



## **WatefCon 2018 Future of Water in Europe**

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**WatefCon 2018:  
Future of Water  
in Europe**

AVEIRO 5-7 SEPTEMBER 2018

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# **Resilience of Integrated Urban Water Systems**

**Dr Kourosh Behzadian**  
**Senior Lecturer, University of West London**

Dr. Kourosh Behzadian, University of West London

Prof. S. Jamshid Mousavi, Amirkabir University of Technology

Prof. Zoran Kapelan, University of Exeter

Prof. Amir Alani, University of West London



**Amirkabir**

University of Technology  
UNIVERSITY OF TECHNOLOGY



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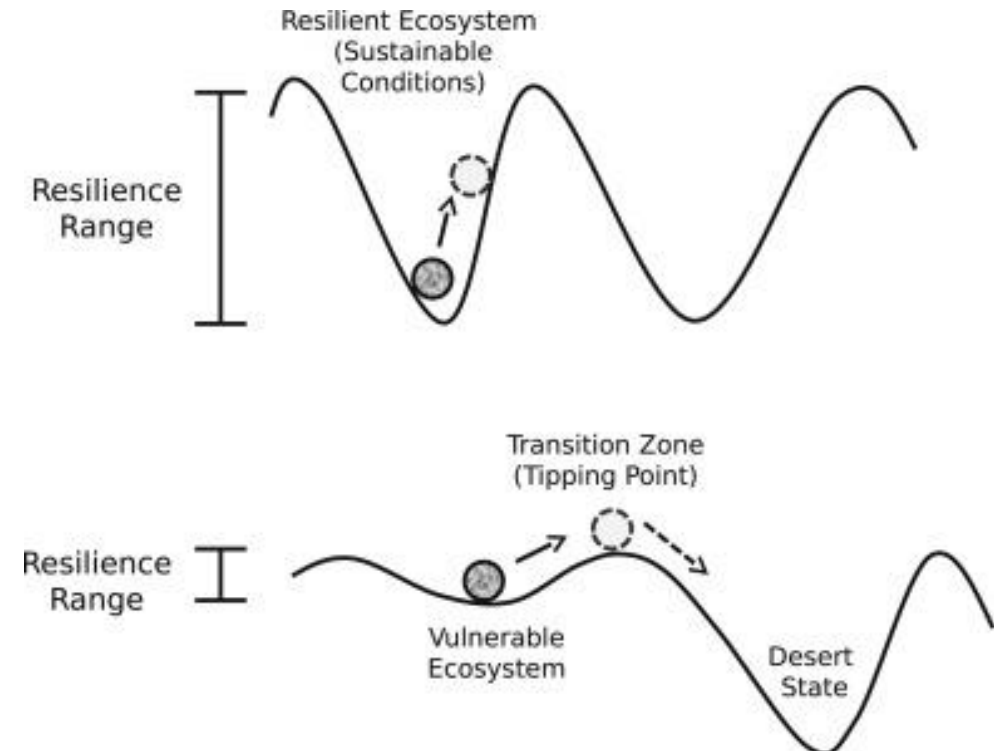
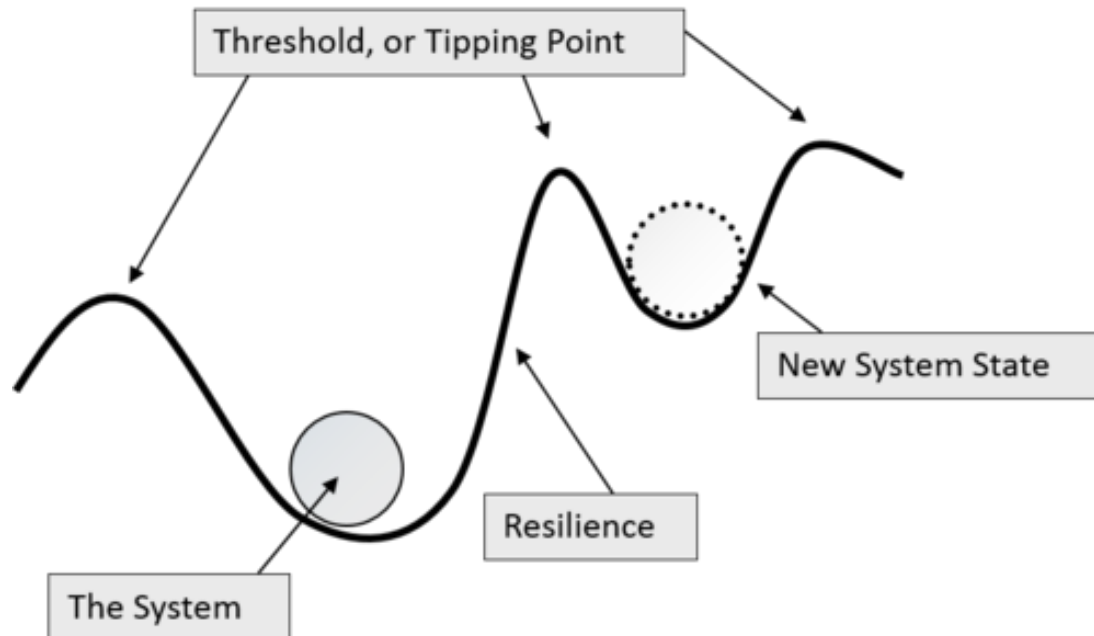
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- **Definition of Resilience in general and water system**
- **Methodology**
- **Case study**
- **Results**
- **Conclusions**

