8TH INTERNATIONAL CONFERENCE
NOVATECH
JUNE 23-27 Lyon 2013
Planning & technologies for sustainable urban water management

WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

1. Organiser / working group:

   Source Control Management (SOCOMA) & Stormwater Harvesting Group (USWH)

   Both part of IWA / IAHR Joint Committee on Urban Drainage (JCUD) operated jointly by the International Water Association (IWA) and the International Association on Hydraulic Engineering and Research (IAHR) http://www.jcud.org/

2. Chair(s): Sylvie Barraud (sylvie.barraud@insa-lyon.fr)
   Gilles Rivard (gilles.rivard@genivar.com)
   Alberto Campisano (acampisa@dica.unict.it)
   Tim Fletcher (tim.fletcher@unimelb.edu.au)

3. Workshop presentation:

Control of stormwater at the source is a principle of increasing interest, both in urban and peri-urban environments. It involves the implementation at a range of scales of stormwater management systems, including stormwater harvesting, with the consequence that stormwater management is not much more multi-functional and decentralised than previously. Whilst the management of stormwater at a decentralised, local scale provides a number of advantages, generalising such techniques is less straightforward.

This workshop, organised jointly by the IWA/IAHR Joint Committee on Urban Drainage (JCUD) working groups: SOCOMA (Source Control Management) and Stormwater Harvesting provides an opportunity to discussion two important questions:

1. How to model the impact of source control and stormwater harvesting at the catchment scale? What effects will they have on the flow regimes of receiving waters? What indicators should we use to assess these?

2. How should we take into account the multiple benefits provided by source control systems.

The workshop will thus comprise two parts: one focussed on catchment-scale modelling and another focusing on multi-critieria assessment of source control systems and its use in their design and operation. The workshop will be built around a number of technical presentations and case-studies, and most important provide plenty of opportunity for interactive discussions.

Organized with the help of :
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Programme

This workshop, organised jointly by the Source Control working group (SOCOMA) and Stormwater Harvesting (USWH) working groups under the IWA/IAHR Joint Committee on Urban Drainage, was focused on two aspects:

1. Modelling the impacts of stormwater harvesting and source control techniques at whole-of-catchment scale (methods for extrapolating site-scale impacts up to catchment-scale impacts). In this theme we will explore the challenges in scaling up site-scale impacts of source control measures to the catchment scale and
2. Multi-criteria evaluation techniques

The workshop combined technical presentations with interactive discussion.

Time slot	Workshop Activity / Topic	Presenters
8:30 am - 9:00 am	Registration	
9:00 am - 9:15 am	Introduction to workshop	**Gilles Rivard,** Chair of SOCOMA working group, & **Alberto Campisano**: Chair of Stormwater Harvesting working group
	Modelling impacts of source control and stormwater harvesting at the catchment-scale	
9:15 am - 9:30 am	**Considerations for modelling source control impacts at the catchment-scale**	**Tim Fletcher** & **Sylvie Barraud**
9:30 am - 9:55 am	Modelling the impact of stormwater source-control infiltration techniques on catchment baseflow	**Perrine Hamel** Monash University, Australia & Stanford University, USA
9:55 am - 10:20 am	Regional scale analysis for the design of storage tanks for domestic rainwater harvesting systems	**Alberto Campisano,** University of Catania
10:20 am - 10:45 am	Optimisation of source control implementation through design parameter exploration	**Matthew Burns,** Monash University & University of Melbourne
10:45 am - 11:00 am	*Coffee break*	
11:00 am - 11:25 am	Hydrologic modelling of source control at the catchment scale. Long-term effects of local stormwater regulations in France.	**Guido Petrucci,** Uni Paris—Est, France
11:25 am - 11.50 am	Recommendations for time-series in modelling rainwater harvesting efficiency	**Ilaria Gnecco**, Genoa University, Italy
11:50 am - 12:20 pm	*Interactive Discussion*	
12:20 pm - 1:45 pm	*Lunch*	
	Multi-criteria analysis for stormwater source control & harvesting strategies.	
1:45 pm - 2:10 pm	**Overview of the challenges and approaches to multi-criteria analysis (MCA)**	**Gilles Rivard**, Genivar, Canada
2:10 pm - 2:50 pm	Multi-criteria evaluation of source control; a state of the art	**Sylvie Barraud**, INSA Lyon, France
2:50 pm - 3:15 pm	Multi-criteria techniques for the operation of infiltration systems	**Priscilla Moura,** UFMG, Brazil
3:15 pm - 3:35 pm	*Coffee break*	
3:35 pm - 4:00 pm	Water Harvesting: Overcoming People to Make it Work in SE USA	**Bill Hunt**, Bio & Ag Engineering - N.C. State (USA)
4:25 pm - 5:00 pm	*Interactive discussion*	

LIST OF PARTICIPANTS - WORKSHOP 3

	Name		Organisation	City	Country
1	HAYASHI	Hidehiko	SHIMIZU CORPORATION	Koto-ku	JAPAN
2	BARRAUD	Sylvie	INSA de Lyon	Villeurbanne	FRANCE
3	HAMEL	PERRINE	Monash University	Monash University	AUSTRALIA
4	NKOULOU	BLAISE	Communauté Urbaine de Douala	Douala	CAMEROON
5	TCHANGANG KAMNANG	ROGER FRANCIS	Communauté Urbaine de Douala	Douala	CAMEROON
6	SILLANPÄÄ	NORA	Aalto University	Lahti	FINLAND
7	SCHEUCHER	ROBERT	Graz University of Technology	Graz	AUSTRIA
8	GEROLIN	AURELIE	Ministère en charge de l'Ecologie (MEDDE)	Tomblaine	FRANCE
9	POELSMA	PETER	Monash university	Clayton	AUSTRALIA
10	MOURA	PRISCILLA	Universidade Federal de Minas Gerais	Belo Horizonte	BRAZIL
11	PETRUCCI	GUIDO	Ecole des Ponts ParisTech	Champs-Sur-Marne	FRANCE
12	CHERQUI	FREDERIC	Insa de Lyon - Université Lyon 1	Villeurbanne Cedex	FRANCE
13	VIRAHSAWMY	HARRY	The University of Melbourne	Melbourne	AUSTRALIA
14	BURNS	MATTHEW	Monash University	Melbourne	AUSTRALIA
15	LOCATELLI	LUCA	Technical Universtiy of Denmark	Kgs. Lyngby.	DENMARK
16	CAMPISANO	ALBERTO	University of Catania	Catania	ITALY
17	BLECKEN	GODECKE	Luleå University of Technology	Luleå	SWEDEN
18	BERRETTA	CHRISTIAN	University of Sheffield	Sheffield	UNITED KINGDOM
19	ÖSTERLUND	HELENE	Luleå university of technology	Luleå	SWEDEN
20	LERER	SARA	DTU Environment	Kgs. Lyngby	DENMARK
21	DAGENAIS	DANIELLE	Université de Montréal	Montréal	CANADA
22	RODER	SILKE	RWTH Aachen	Aachen	GERMANY
23	ROSA	ALTAIR	EESC/USP - PUCPR	Curitiba	BRAZIL
24	MARKLUND	STEFAN	Luleå University of Technology	Luleå	SWEDEN
25	FLETCHER	TIM	University of Melbourne	Burnley	AUSTRALIA
26	ZHANG	SIYU	LEESU/ENPC	Champs sur Marne	FRANCE
27	LEPETIT	JULIEN	AECOM	Canberra	AUSTRALIA
28	GNECCO	Ilaria	University of Genoa	Genoa	ITALY

Some pictures of the workshop...

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WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Introduction to workshop

Gilles Rivard, Chair of SOCOMA working group, &
Alberto Campisano: Chair of Stormwater Harvesting working group

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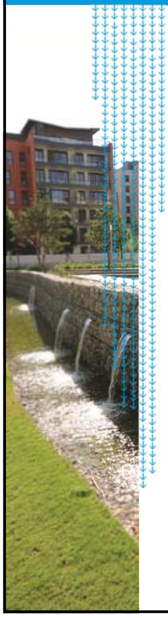
novatech 23>27 JUIN Lyon 2013 — Stratégies & solutions pour une gestion durable de l'eau dans la ville / Planning & technologies for sustainable urban water management



Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Analyse multicritère et modélisation à l'échelle des bassins versants pour le développement du contrôle à la source et de stratégies de récupération des eaux pluviales

SOCOMA / Urban Stormwater Harvesting Group (USWH)

SOCOMA/SWH Workshop - INTRODUCTION

Working Groups of IWA/IAHR Joint Committee

SOCOMA (Source Control Management)

Studies source controls, which are defined as all measures applied to control stormwater before it enters sewers or the receiving systems (surface water or groundwater). The group's objective is to facilitate the development of these techniques, by conducting research and experiments, and disseminating the results by various means.

http://graie.org/SOCOMA/

USWH (Urban Stormwater Harvesting)

Newly established in September 2012, with the focus of promoting the appropriate and beneficial use of storm water harvesting (SWH) in urban drainage systems.

Alberto Campisano
acampisa@dica.unict.it).

Other closely related Working Group
WSUD (Water Sensitive Urban Design)

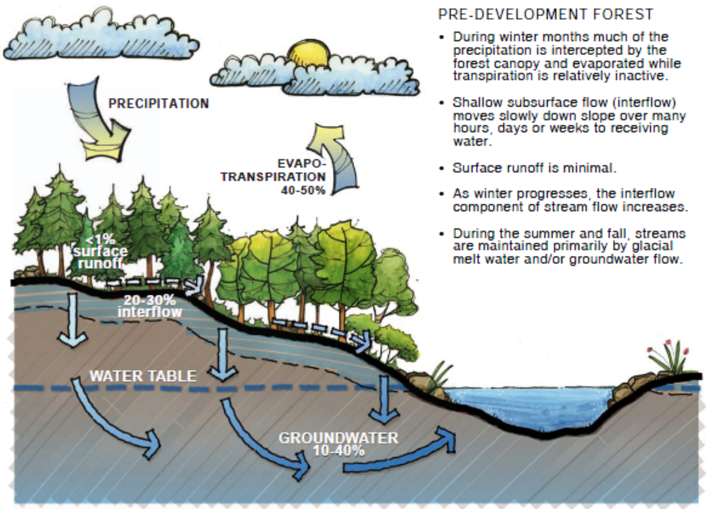
SOCOMA/SWH Workshop - INTRODUCTION

MAIN THEMES FOR THE WORKSHOP

1. How to model the impact of source control and stormwater harvesting at the catchment scale? What effects will they have on the flow regimes of receiving waters? What indicators should we use to assess these?

2. How should we take into account the multiple benefits provided by source control systems

SOCOMA/SWH Workshop - INTRODUCTION

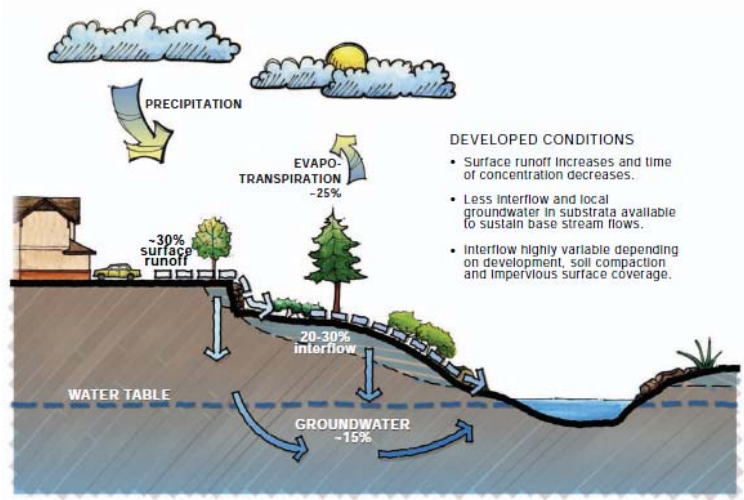


PRE-DEVELOPMENT FOREST

- During winter months much of the precipitation is intercepted by the forest canopy and evaporated while transpiration is relatively inactive.
- Shallow subsurface flow (interflow) moves slowly down slope over many hours, days or weeks to receiving water.
- Surface runoff is minimal.
- As winter progresses, the interflow component of stream flow increases.
- During the summer and fall, streams are maintained primarily by glacial melt water and/or groundwater flow.

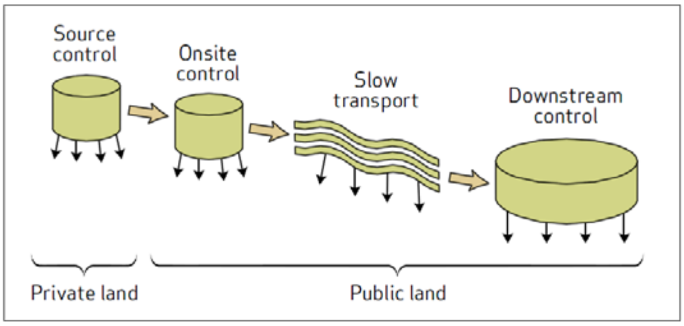
(Pudget Sound, 2012)

SOCOMA/SWH Workshop - INTRODUCTION



(Pudget Sound, 2012)

SOCOMA/SWH Workshop - INTRODUCTION



(Stahre, 2008)

Importance of source control for integrated watershed management

l'eau dans la ville / water in the city

SOCOMA/SWH Workshop - INTRODUCTION

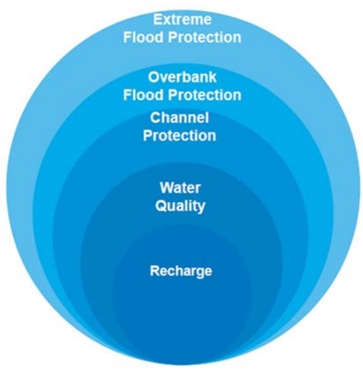
Stormwater management basic principle : mitigate effects of urban development

- Definition of «predevelopment conditions »
- Performance criteria (pollutant loads, stream geomorphology and habitat, flooding)

SOCOMA/SWH Workshop - INTRODUCTION

PARAMETERS FOR CONTROL OBJECTIVE

- Design volume
- Release rates (discharges)
- Effluent concentration



(Minnesota, USA (2008))

SOCOMA/SWH Workshop - INTRODUCTION

- SESSIONS FOR WORKSHOP
  - Modelling at the catchment scale
    - Potential and limits of source control
  - Multi-criteria analysis
    - Objectives numerous and complex
    - Necessary to assess overall performance
    - Optimization (conflicting goals, costs)

WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Modelling impacts of source control & stormwater harvesting at the catchment-scale

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WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Modelling impacts of source control and stormwater harvesting at the catchment-scale

Considerations for modelling source control impacts at the catchment-scale

Tim Fletcher University of Melbourne (Australia) &
Sylvie Barraud INSA Lyon (France)

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Stratégies & solutions pour une gestion durable de l'eau dans la ville

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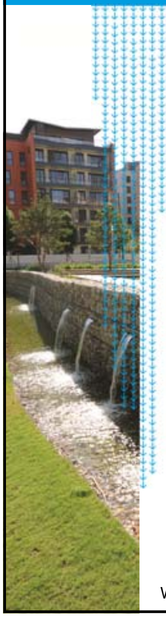


Considerations for modelling source control impacts at the catchment-scale

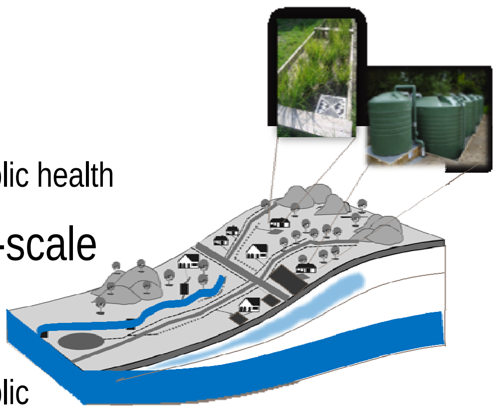
Tim Fletcher & Sylvie Barraud

INSA LYON · LGCIE · THE UNIVERSITY OF MELBOURNE

With thanks to: Matt Burns, Perrine Hamel, Harry Virahsawmy

What do we need to model ?

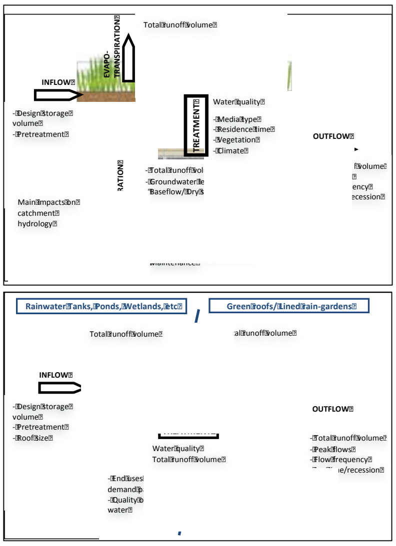
- behaviour of system
  - hydrologic
  - hydraulic
  - water quality
  - effects on ecosystem & public health
- transfer to catchment-scale
  - surface
  - subsurface
  - effects on ecosystem & public health



Individual system performance

Infiltration / biofiltration

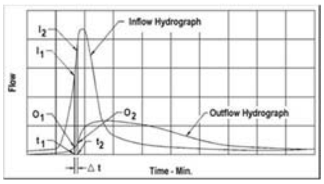
Detention - type



1. Hydrology
2. Hydraulics
3. Water quality
4. Ecosystem & public health

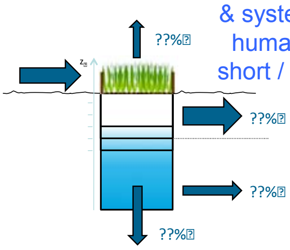
Individual system performance - *hydrology*

Well – established | Some knowledge | Knowledge gaps

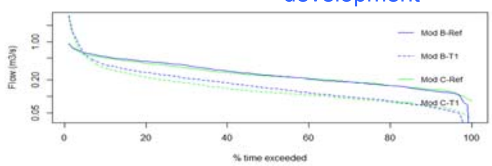


Impact of SCMs on hydrograph, particularly for peak flows

Water balance of complex / 'new' systems & systems involving human behaviour short / medium term

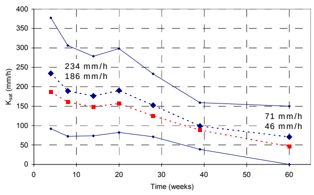


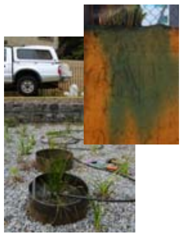
Local similarity of low-flow regimes to pre-development



Individual system performance – *hydraulic behaviour*

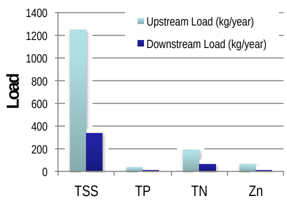
Well – established | Some knowledge | Knowledge gaps

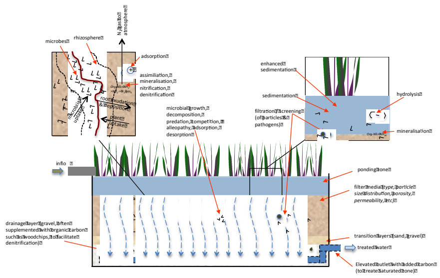


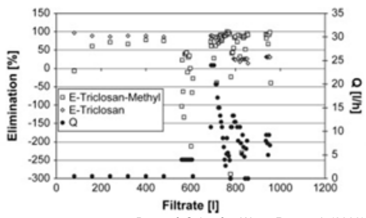


Individual system performance – *water quality*

Well – established | Some knowledge | Knowledge gaps



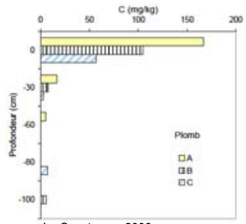




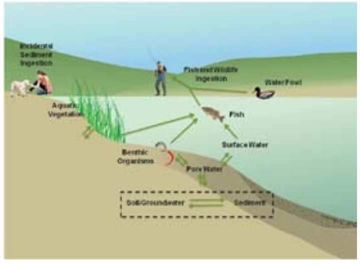
Bester & Schaefer: Water Research (2009)

Individual system performance – *ecol & public health*

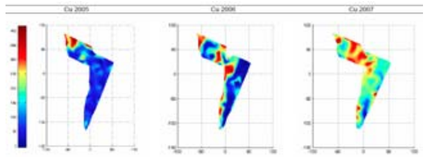
Well – established   Some knowledge   Knowledge gaps



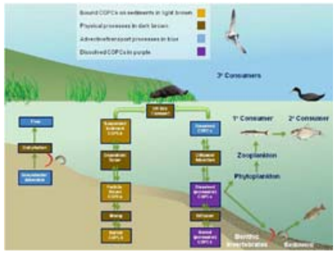
Le Coustumer, 2008



www.itrcweb.org/contseds-bioavailability/consed_2.htm

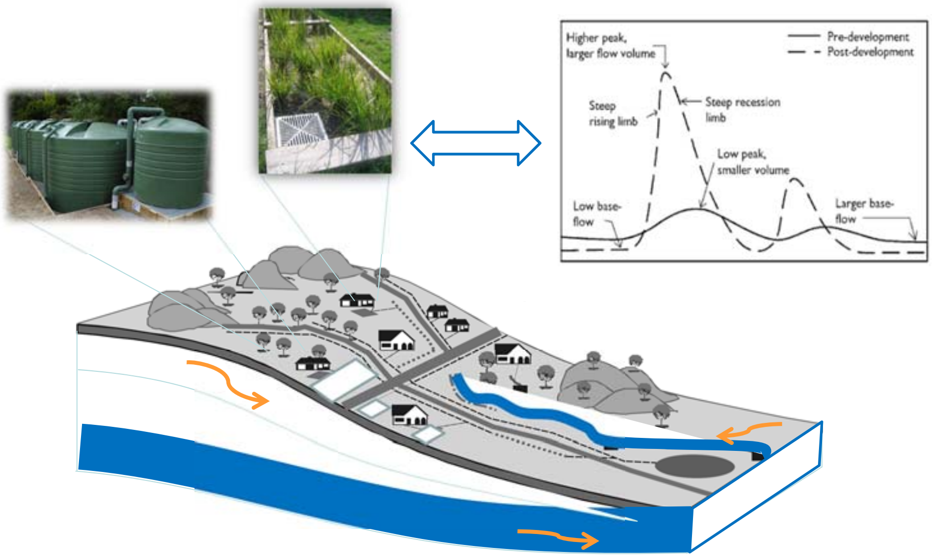


Pollutant / contaminant accumulation and transfer risk to humans and organisms



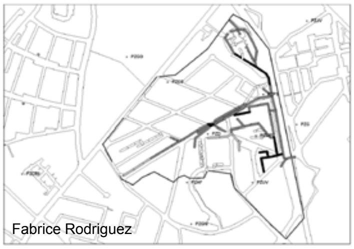
Bester & Schaefer: Water Research (2009)

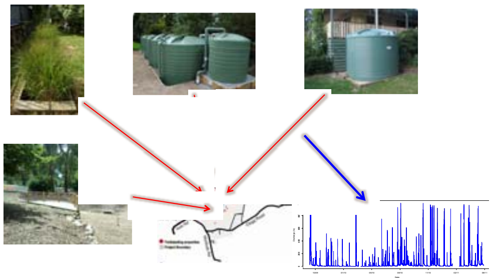
Transfer from site to catchment scale



Site-to-catchment: surface processes

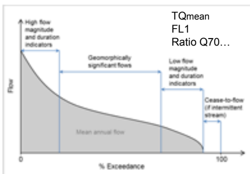
Well – established	Some knowledge	Knowledge gaps
Propagation H_20 through constructed network	Pervious area runoff to impervious areas	Propagation of stochastic behaviour
	Characterisation / transformation & propagation of pollutants through constructed / natural network	Diachronic modelling (long-term)

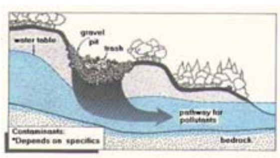


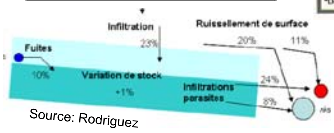


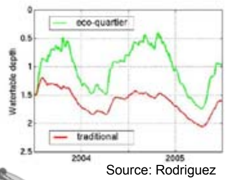
Site-to-catchment: subsurface processes

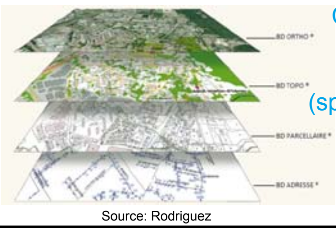
~~Well – established~~	Some knowledge	Knowledge gaps
Indicators to assess catchment-scale performance (esp. low flows, quality, public health)		Pollutant transfer
Interactions with stormwater network		
	Catchment-scale effect of implementation (spatial arrangement, scale)… model structure	

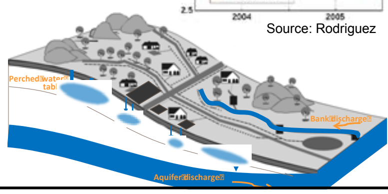










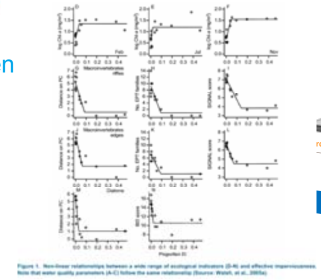


Site-to-catchment: ecological & public health

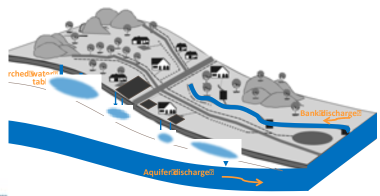
~~Well – established~~

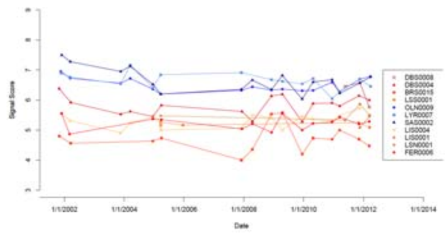
Relationship between hydrol, WQ & ecosystem health

Some knowledge



Knowledge gaps

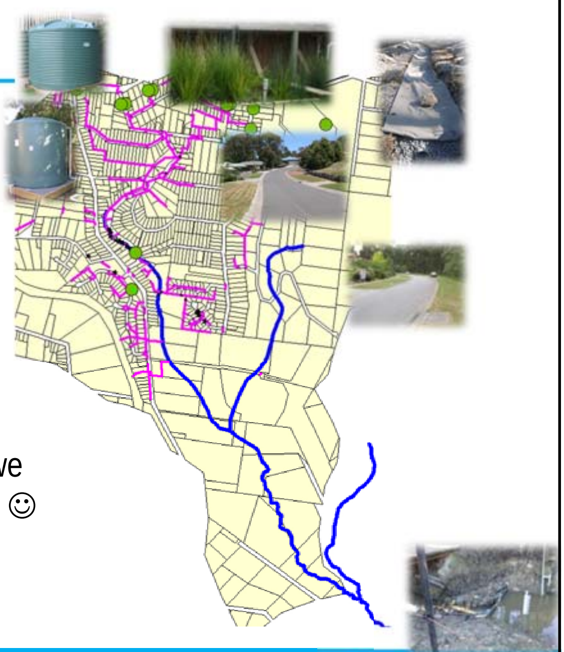




Effect of catchment-scale implementation on ecosystem & human health indicators

In conclusion

- At the site-scale
  - we can model some things not others
  - few work on long-term
- At the catchment-scale
  - apart from peak flows, we live in blissful ignorance ☺ and opportunity thus abounds



l'eau dans la ville / water in the city

Presentations

The impact of model structure on the representation of source control impacts on baseflows	**Perrine Hamel**
Regional scale analysis for the design of storage tanks for domestic rainwater harvesting systems	**Alberto Campisano**
Optimisation of source control implementation through design parameter exploration	**Matthew Burns**
Hydrologic modelling of source control measures at the catchment scale used to assess the relevance of French local water policies	**Guido Petrucci**
Recommendations for time-series in modelling rainwater harvesting efficiency	**Ilaria Gnecco**

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Modelling impacts of source control and stormwater harvesting at the catchment-scale

Modelling the impact of stormwater source-control infiltration techniques on catchment baseflow

Perrine Hamel Monash University, Australia &
Stanford University, USA

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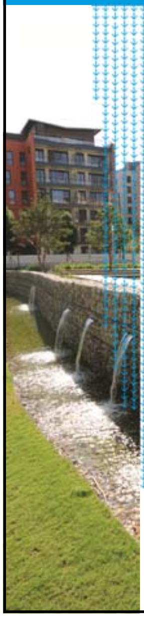
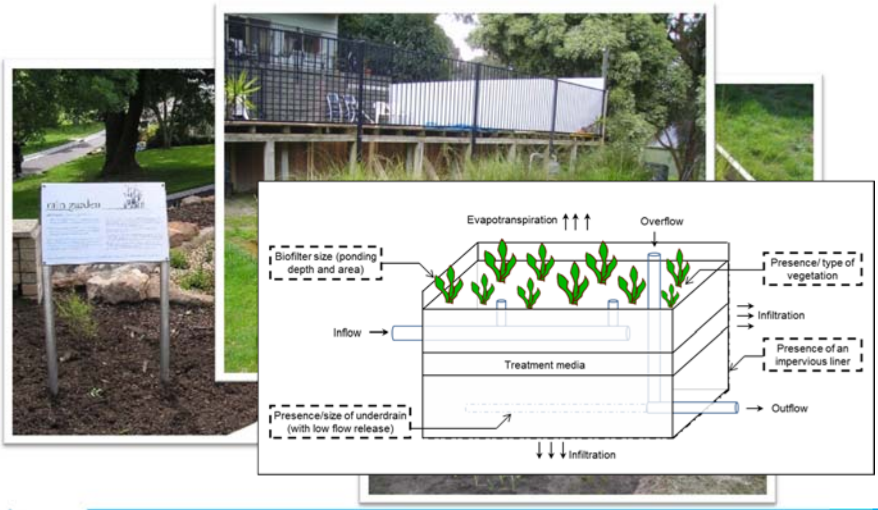


Modelling the impact of stormwater source-control infiltration techniques on catchment baseflow

Perrine Hamel, Tim Fletcher

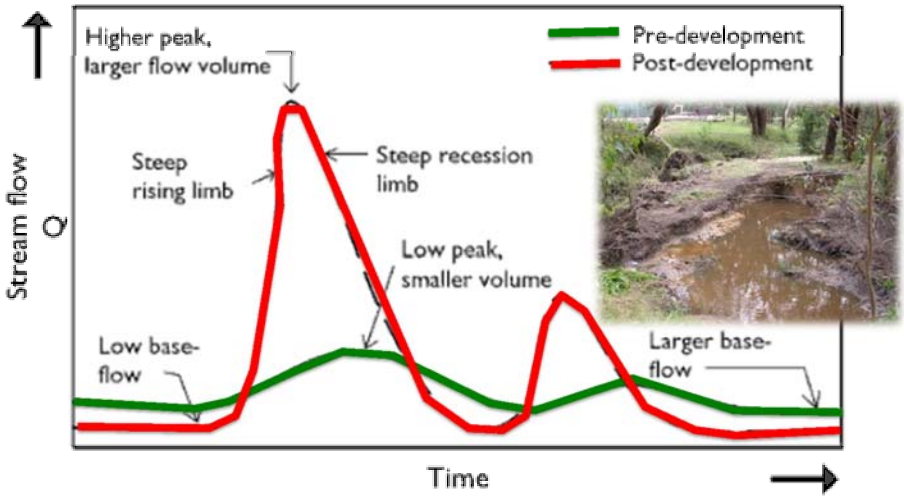
Raingarden?

