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Resilience of Integrated Urban Water Systems

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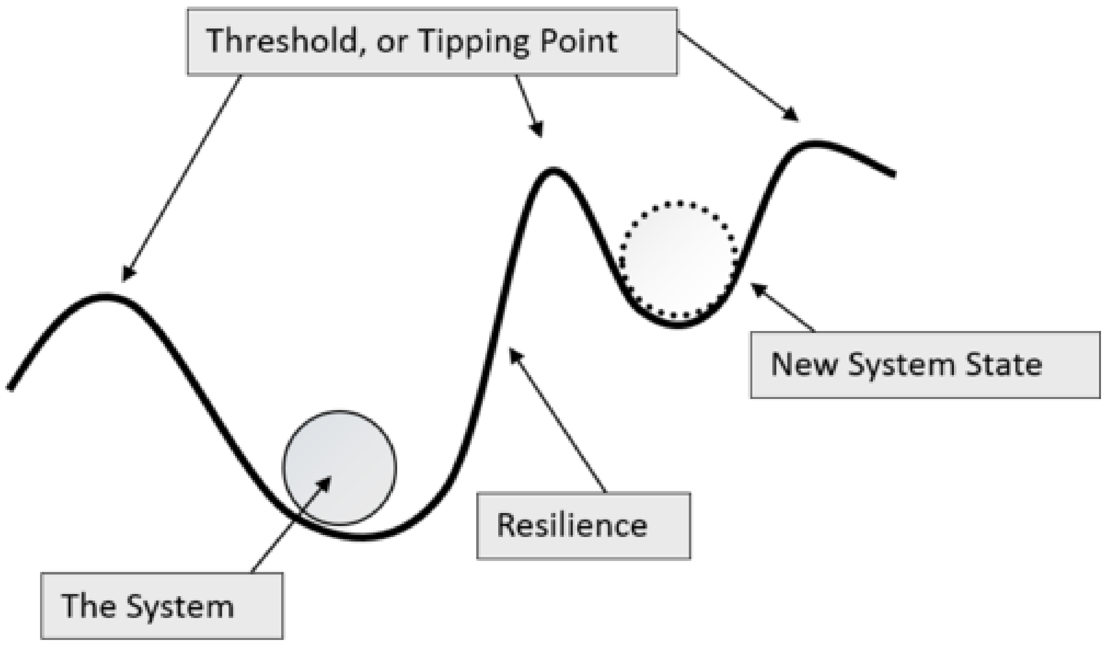
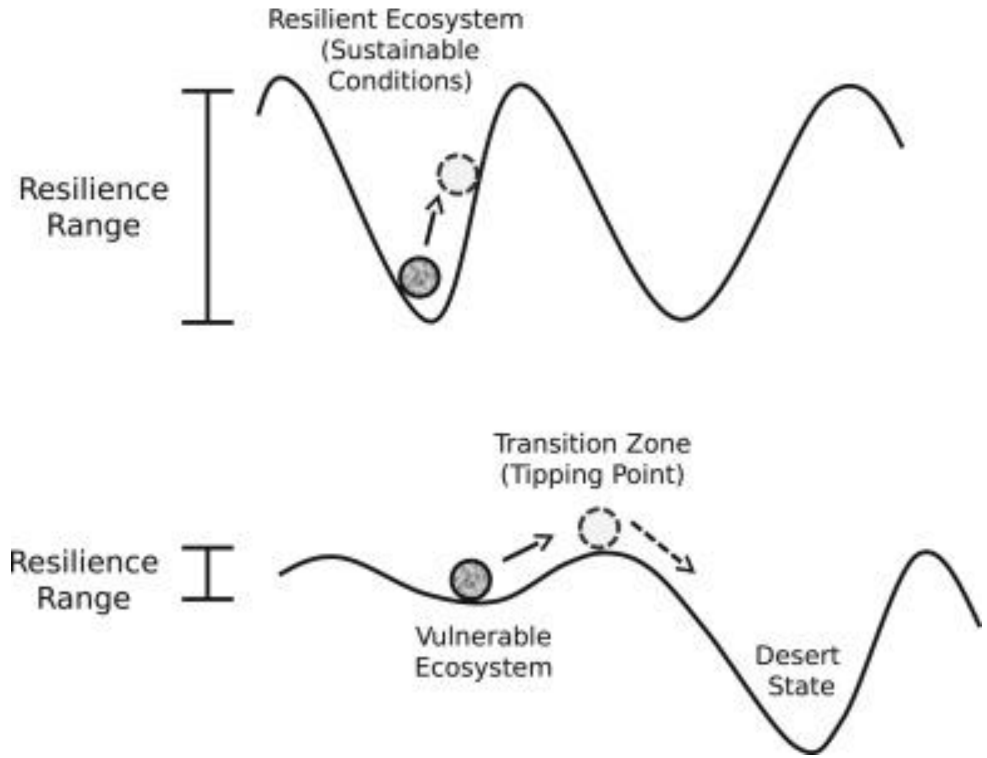
System Resistance vs System Resilience

Two complementary concepts when designing/retrofitting system

- System resistance is the ability to prevent system from structural or functional failures.
- System resilience is the ability to withstand (i.e. absorb and bounce back from) shocks and pressures, whether economic, climatic or demographic in nature.





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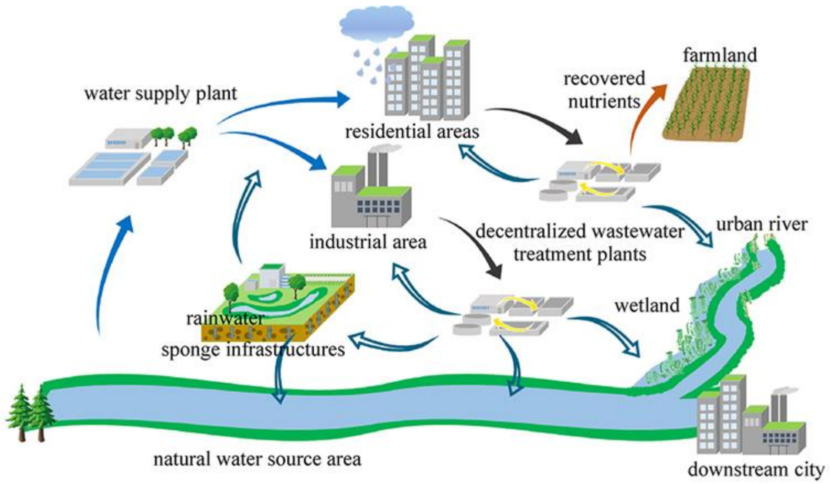
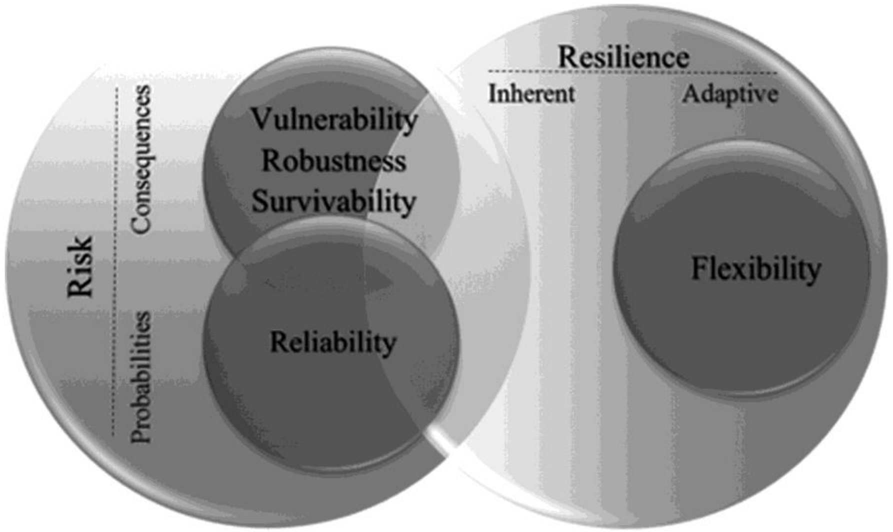
Resilience as a KPI of Sustainability criteria in water system

