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Improving Efficiency of Integrated Urban Water Systems Using Smart Rainwater Harvesting Schemes

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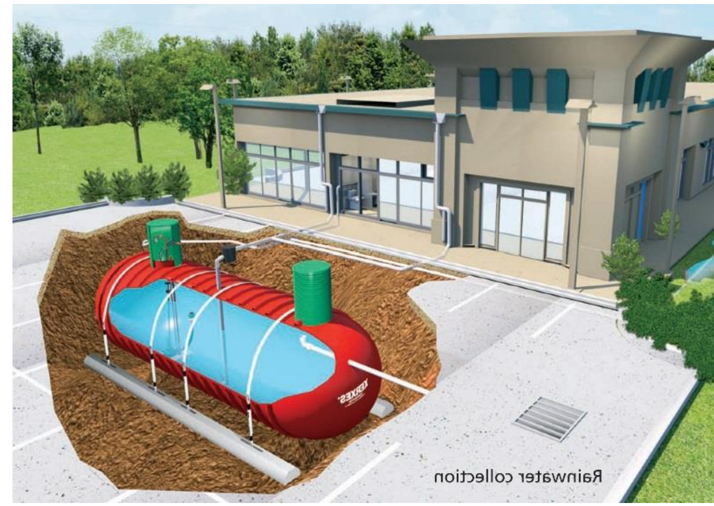
Outline

- Why do RWH schemes need to be smart?
- Key questions for Smart RWH?
- Aims/objectives
- Methodology
  - Case study
- Results
  - Smart or non-smart?
- Conclusions

RWH & need to be smart?

- High ranked intervention in urban water systems (UWS) are those supporting all water supply, stormwater and wastewater subsystems such as rainwater harvesting (RWH).
- Water recycling schemes received a lot of attention as a reliable alternative water resource.
- RWH schemes usually harvest rainwater from impervious surfaces for non-potable uses (irrigation and toilet flushing).
- This configuration in conventional RWH schemes is static, i.e. non-smart, as water supply based on pre-defined priorities.
- The main disadvantage is that water volume in the tank cannot be controlled (may be overflowed during abundant rainfall periods).

Rainwater Harvesting Scheme



Key questions in Smart RWH schemes?

- **Can we make the RWH system smarter by:**

    -allocating rainfall more intelligently?

    -maximising the RWH impact on attenuate flood?

- **What are the limits of water sources and uses to make RWH scheme as being smart system?**
- **What specifications are required to setup smart RWH scheme?**

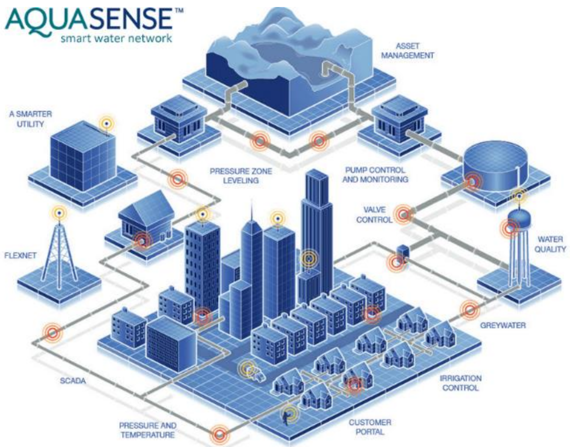
Traditional (non-smart) system

Transition to

Smart system

Aim/objectives

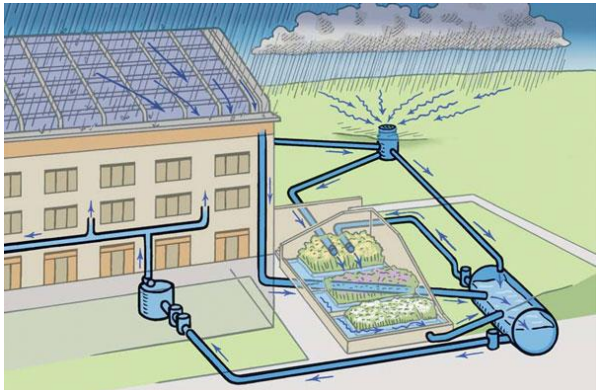
- Explore the potentials of a smart RWH in an integrated UWS for reducing urban flooding while supplying water for non-potable use.
- Identify the optimal operation/parameters of smart RWH to achieve the best performance in the integrated UWS
- Compare smart RWH with non-smart RWH schemes an the status quo (i.e. no RWH).



Transition ***towards smart cities***

Methodology

- **Smart RWH scheme operates based on sensors to measure rainfall depth/water volume in tank and actuators (i.e. valves/pumps) to proactively control volume/level in tank.**
- **Required water demands are assumed to be supplied from the RWH tank if water is available in tank otherwise mains water.**
- **Multi-objective optimisation model used to identify the best operation/parameters for the smart RWH scheme using NSGA-II**