# 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.

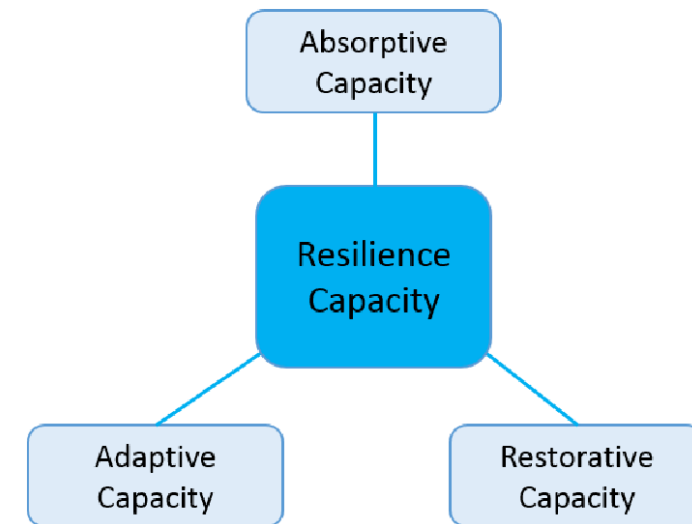
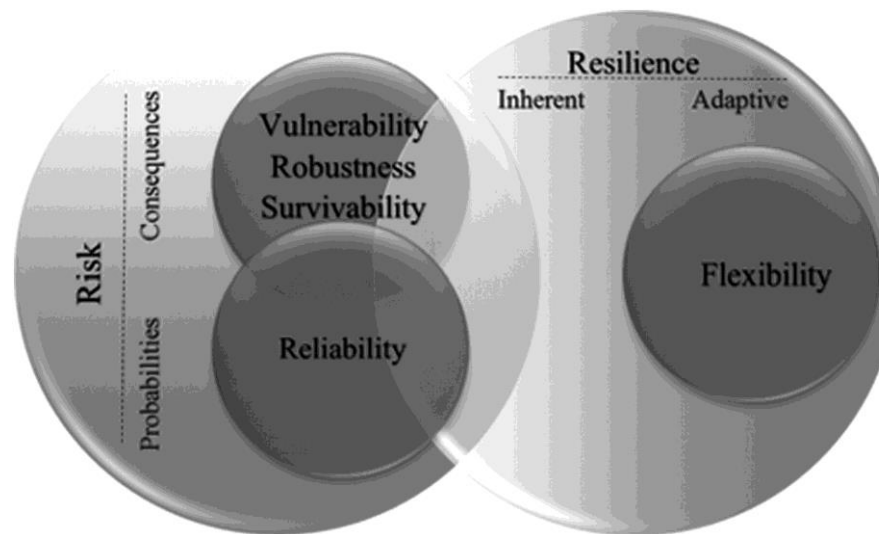
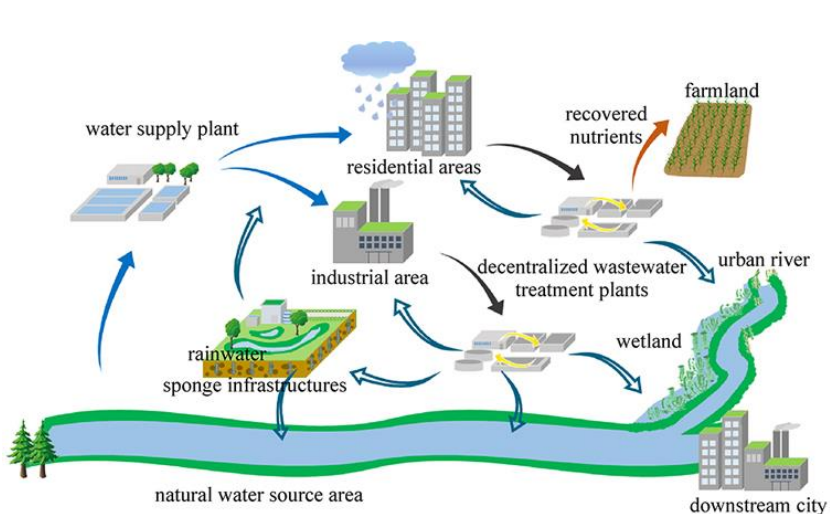