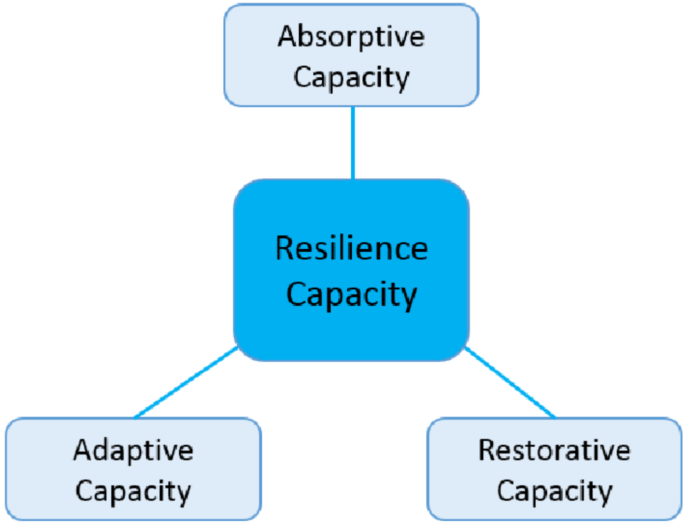
Resilience definition

- how quickly a system can be recovered from a failure/unsatisfactory to normal/satisfactory state (Hashimoto et al. 1982)
- resilience is to minimise the level of service failure magnitude and duration (Butler et al. 2017)

➢ Due to different interpretations of resilience, it should be defined as a multi-component indicator in water systems for both water supply and wastewater/stormwater systems





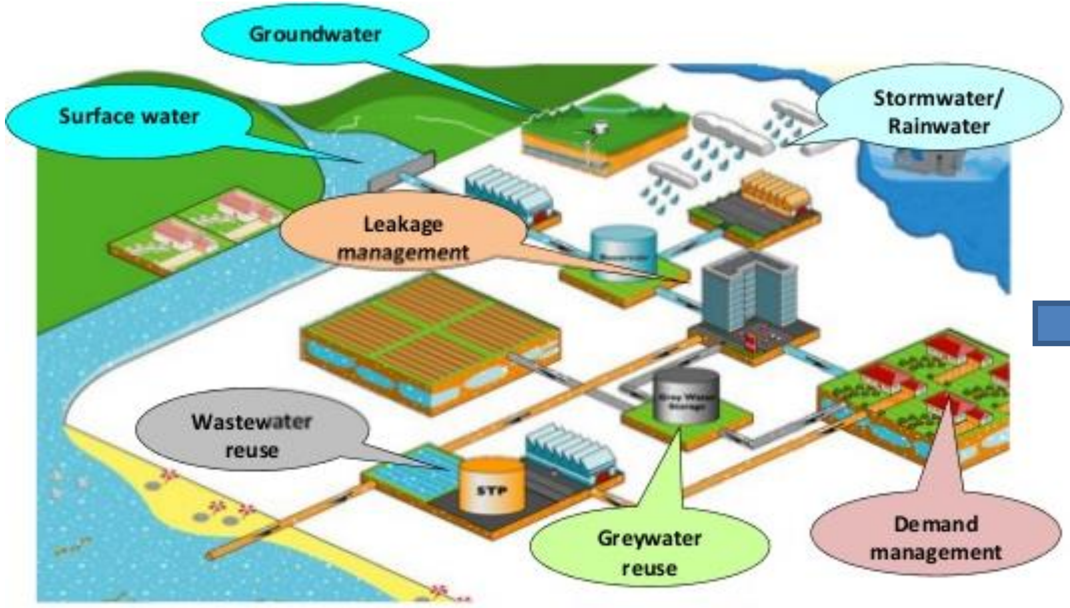


Methodology

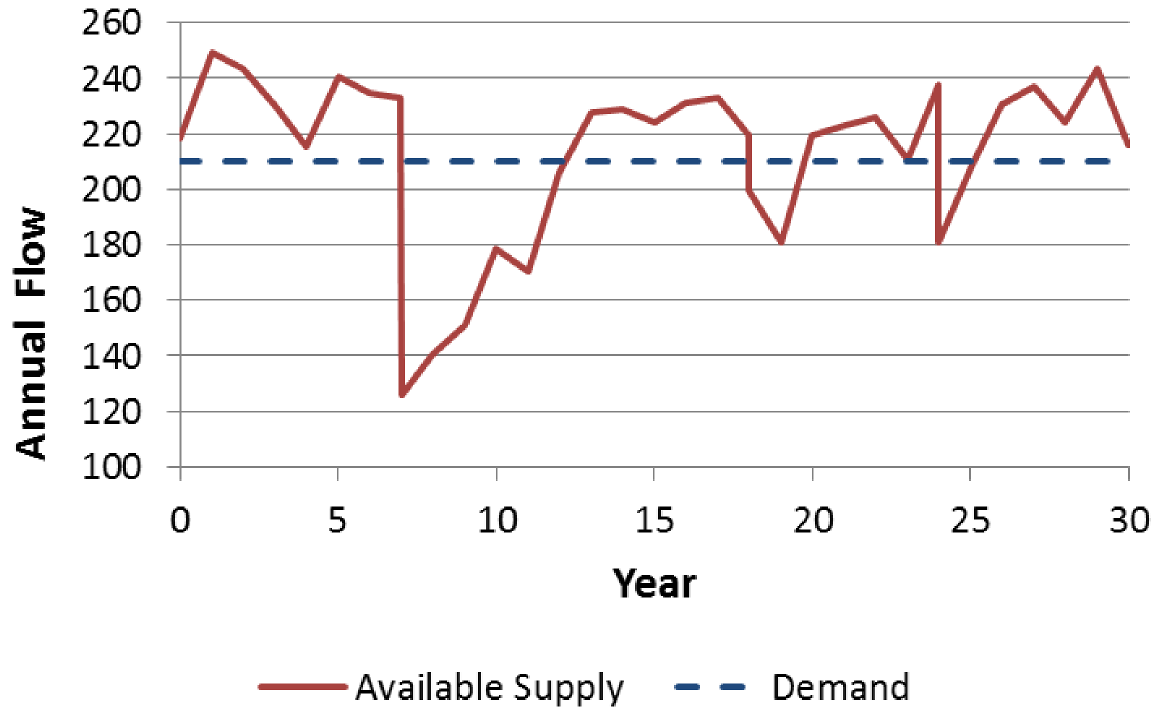
- **Aim: developing new multi-component resilience indicators for Integrated UWS to evaluate intervention strategies for both water shortage and flood resilience**

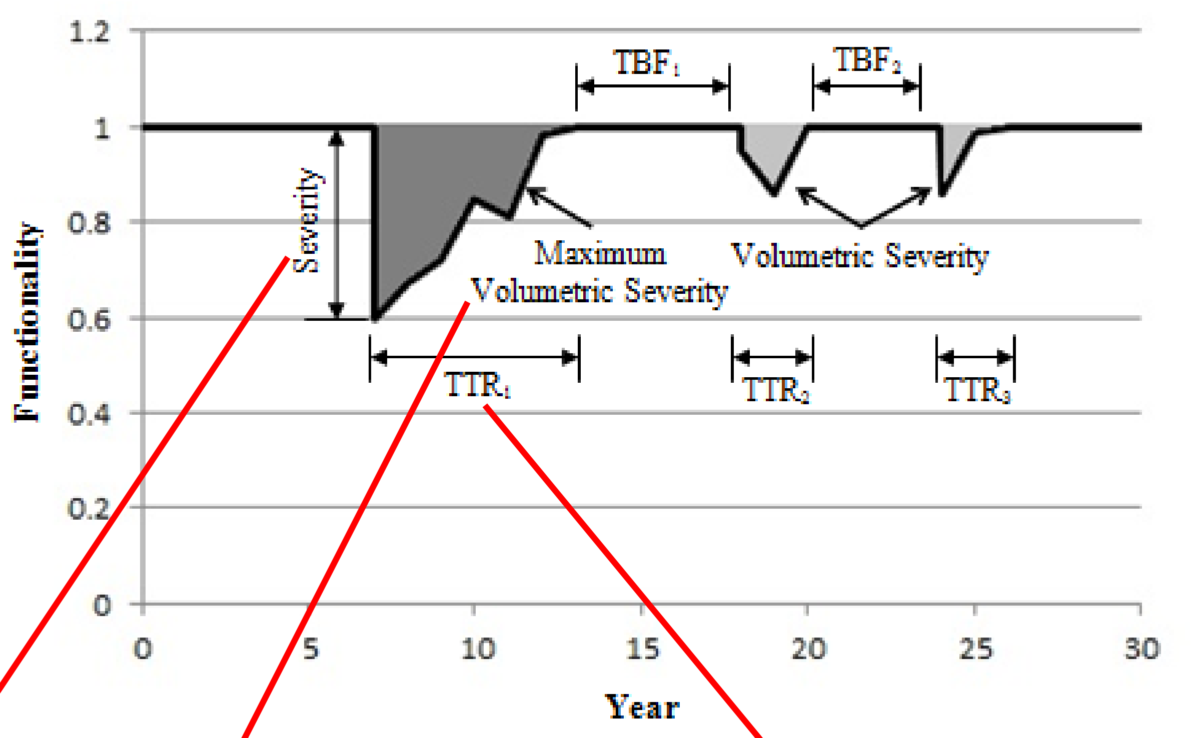
- **Resilience indicators are estimated by using a conceptual urban water metabolism model.**