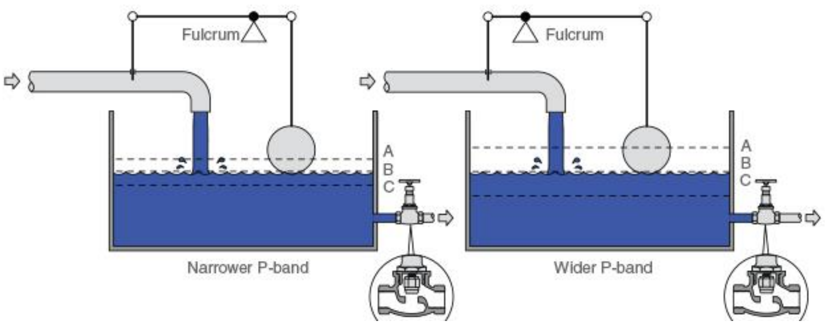
Source: http://www.smartwatertech.co.nz

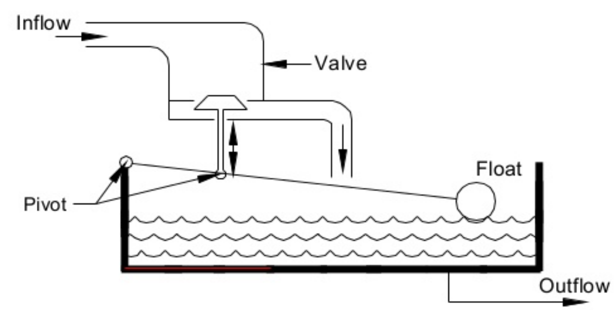
Methodology

- **Smart RWH actuators release specific water volume (R_t) as a function of water volume (V_t) and inflow into the tank (I_t):**
- $$R_t = a_i (V_t + I_t)^{b_i} \quad i = 1, \ldots, 12$$

***a* and *b* are two parameters with different values for each calendar month, which are optimised.**

- **Released water (R_t) allows tank to keep some space free and on standby for future rainfall and mitigate potential flooding.**





Multi-objective optimisation model

Objectives

1. minimise **total potable water** supplied from the mains (i.e. conventional distribution system)
2. minimise **total urban flooding** (i.e. total volume of stormwater which exceeds the capacity of a sewer system in a one-year simulation).

Total number of decision variables is equal to 24 coefficients (a_i,b_i) for 12 months

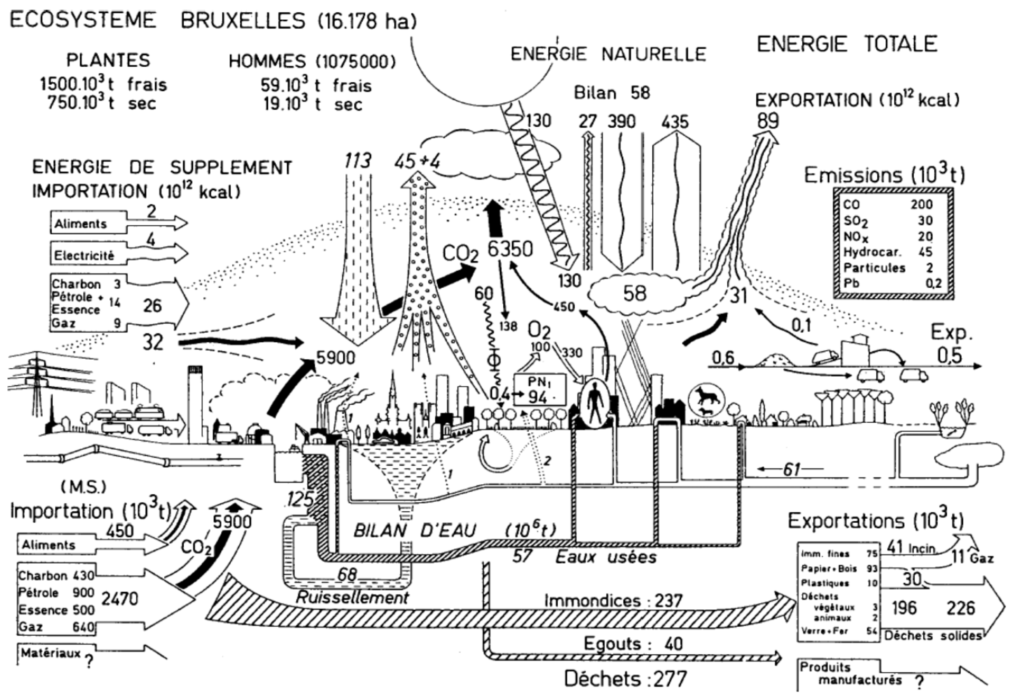
a_1	b_1	a_2	b_2	…	a_{11}	b_{11}	a_{12}	b_{12}
Month#1		Month#2			Month#11		Month#12	

Structure of genes (decision variables) for each chromosome (solution)

Methodology

- The objective functions of the optimisation model are calculated based on the performance assessment of these schemes in an integrated UWS, which is undertaken by using the WaterMet^2 model:

Urban Metabolism Concept



Source: Duvigneaud and Denaeyer-De Smet, 1977

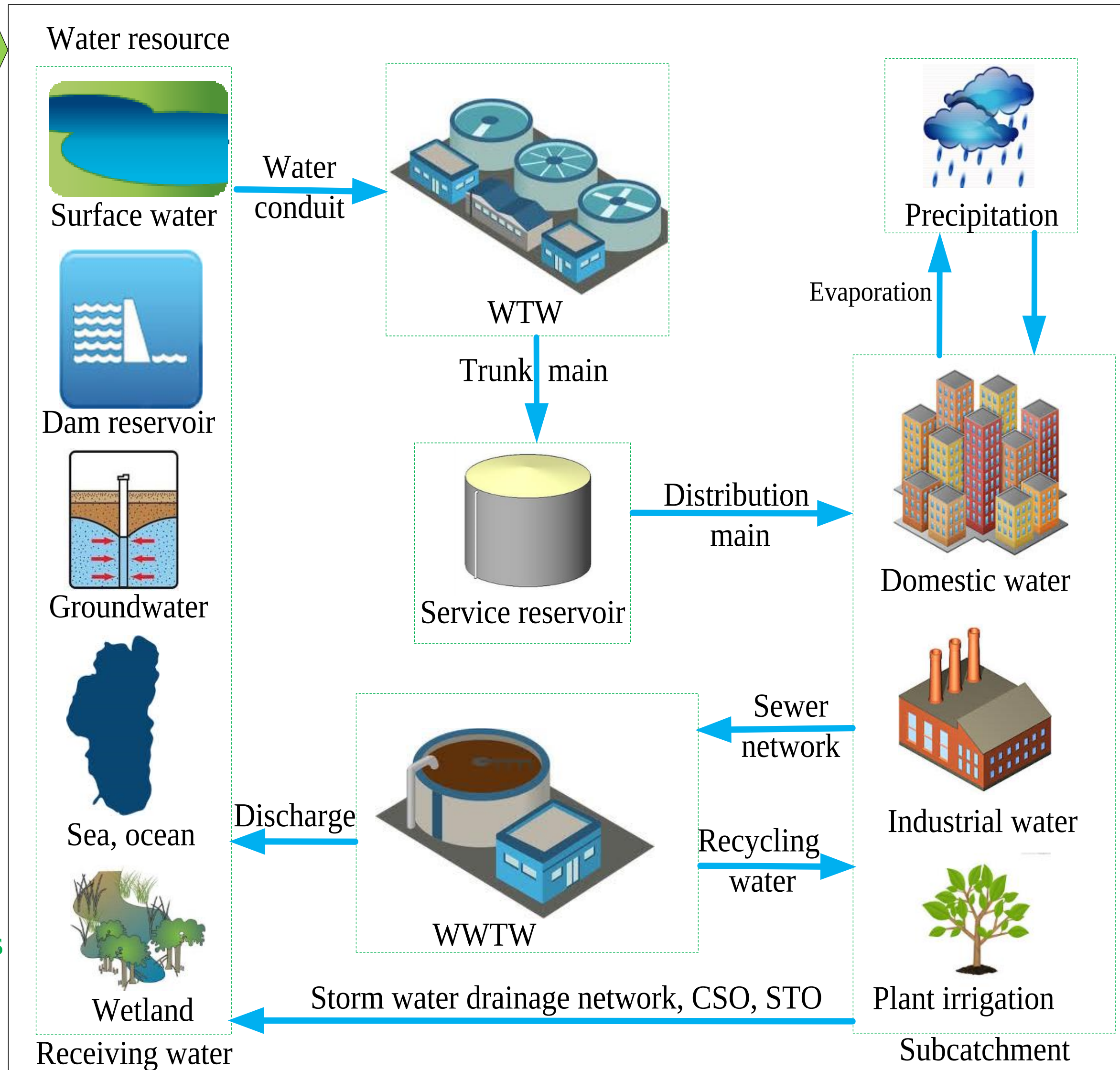
Methodology (Urban System)

Model input:

- Weather data time series
- Inflow time series to water resources
- Database of pipeline characteristics

- Characteristics of Components Including:
- Transport/Storage capacity
- Consumption per unit volume of water for:
- Energy sources
- Chemicals
- Resource recovery
- Operational cost

- Water demand per capita/ Daily water demand
- Demographic information
- Hydrologic characteristics
- Number of properties



Model output:

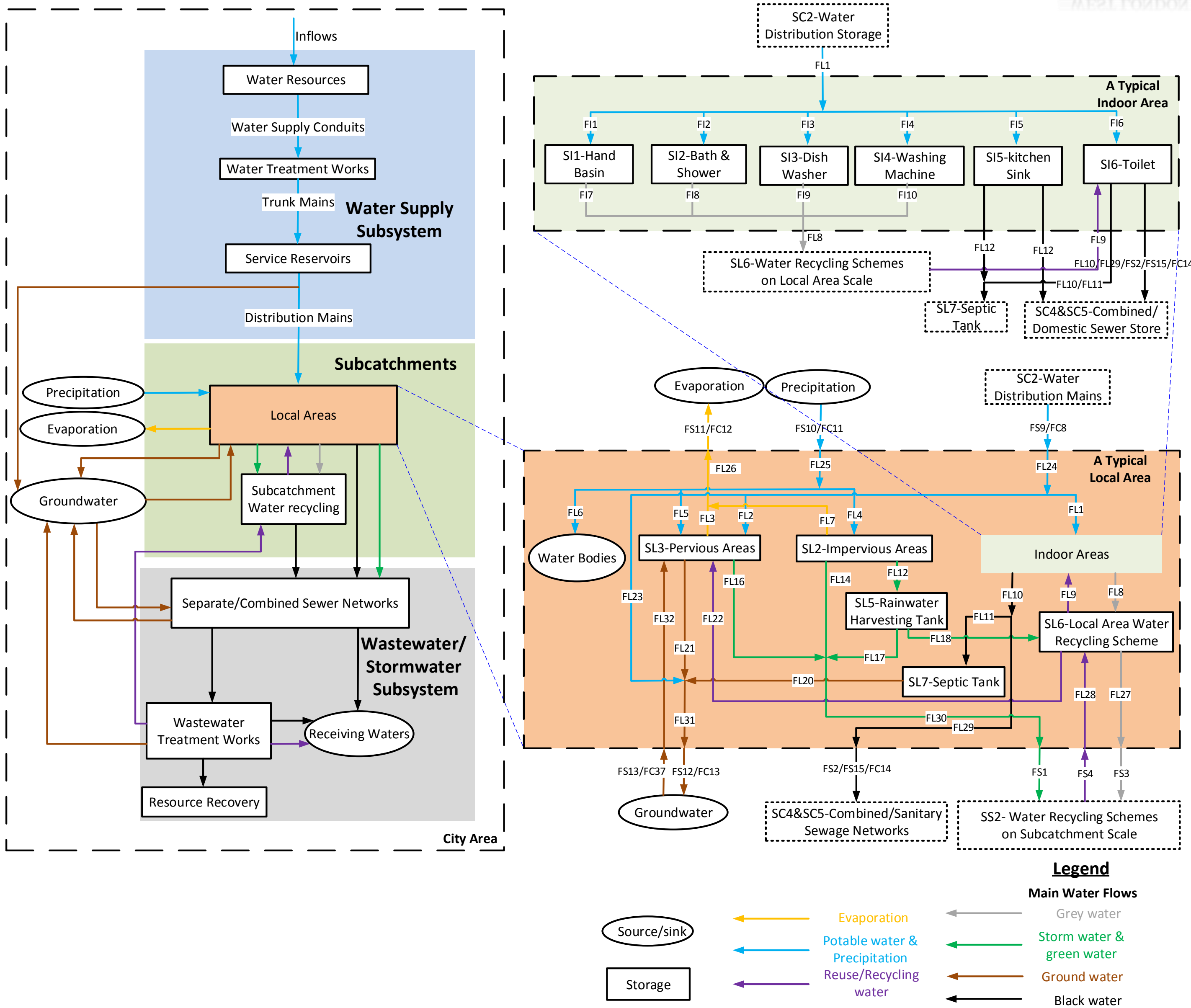
- Water flow
- Energy flow
- GHG flow
- Acidification flow
- Eutrophication flow
- Material flux
- Chemical flux
- Pollutant flux
- Cost flux