Raingarden?

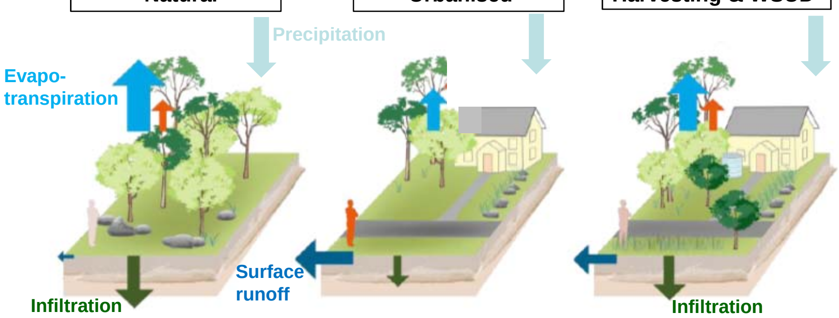


Stormwater harvesting?

Impact on the flow regime → stream health



Impact on the water budget



Modification of the catchment water balance by urbanisation

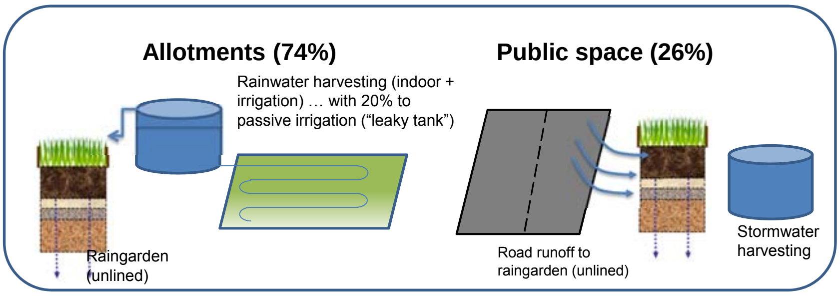
Research questions

- **Impact** of source-control techniques on the (low) **flow regime** of an urban catchment?
  (Best strategy for implementation?)
  → A lot of literature…

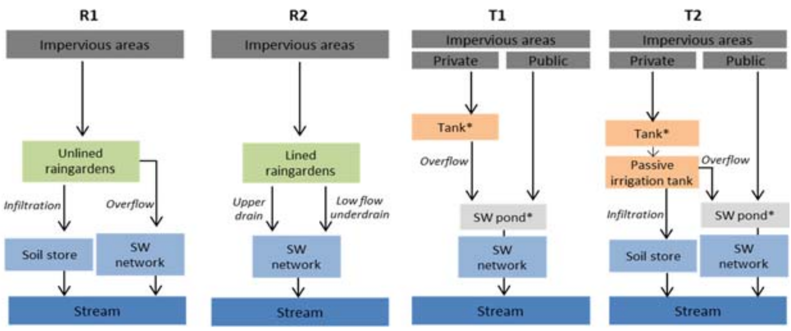
- **Predictive performance** of models?

Objectives

- Evaluate how **model structure** influences the predicted changes in flow regime resulting from **alternative stormwater management** strategies;
- Illustrate the application of the **flexible approach** to catchment modelling for urban hydrology (Clark, M.P., McMillan, H.K., Collins, D.B.G., Kavetski, D., Woods, R.A., 2011. Hydrological field data from a modeller's perspective: Part 2: process-based evaluation of model hypotheses. Hydrological Processes 25(4): 523-543. DOI: 10.1002/hyp.7902)

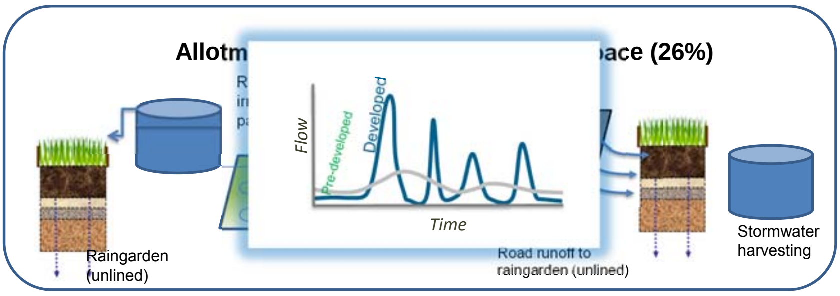


Methods



Objectives

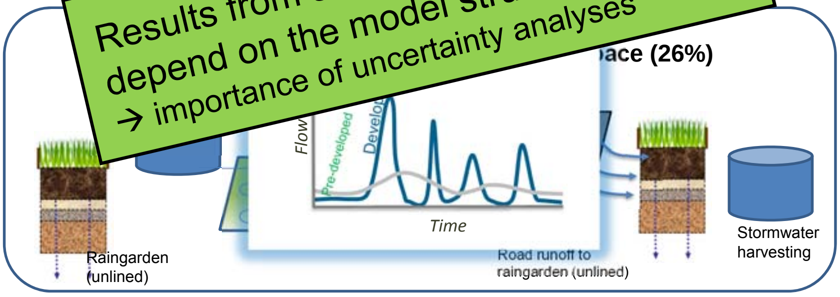
- Evaluate how **model structure** influences the predicted changes in flow regime resulting from **alternative stormwater management** strategies;
- Illustrate the application of the **flexible approach** to catchment modelling for urban hydrology



Objectives

- Evaluate how **model structure** influences the predicted changes in flow regime resulting from **alternative stormwater mana**… ategies;
- Illustrate the application of the **flexib**… modelling for urban hydrology…

Results from scenario simulations do depend on the model structure
→ importance of uncertainty analyses



Methods

- Calibrated **3 MUSIC models** to McMahons catchment (natural/reference catchment)

  → used **diagnostic "signatures"** to develop physically meaningful models

- Simulated **urbanisation** of the catchment with traditional stormwater management techniques (end-of-pipe)
- Evaluated the **influence** of the **model structure** on the results predicted with various **scenarios** (raingardens + tanks)

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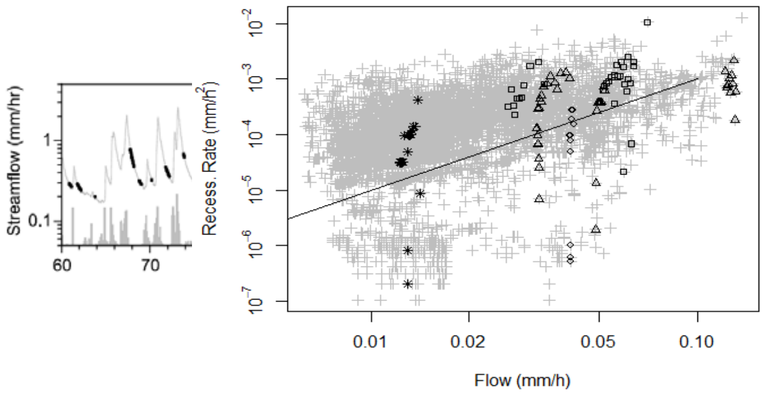
Model development

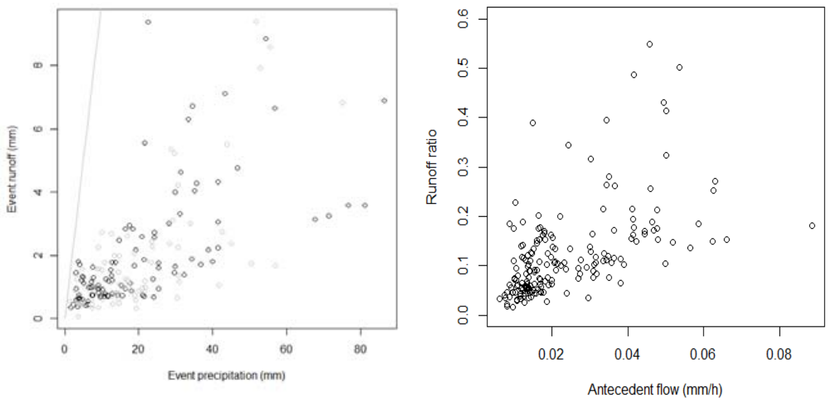
- Recession plots



→ Number of reservoirs

Model development

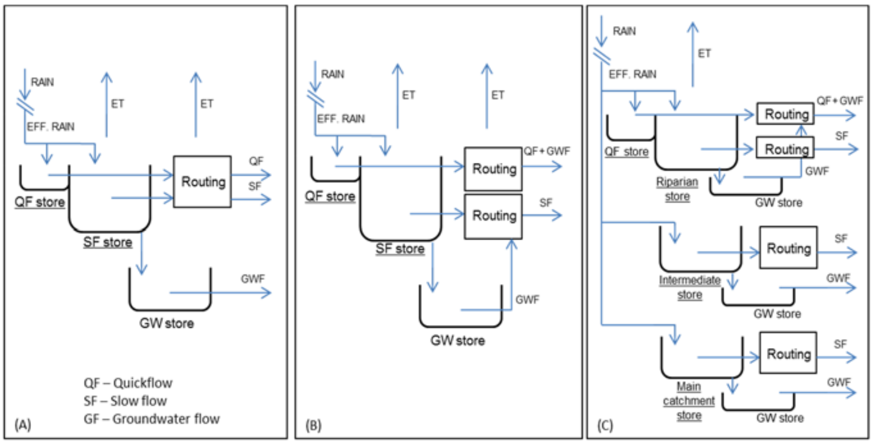
- Rainfall-runoff analyses (Hydromad R package)



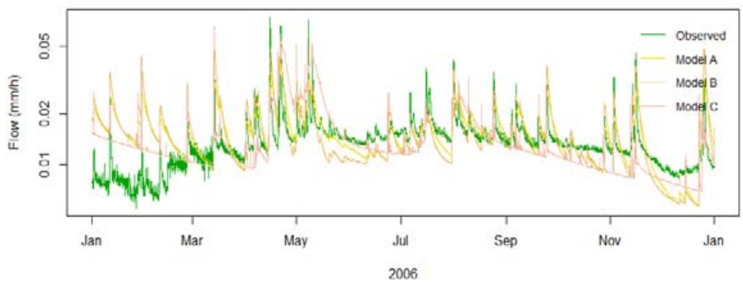
→ Storage capacity/percolation to groundwater

Model development

- 3 model structures



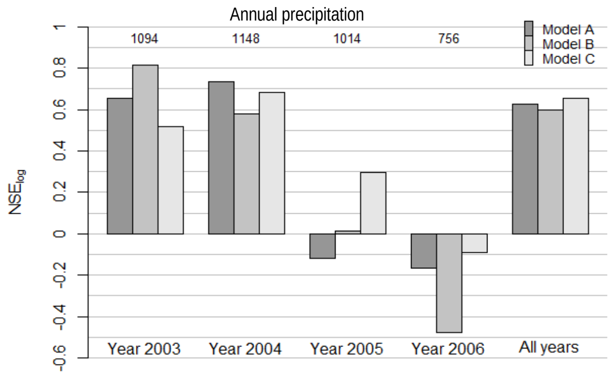
Model calibration/validation



Model	NSE_{log}	NSE	Ratio Q_{mean}	Ratio Q90	Ratio Q50	Ratio St.dev.
A	0.63	0.64	1.00	1.02	1.14	0.77
B	0.60	0.59	1.06	1.06	1.25	0.82
C	0.66	0.58	0.94	0.98	1.07	0.82

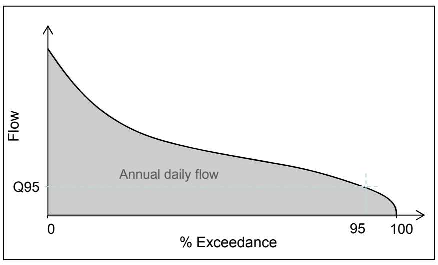
Model calibration/validation

- Differential split sample tests



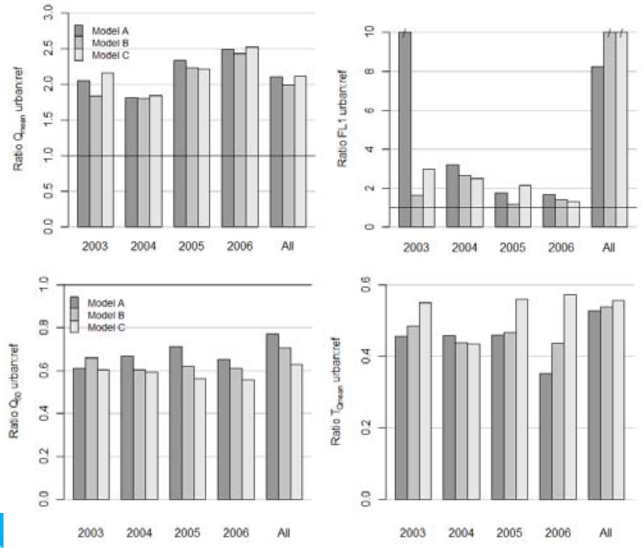
Results

- Metrics (based on the baseflow metrics selection study):
  - total flow volume (annual daily flow, or ADF),
  - 95th percentile (Q95),
  - ratio of 95th percentile over ADF (Q95/ADF),
  - the frequency of low flow spells (FL1).

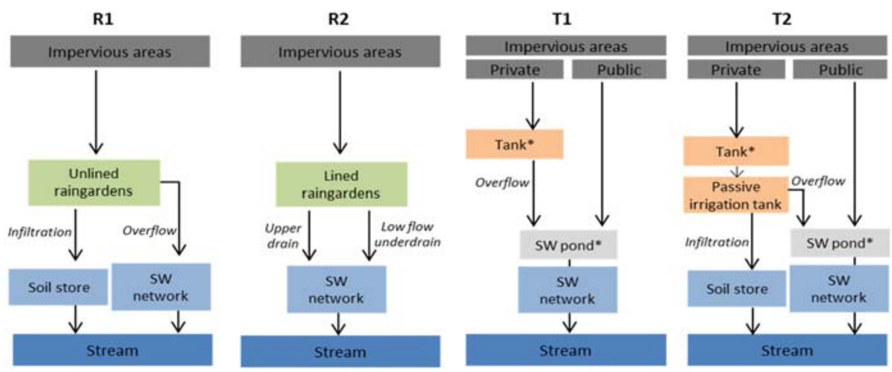


Results

- Ratios of flow metrics (Urban/Reference)

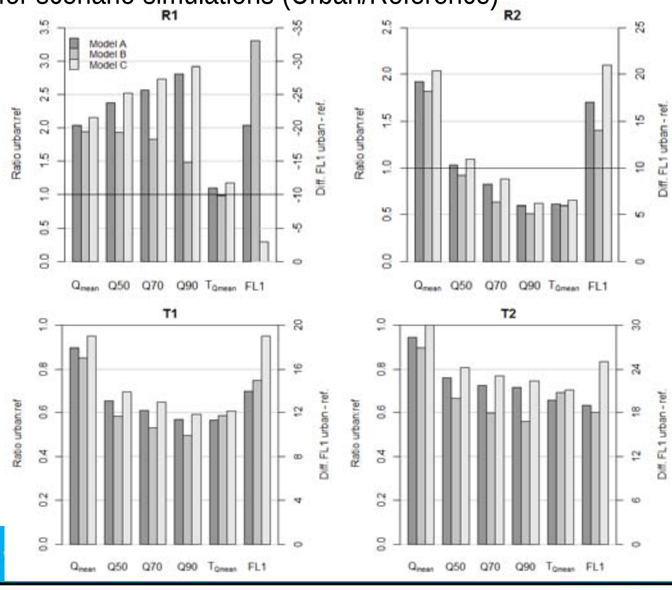


Scenarios



Results

- Ratios for scenario simulations (Urban/Reference)



Lessons

- Catchment modelling for stormwater management
  – Range of **performance criteria**
  – Potential of the flexible approach to catchment modelling
- Development of structural uncertainty analyses
  – Has important consequences on **predictions**
  – Multiple models approach remains rare in the stormwater modelling literature

Perspectives

- Selection of assessment metrics
  - Better compare/account for low flows in stormwater management studies (e.g. environmental flow frameworks)
  - Hamel, P., Fletcher, T.D., Daly, E. (2013). Source-control stormwater management for mitigating the impacts of urbanisation on baseflow: A review. Journal of Hydrology, 485: 201-211
  - Hamel, P., Daly, E., Fletcher, T.D. (in review) Which baseflow metrics should be used in assessing flow regime of urban streams?
- Development of structural uncertainty analyses
  - Increased use of multiple modelling approach → better compare different strategies for stormwater management
  - Hamel, P., Fletcher, T.D. (in press) The impact of stormwater source-control strategies on the (low) flow regime of urban catchments. *Proceedings of the 8th International Novatech conference 2013*

Acknowledgements

PhD supervisors and colleagues, Centre for Water Sensitive Cities

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centre for water sensitive cities

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International Association for Hydro-Environment Engineering and Research
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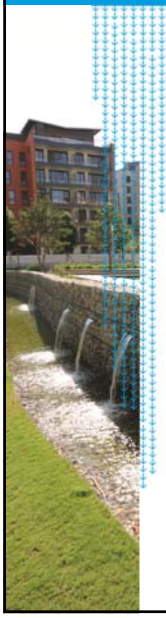
WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Modelling impacts of source control and stormwater harvesting at the catchment-scale

Regional scale analysis for the design of storage tanks for domestic rainwater harvesting systems

Alberto Campisano, University of Catania (Italy)



Workshop on

Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Regional scale analysis for the design of storage tanks for domestic rainwater harvesting systems

A. Campisano

Dept. of Civil and Environmental Engineering, University of Catania, Italy

Introduction

Multiple benefits of Rain Water Harvesting (RWH):

- Historically adopted as back-up source to cope with restricted availability of freshwater [Fewkes and Butler, 2000; Ghisi and Ferreira, 2007; Eroksuz and Rahman, 2010]
- Also help increasing the retention efficiency of urban catchments by retaining rainfall volumes temporarily [Fletcher et al., 2007; Burns et al., 2010; Petrucci et al., 2010]

Introduction

- Rain water replacing water from mains in case of domestic uses requiring lower quality in comparison to potable water (WC, gardens, terraces) [Vickers, 2001]
- Up to 30% water used in houses is consumed for toilet flushing [Butler et al., 1995; Lazarova et al., 2003]
- Prioritary use to address rooftop rain water to the flush of toilets also because the use would be compatible with the needed water quality

Introduction

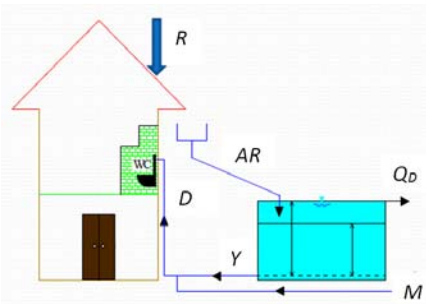
- Existing studies reveals that optimal tank capacity depends on several local variables (precipitation patterns, rooftop area, demand, etc.) [Aladenola and Adeboye, 2009]
- Need to generalise results. Researchers investigated the water saving variability at different spatial and temporal scales [Fewkes, 2000; Palla et al., 2011] using also dimensionless methods

Aim of the study

- To investigate potential for water saving and volumetric retention provided by RWH tanks
- To define a methodology (based on daily water balance simulations) to determine multiple benefits at a regional scale using a dimensionless approach.
- To check applicability of the methodology to daily rain data series of 17 pluviometric stations in Sicily

Methodology

- Water balance simulation of the tank using a simple scheme
- Storage and relaunch of rain water from the tank up to the toilet cistern



- Use of the water from mains just in case that the rain water tank is empty
- Excess water coming from the rooftop discharged as tank overflow

Methodology

- To analyse different combinations of the variables influencing the RWH performance, two dimensionless parameters are used:

$$s_m = \frac{S}{D \cdot n_D / n_R}$$

(modified storage fraction)

$$d = \frac{D}{A \cdot R}$$

(demand fraction)

- S = tank storage capacity (m^3)
- D = water demand for toilet flushing (m^3) over the considered period
- n_D = dry weather days in the year
- n_R = rainy days in the year
- A = net rooftop area (m^3)
- R = total rainfall in the period (m)

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Methodology

- Water saving and overflow discharge performances respectively calculated as:

$$W_S = \left(\frac{\sum Y}{\sum D}\right) \cdot 100$$

(water saving)

$$O_D = \frac{\sum Q_D}{\sum AR} \cdot 100$$

(overflow discharge)

Y = yield volume from the storage tank (m^3)

Q_D = overflow volume from the storage tank (m^3)

- Set up of daily water balances for each year of each series
- Statistical elaborations. Frequency analysis with frequency levels 50%, 75% and 90% to characterize W_s and O_D

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Methodology

- Determination of regional regressive equations to relate W_s and O_D for all the analysed pluviometric stations to the dimensionless parameters:

$$W_S = \frac{a_1 \cdot s_m}{b_1 + s_m} \cdot d^{c_1} \qquad O_D = 100 - \frac{a_2 \cdot s_m}{b_2 + s_m} \cdot d^{c_2}$$

a1, b1, c1, a2, b2, c2 = regression calibration parameters

- The form of equations assures the expected asymptotic increase of W_s and the asymptotic decrease of O_D as s_m increases (asymptote depending on d)

Application to the case study

- Daily precipitation data from 17 pluviometric stations in Sicily

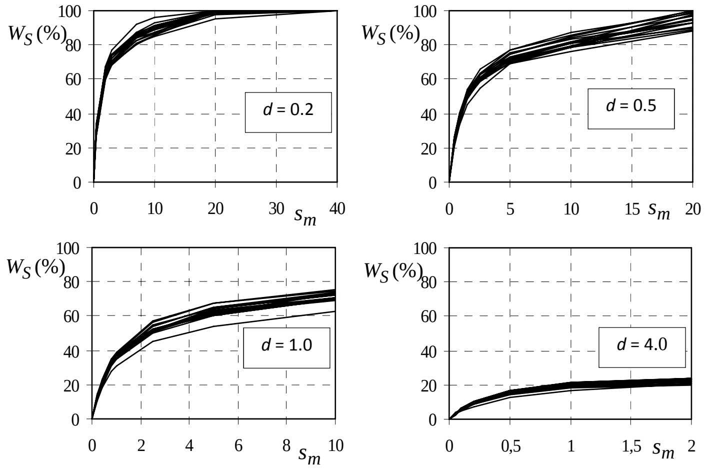
- Stations chosen according to:
  - distribution over the island;
  - length of the series (at least 25 years of records);
  - high variability of rainfall (400-1300 mm/year) and of rainy days in the year (46-88)

- Simulations for the following parameter ranges:

  d = 0.2 - 4.0 and s_m = 0.05 – 40

  to consider values of demand, storage tank, rooftop area and precipitation in the range of practical applications

Results (water saving)



- f = 50%
- As s_m increases:
  - W_s increases
  - Slope decreases
- As d increases:
  - W_s decreases
  - Slope decreases

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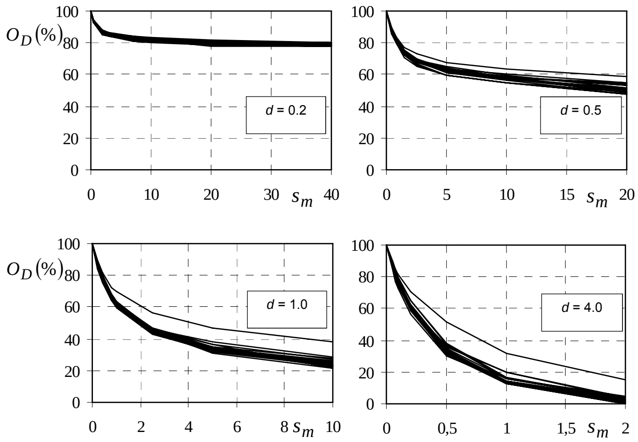
Results (overflow volumes)



- f = 50%
- As s_m increases:
  - O_D decreases
  - Slope decreases
- As d increases :
  - O_D decreases (with zero values for d=4)
  - Slope increases

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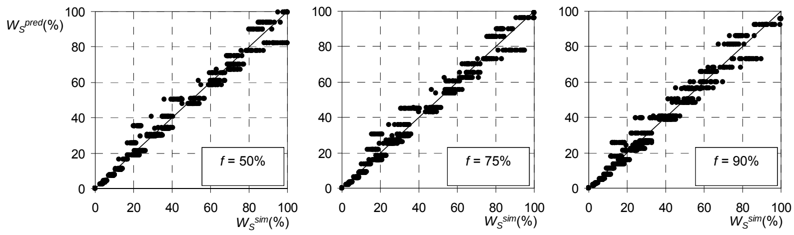
Regional regressions

$$W_S = \frac{a_1 \cdot s_m}{b_1 + s_m} \cdot d^{c_1}$$

f	a_1	b_1	c_1	R^2	MAE
50%	75.645	1.226	-0.206	0.981	2.934
75%	71.170	1.399	-0.227	0.979	3.005
90%	65.491	1.547	-0.259	0.976	3.186



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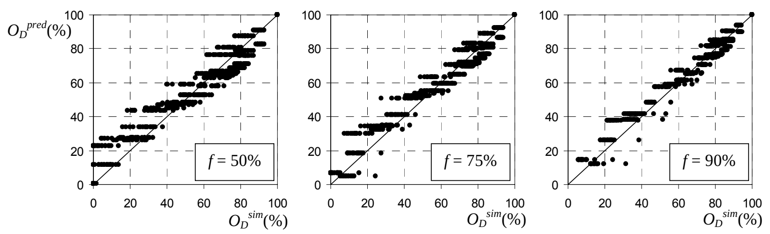
Regional regressions

$$O_D = 100 - \frac{a_2 \cdot s_m}{b_2 + s_m} \cdot d^{c_2}$$

f	a_2	b_2	c_2	R^2	MAE
50%	66.763	0.732	0.597	0.961	3.869
75%	74.472	0.664	0.543	0.946	4.948
90%	81.504	0.572	0.482	0.925	6.168



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Example of application

- House with 4 people and A = 112 m^2.
- 8 flushes/percapita per day each of 7 litres = daily flushing demand D equal to 0.224 m^3.
- Rain storage tank with volume S=1.0 m^3.

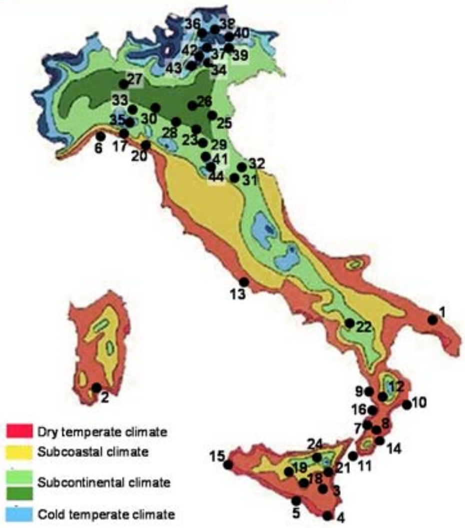
Gela
R =401 mm/year
n_R= 49; n_D= 316
d =1.82
s_m= 0.70
Ws =24.20%
O_D= 53.48%

Zafferana Etnea
R =1311 mm/year
n_R= 81; n_D= 284
d = 0.56
s_m= 1.28
Ws =43.51%
O_D= 70.11%

- For the two cases, about 1/4 or 2/5 of the water needed for toilet flush could be recovered by a DRWH system
- Significantly high values of the overflow discharge show the availability of further resource for other domestic uses

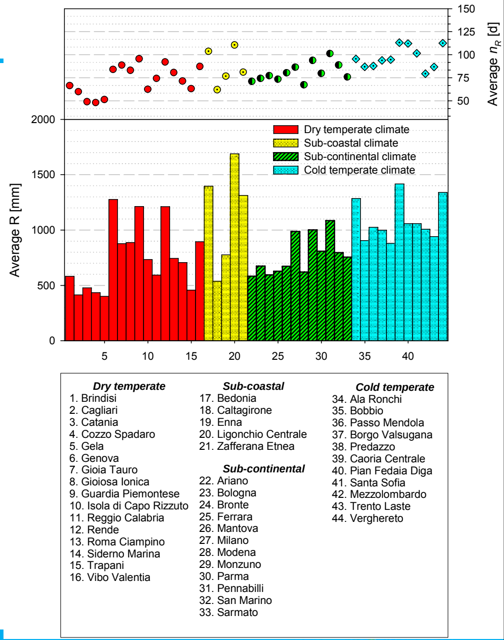
Climatic zoning in Italy

- Use of Koppen-Geiger classification to identify the 4 main different climates within the Italian territory
- Selection of 44 sites within the 4 climate zones to examine the possible extension of the methodology to the whole peninsula



Climatic zoning in Italy

- Yearly precipitation in the range 420-1700 mm
- n_R values tends to increase from 73 days (dry temperate sites) to 95 days (cold climate sites)



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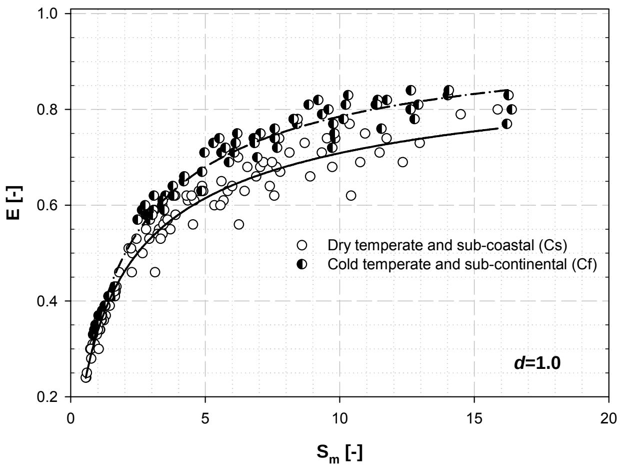
Results

Water saving efficiency vs storage fraction for *d*=1.0.