- **Intervention strategies are water recycling schemes (i.e. RWH and GWR) that have concurrent impact on all water supply, stormwater and wastewater subsystems.**



Multi-component resilience indicators in water system





Max Severity= $Max\left(\frac{D_i - S_i}{D_i}\right) \times 100$

Max volumetric severity= $Max\left(\frac{\sum(D_i - S_i)}{\sum D_i}\right) \times 100$

Min recovery rate= $\frac{1}{Max\ T_F}$

T_F :the length of time during which water demand is not fully delivered

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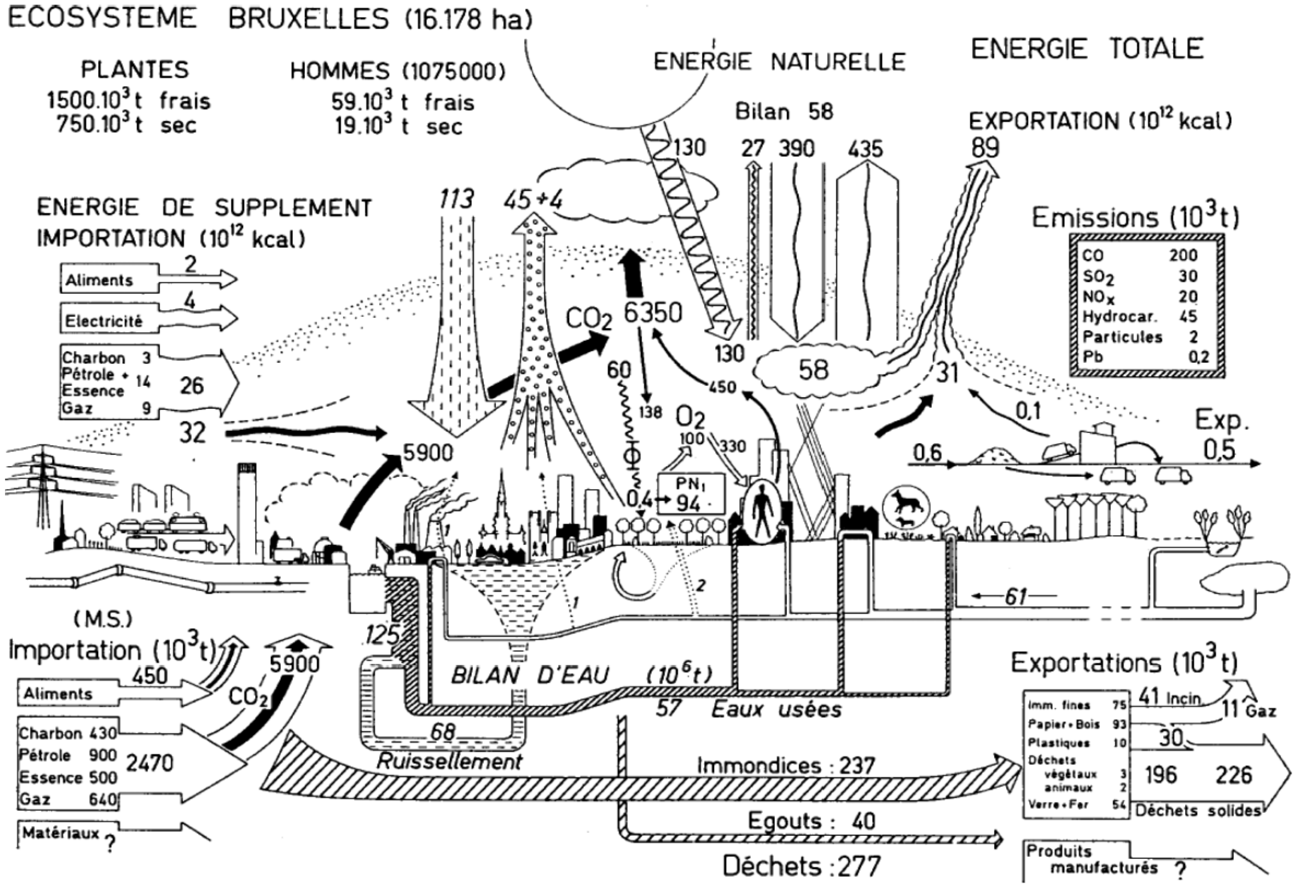
Multi-component resilience indicators in UWS

No	Name	Water supply system	Sewer system
1	**Min recovery rate**	$\frac{1}{Max\ T_F}$ Max T_F = the longest failure duration i.e. time period that water demand is not fully delivered	$\frac{1}{Max\ T_F}$ Max T_F = the longest failure duration i.e. time period that runoff exceeds sewer capacity
2	**Average recovery rate**	$\frac{1}{Ave(T_F)}$ Ave (T_F)= average failure duration over the planning horizon	$\frac{1}{Ave(T_F)}$ Ave (T_F)= average failure duration over the planning horizon
3	**Max Severity**	$Max\left(\frac{D_i - S_i}{D_i}\right) \times 100$ S_i = water supply and D_i = water demand at time step i	$Max\left(\frac{R_i - C_i}{C_i}\right) \times 100$ R_i=runoff generated and C_i= conveyance capacity at time step i
4	**Average severity**	$Ave\left(\frac{D_i - S_i}{D_i}\right) \times 100$ Average water deficit over the planning horizon is calculated.	$Ave\left(\frac{R_i - C_i}{C_i}\right) \times 100$ Average excess runoff over the planning horizon is calculated.
5	**Max volumetric severity**	$Max\left(\frac{\sum(D_i - S_i)}{\sum D_i}\right) \times 100$ The largest consecutive water deficit is calculated.	$Max\left(\frac{\sum(R_i - C_i)}{\sum C_i}\right) \times 100$ The largest consecutive excess runoff is calculated.
6	**Average volumetric severity**	$Ave\left(\frac{\sum(D_i - S_i)}{\sum D_i}\right) \times 100$ Average consecutive water deficit over the planning horizon is calculated.	$Ave\left(\frac{\sum(R_i - C_i)}{\sum C_i}\right) \times 100$ Average consecutive excess runoff over the planning horizon is calculated.

Urban Metabolism Concept

- **Long-term Performance of integrated Urban Water System (UWS) is assessed by Urban Water Metabolism concept**
- **BAU and any intervention strategies are evaluated by using the WaterMet^2 model**