# Resilience as a KPI of Sustainability criteria in water system

## 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)

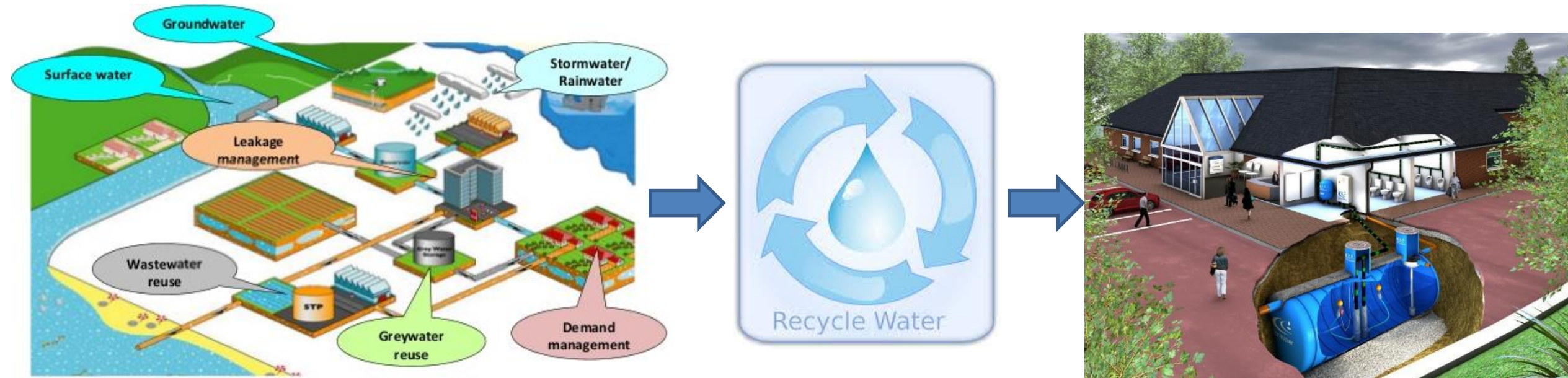
➤ Due to different interpretations of resilience, it should be defined as a **multi-component indicator** in water systems for both water supply and wastewater/stormwater systems