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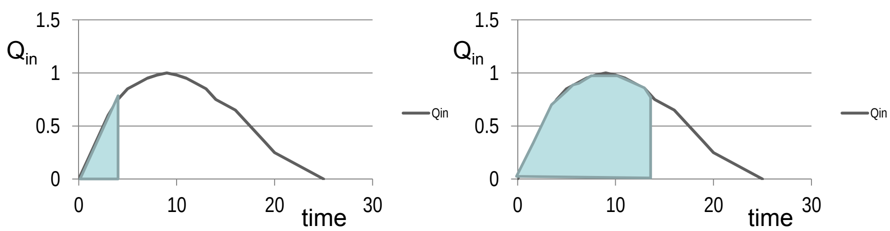
Conclusions

- Methodology to evaluate water saving and retention performance of RWH tanks at regional level
- Application to 17 pluviometric stations in Sicily
- Results show high values of water saving with tanks characterised by capacity of 3-10 times the daily water demand for toilet flushing
- High values of overflow show the availability of resource also for other domestic uses
- Preliminary results show the possibility to extend the methodology to other precipitation regimes

Perspectives

- Need to investigate the performance at larger spatial scales and under climate change scenarios.
- Results open to research whether DRWH systems at sub-daily time scales (i.e. at scale of rainfall event) can help reducing peak flow discharges too.



Thanks

…Rainwater harvesting…

Thank you for
your attention !

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WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Modelling impacts of source control and stormwater harvesting at the catchment-scale

Optimisation of source control implementation through design parameter exploration

Matthew Burns, Monash University &
University of Melbourne (Australia)

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Stratégies & solutions pour une gestion durable de l'eau dans la ville

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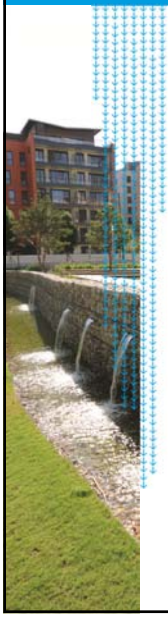


Optimization of source control implementation through design parameter exploration

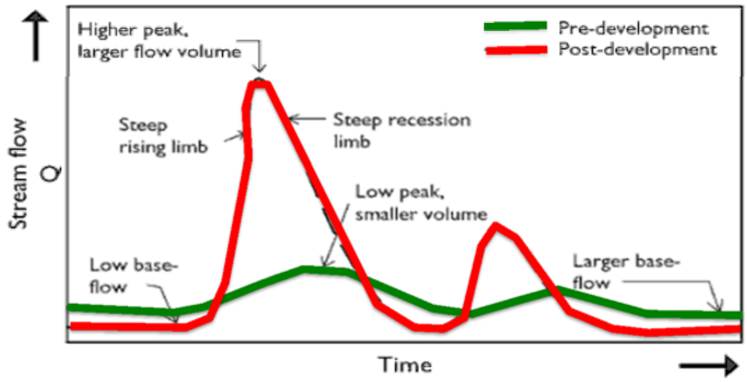
Matthew Burns and Tim Fletcher

Introduction

The drainage-efficiency approach to stormwater management…

Introduction

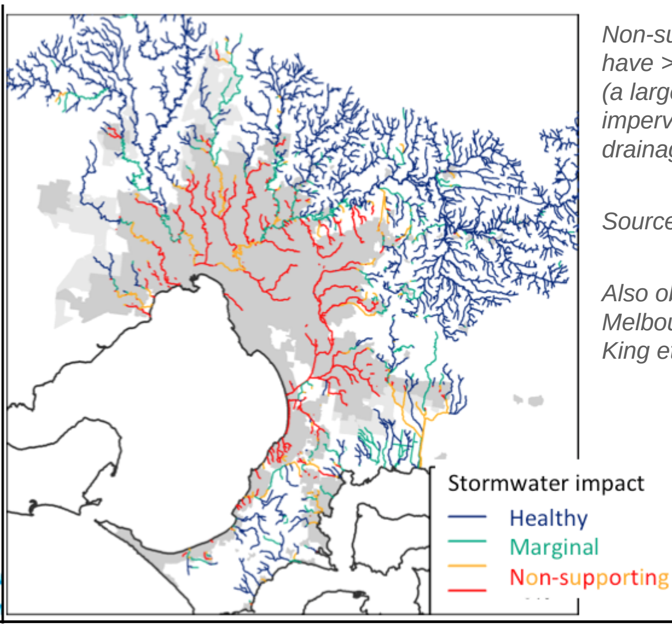
This conventional approach to stormwater management causes changes to flow regimes…



Introduction

These changes to the flow regime (and water quality) degrade the health of urban streams…

Introduction



Non-supporting streams have >2% DCI (a large-scale estimate of impervious area with direct drainage connection)

Source: Walsh, 2013

Also observed outside of Melbourne (e.g. Maryland, King et al., 2011)

Introduction

To protect or restore urban streams, a complete approach to urban stormwater management is needed, which aims to protect or restore ecologically important elements of the pre-development hydrograph…

Low-flow hydrology

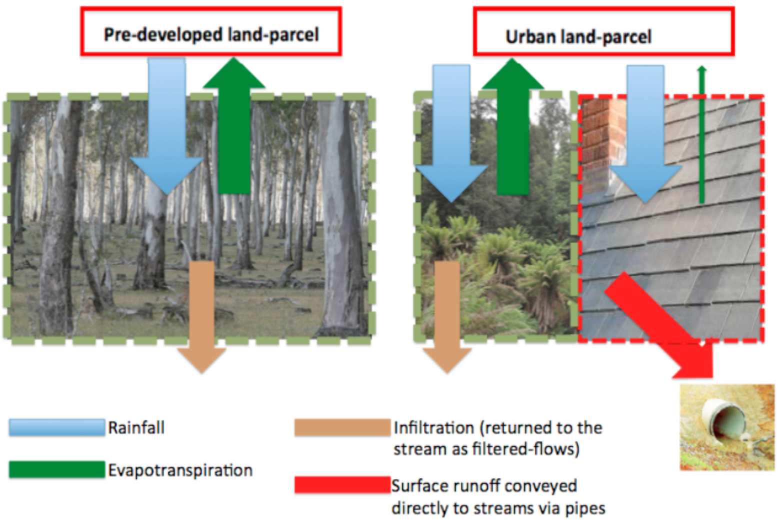
High-flow hydrology

Introduction

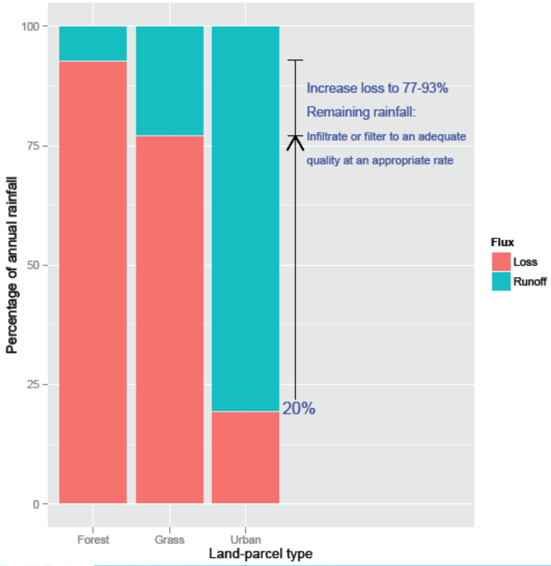
Flow-regime management (Burns et al., 2012)

Protect or restore natural hydrologic processes at small scales, with the aim of restoring natural flow regimes at larger scales downstream

Introduction



Introduction



New stormwater management objectives for flow-regime management…

From impervious surfaces…

1. Increase the amount of rainfall lost to evapotranspiration and/or harvesting…
2. Infiltrate remaining rainfall…
3. Decrease the frequency and volume of surface runoff delivered to stream

Introduction

For this work, we aimed to test if a common source-control strategy could achieve these three flow regime objectives

Methods

A combined system: rainwater tank + rain-garden

1. Impervious roof draining to a rainwater tank
2. Impervious pavement draining to a rain-garden
3. Overflow from tank directed to rain-garden

Methods

Very large parameter space…

- 3 climates (dry, temperate, wet)
- 3 urban densities (low, medium, high)
- 5 rainwater tank sizes (1 kL, 2.5 kL, 5 kL, 10, kL, 20 kL)
- 4 internal demand scenarios (toilet, toilet + clothes washing, toilet + clothes washing + hot water, ALL internal)
- 2 external demand scenarios
- 2 possible directions for passive irrigation
- 5 possible tank storage levels to engage passive irrigation
- 2 cases concerning how much roof area drains to tanks
- 4 possible rain-garden sizes

3 * 3 * 5 * 4 * 2 * 2 * 5 * 2 * 4 = 28,800 design configurations!

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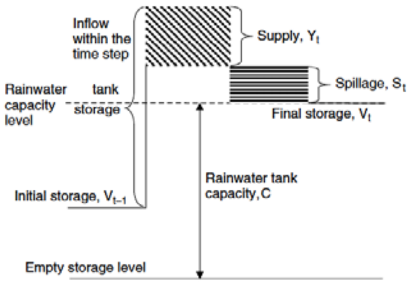
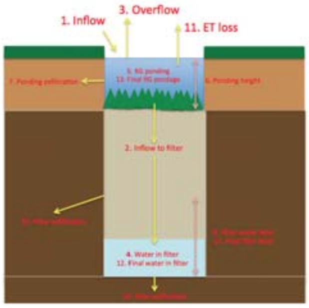
Methods

Conceptual modelling (coded in R)

Tank model (Mitchell, 2007)



Rain-garden model



Methods

28,800 modelling scenarios

12 years on a 6-min timestep…

Each scenario run on my MAC took ~ 4 mins ☹

Methods

Cluster computing was utilized to complete the modelling in ~24 hours (compared to 3 months using a single machine)

Much easier for trouble shooting

The interface allowed the user to easily sample the parameter space

Methods

We selected modelling scenarios that achieved the hydrologic restoration targets…

Results

In general, a limited number of design configurations achieved optimal performance. Highlights the importance of design to restore flow regimes at small scales

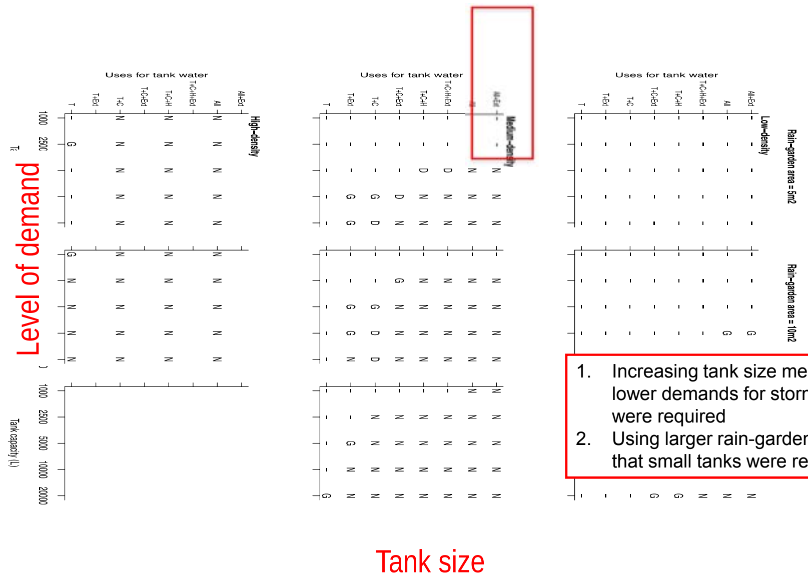
Parameter

Parameter	Low-density			Medium-density			High-density		
	D	T	W	D	T	W	D	T	W
Number of configurations that met targets	138	92	36	873	758	650	627	560	584
Complying configurations as % of 3200 trialled	4	3	1	27	24	20	20	18	18
% of complying configurations with:									
50% of roof draining to the tank	0	0	0	17	17	27	24	24	37
100% of roof draining to the tank	100	100	100	83	83	73	76	76	63
Tank used for T only	0	0	0	10	7	2	15	8	0
Tank used for T and C	6	5	0	25	24	16	27	28	27
Tank used for T, C and H	33	30	28	32	33	36	29	31	35
Tank used for all demands	61	64	72	33	36	46	30	32	38
Tank not used for external demands	43	41	39	45	44	44	100	100	100
Tank used for external demands	57	59	61	55	56	56	–	–	–
Passive irrigation from top 100% of tank	18	18	25	16	16	17	16	15	13
Passive irrigation from top 75% of tank	22	25	31	21	21	21	20	21	20
Passive irrigation from top 50% of tank	24	24	31	21	22	22	21	21	23
Passive irrigation from top 25% of tank	20	20	14	21	22	22	21	22	23
No passive irrigation	16	13	0	21	20	18	21	21	22
1-kL tank	0	0	0	3	1	0	12	11	12
2.5-kL tank	0	0	0	12	12	12	22	21	20
5-kL tank	12	3	0	24	23	21	22	23	22
10-kL tank	33	30	25	29	30	31	22	23	23
20-kL tank	55	66	75	31	33	37	22	23	23
Passive irrigation to drain	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	51	52
Passive irrigation to garden	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	49	48
2-m² rain-garden	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	20	17
5-m² rain-garden	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	26	37
10-m² rain-garden	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	54	46
20-m² rain-garden	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	–	–	–

1. It was possible to achieve the targets across all climates and urban densities
2. For low-density urban land-parcels, very large tanks required
3. More flexibility in demand for less dense urban land-parcels

Results

Interaction of design parameters was important…



1. Increasing tank size meant that lower demands for stormwater were required
2. Using larger rain-gardens meant that small tanks were required

Discussion

It was possible to restore near natural flow regimes at small scales using a combination of stormwater harvesting and infiltration

Easier to achieve the targets in more dense urban settings

Results underscore the importance of careful design

Discussion

Policy mechanisms required to stipulate stormwater harvesting and infiltration

Urban design challenges remain

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WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Modelling impacts of source control and stormwater harvesting at the catchment-scale

Hydrologic modelling of source control at the catchment scale. Long-term effects of local stormwater regulations in France

Guido Petrucci, Uni Paris—Est, France

Hydrologic modelling of source control at the catchment scale.
Long-term effects of local stormwater regulations in France.

SOCOMA workshop – Novatech 2013
23/06/2012

Guido Petrucci
guido.petrucci@leesu.enpc.fr

Context and introduction

- PhD research (2008-2012) : comparison between current practices and hydrologic rationality for French source control strategies
- Starting point :
  - BMPs in France (and elsewhere) become systematic…
  - … because SC regulations are becoming systematic
  - Future hydrologic behaviour of urban catchments will increasingly depend on SC regulations
  - Are current regulations preparing a hydrologically good future ?

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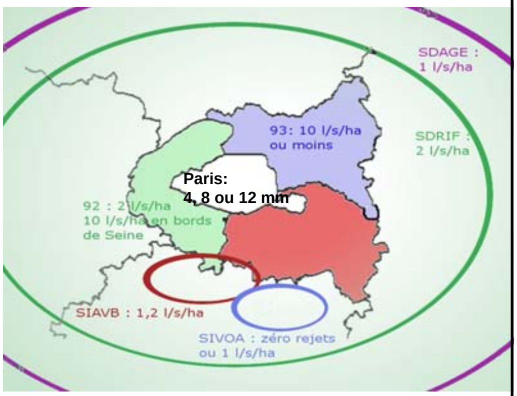
Some doubt raised by current regulations

- Seine-Saint-Denis : ~1 Mm^3 of BMPs (14-20 mm over impervious surface) not included in management models of the sewer system
- Incoherence among scales
- Similar areas with different values and different areas with similar values
- Really strict values
- …



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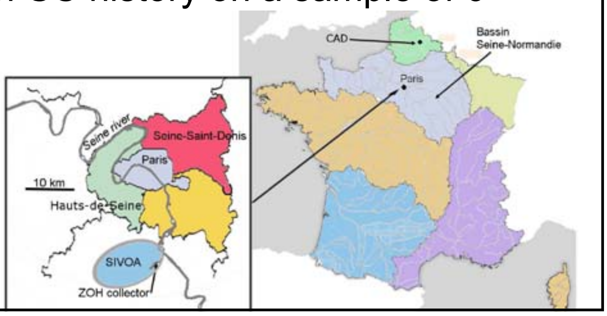
Analysis of current practices

How local authorities develop SC regulations ?

Which logics are followed ?

Methods

- Reconstruction of SC history on a sample of 6 local authorities
- Interviews with technicians
- Comparative analysis



Some results of the analysis

- SC regulations with several objectives (political perspective)
  - Flood prevention, sustainable development (improvement of urban and downstream environment, heat island,…), costs reduction, "pedagogic function"
- Only flood prevention is quantified in most studies (technical perspective)
  - Strong "hydrologic shortcuts", e.g. linear approach to pass from parcel to catchment (and vice versa)
- A common and generalized logic: "**incremental vision**" of source control :

  A stricter regulation → a "better" stormwater management

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Hydrologic modelling: is the "incremental vision" true?

- A more strict regulation is always "better" than a less strict one ?
- Simulation of SC regulations
- On distributed models of two urban catchments
  - ZOH (Paris region), 5 km²
  - Gohards (Nantes), 2 km²
- Methods:
  - Setup and calibration of a classical urban hydrology model (SWMM 5)

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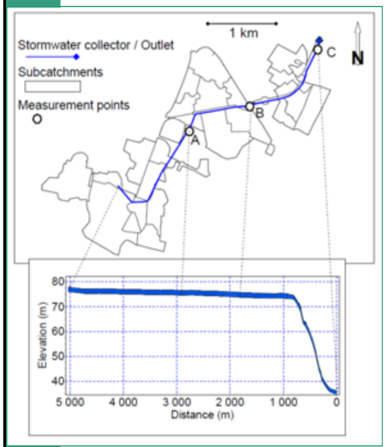
The two urban catchments

ZOH – south of Paris

Les Gohards - Nantes

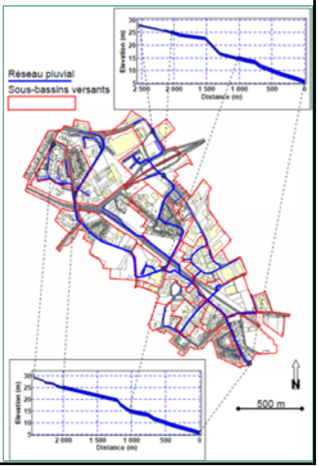


Separated sewer

	Area	
450 ha		180 ha
	Imperviousness	
31%		38%

Model calibration

GA to maximize Nash criteria on one-month simulations



What we model? Two types of regulations

- On volume (*y* mm)
  - Infiltration-based

- On flow-rate (*x* l/s/ha)
  - Storage-based

- Hypotheses: complete application of BMPs, constant urbanisation
- “*What would have happened if the regulation was applied since the beginning of urbanisation?*”

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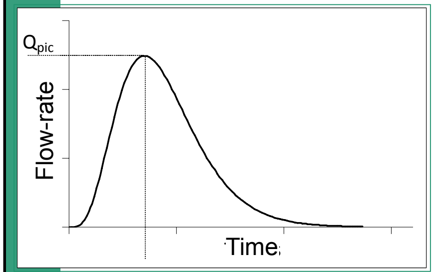
What we look at? Indicators of the hydrologic behaviour

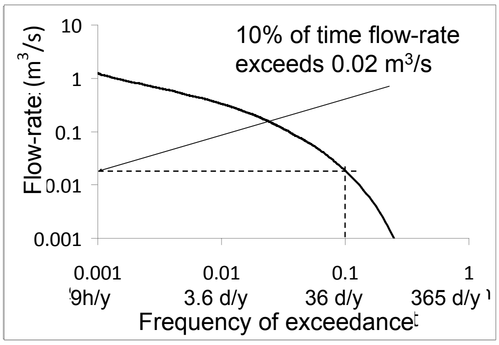
- Two objectives

1. Flood reduction
   → Peak flow-rates



Design rainfall, T = 10 years

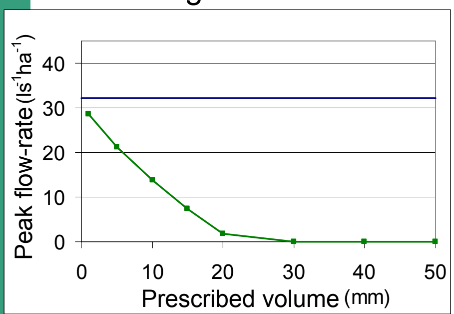
2. Receiving water protection
   → Current flow-rates (stream erosion, combined sewer overflows,...)
   → Flow duration curves



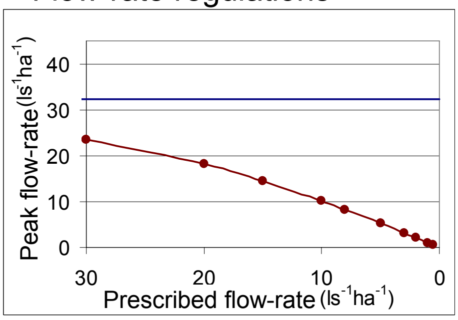
Results (1) : peak flow-rates

Design rainfall, T = 10 years, ZOH catchment

Volume regulations



Flow-rate regulations

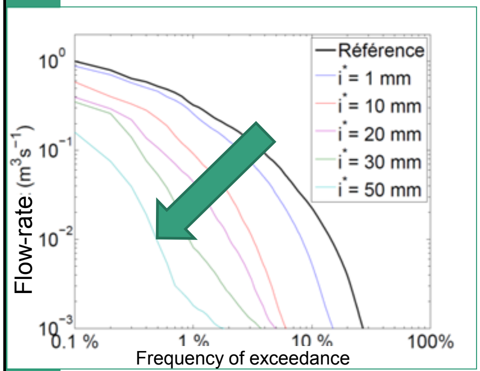


- The two types of regulations reduce peak flow-rates;
- More strict regulations are more effective

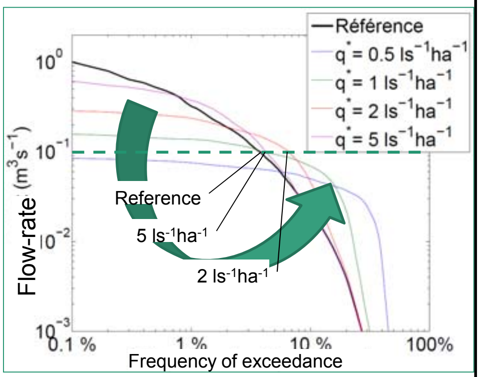
Results (2): current flow-rates

Flow duration curves (annual median, data: 15 years), ZOH catch.

Volume regulations



Flow-rate regulations



- Two different behaviours

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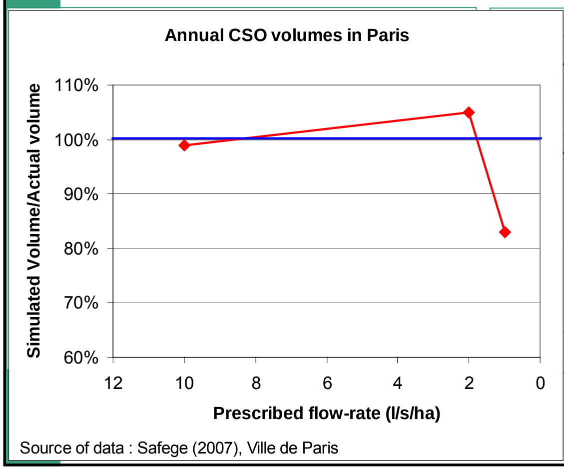
1. Introduction 2. Current practices 3. **Hydrologic modelling** 4. Conclusions

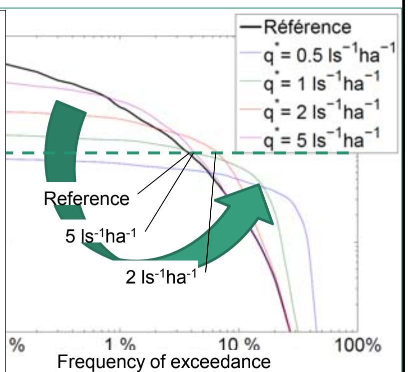
Results (2): current flow-rates

Flow duration curves (annual median, data: 15 years), ZOH catch.

Volume regulations

Flow-rate regulations





Results (3) : flow-rate regulations and validity of the "incremental vision"

A more strict regulation is always "better" than a less strict one ?

- **Yes** (but…), if we look only to peak flow-rates
- **No**, if we look also to receiving water bodies

Maybe the "incremental vision" was good for a pioneering phase (i.e. multiplying experiences), but **not for systematic diffusion**

By an operational point of view :

- Local authorities should be very careful when choosing a flow-rate regulation → local studies
- Volume regulations seems "safer" in case of doubt (but it can depend on the objectives, on the catchment,…)

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1. Introduction 2. Current practices 3. Hydrologic modelling 4. **Conclusions**

Conclusions

- Opposition between BMPs (parcel scale) and SC (catchment scale) :
  - It is not just a matter of scale!
  - SC is more than multiplying BMPs: it is a coordination of individual efforts to achieve common objectives
  - Instruments and competences necessary to achieve a good SC are not the same than for good BMPs
- If we want SC regulations to prepare a hydrologically good future, we have to take into account all of our objectives in their elaboration
  - New instruments, evolution of technical practices, etc.

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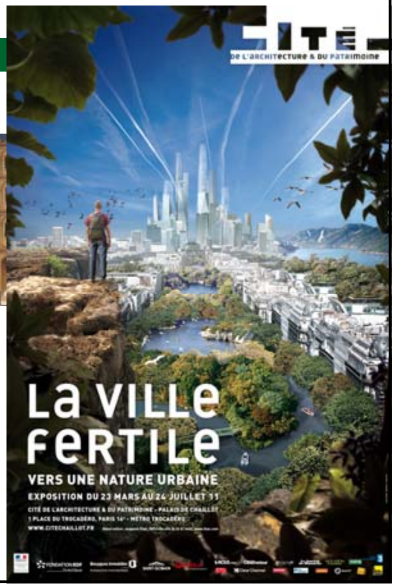
Thank you

The ideal city in 1470...

... the pervious one in 2013?



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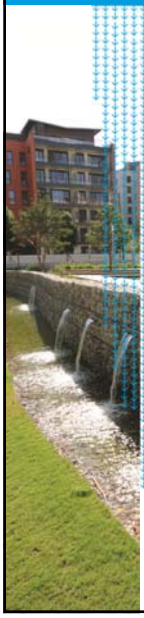
WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Modelling impacts of source control and stormwater harvesting at the catchment-scale

Recommendations for time-series in modelling rainwater harvesting efficiency

Ilaria Gnecco, Genoa University, Italy



RECOMMENDATIONS FOR TIME-SERIES IN MODELLING RAINWATER HARVESTING EFFICIENCY

Ilaria Gnecco

Dept. of Civil, Chemical and Environmental Engineering
University of Genoa

Introduction

- *Rain Water Harvesting* (**RWH**) is recognised as:

✓ *One of the widely accept solutions to save potable water in buildings*;
  → European Union puts priority on water saving including RWH.
  → RWH is a good practice in terms of sustainable development in cities.

✓ *One of the tools to controls storm water runoff at the source;*
  → RWH contribute to reduce the volume of storm water conveyed by the sewer network.
  → RWH contribute to limit the impact of storm water on the quality of receiving bodies.

The present study aims at assessing the *optimum performance* of RWH systems under various climatic (i.e. precipitation regime) and operational conditions (i.e. storage) in order to improve the reliability and understanding of the ***system design***.

Objectives

1 The impact of the *RWH system characteristics*

→ To assess the performance of rainwater harvesting systems under various climatic and operational conditions

2 The influence of the *time series length of precipitation records*

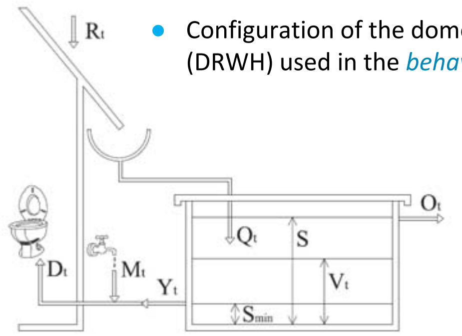
→ To assess the reliability of system performance evaluated on continuous simulation

3 The influence of *rainfall characteristics* on the system behaviour

→ To identify the hydrologic variables that most significantly affect the optimal design of rainwater harvesting systems

Methodology (I)

- Configuration of the domestic rainwater harvesting system (DRWH) used in the *behavioural model*



R_t → Rainfall
Q_t → Inflow
D_t → Water Demad
S → Tank capacity
V_t → Stored volume
O_t → Overflow volume
Y_t → Rainwater supply
M_t → Main supply

Daily mass balance equation

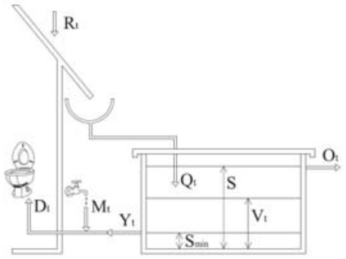
$$V_t = Q_t + V_{t-1} - Y_t - O_t$$

Rainfall-runoff process

$$Q_t = \phi \cdot R_t \cdot A$$

- Rainwater R_t is collected only from rooftops to limit the water quality issue;
- The water demand D_t is limited to toilet flushing occurring at constant rate.