Source: Duvigneaud and Denaeyer-De Smet, 1977

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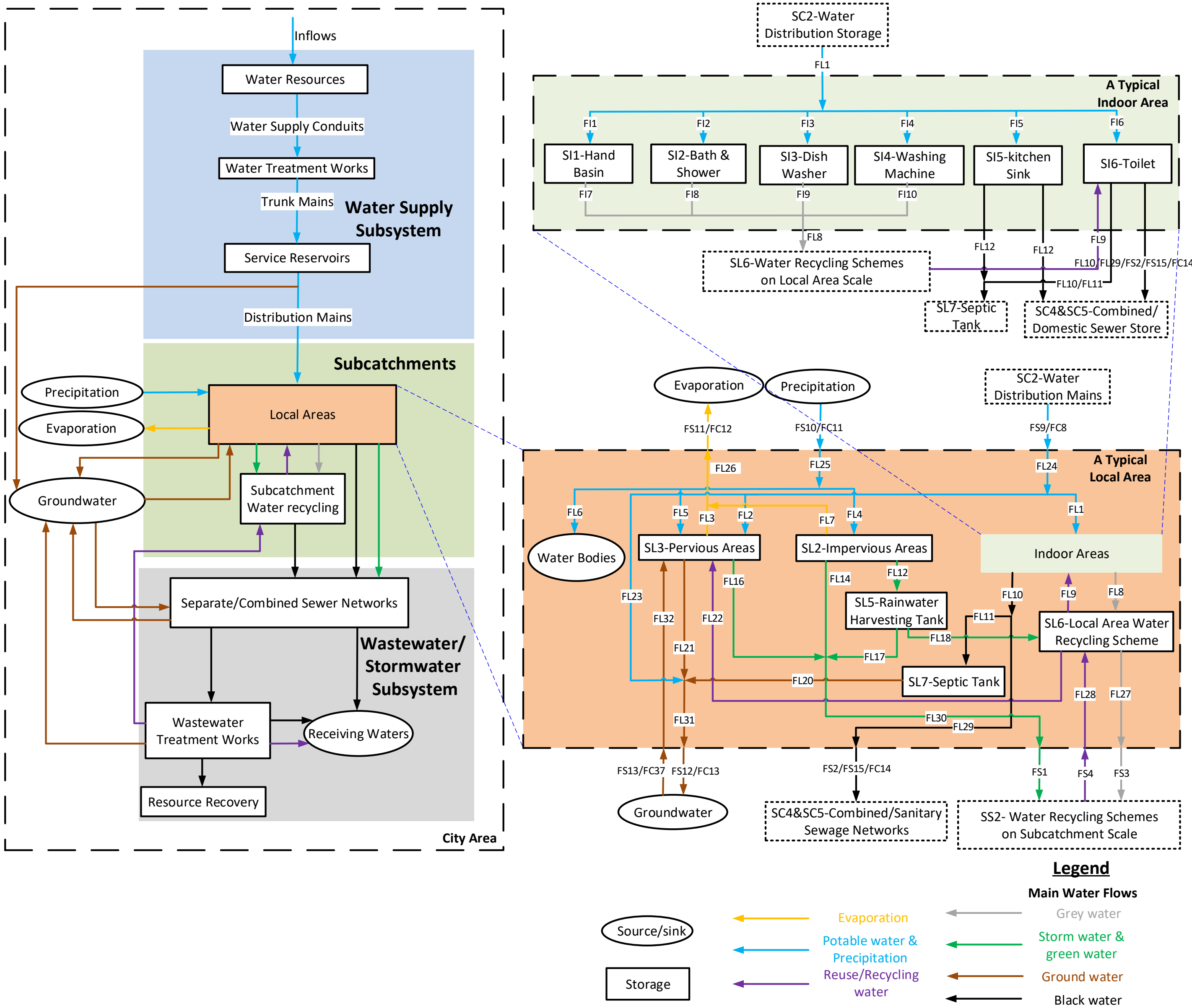
WaterMet² Conceptual Model

Intervetion Technologies

Quantitative metabolism

Resilient Performance & other performance indicators



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WaterMet^2 model Interfac

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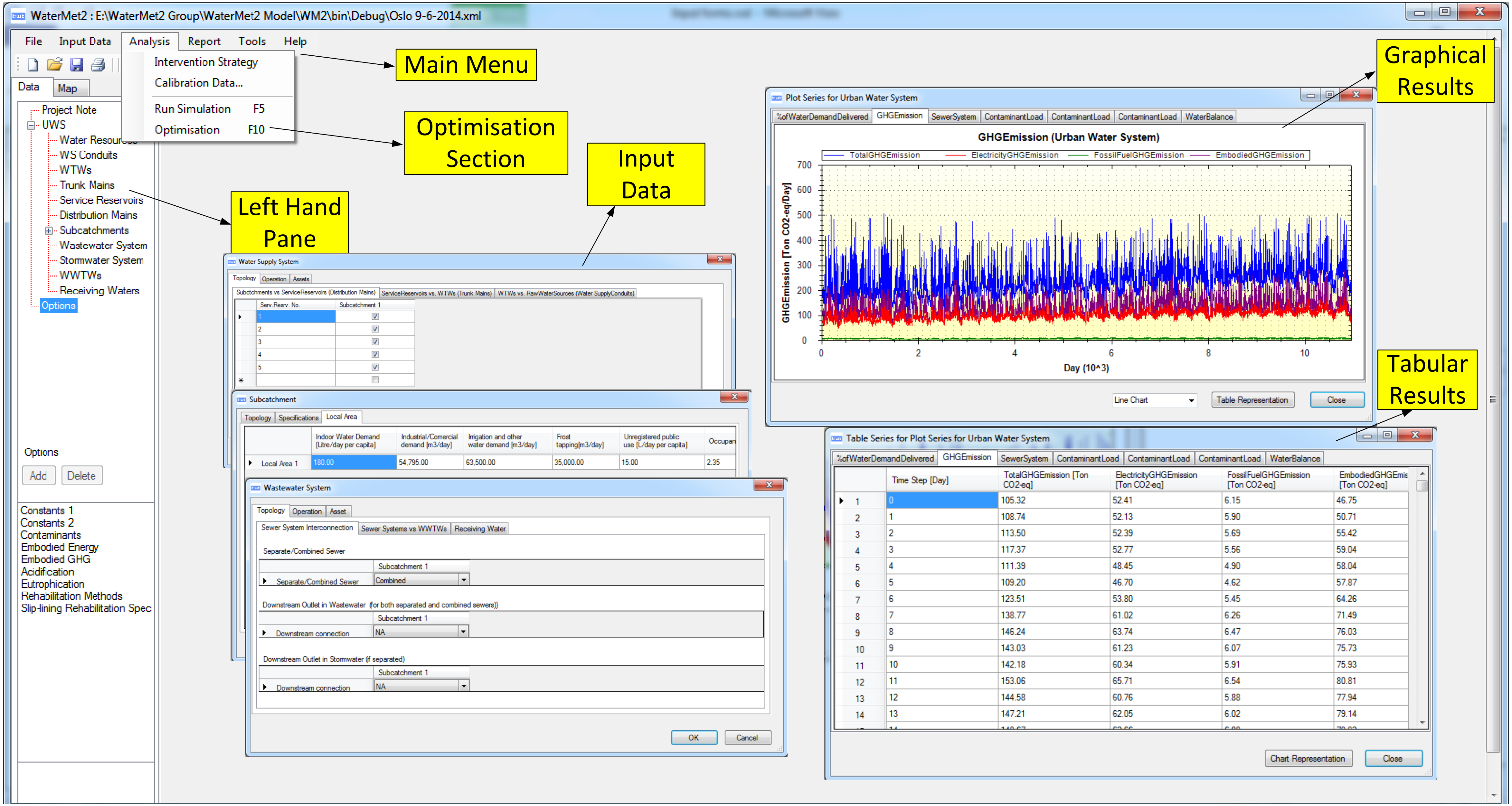
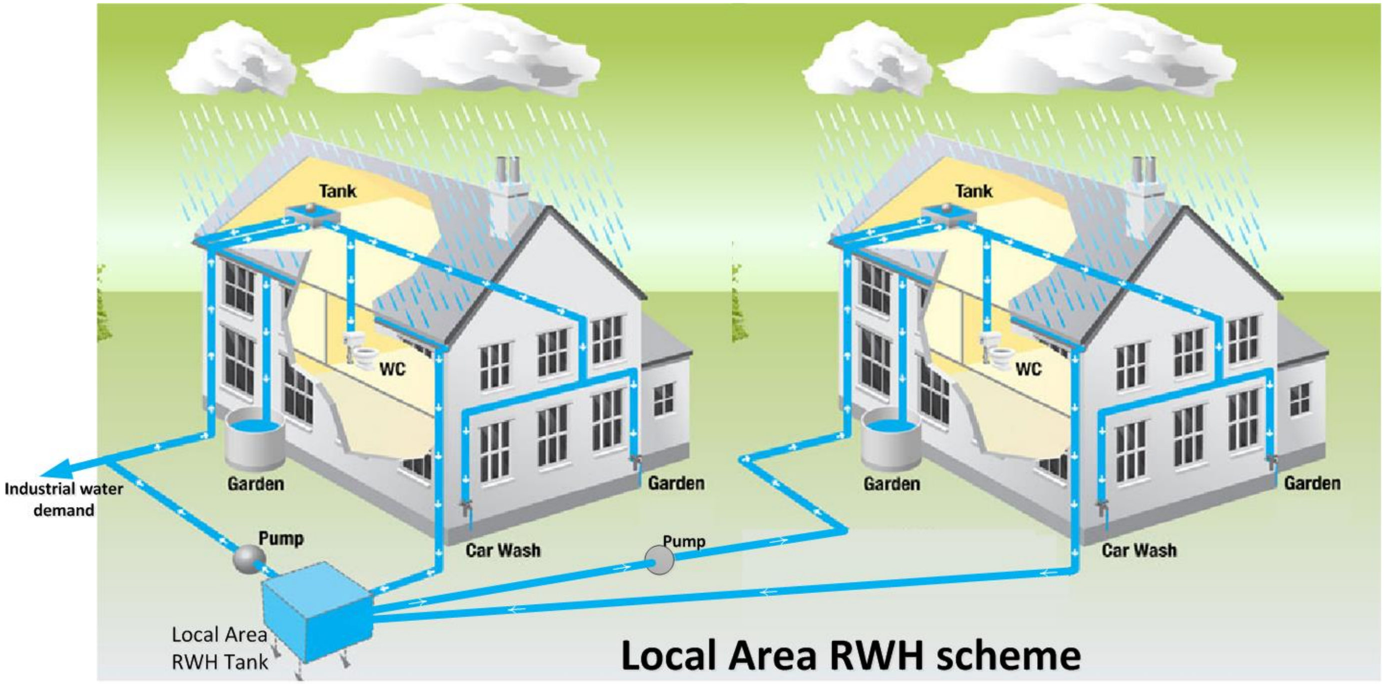
TRANSITIONS TO THE URBAN WATER SERVICES OF TOMORROW