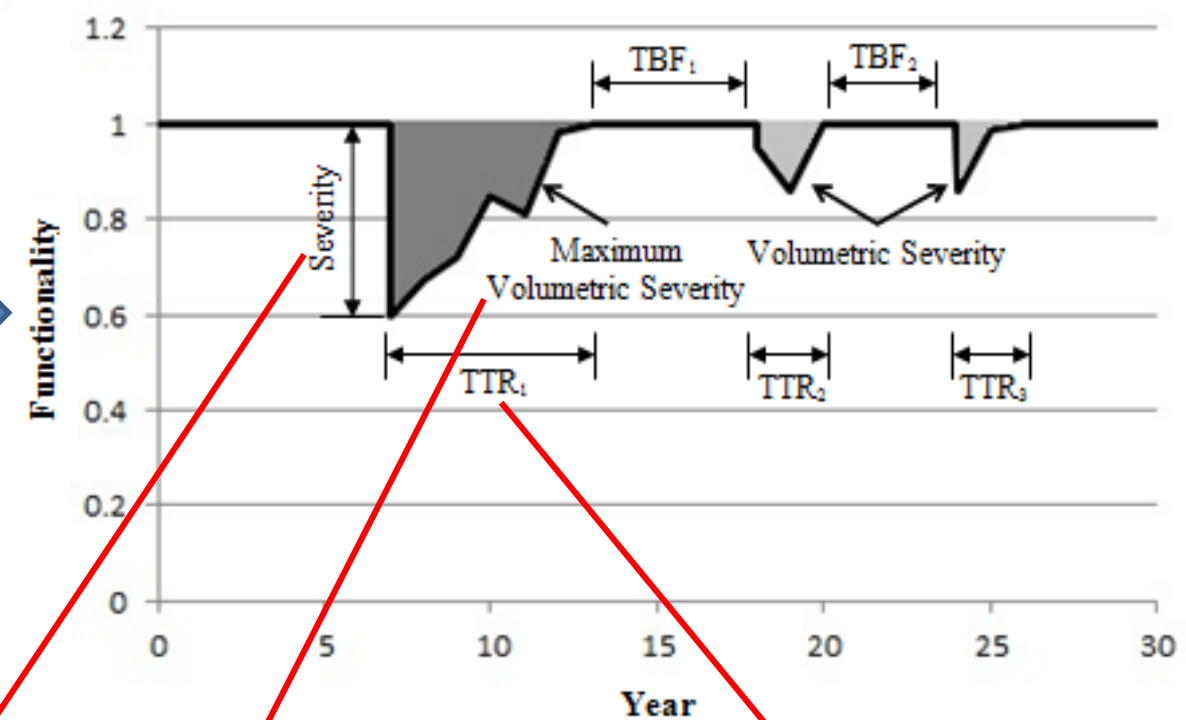
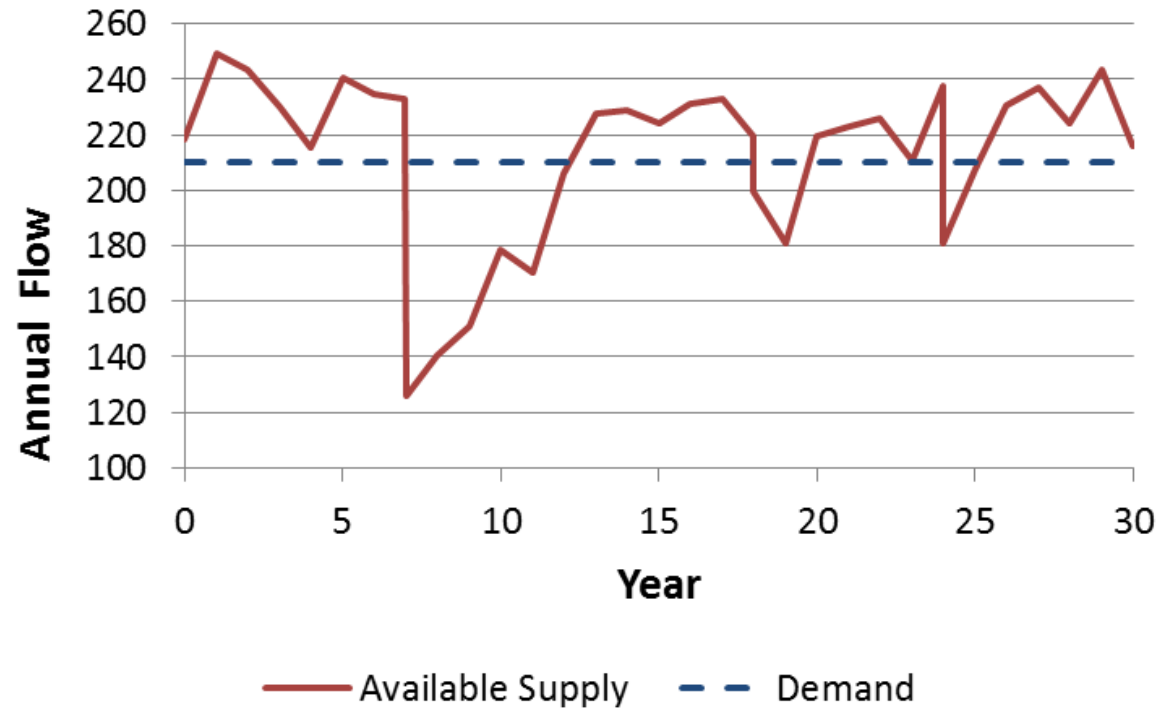
# Methodology

