NOVATECH 2010

Design, modelling and implementation of stormwater source control technologies

A workshop of the International Working Group on Source Control and Stormwater Management

(IWA/IAHR Joint Committee on Urban Drainage)

Workshop Organisers: Sylvie Barraud[1], Gilles Rivard[2] & Tim Fletcher[3]
([1]Lyon 1 University /INSA Lyon, France, [2]Aquapraxis, Canada & [3]Monash University, Austalia)

Sunday June 27th, 2010

Acknowledgement: Thanks to the team of GRAIE (Elodie Brelot, Lucie Dupouy, Ophélie Chassard and Christiane Alonso for their assistance in coordinating and preparation of workshop materials

Design, modelling and implementation of stormwater source control technologies

Conception, modélisation et retours d'expérience dans le domaine de la gestion des eaux pluviales à la source

Workshop short presentation:
The aim of the workshop was to examine aspects relating to the design and implementation of stormwater source control technologies. The workshop, following the previous SOCOMA workshop held in Lyon in 2007 (see http://graie.org/SOCOMA), has been specifically focussed on the modelling and performance evaluation of source control techniques. It has also evaluated the lessons of implementation, based on a number of important case studies. Each of these themes has included a general presentation of the current state of the art in terms of understanding, research, before exploring particular aspects in detail, through interactive presentations and discussions.
The workshop will result in publication of review articles, summarising the current state of the art in the modelling, performance evaluation and implementation of source control strategies.

Présentation du Workshop :
L'objectif du workshop a été d'aborder différents aspects concourant à la conception, la mise en œuvre de stratégies de contrôle à la source en matière de gestion des eaux pluviales.
Ce workshop qui fait suite à celui de 2007 qui s'est tenu à Lyon (http://graie.org/SOCOMA) a été plus particulièrement consacré à la modélisation de ces systèmes et leur utilisation en terme opérationnel (pour planifier, concevoir et gérer), à l'analyse de performance et aux retours d'expérience tant en terme technique, environnemental, socio-économique qu'en terme de gouvernance.
Ces différents thèmes ont fait l'objet d'une présentation générale permettant de faire un point sur les connaissances, les recherches et les savoir faire existants sur le thème, suivie de plusieurs focus sur des aspects particuliers du thème.
Ce workshop s'est donné pour objectif de servir de support à la rédaction d'articles de synthèse internationale sur la conception, la modélisation et les problèmes d'implantation de gestion des eaux pluviales à la source.

WORKSHOP TIMETABLE

Time slot	Workshop Activity / Topic	Presenters
9:00 am - 9:10 am	Introduction to workshop	**G. Rivard,** Chairman of SOCOMA work group, Canada
Modelling		
9:10 am - 9:20 am	***General literature overview on modelling followed by a focus on :***	*Coordinator:* ***S. Barraud****
9:20 am -10:00 am	Modelling urban stormwater impact mitigation by using BMPs at the catchment scale - Implementation of Source Control systems in Italy	**G. Freni & G. Mannina**, Palermo University, Italy
10:00 am - 10:40 am	Opportunities and drawbacks of simulating infiltration processes	**S. Fach,** Innsbruck University, Austria
10:40 am - 11:00 am	*Coffee break*	
Source control performance		
11:00 am - 11:10 am	***General literature overview followed by a focus on :***	*Coordinator:**T. Fletcher****
11:10 am-11:50 am	"Green" technologies and infrastructures for the control and treatment of impervious surface runoff	**B. Ellis**, Urban Pollution Research Centre, Middlesex University, UK
11:50 am-12:30 am	Elements in favour of source control: The experience of the French on-site observatory OTHU	**S. Barraud**, Lyon 1 University / INSA Lyon & **A. Foulquier**, Lyon 1 University, France
12:30 pm - 2 :00 pm	*Lunch*	
Implementation and adoption: success, failure and lessons learnt		
2:00pm - 2:10pm	***Introduction followed by focus on :***	*Coordinator:* ***G. Rivard****
2 00 pm - 2:40 pm	Lessons from a catchment-scale public & private-land retrofit project	**T. Fletcher & M. Burns,** Monash University, Australia
2:40 pm - 3:20 pm	Lessons from the Shepherd Creek experiment.	**B. Shuster,** National Risk Management Research Laboratory, Office of Research and Development, USEPA, USA
3:20 pm - 3:40 pm	*Coffee break*	
3:40 pm - 4:00 pm	Some lessons learnt about Source Control strategies in France	**C. Carré** - Paris 1 University, France
4:00 pm – 4:40 pm	Lessons learnt and experiences about Source Control strategies in Brasil	**N. Nascimento** – UFMG, Brazil
4:40 pm - 5:00 pm	**Discussion**	

* With the help of SOCOMA Work Group

INTRODUCTION TO WORKSHOP

G. Rivard

Chairman of SOCOMA work group,
Aquapraxis, Canada

NOVATECH 2010

Design, modelling and implementation of stormwater source control technologies

Gilles Rivard, Sylvie Barraud & Tim Fletcher

Overview

1. Background to SOCOMA
2. Workshop objectives
   - Modelling
   - Performance
   - Implementation and lessons learnt
3. Forum and discussion

Planned outputs

1. Ongoing development of SOCOMA website (www.graie.org/SOCOMA):

2. A number of publications synthesizing current state of the art

Programme (morning)

Time slot	Workshop Activity / Topic	Presenters
9.00 am – 9.10 am	Introduction to workshop	**G. Rivard,** Chairman of SOCOMA work group,
Modelling		
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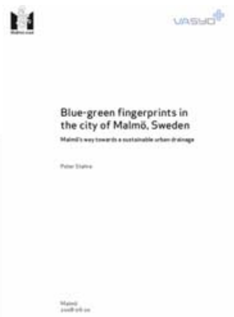
	Lunch	

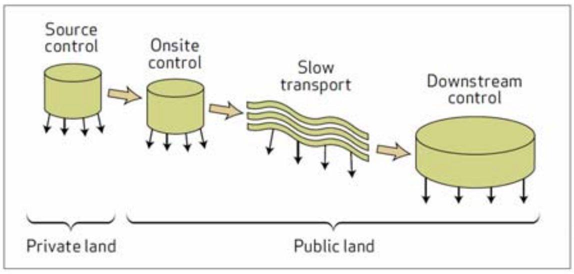
Programme (afternoon)

Time slot	Workshop Activity / Topic	Presenters
Implementation and adoption: success, failure and lessons learnt		
2 00 pm – 2 10 pm	***Introduction followed by focus on :***	*Coordinator:* ***G. Rivard****
2 10 pm – 2 40 pm	Lessons from a catchment-scale public & private-land retrofit project	**T. Fletcher & M. Burns** Monash University, Australia
2:40 pm - 3:20 pm	Lessons from the Shepherd Creek experiment.	**B. Shuster,** National Risk Management Research Laboratory, Office of Research and Development,
3:20 pm - 3:40 pm	*Coffee break*	
3:40 pm - 4:00 pm	Some lessons learnt about Source Control strategies in	**C. Carré** - Paris 1 University, France
4:00 pm - 4:40 pm	Lessons learnt and experiences about Source Control strategies in Brasil	**N. Nascimento** – UFMG, Brazil
4:40 pm - 5:00 pm	**Discussion**	

Source Control in Context



Part of aTreatment train system



Specific potential for hydrological restoration

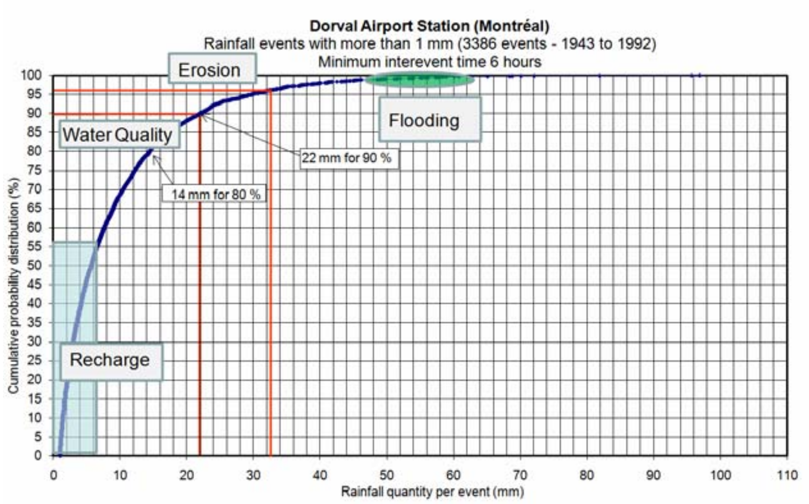
Runoff Volume Reduction

Preservation – flow regimes

Water quality

Water cycle

Source Control in Context



Source Control in Context

	Characteristic of source-control technologies	Ref./Rationale
Advantages	- Easier implementation: smaller volumes are often technically easier to manage (for example, groundwater mounding with infiltration is less probable) - Greater private investment: cost of management system relying on source-control will be in part supported by private sector. Techniques at the parcel scale do not involve any land opportunity cost. - Greater direct private benefits (e.g. reuse of water) - Potential microclimate benefits (reduce heat island effect)	- Typical design of small systems in local guidelines (e.g. Melbourne Water) - (Environmental Services Division, 2009) - (Brown, 2010) - (Endreny, 2008)
Drawbacks	- Limited volume treated (integration to landscape can be restrictive in dense urban context): effects of peak flows (floodings, erosion) are thus hardly mitigated - Complexity of negotiation: implementation on private parcels is subject to public commitment; drivers for a large scale implementation may be complex. - Few economies of scale (for construction and potentially for maintenance): larger systems generally show a lower cost per unit volume treated. - Uncertain maintenance regimes (in private properties)	- (Burns, et al., 2010b) - (Fletcher, et al., 2010a) - (Environmental Services Division, 2009) (Wossink & Hunt, 2005) - (Environmental Services Division, 2009, Chap.7)

Fletcher & Hamel

General literature overview

INTRODUCTION - MODELLING IN THE FIELD OF SOURCE CONTROL

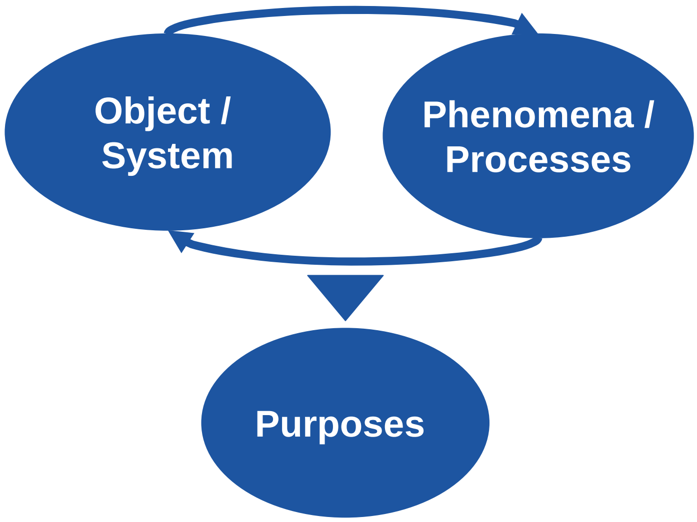
S. Barraud

Lyon 1 University / INSA lyon, France

Introduction
Modelling in the field of source control

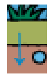
Sylvie Barraud

Modelling

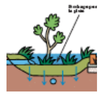


Object / System (Spatial scale)

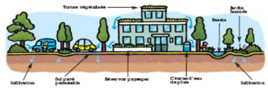
- At the scale of a portion
  (1 part of a technique)



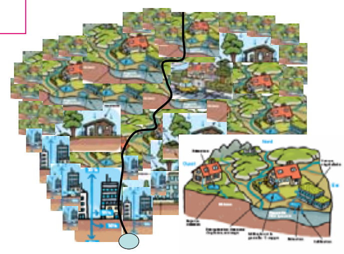
- At the local scale
  (1 technique)



- At the semi local scale
  (a set of connected techniques / quarter)



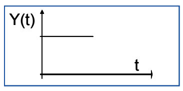
- At the catchment scale



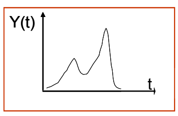
Phenomum / Process (temp. scale)

- Quantity
  (hydraulic / hydrologic)
- Quality (pollution)
  - Efficiency
  - Impact on environment
- Socio-economic

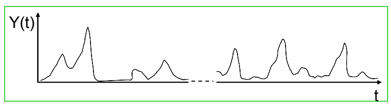
- Instantaneous / Constant



- Event based / Intra-event based



- Long term

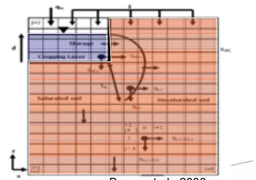


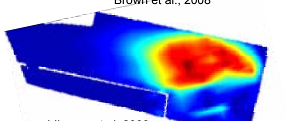
Purpose

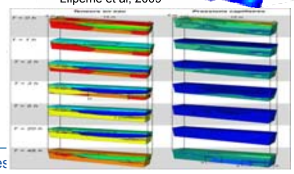
- Process-understanding   input → ? → output

e.g. 2D /3D modelling

- of a trench
- of a retention system (settling)
- water transfer during infiltration
- ….


Brown et al., 2008


Llipeme et al, 2009


Goutaland et al, 2008

Purposes

- Process-understanding   input → ? → output
- Prediction   input → Model → ?

Quantity

(run-off formation / hydr. Efficiency / impact on receiving waters)

Pollution (generation / treatment / impact)

e.g.

- PULS model
- Run-off coefficient per type of structure / area

…

- Hydraulic eff. Series of mixed waterbodies /
- First order kinetic (K-C*) decay algorithm

…

Canoe

Mouse

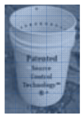
SWMM

MUSIC

Storm.BMP / Storm.xxl

…

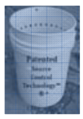
Purposes



- Process-understanding — input → ? → out
- Prediction — input → Model → ?
- Decision — ? → Model → output

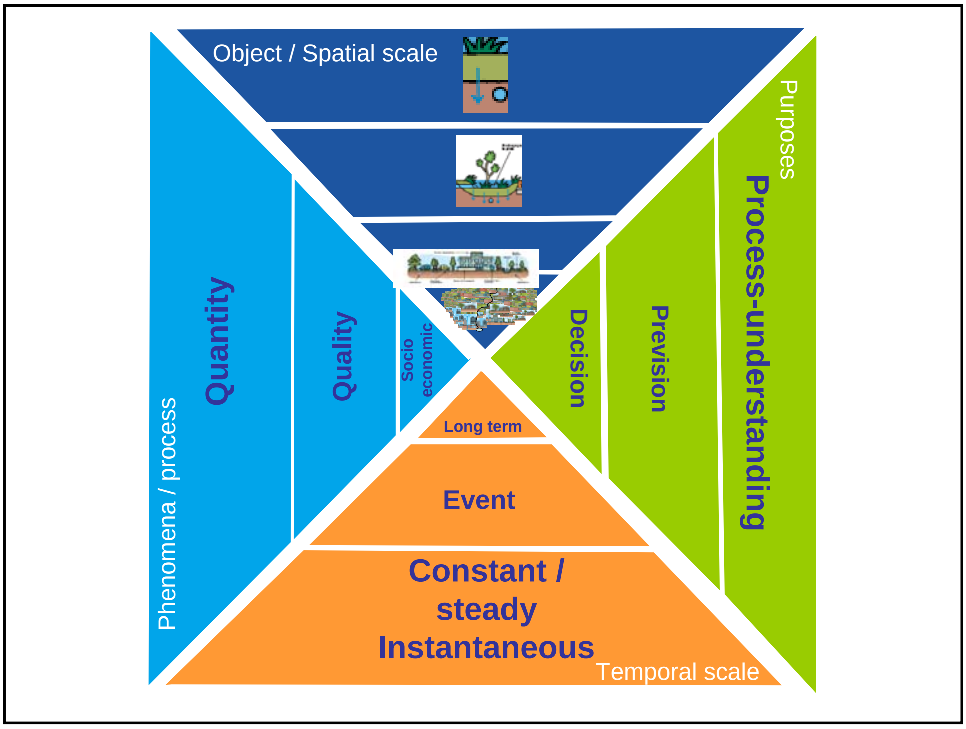
Optimisation Model	▶	Optimal location
Life cost analysis	▶	Model UKWIR / WERF …
Multicriteria analysis …	▶	SWARD, DAYWATER ECOPLUIES AvDren…

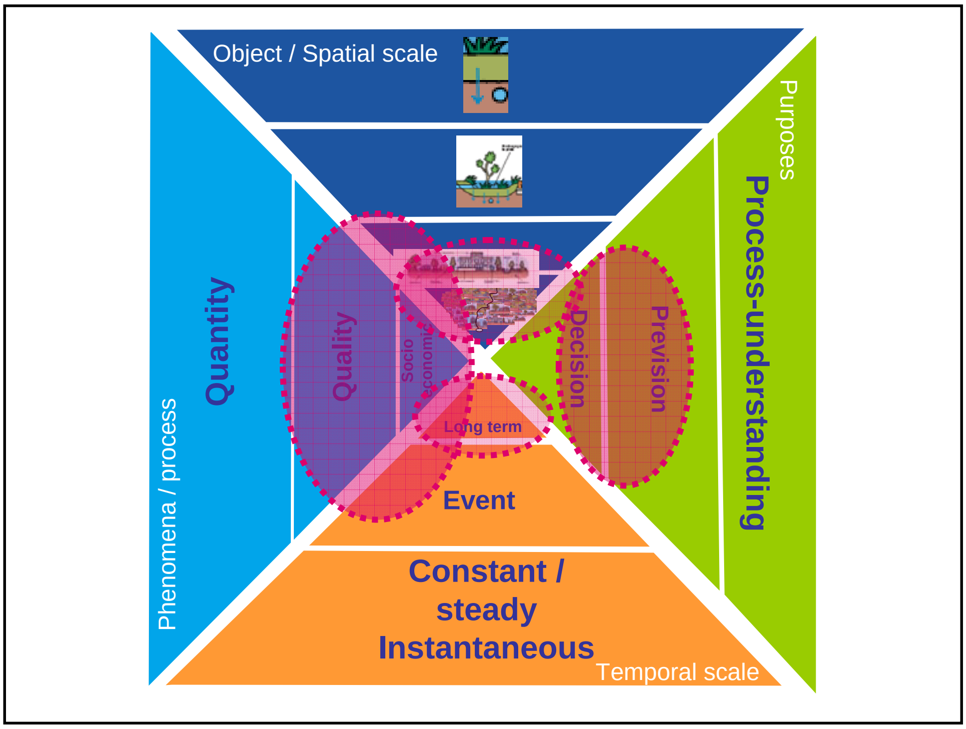
Purposes



- Process-understanding — in → ? → out
- Prediction — in → Model → ?
- Decision — ? → Model → out

- Design
- Diagnostic / Simulation
- Urban planning
- Maintenance
- …


Object / Spatial scale
Purposes
Process-understanding
Prevision
Decision
Quantity
Quality
Socio economic
Phenomena / process
Long term
Event
Constant / steady
Instantaneous
Temporal scale


Object / Spatial scale
Purposes
Process-understanding
Prevision
Decision
Quantity
Quality
Socio economic
Phenomena / process
Long term
Event
Constant / steady
Instantaneous
Temporal scale

MODELLING URBAN STORMWATER IMPACT MITIGATION BY USING BMPS AT THE CATCHMENT SCALE

IMPLEMENTATION OF SOURCE CONTROL SYSTEMS IN ITALY

G. FRENI & G. Mannina

Palermo University, Italy

Modelling

Modelling urban stormwater impact mitigation by using BMPs at the catchment scale. Implementation of Source Control systems in Italy

Gabriele Freni[1], Giorgio Mannina[2]

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ABSTRACT

The continuous growth of urban areas and the increasing public awareness about environmental impact of stormwater raised high interest on quality impact on the receiving water quality. Indeed, in the last decades, large efforts have been provided for improving urban drainage systems in order to mitigate environmental impacts. In the last years the limitation linked to the traditional urban drainage scheme were pointed out and new approaches are developing introducing more natural methods for retaining and/or disposing of stormwater (Emerson et al. 2005; Bledsoe 2002; Niemczynowicz 1994). These mitigation measure are generally called Best Management Practices (BMP) or Sustainable Urban Drainage System or Low Impact Developments and they include practices such as infiltration and storage tanks in order to reduce the peak flow, increasing the time it takes to reach the receiving water system and retaining at least part of the polluting components. The selection of the best mitigation measure for a specific site is still a controversial topic and several factors should be taken into account. The integration of such mitigation measures in an integrated urban drainage model can provide an interesting tool for comparing different mitigation solution at catchment scale and for selecting the best technique.

In the present study, a comprehensive BMP modelling approach will be presented in order to allow one to evaluate the mitigation efficiency of different BMP schemes including infiltration and storage facilities. The comprehensive BMP modelling approach consists in two main sub-modules: the urban drainage model and the BMP model. The former enables one to assess the hydrograph and the pollutograph at the BMP inlet, on the other hand, the latter models the BMP evaluating the main processes that control the BMP outflow (in terms of both quantity and quality aspects). The urban drainage model is based on a conceptual simplified model developed during previous studies (Mannina and Viviani, 2010) and reproduces the physical phenomena that take place both in the catchments and in the sewers, allowing to determine the hydrograph and pollutograph in the sewer. For the assessment of the latter, particular care is taken about sediment transformation in sewers, considering their cohesive-like behaviour caused by organic substances and by physical-chemical changes during the sewer sediment transport. The catchment urban drainage system is modelled coupling two reservoirs in series and the phenomena that take place during both dry and wet period are developed. Indeed water quality of storm water runoff varies widely depending on the surface use and pollution dry weather. For this reason,

particular care was addressed towards the antecedent dry weather period responsible of the pollution of storm water and the first flush phenomena. Regarding the BMP model, a conceptual model taking particular care in simulating clogging phenomena that take part during their life cycle reducing mitigation efficiency was employed (Freni et al., 2009). The model introduces the concept of an “effective area” as the horizontal area below the trench bottom where the infiltration paths become linear and parallel, so the phenomenon can be considered one-dimensional. According to this definition, it is possible to use a one-dimensional model in order to estimate the infiltration flow rate (Freni et al., 2009). This assumption has the drawback of neglecting the infiltration process around the BMP structure and assuming equilibrium between the stored water volume in the structure and the infiltrated volume in the soil where the flow paths are vertical. The model simulates the hydraulics of an infiltration structure that is supposed to operate as a nonlinear reservoir, equipped with a weir that simulates the overflows to the drainage system or the catchment surface when the infiltration device reaches saturation. The infiltration flow is evaluated using the Green-Ampt equation.

In order to gain insight on the best technique, this study compares different distributed and centralized urban stormwater management techniques, including infiltration and storage facilities. A long-term simulation is employed to account for the effects of sediments in BMPs, which generally reduce the hydraulic capacity. The results allow us to draw some conclusions on the peculiarities of BMP techniques, on the possibility of integrating different techniques for improving efficiency and on BMP maintenance planning.

A specific survey was carried out to characterize the soils’ infiltration capacities. Using the results from the case study, some general conclusions can be drawn:

- centralized techniques are more robust and can be effective also with small specific design volumes;
- BMPs based on stormwater infiltration process can be effective if the soil infiltration capacity allows their use, but their efficiency can be reduced by clogging (in the presented case study, small infiltration structures were 40% clogged after only 6 years of service);
- mixed configurations, involving both source controls and centralized techniques are, in some cases, more efficient than centralized controls (maintaining the same design specific volume) by avoiding frequent sewer flushing during wet periods and protecting receiving waters from frequent CSO spills.

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NOVATECH 2010

Modelling urban stormwater impact mitigation by using BMPs at the catchment scale
Implementation of Source Control systems in Italy

G. Freni, G. Mannina

Best Management Practices

- These practices are aimed to limit the water volumes arriving to the sewer system, reducing the pollutant loads and peak discharges: the objectives can be matched by mean of storage and/or infiltration structures
- Storage devices provide volume for temporarily detain runoff and dispose of it to the drainage system after rainfall event
- Infiltration devices dispose of storm water runoff to the ground during and after the rainfall event. Only overflows are delivered to the drainage system
- Infiltration devices are subjected to clogging that progressively reduce their mitigation efficiency

Background and focus

Stormwater management offers a wide range of technical solutions (with pro and cons)

Common examples:

- Storage devices (large available experience, land needs, continuous maintenance)
- Infiltration devices (invert urbanization effect, clogging, environmental impact?)
- Filtering devices (work specifically on water quality, small experience on long term efficiency, expensive, climatic issues)

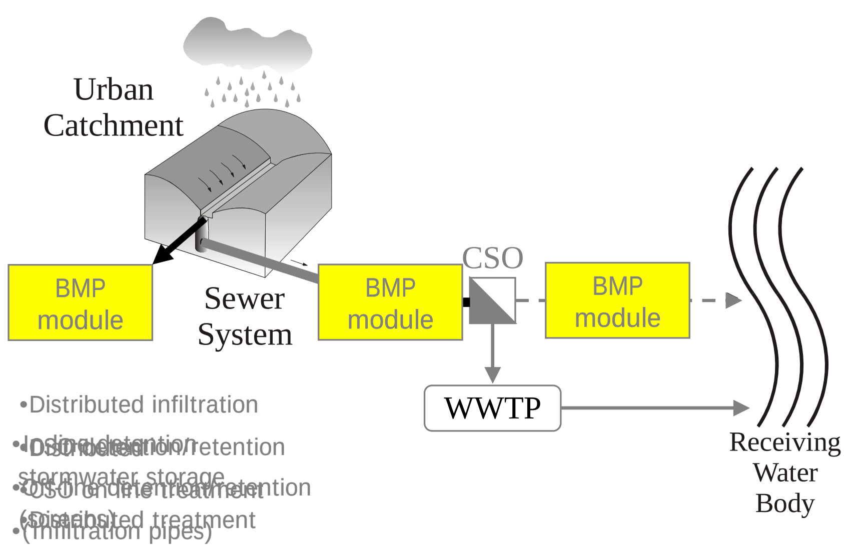
Objective of the present study

- Develop a simplified model in order to simulate infiltration devices both for single event and for long term analysis
- Implement clogging analysis in order to take into account long term efficiency reduction
- Compare infiltration and storage devices efficiency using long continuous rainfall series

Integrated BMP model

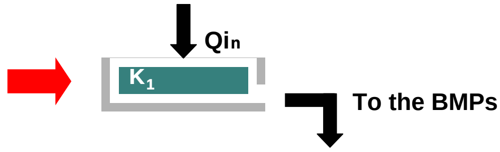
- ➢ Urban drainage model
- ➢ BMP model

Urban drainage model (Mannina, 2005)
+ Stormwater Management module



Flow and solids inputs to the BMP device

Flow propagation



Hydrograph

Linear reservoir model

Solids concentration:

- Build up
- Wash-off

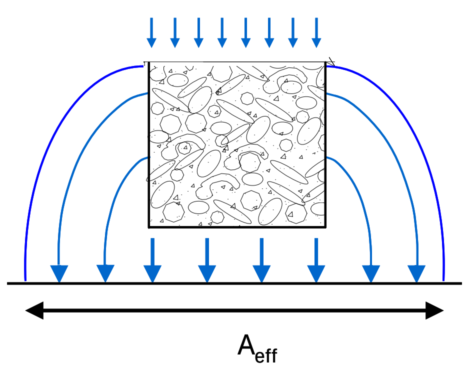
Catchment-system

Alley and Smith (1982)

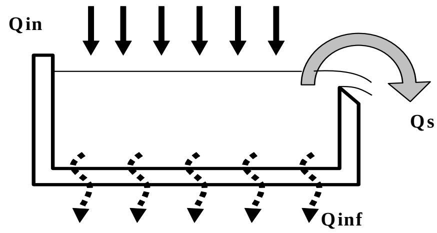
Pollutograph

Infiltration modelling hypotheses

- Vertical and 1-D infiltration paths at a certain distance below the infiltration structure bottom
- Uniform infiltration in the infiltration structure
- Clogging starting from the bottom and uniformly distributed in the structure



Infiltration Source Controls: model schematization



- The model simulates the hydraulics of an infiltration structure which is supposed to operate as a non-linear reservoir
- Dropped common simplifications:
  - Time/Initial conditions dependent infiltration rate
  - Clogging is simulated

Infiltration BMP model scheme

Model equations

Hydraulic module:

$$\begin{cases} Q_{in} - Q_{inf} - Q_s = \dfrac{dS}{dt} \\ Qs = \mu_s W h \sqrt{2gh} \end{cases}$$

$S = n\ B\ L\ h_w$

n: filler porosity

h_w: hydraulic height

B: trench width

L: trench length

W: weir lenght

h: hydraulic height above the weir

µ: weir coefficient

Quality module: $M_{in} - M_s = \dfrac{dC_i S}{dt}$

The infiltration model: infiltration process

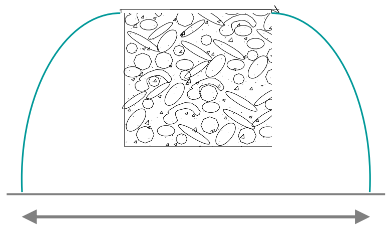
- Infiltration both from the bottom and from the sides
- 1D Green-Ampt equation
- Effective infiltration area depending on soil infiltration capacity