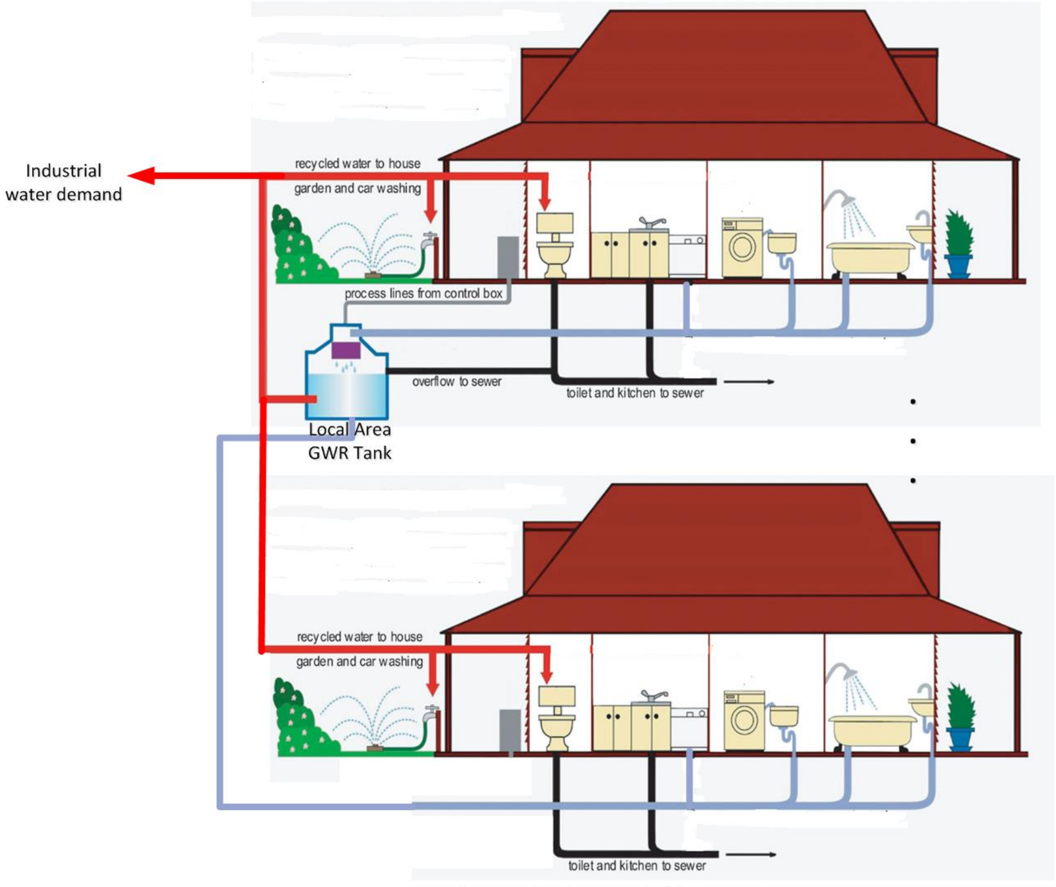
Water recycling schemes

- Two water reuse schemes are analysed:

1. rainwater harvesting (RWH)
2. grey water recycling (GWR)



Local Area RWH scheme

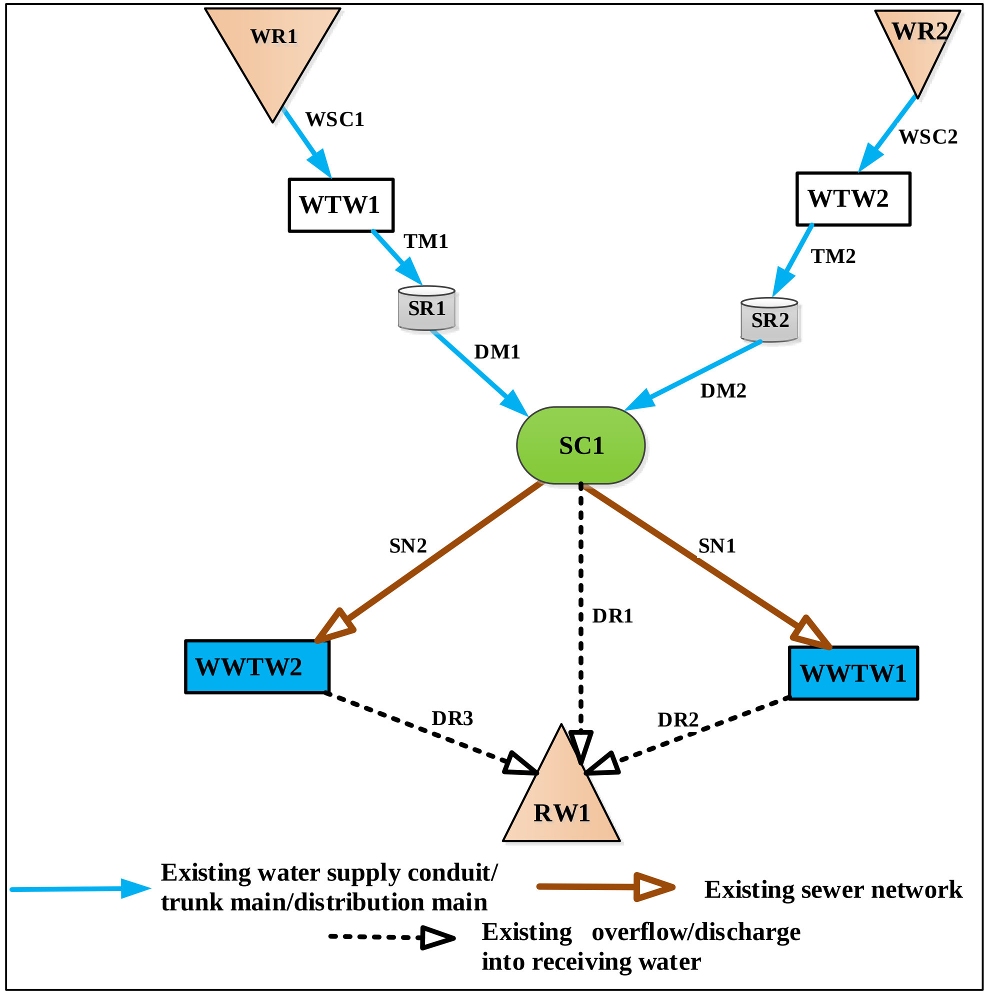


Local Area GWR scheme

- Performance of two individual intervention strategies including RWH and GWR schemes with different capacities are compared with business as usual (BAU) state

Case study (Oslo, Norway)

- Single subcatchment with two associated local areas with/without water recycling scheme
- Simulation: daily time step with a duration of 30 years planning horizon
- 320,000 household properties.
- Household RWH full tank capacity: 3 m^3
- Annual average rainfall depth: 803 mm
- Indoor water demand: 180 L/day/capita
- Total area of surfaces: 8,450 ha
- Proportion of roof, pavement and roads surface areas: 16%



Assumptions for RWH and GWR schemes

- **Single representative RWH/GWR tank with 50% of household adoption rate in four capacities.**
- **RWH collects runoff from roofs, roads and pavements and to supply water for toilet flushing and garden watering (irrigation) and industrial usages.**
- **GWR collects greywater from hand basin, dishwasher, shower, washing machine and treated greywater is used for toilet flushing, garden watering and industrial uses.**