Methodology (II)



YAS Operating Rule

The stored volume V_t is evaluated after spillage .

$$Y_t = \min\begin{cases} D_t \\ V_{t-1} \end{cases} \qquad V_t = \min\begin{cases} V_{t-1} + Q_t - Y_t \\ S - Y_t \end{cases}$$

- ✓ Conservative irrespective of the model time scale (Fewkes, 2000)
- ✓ Less sensitive to system capacity and water demand variation (Mitchell, 2007)

- Initial condition → the volume stored in the tank is set up initially empty
- The performance analysis of the DRWH system under various climate and operational condition is carried out as a function of two non-dimensional parameters:

Demand fraction *D/Q* defined as the ratio between the annual water demand D and the annual inflow volume Q.

Storage fraction *S/Q* defined as the ratio between the storage capacity of the system S and the annual inflow volume Q.

Methodology (III)

DRWH performance assessment is examined by means of the following indices:

- Two non-dimensional indices as a measure of the system quantitative performance

Water – saving efficiency E_T

$$E_T = \frac{\sum_{t=1}^{T} Y_t}{\sum_{t=1}^{T} D_t}$$

defined as the ratio between the supplied volume of rainwater and the water demand during the entire simulation period.

Rainwater Overflow ratio O_T

$$O_T = \frac{\sum_{t=1}^{T} O_t}{\sum_{t=1}^{T} Q_t}$$

defined as the ratio between the volume of rainwater exceeding the storage capacity and the inflow during the entire simulation period.

- A time-based index as a measure of the system qualitative performance

Detention Time *T* defined as the median value of the time period during which water is temporarily stored in the tank (expressed in days).

Model scenarios (I)

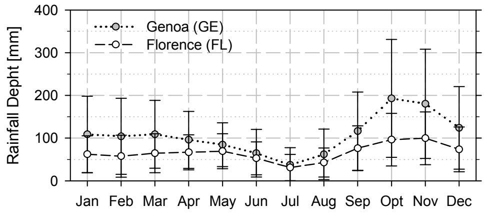
1. Precipitation Regime

→ 2 historical rainfall data series (more than 100 years of daily records)

		Genoa- GE	Florence - FL
Latitude	[° ′ N/S]	44° 24′ N	43° 46′ N
Longitude	[° ′ E/W]	8° 58′ E	11° 25′ E
Elevation	[m a.s.l.]	40	75
Observation period	[yyyy-yyyy]	1833 - 1980	1813-1979
Mean annual precipitation	[mm]	1280	821
Annual precipitation c.v.	[-]	0.24	0.30
ADWP	[d]	6.3 ± 7.1	6.2 ± 14.1
Event rainfall duration	[d]	1.95 ± 1.42	1.96 ± 1.50
Event rainfall depth	[mm]	29.0 ± 43.3	17.9 ± 30.9
Event rainfall intensity	[mm/h]	0.5 ± 0.6	0.4 ± 0.4

- The rainfall time series length for GE and FL are respectively 148 and 167 years
- GE and FL differ in terms of total annual precipitation;
- Rainfall event characteristics are comparable for the two sites

- the Florence time series reveals a continental climate behaviour with a limited monthly variability when compared to Genoa



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Model scenario (II)

2. Water Demand Scenario

→ 3 different residential typologies have been considered by assuming low, medium and high occupancy densities

	Q	Low		Medium		High	
		D	D/Q	D	D/Q	D	D/Q
	[m³/y]	[m³/y]	[-]	[m³/y]	[-]	[m³/y]	[-]
Genoa	205	102	0.40	277	1.08	599	2.34
Florence	162	64	0.39	175	1.07	380	2.31

Resulting in 3 demand levels:

- low (D/Q~0.4),
- medium (D/Q~1),
- high(D/Q~2.3)

3. Storage Capacity Scenario

→ 8 storage capacity ranging between 5 to 400 m³

- S/Q > 0.01 is required to enable the accurate implementation of the behavioural model at a daily temporal resolution (Fewkes and Butler, 2000);
- High storage capacity have been chosen in order to indicate the system performance irrespective of tank sizing.

Storage capacity	S/Q [-]	
[m³]	Genoa	Florence
5	0.02	0.03
10	0.04	0.06
35	0.14	0.21
50	0.20	0.31
80	0.31	0.49
180	0.70	1.10
250	0.98	1.52
400	1.56	2.44

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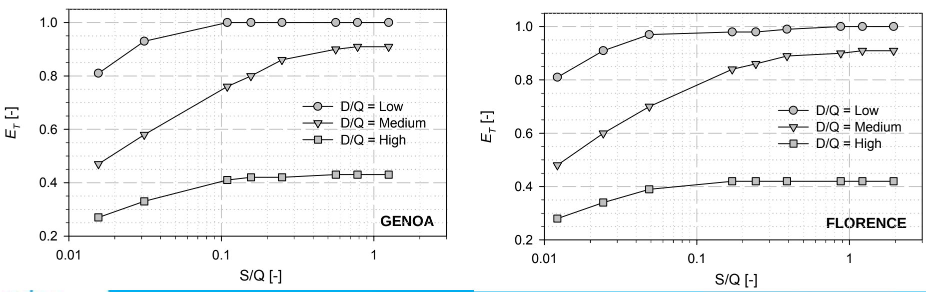
Results (I)

1 RWH system characteristics

Water – saving efficiency E_T

- At high demand fraction: E_T is limited in the 0.2-0.4 range irrespective of the storage capacity → Limited performance of the RWH system;
- At low demand fraction: E_T gradually increases from 0.8 to 1.0 until S/Q is equal to 0.1 → Elevated performance even with small storage tank;
- At medium demand fraction: storage fraction in the range 0.01-1 determine an increase in the E_T values from 0.5 to 0.9.



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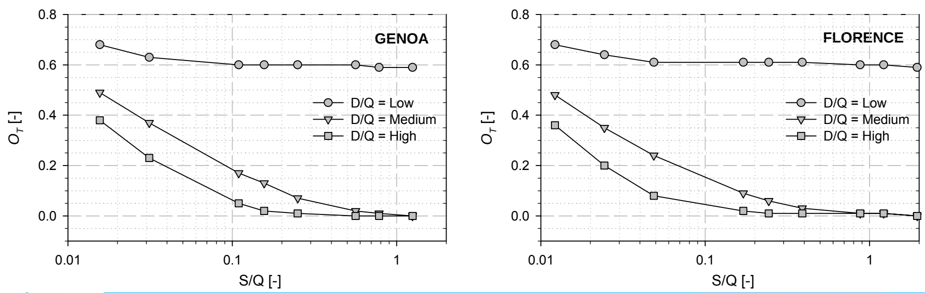
Results (II)

1 RWH system characteristics

Rainwater Overflow ratio O_T

- At high demand fraction: O_T depends on storage fraction only in the 0.01-0.1 range;
- At low demand fraction: O_T keeps fairly constant and equal to 0.6 irrespective of the storage capacity;
- At medium demand fraction: storage fraction in the range 0.01-1 determine a reduction in the O_T values from 0.5 to 0.

→ The demand fraction D/Q is the main parameter controlling the system behaviour



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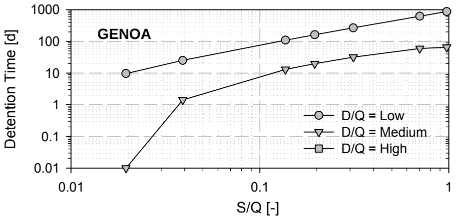
Results (III)

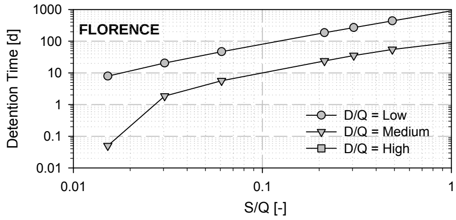
1 *RWH system characteristics*

Detention Time *T*

- At low demand fraction: *T* exponentially increase with the storage fraction and *T* < 30 days for the storage fraction < 0.1;
- At medium demand fraction: T rapidly increase for storage fraction in the range 0.01, 0.1 and generally T < 10 days for S/Q < 0.1.

→ The storage fraction S/Q basically control the detention time thus affecting the quality of the supplied rainwater





Objectives

1 The impact of the *RWH system characteristics*

→ D/Q and S/Q are non-dimensional design parameters which can be used to maximize the water-saving efficiency and minimize the rainwater detention time into the tank.

2 The influence of the *time series length of precipitation records*

→ To assess the reliability of system performance evaluated based on continuous simulation

The influence of *rainfall characteristics* on the system behaviour 3

→ To identify the hydrologic variables that most significantly affect the optimal design of rainwater harvesting systems

Sensitivity Analysis

2 *Time series length of precipitation records*

The sensitivity analysis is here performed with respect to the total water-saving efficiency (i.e. the efficiency calculated over the entire simulation period).

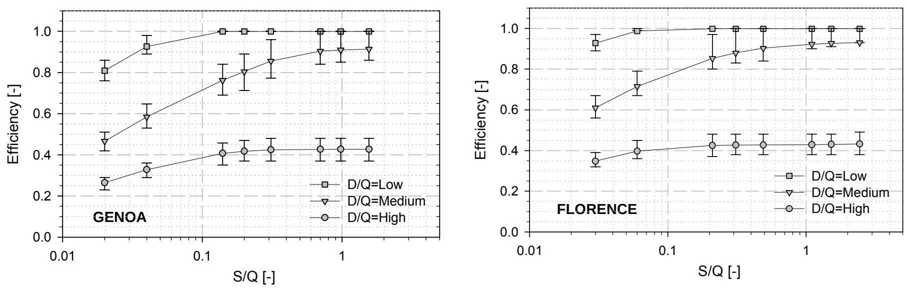
- The sensitivity analysis is carried out with respect to partial rainfall data series characterized by durations of 30 and 50-years, together with the complete data series results assumed as a reference scenario.
- A moving time window is used to extract from the centenarian time series of Genoa and Florence a number of partial time series of daily rainfall data:
  - Genoa: 119 and 99 realizations of successive 30 and 50 years of daily rainfall records;
  - Florence: 138 and 118 realizations of successive 30 and 50 years of daily rainfall records;
- The difference between the reference scenario and the 30-years and 50-years scenarios of input rainfall data is expressed as the absolute value of the relative percentage difference between the total water-saving efficiency of the partial duration time series and the total efficiency for the reference time series as follows:

$$|RPD_i| = 100 \cdot \frac{|E_{T_i} - E_{Tr}|}{E_{Tr}}$$

Reference scenarios

2 *Time series length of precipitation records*

→ In each graph the mean value and the corresponding standard deviation of the efficiency calculated on the annual basis are reported.



- Results from the Genoa and Florence data sets are consistent.
- The variability of the efficiency is more noticeable at medium demand fractions generally irrespective of the storage fraction, while it decreases at high and low demand fractions.
- The standard deviation of the annual efficiency provides a first rough measure of the variability ascribable to the rainfall data series length.

Results

2 *Time series length of precipitation records*

Genoa data set

mean value of $|RPD_i|$

(10th and 90th percentiles)

$$|RPD_i| = 100 \cdot \frac{|E_{T_i} - E_{Tr}|}{E_{Tr}}$$

D/Q [-]	T [y]	Storage fraction S/Q [-] 0.02	0.04	0.14	0.20	0.31	0.98
Low	50	1.1 (0.0÷2.5)	0.7 (0.0÷1.1)	0.0	0.0	0.0	0.0
	30	1.0 (0.0÷3.7)	0.9 (0.0÷2.2)	0.0	0.0	0.0	0.0
Medium	50	1.7 (0.0÷4.3)	1.5 (0.0÷3.4)	1.5 (0.0÷2.6)	1.7 (0.0÷3.8)	1.8 (0.0÷4.7)	2.3 (0.0÷5.5)
	30	1.1 (0.0÷6.4)	1.9 (0.0÷3.4)	2.8 (1.3÷3.9)	2.5 (0.0÷5.0)	2.1 (0.0÷5.8)	2.3 (0.0÷6.8)
High	50	2.3 (0.0÷7.4)	1.9 (0.0÷6.1)	2.4 (0.0÷7.3)	2.4 (0.0÷7.1)	2.5 (0.0÷4.8)	2.3 (0.0÷7.0)
	30	1.3 (0.0÷7.4)	1.6 (0.0÷6.1)	3.2 (0.0÷9.8)	3.1 (0.0÷9.5)	2.6 (0.0÷7.1)	2.7 (0.0÷7.0)

- The average of the RPD absolute values ranges from 0.7% to 2.5% for 50-years time series and from 0.9% to 3.2% for 30-years time series;
- Similar results have been obtained for the Florence dataset: the average of the RPD absolute values is generally below 5%

Objectives

1 The impact of the *RWH system characteristics*

→ **D/Q and S/Q are non-dimensional design parameters which can be used to maximize the water-saving efficiency and minimize the rainwater detention time into the tank.**

2 The influence of the *time series length of precipitation records*

→ **Results of the sensitivity analysis demonstrate the reliability of system performance evaluated based on continuous simulation over at least 30 years with respect to long-term simulations**

3 The influence of *rainfall characteristics* on the system behaviour

→ To identify the hydrologic variables that most significantly affect the optimal design of rainwater harvesting systems

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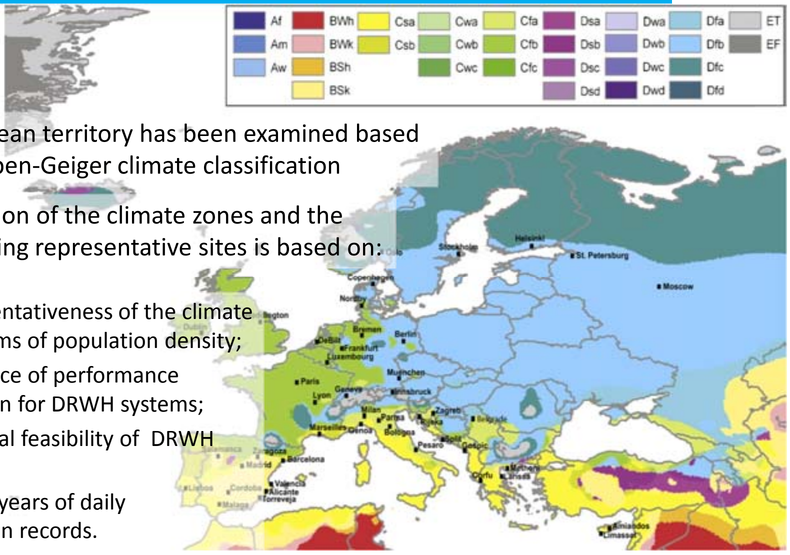
Sites selection (I)

3 *The rainfall characteristics*



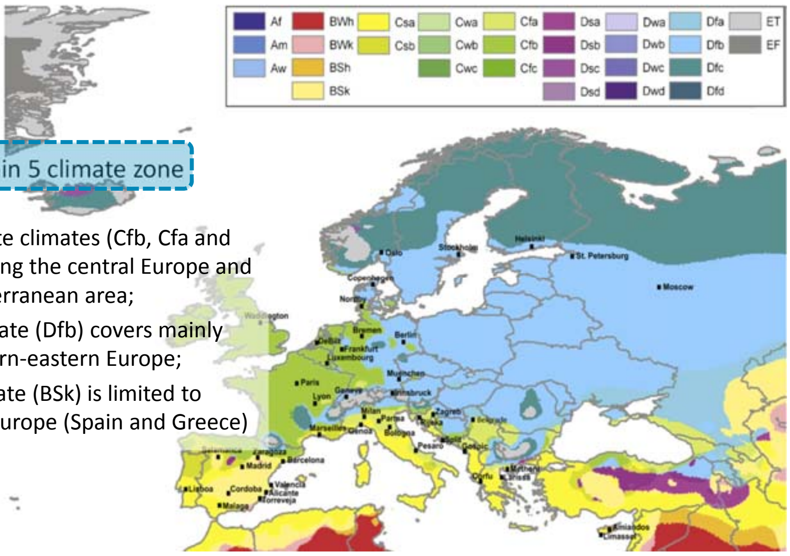
→ The European territory has been examined based on the Koppen-Geiger climate classification

→ The selection of the climate zones and the corresponding representative sites is based on:

- the representativeness of the climate zone in terms of population density;
- the relevance of performance optimization for DRWH systems;
- the technical feasibility of DRWH systems;
- At least 30 years of daily precipitation records.

Sites selection (II)

3 *The rainfall characteristics*



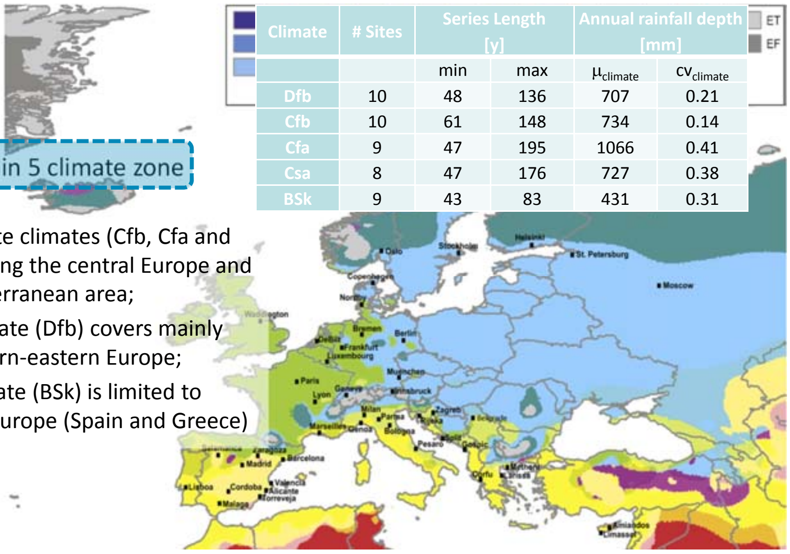
46 sites within 5 climate zone

- 3 temperate climates (Cfb, Cfa and Csa) covering the central Europe and the Mediterranean area;
- 1 cold climate (Dfb) covers mainly the northern-eastern Europe;
- 1 arid climate (BSk) is limited to southern Europe (Spain and Greece)

Sites selection (II)

3 The rainfall characteristics

Climate	# Sites	Series Length [y]		Annual rainfall depth [mm]	
		min	max	$\mu_{climate}$	$cv_{climate}$
Dfb	10	48	136	707	0.21
Cfb	10	61	148	734	0.14
Cfa	9	47	195	1066	0.41
Csa	8	47	176	727	0.38
BSk	9	43	83	431	0.31



46 sites within 5 climate zone

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- 1 arid climate (BSk) is limited to southern Europe (Spain and Greece)

Methodology

3 The rainfall characteristics

1. Model Scenarios

→ The demand fraction is assumed equal to 1 at each site.

- In this case the system performance can be optimized as a function of the system capacity (operational condition)

→ Storage fractions S/Q range from 0.01 to 1 at each site.

- S/Q > 0.01 is required to enable accurate model implementation at a daily temporal resolution.

2. Statistical Analysis

→ *Simple linear regression* analysis to examine the impact of hydrologic characteristics on the performance of DRWH system

- INDIPENDENT variables

  → Rainfall event characteristics (depth, duration, intensity and ADWP)

⇨

- DIPENDENT variables

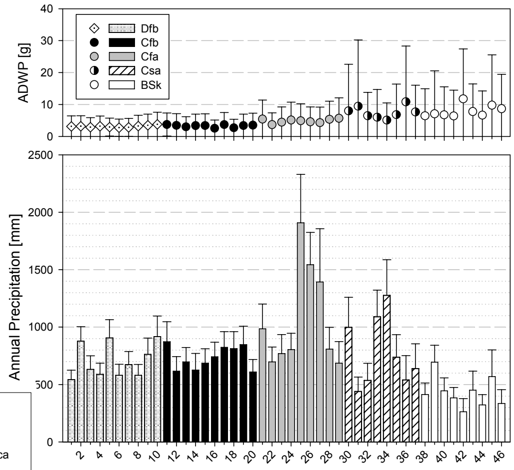
  → DRWH system performance (E_T and T)

Precipitation regime

3 *The rainfall characteristics*

→ Hydrologic characterization on annual basis and at the event scale

- Dfb and Cfb: no seasonality and frequent rainfall events (ADWP = 3 d)
- Cfa: wide range of variation of the annuall rainfall depht and ADWP = 5 d
- Csa and BSk: less frequent event (ADWP = 10 d) and remarkable inter-annual variability



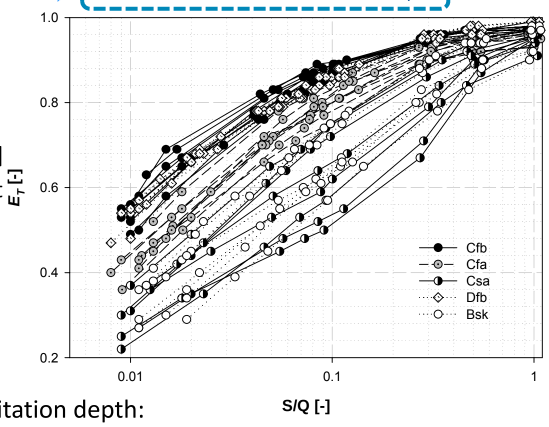
Dfb	*Cfb*	*Cfa*	*Csa*	*BSk*
1. Stockholm	11. Zagreb	21. Milan	30. Amiandos	38. Larissa
2. Innsbruck	12. Paris	22. Belgrade	31. Limassol	39. Methoni
3. Helsinki	13. Bremen	23. Pesaro	32. Marseilles	40. Madrid
4. Berlin	14. Frankfurt	24 Split	33. Corfu	41. Salamanca
5. Muenchen	15. Nordby	25. Shkodra	34. Genoa	42. Torreveja
6. St.Petersburg	16. Dublin	26. Rijeka	35. Lisboa	43. Valencia
7. Moscow	17. Lyon	27. Gospic	36. Malaga	44. Zaragoza
8. Copenhagen	18. Debilt	28. Parma	37. Barcelona	45. Cordoba
9. Oslo	19. Luxembourg	29. Bologna		46. Alicante
10. Geneva	20. Waddington			

Results (I)

3 *The rainfall characteristics*

- The total water-saving efficiency increases with the storage fraction → E_T in the range [0.2, 0.98]
- Three different trends are observed:
  - → Dfb/Cfb climates reveal the highest performance: E_T [0.55, 0.98]
  - → Csa/Bsk climates show the lowest and more variable performance: E_T [0.3, 0.95]
  - → Cfa show intermediate performance and consistent across the sites: E_T [0.55, 0.98]

Water – saving efficiency E_T



→ No influence of the annual precipitation depth: the parameters of each site are normalized with respect to the annual inflow.

→ The variability of performance can be ascribed to the variability of the inter-annual precipitation characteristics in terms of ADWP

Results (II)

3 *The rainfall characteristics*

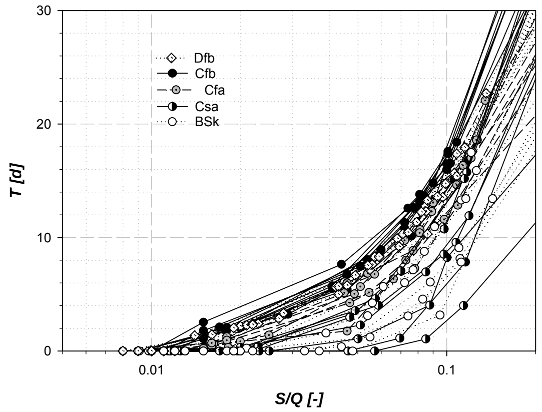
Detention Time *T*

- The detention time rapidly increase with the storage fraction
- Three different trends are observed:

  → Dfb/Cfb show the highest detention time values: T > 15 days for S/Q = 0.1

  → Csa/Bsk show the best performance: T values < 4 days until S/Q equals to 0.05.

  → Cfa show intermediate performance: T > 8 days for S/Q = 0.1

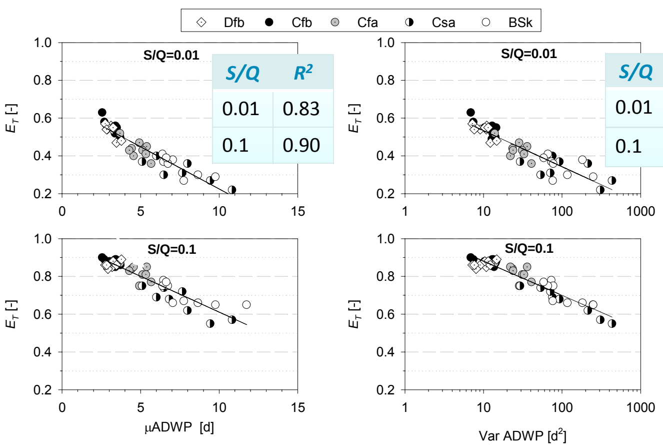


The contrasting goals of maximizing the water-saving efficiency and minimizing the detention time can be partially solved by increasing the storage tank capacity for precipitation regimes characterized by long ADWP

Results (III)

3 *The rainfall characteristics*

The coefficient of determination R^2 value reveals the following sequence in terms of order of magnitude: *ADWP* ($R^2 > 0.8$) > *d* ($R^2 \sim 0.5$) > *i* ($R^2 \sim 0.2$) > *h* ($R^2 < 0.2$).



S/Q	*R²*
0.01	0.83
0.1	0.90

S/Q	*R²*
0.01	0.89
0.1	0.86

→ *The ADWP is the main hydrologic parameter affecting the system behaviour*

Results (III)

3 *The rainfall characteristics*

E_T	µADWP			Log (varADWP)		
S/Q	R^2	Norm.	Cost. Var.	R^2	Norm.	Cost. Var.
0.01	0.89	●	●	0.83	●	○
0.02	0.87	●	●	0.84	●	○
0.05	0.92	●	○	0.91	●	○
0.08	0.88	●	○	0.92	●	●
0.10	0.86	●	○	0.90	●	●

● passed test
○ failed test

T	µADWP			Log (varADWP)		
S/Q	R^2	Norm.	Cost. Var.	R^2	Norm.	Cost. Var.
0.02	0.64	○	●	0.68	●	●
0.05	0.75	●	●	0.72	●	●
0.08	0.69	●	●	0.65	●	●
0.10	0.53	○	●	0.48	●	●

Water – saving efficiency E_T

- Significant correlation between E_T and ADWP;
- Regression model adequacy confirmed by the normality test results;
- The standardized residuals are in the [-3, 3] range

Detention Time *T*

- The correlation between *T* and ADWP still emerges;
- The constant variance test is always passed;
- The use of the median value as dependent variable could affect the results

Objectives

1 The impact of the *RWH system characteristics*

→ **D/Q and S/Q are non-dimensional design parameters which can be used to maximize the water-saving efficiency and minimize the rainwater detention time into the tank.**

2 The influence of the *time series length of precipitation records*

→ **Results of the sensitivity analysis demonstrate the reliability of system performance evaluated based on continuous simulation over at least 30 years with respect to long-term simulations**

3 The influence of *rainfall characteristics* on the system behaviour

→ **Statistical results point out a strong correlation between the antecedent dry weather period and the performance indices with respect to the different operational condition**

Conclusions

→ The proposed approach can provide a useful support to the definition of European standards and guidelines for the optimal design of DRWH systems.

→ RWH systems provide a suitable solution to be combined with source control system (i.e. green and blue roofs) to contribute to a sustainable water management in urban areas.

→ Experimental study is actually carried on:

- to provide measurements of the effective DRWH system performance for validation purposes;
- to investigate the quality degradation of rainwater during storage.

References

Campisano A., Gnecco I., Modica C. and Palla A. (2013). Designing domestic rainwater harvesting systems under different climatic regimes in Italy, *Water Science & Technology*, 67(11), 2511-2518.

Palla A., Gnecco I. and Lanza L.G. (2011). Non-dimensional design parameters and performance assessment of rainwater harvesting systems. *Journal of Hydrology*, 401(1-2), 65-76.

Palla A., Gnecco I., Lanza L.G. and La Barbera P. (2012). Performance analysis of domestic rainwater harvesting systems under various European climate zone. *Resources, Conservation and Recycling*, 2012, 62, 71-80.

Objectives

1 the influence of the *time series length of precipitation records*

→ To assess the reliability of system performance evaluated based on continuous simulation

2 the impact of the *precipitation regimes* in Europe

→ To assess the optimum performance of rainwater harvesting systems under various climatic and operational condition

3 The influence of *rainfall characteristics* on the system behaviour

→ To identify the hydrologic variables that most significantly affect the optimal design of rainwater harvesting systems

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Results (I)

1 RWH system characteristics

Results of the behavioural model consist of daily time series of the output variables (i.e. the supplied rainwater volumes, the water volumes stored in the tank, the overflow volume and the detention time)

- the water-saving efficiency behaviour as a function of the storage fraction with respect to three water demand fractions (high, medium and low) for each investigated time series.
- In each graph the mean value and the corresponding standard deviation of the efficiency calculated on the annual basis are reported.