Initial and saturation water content

$$Q_{inf}\ max = K_s\left(1 - \frac{\psi(\vartheta_s - \vartheta_0)}{F}\right)\cdot A_{eff}$$

hydraulic conductivity

wetting front pressure head



Effective infiltration trench area

If $Q_{in} \leq Q_{inf}$ then $Q_{inf} = Q_{in}$

If $Q_{in} > Q_{inf}$ then $Q_{inf} = Q_{inf}max$

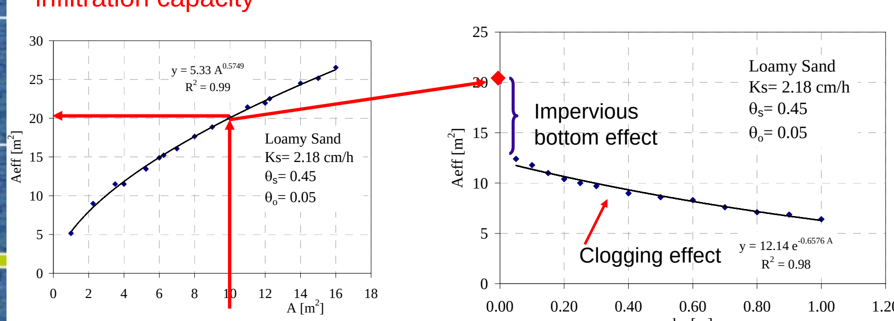
Clogging simulation:

$$\frac{dC_i W}{dt} = M_{Sed,in} - M_{Sed,out}$$

Evaluation of the effective infiltration area

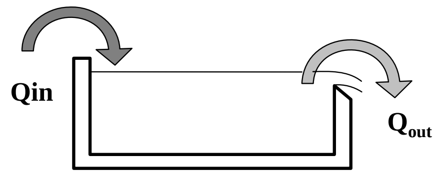
The effective infiltration area has been linked with the geometrical trench bottom area and with saturated soil infiltration capacity

The effective infiltration area has been linked with the clogging level



The proposed model: storage tank

- The captured volume is isolated from the system
- When the basin is full, runoff goes directly to the drainage system
- Cleaning process at the end of each event



$$\frac{dW}{dt} = Q_{in} - Q_{out}$$

Continuity equation

$$\frac{dC_i W}{dt} = M_{Sed,in} - M_{Sed,out}$$

Mass balances

Model Application: the case study

The experimental catchment **Parco d'Orleans – Palermo (I)**

Continuous simulation (1994 – 1999)

4 soil types

2 specific volumes

		TYPE OF SOIL				
	PARAMETER	Sandy-Loam	Loamy-Sand	Sand	Gravel	Unit
Soil characteristics	θ_s	0.45	0.43	0.44	0.55	-
	θ_0	0.05	0.04	0.02	0.01	-
	ψ	0.11	0.10	0.09	0.08	m
	k_s	2.18	6.12	23.41	36	cm/h

Model Application: rainfall data

Rainfall data are collected since 1993 with a tipping bucket raingauge and data logger at **maximum time resolution of 1 sec**.
Discharge data are collected since the same year with an **ultrasonic flow meter** installed at basin outlet
From this archive, a 6-years **continuous rainfall series have been extracted** and used for the simulations

	1994*	1995	1996	1997	1998	1999
Rainfall depth [mm]	285	552	655	602	634	582
N° Events (Vrain>2mm)	22	56	63	73	66	57
Average ADWP [days]	5.5	4.5	3.8	4.3	4.1	4.6
Average rainfall intensity [mm/h]	7.2	8.5	9.7	7.7	5.8	6.2
Maximum 5min rainfall intensity [mm/h]	37.8	42.2	57.8	36.5	40.2	42.8
Maximum 10min rainfall intensity [mm/h]	27.3	28.5	34.3	22.4	33.6	29.2
Maximum 15min rainfall intensity [mm/h]	22.1	23.2	25.6	19.8	22.7	24.2

** 6 months*

Reliability of the infiltration model

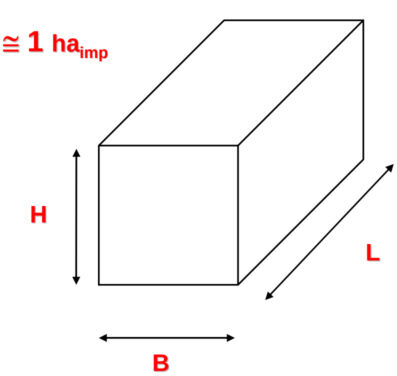
Reliability of the model was assessed by comparing its results with a physically based model calibrated on real infiltration test

Design criteria **20 m^3/ha_{imp}**

Filler void ratio **0.5**

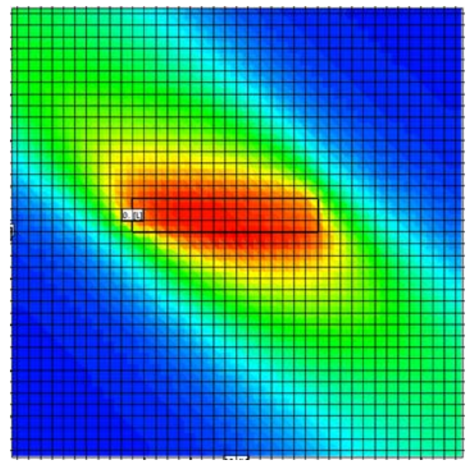
Connected catchment **≅ 1 ha_{imp}**

- **L = 5 m**
- **B = 2 m**
- **H = 2 m**

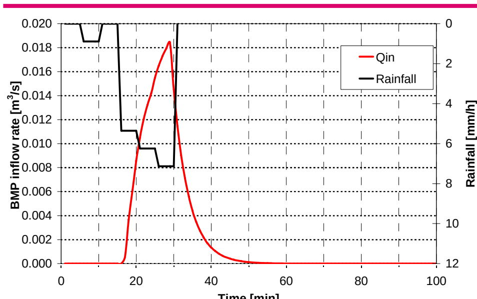


Physically based MODFLOW model

- Steady and non-steady flow
- Confined or unconfined layers
- anisotropic hydraulic conductivities
- 3D Richards Equations with finite volumes approach
- Input flow simulated as external stress



Infiltration model structure validation

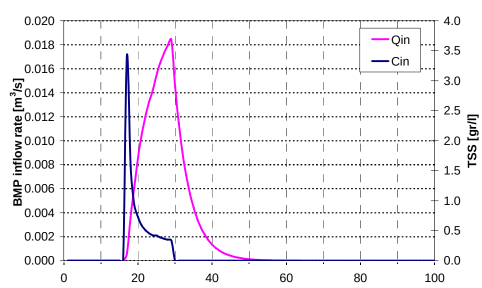


No 22 1994

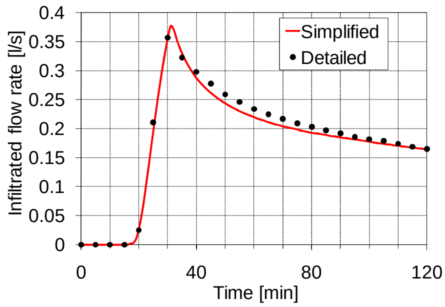
Rainfall Duration:
36 min

Rainfall Max Intensity:
7.7 mm/h

Rainfall average Intensity:
4.3 mm/h

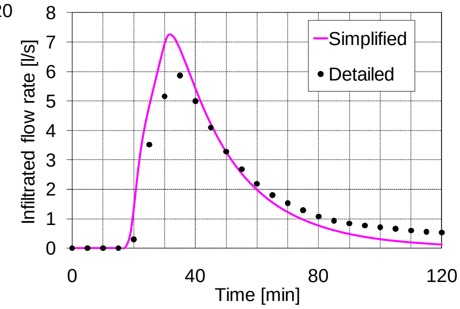


Infiltration model structure validation



Loamy-sand:

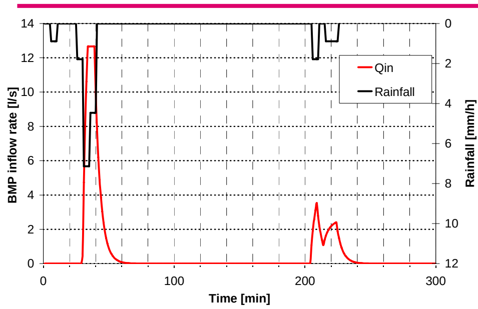
- ϑ_0 **0.05**
- ϑ_0 **0.453**
- K_s **2.18 cm/h**



Coarse gravel:

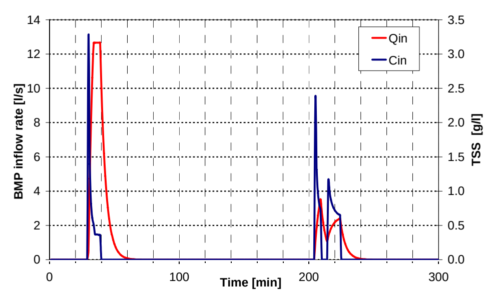
- ϑ_0 **0.01**
- ϑ_0 **0.55**
- K_s **36.0 cm/h**

Infiltration model structure validation

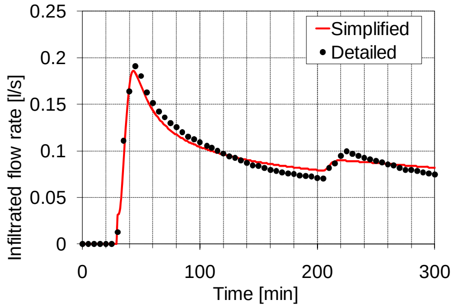


No 649 1999

Rainfall Duration:
230 min
Rainfall Max Intensity:
7.2 mm/h
Rainfall average Intensity:
2.5 mm/h



Infiltration model structure validation



Loamy-sand:

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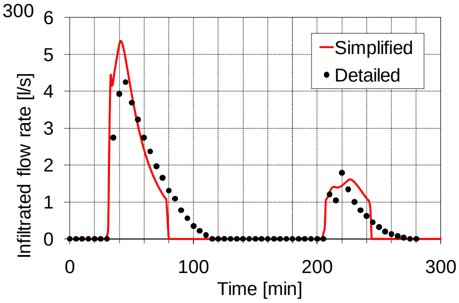
Coarse gravel:

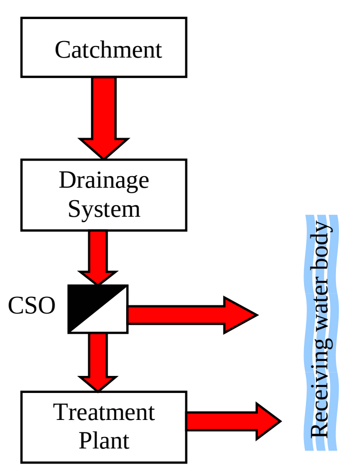
- ϑ_0 0.01
- ϑ_0 0.55
- K_s 36.0 cm/h

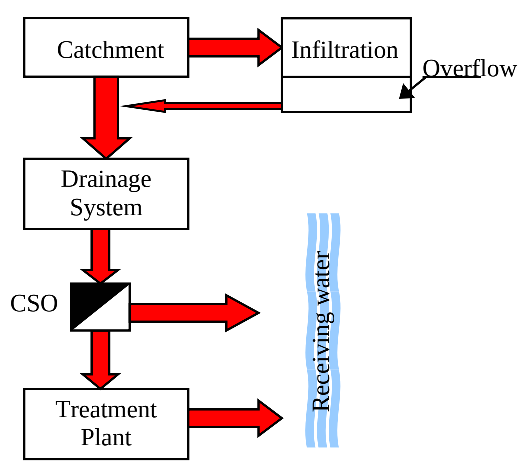


BMP planning schemes selected for the analysis

1) "do nothing" option

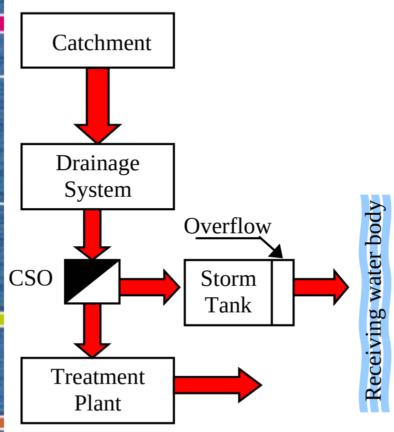
2) Source control (distributed stormwater infiltration)



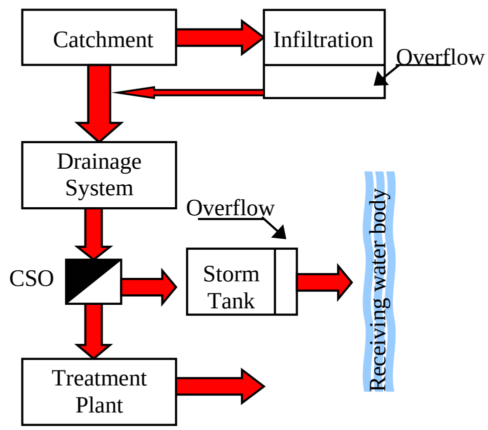


BMP planning schemes selected for the analysis

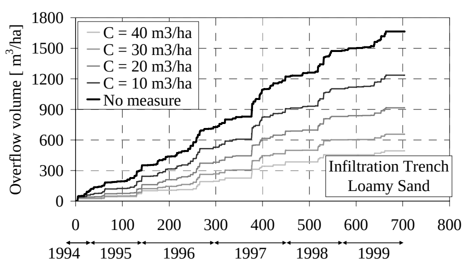
3) End-of-pipe control (centralised storage)



4) Mixed scenario (distributed infiltration + centralised storage)



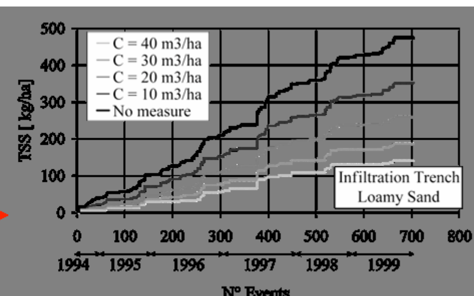
Source Control scenario (2) – Distributed infiltration



Loamy-sand:

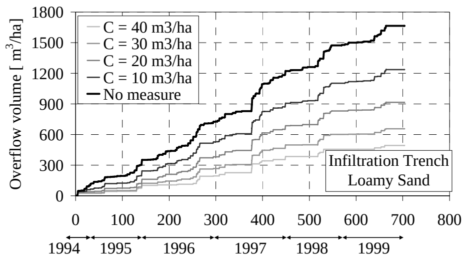
- ϑ_0 0.04
- ϑ_s 0.43
- K_s 6.12 cm/h

TSS LOAD REDUCTION →



**CLOGGING EFFECT:
10 – 40% in 6 years**

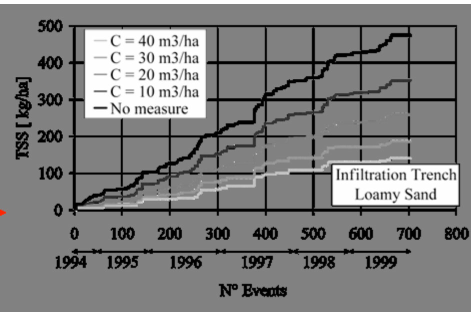
Source Control scenario (2) – Distributed infiltration



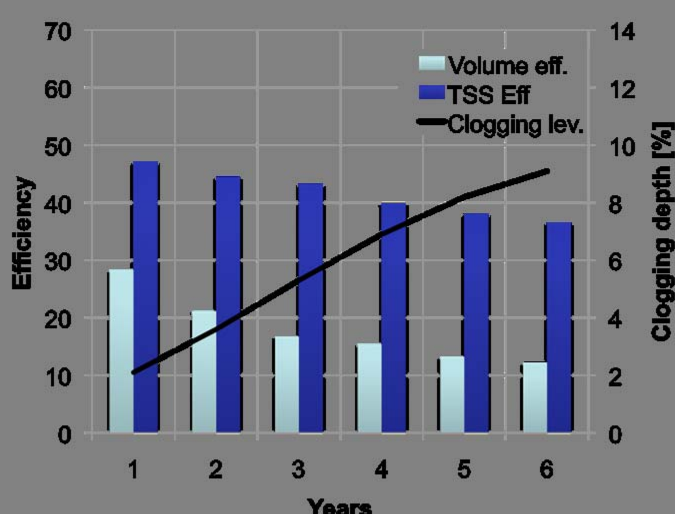
Loamy-sand:

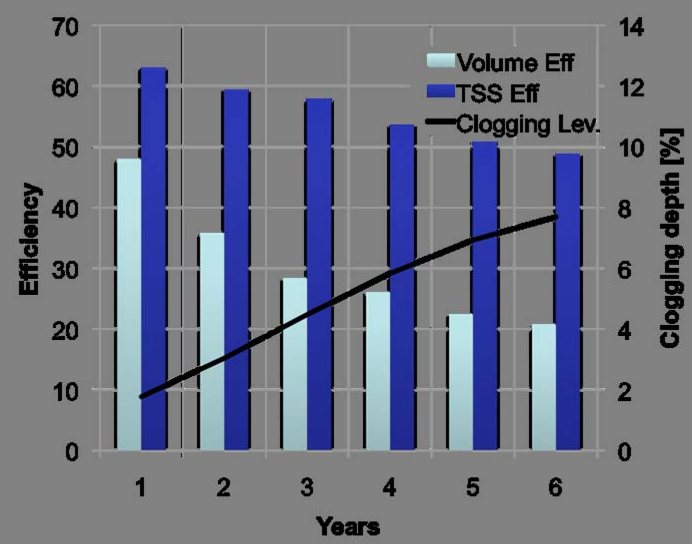
- ϑ_0 0.04
- ϑ_s 0.43
- K_s 6.12 cm/h

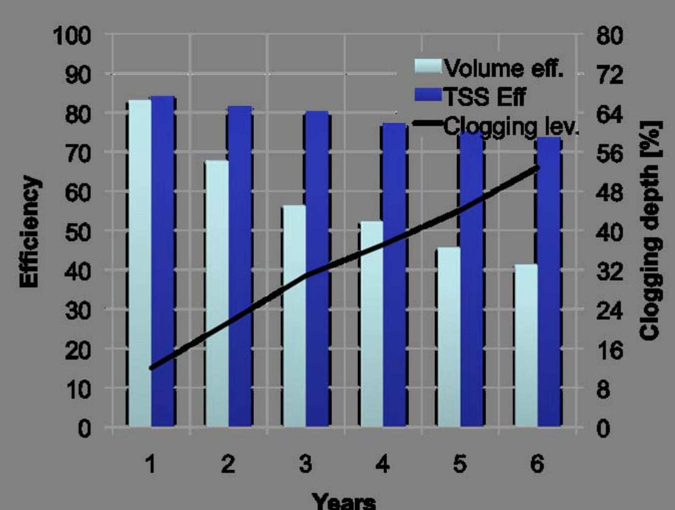
TSS LOAD REDUCTION →



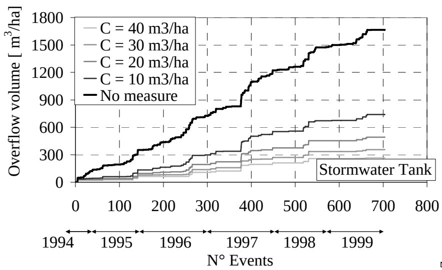
CLOGGING EFFECT:
5 – 60% in 6 years




70
60
50
40
30
20
10
0
Efficiency
14
12
10
8
6
4
2
0
Clogging depth [%]
Volume Eff
TSS Eff
Clogging Lev.
1
2
3
4
5
6
Years

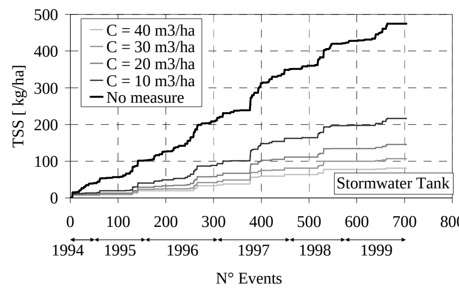

100
90
80
70
60
50
40
30
20
10
0
Efficiency
80
72
64
56
48
40
32
24
16
8
0
Clogging depth [%]
Volume eff.
TSS Eff
Clogging lev.
1
2
3
4
5
6
Years

End-of-pipe control scenario (3) – Storage

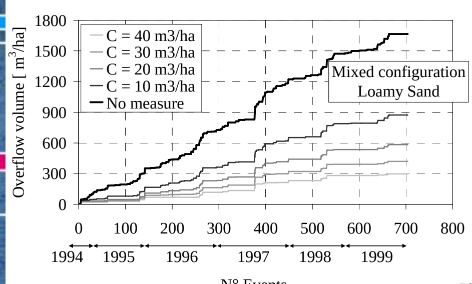


CSO VOLUME REDUCTION

TSS LOAD REDUCTION



Mixed Control scenario (4)

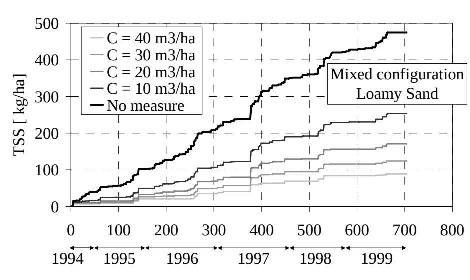


Loamy-sand:

- ϑ_0 0.04
- ϑ_s 0.43
- K_s 6.12 cm/h

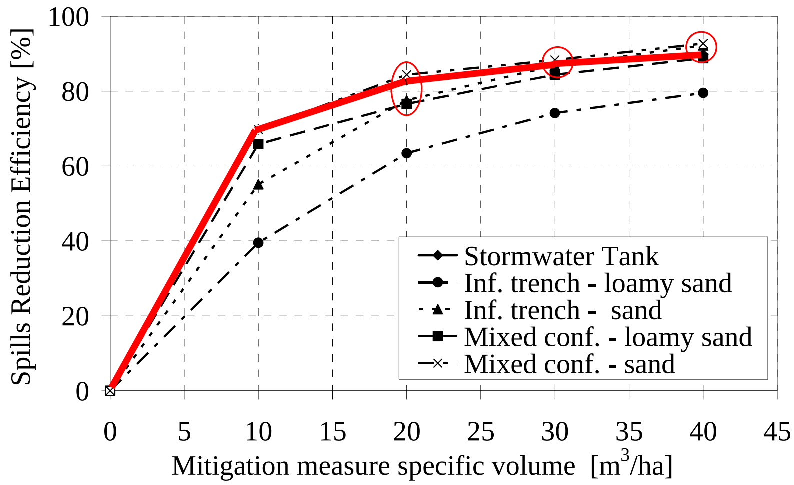
CSO VOLUME REDUCTION

TSS LOAD REDUCTION

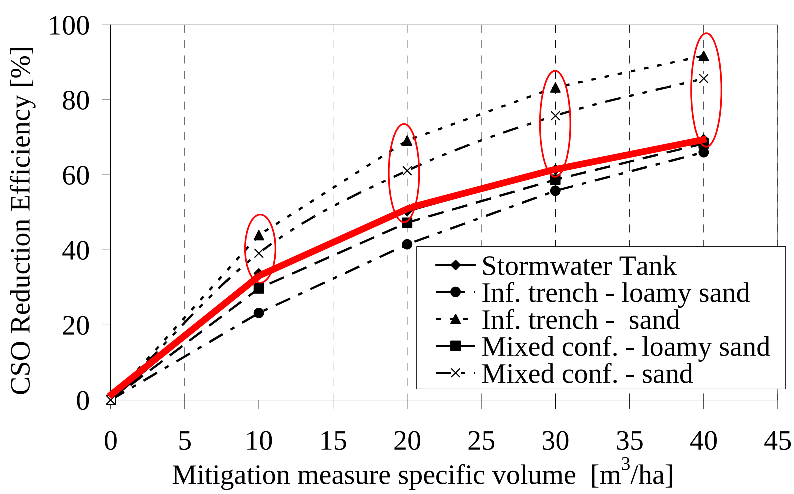


CLOGGING EFFECT:
8 – 25% in 6 years

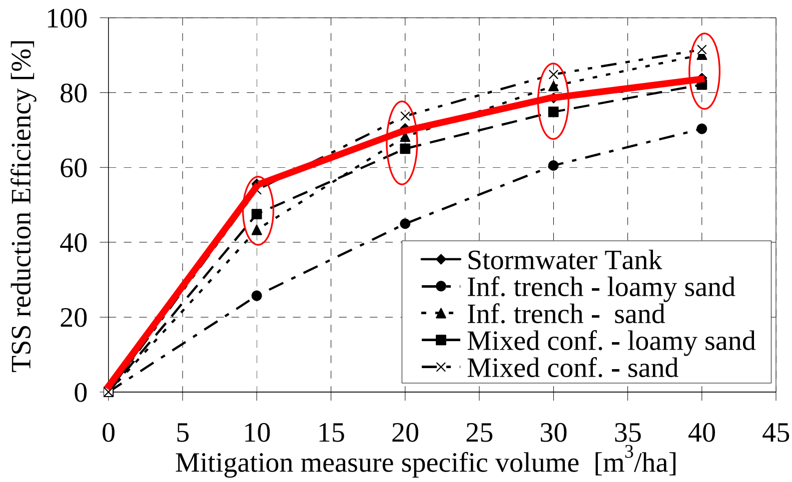
Global efficiency of different scenarios



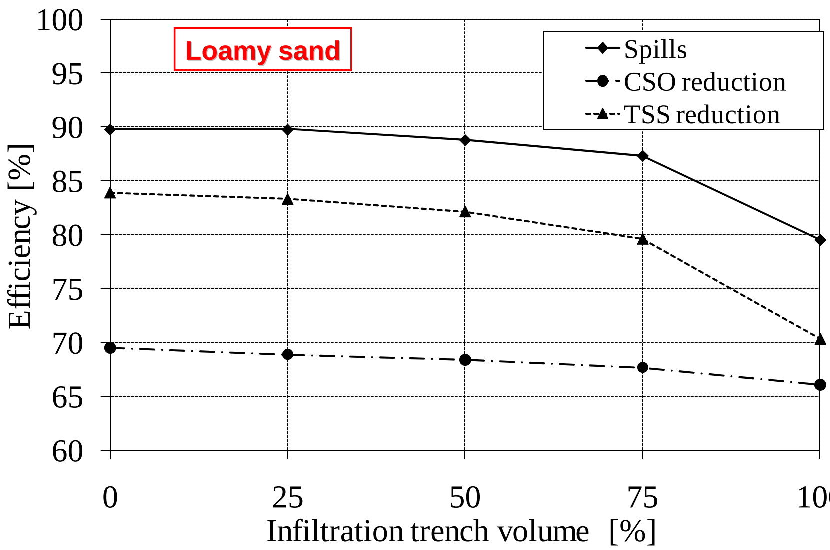
Global efficiency of different scenarios



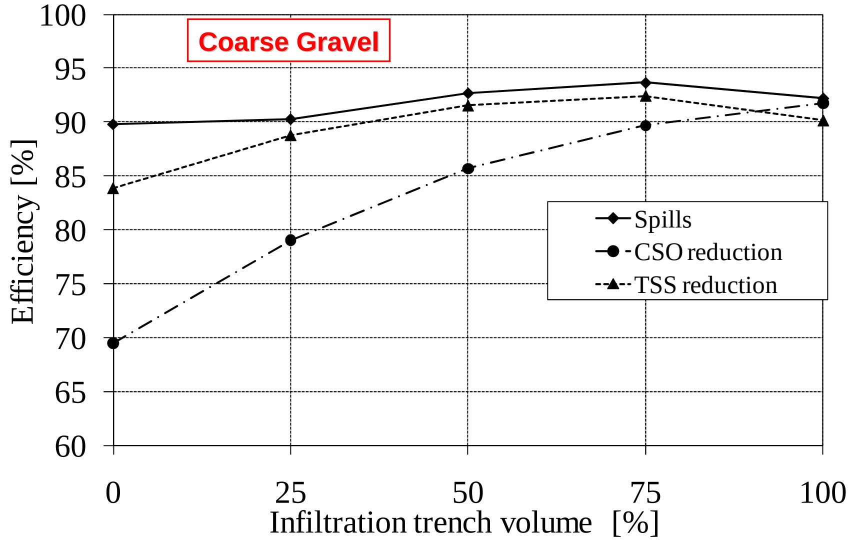
Global efficiency of different scenarios