Percentage of conventional design capacity	RWH	GWR
10% of full capacity	0.048 MCM	9,750 m^3
25% of full capacity	0.12 MCM	19,500 m^3
50% of full capacity	0.24 MCM	39,000 m^3
100% of full capacity	0.48 MCM	78,000 m^3

Results: Recovery rate resilience indicators

Strategies:

1- BAU

2-RWH(0.048MCM)

3-RWH(0.12MCM)

4-RWH(0.24MCM)

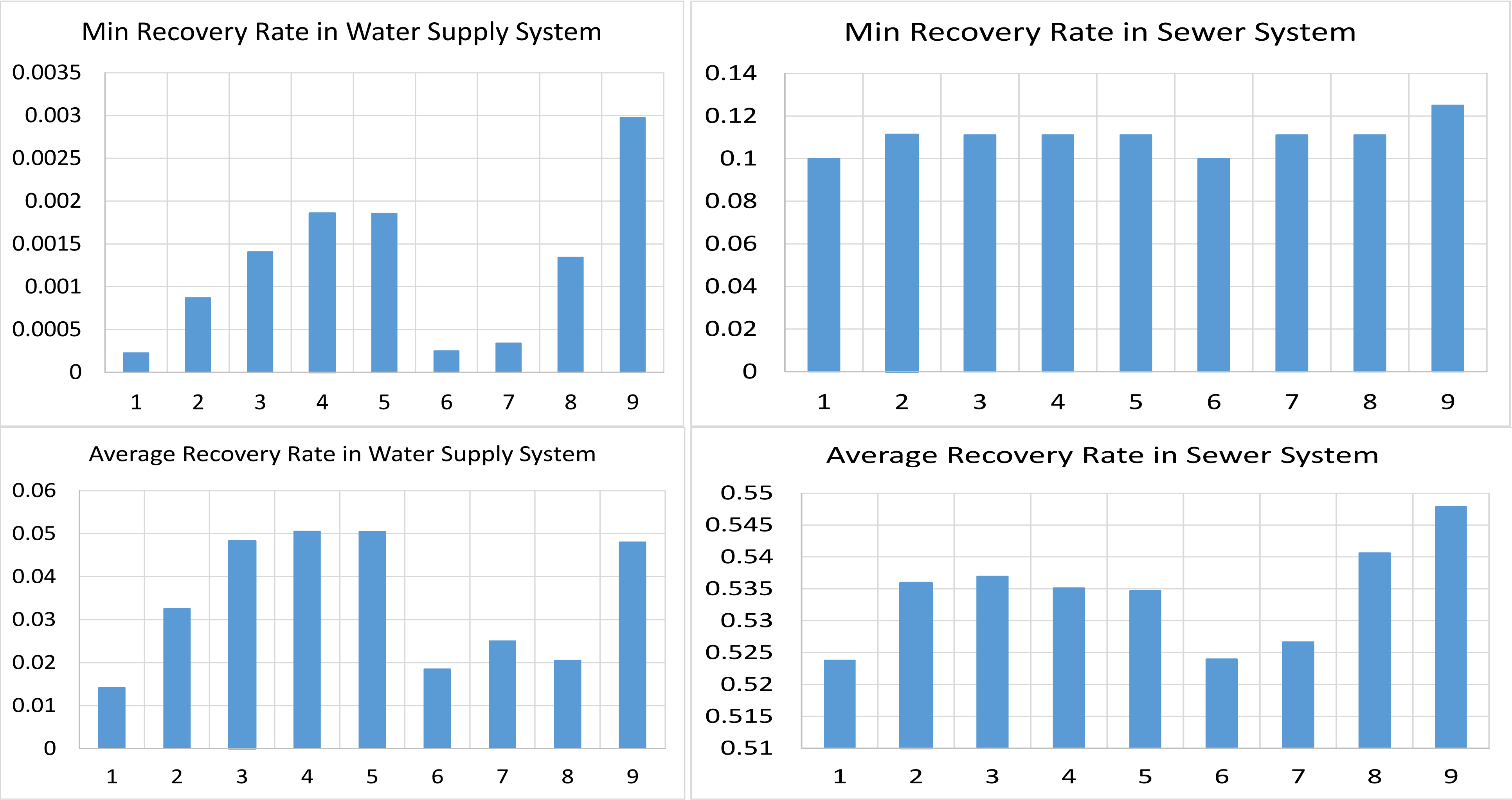
5-RWH(0.48MCM)

6-GWR(0.00975MCM)

7-GWR(0.0195MCM)

8-GWR(0.039MCM)

9-GWR(0.078MCM)



Results: Severity-related resilience indicators (%)

Strategies:

1- BAU

2-RWH(0.048MCM)

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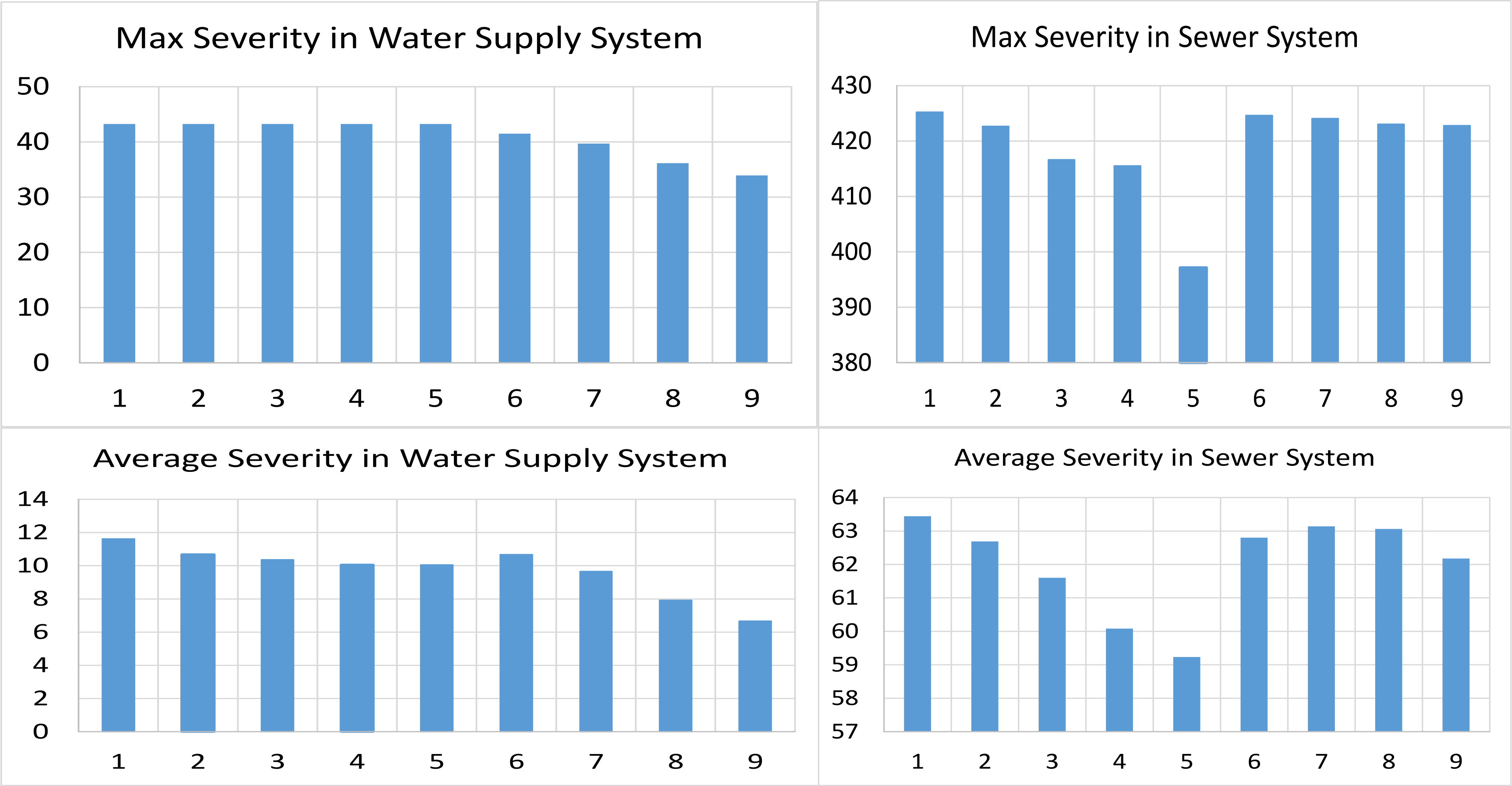