WaterMet^2 Conceptual Model

Water/Energy balance+ Technologies

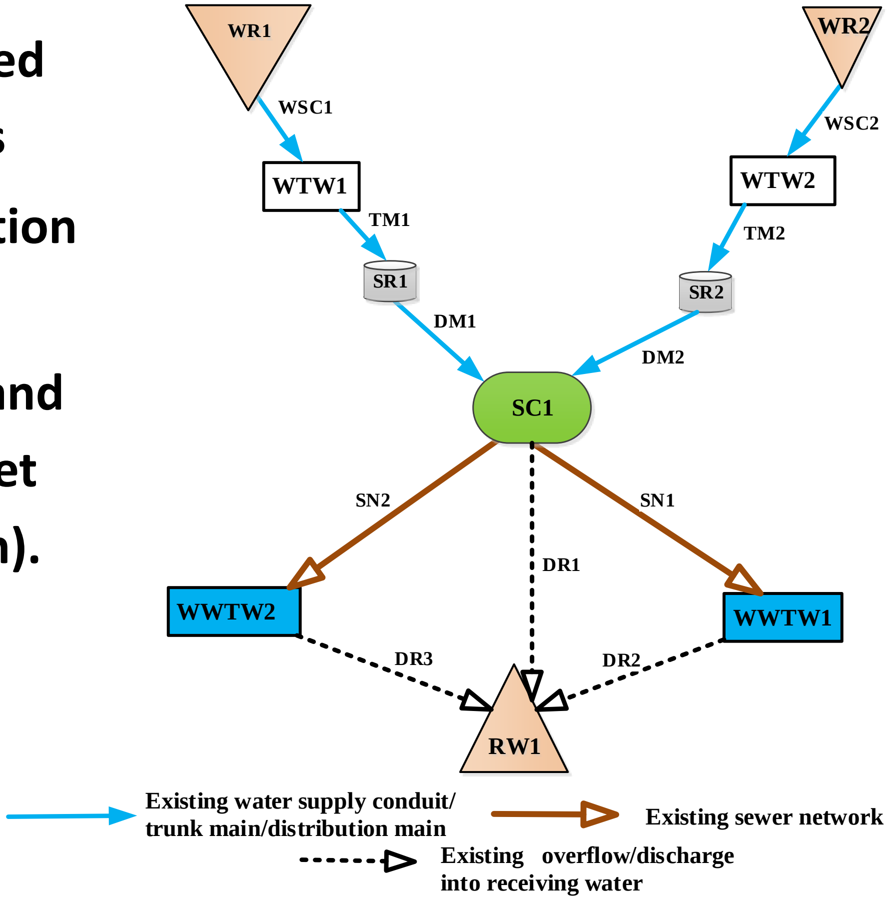
Quantitative metabolism

Performance impacts



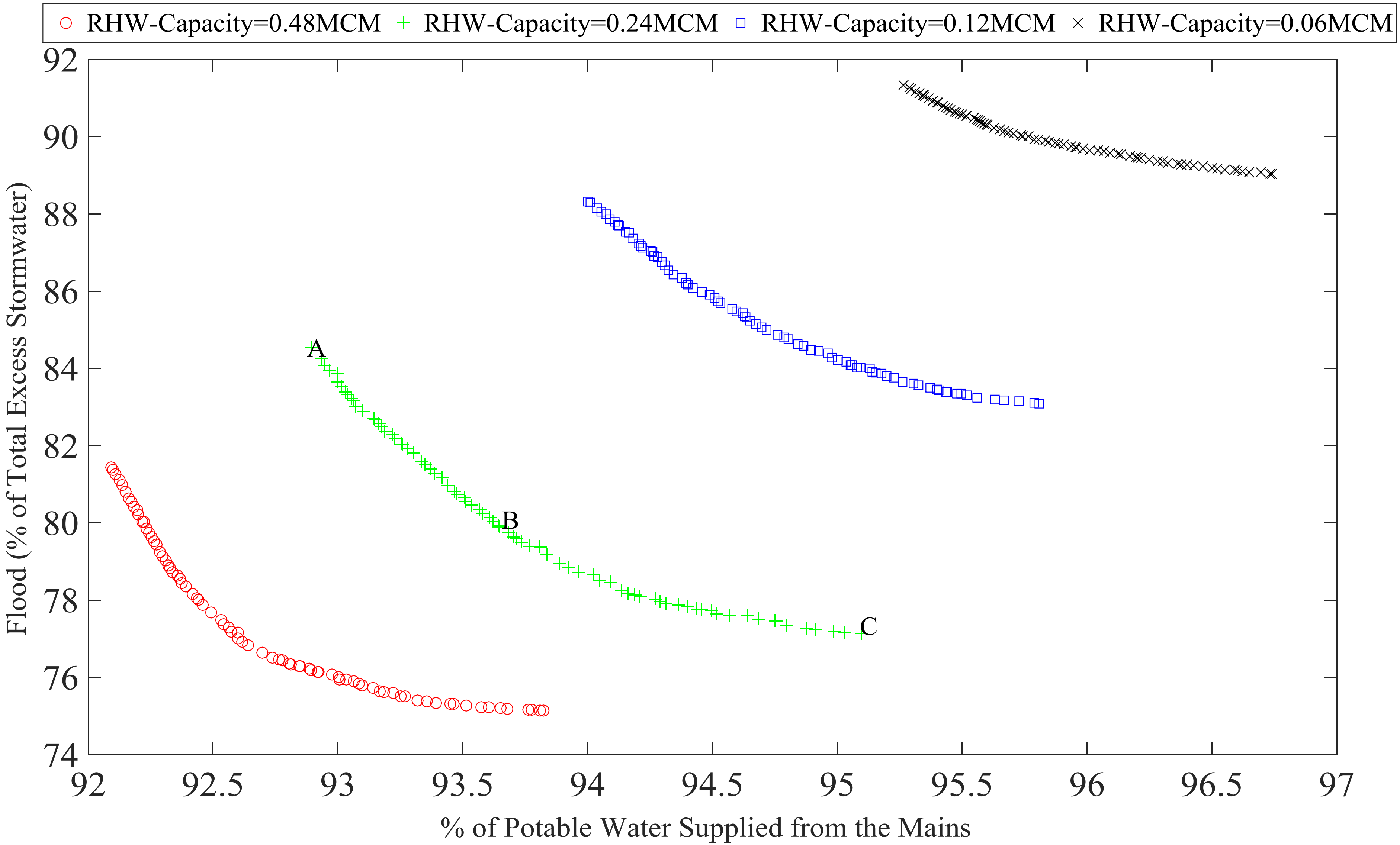
Oslo Case Study Model

- Single subcatchment with **two** associated **local areas** with/without RWH schemes
- Simulation: **daily time step** with a duration of one year time horizon
- RWH **collects** runoff from roofs, roads and pavements and to **supply** water for toilet flushing and garden watering (irrigation).
- **320,000** household properties.
- Household RWH tank capacity: **3 m^3**

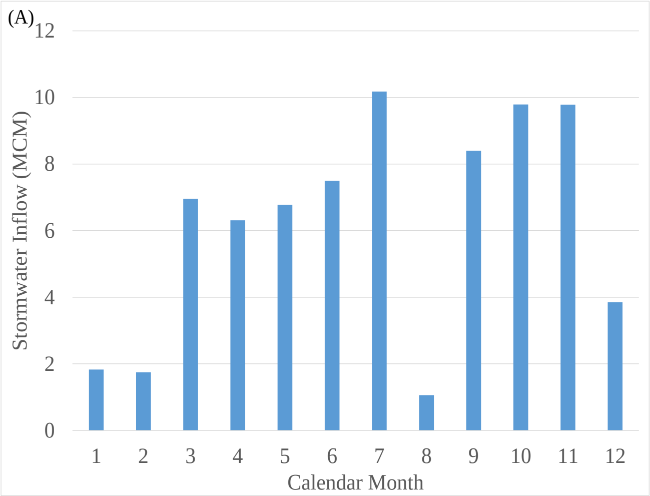


- **Four tank capacities** in proportion to the full tank capacity are analysed:
- 1) **12.5%** of full capacity, 0.06 MCM; 2) **25%** of full capacity, 0.12 MCM;
- 3) **50%** of full capacity, 0.24 MCM; 4) full capacity, (100%) 0.48 MCM.

