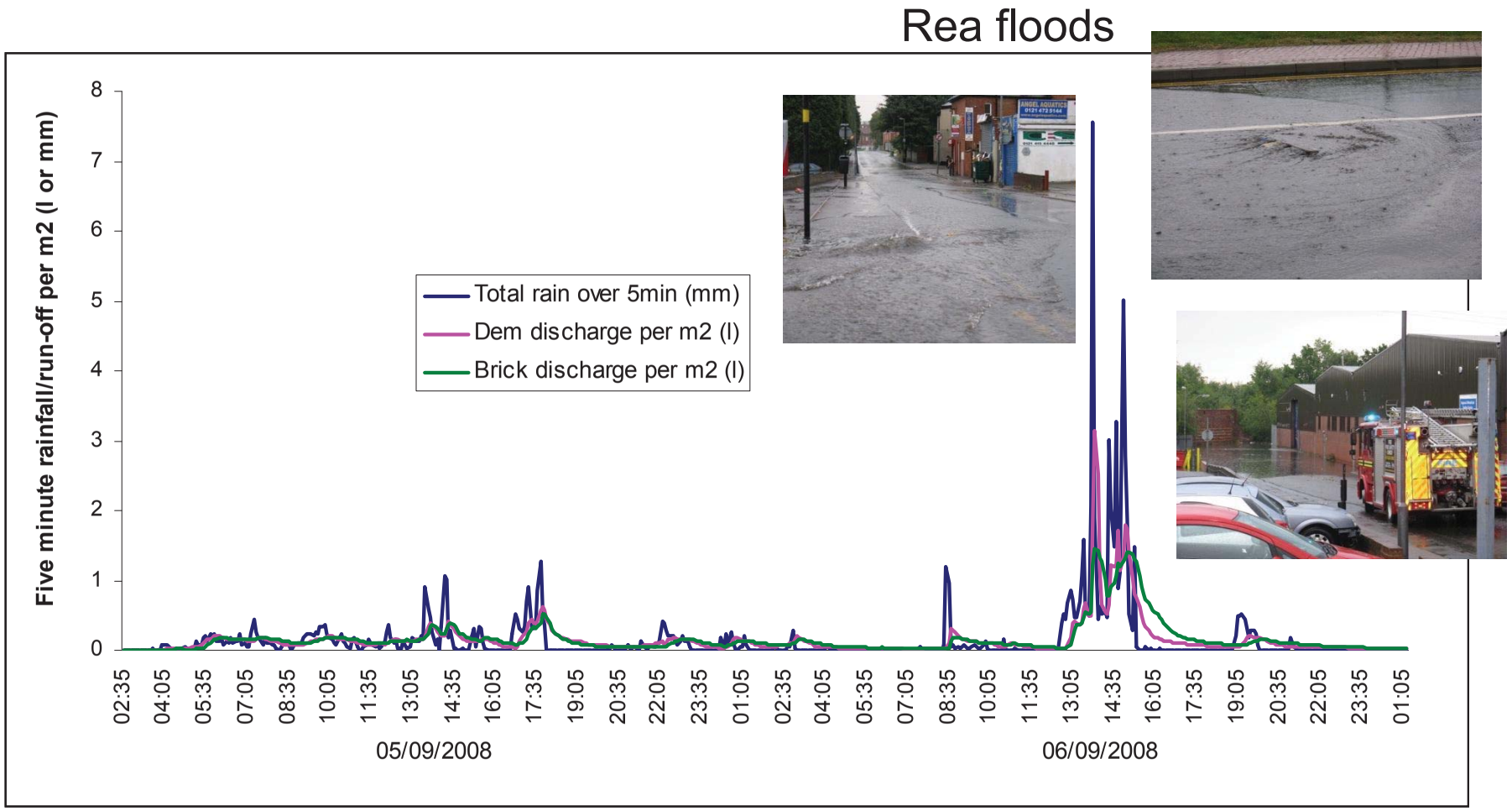
Sixth Framework Programme (2002-2006)

Hydrological function of green roofs



Hydrological function of green roofs

Rea floods

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Sixth Framework Programme (2002-2006)

Typical existing literature

- E.g. Mentens et al. 2006. Landscape & Urban Planning 77: 217-226
- Meta-analysis of existing literature from Germany
  - Run-off mainly a function of roof depth
  - No effect of roof age, slope angle & length
  - Average run-off 80% of winter rainfall, 52% of summer rainfall
- Assumed 10% of all the buildings in Brussels had 10cm deep green roof → 2.7% reduction in total run-off, 3.5% in the city centre