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WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Multi-criteria analysis for stormwater source control & harvesting strategies

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Overview of the challenges and approaches to multi-criteria analysis (MCA)

Gilles Rivard, Genivar, Canada

Overview of the challenges and approaches to multi-criteria analysis (MCA)

Aperçu des défis et des approches pour une analyse multicritères (AMC)

SOCOMA / Stormwater Harvesting Group (SWH)

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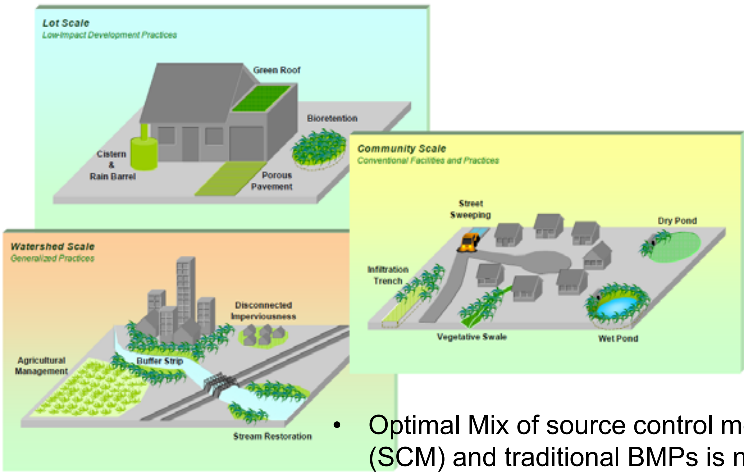

(Sustain, US EPA, 2011)

- Optimal Mix of source control measures (SCM) and traditional BMPs is not obvious
- Analysis of many interrelated parameters necessary and at different scales

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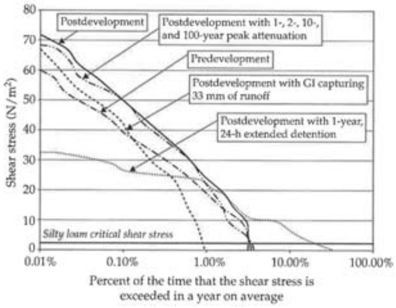
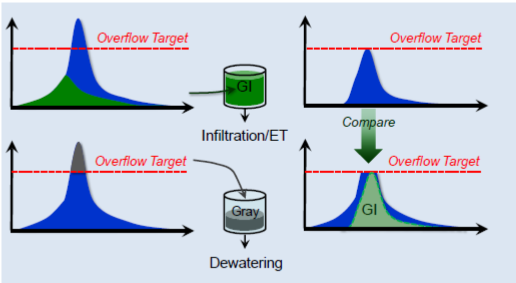
Different drivers can influence the selected criteria for the analyses and their respective weights

Geomorphology and habitats



(WEF/ASCE, 2012)

Combined Sewer Overflows (CSOs)



Sustain, US EPA, 2011

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Criteria and weights

Operational components	
Criteria	
Interdependence	Allowance for the interdependence of different criteria
Completeness	Need for the completeness of the criteria
Non-linear preferences	Possibility to express non-linear valuation patterns
Weights	
Transparency of process, type of weights	Type of the procedure of deriving values for the weights
Meaning	Interpretation and role of weights in the evaluation process
Solution finding procedure	Type of procedure used for the comparison of alternatives
Issues addressed by results	Interpretation of the results generated by the use of method

(De Montis et al., 2000)

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Applicability of MCDA methods – user context

Project constraints	
Costs	Implementation costs in the specific user situation
Time	Implementation time in the specific user situation
Structure of problem solving process	
Stakeholder participation	Possibility to include more than one person as decision maker
Problems structuring	Existence of mechanisms supporting the structuring of the problem
Tool for learning	Support of learning processes
Transparency	Promotion of transparency in the decision making process
Actor communication	Support of the communication between opposing parties

(De Montis et al., 2000)

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Applicability of MCDA methods – problem structure

Indicator characteristics	
Geographical scale	Applicability of different geographical scales for one case
Micro-macro link	Applicability of different institutional scales for one case
Societal/technical issues	Possibility for the consideration of both societal and technical issues
Methods combination	Possibility of methods combination
Data situation	
Type of data	Type of data supported as values for the indicators
Risk/uncertainties	Possibilities for the consideration of evaluation risk and/or uncertainties
Data processing amount	Processing amount needed to compile the data required for the method
Non-substitutability	Possibility to consider sustainability standards and non-substitutability

(De Montis et al., 2000)

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Table 1. Criteria and Indicators within the MCA

CRITERIA (AoC)	INDICATORS
Technical	Flood Control
	Pollution Control
	System Adaptability
Environmental	Receiving Water Volume Impact
	Receiving Water Quality Impact
	Ecological Impact
Operation and Maintenance	Maintenance and Servicing Requirements
	System Reliability and Durability
Social and Urban Community Benefits	Public Heath and Safety Risks
	Sustainable Development
	Public/Community Information and Awareness
	Amenity and Aesthetics
Economic	Life Cycle Costs
	Financial Risk/Exposure
	Long Term Affordability
Legal and Urban Planning	Adoption Status
	Local Building and Development Issues
	Urban Stormwater Management Regulations

Essential and desirable criteria

(Ellis et al., 2011)

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Table 2 Benchmark standards and units for the economic AOC/criteria

Primary Indicator	Secondary Indicator	Benchmarks	Threshold values/units
Life Cycle Costs	a. Investment and operational costs	- Design and capital costs - Operational & Maintenance costs - Sediment monitoring and disposal costs - Site decommissioning costs	Average Cost (£); **N** £/annum; **N** Average Cost (£); **N** Cost(£); **N**
	b. Community cost	- Stormwater charges - O&M costs	Increase/Decrease; **D** Yes/No; **D**; £/year **N**
Financial Risks	Risk exposure	- Cost-benefit analysis - Investment loss risk - Site reclaim value - System failure insurance	C:B ratio; **N** H/M/L; **D**: Average Loss (£); **N** H/M/L; **D**: £; **N** Yes/No; **D**
Affordability	Long term affordability	- Adoption and liability coverage - Economic add-on value (enhanced land/property values) - Amenity income streams - Long term management provision and costs	H/M/L; **D**: Cost (£); **N** Value/ha or unit (£); **N** £/annum; **N** H/M/L; **D**: £/annum; **N**
Land cost	Land take	Land costs	£/m^2; **N**: £/housing unit; **N**

KEY: **N** = Numeric measurement unit; **D** = Descriptive measurement unit
H = High value/impact; **M** = Medium value/impact; **L** = Low value/impact

L. Scholes, J. B. Ellis and D. M. Revitt, 2008

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Table 2. Examples of Indicators and Benchmarking

Criteria	Indicator	Benchmark	Units
Technical	Flood control	Overflow frequency	1…n
		Design storm return interval	RI yrs
		Extreme event control	H/M/L
	Pollution control	Dissolved pollutant capture	%; H/M/L
		Solid(s) pollutant capture	%; H/M/L
	System Adaptability	Ease of retrofitting	H/M/L
		Design freeboard	% ; Volume, m^3
Environmental	Receiving Water Volume Impact	Downstream erosion	H/M/L
		Thermal effects	C°
		Groundwater levels	Depth; m
	Receiving Water Quality Impact	Compliance with RWQ standards	%; mg/l
		Threshold pollutant concentrations	mg/l
	Ecological Impact	Biotic diversity	Biotic scores

(Ellis et al., 2011)

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Other example - Criteria and weights

Table 1. Weighting of the three categories of assessment criteria and the associated indicators.

Aspect	Weight		Indicator
Environmental	0.4	0.3	1. Addresses a known / significant water quality issue
		0.3	2. Project addresses more than one known / significant water quality issue
		0.3	3. Consideration of broader water cycle management issues
		0.1	4. Consideration of broader water cycle management issues
Engagement	0.3	0.5	1. Local government capacity building
		0.5	2. Commitment to community awareness raising or education
Financial	0.3	0.33	1. Capital cost effectiveness of WSUD component of the project
		0.33	2. Maintenance cost effectiveness of WSUD component of the project
		0.33	3. Financial commitment to the project by local government

(M. Urrutiaguer, S. Lloyd and S. Lamshed (2008))

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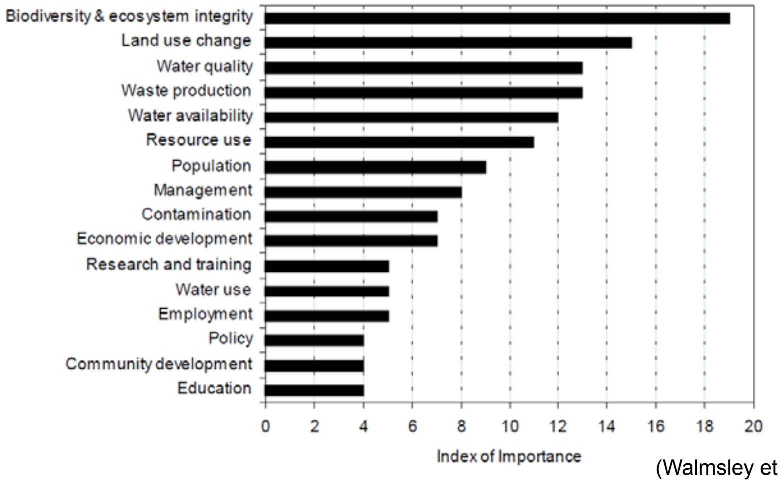
Index of importance for the various indicator categories



(Walmsley et al., 2001)

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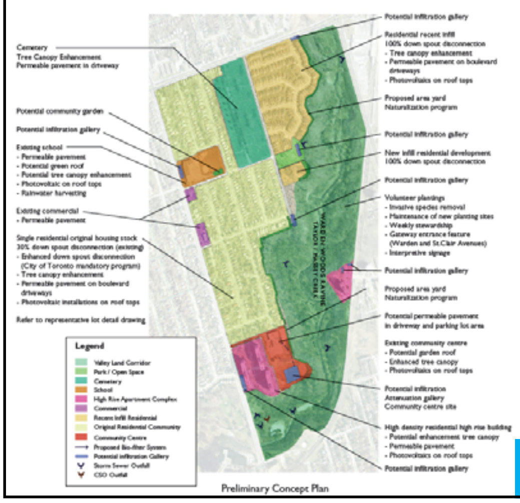
DON RIVER WATERSHED SITE EVALUATION (TORONTO, CANADA)

(Canada Mortgage and Housing Corporation)



Three scenarios modelled :

- pre-development agricultural conditions;
- existing urban conditions;
- proposed conditions with stormwater source control

Rainfall modelled:

- 5 mm and 25 mm ;
- 2-year up to 100-year;

Results:

- For the most frequent category of storms (5-25 mm of precipitation), peak flows were reduced 40-45% and runoff volume is decreased by about 20-45%.;
- 5-100-years reduction by 20-35%

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Rainfall modelled:
- 5 mm and 25 mm ;
- 2-year up to 100-year;

Results:
- reduction in peak flow rates from 30% for a 100 year storm event to 80% for a 5 mm storm;
- runoff volumes reductions : 20-85%

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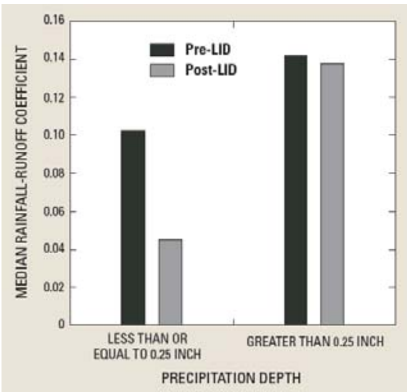
Effects of Low-Impact-Development (LID) Practices on Streamflow, Runoff Quantity, and Runoff Quality in the Ipswich River Basin, Massachusetts: A Summary of Field and Modeling Studies



Average runoff coefficients (Pre- and Post-LID)

(Zimmerman et al., 2010)

- Benefits of LID practices are greatest when the percentage of effective impervious area is large and the LID enhancements can substantially redirect storm runoff away from conveyances leading to streams or lakes.
- In LID-retrofit simulations, reducing effective impervious area by 50 percent minimally affected streamflow in most subbasins analyzed, because the effective impervious area in the subbasin was a relatively small percentage of the overall area.
- **Differing benefits at the local scale vs the basin**

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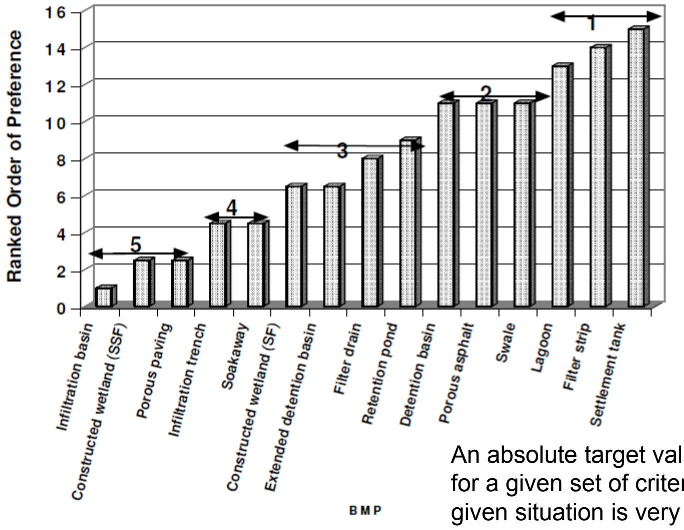
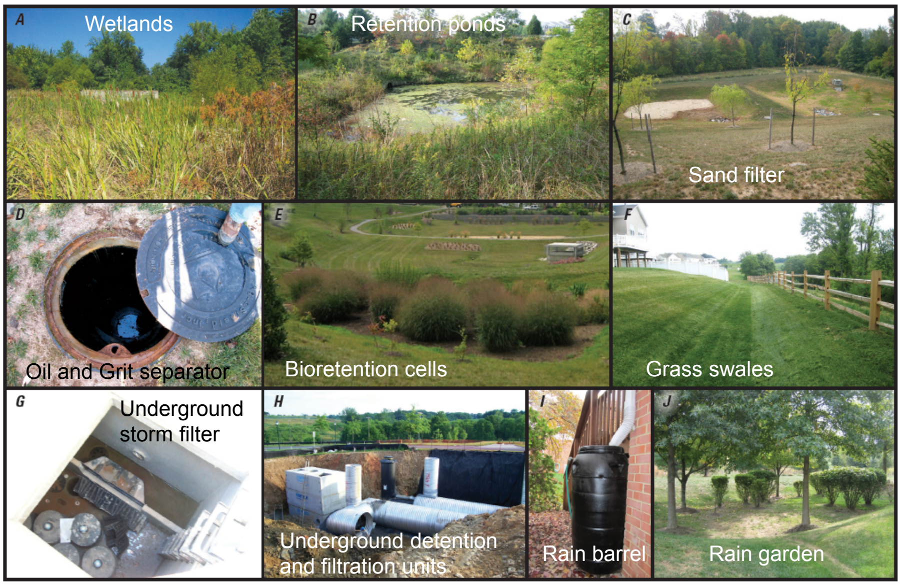


Scaling and Scoring for SUDS Total Suspended Solid (TSS) Removal Potential

(Ellis et al., 2011)

An absolute target value of sustainability for a given set of criteria within a given situation is very difficult to determine



Effects of Urban Stormwater-Management Strategies on Stream-Water Quantity and Quality

(USGS, 2012)

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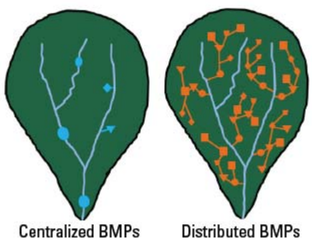

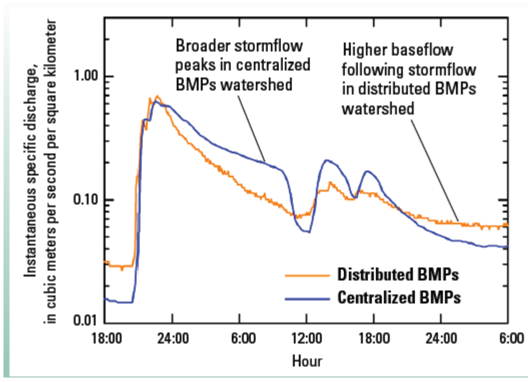

Important differences in stream discharge from watersheds with contrasting stormwater-management strategies

(USGS, 2012)

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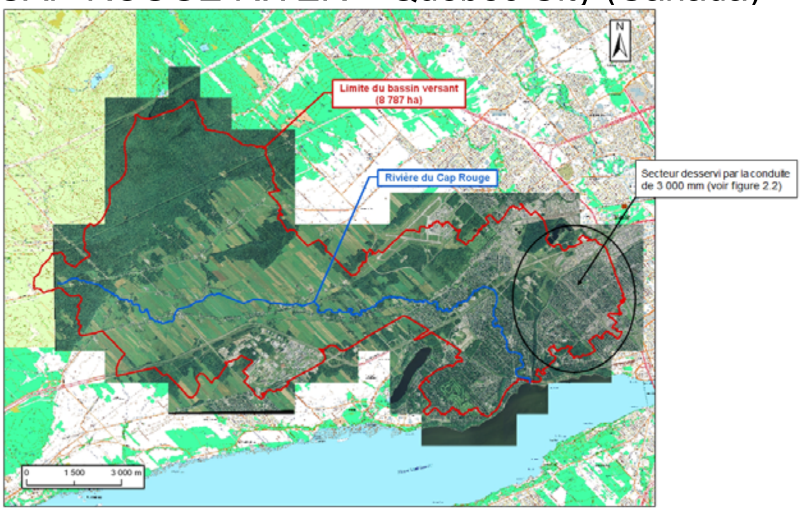
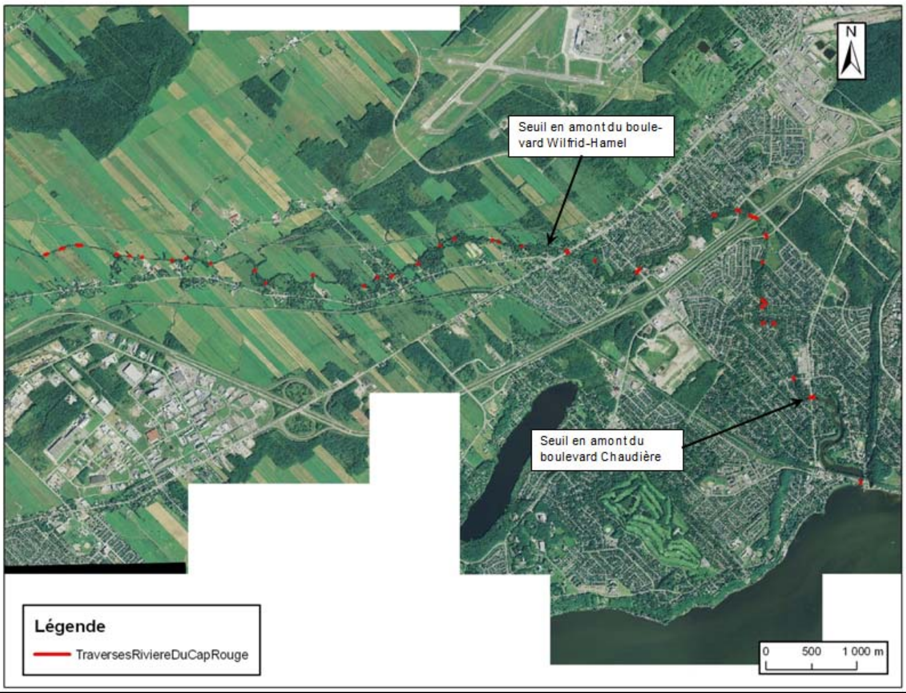
CAP-ROUGE RIVER – Quebec City (Canada)





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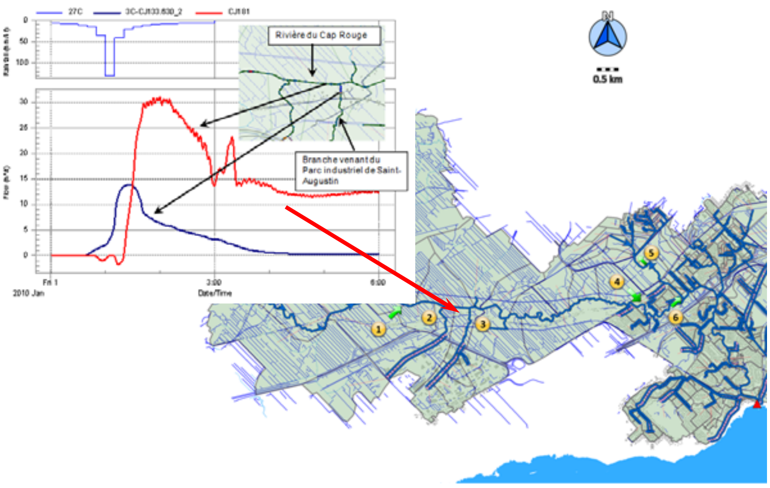

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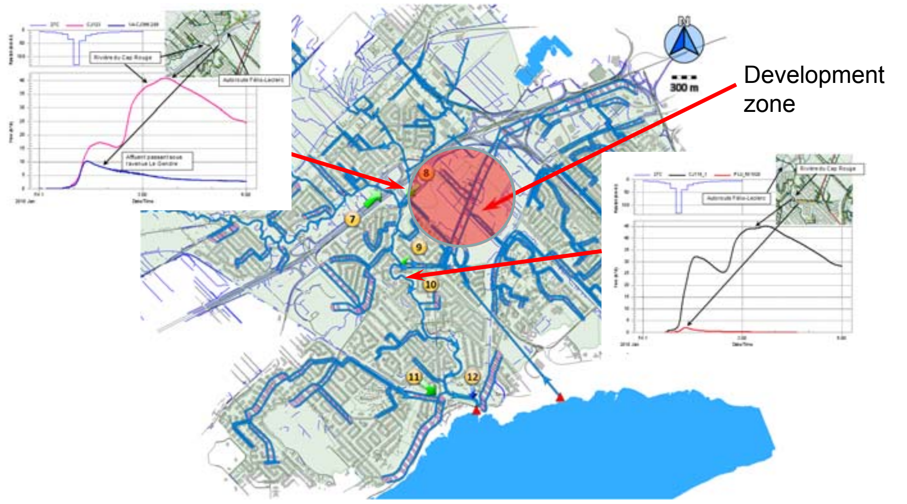

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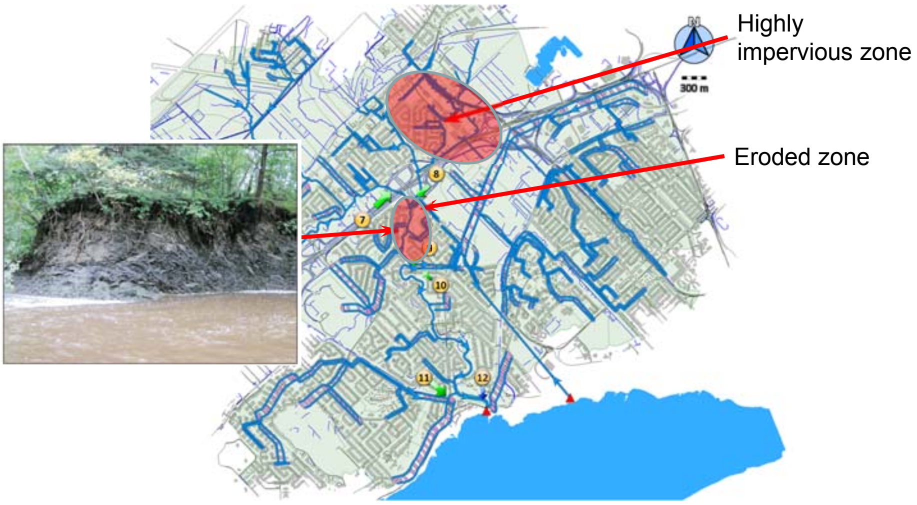

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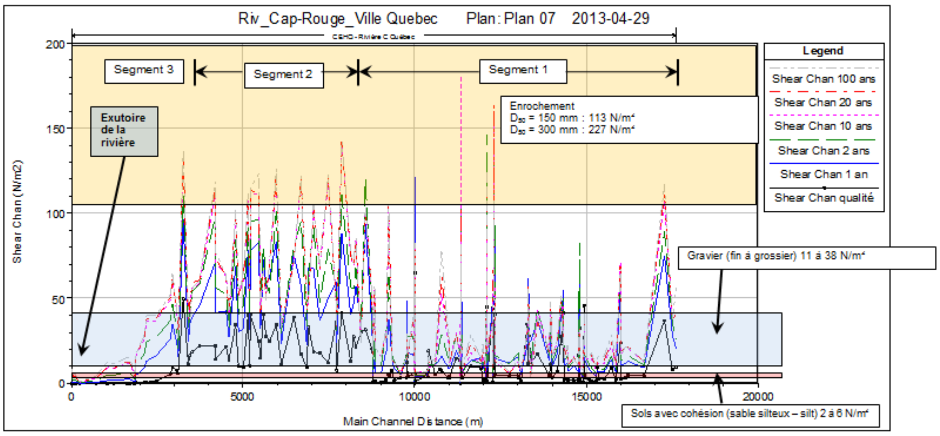

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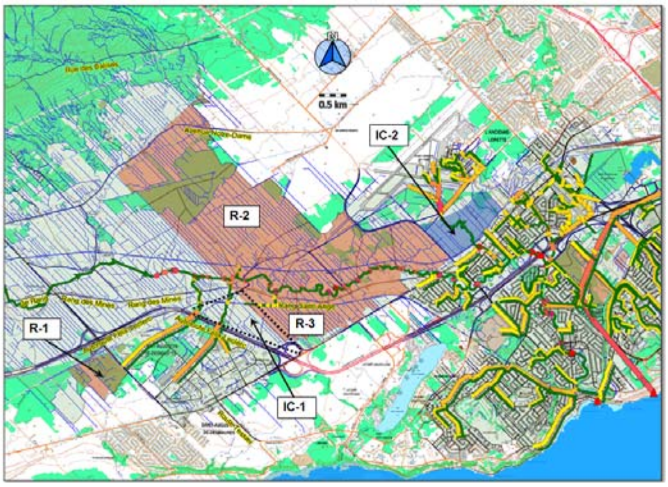

l'eau dans la ville / water in the city

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SO, WHAT ARE THE SOURCE CONTROL MEASURES THAT SHOULD BE BUT IN PLACE ?

1. For new developments
2. Is it realistic to modify the controls previously put in place – at what benefits for the river ?
3. What is the optimal mix to protect the river from geomorphological impacts, its quality and flooding ?

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1. For new developments
2. Is it realistic to modify the controls previously put in place – at what benefits for the river ?
3. What is the optimal mix to protect the river from geomorphological impacts, its quality and flooding ?

l'eau dans la ville / water in the city   nova TeCH Lyon 2013

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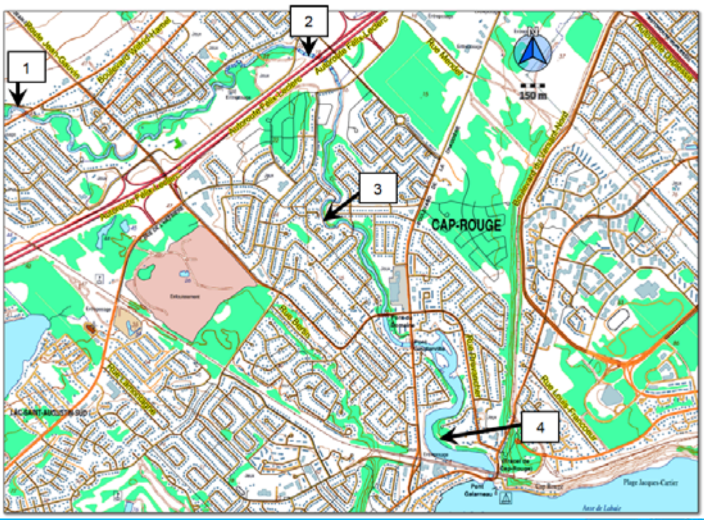
Comparison of the benefits for different scenarios at 4 points in the river



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Scenarios

1. New development : Retention basins for three levels of control at pre-development levels (1 in 1 year, 1 in 10 and 1 in 100 y)
2. As 1 but with a lower control to release quality volume (runoff for 25 mm rainfall) in 24 h
3. As 1 but with a control to release the 1 in 1 y volume **after** development in 24 h
4. As 1 but adding infiltration of 6 mm for all new developments

The scenarios are compared to the actual conditions four points to assess the benefits for the river

SOCOMA/SWH Workshop – Challenges - MCA

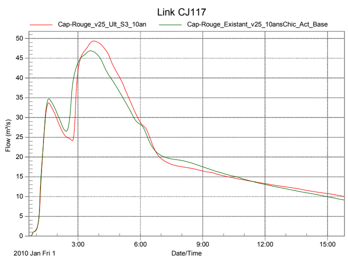
RESULTS

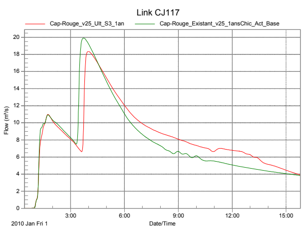
1. Impacts are different for frequent or rare events
2. Relative impacts and benefits change for different reaches in the river
3. The location of the development zones should be considered (upstream vs downstream)
4. The infiltration of 6 mm has an effect for the runoff volume at the local level but its impact is less at the catchment level

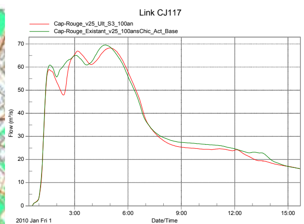
SOCOMA/SWH Workshop – Challenges - MCA

RESULTS

Scenario 3
Influence of events
All results at **point 3**
Return periods
1 y, 10 y and 100 y







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SOCOMA/SWH Workshop – Challenges - MCA

FOOD FOR THOUGHT AND DISCUSSION

Construction, operation and maintenance	Life cycle costs

Basin scale design and performance of source control measures	• LIDs reduce runoff volume and hydrologic response
	• Global performance related to:
	  • % imperviousness
	  • Density of LIDs
	  • Location of LIDs in the basin

Are LIDs more effective than traditional BMPs for improving hydrology and flood control at the basin scale?	Are LIDs more effective than traditional BMPs for improving water quality at the basin scale? For ecological or geomorphological benefits ? What metrics should be used ?