Different solutions in the mixed configurations



Different solutions in the mixed configurations



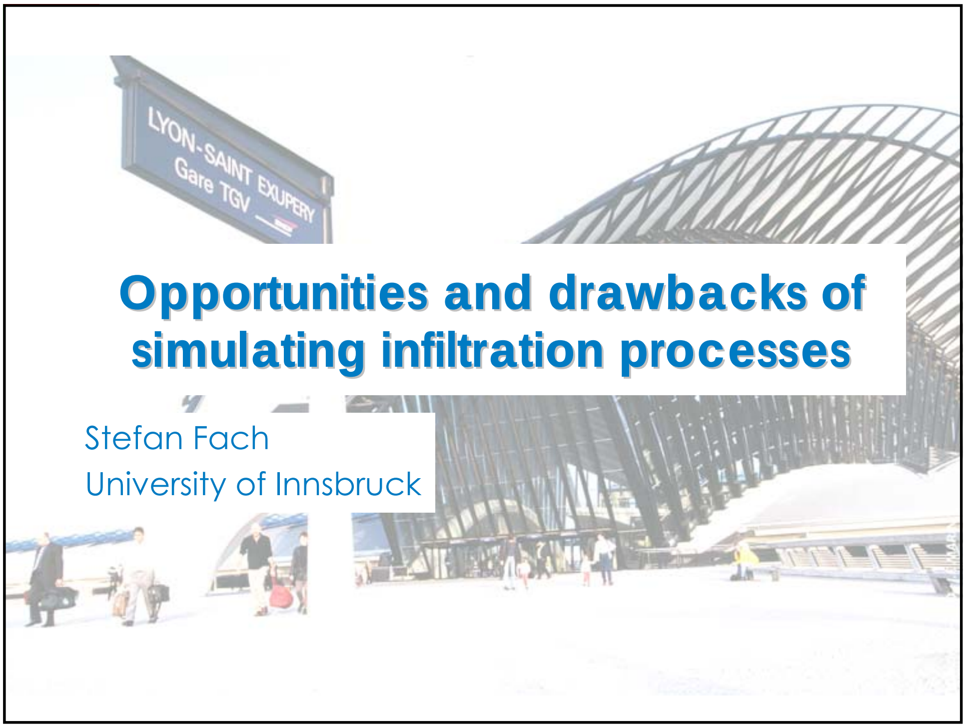
Conclusions

- **End-of-pipe techniques** result to be more **robust** for CSO mitigation and they can be effective also with small specific design volumes
- **Distributed BMPs** based on stormwater infiltration process can be **effective if soil infiltration capacity allows**
- **Infiltration** BMP **efficiency** can be much **reduced by clogging phenomena**
- **Mixed configurations** can be **as much efficient as end-of-pipe controls** avoiding frequent sewer flushing during wet periods

OPPORTUNITIES AND DRAWBACKS OF SIMULATING INFILTRATION PROCESSES

S. Fach

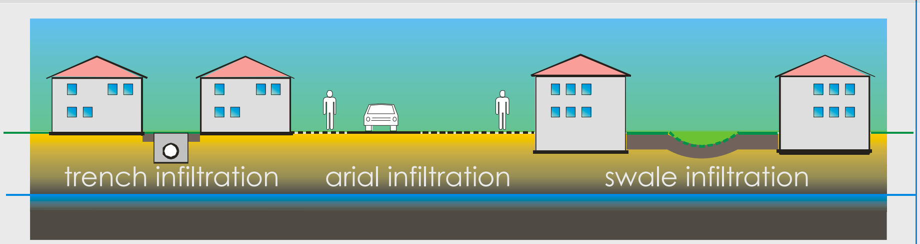
Innsbruck University, Austria



Opportunities and drawbacks of simulating infiltration processes

Stefan Fach
University of Innsbruck

Reasons for simulating infiltration



impact of roof and street runoff on

- urban hydrology, soil, seepage and groundwater

modelling of infiltration processes

- calculation of flow rates based on rain data
- transport and accumulation of pollutants
- pollutant concentrations in filter media and soil

Comparison of infiltration models

	conceptual models	finite element models
computational effort	low (within minutes)	high (within hours)
flow process	Darcy's law	Richard's equation
constraints	(saturated) homogeneous soil	mesh resolution (const. characteristics per cell)
pollutant retention	-	adsorption isotherms
constraints	-	equilibrium conditions (residence time)
purpose	system analysis, i.e. interaction with other compartments in urban drainage systems	detailed understanding of flow and pollutant transport processes

Application of a conceptual model

objective

- verification of design process acc. to guideline

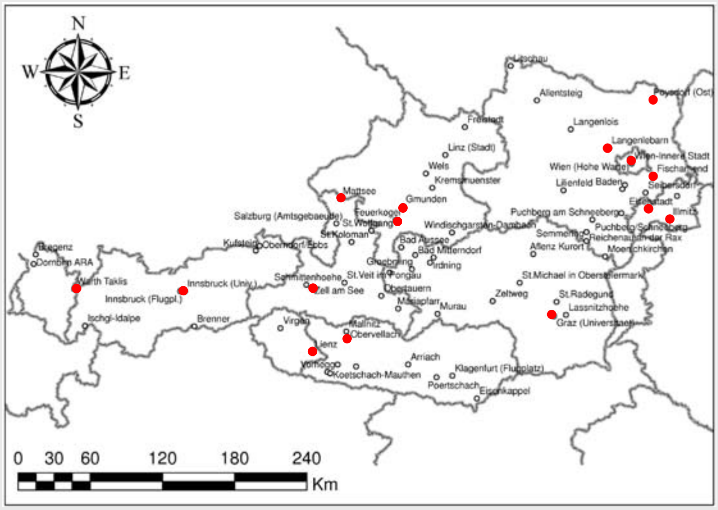
design process

- fictitious effective impervious area of 100 m^2
- fictitious hydraulic conductivity 10^{-6} m/s .. 10^{-4} m/s
- dimensioning of swales and trenches
- using rain data with 5 year return period
- spatially distributed over Austria (18 places)

verification

- long-term simulation with a conceptual model

Spatial distribution of locations



Pluviographs in detail

station	begin	end	location	state	evaporation
7704	01.01.1992	31.12.2006	Eisenstadt	Burgenland	**625-650**
7818	01.01.1991	31.12.2003	Illmitz	Burgenland	**625-650**
18121	01.01.1987	31.12.2006	Obervellach	Carinthia	600-625
19821	01.01.1983	31.12.2006	Weißensee-Gatschach	Carinthia	500-550
6050	01.01.1985	31.12.2003	Fischamend	Lower Austria	**625-650**
4081	01.01.1993	31.12.2006	Langenlebarn	Lower Austria	600-625
2503	01.01.1993	31.12.2006	Poysdorf-Ost	Lower Austria	600-625
6611	01.01.1993	31.12.2006	Feuerkogel (Tawes)	Upper Austria	500-550
6620	01.01.1983	31.12.2006	Gmunden	Upper Austria	**625-650**
6411	01.01.1986	31.12.1997	Mattsee	Salzburg	**625-650**
6415	01.01.1999	31.12.2006	Mattsee	Salzburg	**625-650**
12322	01.01.1985	31.12.2006	Zell am See	Salzburg	550-600

Pluviographs in detail

station	begin	end	location	state	evaporation
9801	01.01.1993	31.12.2006	Aigen/Ennstal	Styria	600-625
16412	01.01.1989	31.12.2006	Graz-Universität	Styria	**625-650**
11804	01.01.1992	31.12.2006	Innsbruck-Univ.	Tyrol	600-625
17901	01.01.1986	31.12.2006	Lienz	Tyrol	600-625
9011	01.01.1984	31.12.2006	Oberndorf/Ebbs	Tyrol	600-625
11305	01.01.1985	31.12.2006	Warth	Vorarlberg	**300-400**
5925	01.01.1985	31.12.2006	Wien-Innere Stadt	Vienna	**625-650**

Effective rainfall (3 parameter model)

initial losses

- due to interception: 0.3 mm

continuing losses

- due to depression storage: 0.0 mm
- initial and final runoff coefficient: 1.0

effective impervious area

$$\Delta A_i = \psi_{final}\left[\Delta P_i - L_{DS}(\varepsilon_{m,i} - \varepsilon_{m,i-1})\right]$$

- P_i effective precipitation (minus initial losses) (mm)
- L_{DS} losses due to depression storage (mm)
- ε_m degree of depression storage filling [0,1]

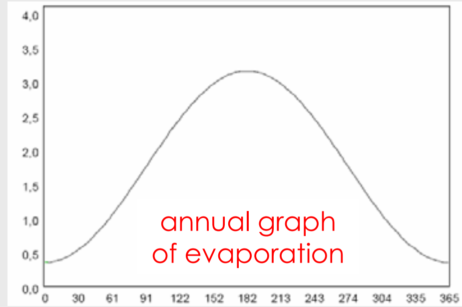
04.06.1993	14:00:00	0.000
04.06.1993	14:05:00	0.000
04.06.1993	14:10:00	0.000
04.06.1993	14:15:00	0.000
04.06.1993	14:20:00	0.000
04.06.1993	14:25:00	0.000
04.06.1993	14:30:00	0.000
04.06.1993	14:35:00	0.000
04.06.1993	14:40:00	0.000
04.06.1993	14:45:00	0.000
04.06.1993	14:50:00	0.000
04.06.1993	14:55:00	0.000
04.06.1993	15:00:00	0.000
04.06.1993	15:05:00	0.100
04.06.1993	15:10:00	0.000
04.06.1993	15:15:00	0.100
04.06.1993	15:20:00	0.100
04.06.1993	15:25:00	1.500
04.06.1993	15:30:00	2.200
04.06.1993	15:35:00	7.200
04.06.1993	15:40:00	5.300
04.06.1993	15:45:00	0.100
04.06.1993	15:50:00	0.000
04.06.1993	15:55:00	0.100
04.06.1993	16:00:00	0.300
04.06.1993	16:05:00	0.300
04.06.1993	16:10:00	0.200
04.06.1993	16:15:00	0.100
04.06.1993	16:20:00	0.000
04.06.1993	16:25:00	0.100
04.06.1993	16:30:00	0.000

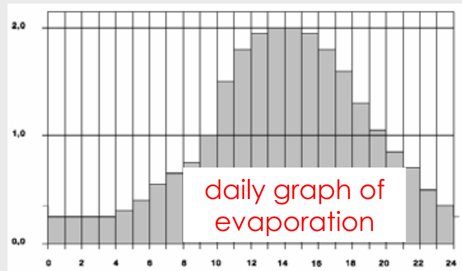
Dry period, surface routing, infiltration

dry weather period
- emptying of depression storage
- effective evaporation per year

surface routing
- unit hydrograph

infiltration process
- acc. to Darcy's law
- reduced hydr. cond. by factor 0.5





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Conceptual model building

effective impervious area
- fictitious roof of 100 m²

infiltration swale or trench
- geometry based on design process

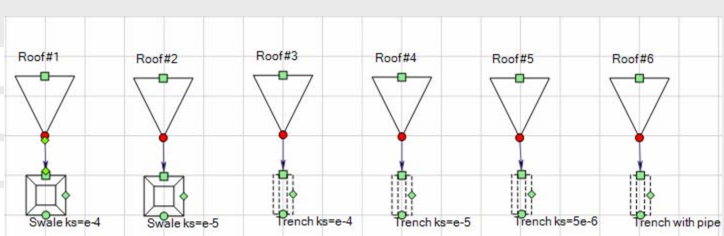
homogeneous subsoil
- characterised by its hydraulic conductivity

effective rainfall

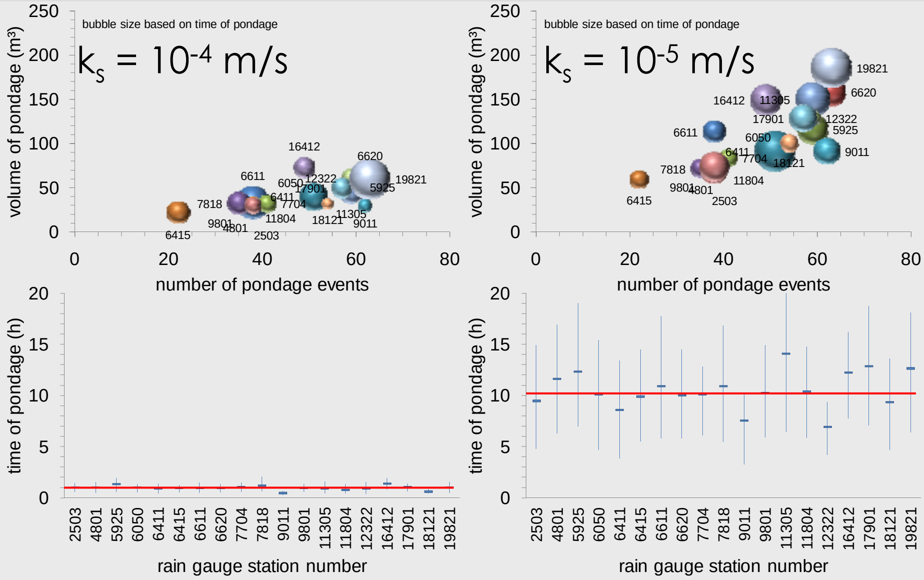
surface routing

translation

infiltration processes



Simulation results for swales



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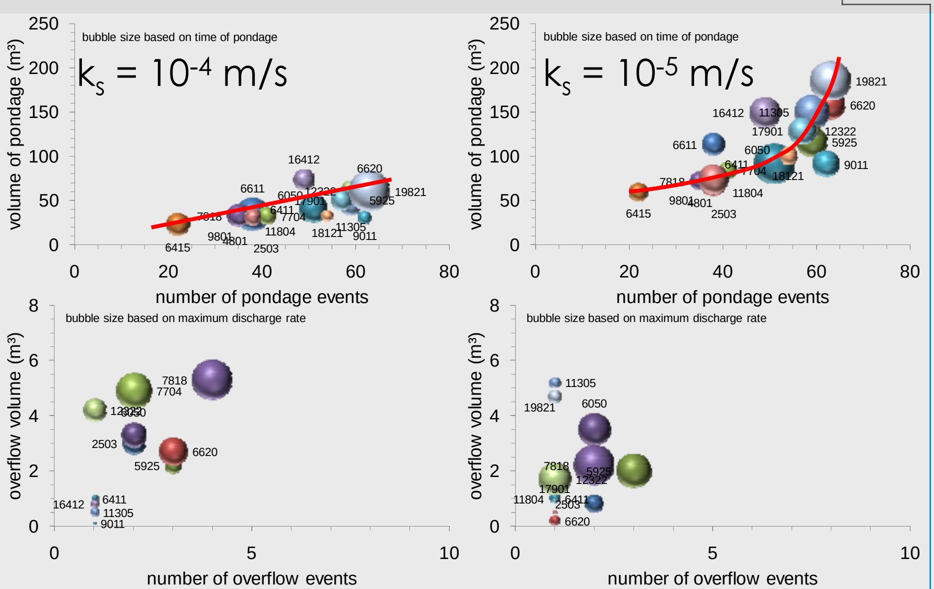
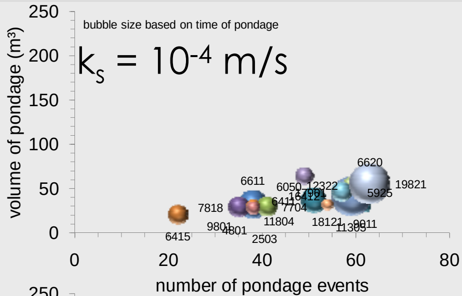
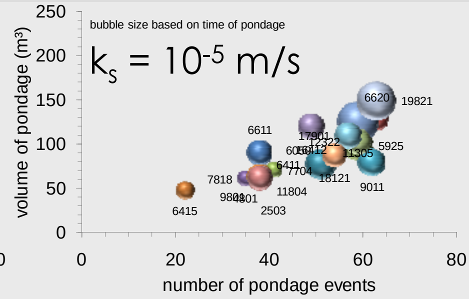
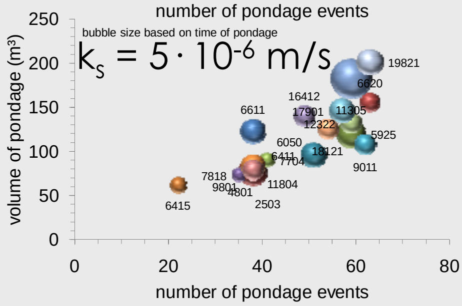
Simulation results for swales



Simulation results for trenches







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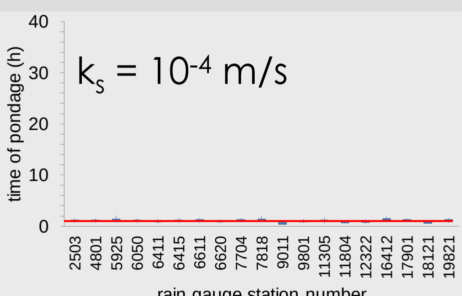
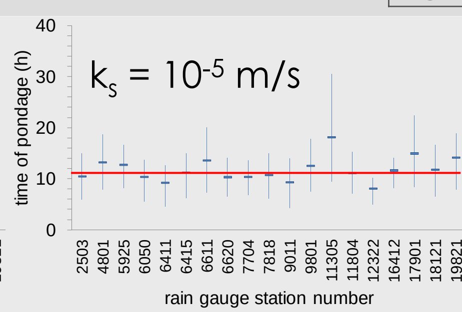
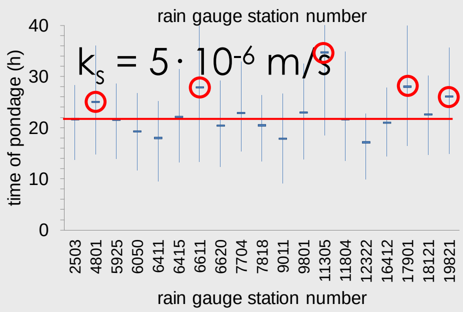
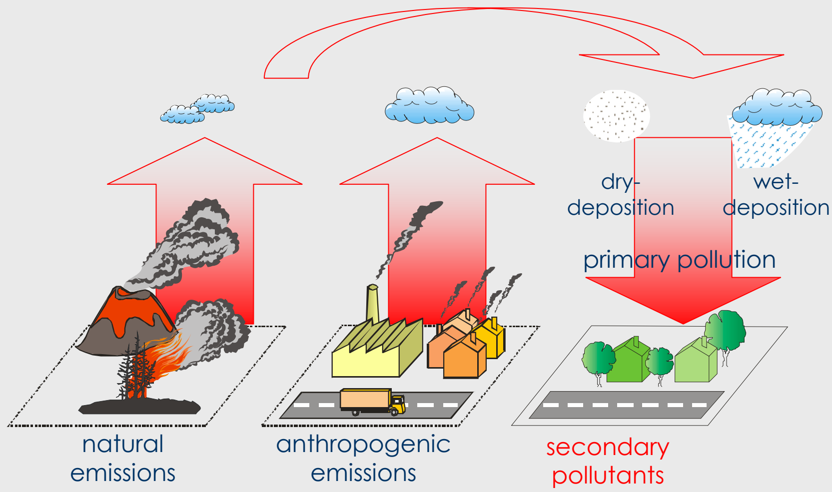
Simulation results for trenches







Impact of emissions on runoff quality



water quality models: limitations with respect to pollutant's build-up

Stormwater runoff concentration matrix

Journal of Contaminant Hydrology 91 (07) p.35

			unsealed surf.	roofs					streets				
			1	2	3	4	5	6	7	8	9	10	11
	parameter	unit	gardens, meadows, cultivated lands	roof runoff, pantiles, concrete tiles, fibr. Cement, glas, bitumen, without zinc	roof runoff, pantiles, concrete tiles, fibr. Cement, glas, bitumen, with zinc	planted roofs	copper sheets	zinc sheets	bicycle paths, footpaths, yards	car parks	streets in residential areas	main roads	motorways
1	el. cond.	[uS/cm]	50	141	141	71	141	141	n.d.	n.d.	n.d.	470	414
2	pH	[-]	5,0	5,7	5,7	7,5	5,7	5,7	7,4	7,4	7,4	7,4	7,4
3	AFS	[mg/l]	12	43	43	n.d.	43	43	74	150	150	163	153
4	BSB_5	[mg/l]	2	12	12	n.d.	12	12	n.d.	11	11	11	32
5	CSB	[mg/l]	19	66	66	n.d.	66	66	70	70	70	105	107
6	P ges	[mg/l]	0,09	0,22	0,22	n.d.	0,22	0,22	n.d.	0,18	0,18	0,29	0,20
7	NH_4	[mg/l]	0,80	3,39	3,39	1,30	3,39	3,39	n.d.	0,1	0,1	0,9	0,5
8	NO_3	[mg/l]	1,54	2,78	2,78	0,59	2,78	2,78	n.d.	2,78	2,78	5,00	2,52
9	Cd	[□g/l]	0,7	0,8	0,8	0,1	0,8	1,0	0,8	1,2	1,6	1,9	3,7
10	Zn	[□g/l]	80	370	1.851	468	370	6.000	585	400	400	407	345
11	Cu	[□g/l]	11	153	153	58	2.600	153	23	80	86	97	65
12	Pb	[□g/l]	9	69	69	6	69	69	107	137	137	170	224
13	Ni	[□g/l]	2	4	4	3	4	4	n.d.	n.d.	14	11	27
14	Cr	[□g/l]	3	4	4	3	4	4	n.d.	n.d.	10	11	13
15	Na	[mg/l]	2,14	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	18	n.d.	108	194
16	Mg	[mg/l]	0,18	n.d.	n.d.	7	n.d.	n.d.	n.d.	n.d.	n.d.	1	5
17	Ca	[mg/l]	7,50	10	10	78	10	10	n.d.	n.d.	n.d.	31	37
18	K	[mg/l]	0,56	n.d.	n.d.	7	n.d.	n.d.	n.d.	4	n.d.	2	5
19	SO_4	[mg/l]	5,46	46,71	46,71	n.d.	46,71	46,71	n.d.	n.d.	n.d.	15	39
20	Cl	[mg/l]	2,26	7,74	7,74	n.d.	7,74	7,74	n.d.	n.d.	n.d.	106	159
21	PAH	[□g/l]	0,39	0,44	0,44	n.d.	0,44	0,44	1,00	3,50	4,50	1,65	2,61
22	Petrol. HC	[mg/l]	0,38	0,70	0,70	n.d.	0,70	0,70	0,16	0,16	0,16	4,17	4,76

n.d. = parameter is not determinable

Constituents in surface runoff as EMC

parameter	unit	grassed area	roofs without metals	metal roofs *)	trafficked areas **)
Cd	(µg/L)	0.7	0.8	0.8 – 1.0	0.8 – 1.9
Zn *)	(µg/L)	80	370	370 – 6000	400 – 585
Cu *)	(µg/L)	11	153	153 – 2600	23 – 97
Pb **)	(µg/L)	9	69	69	107 – 170
PAH_{EPA}	(µg/L)	0.39	0.44	0.44	1.0 – 4.5
TSS	(mg/L)	12	43	43	74 – 163
pH-value	(-)	5.0	5.7	5.7	7.4

*) no simultaneous occurrence in roof runoff **) origin: leaded fuel

Application of a finite element model

objective

- concentrations after 50 years of operation
- evaluation by means of critical values

verification

- long-term simulation of a grassed swale, trench and different types of permeable pavements
- loads based on stormwater runoff conc. matrix
- pollutant transport processes accounted for
  - advection, diffusion, dispersion, adsorption
- variation of the hydrogeology (2 sub-soils)

Flow processes and pollutant transport

- unsteady flow with Richards equation

$$\frac{\partial \theta}{\partial t} = \frac{\partial}{\partial x} k_x(\theta) \frac{\partial \psi}{\partial x} + \frac{\partial}{\partial y} k_y(\theta) \frac{\partial \psi}{\partial y} + Q$$

- suction head – saturation relation with van-Genuchten equation

$$S_e(\psi) = S_r + \frac{S_S - S_r}{(1 + (\psi \cdot A)^n)^m}$$

- adsorption according to Langmuir isotherm

$$C_a = \frac{k_1 \cdot C}{1 + k_2 \cdot C}$$

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Model input parameters

seepage flow

- porosity boratory tests
- conductivity boratory tests
- van-Genuchten boratory tests

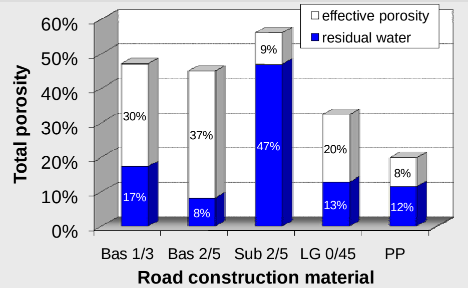
pollutant transport

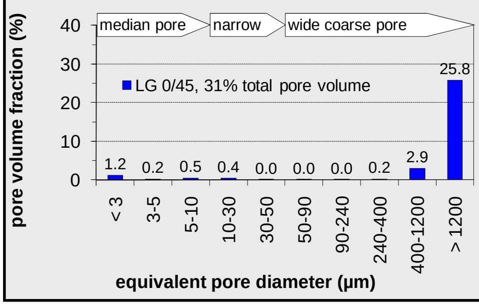
- coefficients for diffusion erature (Vnýsek)
- coefficients for dispersio erature
  - longitudinal 10 of model size
  - transversal 100 of model size
- coefficients for adsorptic boratory tests

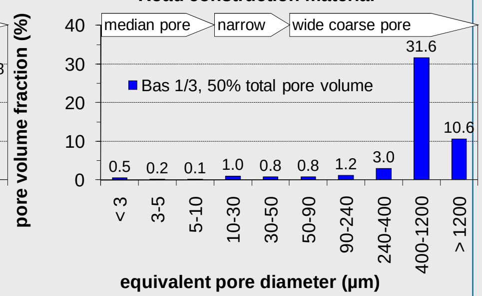
Model input parameters

Total porosity

- effective porosity
- residual water







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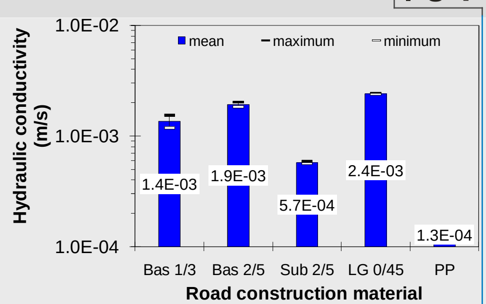
Model input parameters

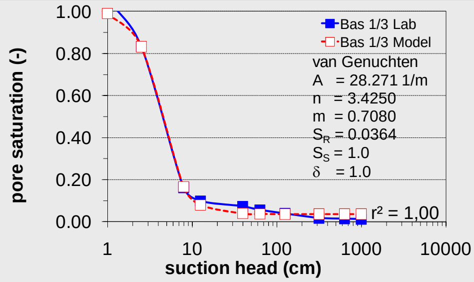
hydraulic conductivity

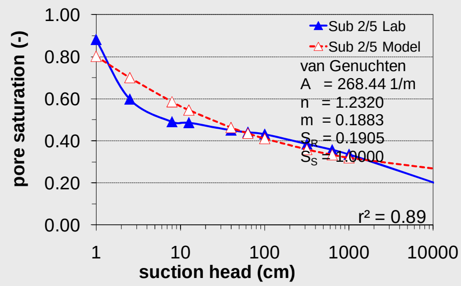
- acc. to DIN 18130-1
- constant head due to container with overflow
- dimensions of apparatus dependent on largest grain size



Model input parameters

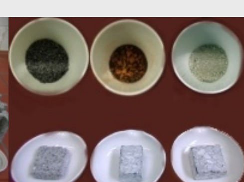
- d_{pore} < 30 µm acc. to Richards and Firemann (1943)
- d_{pore} > 30 µm acc. to Wolkewitz (1960)





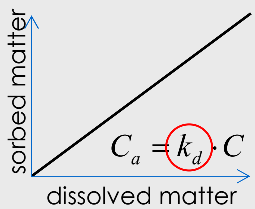
Batch tests for adsorption isotherms

- breaking and sieving (< 2 mm)
- adding of heavy metal dilutions
- batch-test until equilibrium is reached
- centrifugation (filtration) of water samples
- analysis of samples (ICP-OES, GC)
- conversion of adsorbed mass (total fraction)
- evaluation of test results with regard to isotherms

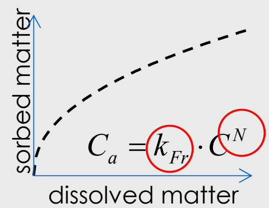



Basis for adsorption isotherms

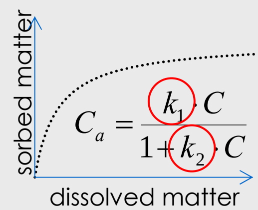
- fixation of dissolved pollutants by particles
- differentiation between forces and mechanics
- phenomenological description of adsorption processes by using 3 types of isotherms
- adsorption isotherms valid for equilibrium conditions



Henry



Freundlich



Langmuir

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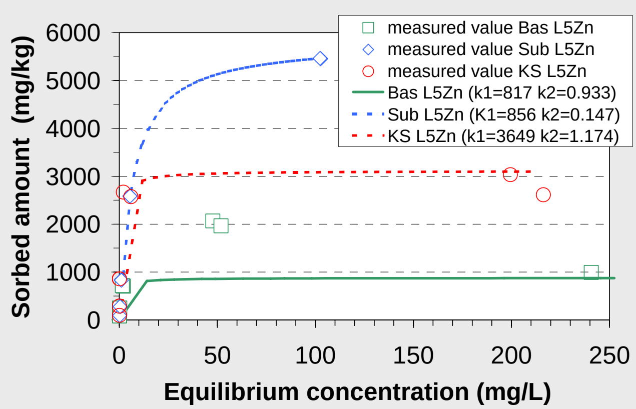
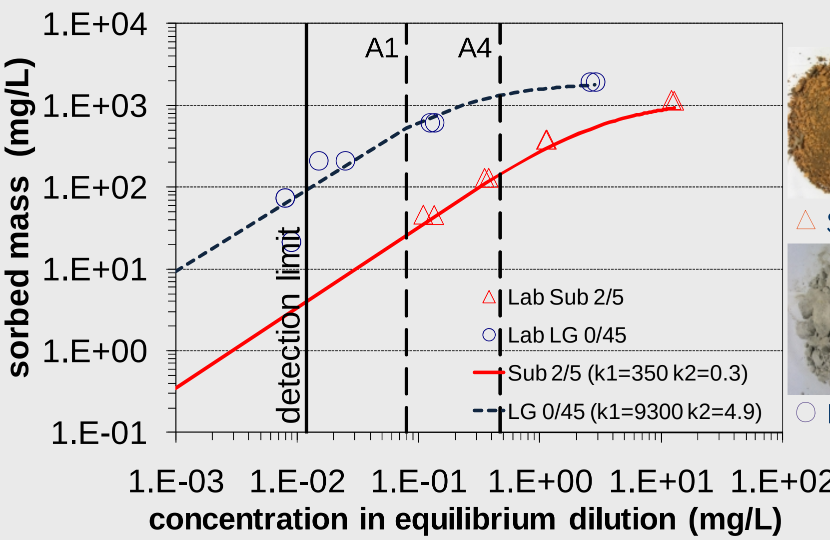
Model input parameter