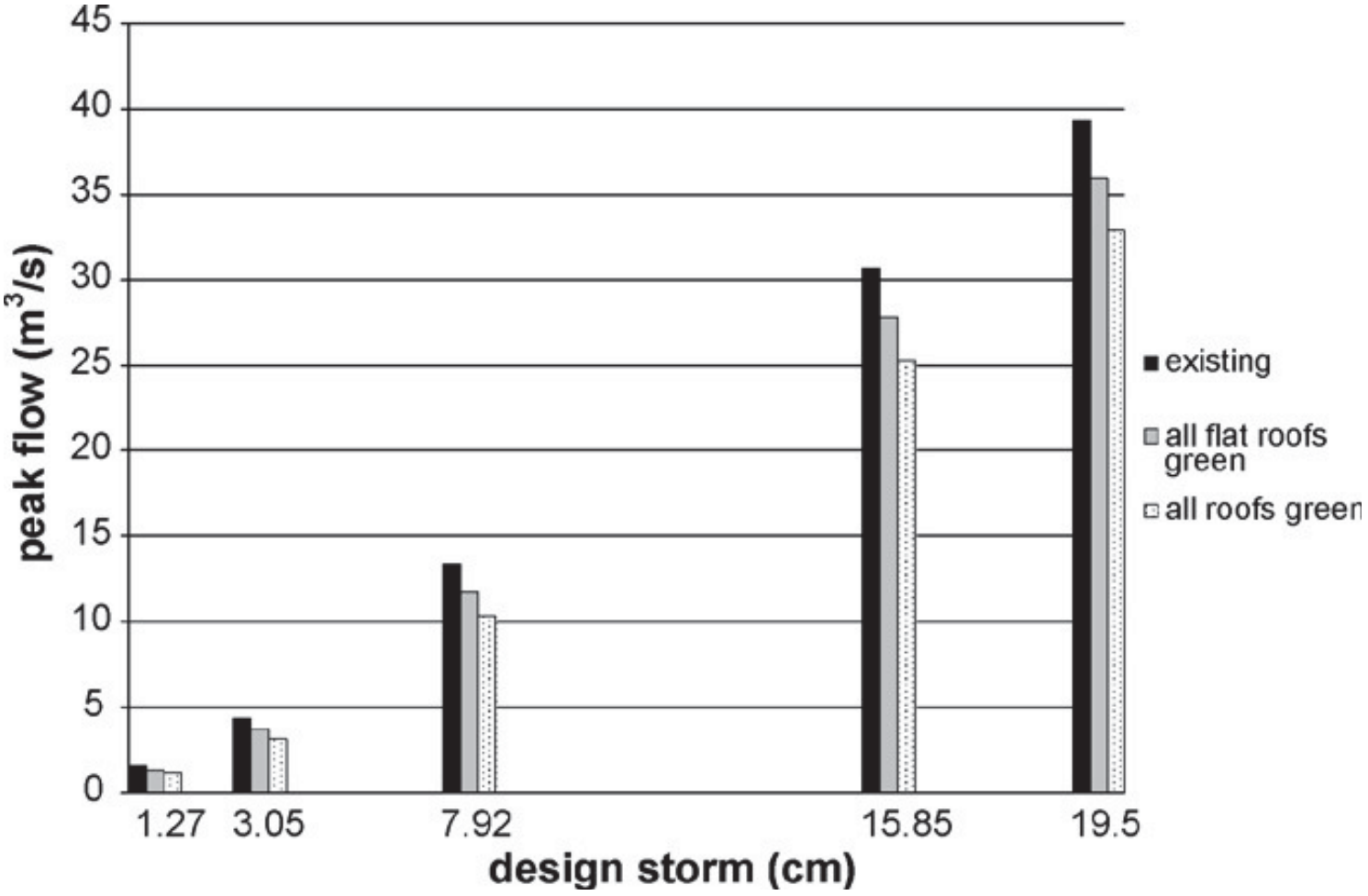
Stormwater management plans

- E.g. Carter & Jackson (2007) Landscape & Urban Planning 80: 84-94
- Tanyard Branch, Athens, Georgia: 56% impervious, 16% roof, 8% flat roof
- 7.6cm deep, expanded slate, *Sedum* roof → 4.5cm max. water holding capacity
- Used Soil Conservation Service curve no. method & StormNet Builder
- Explored different scenarios
  - Existing land cover, all roofs greened, all flat roofs greened
  - Modelled several storm events
- Greatest impact on city centre areas (flat roofs -39.9% to -4%)