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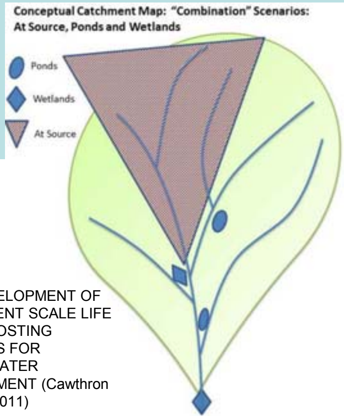
FOOD FOR THOUGHT AND DISCUSSION

Scales of LID effectiveness evaluation (Washington State, 2013)



THE DEVELOPMENT OF CATCHMENT SCALE LIFE CYCLE COSTING METHODS FOR STORMWATER MANAGEMENT (Cawthron Institute, 2011)

- Internal Scale Effectiveness Studies (sizing and media composition)
- External Scale Effectiveness Studies
- Basin Scale Effectiveness Studies (scaling up and spatial/temporal effects)
- Organizational, institutional scale

8TH INTERNATIONAL CONFERENCE NOVATECH JUNE 23>27 Lyon 2013 Planning & technologies for sustainable urban water management

the international water association

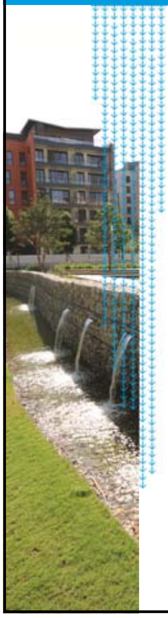
International Association for Hydro-Environment Engineering and Research
Supported by CEDEX

WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Multi-criteria analysis for stormwater source control & harvesting strategies

Multi-criteria evaluation of source control: a state of the art

Sylvie Barraud, INSA Lyon, France



INSA LYON

Multi-criteria evaluation of source control: a state of the art

Sylvie BARRAUD

MCDA problems

- are supposed to <u>help</u> DM to: select, choose a solution, sort good solutions, …
- among a set of <u>actions</u> (alternatives, solutions, scenarios…)
- according to different <u>criteria</u> (Perf. indicators, …)
  - supposed to reflect different points of view /stakes (sometimes <u>conflicting</u>) and
  - estimated with the available information

MCDA problems

- Decision Aid: Select, choose good solutions, …
- among a set of actions (altern scenarios…)
- according to different criteria (Perf. indicators, …)
  - supposed to reflect different points of view /stakes (sometimes conflicting)
  - which are not expressed in a same unit
  - which can be estimated with different quality of information

Actions = alternatives to be compared, sorted, ranked, …

Discrete problem

(# Continous optimization problem)

MCDA problems

- Decision Aid: Select, choose a solution, sort good solutions, …
- among a set of actions (alter scenarios…)
- according to different criteria (Perf. indicators, …)
  - supposed to reflect different points of view /stakes (sometimes conflicting)
  - which are not expressed in a same unit
  - which can be estimated with different quality of information

Criteria = Measures of different objectives (problem set)

DM(s)

l'eau dans la ville / water in the city — novatech Lyon 2013

My MCDA problems

- Program of stormwater investments to prevent urban catchments from flooding

Municipalities + "operational experts" + Researchers

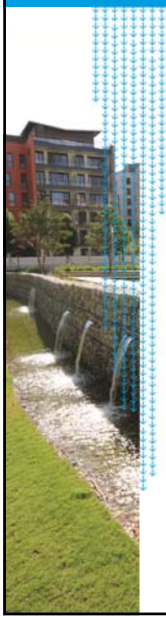
- Choice of a good stormwater management scenario including ATs / SUDs / BMPs / LIDs (design)
- Global assessment of existing retention / infiltration systems

l'eau dans la ville / water in the city

novatech 23>27 JUIN Lyon 2013

Stratégies & solutions pour une gestion durable de l'eau dans la ville

Planning & technologies for sustainable urban water management



Different approaches (Problem setting & solving)

Approaches Monodimensional

Objectives | Criteria/ attributes

1 Aggregation of criteria

Objectives	Criteria/ attributes
1	$K_1 = u_1(a_i)$
2	$K_2 = u_2(a_i)$
…	…
k	$K_k = u_k(a_i)$
…	…
m	$K_m = u_m(a_i)$

→ Function → $U(a_i) = f(u_1(a_i), \ldots, u_m(a_i))$

Actions | 2 **Comparison**

- a_1 → $U(a_1)$
- a_2 → $U(a_2)$
- … …
- a_n → $U(a_n)$

« Optimum »

3 **Methods**

U : Economic function (1 dim)
: Utility function (dimension less)

Many many methods exist :
Cost/benefit, Whole life costing

Weighted sum, *MAUT*, *Topsis* (proximity to an ideal and anti-deal action, …)

For exemple: the *weighted sum*

Objectives

Table 1: MCC performance matrix for 15 different structural BMPs and 6 criteria.

		Performance scores															Weighting	
		Filter drain	Porous asphalt	Porous paving	Green roofs	Settlement tank	Filter strip	Swales	Soakaways	Infiltration trench	Infiltration basin	Retention ponds	Detention basins	Extended detention basin	Lagoon	Constructed wetland	Indicators	Criteria
Technical	Flood control																	
	Pollution control																	
	Adaptability to urban growth																	
Environmental	Impact on receiving water volume																	
	Impact on receiving water quality																	
	Ecological impact																	
Operation & Maintenance	Maintenance & servicing requirements																	
	System reliability and durability																	
Social and Urban Community Benefits	Public H&S risks																	
	Sustainable development																	
	Public/community information & awareness																	
	Amenity & aesthetics																	
Economic Costs	Life Cycle Costs																	
	Long term affordability																	
Legal & Urban Planning	Adoption Status																	
	Building development issues and stormwater regulations																	
TOTAL	(Sum of score x weight: %)																100	100

EU Daywater
(Thevenot et al., 2008)

Main drawbacks

- Compensatory effects (that can be accepted but often ignored…)

	Inv (M€)	Env.
	K1	K2
weights	0.4	0.6
a1	9	3
a2	1	8
a3	2.25	7
Max	9	8

Normalisation

The lower the better

	Inv (M€)	Env.	Weighted sum	
max	K1	K2		
	0.4	0.6		
a1	9/9	3/8	0.4 x 9/9 + 0.6 x 3/8 =	0.625
a2	1/9	8/8		0.644
a3	2.25 /9	7/8	0.4 x 0.25 + 0.6 x 0.875 =	0.625

Main drawbacks

- High sensitivity to normalisation proc.

The lower the better

	Inv (M€)	Env.
	K1	K2
weight	0.4	0.6
a1	9	3
a2	1	8
Max	9	8
sum	10	11

Normalisation by max	K1	K2	Weighted sum
a1	1.00	0.38	0.625
a2	0.11	1.00	0.644

Normalisation by sum	K1	K2	Weighted sum
a1	0.90	0.27	0.524
a2	0.10	0.73	0.476

No coherence

Approaches Graphical

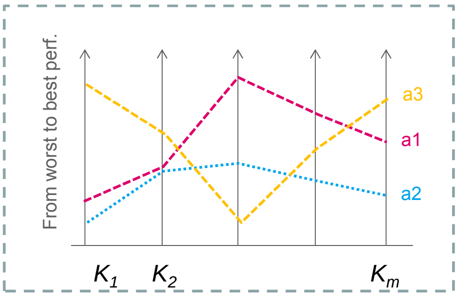
Objectives | Criteria

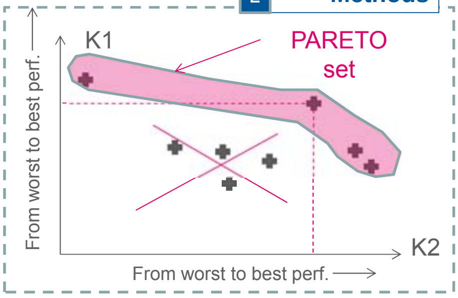
Objectives	Criteria
1	K_1
2	K_2
…	…
k	K_k
…	…
m	K_m

1 Comparison

Each one is expressed in its own "natural" unit

2 Methods





Approaches Graphical

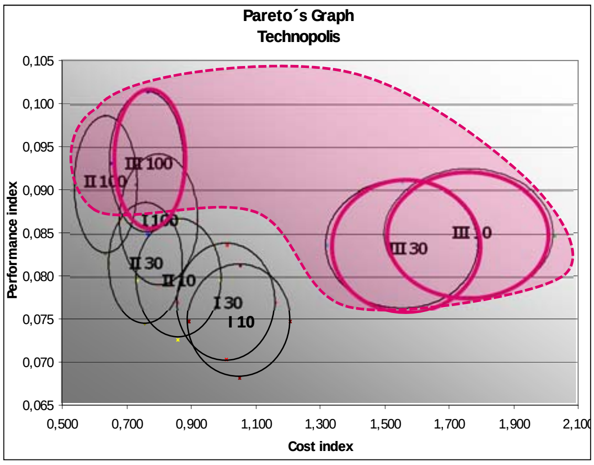
Cost index

Aggregation of sub-costs

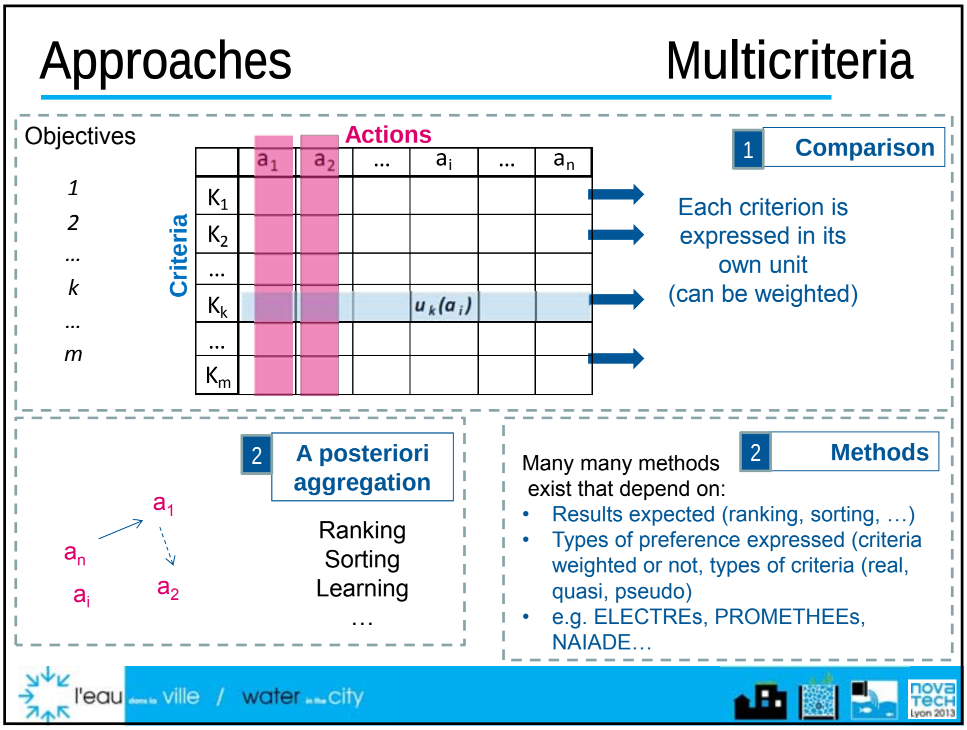
Non financial index (benefit)

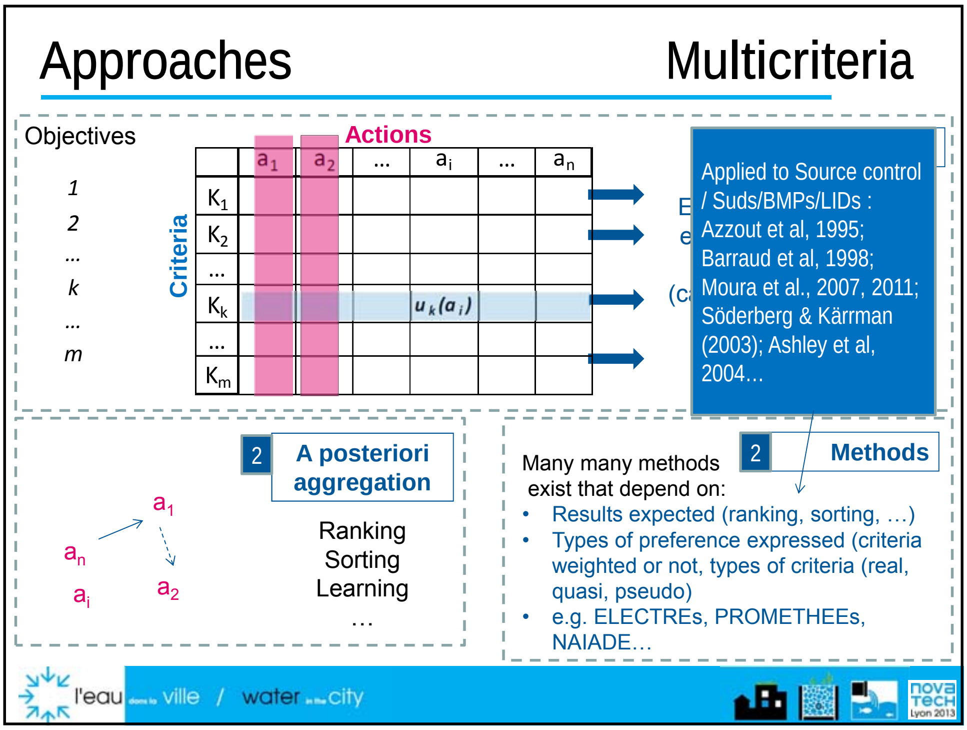
Aggregation of sub-performances

Environmental
Sanitary
Social



(Moura, Baptista et al, 2004) - Castro & Baptista (2004)


Approaches
Multicriteria
Objectives
1
2
…
k
…
m
Actions
Criteria
a1
a2
…
ai
…
an
K1
K2
…
Kk
…
Km
uk(ai)
1 Comparison
Each criterion is expressed in its own unit (can be weighted)
2 A posteriori aggregation
Ranking
Sorting
Learning
…
2 Methods
Many many methods exist that depend on:
• Results expected (ranking, sorting, …)
• Types of preference expressed (criteria weighted or not, types of criteria (real, quasi, pseudo)
• e.g. ELECTREs, PROMETHEEs, NAIADE…
l'eau dans la ville / water in the city
nova tech Lyon 2013


Approaches
Multicriteria
Objectives
Actions
Criteria
uk(ai)
Applied to Source control / Suds/BMPs/LIDs : Azzout et al, 1995; Barraud et al, 1998; Moura et al., 2007, 2011; Söderberg & Kärrman (2003); Ashley et al, 2004…
2 A posteriori aggregation
Ranking
Sorting
Learning
…
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Many many methods exist that depend on:
• Results expected (ranking, sorting, …)
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l'eau dans la ville / water in the city
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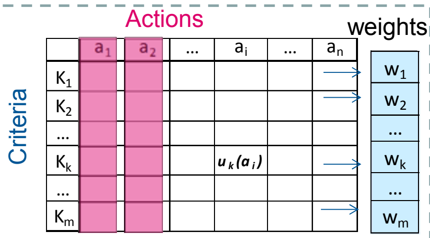
Example — Electre II (ranking)



1 Pairwise Comparison

Does « a_1 outranks a_2 » ?

-According to a **concordance** index
(for the criteria for which a_1 is better than a_2)

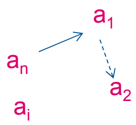
$$C(a_1,a_2)=\frac{w^+(a_1,a_2)+w^=(a_1,a_2)}{\sum w_j}$$

-According to **discordance** indexes
(for the criteria for which a_1 is worse than a_2)

$$D_j(a_1,a_2)=|u_j(a_1)-u_j(a_2)|$$

➡ Concordance / Discordance thresholds

2 A posteriori aggregation

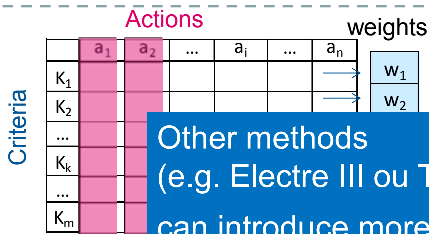


Direct ranking

Indirect ranking

Median & final ranking

Example — Electre II (ranking)



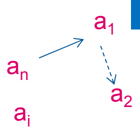
1 Pairwise Comparison

Does « a_1 outranks a_2 » ?

Other methods
(e.g. Electre III ou Tri)

can introduce more refinement in pref. modelling of each criterion

(e.g. indifference thresholds ➔ uncertainties (fuzzy concepts))

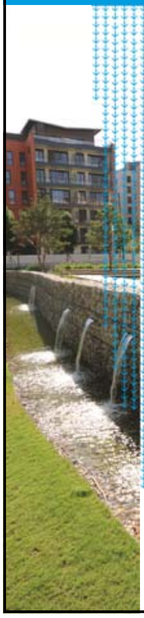


Indirect ranking

Median & final ranking

$$D_j(a_1,a_2)=|u_j(a_1)-u_j(a_2)|$$

➡ Concordance / Discordance thresholds



My experience
Problems encountered
in MCDA elaboration

MCDA elaboration steps

Aims
(problem - objectives)

Criteria / indicators
definition

Invidual quality test of
the indicators

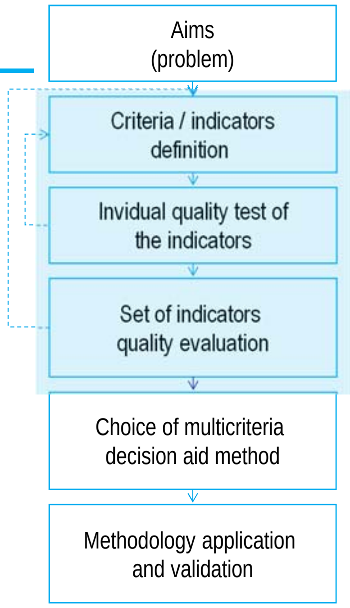
Set of indicators
quality evaluation

Choice of multicriteria
decision aid method

Methodology application
and validation
(parameter evaluation
e.g. weight)
(robust.& sensitivity analysis)

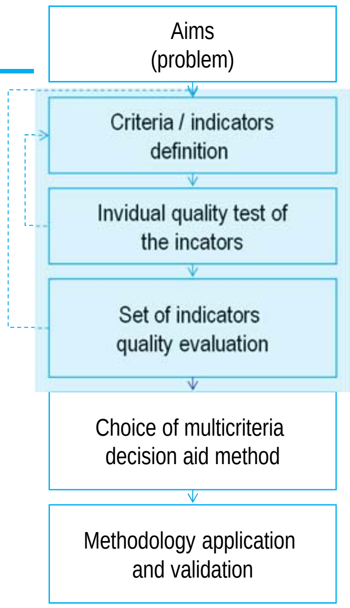
MCDA elaboration steps

- Construction of a consistent set of criteria
  1. Quality of each criterion
  2. Quality of the set (Number de criteria and potential redundancy that can impact the decision proposal, …)



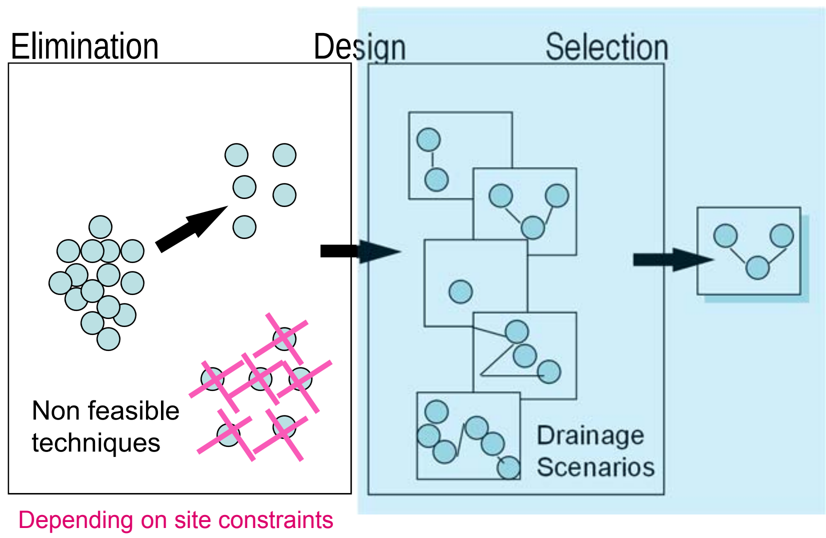
MCDA elaboration steps

- Construction of a set of criteria
  1. Quality of a criterion
  2. Quality of the set (Number de criteria and potential redundancy that can impact weights, …) (PB1)



PB1- Choice of a good stormwater project at the design stage

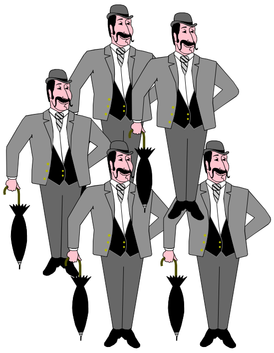
Decision Procedure (1994)



l'eau ville / water city

Definition of the decision criteria

List of general criteria that could be used for a wide range of local studies constructed iteratively



27 criteria

Expert group

Consistent family of criteria ?

Criteria family	Criteria
Urban integration	C1 : Landscape impact (*)
	C2 : Urban planning constraints (*)
	C3 : Possibility of leisure functions (*)
Economic aspects	C4 : On-site preliminary studies to be made (*) or (**)
	C5 : Investment cost (**)
	C6 : Legal status of the construction (public, private) (*)
	C7 : Profitability of strategy compared to zone development schedule (*) or (**)
Hydraulic efficiency	C8 : Strategy's capacity to withstand exceptional storm events (*)
	C9 : Impact in case of overflow (*) or (***)
Scenario environmental and user-safety impact	C10 : Population impact (*)
	C11 : Risks for the safety of people during normal functioning (*)
	C12 : Aptitude to be used for other technical functions (*)
	C13 : Polluted solids retention capacity (***)
	C14 : Chronic-type dissolved pollutant retention capacity (***)
	C15 : Effectiveness against accidental pollution (*)
Implementation aspects	C16 : Suitability for rapid implementation (*)
	C17 : Impact of construction on the population (*)
	C18 : Ease of follow-up (*)
Maintenance and operation aspects	C19 : Usual maintenance frequency (*) or (**)
	C20 : Type of equipment needed for usual maintenance (*) or (**)
	C21 : Controllability of maintenance (*)
	C22 : Waste recovery during routine maintenance (*)
	C23 : Energy consumption (*)
	C24 : Risks for maintenance operatives' safety (*)
	C25 : Possible degradation of construction (*)
Ease of renovation	C26 : Ease of renovation
	C27 : Suitability for waste recovery during rehabilitation

Nature of criterion evaluation: (*) qualitative, (**) quantitative, (***) ordinal.

Decision criteria

– urban integration	(3)
– economic aspects	(4)
– hydraulic efficiency	(2)
– influence of the scenario on its environment and on the safety of users	(6)
– implementation	(3)
– Maintenance and operation aspects	(7)
– aptitude to be easily renovated	(2)

→ ELECTRE III

A-posteriori analysis

- Application to 3 real case studies
  - Relevance of the methodology
  - High number of criteria: a barrier to current use
    (too much work, hidden redundancy, loss of understanding)

↓

- Reduction method
  - Identification of common non discriminating criteria and their reasons (3 studies)

A-posteriori analysis

- Criterion C1
- Criterion C2
- Criterion C3
- Criterion C4

.
.
~~Criterion j~~
.

- Criterion C25
- Criterion C26
- Criterion C27

For the 3 Case studies

Impact of the criterion removal on the initial ranking of the scenarios

(ELECTRE III) ?

Strategy of elimination

$$D_j = 1 - E_j = 1 - \left[-\frac{1}{ln(n)} \cdot \sum_{i=1}^{n} u_j(a_i) \cdot ln(u_j(a_i)) \right]$$

$$u_j(a_i)^* = u_j(a_i) \Big/ \sum_{i=1}^{n} u_j(a_i)$$

$$m_j = \frac{D_j}{\sum D_j}$$

Discriminating power / dispersion measure of the set of actions on a criterion j

n : number of scenarios for a case study k

$U_j(a_i)$: performance of the scenario i according to criterion j

$U_j(a_i)^*$: normalised performance

criterion removal according to the increasing order of *mj* values.

What did we learn ?

- By definition

The non discriminating criteria (that did not change the ranking on the 3 studies) was those that did not present **contrasted** evaluation according to the different scenarios

What did we learn ?

- Different reasons
  – The 3 case studies did not cover the full range of situations (criteria not relevant for the set of scenarios compared)

  E.g. *Safety of maintenance staff* ➔ *not eliminated*

  – Certain criteria were not very relevant because always taken into account in the design process

  E.g. *Impact of the construction of a scenario on the pop.* ➔ *eliminated*

What did we learn ?

- Different reasons
  - Certain criterion families were over represented & redundant

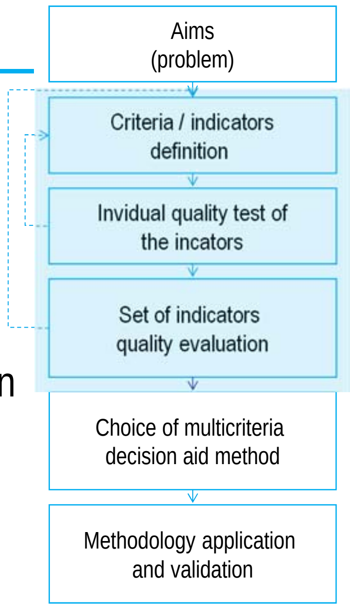
  E.g. *Maintenance (7 criteria / 27)* ➔ *Grouped and reformulated*

  - Certain criteria were so difficult to evaluate that, “*by precaution*”, all the scenarios were evaluated at the same level (high weights)

  E.g. *Pollution* ➔ *Cannot be eliminated (need some more research…)*

MCDA elaboration steps

- Construction of a set of criteria
  1. Quality of a criterion (PB2)
  2. Number de criteria and potential redundancy that can impact weights (PB1)



PB2- Problem of the performance assessment of existing infiltration systems

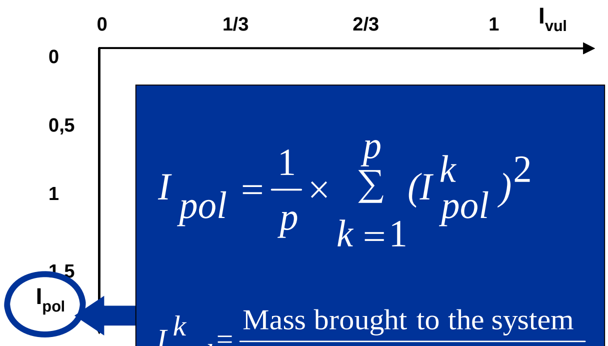
MCDA elaboration steps

Aims (problem) → Criteria / indicators definition → Invidual quality test of the incators

- Relevance — Does it correspond to a relevant & well accepted aspect to verify?
- Accessibility — Is the indicator easy to calculate and are the data for its calculation available at an acceptable cost?
- Fidelity — Can the indicator be estimated with a constant bias? Can it be evaluated in the same way by different appraisers?
- Objectivity — Is it ambiguous? Can it be interpreted in the same way by different potential appraisers?
- robustness — Does it give stable results according to the variation of uncertain parameters?
- Sensibility — Does it discriminate different strategies properly?
- univocity — Does it give a single trend?