- **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



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

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

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

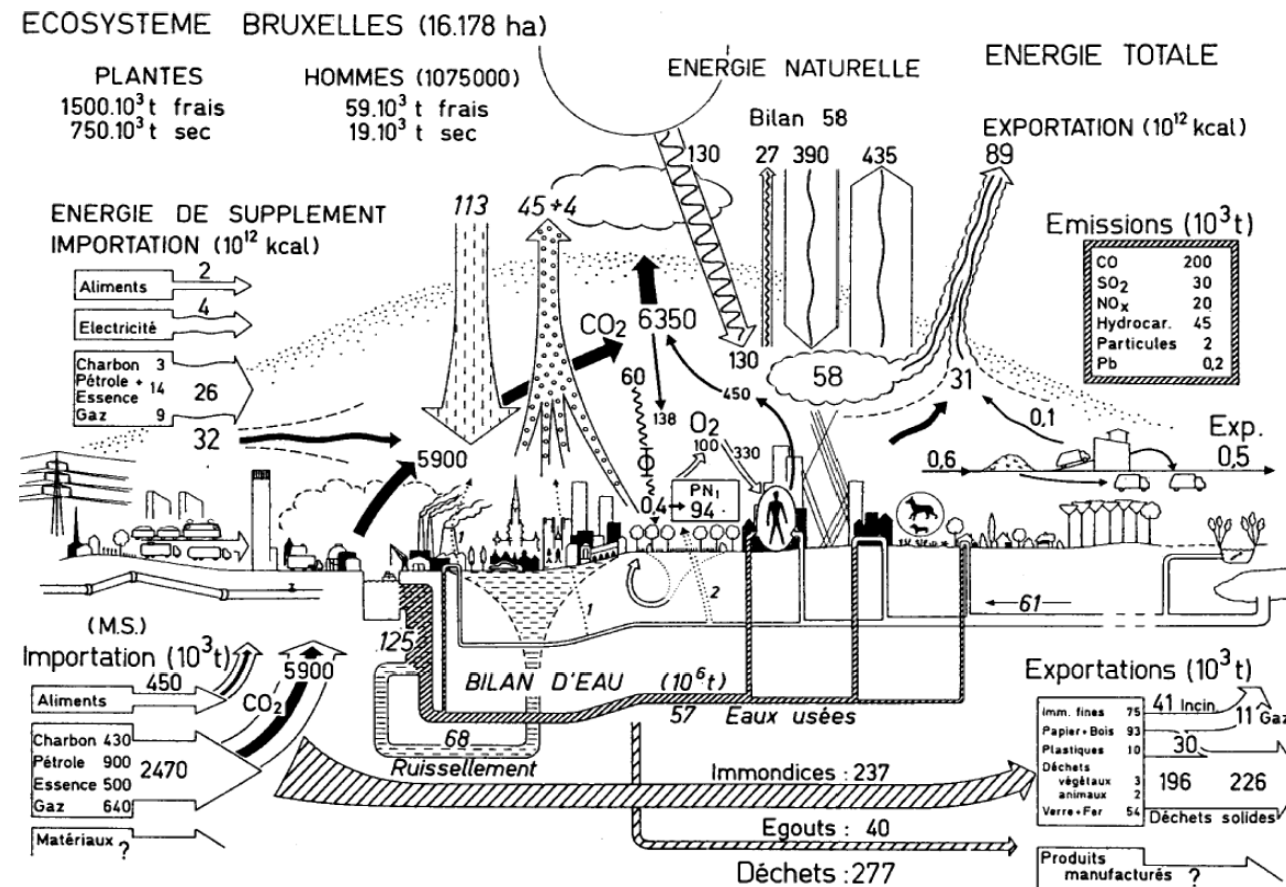
$T_F$ : the length of time during which water demand is not fully delivered