Rainfall (24h)	1.27cm			3.05cm			7.92cm (1 year 24h)		
Scenario	Existing	All green	All flat green	Existing	All green	All flat green	Existing	All green	All flat green
Run-off volume & reduction	4810m^3	-36.8%	-18.9%	31940m^3	-16.9%	-8.3%	134210m^3	-7.6%	-3.6%
Rainfall (24h)	15.85cm (25 year 24h)			19.51cm (100 year 24h)					
Scenario	Existing	All green	All flat green	Existing	All green	All flat green			
Run-off volume & reduction	315900m^3	-4.1%	-1.9	401260m^3	-3.4%	-1.6%			

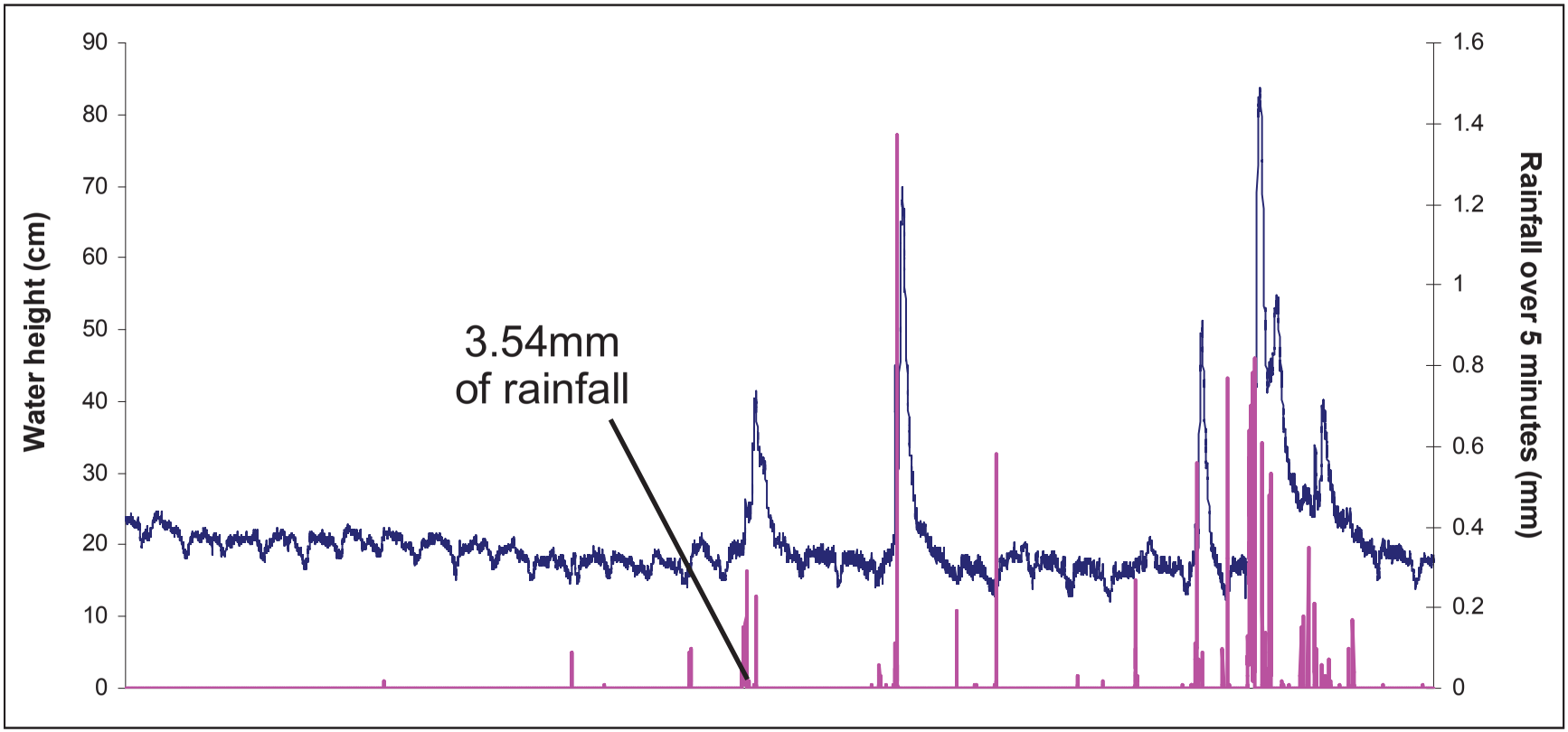
- 60% of storm events <1.27cm, 85% <3.05cm
- Drainage infrastructure mainly designed for 25 year event → % reductions in pipe diameter not large enough to drop down a size, so no potential savings