- batch tests acc. to EPA/530-SW-87-006-F
- sorption coefficients k1 and k2



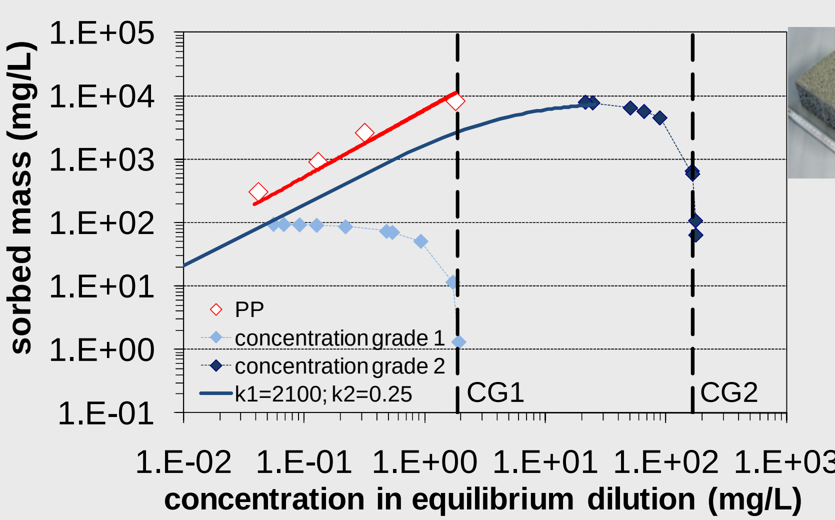
Langmuir adsorption-isotherms

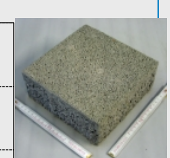


△ Sub 2/5

○ LG 0/45

Impact of residence time

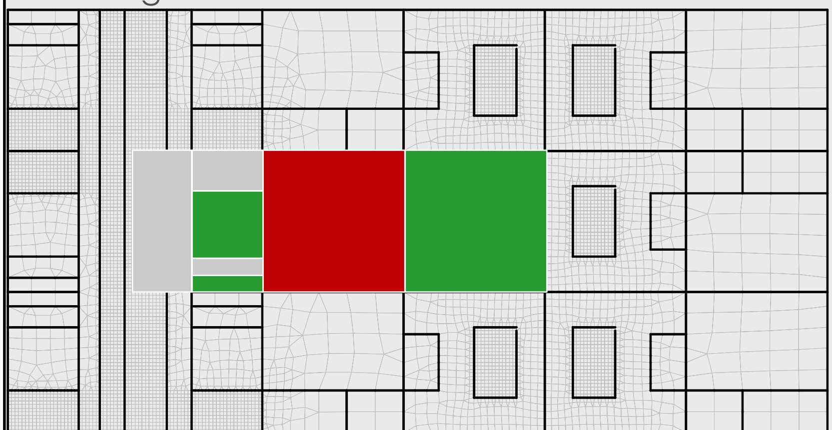




PP

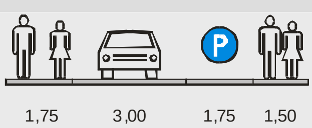
Finite element mesh

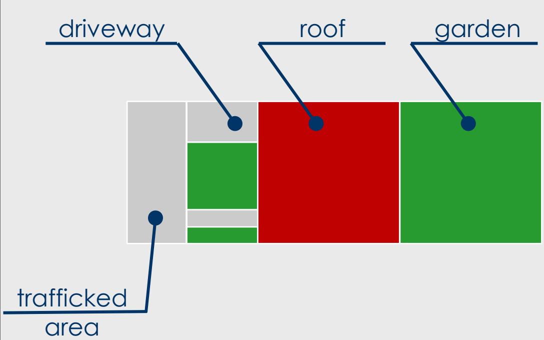
- mesh resolution dependent on hydraulic significance



groundwater flow direction →

Concept of runoff concentration





- model site
  - road of type „AS3“ (residential road)
  - 40 % as degree of land use
  - 1.8 : 1 as ratio of roof and trafficked area
- input concentrations
  - acc. to stormwater runoff concentration matrix

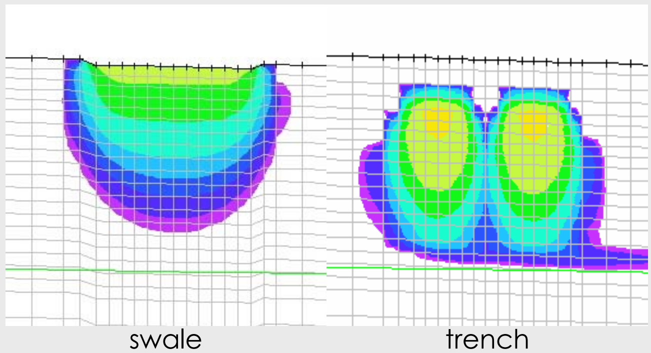
Results of finite-element computation

impact of the type of device on water quality

- subsoil: gravelly sands above sandy marl
- runoff character: copper roof (Cu 2.6 mg/l)

seepage concentration

- 0.01 – 0.02 mg/l
- 0.02 – 0.05 mg/l
- 0.05 – 0.10 mg/l
- 0.10 – 0.20 mg/l
- 0.20 – 0.50 mg/l
- 0.50 – 1.00 mg/l
- 1.00 – 2.00 mg/l
- 2.00 – 5.00 mg/l
- 5.00 – 10.00 mg/l



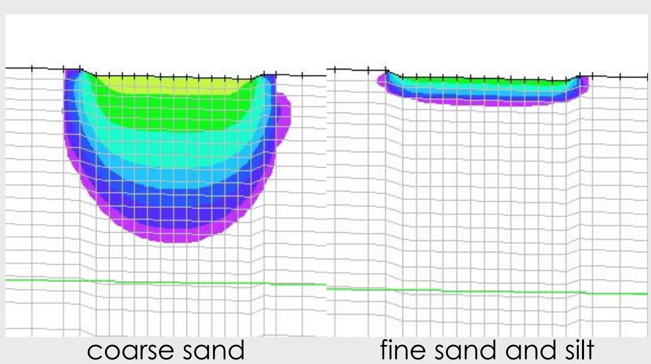
Results of finite-element computation

impact of the geology on water quality

- subsoil: varying Quaternary above sandy marl
- runoff character: copper roof (Cu 2.6 mg/l)

seepage concentration

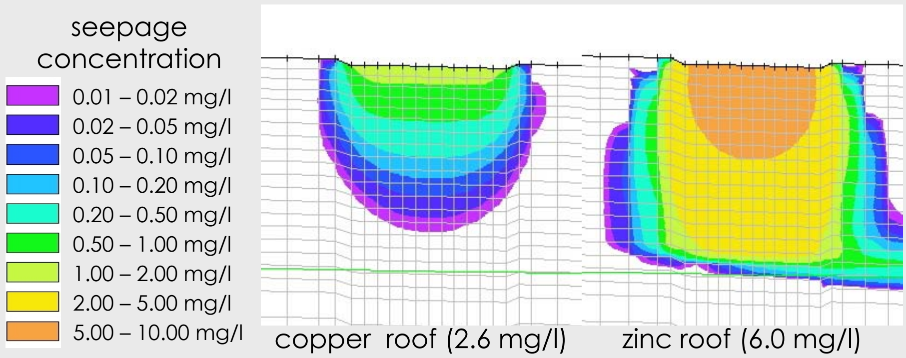
- 0.01 – 0.02 mg/l
- 0.02 – 0.05 mg/l
- 0.05 – 0.10 mg/l
- 0.10 – 0.20 mg/l
- 0.20 – 0.50 mg/l
- 0.50 – 1.00 mg/l
- 1.00 – 2.00 mg/l
- 2.00 – 5.00 mg/l
- 5.00 – 10.00 mg/l



Results of finite-element computation

impact of the runoff area on water quality

- subsoil: gravelly sands above sandy marl
- runoff character: copper roof or zinc roof



Simulation results vs. critical values

runoff type		**zinc roof (6.0 mg/l)**	
subsoil characteristics'		fine sand	coarse sand
adsorbed mass in first layer of finite mesh	(mg/kg)	*78 (60)*	*99 (60)*
adsorbed mass 1 m below base of device	(mg/kg)	55 (150)	*149 (60)*
seepage concentration 1 m below device	(µg/l)	190 (500)	*5580 (500)*
seepage concentration acc. to national act	(µg/l)	< 10 (500)	*990 (500)*
depth, where critical value is reached	(m)	~ 2.1	~ 4.0
substitution rate for the first 20 cm	(a)	~ 10	~ 2

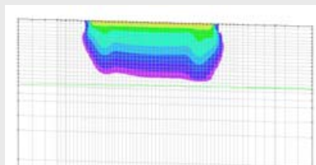
Results of finite-element computation

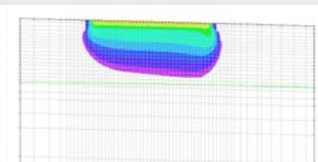
impact of the runoff area on water quality

- subsoil: gravelly sands above sandy marl
- runoff character: zinc roof (Zn 4.17 mg/L)

seepage concentration

- 0.01 – 0.02 mg/l
- 0.02 – 0.05 mg/l
- 0.05 – 0.10 mg/l
- 0.10 – 0.20 mg/l
- 0.20 – 0.50 mg/l
- 0.50 – 1.00 mg/l
- 1.00 – 2.00 mg/l
- 2.00 – 5.00 mg/l
- 5.00 – 10.00 mg/l


Concrete block pavers with infiltration joints


Grass pavers filled with substrate

only small variations in simulation results due to simplified (model) approach

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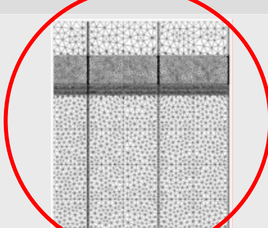
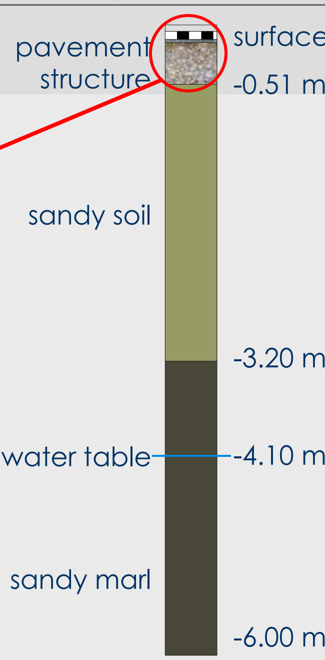
Simulation model





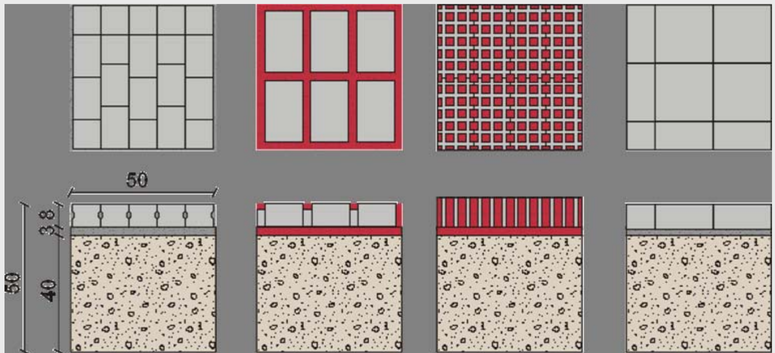
finite element mesh

- 4,000 nodes
- triangular elements

input concentrations

- Pb: 0.087 mg/L
- Cu: 1.688 mg/L
- Zn: 4.036 mg/L

Types of pervious pavements



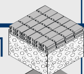
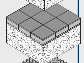
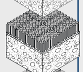
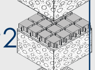
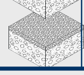
type of paver	blocks with small joints	blocks with large joints	grass paver	porous paver
name	CB #1	CB #2	GP	PP
jointing	basalt 1/3	substrate 2/5	substrate 2/5	basalt 1/3
bedding	basalt 2/5	substrate 2/5	substrate 2/5	basalt 2/5
road base	limestone 0/45	limestone 0/45	limestone 0/45	limestone 0/45

Simulation results for copper

type of paver	seepage concentration		adsorped pollutants	
	below subgrade	unsaturated – saturated soil	in pavement structure	in soil
	(mg/L)	(mg/L)	(mg/kg)	(mg/kg)
CB #1	*0.288*	0.002	*135*	36
PP	*0.373*	0.004	105	51
GP	*0.296*	0.003	*117*	46
CB #2	*0.290*	0.002	*132*	40

exceedence of critical values expressed in italics

Evaluating road constructions

pavement structure		roof			road
type	ratio of jointing	clay, concrete and glass	Zn	Cu	Pb, Zn
CB #1 	14 %	++	++	+	++
PP 	(4 %)	++	++	++	++
GP 	50 %	++	++	+	++
CB #2 	30 %	++	++	+	++
PA 	–	+	-	-	+

++ seepage and particle concentration below critical value
\+ seepage conc. met and particle conc. exceeded
\- seepage concentration exceeded

Conclusion and outlook

conceptual infiltration models

- low demand for model input parameters
- suitable for analysis in catchment scale
- comparison of various spatial arrangements
- evaluation of different devices with respect to
  - number of overflows, overflow volume, time of pondage

constraints

- constant infiltration performance
- homogeneous subsoil
- restricted possibilities for calibration/validation
  - number of pondage events, pondage depth

Conclusion and outlook

finite element infiltration models

- high demand for model input parameters
- suitable for mass flux analysis of a single device
- long-term effect with regard to pollutant transport
- comparison of various filter medias
  - seepage and particle bound concentration

constraints

- detailed structure vs. computational effort
- adsorption isotherms developed for steady state
- restricted possibilities for calibration/validation
  - particle bound concentration, measured water level

General literature overview

SOURCE CONTROL PERFORMANCE

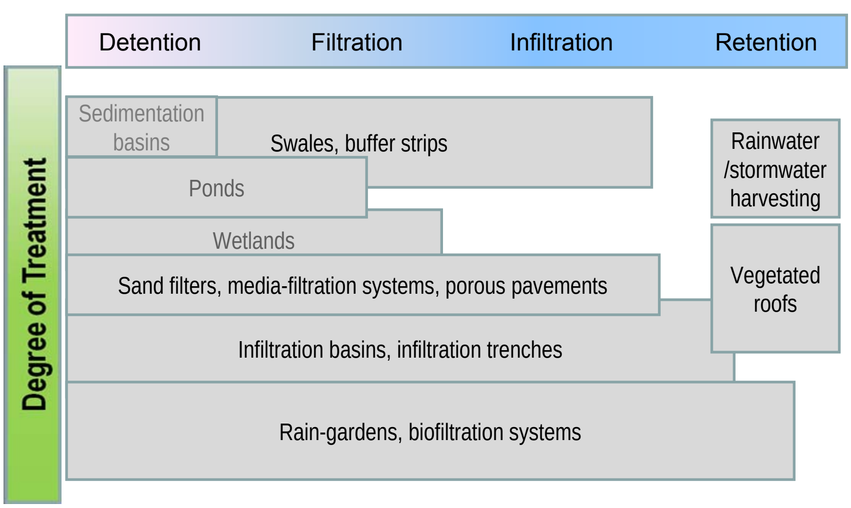
T. Fletcher & P. Hamel

Monash University, Australia

Source control performance

T. Fletcher & P. Hamel

A continuum of techniques



Swales & buffer strips

- May provide some infiltration

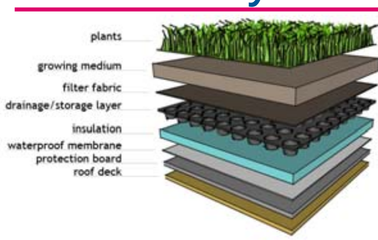
Infiltration systems

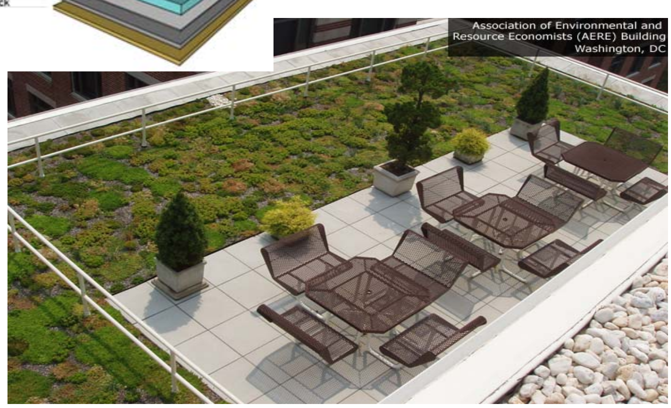
- Trenches, basins
- Vegetated, non-vegetated

Filtration systems

- Vegetated or unvegetated
- Sand filters, media filtration systems
- Discharge - stormwater network

Retention systems



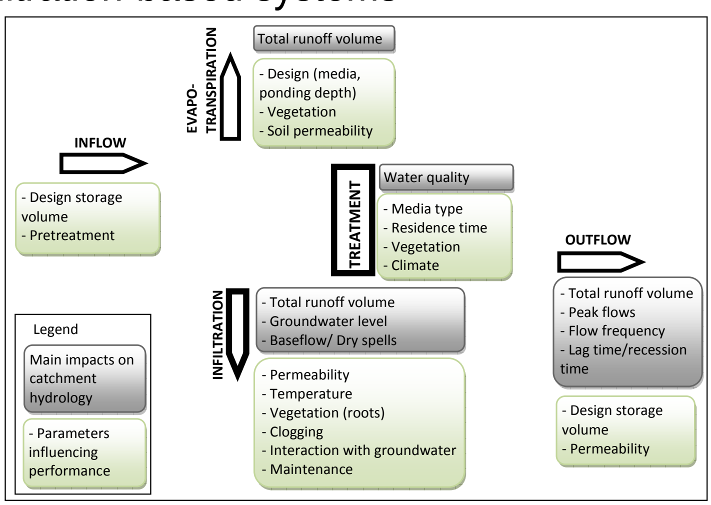


Rainwater / stormwater harvesting

- Above-ground, under-ground
- Wide range of uses

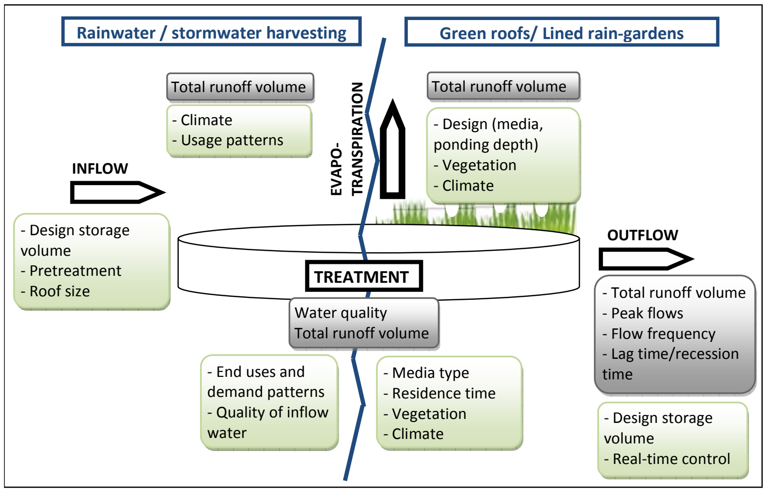
Factors governing performance

- Infiltration-based systems



Factors governing performance

- Retention-based systems



Reported performance: hydrology

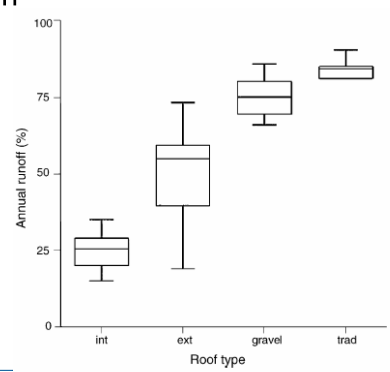
- Infiltration-type techniques
  - All depends on scale (relative - catchment) and design
  - Generally improving with time…

Technique	Runoff reduction (annual coefficient)
Swales/ Filter strips (unvegetated and vegetated)	40 - 60%
Infiltration trench/ basin	50 - 90%
Bio-infiltration (incl. Unlined raingardens)	40 - 80%
Porous pavements	45 - 75%

Reported performance: hydrology

- Retention-type techniques
  - Harvesting: storage volume and usage pattern
  - Vegetated roofs, lined rain-gardens: storage volume, evapotranspiration

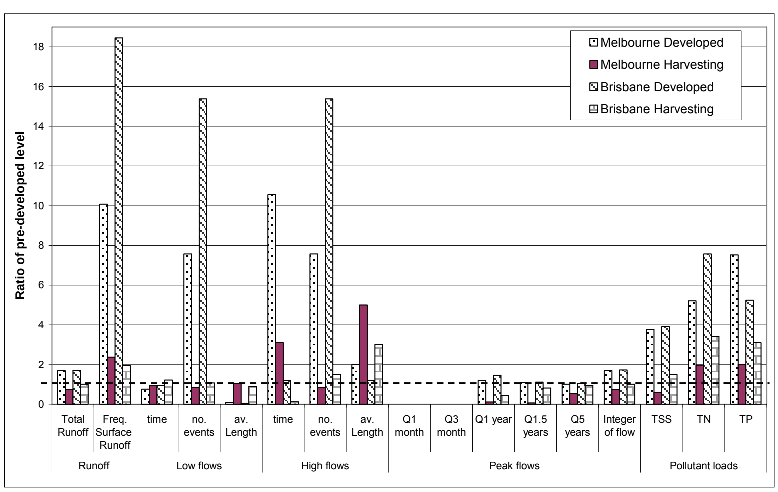
Technique	Runoff reduction (annual coefficient)
Vegetated roofs	55-65%
Lined rain-gardens	10-40%



USEPA (Struck, Rowney & Pechacek, 2009)

Reported performance: hydrology

- Harvesting



Reported performance: water quality

Measure	Total N (%)	Total P(%)	TSS (%)	Heavy metals (%)
Swales/ Filter strips (unveg.+veg.)	25 - 40%[1] (55 - 74%)[2]	30 - 50%[1] (52 - 76%)[2]	60 - 80%	20 - 60%
Infiltration trench/ basin	50 - 70%[1] (57 - 92%)[1]	40 - 80%[1] (63 - 93%)[2]	65 - 99%	50 - 95%
Biofiltration / bio-infiltration	50 - 70%[1] (64 - 92%)[2]	40 - 80%1 (55 - 90%)2	65 - 99%	50 - 95%
Porous pavements	60 - 80%[1] (59 - 81%)[2]	40 - 80%[1] (59 - 81%)[2]	70 - 99%	40 - 90%

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2. Schueler, T., Hirschman, D., Novotney, M., & Zielinski, J. (2007). *Urban Stormwater Retrofit Practices*: Center for Watershed Protection.

Issues and knowledge gaps

- Interaction between systems (scales, low-flow impacts)
- Indicators for integrated design (multi-criteria)
- Infiltration: clogging – mechanisms, solutions, role of vegetation
- Local performance data (where needed)
- Performance for priority pollutants
- Vegetated roofs: optimising water quality

"GREEN" TECHNOLOGIES & INFRASTRUCTURES FOR THE CONTROL AND TREATMENT OF IMPERVIOUS SURFACE RUNOFF

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Performance

The application of vegetative-based BMP source approaches for sustainable urban stormwater watershed planning

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1. Introduction

First-generation surface water drainage followed the conventional practice established by "all-to-the-sewer" wastewater conveyance (Chocat *et al.*, 2004) with rainfall-runoff from impermeable urban surfaces being separately sewered. This paradigm argued for the rapid collection and conveyance of impermeable surface runoff with pipes sized according to the Rational formula. Hydraulic and conveyance capacity comprised the driving design criteria and as stormwater flows were considered to be "unpolluted", direct untreated discharges to receiving waters from surface water outfalls (SWOs) were deemed technically appropriate and environmentally acceptable. The increasing awareness of the pollution potential associated with such diffuse, non-point urban discharges led to the introduction of a second-generation infrastructure based on best management practices (BMPs) or "sustainable" drainage systems (SUDS). These alternative techniques have been superimposed onto the conventional below-ground sewer drainage system to provide a hybrid solution to address both flow and quality surface water issues. This second-generation drainage approach has been adopted at varying scales and intensities within urban areas across the world, although many alternative BMP drainage technologies have met considerable resistance to their large-scale implementation on performance, institutional, legislative and planning grounds (GAO, 2007; Ellis, 2009a). Nevertheless, such BMP approaches currently form the core mitigation philosophy of the US EPA National Pollutant Discharge Elimination System (NPDES) and associated permit program under Section 402 and 101 requirements of the Clean Water Act (CWA) as well as being proposed as essential drainage elements in UK development planning for pluvial flooding and pollution control (CLG, 2006).

However the approach remains essentially based on piecemeal site development and primarily driven by hydraulic requirements of peak storm volume attenuation, storage and treatment, rather than by integrated, catchment-based ecosystem precepts. The US EPA are now reviewing their NPDES policy direction and are considering the adoption of a watershed-based approach for NPDES permits (EPA, 2007) along the lines already contained within the European Union Water Framework Directive (WFD). This shift in philosophy is consonant with a move towards "green infrastructure" thinking in urban stormwater management (Novotny and Brown, 2007). The provision of a "green water" resource base would provide a tangible link with ecosystem services of direct value to the urban community but requires appropriate land use planning controls with strategic spatial planning approaches applied to both urban development and regulatory policy. Such approaches constitute a major re-thinking and re-orientation for established second generation BMP drainage philosophy such that a third-generation of surface water drainage systems may be needed to fully and satisfactorily address this need for a more sustainable, holistic watershed-scale solution (Ellis, 2009b; Marsalek and Schreier, 2009). This paper considers the need for, and basis of, such a new management and planning direction and illustrates some of the advantages and opportunities that might accrue from mitigating approaches that more closely mimic the pre-urban water balance. Such approaches require a better understanding of hydrologic processes and urban land use factors in order to achieve more sustainable watershed planning.

1. The impermeable surface model

The traditional growth model for urban expansion depicts an exponential relationship between the expansion of the impervious surface and receiving water runoff volume and quality (Figure 1). There is also a widespread belief that the onset of impacted conditions as measured by biotic diversity commences at a baseline of between 10% - 15% impervious cover (IC) with non-sustaining, in-stream aquatic ecologies being evidenced at impervious levels exceeding 40% - 45% (Brabec *et al.*, 2002). Inspection of Figure 1 would suggest that even a threshold of 25% IC might lead to severely impacted conditions under which receiving water quality and aquatic biodiversity becomes significantly depressed. The traditional impervious model, particularly when based on effective impervious area (EIA), also assumes that permeable areas such as open spaces, parkland, gardens etc., do not contribute to runoff. However, such impervious cover modeling predictions are highly generalised and cannot be universally applied to all urban receiving waters (CWP, 2003). Prior water diversions, riparian alterations and land drainage works are all likely to already have degraded the "greenfield" site before development whilst low gradients (<1%) ameliorate the negative effects of initial impermeable cover. On the other hand, there is evidence that riparian woodland, shrub and other vegetative growth tends to mitigate the impact of impervious cover and this appears to be particularly the case for geomorphic and biodiversity indicators which do not degrade much below 15% IC (Cianfranci *et al.*, 2006) in the presence of such vegetation cover.

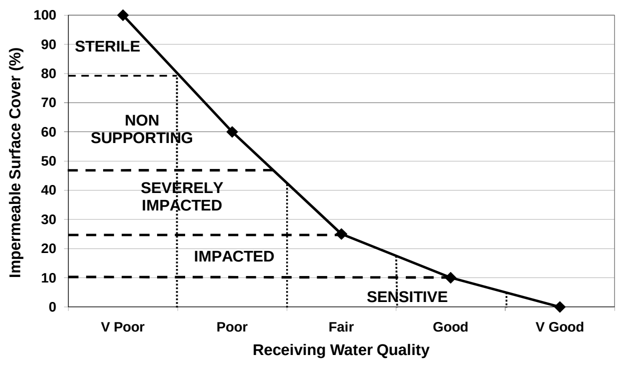

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Figure 1. The impervious cover model

There is considerable supporting evidence that a significant riparian vegetative cover serves at least to suppress the onset effect of urban growth on receiving waters by up to some 15% - 20% impervious cover (Wang *et al*., 2001). Aquatic ecosystems appear to be much more sensitively impacted by the yield of and exposure to toxic sediment within the contributing sub-watershed(s) than by most other urban growth factors. Watershed metrics other than impervious cover, such as percentage vegetative cover and open space or road density might prove to be more appropriate indicators of urbanization, with vegetated cover being effectively the reciprocal of impervious cover. The outcomes of second-generation BMP systems on the receiving water flow, quality and ecological regime need to be considerable to be detected given the statistical variability in the impervious cover model, especially at IC levels less than 10% - 20%. However, pollutant load reductions by BMPs in sub-catchment receiving waters can be normally detected as long as the IC does not exceed 30% - 40% (CWP, 2003).