# Multi-component resilience indicators in UWS

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





# WaterMet<sup>2</sup> Conceptual Model

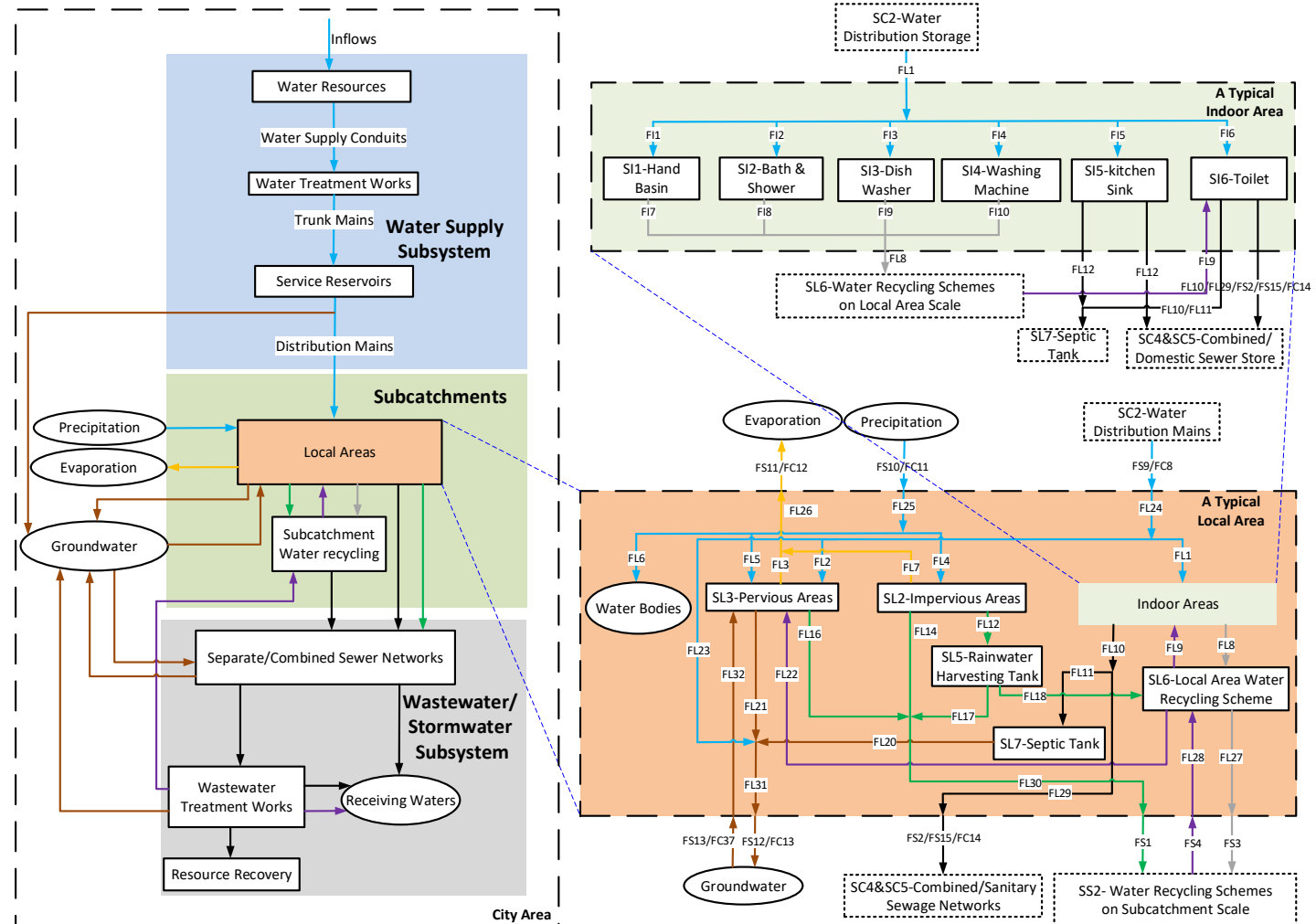
**Intervention  
Technologies**



**Quantitative  
metabolism**

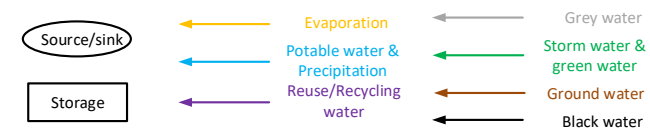


**Resilient  
Performance &  
other  
performance  
indicators**



## Legend

### Main Water Flows



WaterMet2 : E:\WaterMet2 Group\WaterMet2 Model\WM2\bin\Debug\Oslo 9-6-2014.xml

File Input Data Analysis Report Tools Help

Intervention Strategy  
Calibration Data...  
Run Simulation F5  
Optimisation F10

**Main Menu**

**Optimisation Section**

**Input Data**

**Left Hand Pane**

Project Note  
UWS  
Water Resources  
WS Conduits  
WTWs  
Trunk Mains  
Service Reservoirs  
Distribution Mains  
Subcatchments  
Wastewater System  
Stormwater System  
WWTWs  
Receiving Waters  
Options

Options  
Add Delete

Constants 1  
Constants 2  
Contaminants  
Embodied Energy  
Embodied GHG  
Acidification  
Eutrophication  
Rehabilitation Methods  
Slip-lining Rehabilitation Spec

**Water Supply System**

Topology Operation Assets

Subcatchments vs ServiceReservoirs (Distribution Mains) ServiceReservoirs vs. WTWs (Trunk Mains) WTWs vs. RawWaterSources (Water Supply/Conduits)

Serv. Resv. No.	Subcatchment 1
1	<input checked="" type="checkbox"/>
2	<input checked="" type="checkbox"/>