Ex.: Lack of Robustness

- PI2: « Low pollution of water resource » <u>Version1</u>

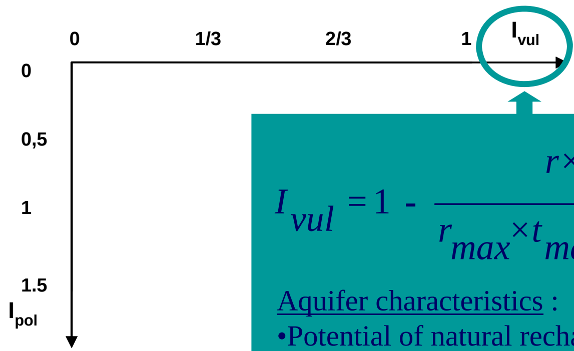


$$I_{pol} = \frac{1}{p} \times \sum_{k=1}^{p} (I^{k}_{pol})^2$$

$$I^{k}_{pol} = \frac{\text{Mass brought to the system}}{\text{Acceptable "limit" mass}}$$

Ex.: Lack of Robustness

- PI2: « Low pollution of water resource » Version1

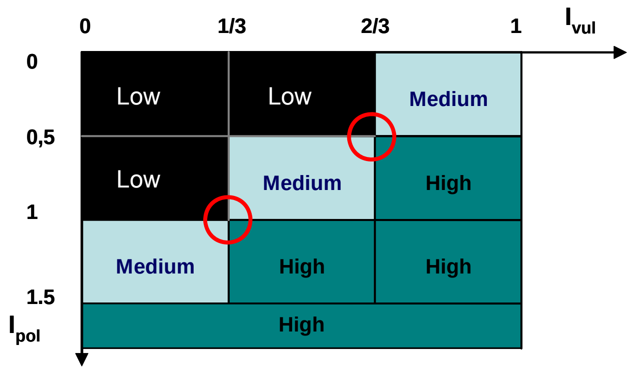


$$I_{vul} = 1 - \frac{r \times t \times zn \times s_y}{r_{max} \times t_{max} \times zn_{max} \times s_{max}}$$

<u>Aquifer characteristics</u> :
- Potential of natural recharge
- Transmissivity,
- Porosity
- Thickness of the unsaturated zone

Ex.: Lack of Robustness

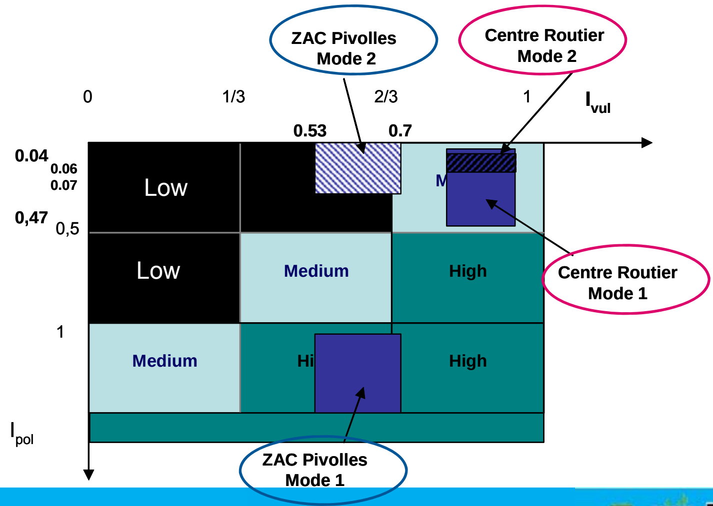
- PI2: « Low pollution of water resource » Version1



l'eau dans la ville / water in the city

Ex.: Lack of Robustness

- PI2: « Low pollution of water resource » Version1



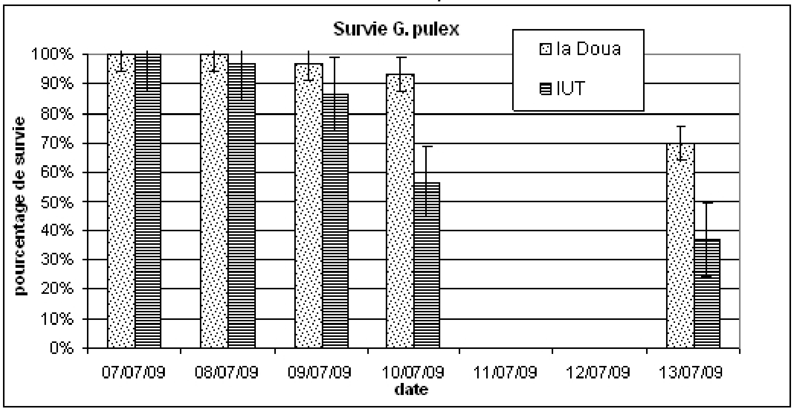
l'eau dans la ville / water in the city

Lead to other research

Marmonier et al, 2010

Gammarus pulex

Niphargus rhenorhodanensis

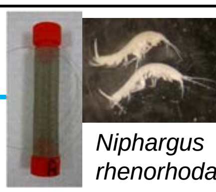


Taux de survie d'Amphipodes épigés (*Gammarus pulex*) encagés dans des piézomètres situés en amont (la Doua en gris clair) ou sous influence (IUT en gris sombre) d'apports d'un bassin d'infiltration (Marmonier et al, 2010).

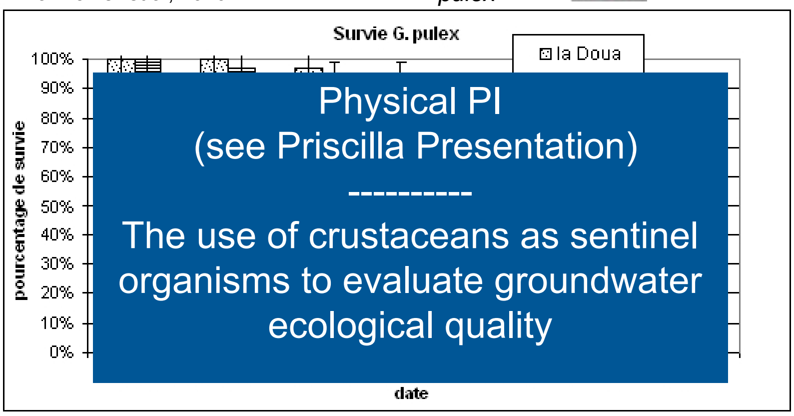
Lead to other research

Marmonier et al, 2010

Gammarus pulex



Niphargus rhenorhodanensis



Physical PI
(see Priscilla Presentation)

The use of crustaceans as sentinel organisms to evaluate groundwater ecological quality

Taux de survie d'Amphipodes épigés (*Gammarus pulex*) encagés dans des piézomètres situés en amont (la Doua en gris clair) ou sous influence (IUT en gris sombre) d'apports d'un bassin d'infiltration (Marmonier et al, 2010).

Some conclusions…

Using a MCDA method does not only help to make decision prescriptions, it also helps:

- to identify the real decision process (transparency, good opportunity for negotiation process between different points of view, …)
- To develop a learning /coherent approach of the domain

l'eau dans la ville / water in the city

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Stratégies & solutions pour une gestion durable de l'eau dans la ville
Planning & technologies for sustainable urban water management

Thank you for your attention !

8TH INTERNATIONAL CONFERENCE NOVATECH JUNE 23>27 Lyon 2013 Planning & technologies for sustainable urban water management

WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Multi-criteria analysis for stormwater source control & harvesting strategies

Multi-criteria techniques for the operation of infiltration systems

Priscilla Moura, UFMG, Brazil

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Stratégies & solutions pour une gestion durable de l'eau dans la ville

Planning & technologies for sustainable urban water management

Multi-criteria techniques for the operation of infiltration systems

Priscilla Moura

WORKSHOP 3 - Analyse multicritère et modélisation à l'échelle des bassins versants pour le développement du contrôle à la source et de stratégies de récupération des eaux pluviales

UFMG UNIVERSIDADE FEDERAL DE MINAS GERAIS

MCDA elaboration steps

Aims (problem)

Spacial scale: drainage system scale

Time scale: system lifespan or a part of it

aims:

- Evaluation of the system in a defined moment;
- Evaluation of the system during its lifespan;
- Comparing alternatives of:
  - projects (design phase);
  - management;
  - retrofit.

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MCDA elaboration steps

Aims
(problem)

to:
- Decision makers
- Designers, managers

Design and **operating phases**

MCDA elaboration steps

Aims
(problem)

Criteria / indicators
definition

Working group:
- Hydrology
- Hydrobiology
- Soil Sciences
- Environmental Sciences
- Chemistry
- Hydrogeology
- Designers
- Professionals in charge of maintenance or control of existing systems

MCDA elaboration steps

Aims (problem)

Criteria / indicators definition

Invidual quality test of the incators

- relevance
- accessibility
- fidelity
- objectivity
- robustness
- sensibility
- univocally

Does it correspond to a relevant aspect to verify?

Is the indicator easy to calculate and are the data for its calculation available at an acceptable cost?

Can the indicator be estimated with a constant bias? Can it be evaluated in the same way by different appraisers?

Is it ambiguous? Can it be interpreted in the same way by different potential appraisers?

Does it give stable results according to the variation of uncertain parameters?

Does it discriminate different strategies properly?

Univocal evaluation

MCDA elaboration steps

Aims (problem)

Criteria / indicators definition

Invidual quality test of the incators

MCDA elaboration steps

Aims
(problem)

Criteria / indicators definition

Invidual quality test of the incators

- relevance
- accessibility
- fidelity
- objectivity
- robustness
- sensibility
- univocally

Working group
application

indicator evaluation submitted to different people

Uncertainty in the application

application

at the moment of the indicator construction

MCDA elaboration steps

Criteria / indicators definition

Invidual quality test of the incators

Set of indicators quality evaluation

- cohesiveness
- exhaustiveness
- non-redundancy

construction of the criteria and application

vis-a-vis the working group point of view

Working group

MCDA elaboration steps

- Aims (problem)
- Criteria / indicators definition
- Invidual quality test of the incators
- Set of indicators quality evaluation
- Choice of multicriteria decision aid method

According to:
- type of indicator
- uncertainities ranges
- kind of result expected

MCDA elaboration steps

- Aims (problem)
- Criteria / indicators definition
- Invidual quality test of the incators
- Set of indicators quality evaluation
- Choice of multicriteria decision aid method
- Methodology application and validation

robustness
+
sensitivity analysis

Operating phase

Evaluate the behavior of an existing system and the strategies to be applied to improve its performance

Flooding Protection

Flooding frequency indicator

$$IS_{HYD1} = \frac{F_{deb}}{F_{dim}}$$

Global hydraulic performance measuring the potential for clogging

$$IS_{HYD2} = \underset{i}{Max}\,(R_i) \qquad IS_{HYD2} = \underset{i}{Max}\,(Ks_i)$$

Low degradation of groundwater quality

- Specific conductivity
- Dissolved oxygen concentration

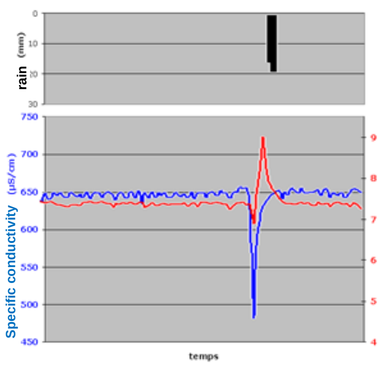
If the system presents a normal functionning

$IS_{NAPPE} = 0$

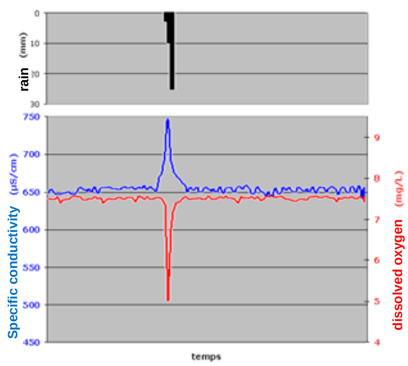
If the system presents an abnormal functionning

$IS_{NAPPE} = 1$

Low degradation of groundwater quality



Normal Functioning



Abnormal Functioning

Aptitude to trap pollution

Pre-treatment efficiency

$$IS_{PT} = \frac{Mp^{MES}}{Map^{MES}}$$

Soil contamination indicator

$$K_1 = \frac{\#\,cas\,[C_{mesi} \leq C_{INIi}]}{\#_{totpol}}$$

IS_{SOL1} : depth where pollution becomes low or nil

IS_{SOL2} : percentage of highly polluted points

Aptitude to be well and easily maintained

$$IE_{MAIN} = \#_{totali} - \#_{NONi}$$

$$IS_{MAIN} = \#_{dysi}$$

Protect users and staff health

potential risk due to soil contamination

$$K_3 = \% \text{ cas } [C_{messi} \leq S_{0,2i}]$$

$$K_4 = \% \text{ cas } [C_{messi} \geq S_{5i}]$$

$$IS_{SAN1} = K_3/100 \text{ si } K_3 < 100\%$$

but

$$IS_{SAN1} = 0 \text{ si } K_4 > 0\%$$

potential risk due to air pollution for users and local residents

$$IS_{SAN2} = \% \text{ cas } \left[\frac{C_{mesAi}}{C_{limAi}} > \alpha \right]$$

potential risk due to pollution of air and soil particles (for workers)

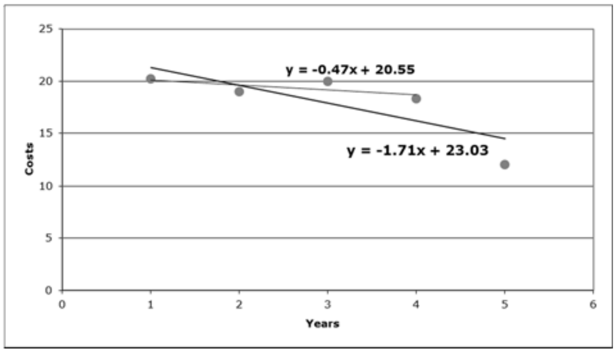
$$IS_{SAN3} = \% \text{ cas } \left[\frac{C_{mesTi}}{C_{limTi}} > \alpha \right]$$

Waste production

$$IS_{DEC} = \frac{Ms_{valor}}{Ms_{cure}}$$

Low maintenance costs

$IS_{COUT} = C_{MAc} - \overline{C_{MPr}}$



Good social acceptance

$IS_{AS} = 0$ if there are complaints about the system since its implantation or its more recent rehabilitation; otherwise $IS_{AS} = 1$

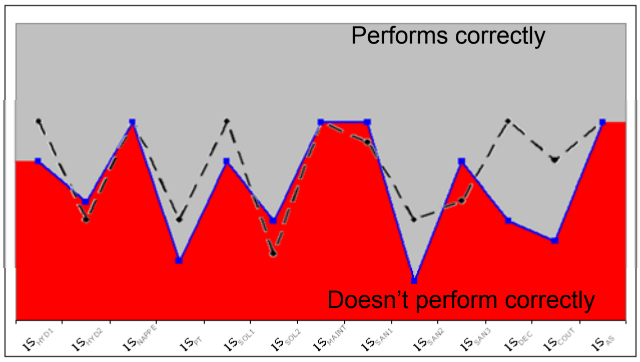
Choice of multicriteria decision aid method

ELECTRE TRI

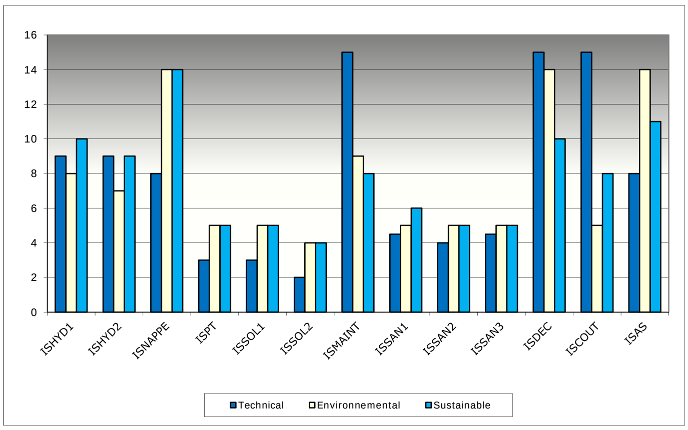
Assignment to a category

Pairwise comparison

Optimistic and pessimistic assignment procedures



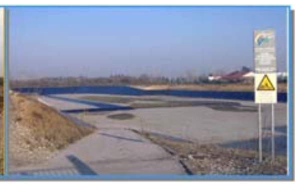
Weighting of the indicators



Application

Application

Django Reinhardt



ZAC de Pivolles

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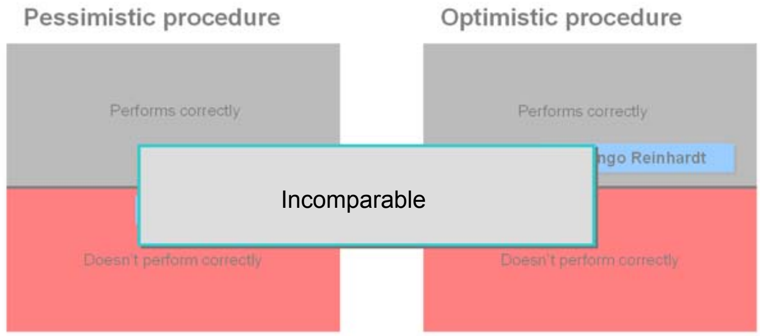
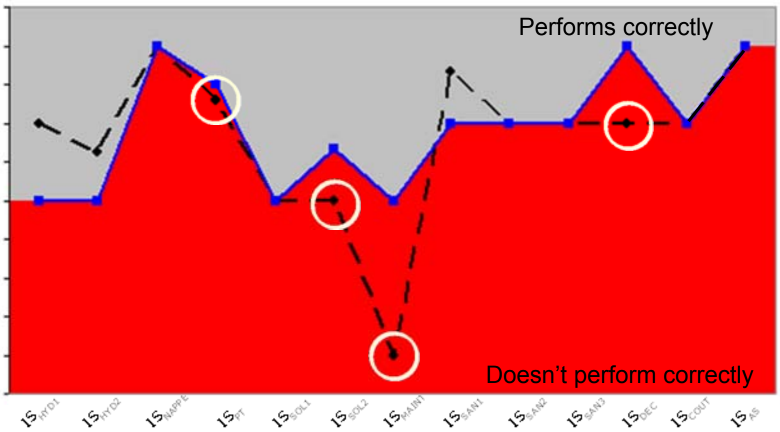
Application – Django Reinhardt retention infiltration basin



Application – Django Reinhardt retention infiltration basin

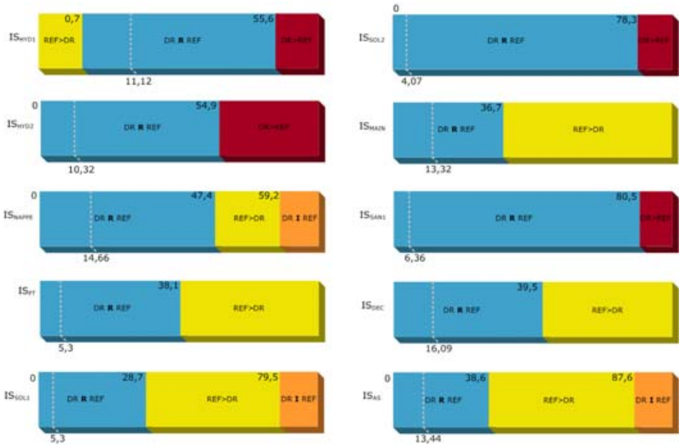


Application – Django Reinhardt retention infiltration basin – Robustness and sensitivity analysis

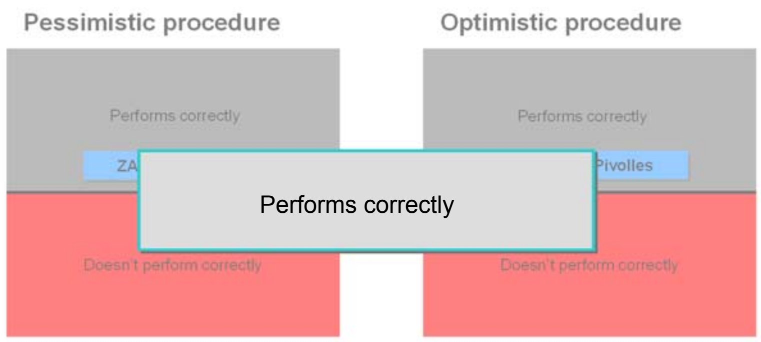
variations in:

- the indicators weights,
- in the thresholds

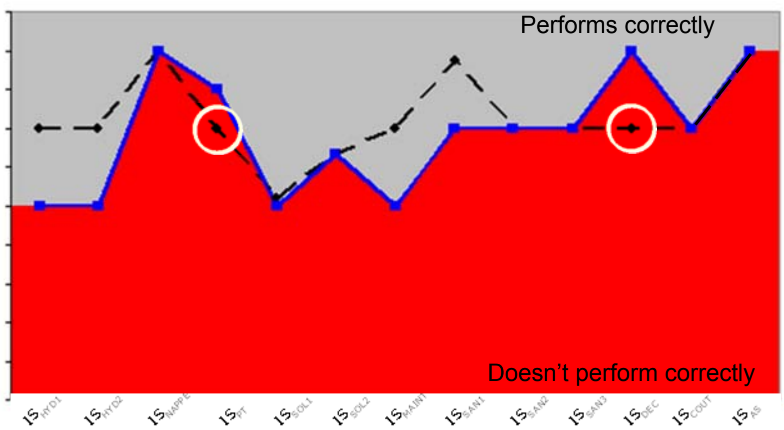
Application – Django Reinhardt retention infiltration basin – Robustness analysis



Application – ZAC de Pivolles retention infiltration basin



Application – ZAC de Pivolles retention infiltration basin



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Conclusions

- Efficient and adapted to test the quality of an existing system;
- Points out the different aspects that have to be improved and indicates the necessary shift in the design of future systems;
- Highlights the lack of information which may draw managers' attention and give tracks of improvement of their practice and organization

l'eau dans la ville / water in the city

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Stratégies & solutions pour une gestion durable de l'eau dans la ville
Planning & technologies for sustainable urban water management

Thank you for your attention!

priscilla.moura@ehr.ufmg.br

RhôneAlpes Région

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NOVATECH
JUNE 23>27 Lyon 2013
Planning & technologies for sustainable urban water management

IWA the international water association

IAHR AIRH International Association for Hydro-Environment Engineering and Research
Supported by CEDEX

WORKSHOP Source control and stormwater harvesting; multi-criteria analysis techniques and catchment-scale modelling approaches

Multi-criteria analysis for stormwater source control & harvesting strategies

Water Harvesting: Overcoming People to Make it Work in SE USA

Bill Hunt,
Bio & Ag Engineering - N.C. State (USA)

NC STATE UNIVERSITY

RWH Workshop – Lyon, FRANCE – 23Juin13

Water Harvesting: Overcoming People to Make it Work in SE USA

Bill Hunt, PE, PhD, D.WRE
Associate Professor & Extension Specialist
Kathy DeBusk, PE
Ph.D. Candidate
NC State University, Raleigh, NC, USA

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So, Does RWH Work in Humid SE?

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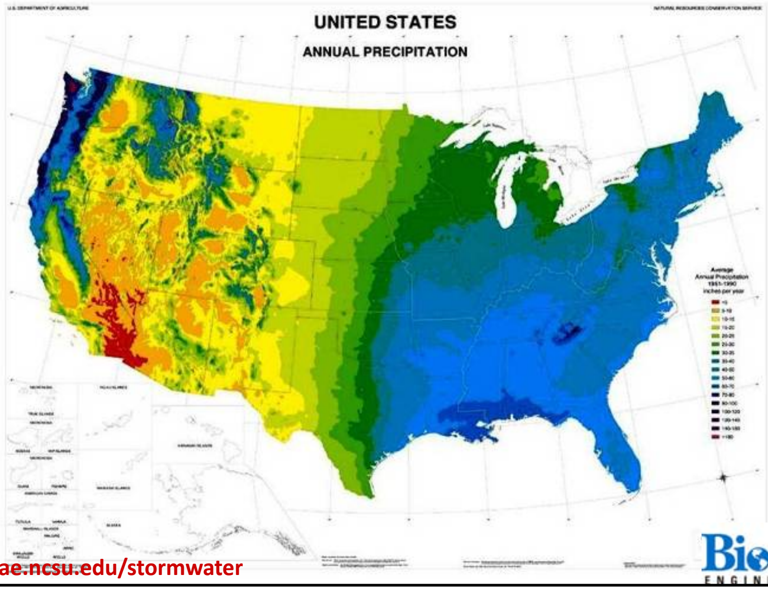
Available Water: Problematic?



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Craven County
Agricultural Center

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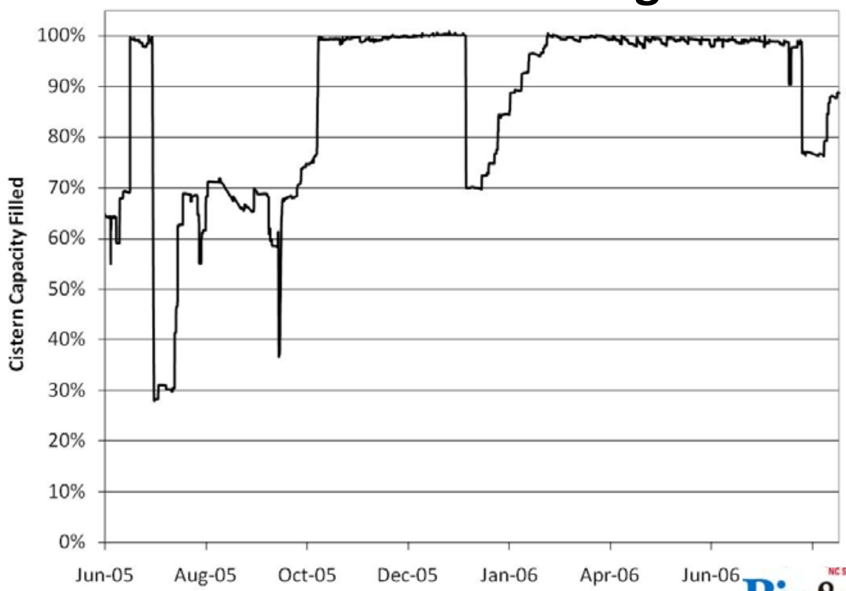
Cistern Use – Craven Co. Ag Center



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WOLFPACK
VENTURE

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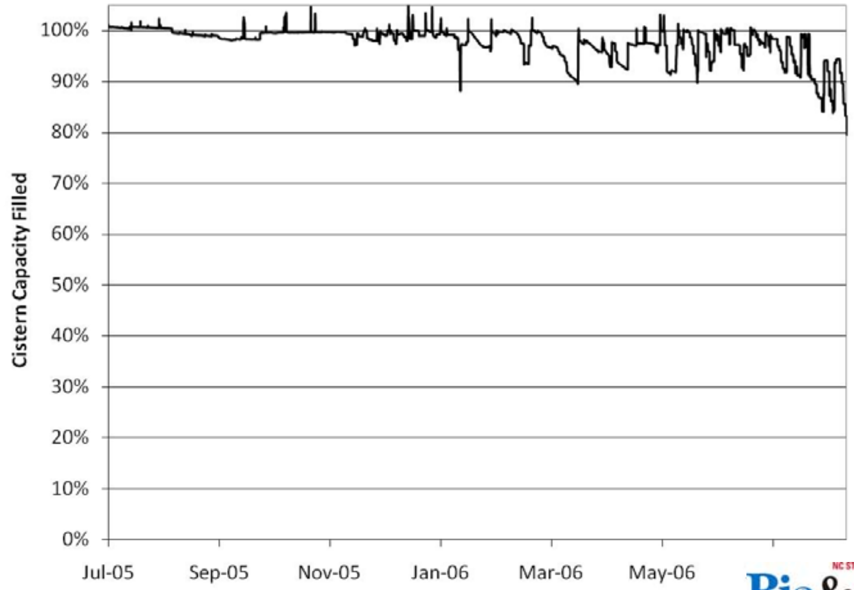
Cistern Use – Kinston Pub. Util.



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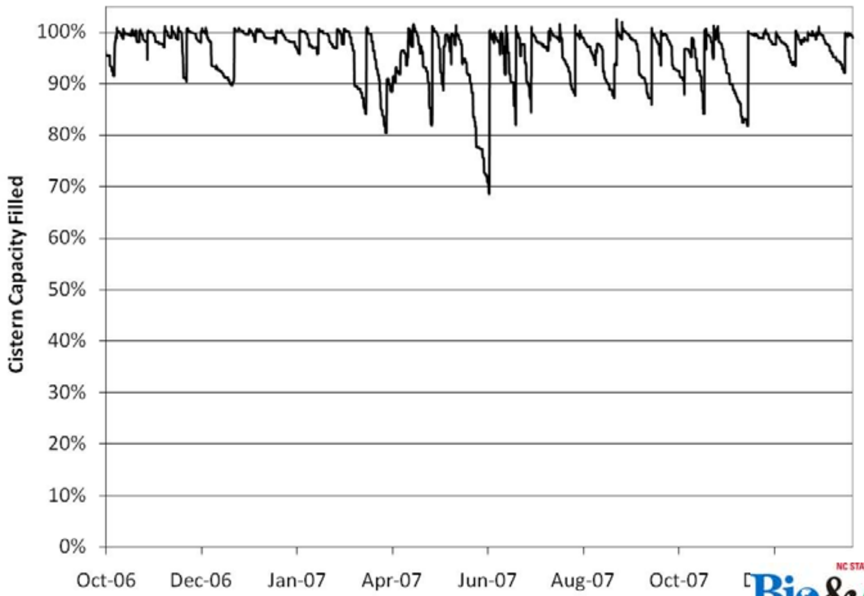
Cistern Use – Prarie Ridge




And then came… the Town of Holden Beach, NC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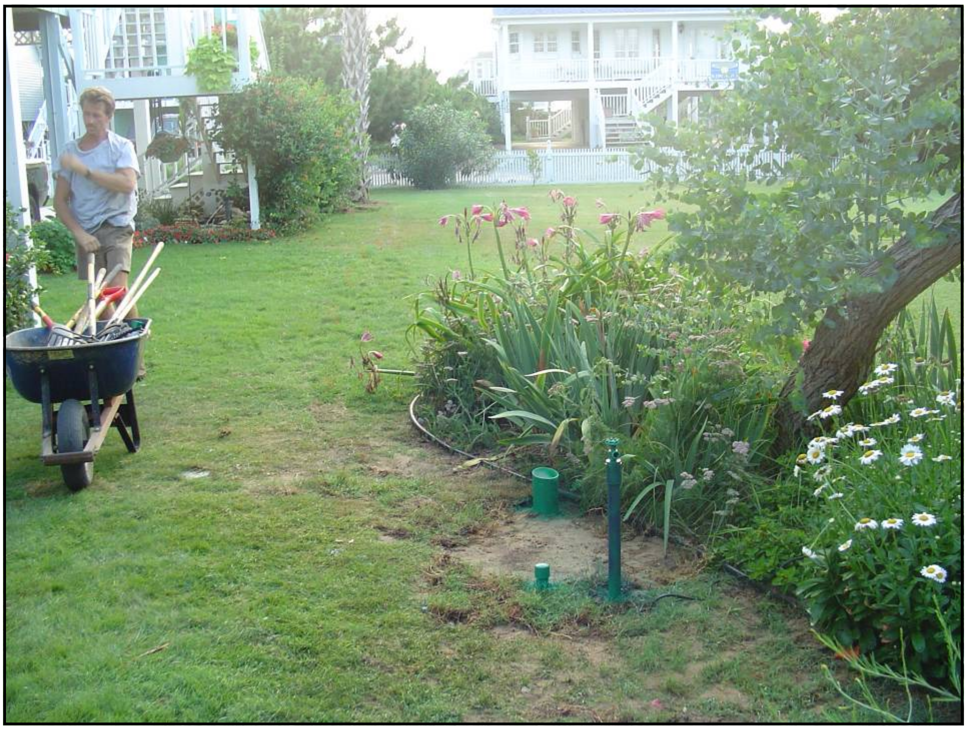

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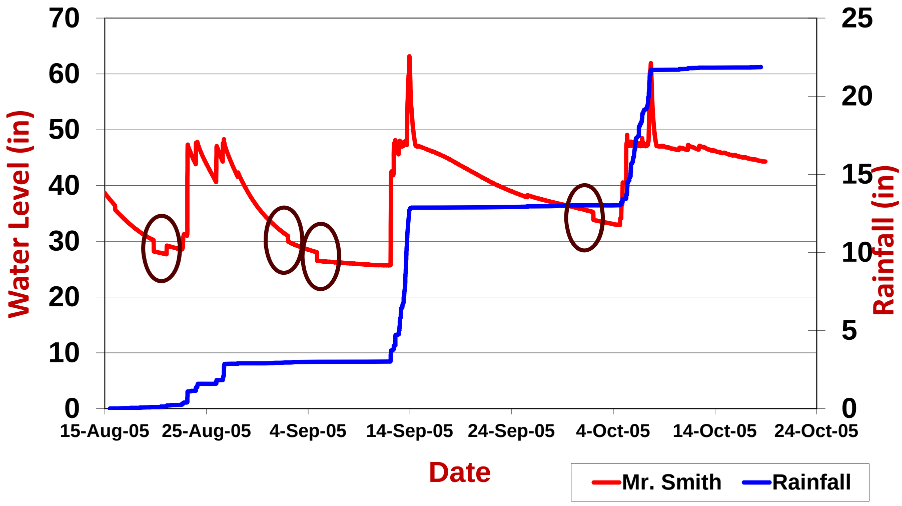
Holden Beach Cistern Water Level : Irrigation of Garden



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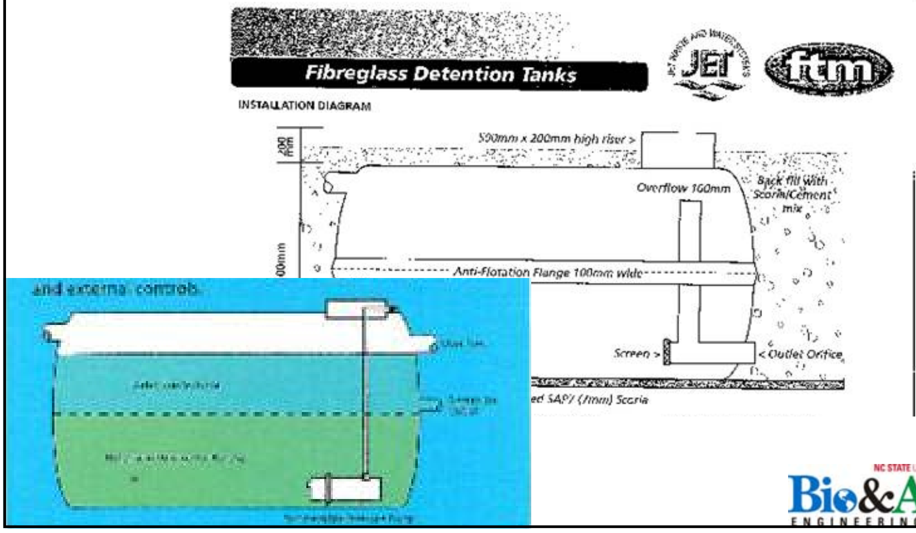
The Key?