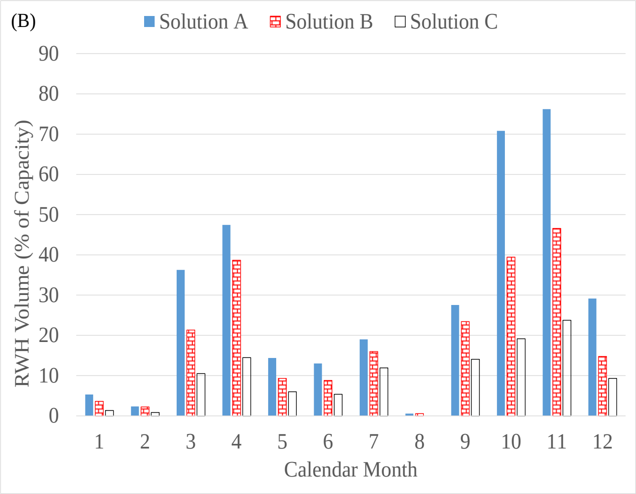
Pareto optimal solutions for different sizes of RWH tank



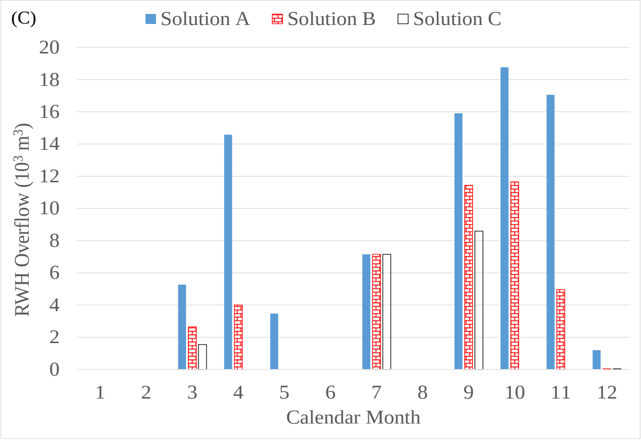
Monthly aggregated results of three solutions of smart schemes