3	<input checked="" type="checkbox"/>
4	<input checked="" type="checkbox"/>
5	<input checked="" type="checkbox"/>

**Subcatchment**

Topology Specifications Local Area

	Indoor Water Demand [L/day per capita]	Industrial/Commercial demand [m <sup>3</sup> /day]	Irrigation and other water demand [m <sup>3</sup> /day]	Frost tapping[m <sup>3</sup> /day]	Unregistered public use [L/day per capita]	Occupan
Local Area 1	180.00	54,795.00	63,500.00	35,000.00	15.00	2.35

**Wastewater System**

Topology Operation Asset

Sewer System Interconnection Sewer Systems vs WWTWs Receiving Water

Separate/Combined Sewer

Subcatchment 1  
Separate/Combined Sewer Combined

Downstream Outlet in Wastewater (for both separated and combined sewers)

Subcatchment 1  
Downstream connection NA

Downstream Outlet in Stormwater (if separated)

Subcatchment 1  
Downstream connection NA

OK Cancel

**Plot Series for Urban Water System**

%ofWaterDemandDelivered GHGEmission SewerSystem ContaminantLoad ContaminantLoad ContaminantLoad WaterBalance

GHGEmission (Urban Water System)

TotalGHGEmission ElectricityGHGEmission FossilFuelGHGEmission EmbodiedGHGEmission

GHGEmission [Ton CO2-eq/Day]

Day (10<sup>3</sup>)

Line Chart Table Representation Close

**Table Series for Plot Series for Urban Water System**

%ofWaterDemandDelivered GHGEmission SewerSystem ContaminantLoad ContaminantLoad ContaminantLoad WaterBalance