The confirmatory evidence for receiving water improvements following BMP introduction for the control of impervious surface runoff is both scarce and contentious. Washington state for example, has introduced over many years, like many other US states, a widespread BMP approach for the mitigation of stormwater impacts, but most second-generation structural devices have proved inadequate to prevent downstream channel erosion, despite increasingly restrictive designs (Bath et al., 2002). It is argued that structural retrofits to urban drainage have also been largely unable to restore pre-development flows or habitat regimes, and that the fundamental cause of aquatic degradation is the conversion, even at very low levels of impermeable surface cover, of riparian forest, woodland and grassland. Woodland and shrub vegetation together with the introduction of riparian buffer zones combined with carefully optimized design of both storage (to control peak flows) and infiltration (for recharge) BMP facilities are seen as the only means of providing aquatic ecosystem protection in the presence of increasing impermeability (Horner *et al*., 2001; CWP, 2003; Cappiella *et al*., 2005).

2. The urban water balance

2.1 Effect of the impervious surface

The extension of impermeable surface cover produces an impact on the local water balance with surface sealing increasing the active effective-runoff area, whilst at the same time increasing surface compaction also decreases the infiltrative capacity. This process relationship is traditionally expressed in the urban water balance equation as: Precipitation (Rf) = Evapotranspiration (ET) + Infiltration (INF) + Impermeable Surface Runoff (IMPr), where IMPr normally refers to the effective impervious area (EIA) of the watershed. Compaction to soil bulk densities exceeding 1.5 gm/cm^3 can be considered as an inevitable side effect of urbanization with surface "sealing" resulting from a combination of original development compaction, vehicle parking and pedestrianisation (USDA, 2001). Urban open spaces, highway verges, parks and playing fields are likely to have higher impermeabilities than "natural" open spaces in rural surroundings, and this can result in substantial contributions from wetted "pervious" areas to overland exceedance flows during extreme storm events. Under these exceedance conditions, the IMPr term in the urban waterbalance equation exceeds the total impervious area (TIA). Such "pervious" flow volumes and overland routing have yet to be fully considered within the majority of urban runoff models. Surface sealing and compaction will therefore result in increased overland runoff flow with runoff volume being generally linearly related to urban land use type and activity as illustrated in Figure 2 based on water balance studies in the UK and Germany (Ellis, 2009b) and confirmed by very similar results reported for Canadian cities (Marsalek and Schreir, 2009).

It has been argued that such hydrological adjustments also result in shorter surface detention times, thus diminishing both evaporation and groundwater recharge. It is certainly the case that reductions in interflow, shallow and deep infiltration processes have characteristic reducing footprints in the urban water balance as impermeable cover increases (EPA, 2005), and this is evident from inspection of Figure 2. However, as also seen from the figure, both shallow and deep infiltration as well as evapotranspiration (ET) remain substantial components of the overall water balance at impervious covers less than 35% or so. This is largely due to the significant depression storage and initial losses that can occur on impermeable urban surfaces and which have been underestimated in most urban runoff modeling studies (Brabec *et al*., 2002; WaPUG, 2004).

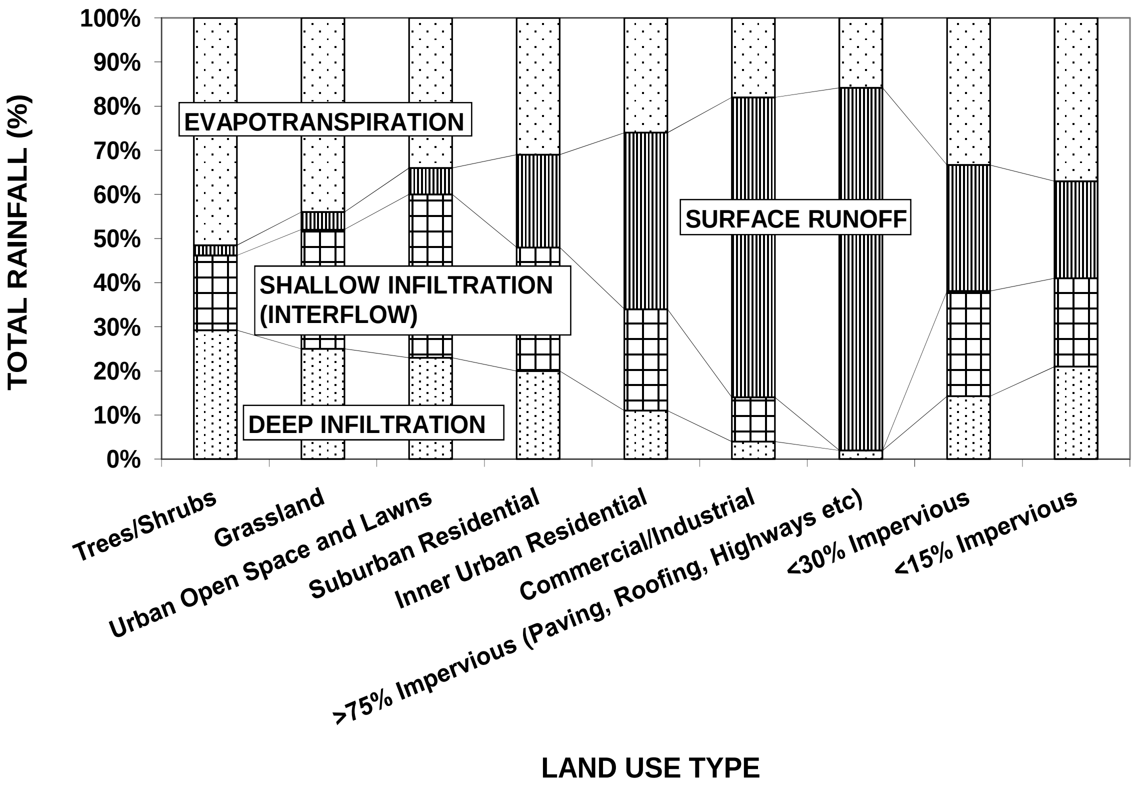

Figure 2. The urban water balance.

Macro (surface roughness), meso (surface puddles) and macro-storage (total connectivity to the drain) components of overall depression storage can add substantially to initial losses (Ellis and Revitt, 2008). Studies in metropolitan Manchester and London in the UK have indicated that residential land use covers up to 50% of the total urban area with medium density housing accounting for some 37% (Gill *et al*., 2008). It is within this latter dominant category that 32% of potential ET surfaces are found e.g lawns, hedges, grass verges, shrubs, trees etc; features which are not commonly represented by traditionally mapping approaches. Lack of inclusion of these types of surface cover will underestimate the ET and INF losses from total impermeable surface runoff. The Grimmond and Oke (1986) model also predicts that "isolated" urban depression storage patches will lose water at enhanced evaporative rates due to the provision of sensible heat from surrounding drier (and frequently hotter) impermeable surfaces. In addition, strong mechanical wind turbulence set up by the uneven urban building profile and boundary conditions results in a vigorous surface-boundary layer effect increasing the evaporation potential.

There is also long standing field evidence that so-called impermeable surfaces can infiltrate significant quantities of both surface water and micro-pollutants (Ellis and Harrop, 1984; Hollis, 1997). This is particularly the case for bitumen (blacktop) surfaces where pore openings, potholes, hollows and cracks develop, especially along and adjacent to roadside gutter channels. Irrigation experiments have indicated that up to 80% of applied surface water on asphaltic, low trafficked street surfaces does not find its way to the gullypot but is either held on the surface or infiltrates into the sub-grade (Hollis and Ovenden, 1988); peak runoff showed an attenuation of 24% for 5 minute rainfall intensities. Laboratory testing of differing paving materials has confirmed the high evaporative and infiltrative capabilities of bitumen surfaces, primarily resulting from depression storage and subsequent evapotranspiration and infiltration (Mansell and Rollet, 2007). Figure 3 shows the distribution of total monthly rainfall from isolated small rainfall events.

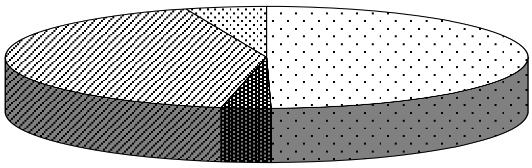

Figure 3. Percentage distribution of water balance components for storm events of <1:5 return interval (RI).

Thus apparently impermeable surfaces can be subject to high and variable losses and therefore conventional water balance modeling of rainfall-runoff overestimates for frequent, low magnitude storm events (<1:5 RI) but also significantly underestimates runoff volumes for infrequent, high magnitude extreme events (>1:30 RI). This has implications for BMP planning which frequently results in over-sizing of treatment devices and particularly in the case of storage BMPs such as detention/retention ponds and wetlands.

2.2 The influence of vegetative surfaces

Streets and highways comprise the most significant flow and pollutant sources and conduits within the urban environment, and serve as primary conveyance pathways to move surface water from rooftops, lawns, driveways, pavements/sidewalks and the street surface itself. Street edge alternative (SEA) retrofitting involving re-vegetation of the impermeable urban surface, not only can attenuate and phyto-remedially treat the final cumulative impermeable surface runoff at source, but can also improve neighbourhood aesthetics, calm traffic flows and act as focal educational centerpieces. Roadside SEA retrofits are ideal planning alternatives in that they deal with the most polluted fractions of impermeable surface runoff whilst at the same time local costs are minimized since the retrofit is located in the dedicated right-of-way. In addition, vegetative introductions may be a viable option for runoff pre-treatment if structural retrofits prove not to be feasible. Biofiltration alternatives such as rain gardens, street planters, tree pits, pocket wetlands, buffer (filter) strips and modified swale channels will enhance both evapotranspiration and infiltration rates such that a100% retention of small rainfall events (<1:1 RI) can be achieved. Field monitoring of SEAs in Seattle, Washington state have observed up to 99% reduction in total volumes of stormwater discharging annually from the street surface (Horner *et al.*, 2002). The capture of such high levels of runoff volume will also give a complementary reduction of up to 65% - 75% of total suspended solids on a long term average basis (Hunt and Lord, 2006).

Such rain gardens, street planters, tree pits and biofiltration features have become common design elements in Low Impact Design (LID) approaches and can make substantial contributions in re-aligning the urban water balance towards "natural" pre-development conditions (Ellis et al., 2004). As yet there have been few studies to attribute the observed rainfall losses to either of evaporative, interflow, shallow or deep groundwater receptors. However, there is an implicit assumption in the prevailing studies of these bioretention facilities that the majority pathway is by infiltration to groundwater (Dietz and Clausen, 2005), hence the recommendation for lining and/or underdrains where there is a potential threat from toxic first-flush pollutants from the road surface and for a minimum 250 - 300 mm amended topsoil cover (Pitt *et al*., 2005). The previous discussion of the urban water balance distribution however, suggests that this assumption may be incorrect, as the dominant losses appear to be associated with ET following on from initial depression storage.

Small scale bioretention retrofits can also be implemented for cycle tracks, play and recreational areas, driveways and playing fields. These retrofits may comprise grass filter (buffer) strips, grass channels or small infiltration and porous paving devices, and may only make up some 5% or so of the total impervious area within the urban sub-catchment. However, they can be readily retrofitted, are low cost options and can help to solve site drainage problems. Vehicle parking areas (> 1.5 – 2.0 ha) also offer good biofiltration opportunities (e.g tree pits, planters, mixed woodland/shrubs, grass filter strips, vegetated swales), especially as more recently constructed parking sites have more generous setbacks for screening, landscaping, noise reduction etc.. Perimeter and island bioretention approaches, together with porous surfacing, can also be used very effectively on smaller vehicle parking sites. Within the larger urban sub-catchment, there is considerable evidence now available to demonstrate the significant reduction in runoff that can be achieved by the introduction of site vegetation and riparian corridors, particularly for low intensity, short duration rainfall events, as evidenced for example in the Baltimore studies of Wang *et al* (2008) or the Vancouver investigations of Asadian and Weiler (2009). The latter studies indicated an urban canopy interception varying between 50% to 61%, corresponding to a net annual loss of 20 – 32 mm of rainfall-runoff.

It is also clear that ET may well be the major factor in determining how much water is available for infiltration and as such, represents the controlling component of the urban water balance profile. Effective stormwater BMP design needs to consider the relative significance of the various water balance processes as well as their seasonal variations. Design approaches which aim for landscape or watershed-scale infiltration which preserve the natural ET pump mechanism as much as possible would considerably improve overall performance. This objective would be supported by the introduction of two- (or even three-) tier vegetation for biofiltration BMPs to maximize the canopy cover. The adoption of a dense, multi-layered vegetation (grass, shrubs and trees) for these BMPs would represent a fundamental shift in the existing rather cosmetic design guidelines for second generation drainage systems.

3. A third generation drainage approach?

3.1 Basis and need for a new approach

Given the contentions and speculations associated with the traditional impervious area cover model and the analysis of the urban water balance, what then are the "best" management practices to provide receiving stream and channel protection as well as water quality and recharge benefits? The foregoing analysis would suggest that there are critical urban land use components which are necessary if a more natural and sustainable water balance and drainage system is to be achieved:

- minimization of impervious areas, local land disturbance and surface compaction. This planning precept is to some extent being recognized with for example, new stormwater regulations for Maryland, US requiring that all re-development sites reduce existing impervious surfaces by at least 50%.
- (re)-introduction and preservation of site and sub-catchment vegetation cover and open space,
- preservation of critical ecological zones such as riparian corridors, wooded wetlands, floodplains etc..

These three primary land use strategies offer basic planning steps to the restoration of an effective urban water balance, the restoral of watershed functions and a framework to ensure adequate water resource protection (Cappiella *et al*., 2008).

The majority of national BMP guidance provide broadly similar design outcomes despite major advances in BMP research that has taken place over the past 5 to 10 years. The majority of design guidance manuals derive narrative tables for the water quantity and quality effectiveness of differing stormwater management practices for different pollutant groups and water balance re-adjustments e.g groundwater recharge, peak runoff and volume controls. Other potential secondary benefits e.g landscape enhancement, recreation/amenity, community acceptance, safety etc., are also often superimposed in the decision-path analysis to identify a suite of recommended BMP devices. The similarity of design guidance outcomes and recommendations can be interpreted as implying that many BMPs being installed may not be applying the most effective or innovative technology and that far too many poorly or under-performing BMPs exist as well as being overdesigned in many cases in terms of water quality performance. This conclusion is confirmed to some extent by reports of failure or under-performing BMP controls, particularly infiltration systems (Schluter and Jefferies, 2005).

A new design approach paradigm may be needed which considers the effect of impervious cover growth from rooftop to the receiving water with the approach specifically aimed at the restoration of more "natural" pre-development water balance conditions (Schueler, 2004). This third generation approach should focus on better low impact site design (LID or cluster development), with a substantial preservation and/or re-introduction of vegetative cover (with a target minimum 30% - 40% canopy cover) within the development, infill or retrofit (Ellis *et al*., 2004). Such percentage canopy cover can increase interception by up to 40% of the total rainfall event depth, retaining between 0.5 – 3 m^3/day and maintaining infiltration rates of up to 30 cm/hour. This level of canopy cover is important to maximize interception, ET and pollutant phytoremediation rates as well as providing shade for the impermeable surface, thus ameliorating the "heat island" effect. The basic aim should be to restore or maintain the original pre-development water balance as much as possible such that vegetative cover should be capable of providing at least the first 10 - 15 mm of stormwater retention and treatment. This would then enable second generation BMPs to offer a more effective attenuation and "polishing" function over a wider range of storm event return periods, providing greater capability for enhanced and sustained receiving water health.

3.2 Vegetation-based source BMPs

As previously argued, streets and associated impermeable surfaces comprise the major source of runoff volume and pollutant loads and it is this general land use category on which the planning focus of BMP approaches needs to be placed to achieve a fully sustainable urban drainage system. One significant vegetative control device incorporated into LID practice is the rain garden or street planter and which is sometimes termed a pocket wetland in European practice. Rain gardens represent a scaled-down combination of infiltration and biofiltration devices. Stormwater runoff from the impermeable surface is diverted into a local hollow where it can percolate through an organic filter medium such as a compost or amended topsoil layer (Pitt *et al.*, 2005). An overflow spillway or overland flow path normally allows for larger storm events which exceed the filtration and retention capacity, although overflow can be by means of a surface pipe. Some of the collected stormwater will percolate down to contribute to interflow and shallow groundwater, with the remainder being discharged off-site via underdrains. In vulnerable groundwater zones, an impermeable geotextile liner can be introduced to prevent infiltration into the underlying unsaturated zone.

A dense low vegetation cover, low water velocities and extended retention times to enhance evapotranspiration are required to ensure performance effectiveness. Curb-cuts can allow exceedance water to flow "downstream" from one rain garden to the next, or to facilitate discharge into an adjacent swale or back into the road gutter channel for entry into a conventional roadside inlet. Such consecutive rain garden cells essentially comprise a cellular treatment train and can achieve high levels of vegetative "canopy" cover within the impermeable area. Such elongated vegetated cells have a long flow path length and high surface roughness along the flow path which increases the time of concentration and residence times. The 2ndAvNW Seattle SEA fully contain and convey the 1:25, 24 hour duration storm event and are capable of detaining up to 60 m^3 within the conveyance system. The SEA is estimated to reduce the IC for the 1 ha residential block by at least 10% (Horner *et al*., 2002).

The utilisation of curb extension planting into SEA design, as well as pavement/sidewalk tree pits and trenches can be readily incorporated into the green street approach with the extensions also providing traffic control measures through reductions in road width. Tree pits serve as mini-detention "puddles" capturing runoff from the paved surface. The use of tree pits set in permeable pavements with a continuous soil trench connecting the pits under the sidewalk, provides a shared soil volume for the vegetation and infiltration devices. Disconnected roof leaders/downspouts can also discharge to such pavement pits and trenches. However, such bioretention facilities need to be used conjunctively in an integrated planning design as they individually have a limited hydraulic capacity. High density cluster development and vegetative landscaping needs to be accompanied by extensive rooftop disconnection, green roofs and where feasible and appropriate, rainwater harvesting (tank storage).

3.3 Costs and performance

Construction costs per hectare of build type need to be identified which incorporate such plot-based biofiltration BMPs and which should comprise an integral element of normal planning design for urban surface drainage. One US study suggests that rain garden retrofits cost (at 2006 prices), between US$140 – 1000 per m^3 stormwater treated, tree pits $250/$m^3$ and grass swales/filter strips $400 – 550/$m^3$ compared to $400 – 1300/$m^3$ for green roofing

(Schueler *et al*, 2007). Grass channel (swale) performance can be as high as 70% - 80% when combined with a high (>70%) vegetative cover and will also require less efficient underdrainage (Hunt and Lord, 2006).

Such bioretention systems can reduce runoff volume by anything between 25% - 60% as a result of evapotranspiration (ET) and infiltration (INF) loss. The key factors in such reductions are soil type and depth as well as local hydraulic gradients. However, adequate and regular vegetation management would also be a key maintenance task for sustained system performance. Post-development instability within the contributing drainage area, poor soil media and adverse elevation and gradients can all affect on-going performance. In areas of potential groundwater vulnerability, infiltrative BMP systems should require mandatory underdrain and surface overflow facilities. The inclusion of green roofs and downspout disconnection into urban green infrastructure would also provide average site volume reductions of up to 34% with peak volume reductions of up to 60% for storm events up to the 1:10 RI period. The combination of such plot and site-based management practices could reduce sediment and bacteria yields by up to 90%, metals by up to 65% and nutrients to between 35% - 60% as well as offering substantial runoff control and help restore urban receiving water ecology (Walsh *et al*., 2005). However, it must be remembered that street runoff can discharge elevated levels of micropollutants such as metals and hydrocarbons which can accumulate on vegetation surfaces and in the surface soil layers of SEA BMPs. Theses biofiltration devices should be maintained in dense vegetation to prevent dust generation and surface soils may need landfill disposal. H
Schueler *et al* (2007) contend that such site-based, integrated micro-biofiltration approaches can address and protect flood, water quality and in-stream erosion objectives up to as much as 40% impermeable cover levels and that they might even be feasible up to 60% IC levels depending on local circumstances. However, to ensure long term performance effectiveness, these vegetative controls should be complemented by optimization of existing site and end-of-pipe second generation BMPs, together with the implementation of advanced treatment techniques to deal with pollution "hotspots", all of which require strict regulatory and planning controls to be successful. Community surveys of resident demand for, and use of, open/green spaces and green infrastructure would also help support municipal planning programs.

3.4 "Leaf-Out" inventory and analysis

Inventories of existing as well as potential vegetative and open space areas within an urban sub-catchment can be derived from GIS survey and/or satellite imagery. Cappiella *et al*., (2005) have described this quantification of potential vegetative canopy cover as "leaf-out" analysis. Such areas would include gardens, parks, playing fields, institutional grounds, bare, derelict and vacant ground, as well as other open space in addition to existing wooded and shrub areas, all of which constitute potential re-vegetation locations. Future planned land use zoning and site development can be superimposed on the leaf-out analysis to identify locations that may be candidates for the introduction of biofiltration SEAs, green roofs, small scale urban forestry, green corridors etc. Adjustments to runoff coefficients resulting from "leaf-out" third generation BMP implementation can be estimated from upgraded water balance models to determine their potential effects upon total and peak runoff volumes as well as pollutant loadings and to assess their effects upon the local water balance (Viavattene *et al*., 2008). The results would also help support the predictions of receiving stream health and ecosystem survival for watershed planning and to support local community environmental stewardship.

4. Conclusions

A feasible strategy to counteract the negative effects of increasing impermeable cover is to develop roof and street vegetative BMPs together with green riparian corridors within sub-catchments, linking open space fragments to increase biodiversity and migratory capacity of both flora and fauna. Such corridors will also provide a connection from the site to the watershed scale as well as offering opportunities for the promotion of local community environmental stewardship. The widespread implementation of roof and SEA retrofits and riparian corridor vegetation together with BMP optimization would provide an appropriate environmental infrastructure framework within which such stewardship could be fostered.

The application of a multi-layered, sub-watershed based approach to urban drainage which jointly and concurrently considers both plot and site infrastructure is needed to enhance the implementation and performance of second generation stand-alone and/or treatment train BMPs. A more intensive planning and regulatory approach which emphasises the importance of retaining or re-establishing the original water balance through reduction or control of impervious cover effects using vegetative surface controls can offer a further means of achieving sustainable urban watershed management. Such passive planning manipulation of the urban micro-climate and water balance through extending green space and infrastructure to maximize evapotranspiration and infiltration processes, can derive clear returns for community investment.

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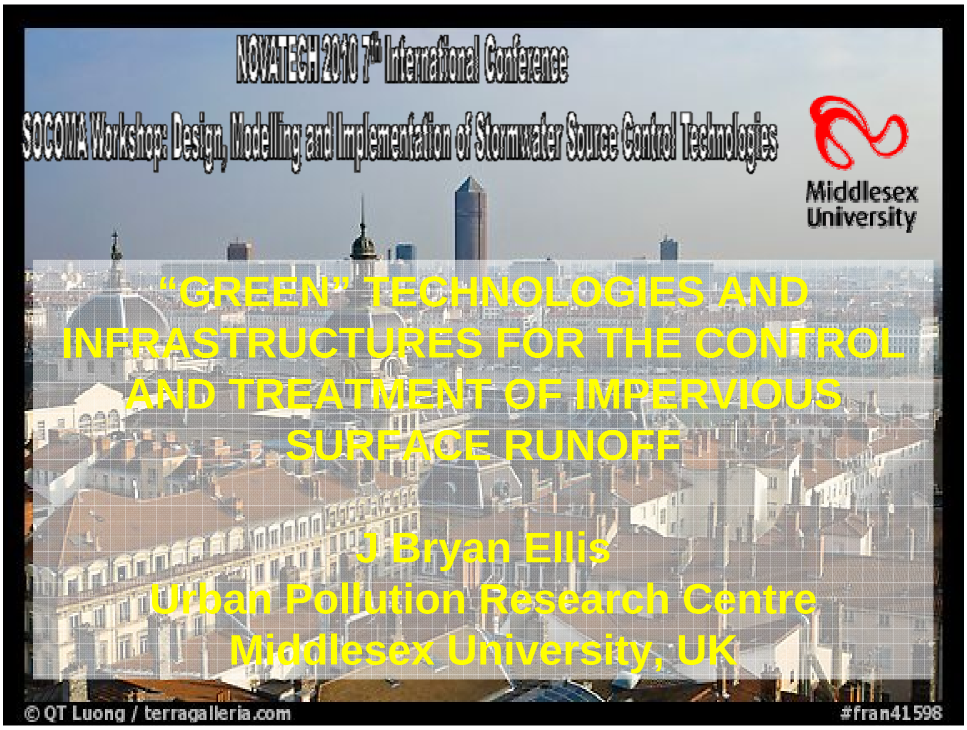
ELEMENTS IN FAVOUR OF SOURCE CONTROL: THE EXPERIENCE OF THE FRENCH ON-SITE OBSERVATORY OTHU

S. Barraud, Lyon 1 University / INSA Lyon &

A. Foulquier, Lyon 1 University, France


NOVATECH 2010 7th International Conference
SOCOMA Workshop: Design, Modelling and Implementation of Stormwater Source Control Technologies
Middlesex University
"GREEN" TECHNOLOGIES AND INFRASTRUCTURES FOR THE CONTROL AND TREATMENT OF IMPERVIOUS SURFACE RUNOFF
J Bryan Ellis
Urban Pollution Research Centre
Middlesex University, UK
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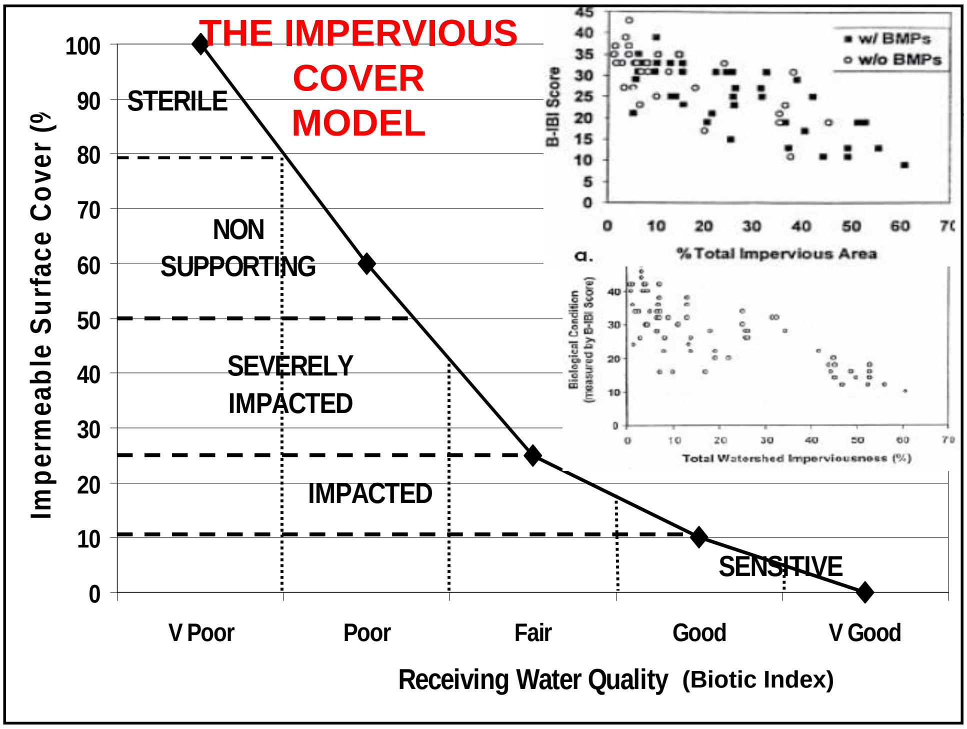
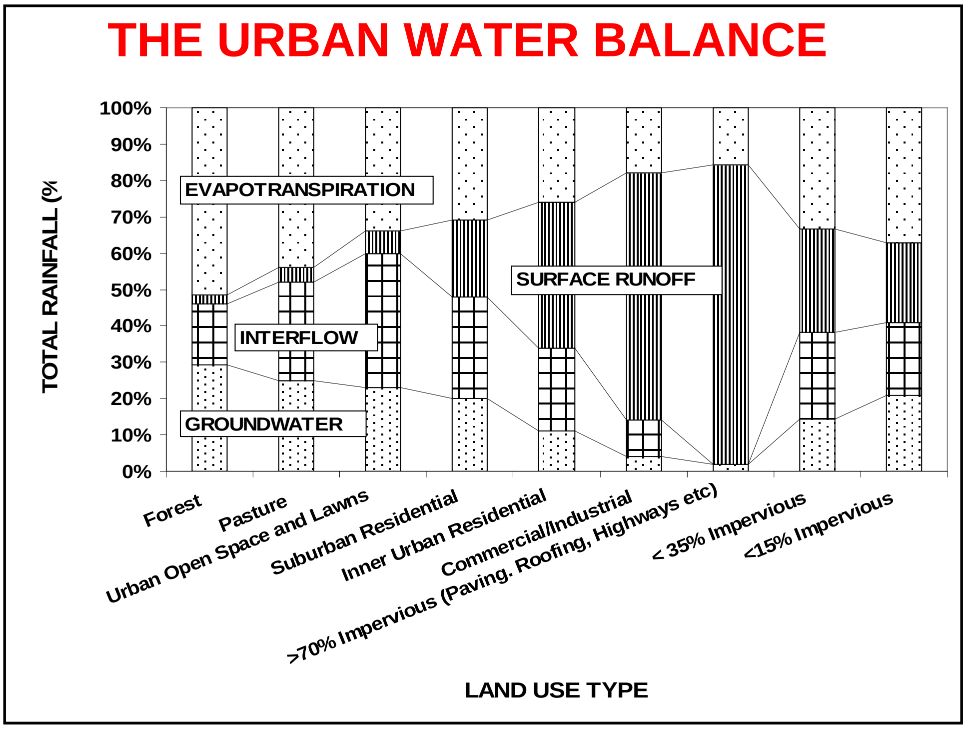
#fran41598