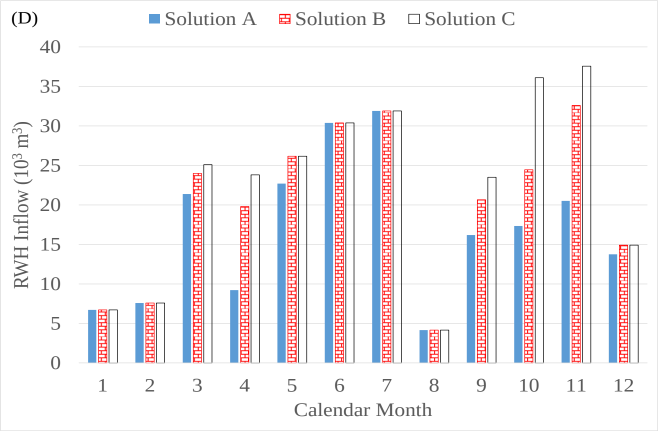
stormwater inflow



average RWH volume

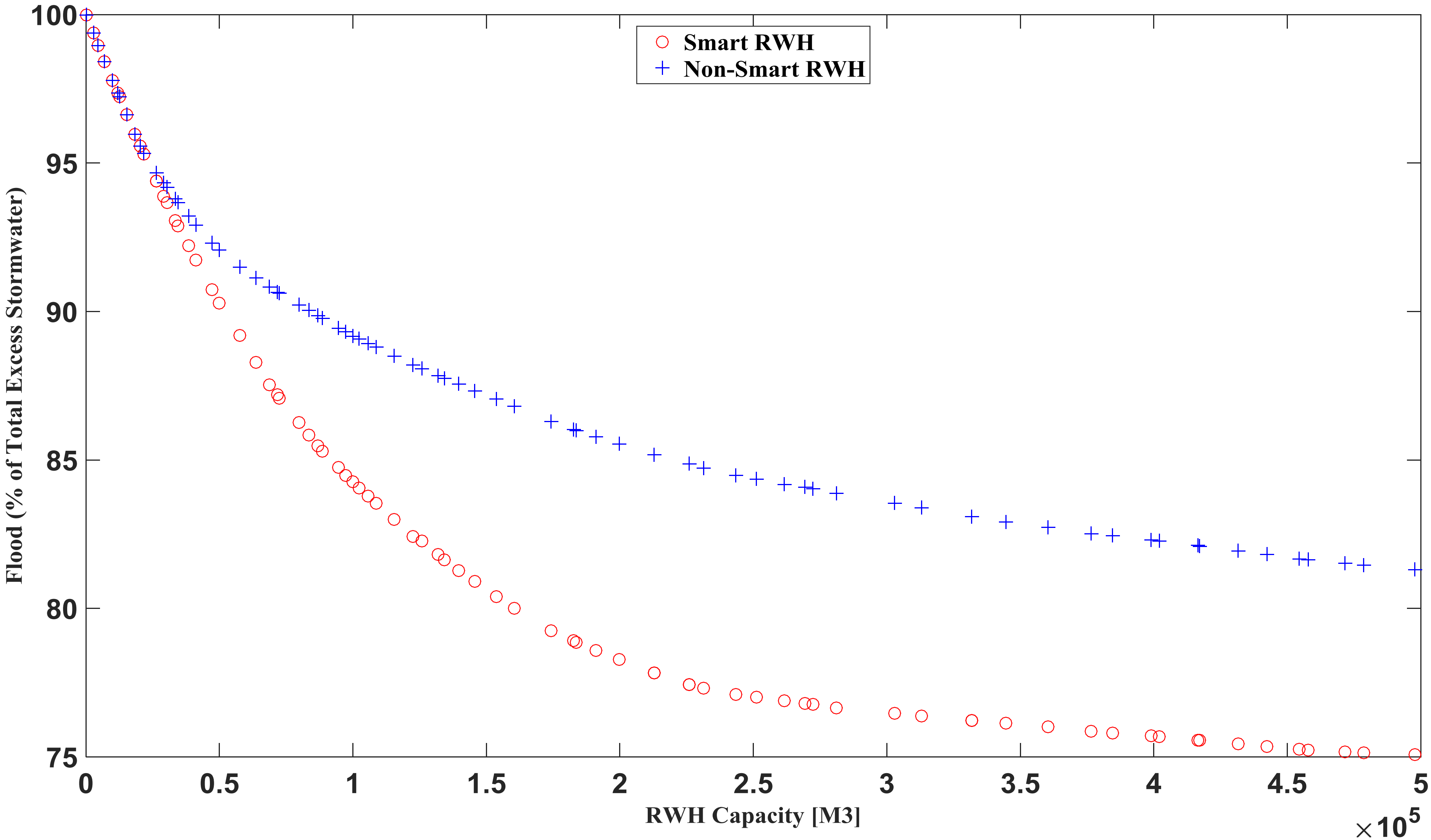


average RWH overflow

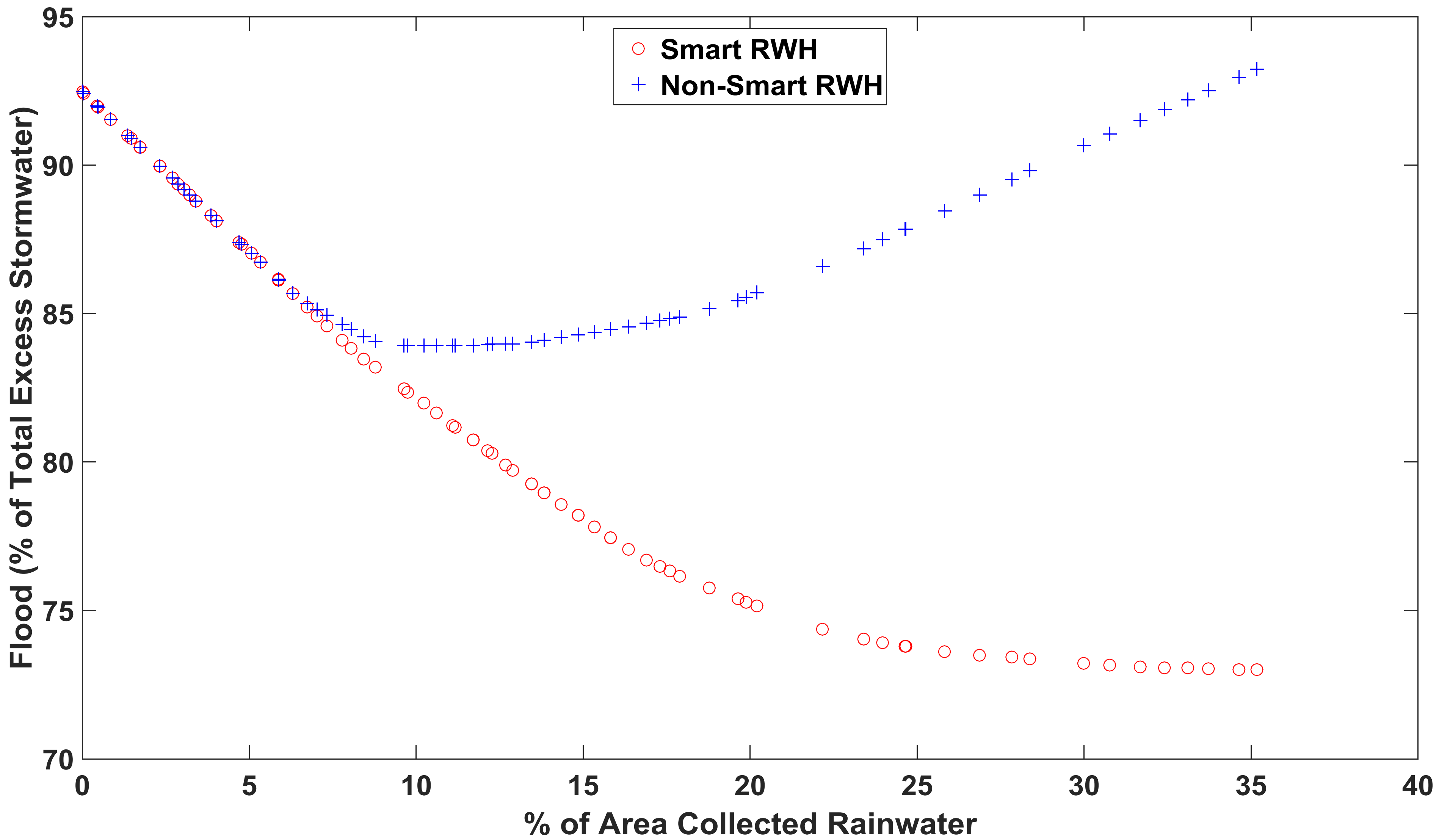


average RWH inflow

Smart or Not Smart RWH?
Pareto Front for Impact of different RWH size

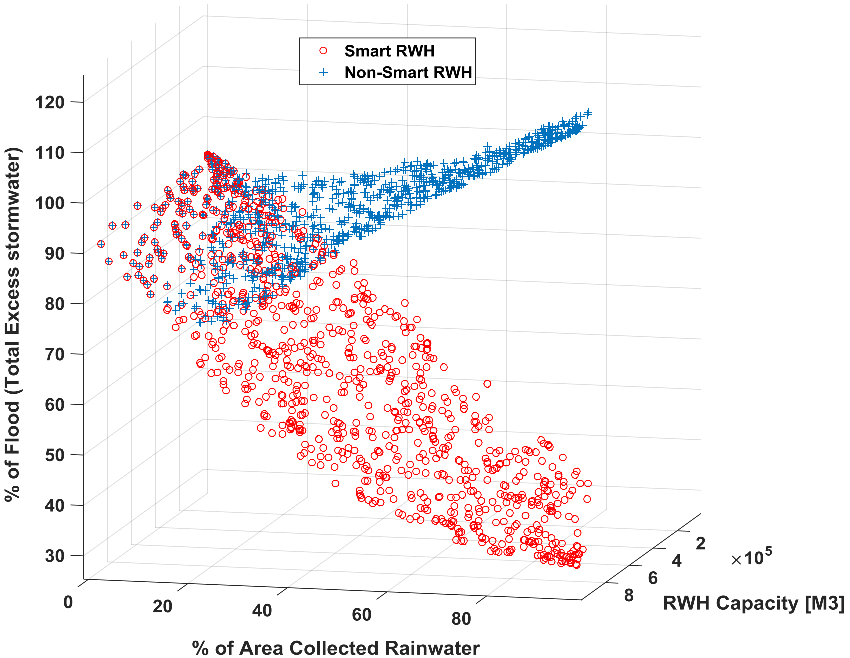


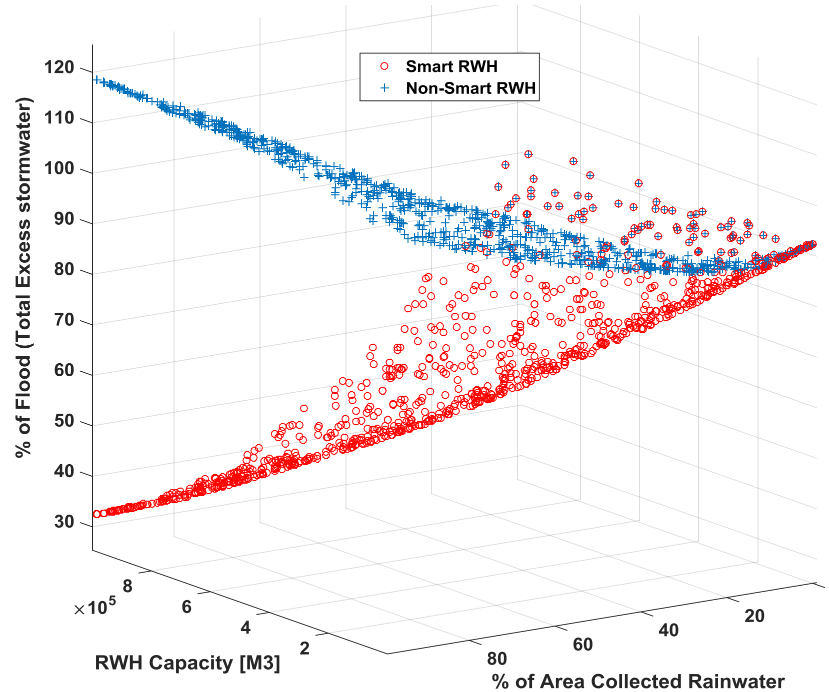
Smart or Not Smart RWH?
Pareto Front for Impact of Area collected rainwater

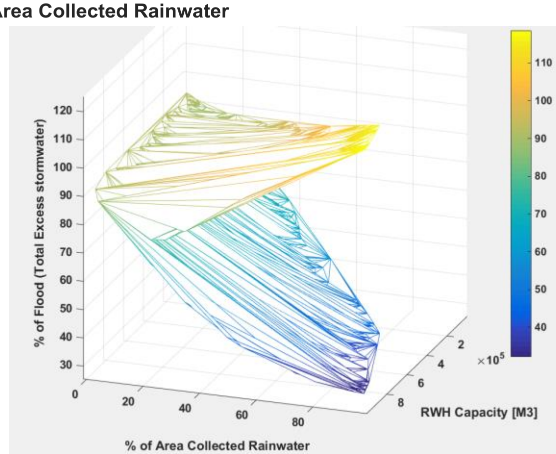