Results: Severity-related resilience indicators (%)

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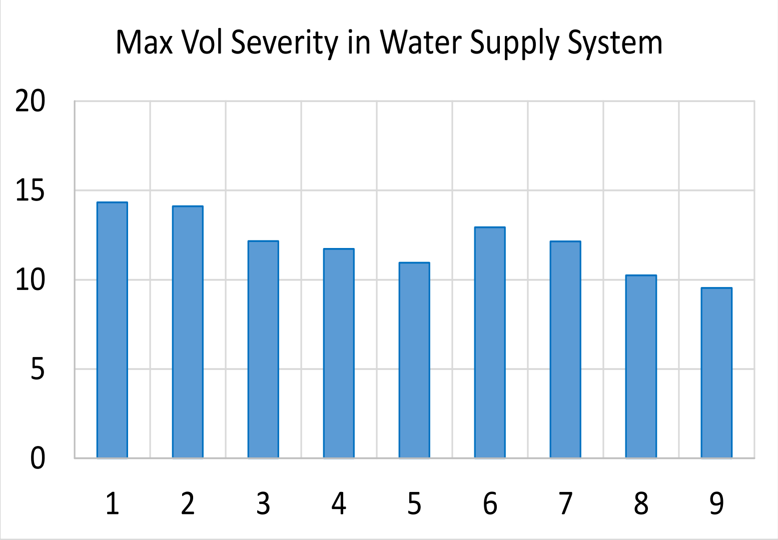

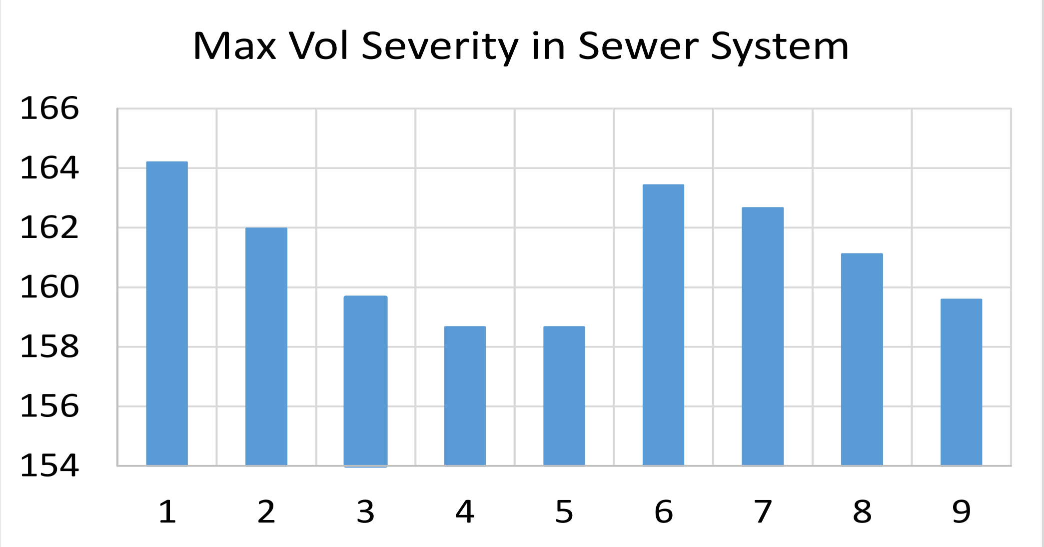

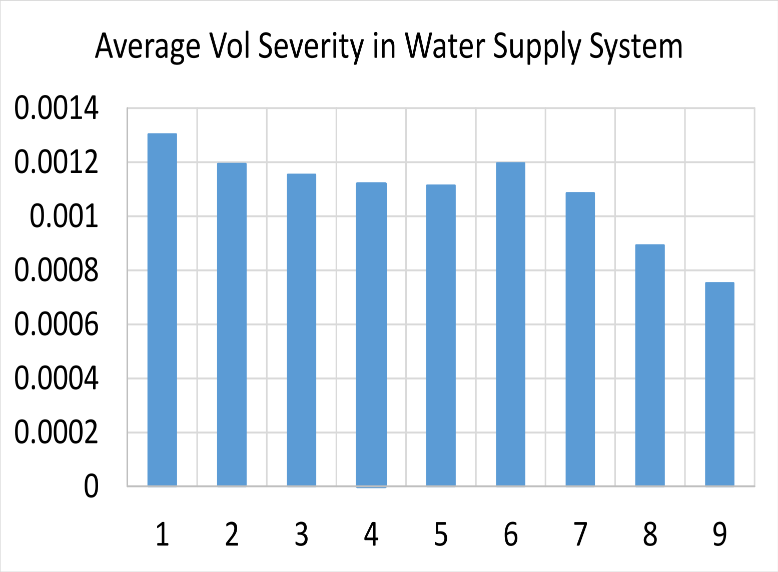

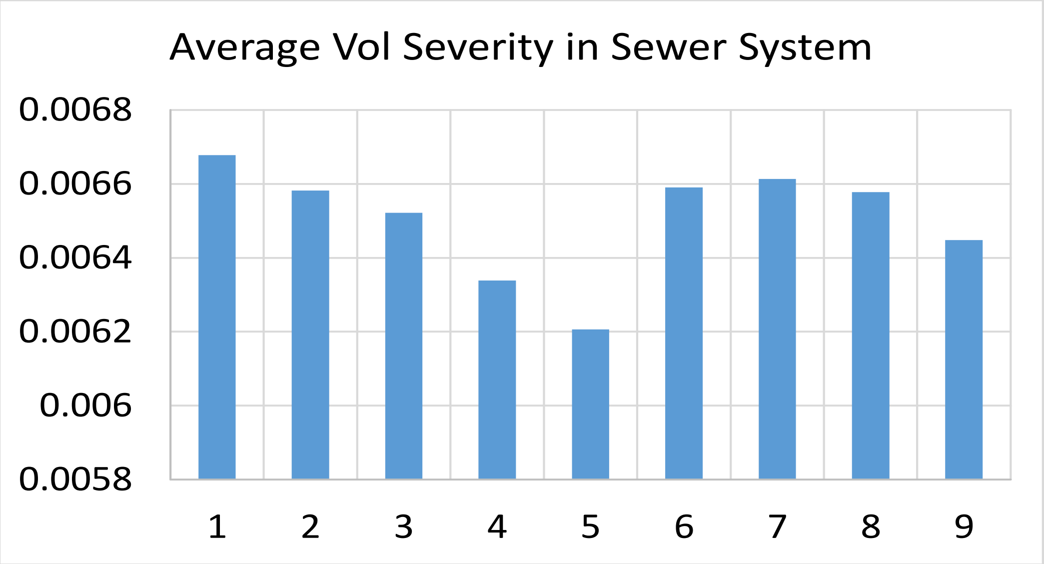

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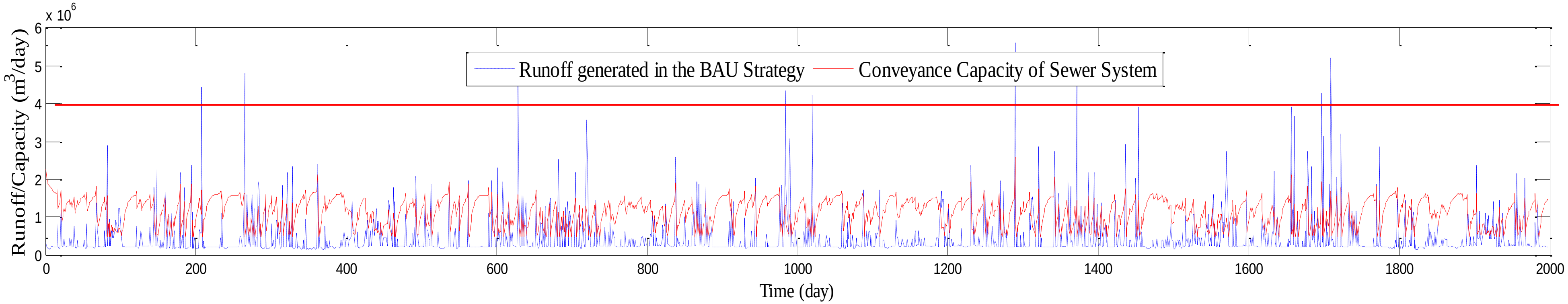
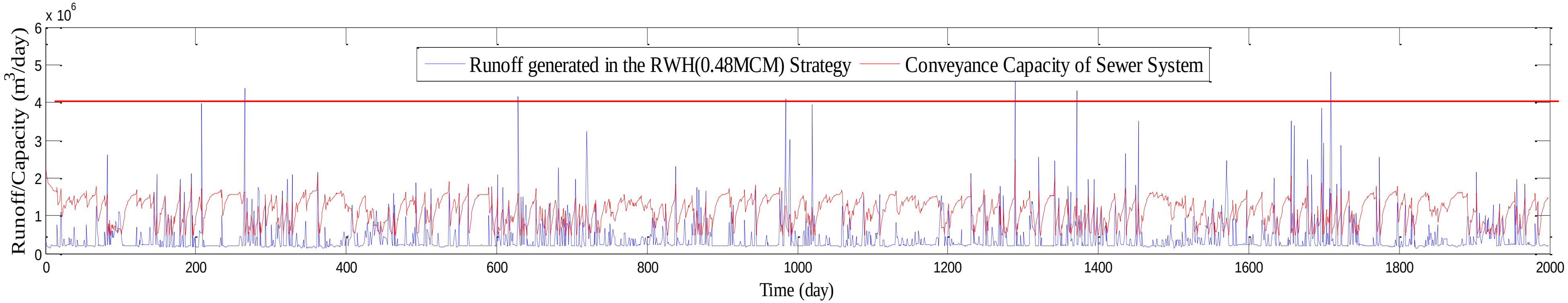
Variations of runoff generated/conveyance capacity of sewer system