1st GENERATION DRAINAGE
DON'T DUMP
DRAINS TO
CHARLES
RIVER
2nd GENERATION DRAINAGE


THE IMPERVIOUS COVER MODEL
Impermeable Surface Cover (%
100
90
80
70
60
50
40
30
20
10
0
STERILE
NON SUPPORTING
SEVERELY IMPACTED
IMPACTED
SENSITIVE
V Poor
Poor
Fair
Good
V Good
Receiving Water Quality (Biotic Index)
B-IBI Score
w/ BMPs
w/o BMPs
% Total Impervious Area
a.
Biological Condition (measured by B-IBI Score)
Total Watershed Imperviousness (%)


THE URBAN WATER BALANCE
TOTAL RAINFALL (%
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
EVAPOTRANSPIRATION
SURFACE RUNOFF
INTERFLOW
GROUNDWATER
Forest
Pasture
Urban Open Space and Lawns
Suburban Residential
Inner Urban Residential
Commercial/Industrial
>70% Impervious (Paving. Roofing, Highways etc)
< 35% Impervious
<15% Impervious
LAND USE TYPE

ET IN THE URBAN WATER BALANCE

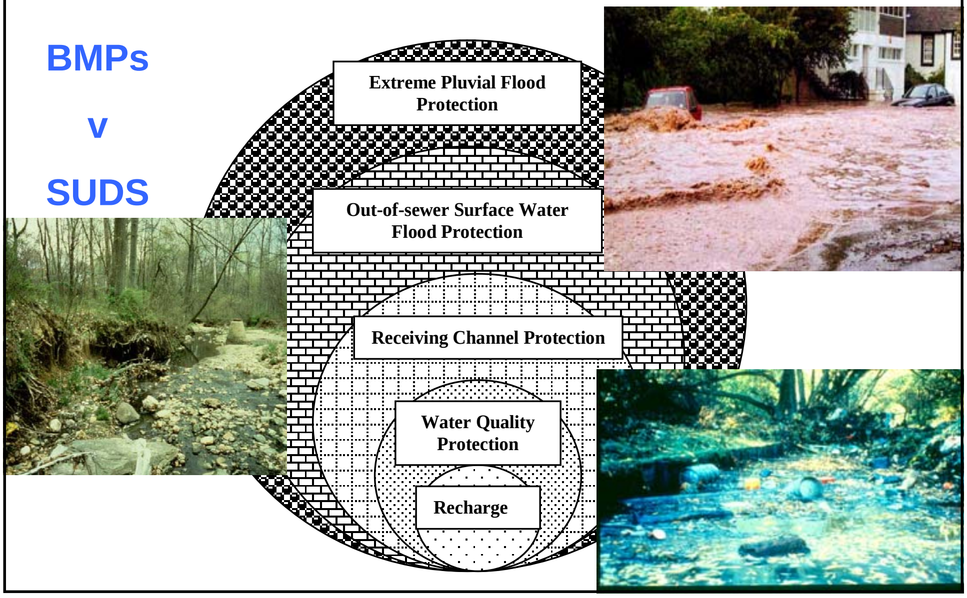
- Can be strongly affected by local conditions e.g climate, soil, topography etc. In arid regions for example, ET under a development scenario can be at least 80% - 97% of pre-development water balance.
- Application of deep infiltration techniques will almost certainly lead to infiltration levels greater than which "naturally" occur. Widespread recharge could exacerbate already high WT levels resulting in changes to local habitat (ephemeral streams to perennial; lengthening flow durations; changes in riparian vegetation) as well as subsoil geotechnical changes.
- ET is function of area available for ET along with storage capacity. If pre- v post-ET areas are unequal, it could be difficult to make this up with storage, especially for "back-to-back" storm events.
- Matching pre-and post-ET under dense development (such as Smart Growth/LID) may NOT be a realistic objective, especially for rainfall patterns that limit the time of ET storage recovery between events.
- Dense urban development is likely to always have to manage excess runoff rather than rely on infiltration/recharge.

URBAN SURFACE WATER DRAINAGE LEVELS OF PROTECTION HIERARCHY

BMPs

v

SUDS



FROM ROOFTOP TO RECEIVING WATER

- Better site design; enhanced LID, Smart Growth, retrofit etc

- IC minimisation (??? Could lead to urban sprawl); downspout disconnection and small scale infiltration

- Rooftop harvesting and treatment

- Site bioretention (rain gardens, street planters, soft street landscaping)

- Enhanced swale channels

- Sub-catchment BMPs (wetlands, retention/detention basins, infiltration basins)

- "Daylight" culverts

- Reforest streamside and "green" corridors

-Eliminate illicit connections

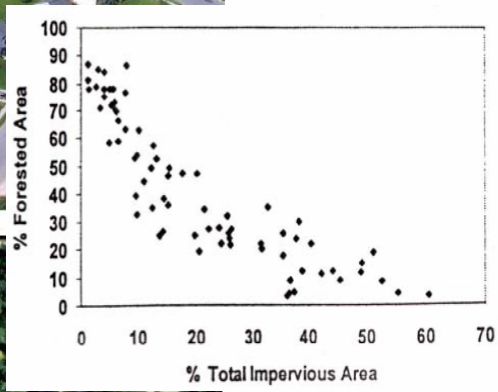
- Target pollution "hotspots" and better ind/comm housekeeping

- Increased public awareness and env campaigns; signage campaigns

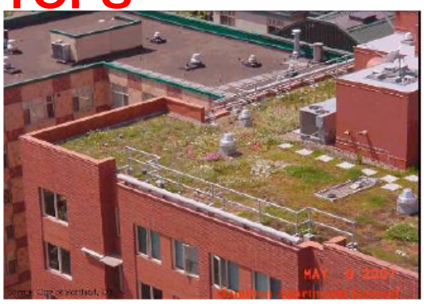
- Financial incentives and discounts for water saving storing schemes

- Enhanced organisational and administrative arrangements/support for wider stakeholder consultation

BETTER SITE DESIGN



GREEN ROOFTOPS

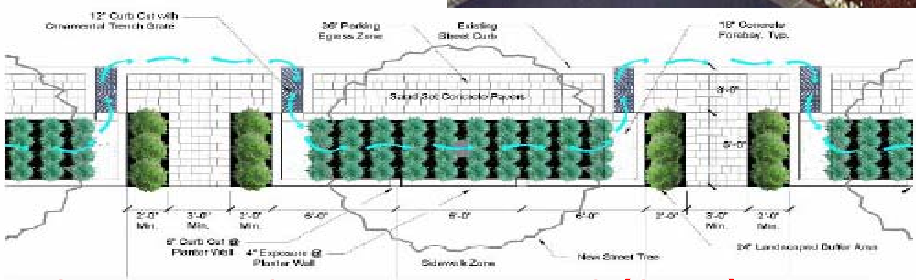


DOWNSPOUT DISCONNECTION

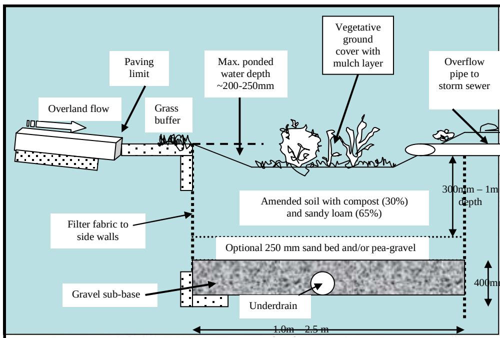
(With rainwater harvesting/reuse)

SMALL SCALE INFILTRATION

2nd Avenue NW SEATTLE



STREET EDGE ALTERNATIVES (SEAs)



STORMWATER RAIN GARDENS/PLANTERS

REGULAR MAINTENANCE

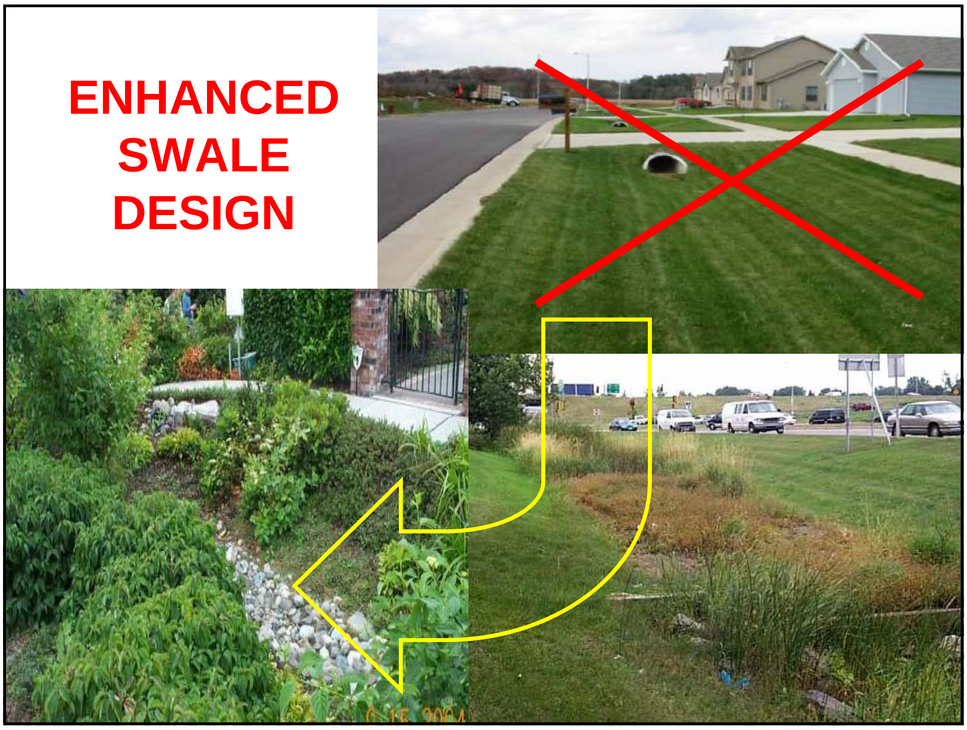
Bioretention can fail when:

Un-stabilized contributing drainage area

Poor media

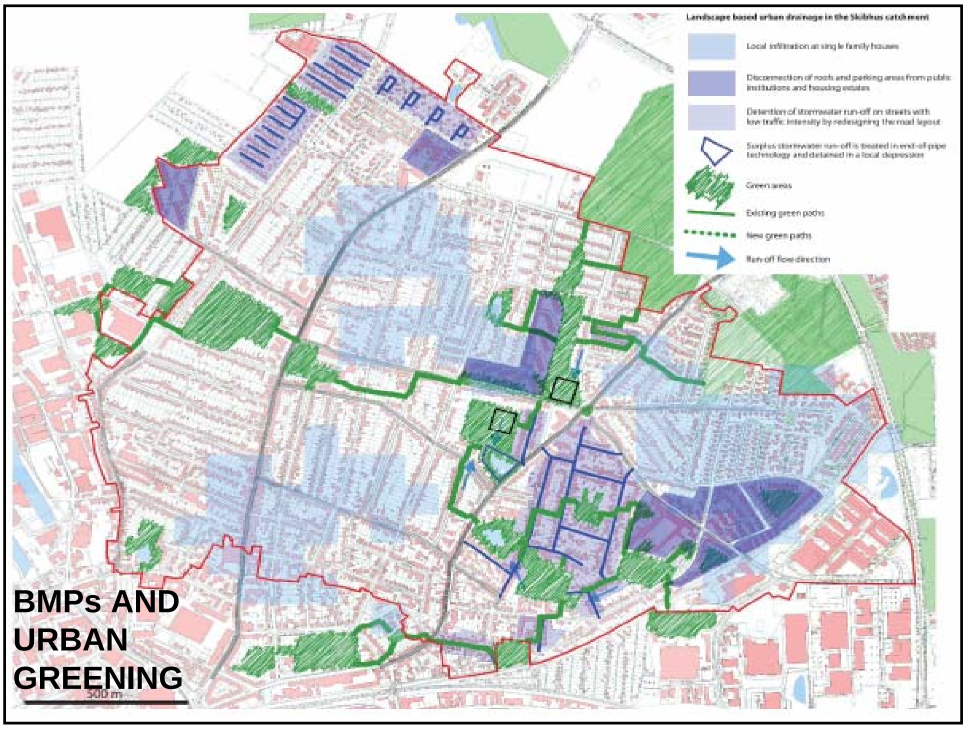
Bad elevations and grades

ENHANCED SWALE DESIGN



"FORESTED" WETLAND ECOSYSTEM

Below ground retrofits
Pollution hotspot operations
Small car park area retrofits
ON-SITE RETROFIT OPPORTUNITIES
Hardscape street conversions
Individual rooftops
Individual streets



Landscape based urban drainage in the Skibhus catchment
Local infiltration at single family houses
Disconnection of roofs and parking areas from public institutions and housing estates
Detention of stormwater run-off on streets with low traffic intensity by redesigning the road layout
Surplus stormwater run-off is treated in end-of-pipe technology and detained in a local depression
Green areas
Existing green paths
New green paths
Run-off flow direction
BMPs AND URBAN GREENING
500 m

3rd GENERATION STORMWATER DRAINAGE

Multi-layered, top-down and bottom-up approaches; address full range of flow events

Jointly and concurrently considers plot, site and sub-catchment infrastructure design

Enhanced LID basis (with modelling) and retrofitting

Focussed on vegetative “leaf-out” analysis; 20%-30% minimum vegetation cover and reduction/suppression of IC effects

Collaborative stakeholder agreement and public acceptance/awareness; fiscal support; supporting institutional frameworks and processes

Regular maintenance schedules

LESSONS FROM A CATCHMENT-SCALE PUBLIC & PRIVATE-LAND RETROFIT PROJECT

T. Fletcher & M. Burns

Monash University, Australia

NOVATECH 2010

Evaluating the multiple benefits of an allotment-scale stormwater retrofit auction

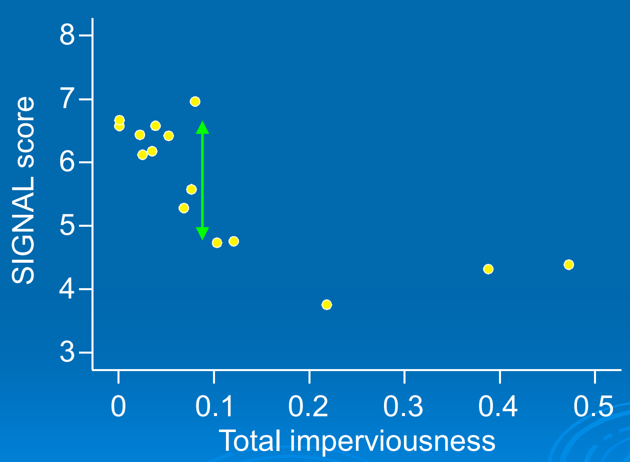
Tim Fletcher, Matt Burns, Chris Walsh, Darren Bos, Veronika Nemes, Sharyn RossRakesh, Toby Prosser, Belinda Hatt & Rhiannon Birch

Overview

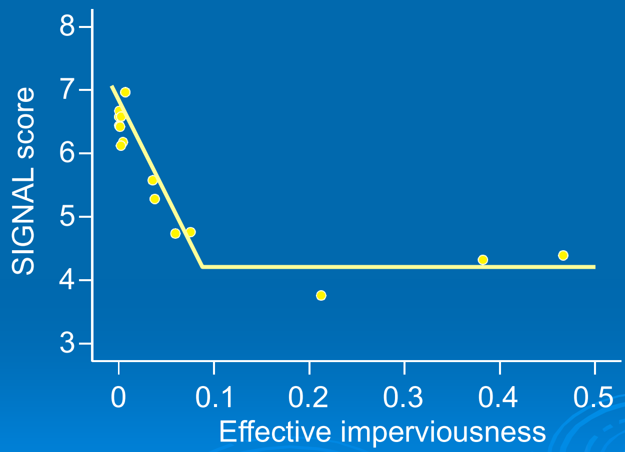
1. Introduction and motivation
2. Project objectives
   – Stormwater auction
   – Environmental Benefit Index
3. The auction process
4. The EB index
5. Results and lessons
6. Performance to date: monitoring

Introduction and Motivation

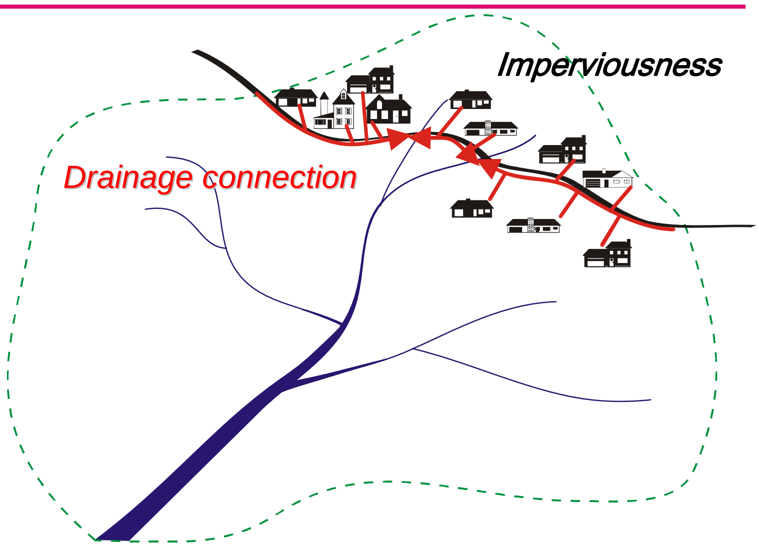
Total Imperviousness

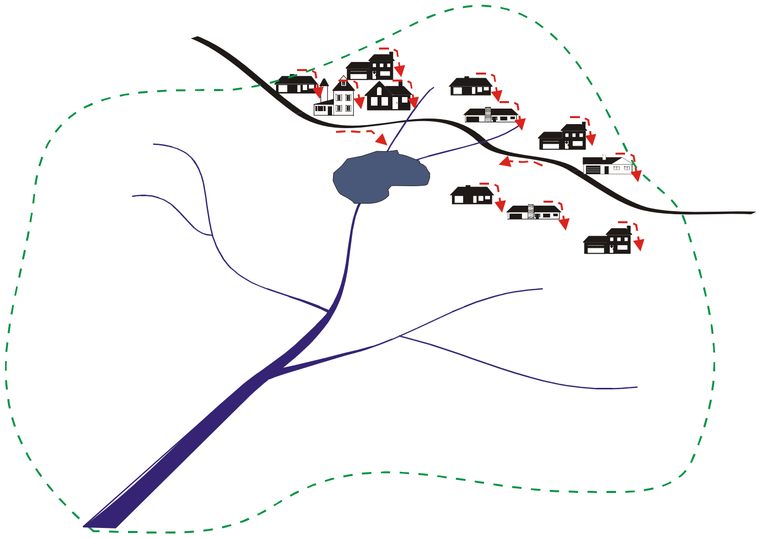


Effective Imperviousness

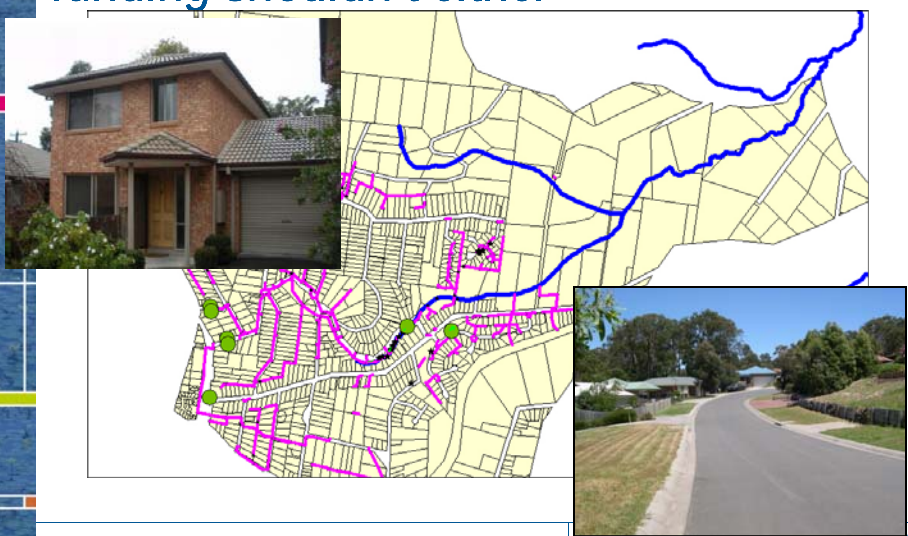


MONASH University
Institute for Sustainable Water Resources



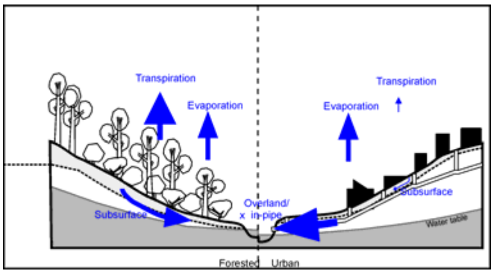


Stormwater doesn’t respect boundaries; *funding shouldn’t either*



How to compare proposed projects?

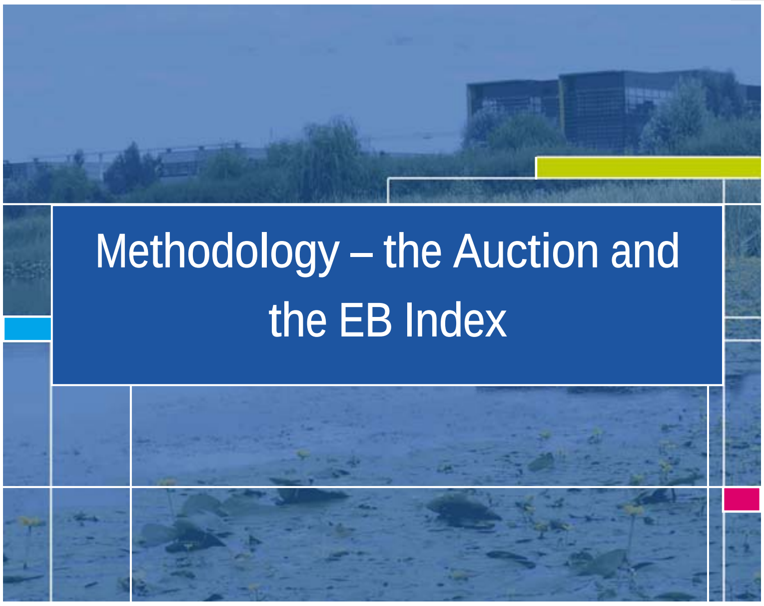
- Current targets simplistic
  - Loads-based reductions (TSS, TP,TN)
  - Suitable for large receiving waters only
  - Ignore the mechanisms of degradation



Objectives

- Test a new “stormwater auction” for funding stormwater retention works on public <u>and</u> private land

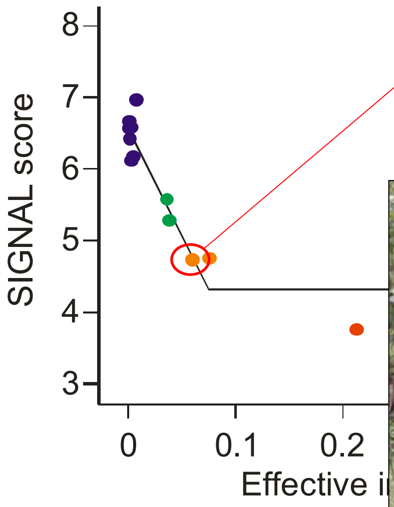
- Develop and test a new Environmental Benefit Index (EBI) for evaluating proposed projects:



Methodology – the Auction and the EB Index

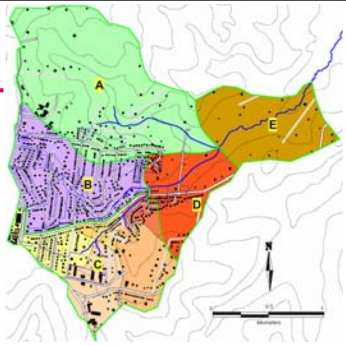
Study catchment

Hypothesis: good ecological state can be restored by restoration of hydrology and water quality



Trial application

- 450 ha catchment
- 13.5% impervious
- 1000 properties
- 750 'connected'
- Aim is to disconnect at least 50%



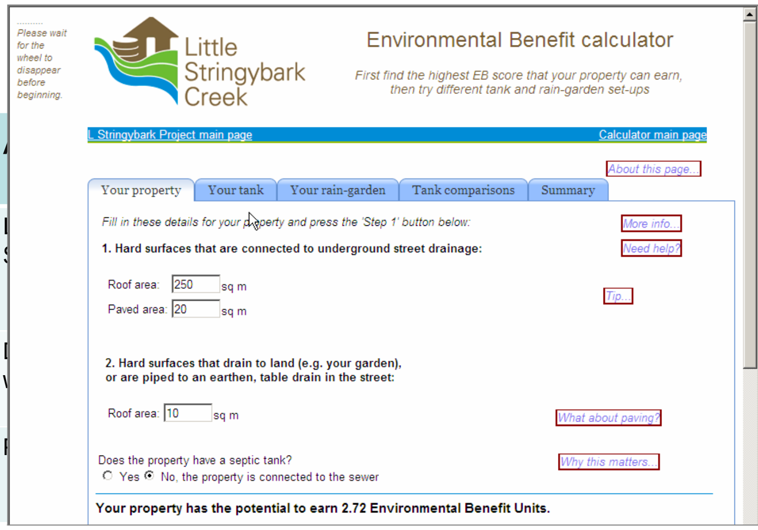
Stormwater Auction

- An auction, that 'purchases' environmental benefits of stormwater management / retention
- Provides a flexible financial incentive
- Uniform-price auction – standard payment per unit of environmental outcome
- Quantifies 'private' vs public benefit
- Communications avenue (pre & post-surveys)

Trial auction - communication

Communication by doing

The Environmental Benefit Index (EBI)



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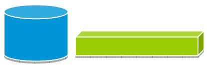
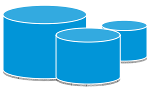
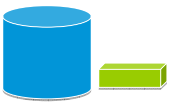
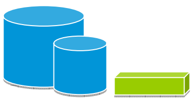
How the auction worked…

Bid (works)	Min. $	Environmental Benefit	$/EB
	$1,870	1.4	$1,335 / EB
	$1,050	0.8	$1,312 / EB
	$1,936	1.1	$1,760 / EB
	$3,100	2.4	$1,291 / EB

1. Reduction in runoff frequency (0.5)
2. Reduction in Total Nitrogen load (0.3)
3. Water savings (0.2)

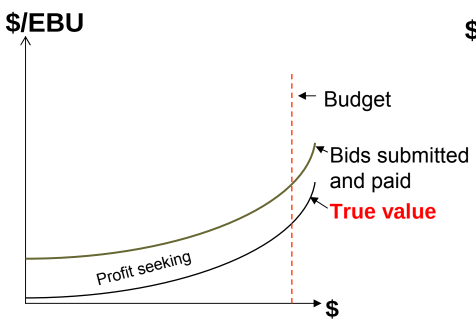
How the auction worked

Bid (works)	Min. $	Environmental Benefit	$/EB
	$1,870	1.4	$1,335 / EB
	$1,050	0.8	$1,312 / EB
	$1,936	1.1	$1,760 / EB
	$3,100	2.4	$1,291 / EB

Two (of many) auction models

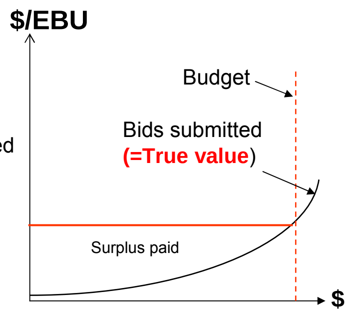
Discriminative vs Uniform price

Successful bidders are paid what they asked for



"My best strategy is to guess the cut-off point and bid at that level."

Successful bidders are paid the bid of the first unsuccessful bidder.



"My best strategy is to reveal my true 'minimum price' and if the price is above my ask, I will even be better off."