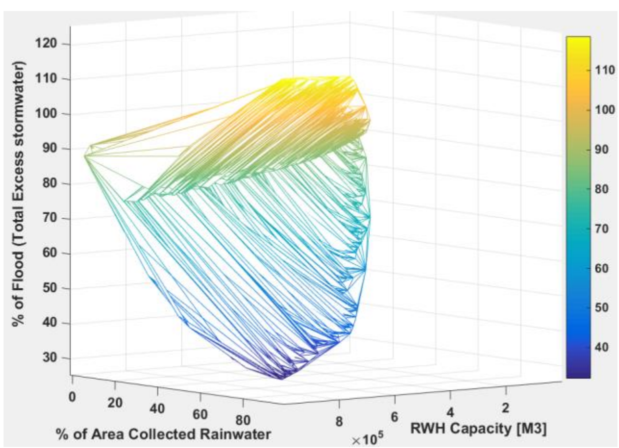
Smart or Not Smart RWH?

Pareto Front for Impact of Area collected rainwater









Conclusions

- New concept of smart RWH schemes was presented for real-time control & improvement of integrated UWS performance.
- Multi-objective operation identified tank configurations and control storage volume based on water demand and inflow.
- Considerable impact can be obtained on the flood peak attenuation and reliable water supply from the mains.
- The best performance of smart RWH depends on selecting proper RWH configuration otherwise no difference may occur between smart & non-smart RWH.
- Smart irrigation system and rainfall prediction models can be coupled with smart RWH for a better water demand allocation.
- Machine learning (e.g. ANN) can further improve smartness process

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Thanks for your attention!

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