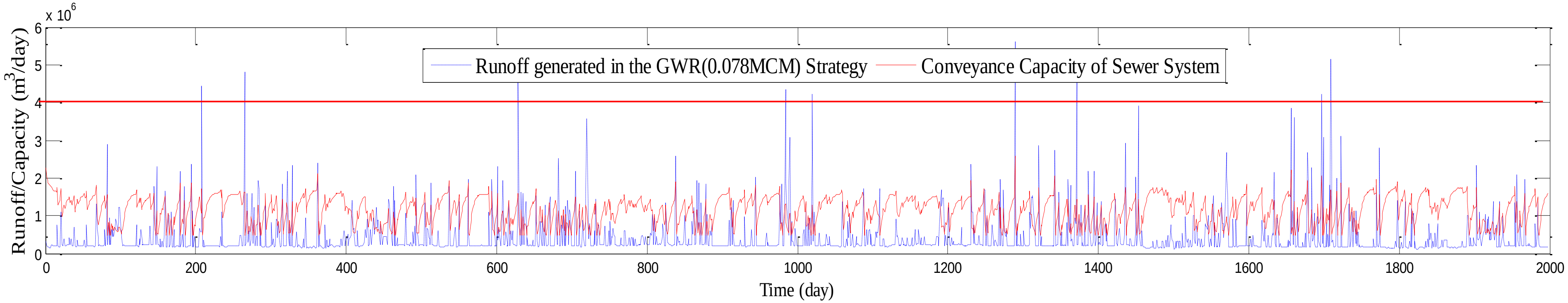
1- Business as usual (BAU)



2-RWH with 0.48 MCM capacity

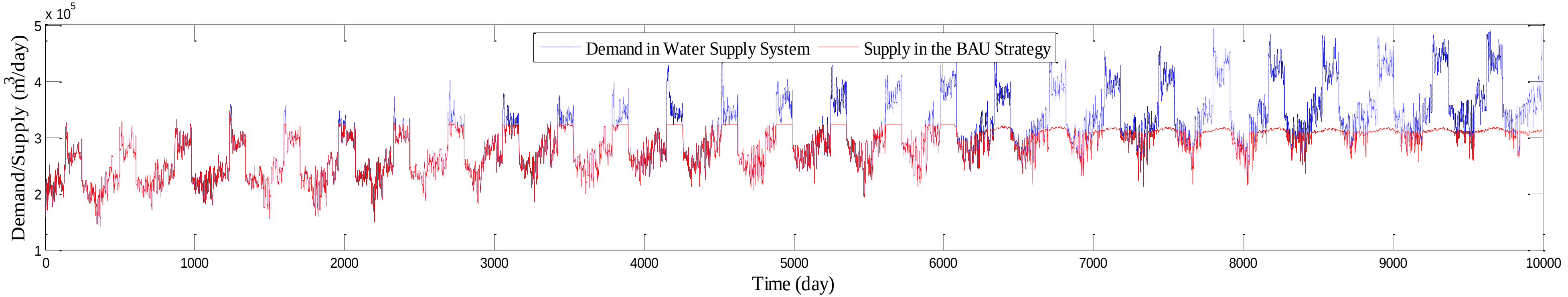


3-GWR with 0.078 MCM capacity

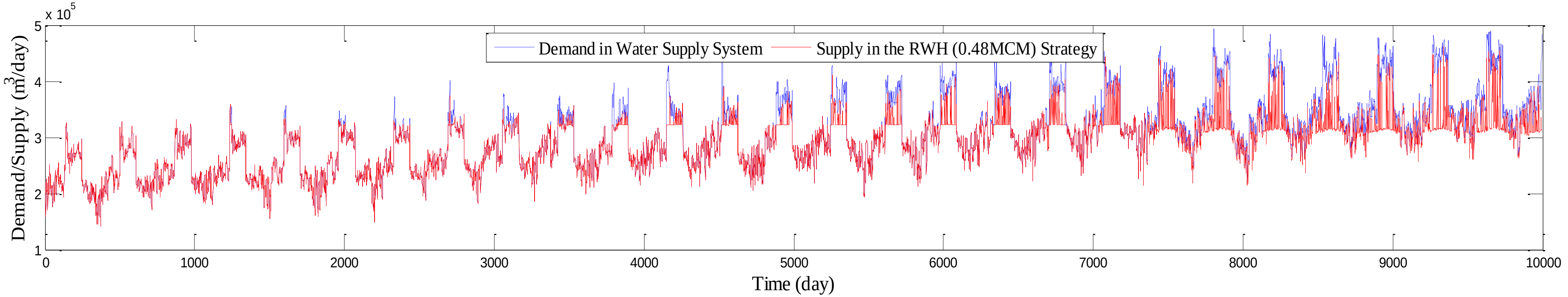


Variations of water demand and supply in three strategies

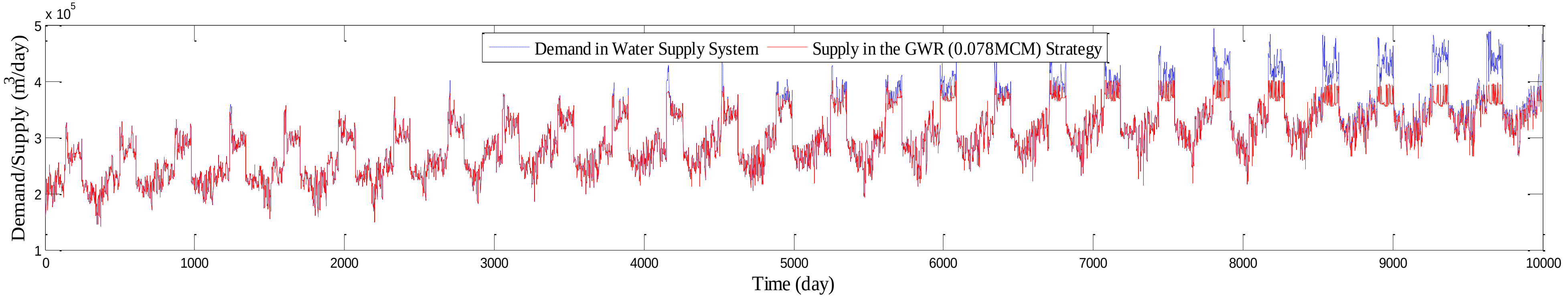
1- Business as usual (BAU)



2-RWH with 0.48 MCM capacity



3-GWR with 0.078 MCM capacity



Conclusions

- Metabolism based approach (WaterMet^2) can be very useful tool for analysis of multi-component resilience in urban water systems for long-term planning horizon.
- Results show there is no single best intervention solution that can reduce both failure duration and magnitude in water supply and sewer systems.
- Performance of intervention strategies for different severity-based resilience indicators seems to be relatively similar.
- Other assessment criteria (e.g. economic and environmental) should also be included when selecting new intervention strategies.
- For generalisation of the findings outlined here, further applications to other case studies are required.

Thanks for your attention!

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