- Design a Slow Leak into the system?



This has become a "norm" in NZ

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RWH & Water Conservation

Main objective:

Have rainwater available to use in lieu of potable water

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RWH & Stormwater Management

Main objective:

Have enough space available in the tank to capture the next storm event

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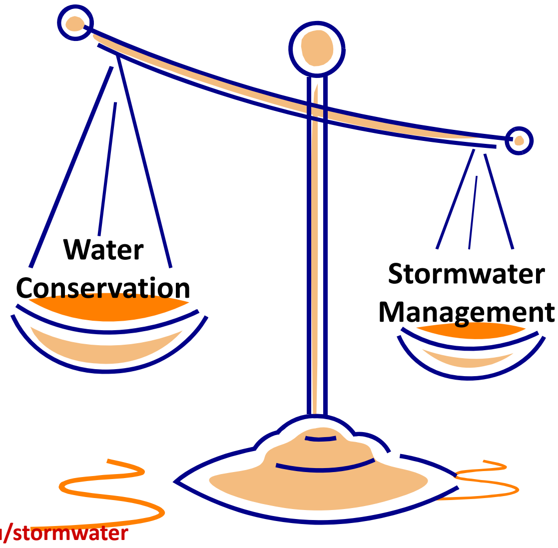
How can we do both?



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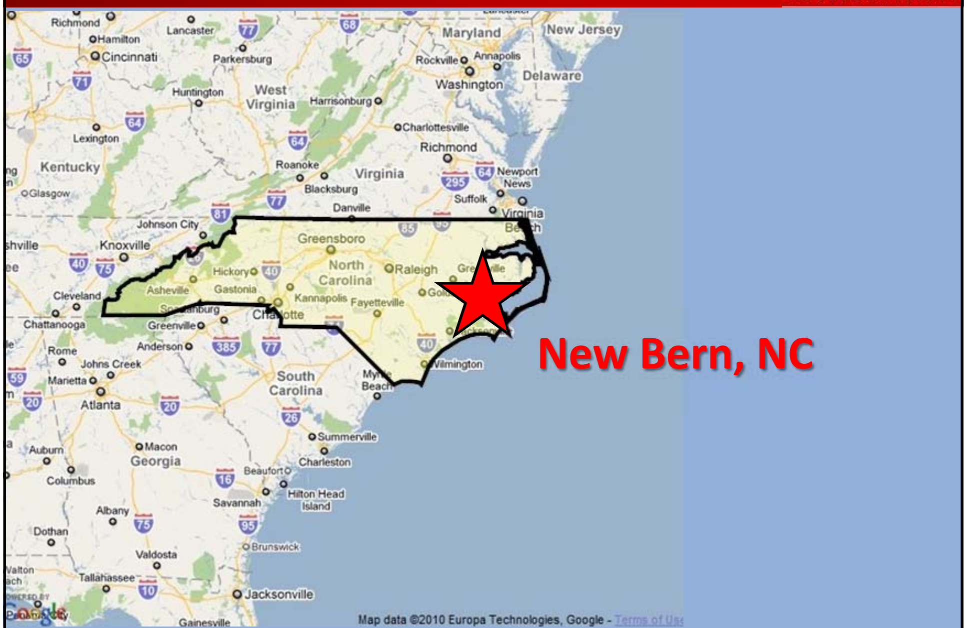

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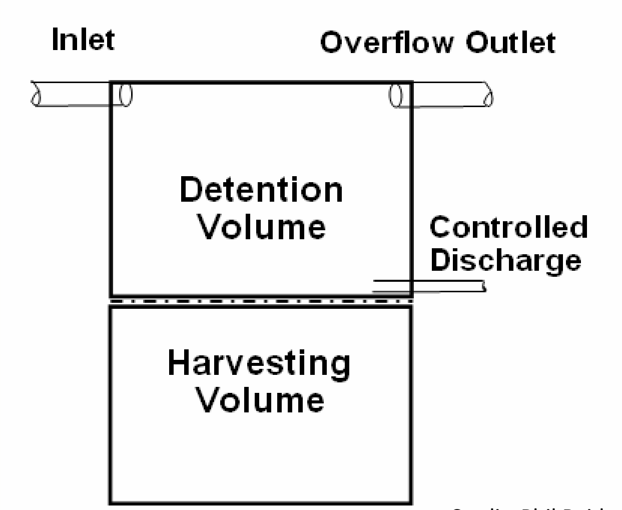
Passive Release Concept



Credit: Phil Reidy

NC Department of Transportation

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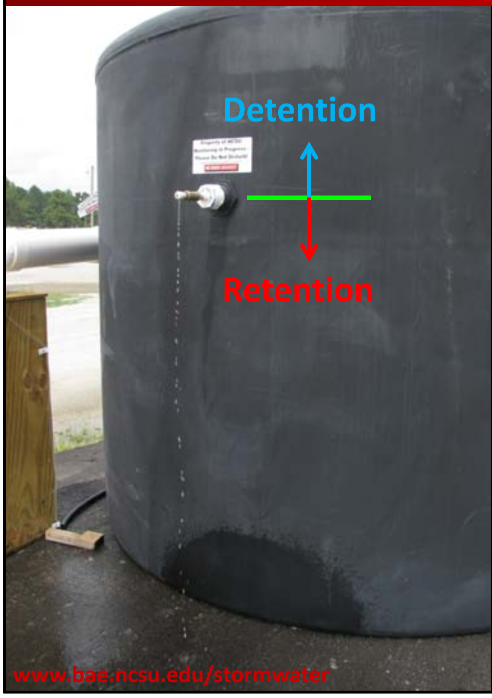

- Detention volume = 2,275 L (~27mm RF)
- Retention volume = 6,055 L
- Drawdown time = 3 days

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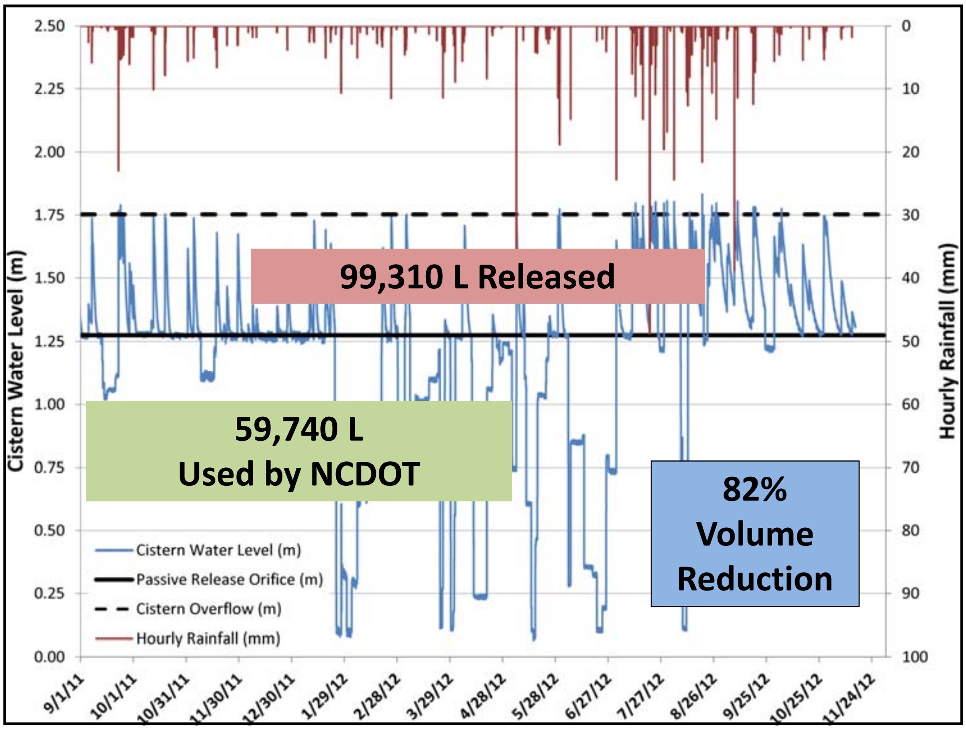
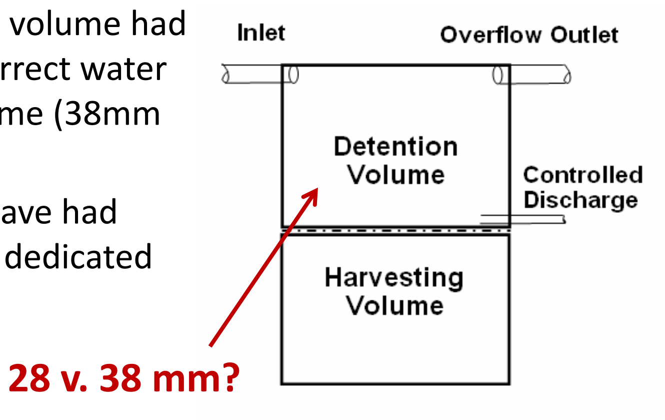


Better Performance if…

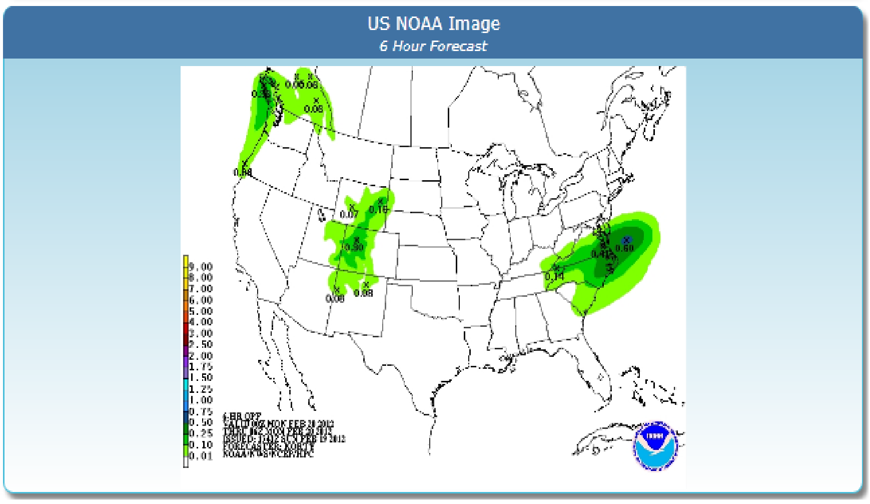
- The capture volume had been the correct water quality volume (38mm v. 28 mm)
- We would have had more space dedicated to rainfall

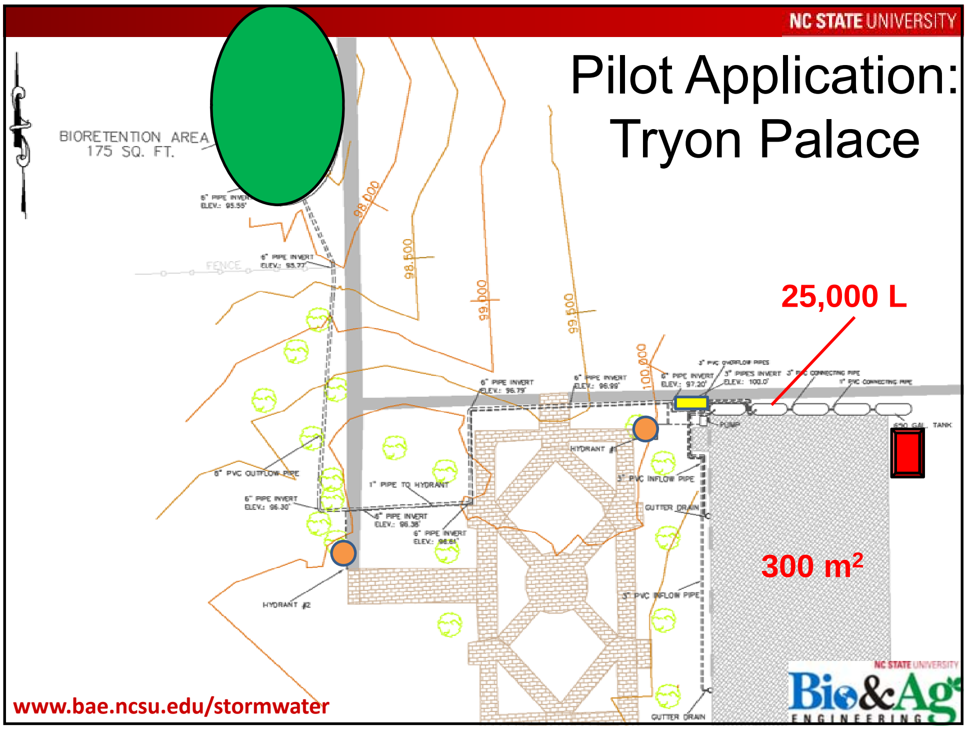


Active Management of RWH

SE QLD, Australia

Weather Forecasts

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Pilot Application:
Tryon Palace
BIORETENTION AREA
175 SQ. FT.
FENCE
98.000
98.500
99.000
99.500
100.000
25,000 L
300 m²
HYDRANT #1
HYDRANT #2
1" PIPE TO HYDRANT
3" PVC INFLOW PIPE
GUTTER DRAIN
PUMP
TANK
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Location for Irrigation

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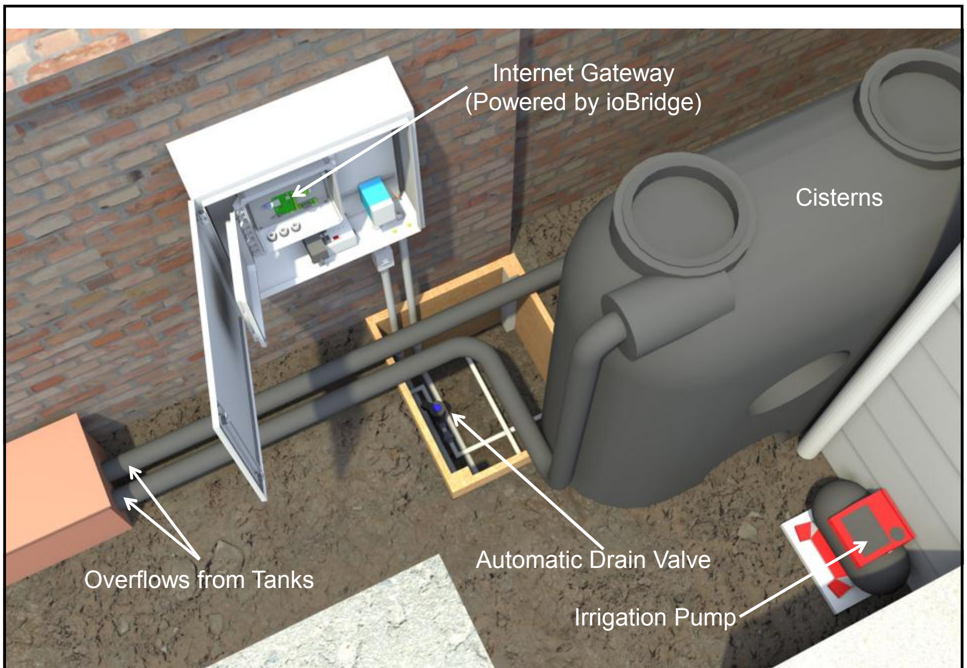
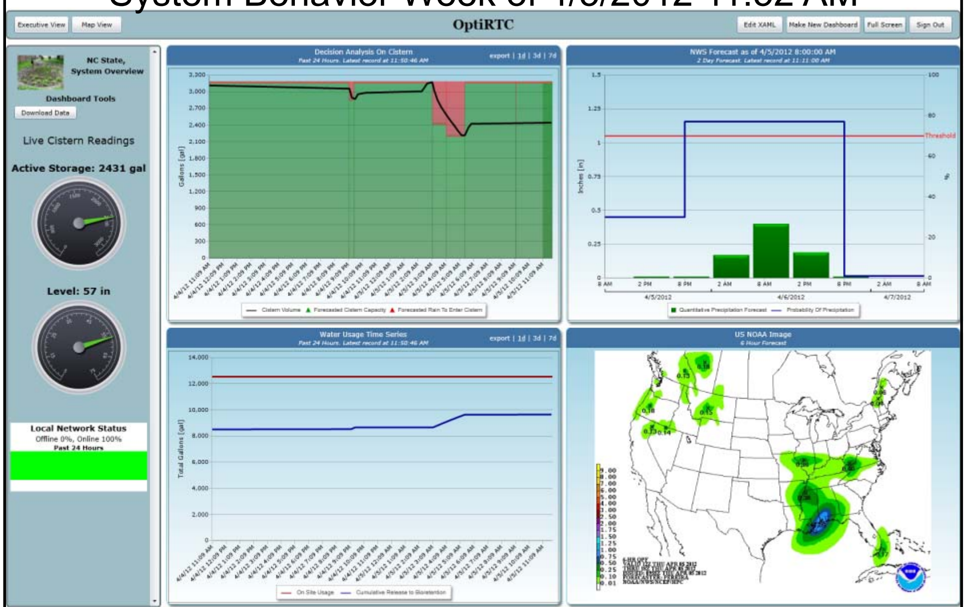


Geosyntec

Discharge Location

Tryon Palace – Dashboard

System Behavior Week of 4/5/2012 11:52 AM



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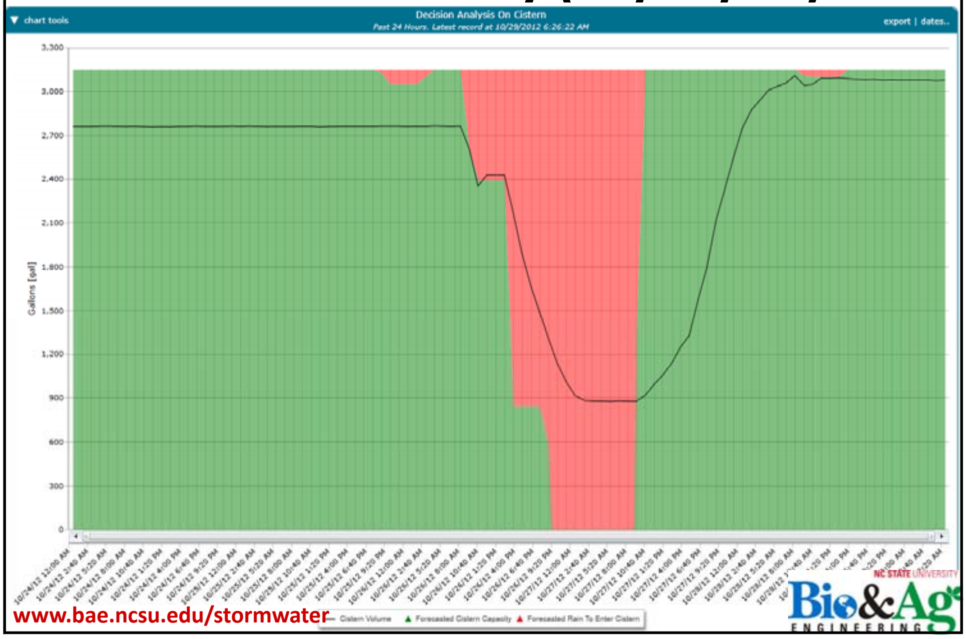
Hurricane Sandy (10/29/12)



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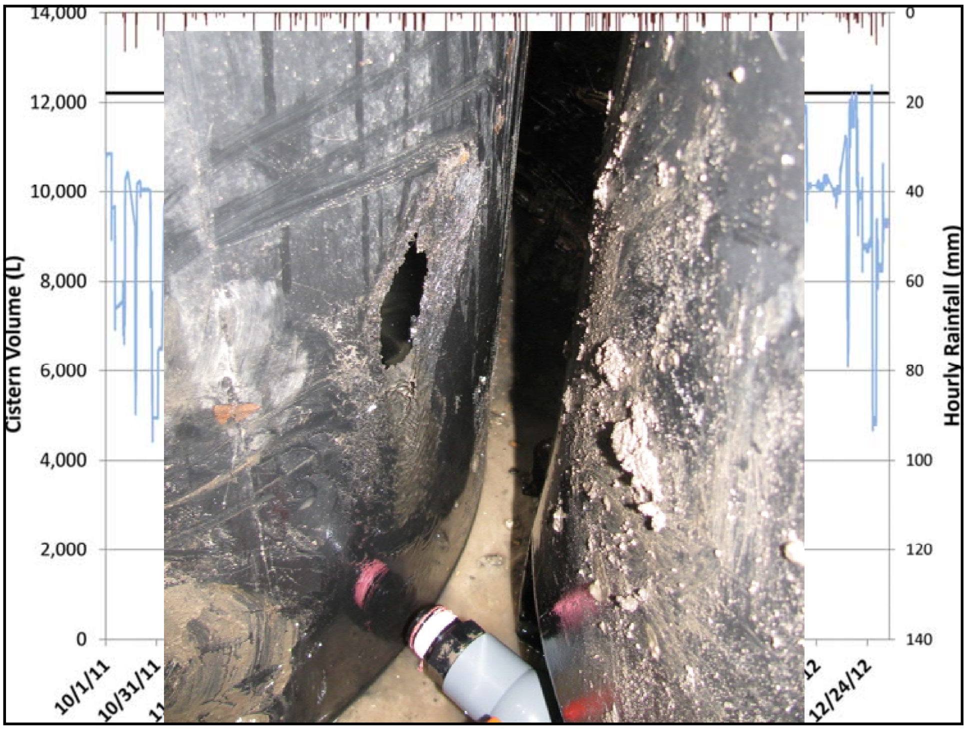

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Tryon Palace Results

Runoff Volume Reduction (%)	91%
Average Peak Flow Reduction (%)	93%
Overflow Frequency (%)	18%
Volume Used (gal)	9,658
Drawdown Volume (gal)	23,414
Volume Released During Rainfall (%)	4%
Demand Events Satisfied (%)	100%

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Other RTC Applications in RWH:

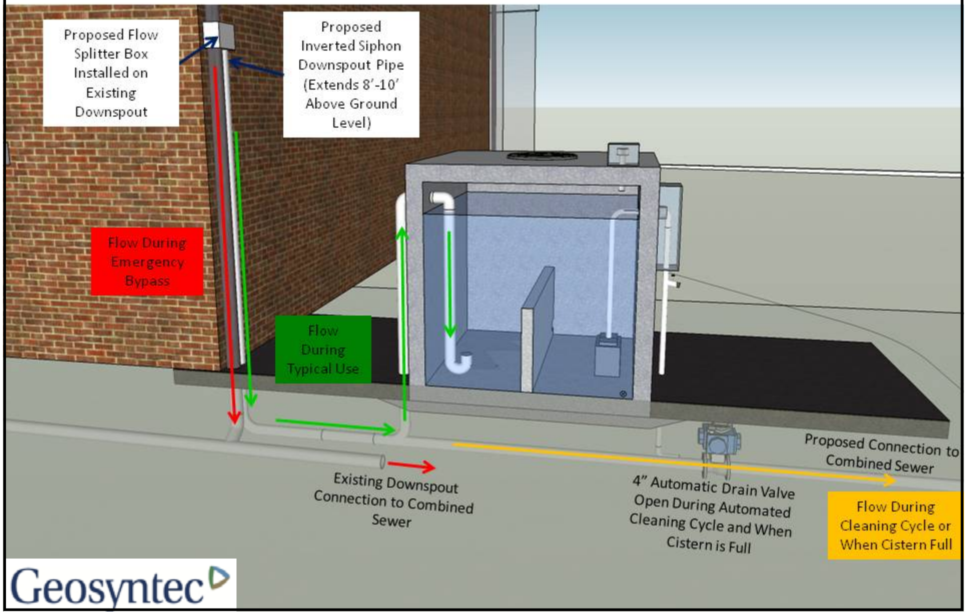
Washington, DC

Engine House #3

Geosyntec

Inverted Siphon Downspout Design

(Note: location of cistern is shown close to building for illustrative purposes only)



Geosyntec

Other RTC Applications in RWH

Renaissance Place

St. Louis, MO

Geosyntec

Harvesting Garden Rendering

Geosyntec

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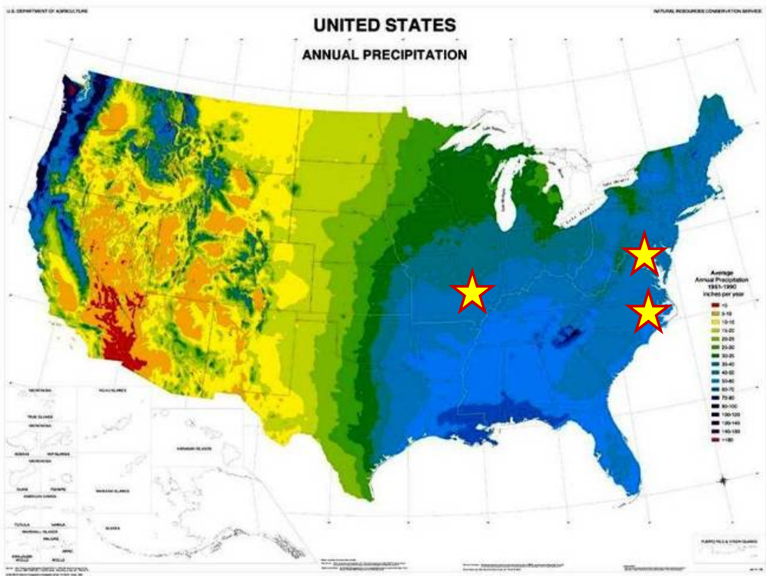

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Passive vs. Active

How do they compare?

	Passive Release (NCDOT)	Active Release (Tryon)
Volume Reduction	82%	91%
Peak Flow Reduction	90%	93%
Overflow Frequency	29%	18%
Dry Cistern Frequency	3%	0%
Demand Events Satisfied	86%	100%
Volume Released During Rainfall	25%	4%

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		NCDOT	Tryon Palace
Traditional System Components	Tank(s)	$ 1,500	$ 4,975
	Filters	$ 200	$ 200
	Pump	$ 450	$ 450
	Piping, Fittings, etc.	$ 95	$ 2,325
	Cistern Foundation	$ 100	$ 265
	Electricity	$ 300	$ 400
	SUBTOTAL	*$ 2,245*	*$8,615*
Release Mechanism Components	Materials	$ 30	$ 4,935
	Installation/ Support	$ -	$ 10,065
	SUBTOTAL	*$ 30*	*$ 15,000*
TOTAL		**$ 2,275**	**$ 23,615**

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Passive Release: Advantages

- Cheap
- Easy to install
- "Guaranteed" stormwater management
- No electricity or human input required

Passive Release: Disadvantages

- Semi-permanent
- Prone to freezing
- "Wasted" water

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Active Release: Advantages

- Optimal stormwater management
- Easily customized
- Decreased contribution to stormflows
- Maximizes usable water volume

Active Release: Disadvantages

- Expensive
- Requires electricity, internet and data storage
- Requires extensive knowledge & tech support
- Something can always go wrong…

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Questions?

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