Stormwater management plans



Carter & Jackson (2007)

River Tame (10/2/08 – 14/3/08)



Birmingham

Birmingham

Summary

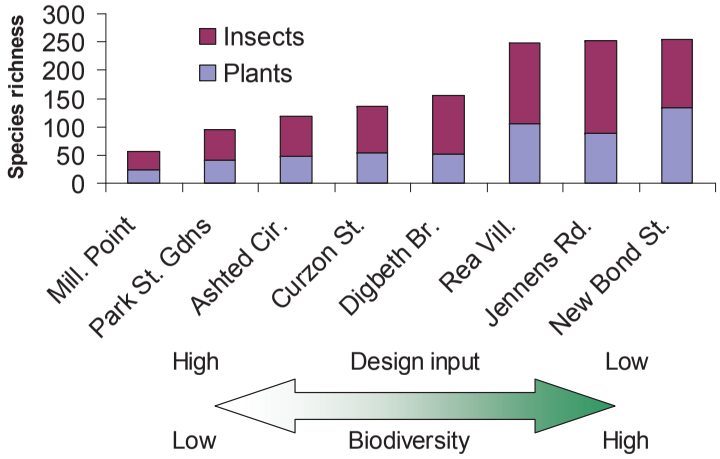
- Potential to move urban streams towards a more natural disturbance regime by reducing the magnitude of small disturbance events
- Effect on large storms is smaller, but can reduce the peak discharge significantly
- In heavily developed areas could be the only SUDS option → areas where green roofs have most potential to prevent localised flooding
- Cannot rely on green roofs alone, but considerable potential for use within an integrated system
- Possibility of using intensive green roofs on small sections of buildings & re-directing drainage from other sub-roofs onto it → much larger SUDS potential

Trade-offs associated with different types of green roofs

- Green roof literature mainly
  - Not peer reviewed (conference proceedings, reports, manufacturers information)
  - Partial (e.g. paid for by green roof manufacturers, researchers charging consultancy fees, etc)
- Tendency to research the advantages of green roofs singly, following the main area of expertise of the authors
  - Lack of appreciation that maximising one environmental benefit will usually trade-off against other environmental benefits
  - Most research on *Sedum* green roofs
- Green roofs therefore often seen as an environmental panacea

Why brown roofs?

- By ‘brown’ roof I mean a roof designed for biodiversity that emulates brownfield sites in an early stage of succession
- Why brown roofs?
  - Often developments on brownfield sites → more ecologically sustainable like for like replacement
  - In an urban context brownfields are associated with the highest no. of rare species & the highest diversity



Donovan *et al.* (2005)

Trade-offs associated with brown roofs

- Recycled aggregate used has low water holding capacity → reduces ability to retain storm-water
- Materials are heavy & variable (sometimes difficult to bolt onto design at late stage or retro-fit)
- They may take several seasons to develop
- Aesthetics are unpredictable, seasonably variable & not to everyone's liking

Photographs Stephan Brenneisen

Why *Sedum* mat?

- Wide range of heavily researched *Sedum* mat products already available
- Highly drought tolerant
- Aesthetics predictable & fairly consistent seasonally
- Almost instant results
- Very light-weight
- Substrates used can absorb a lot of water

Greengrid (Trelleborg) *Sedum* units with *Sedum acre* in flower

Trade-offs associated with *Sedum* mat roofs

- Slow release fertiliser used in many products → can lead to organic pollution
- Designed growth substrates & the *Sedum* mat are expensive & often associated with high energy and nutrient inputs
- Bizarre habitats with low structural diversity → limited value for wildlife
  - Although their value can be increased by the addition of other plants (e.g. chives, maiden pink) & tends to increase over time as weedy species colonise
- Monoculture type aesthetics not to everyone's liking

Summary & Conclusions

- Green roof technology is advanced & problem free
- The capital cost of green roofs can be justified in the long term both privately & publicly due to a range of environmental gains
- They have considerable potential for use in SUDS, but will not provide a stand-alone solution
- The scientific understanding of the benefits of green roofs varies by subject & there are usually environmental trade-offs associated with different green roof types

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SWITCH

Sixth Framework Programme (2002-2006)