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Results

Auction results

750 eligible (connected) properties

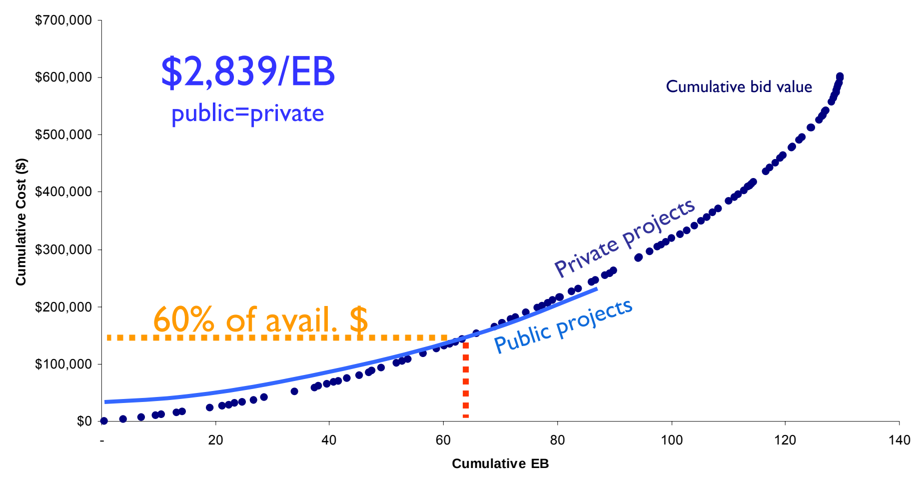
→ 303 expressions of interest (40%)

→ 103 bids (14%)

→ 59 projects initially funded (7%)

- **Owners paid 10% of cost, "state" paid 90%**

People weren't as pure as predicted

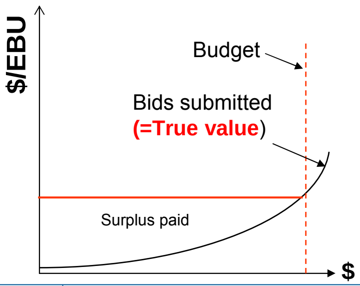


So we offered the 'cut-off' price to those who bid above it; 23 bidders accepted (saving us $43,000)

Lessons from the auction

- Generally very good community reaction, but
- Some people found it complex
- Auction process needs to be simpler
  - People 'profit-seeking' because they didn't understand

"My best strategy is to reveal my true 'minimum price' and if the price is above my ask, I will even be better off."



How to improve it? – 2nd phase

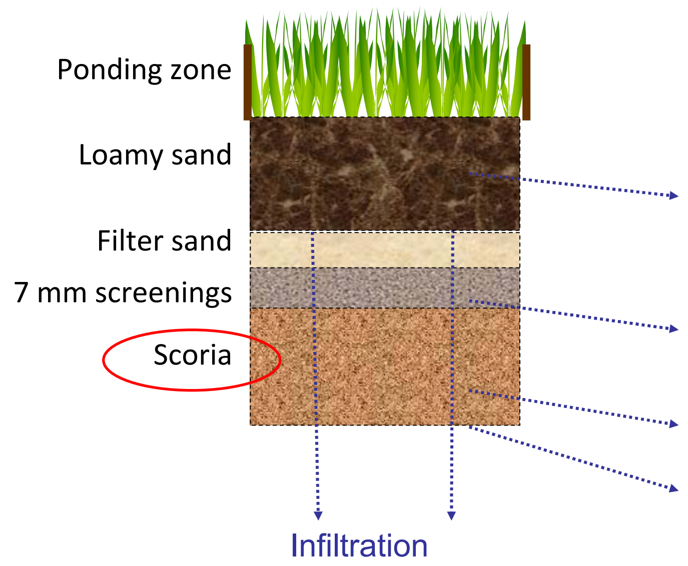
- Testing a simpler more 'assisted' incentive model:
  - Stormwater fund "calls" for projects at a set price per EB unit (e.g. $1500/EBU)
  - Up-front visit by plumber & project officer
  - Plumber gives quote project makes funding offer immediately
  - Price rises over time (e.g. every 60 days)
  - Landholder applies when the price satisfies their minimum price

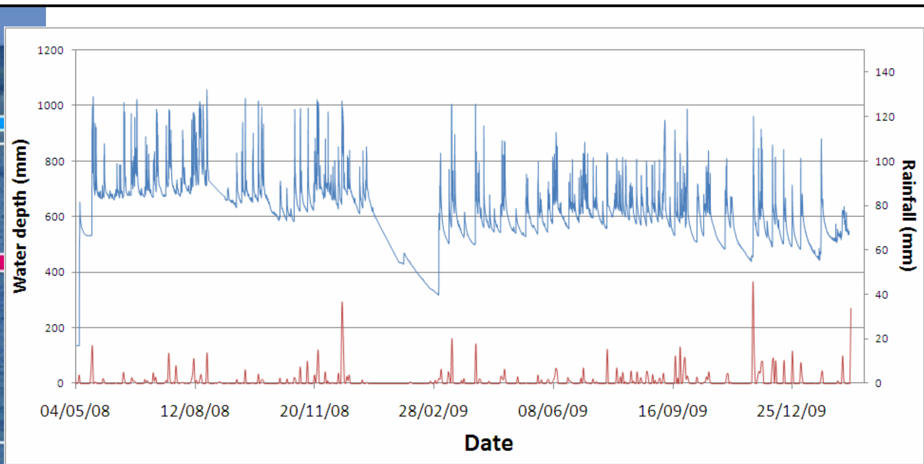
How are the systems working? – Monitoring

Hydrologic Monitoring

- Opportunities to monitor the hydrologic performance of real systems at a range of scales…

Example 1: Allotment scale rain-garden



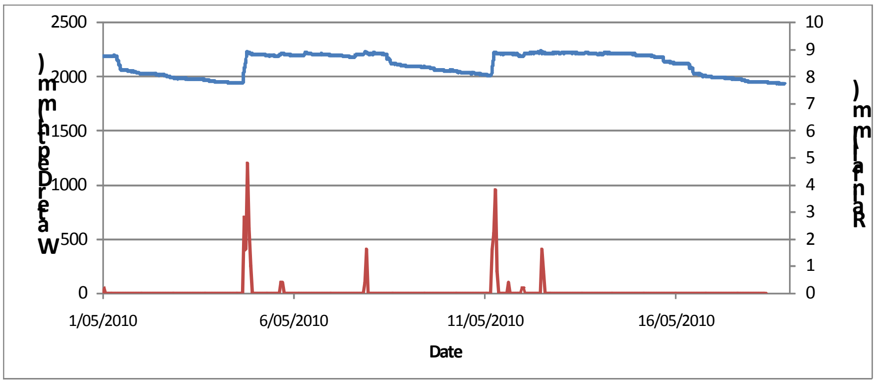


- Rare overflow
- Fast shallow exfiltration
- V slow deep exfiltration (most difficult soils in Melb)
- Substantial ET losses (increase with time)
- Near-complete restoration of block's hydrologic cycle

Example 2: Allotment scale rain-water tank

Medium sized tank (3500L) draining ~ 300 m² of roof servicing the indoor demands of two people

Example 2: Allotment scale rain-water tank

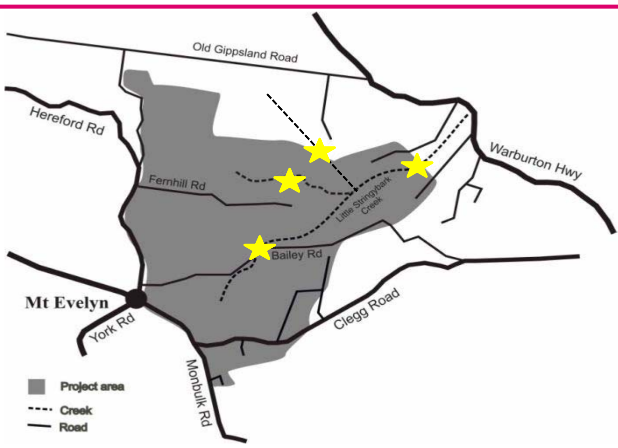


- Likely overflow a few times – emphasizes the need to connect overflow to garden or other system (e.g. rain-garden)
- Limited tank drawdown - potential to harvest more rainwater

Example 3: Streetscape scale – Infiltration Basin

- We plan to monitor the hydrologic performance of this system and others…

Example 4: Catchment Scale



- Currently monitoring streamflow at these four locations within our study catchment

LESSONS FROM THE SHEPHERD CREEK

B. Shuster

National Risk Management Research Laboratory, Office of Research and Development, USEPA, USA

EPA United States Environmental Protection Agency

The Shepherd Creek experience and some lessons learned

William D. Shuster, Matthew M. Morrison, Jake J Beaulieu,

Armah de la Cruz (NERL MCEARD), Dennis Lye (NERL MCEARD), and

Hale W Thurston

EPA United States Environmental Protection Agency

The notion of sustainability in environmental management

• We posit that two attributes of sustainable urban environmental management include **citizen participation**; and managing at the root of the problem with **source controls** that impart a systemic impact

• By engaging the interest of citizens and making SW management a part of everyday business, this may sustain the effectiveness of these approaches

• We therefore substitute **social and cultural capital** for the presently dominant **technological and natural resource-intensive capital**

Pilot Project – basic questions

Objective:
We tested the legal and economic feasibility of installing on-lot storm water management practices in an existing subdivision and the hydrologic and ecological response to this type of management

Research Questions:
1) Can a market-based mechanism provide appropriate incentives to install on-lot management practices throughout this small, midwestern US watershed?
2) Will the incentives induce the placement of an adequate number of management practice, and such that significant hydrologic and ecological improvements are realized in this watershed?

What we did

- In the USA, we do not have a regulation that covers stormwater quantity on private property, so we need a voluntary mechanism
- We recruited participants into storm water abatement via incentives or "voluntary offset" measures administered through a reverse auction
- The benefits of an auction are that it is made available to everyone in the watershed, and there is no penalty for non-participation, and may be more cost-effective than a hand-out
- We paid willingness-to-accept bid (how much compensation is needed by a landowner for loss of opportunity), installed rain barrels, rain garden, and maintained these for 3-year study period
- We used the auction to determine costs and understand stakeholder preferences in the management of a major environmental stressor

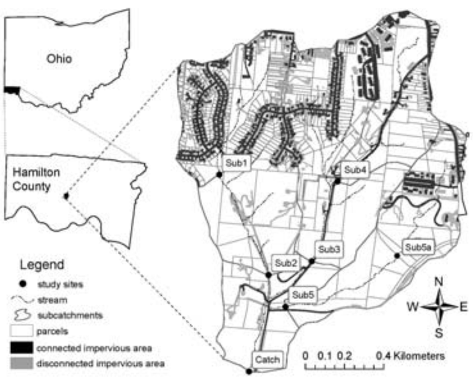
Since the majority of impervious area in the Shepherd Creek watershed is in rooftops and driveways (and on private property), we have taken a modular retrofit approach with:

Rain garden (one, 16 m^2)

Rain Barrel (up to four)

Site details and experimental design

- 1.8 km^2 watershed
- 13% TIA
- Mixed land uses: residential, forest, farm
- Stormwater is major stressor
- BACI design (before-after-control-impact)
- Two controls (1, 6), four treatments (2, 3, 4 & 5)
- Additional gages at neighborhood-scale outfalls



EPA United States Environmental Protection Agency

Balancing Cost vs. Anticipated Effectiveness

Process:
- Place retrofit stormwater management practices (SWMPs) on the parcels of willing participants (low bids = least cost to us)
- In short, put SWMPs on parcels where they are most effective and cheapest to site
- Bids ranked based on cost (bid amount and installation cost) and environmental benefits so that **Rank = Cost ÷ EBI**
- Bids awarded until $$ exhausted or reserve met

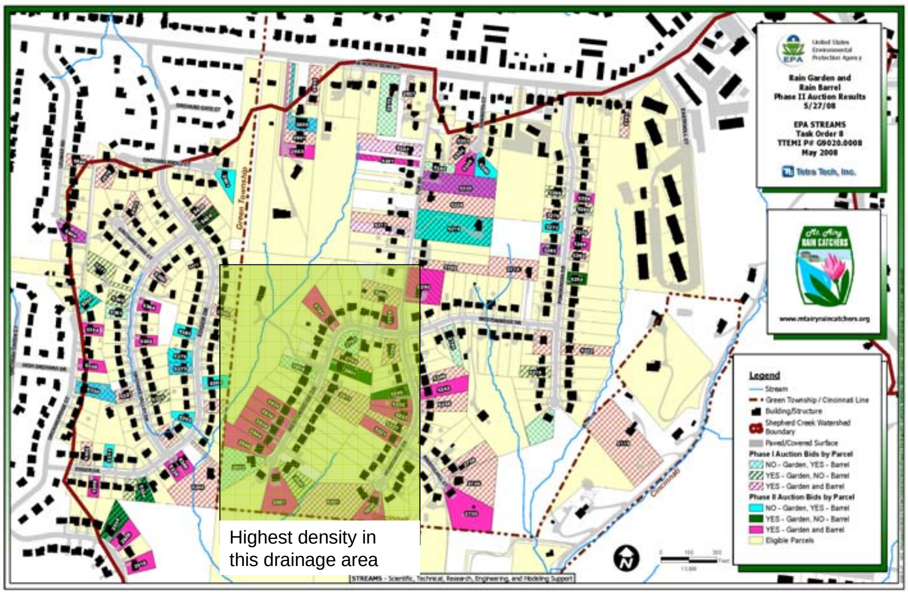
Environmental Benefits Index (EBI) is estimated based on:

Rain Barrels
- number of barrels
- % rooftop area connected to storm sewers

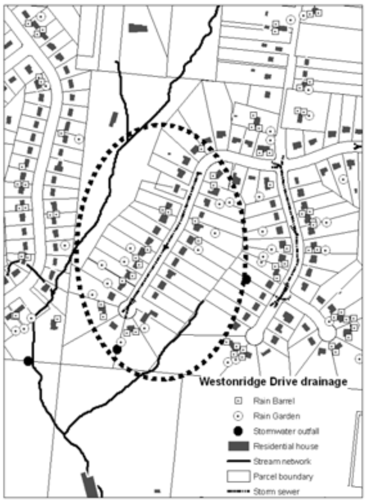
Rain Gardens
- % total impervious area
- soils on property
- proximity to stream channel

EPA

Combined 2007, 2008 Auction results

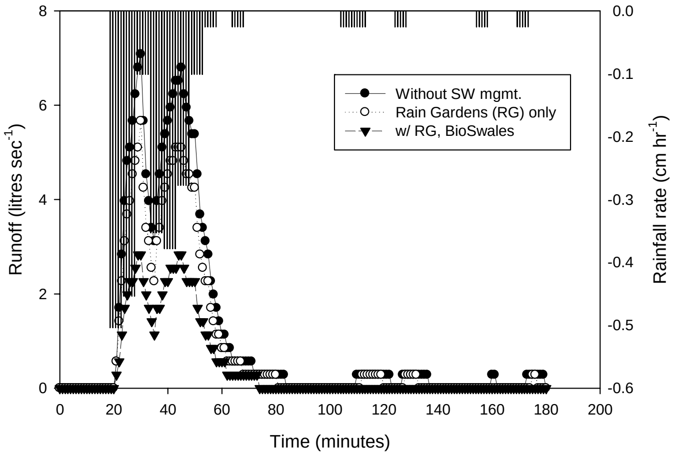


Revised hypothesis



- H_o: Change in catchment hydrology due to stormwater quantity management will be found where stormwater management has been most densely implemented
- 50% adoption in this small catchment
- Drains to a single stormwater outfall

SWMM-LID Model output – small rainfall event



- Hydrograph follows rain pattern (predominance of transportation surface)
- Stormwater management with Rain Gardens/Barrels predicted to slightly decrease magnitude of peaks
- Suggests expanded retrofit approach to address runoff contribution from paved surfaces with road-side bioswales

EPA United States Environmental Protection Agency

More impacts of management

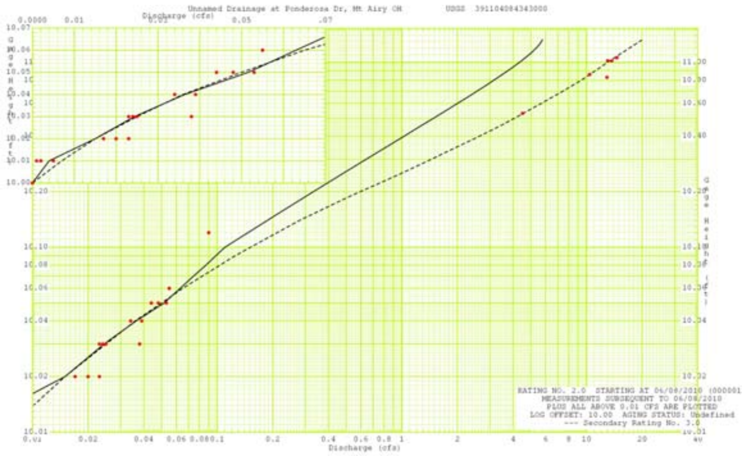
- Maintaining or increasing connectivity of stormwater source to stormwater management practices regulates effectiveness
- The downspout connection to the storm sewer was severed during rain barrel installation)
- When the rain barrel is returned to service after the winter, the overflow pipe from the rain barrel generally does not go back into the storm sewer inlet
- The overflow is routed to the rain garden or to the turf area where overflows are infiltrated
- A good qualitative indicator of the effectiveness of this process is that we have no complaints among neighbors, no RG/RB failures
- Therefore, citizen innovators have disconnected more impervious area than we anticipated

EPA United States Environmental Protection Agency

Measurement of flashy flows

- We measured discharge at stormwater outfalls with these simple stilling well-float plumbed to a pipe extension
- Shaft encoder used to record depth
- Depth converted to discharge via rating
- Variable time resolution: 1 sec. in wet weather, 1 hour in dry weather
- Surcharging and pressurization impacted accuracy of rating

New versus old rating



- The solid black line is the old rating, the dashed line is the new modified rating to fit the top-end observations

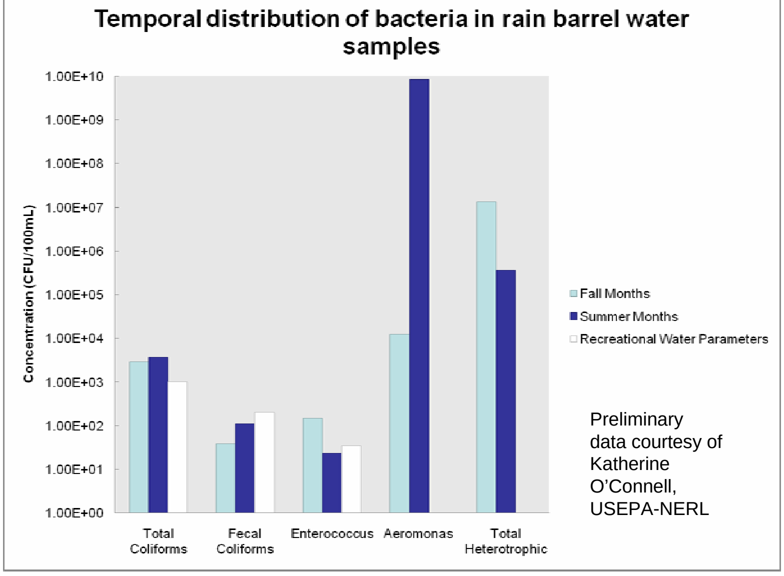
Establish a reliable, accurate rating

- The ratings have the “observations" at the upper end plotted to show the difference from the previous rating
- All measurements above 1 cfs on the rating were derived by multiplying the Acoustic Doppler Velocity Meter's velocity reading for each peak by a computed area based the flow depth for the computed peak gage height to get a discharge in cubic feet per second.
- The current theoretical rating at the site will be improved by:
  1) improving the computation of energy losses due to friction effects
  2) extending the rating for pressure flow conditions.

Rain barrel water quality – not what we expected

- Rain barrels (n = 9) are monitored every 15 minutes for level to record supply-demand
- Water quality sampling every 2 weeks
- Water from all barrels in our sample set is used primarily for watering outdoor plantings or run into rain gardens
- Two residents also use some of the rain barrel water for watering indoor plants
- pH (5.1 to 6.1); conductivity (23.6 to 102.5 µS/cm); turbidity (0.6 to 20 NTU), and TOC (4.9 to 39.2 ppm)

Microbial water quality



Preliminary data courtesy of Katherine O'Connell, USEPA-NERL

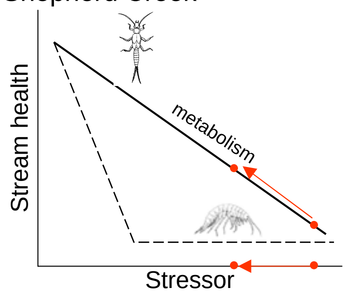
Circumstances

- We observed algal biomass in some barrels, noted a water quality gradient and subsequently attempted to characterize this
- Source: deposition of avian, small mammal fecal matter on roofs
- Typically a good supply of carbon to support heterotrophs – the gutter contains plenty of organic matter
- Gutter may act as a reactor of sorts – fecal matter and material left by airborne deposition are washed into gutter, then leached through gutter contents, then into the rain barrel
- Variable residence times dependent on rainfall

Measures of stream health

Measures of stream health

- Traditionally based on the biotic community.
- No relationship between stressor and metric at high stress levels.
- Functional metrics (e.g., photosynthesis and respiration) may be more sensitive across a broader level of stress levels.
- Also provides a direct measure of ecosystem function, which is often the target of restoration projects. We are now measuring community metabolism in the Shepherd Creek



More impacts of management

- Rain gardens seem to have plenty of unused capacity (average of ~4 m^3 when relatively dry)
- This is due to placement in landscape, connectivity to rain barrel overflow, sheet flow sources
- Connectivity with runoff sources has been in some cases enhanced by the landowners – they "get" the connection between SW management and the rain garden
- We are interested in better understanding how rain barrels may be a potentially effective approach to initially engaging citizens in their new role as a stormwater manager
- Deployment of rain barrels may be a good first step in the phased recruitment of citizen stormwater managers that would eventually lead to installation of rain gardens, larger cisterns, green roofs, etc. in a broader program of decentralized stormwater management

Overarching lessons

- We will continue to monitor through May 2011
- The operation and maintenance of the 2007 cohort of practices has ended – license reverts to homeowner
- We still need additional stormwater quantity detention targeted to transportation surfaces to better match scale of management to catchment conditions
- We have optimized some reliable outfall discharge monitoring techniques
- Combination of structural and functional measures to assess ecosystem-level response to management inputs
- BACI versus weight-of-evidence approaches, qualitative indicators of effectiveness (pass-fail)
- To front-load for success, form a central authority to handle administration, operation and maintenance of stormwater management practices (www.mtairyraincatchers.org)

SOME LESSONS LEARNT ABOUT SOURCE CONTROL STRATEGIES IN FRANCE

C. Carré
Paris 1 University, France

Some lessons learnt in France about Source Control strategies

Catherine CARRE – University Paris

A general implementation

- In a context of legislative incentives since 30 years

1977	→	1991 DERU	→	1992 2d WATER law	→	2006 3d WATER Law
Storage and infiltration are allowed instead of pipes		Waste water pollution must be treated even when raining		Land use planning must propose measures to limit impervious surfaces and control stormwaters		Municipalities are responsable for urban runoff (collect, transport, treatment are a public service)

A general implementation

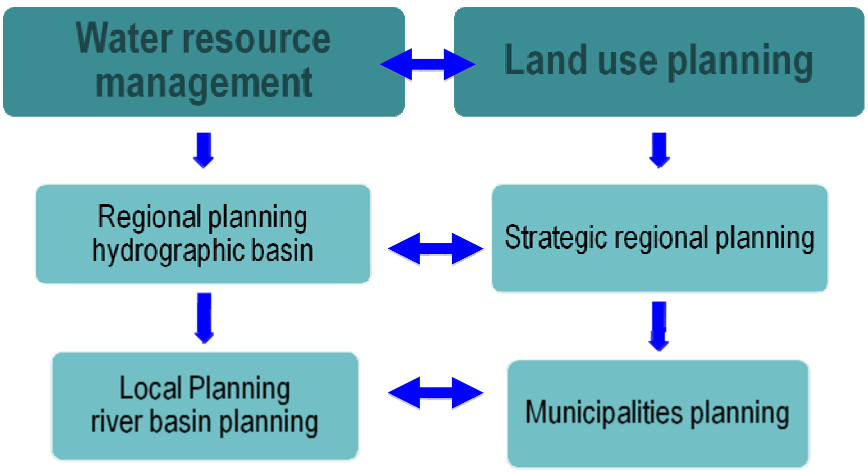
CU Bordeaux

- Public
  - 82 basins
- - 2,5 Millions m^3
- Private
  - 11 500 Storage structures between 1982 et 2007
  - 1,7 Million de m^3

CG de Seine-Saint-Denis

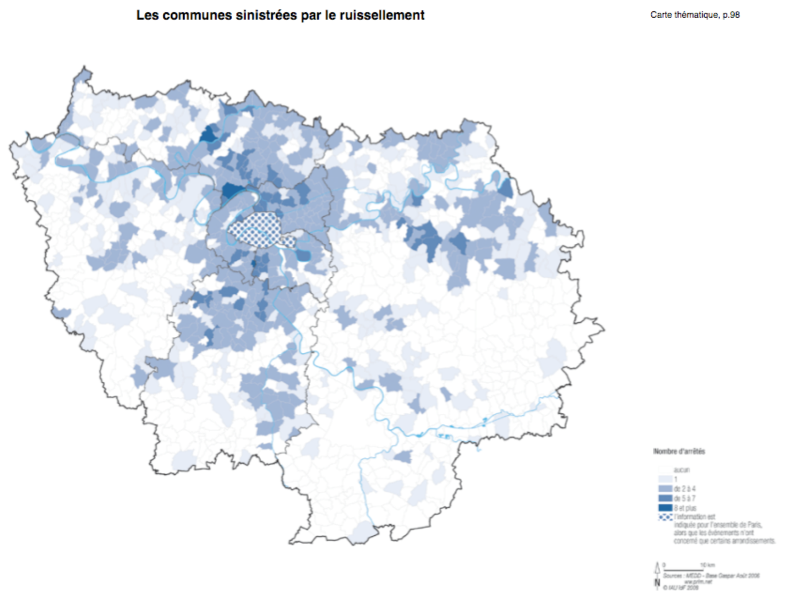
- Public
  - storage : 1,4 Million m^3
- Private
  - 900 storage structures between 1985 et 2009
  - 650 000 m^3

Coupling water management and land use planning



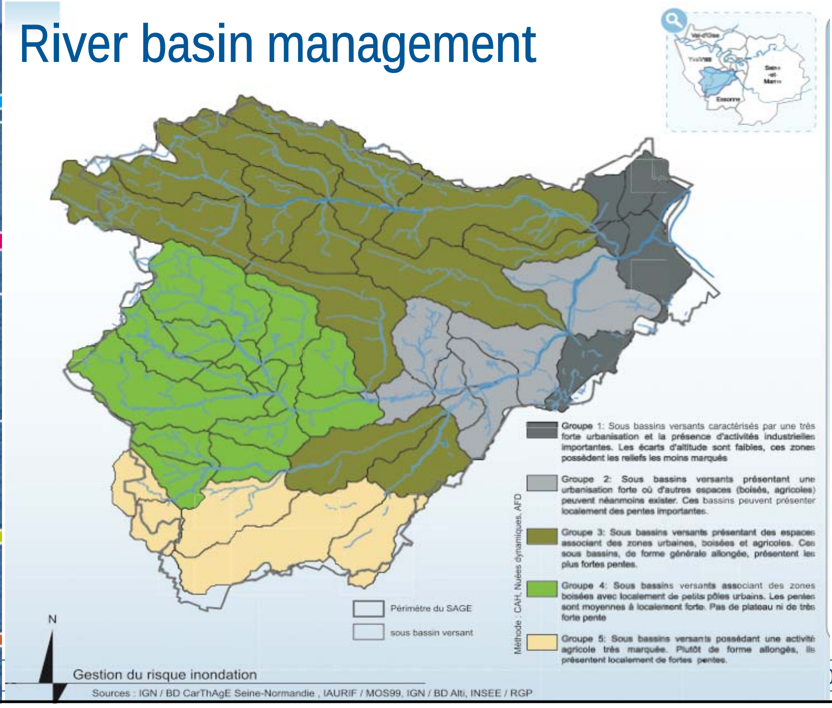
Regional water management

Regional land use planning

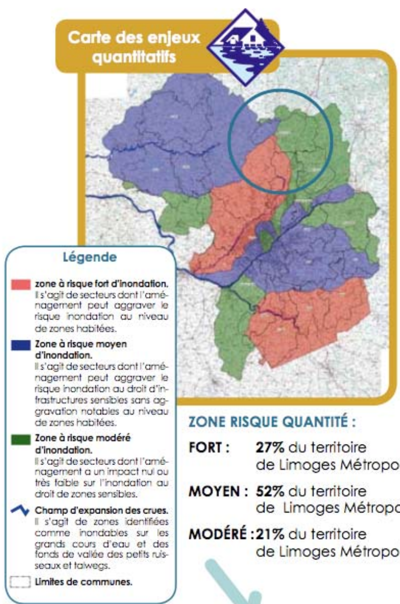


source : Schéma directeur de la région Île-de-France, projet adopté par délibération du Conseil régional le 25 septembre 2008, sous réserve de contrôle de légalité

River basin management



Quels sont les zones sur le territoire de Limoges Métropole ?

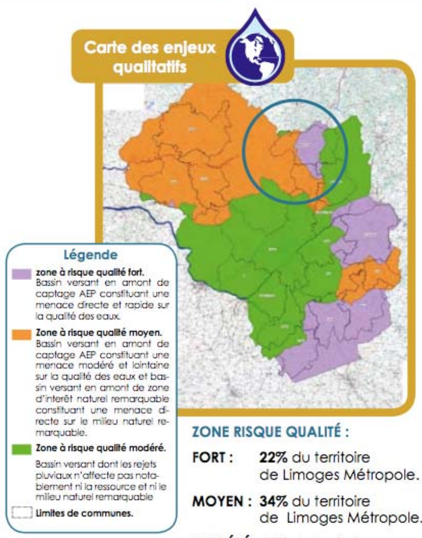


ZONE RISQUE QUANTITÉ :

FORT : **27%** du territoire de Limoges Métropole.

MOYEN : **52%** du territoire de Limoges Métropole.

MODÉRÉ : **21%** du territoire de Limoges Métropole.



ZONE RISQUE QUALITÉ :

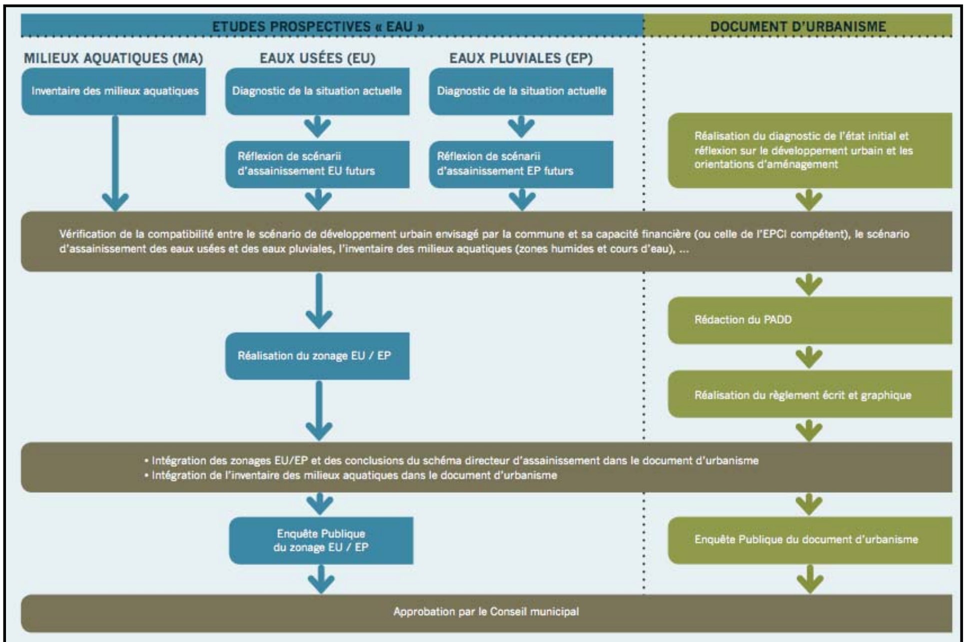
FORT : **22%** du territoire de Limoges Métropole.

MOYEN : **34%** du territoire de Limoges Métropole.

MODÉRÉ : **44%** du territoire de Limoges Métropole.

DÉMARCHE

DU GUIDE DES BONNES PRATIQUES



A large spectrum of objectives beside flood control

- Wastewater treatment: source control helps increasing treatment plants' capacities
- Source control with water re-use as a way to protect water resource
- Financial: to reduce sanitation cost
  → to adjust urban projects to a global cost including sanitation and habitat protection

Behind this apparent success some general limits

- Target remains focused on run-off control and not on pollution
- Objectives are (was) rarely esthetical or ecological but mainly flood control and cost reduction
- A report on private devices to avoid public expenses
- Combination of practices (public / private) and scales (from « roof to river ») is not evaluated

Interrogation on municipal prescriptions

- 4 types of recommandations
  - Sewer disconnection (Infiltration if permitted or flow limitation)
  - Type of stormwater mesures or treatments
  - Device maintenance
  - Technical design and compliance
- A large variety of prescriptions
  - An outflow of 1,2 to 15 l/s/ha for all kind of rain
  - A storage net volume according to the size of the project (l/m²)

➔No justification for flow limits or surface limits, and no real adaptation to local context

- A flow limited to 1,2 l/s/ha on a property of 200 m^2 means a structure with an output of 0,024 l/s !

A defect of maintenance

Both for public and private structures

- In Bordeaux

  30% of the private structures were non compliant

  - 44% had been without any maintenance since their construction

  - 49% were out of order

  - 7% were abandonned

- In Paris suburban municipalities

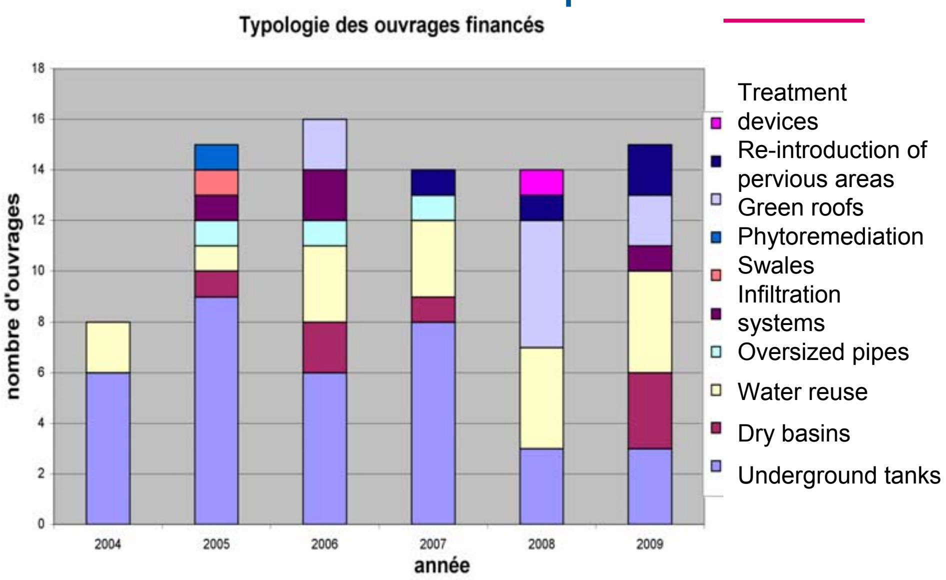
  48 % of the public structures and 72 % were without maintenance

Bordeaux private structures in 2007

Dry basins	Ponds	Storage pipe	Tanks	Swales	Green roof / Roof storage	Porous pavements	Source Infiltration systems	TOTAL
31	2	26	11	14	7	136	36	263
12 %	1%	10%	4%	5%	2%	52%	14%	100%

Par type de solution compensatoire								
Bassin sec	Bassin eau	Collecteur	Réservoir	Noues	Toiture terrasse	Structure réservoir	Autonome infiltration	Total
31	2	26	11	14	7	136	36	263
11,8 %	0,7 %	10 %	4,2 %	5,3 %	2,6 %	51,7 %	13,7 %	100 %

Paris suburban municipalities



Propriétaire	Technique utilisée	Entretien réalisé	Fonctionnement correct
Collectivité	Bassin à ciel ouvert (87 m^3)	Oui	Oui
Collectivité	Noue	Oui	Oui
Collectivité	Tranchée drainante	Oui	Oui
Collectivité	Puits d'infiltration	Oui	Oui
Collectivité	Canalisation surdimensionnée (814 m^3)	Oui	Oui
Collectivité	Bassin à ciel ouvert (250 m^3)	Oui	Oui
Collectivité	Bassin enterré (400m3)	Oui	Oui
Collectivité	Canalisation surdimensionnée (188 m^3)	Oui	Oui
Collectivité	Bassin enterré (100 m^3)	Oui	Oui
Collectivité	Bassin enterré	Oui	Non (pas de possibilité de vidange)
Collectivité	Puits d'infiltration	Non	Oui
Collectivité	Toitures terrasses minérales et végétales (110	Non	Oui
Collectivité	Bassin enterré (39 m^3)	Non	Oui
Collectivité	Toiture terrasse minérale	Non	Oui
Collectivité	Toiture terrasse minérale (1900 m^2)	Non	Non (pas de régulateur)
Collectivité	Canalisation surdimensionnée (50 m^3)	Non	Non (pas de régulateur)
Collectivité	Canalisations surdimensionnées (368 m^2)	Non	? (pas d'accès au bassin et au régulateur)
Collectivité	Bassin enterré (60 m^3)	Non	? (Pas d'accès au bassin)
Collectivité	Toiture terrasse végétale	Non	Oui
Privé	Toiture terrasse minérale	Oui	Oui
Privé	SAUL (30 m^2)	Oui	Oui
Privé	Bassin enterré (20 m^2)	Oui	Oui
Privé	Puits d'infiltration	Oui	Oui
Privé	Toiture terrasse minérale (1700 m^2)	Oui	Oui
Privé	Bassin enterré (18 m^2)	Non	Oui
Privé	Canalisation surdimensionnée (1200 m^3)	Non	Oui
Privé	SAUL (43 m^3)	Non	Non (régulateur non entretenu)
Privé	Canalisation surdimensionnée (25 m^3)	Non	Non
Privé	Bassin enterré (32 m^3)	Non	? (Pas d'accès)
Privé	Bassin enterré (88 m^3)	Non	? (Pas d'accès)
Privé	Bassin enterré (42 m^3)	Non	? (Pas d'accès)
Privé	Bassin enterré (31 m^2)	Non	? (Pas d'accès)

Defaults of conception and installation

- In Paris the main reasons are
  - A lack of control
  - A lack of drainage
  - An incessibility to the structure

Cultural limitation as well

- Some municipalities won’t prescribe source control on the idea that people are too indicisciplined to accept such prescriptions
- On the other hand, other municipalities are scared to loose their control if they rely on source control

Visible but not understood

A small paradox?

- Technicians in the same report identify that:
  - in general the devices have played their part during the storm
  - the structures are not looked after properly
  - There is a lack of assessment of objectives and results
- Source control (structural and not structural) must be developed
  - Lack of maintenance must not be an argument to drop SUDS

In the air

- SUDS supposed to be controled by municipal services, from design to maintenance
  - Maintenance is more important than the type of structures
  - Collaboration must be found between public and private actors (information, hotline, financial share….)
- SUDS and most of all water integration in city development produce urban equipement appreciated by inhabitants

LESSONS LEARNT AND EXPERIENCES ABOUT SOURCE CONTROL STRATEGIES IN BRASIL

N. Nascimento

UFMG, Brazil

Lessons learnt and experiences about source control strategies in Brazil

SOCOMA Workshop on
Design, modelling and implementation of source control technologies

Nilo Nascimento
Lyon, 27th June 2010

UFMG

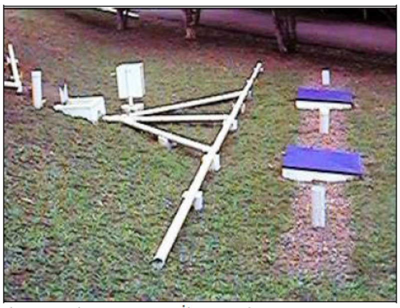
Lessons learnt and experiences about source control strategies in Brazil

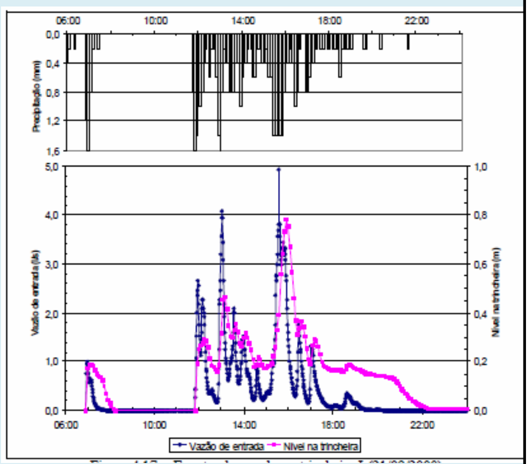
Introduction:

- Urban drainage for a long time influenced by traditional concepts
- Process of innovation following the democratization process (from the 1990'):
  - Participatory process: city councils, participatory budgeting
  - Close cooperation between municipalities and universities
- Two examples: Porto Alegre and Belo Horizonte

Porto Alegre experience

IPH-UFRGS





Souza and Goldenfum (2004)

IPH-UFRGS

Marques et al. (2008)
www.iph.ufrgs.br

Porto Alegre experience

Prefeitura Municipal de Porto Alegre

DECRETO N º 15.371
de 17 de novembro de 2006

PREFEITURA MUNICIPAL DE PORTO ALEGRE
DEP – DEPARTAMENTO DE ESGOTOS PLUVIAIS

PLANO DIRETOR DE DRENAGEM URBANA
Manual de Drenagem Urbana

Volume VI

Instituto de Pesquisas Hidráulicas
Universidade Federal do Rio Grande do Sul

Setembro/2005

Porto Alegre experience

SUMÁRIO

Manual main contents:

- Concepts on urban hydrology and urban drainage
- Rainfall-runoff and hydraulic modelling
- Source control: concepts, design, building and operation

Porto Alegre: stormwater management law

- New urban developments are limited to a specific flow of 20.8 l/s.ha to drain to the public sewer system
- In order to meet this requirement, urban developers may employ storage devices to be designed as follow:
  - If A < 100 ha, Storage volume = 4.25 I_{surf}
  - If A > 100 ha, hydrologic design for T = 10 y

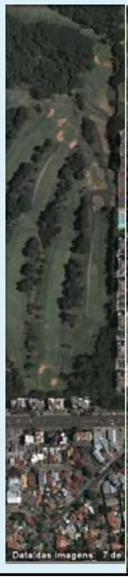
Porto Alegre: stormwater management law

- Urban developers may also employ other source control alternatives:
  - Draining to connected pervious areas: 40% reduction on I_{surf}
  - Draining to impervious pavement: 50% reduction on I_{surf}
  - Draining to non-connected perv. areas: 80% reduction on I_{surf}
  - Draining to infiltration trenches: 80% reduction on I_{surf}

Porto Alegre: stormwater management law

Porto Alegre:
stormwater management law

Porto Alegre:
environmental law: compensating measures



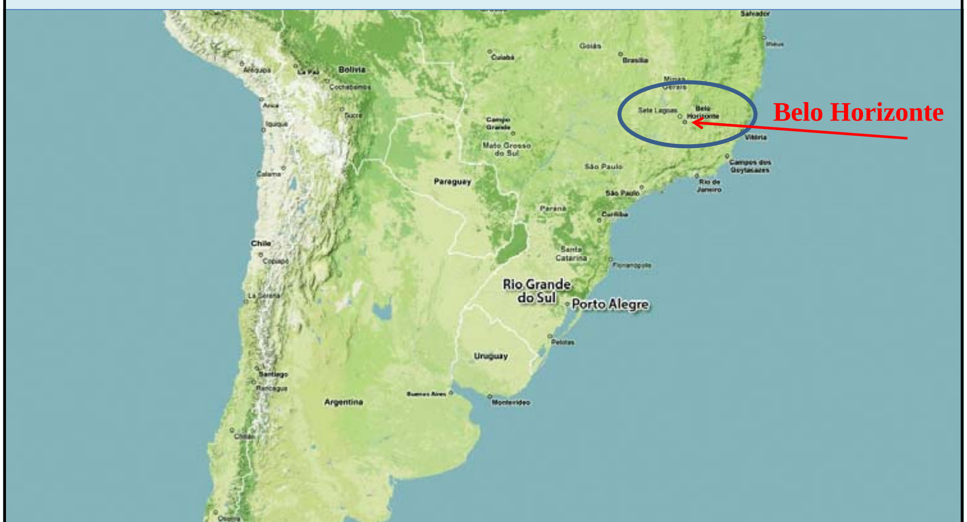
Porto Alegre:
environmental law: compensating measures

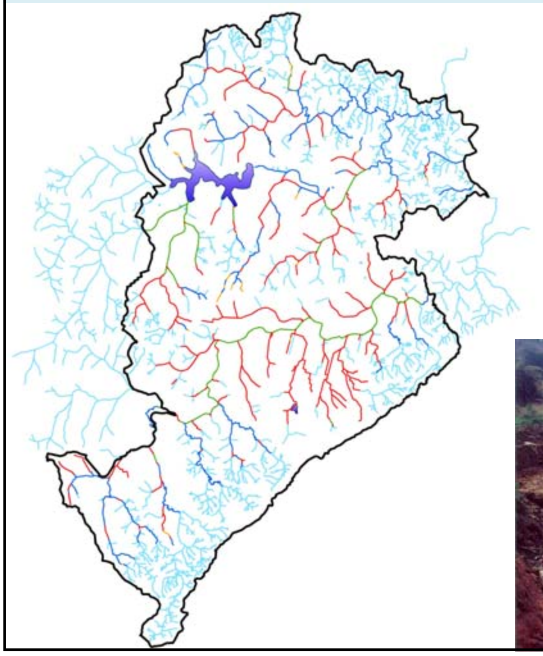
Porto Alegre:
environmental law: compensating measures

Porto Alegre:
stormwater management law

- Some results of this policy (source: Tucci ,2009):
  - 40 new urban developments adopted source control measures
  - Most of them are detention structures: dry DB set up in green areas
  - 30% are privately operated (land owners)
  - 70% are operated by the municipality

Belo Horizonte experience





Conventional and simplified approach:

- Focus on structural solutions
- Lack of a monitoring system
- Lack of integration between stormwater management and other urban policies

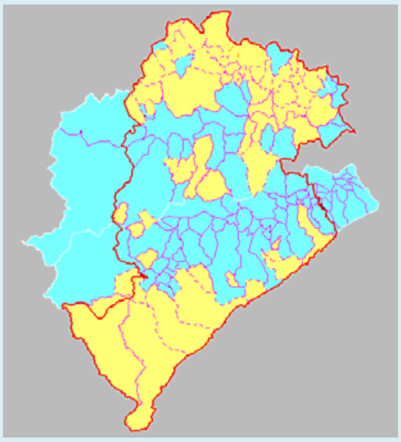
The DRENURBS river restoration programme

The DRENURBS programme

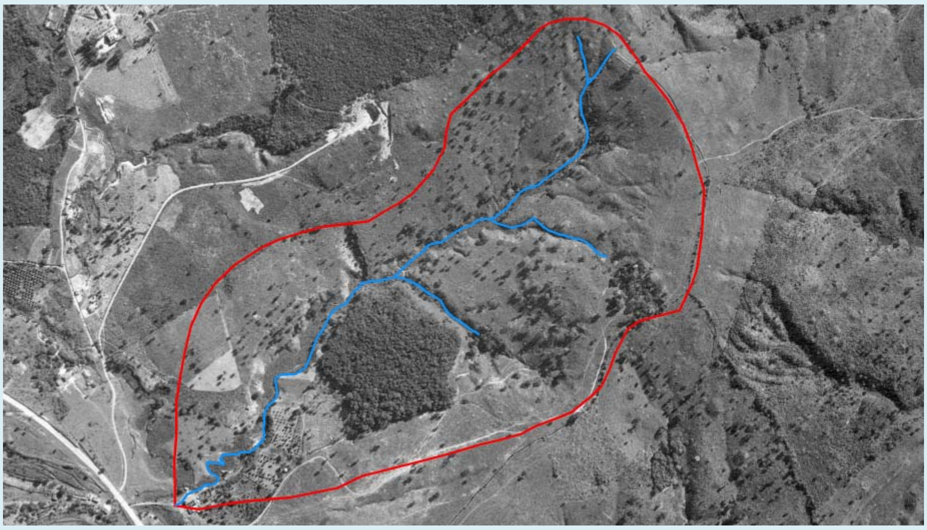
- Main focus: river restoration
  - Pollution control
  - Flood control
- Housing:
  - Removing people from risky areas
  - Relocating people in the neighbourhoods
- Creation of green areas and leisure facilities

The DRENURBS programme

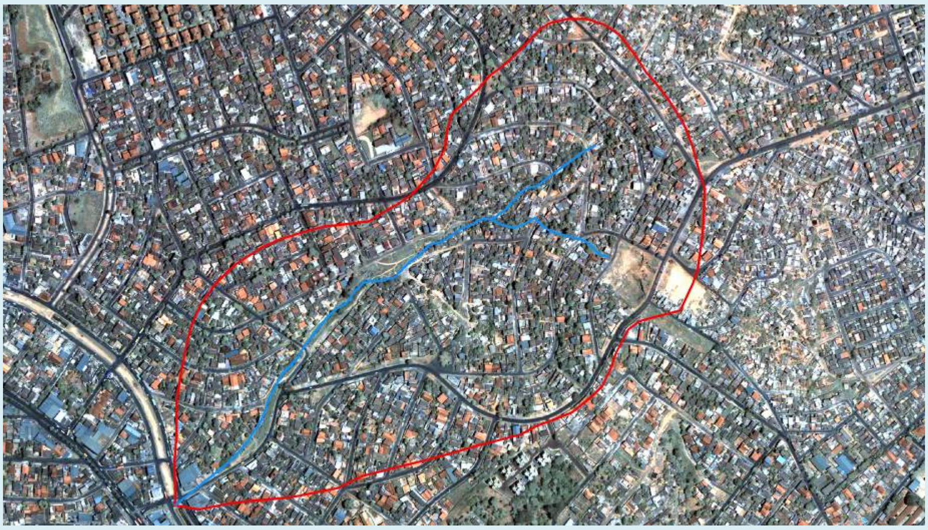
- 47 catchments
- 178 km^2
- 97 creeks (140 km)
- 980,000 inhabitants



Baleares creek (Macedo, 2008)



Baleares creek (Macedo, 2008)



Baleares creek (Macedo, 2008)

Córrego Baleares, BH

1º de Maio Creek

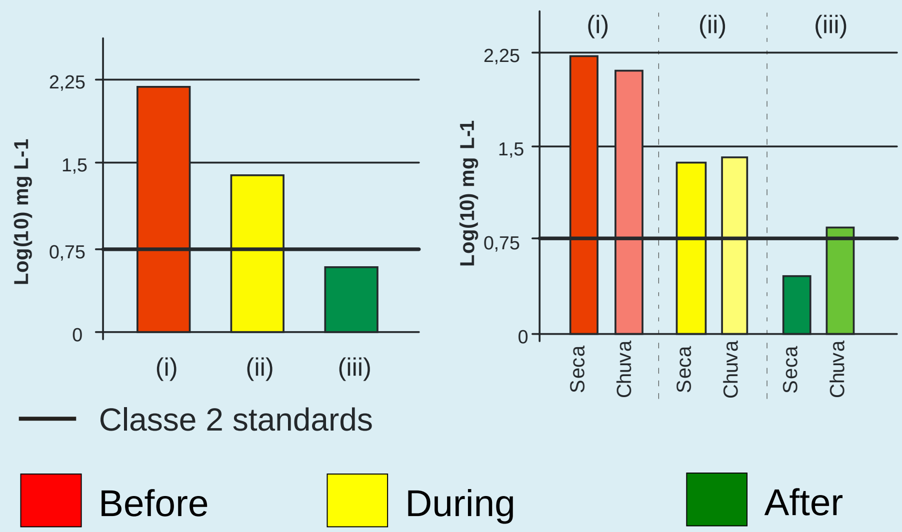
The initial state

The project

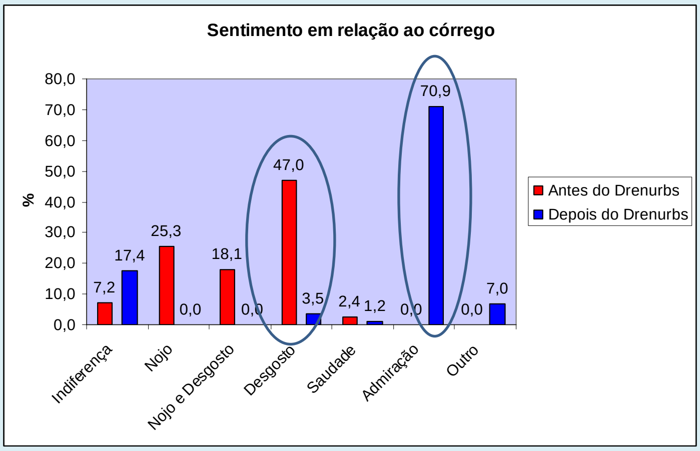
1º de Maio today

BONSUCESSO catchment (Aroeria, 2010)

Baleares Creek – BOD (Macedo, 2009)



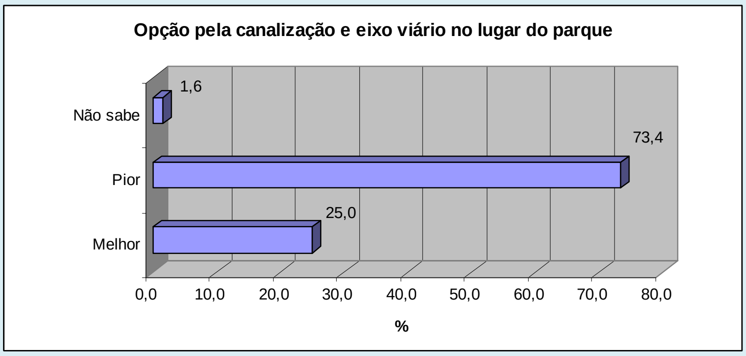
How do you perceive the creek now?



Baleares creek (Medeiros, 2008)

Public perception of interventions

Lining the creek would be better?



1º de Maio creek (Medeiros, 2008)

The participatory process

- Citizen involvement into the urban water management:
  - Multiple uses of drainage facilities
  - Contribution to maintenance
  - Reduction on vandalism
  - Control the illegal occupation
- Education for sustainability
- Social inclusion
- Reduction on the role of corruption in the decision making process

Discussion

- Some points still to be addressed:
  - From creek restoration to catchment management
  - Emerging issues as
    - Wet weather diffuse pollution
    - Climate change
  - Water management at other territorial scales:
    - The metropolitan area
    - The river basin

Stormwater management at catchment level

Public acceptance of BMP's

in urban drainage:

- Confidence on the systems
- Assuming responsibilities: O&M
- Absorbing costs: capital and O&M
- Perspectives for economic and financial incentives

Perspectives

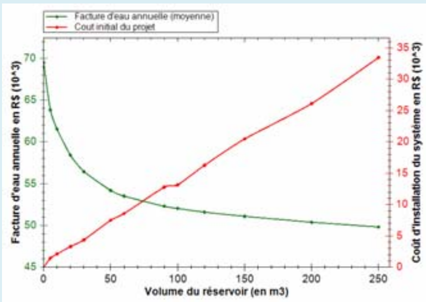
- The EU SWITCH project in Belo Horizonte:
  - Experiments and demonstrations on:
    - Detention and infiltration trenches
    - Artificial wetlands
    - Rainwater harvesting
  - Flood damage assessment
  - Emergency planning: floods

SWITCH

Rainwater harvesting

Municipal schools:

- Rainwater supplies 20%-30% of water
- Water used for cleaning, irrigation and in toilets
- Other benefits:
  - Educational
  - Family and community involvement



SWITCH

Rainwater harvesting

Urban agriculture experiment:

- Rainwater irrigation:
  - Supplies up to 40% of water
  - Overflows are infiltrated
  - Reduction on runoff and WWDP
- Other benefits:
  - Recycling organic wastes
  - Food security and income
  - Cultural memory and solidarity

SWITCH

Experiments with infiltration and detention devices in Belo Horizonte: the UFMG campus experiment

Infiltration trench

Detention trench

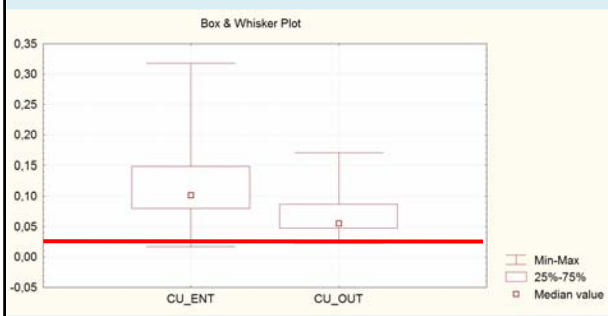
SWITCH

Pollutant concentration distributions

56 samples In
10 samples Out

SWITCH

Pollutant concentration distributions



56 samples In
10 samples Out

SWITCH

Perspectives

- The SWITCH project in Belo Horizonte:
  - Economic assessment:
    - River corridors and green areas
    - Water consumption policies
  - Governance assessment
  - Training and capacity building
  - Learning alliance approach

Perspectives

- FINEP project – starting in 2010 :
  - Research project on urban waters:
    - Investments of 6 million Euros in 2 years, 2 million on urban drainage
  - Network of 16 universities and municipalities
  - Three main focus:
    - Urban hydrologic processes: monitoring and modelling
    - Source control efficiency assessment, design criteria
    - Urban planning and regulation for source control adoption


Técnicas Compensatórias
em
Drenagem Urbana

Márcio Benedito Baptista
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ABRH

Thank you!

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FORUM / DISCUSSION

Coordinated by:

G. Rivard

NOVATECH 2010

FORUM - DISCUSSION

Modelling

- Existing approaches
  - Types of modelling tools, Conceptual bases
- Identified needs and gaps
- Design issues
  - Design storms – rainfall data
  - Level of service
  - Clogging

Source Control Performance

- Parameters influencing performance
- Objectives and indicators
- Scale and spatial arrangement

Implementation and Adoption

- Institutional barriers/problems
- Implementation / key factors for success

Planned outputs: *publications*

- Modelling and tools for source control,
  - decision-support, design, evaluation, maintenance
- Hydrologic performance
  - capacity to restore 'more natural' flow regimes
- Pollutant removal performance
  - For receiving waters (surface and ground)
  - For public health risk management
- Implementation and social impacts
- Synthesis: state of the art in source control management for urban stormwater

We would like your contributions…

- What tools do you use or do you know of?
- What tools do you need (what are the gaps)?
- Do you know of any experiments / *well-monitored* studies on:
  - Hydrologic performance
  - Water quality performance
  - Implementation
  - Social impacts

Future workshops

- What topics would you like to cover?
  - Decision-support?
  - Modelling
  - Maintenance?
  - Monitoring?
  - Lifecycle costs?
  - Effects on receiving waters?
  - Policy and regulation?
  - Effects of climate?