	Time Step [Day]	TotalGHGEmission [Ton CO2-eq]	ElectricityGHGEmission [Ton CO2-eq]	FossilFuelGHGEmission [Ton CO2-eq]	EmbodiedGHGEmission [Ton CO2-eq]
1	0	105.32	52.41	6.15	46.75
2	1	108.74	52.13	5.90	50.71
3	2	113.50	52.39	5.69	55.42
4	3	117.37	52.77	5.56	59.04
5	4	111.39	48.45	4.90	58.04
6	5	109.20	46.70	4.62	57.87
7	6	123.51	53.80	5.45	64.26
8	7	138.77	61.02	6.26	71.49
9	8	146.24	63.74	6.47	76.03
10	9	143.03	61.23	6.07	75.73
11	10	142.18	60.34	5.91	75.93
12	11	153.06	65.71	6.54	80.81
13	12	144.58	60.76	5.88	77.94
14	13	147.21	62.05	6.02	79.14

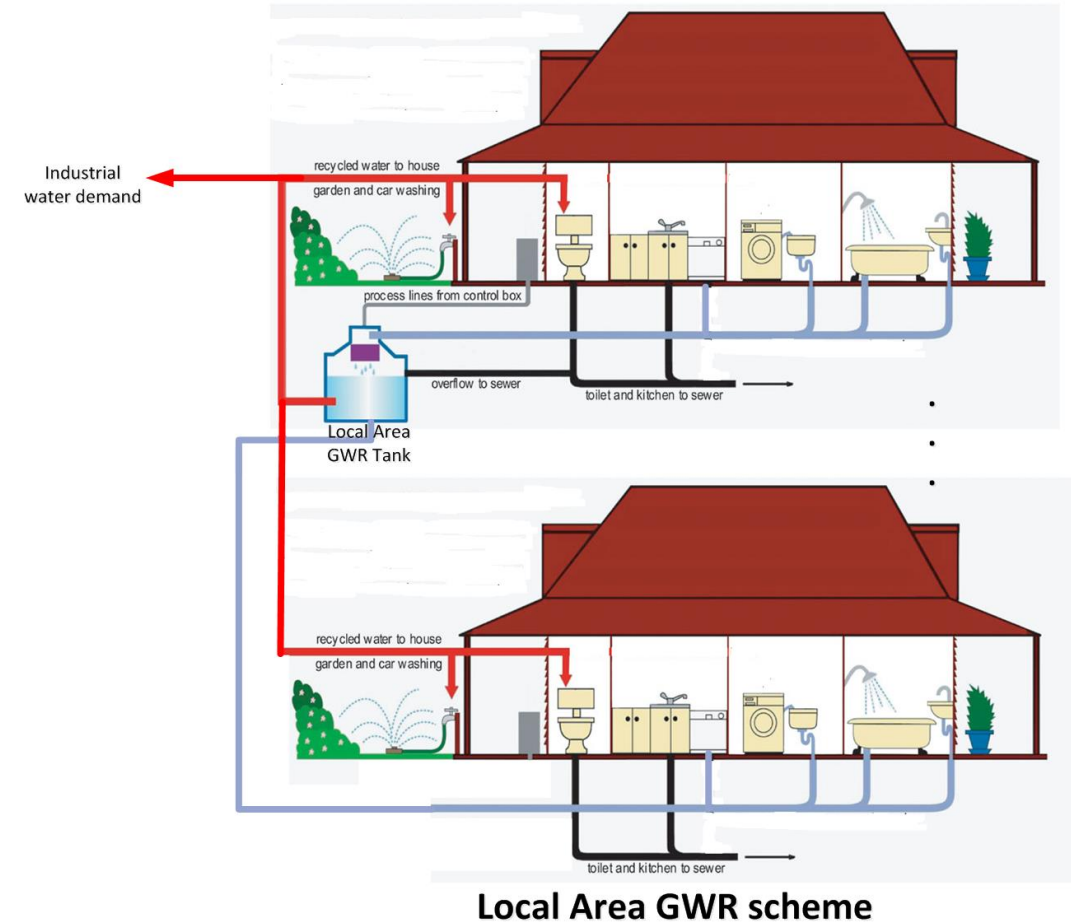
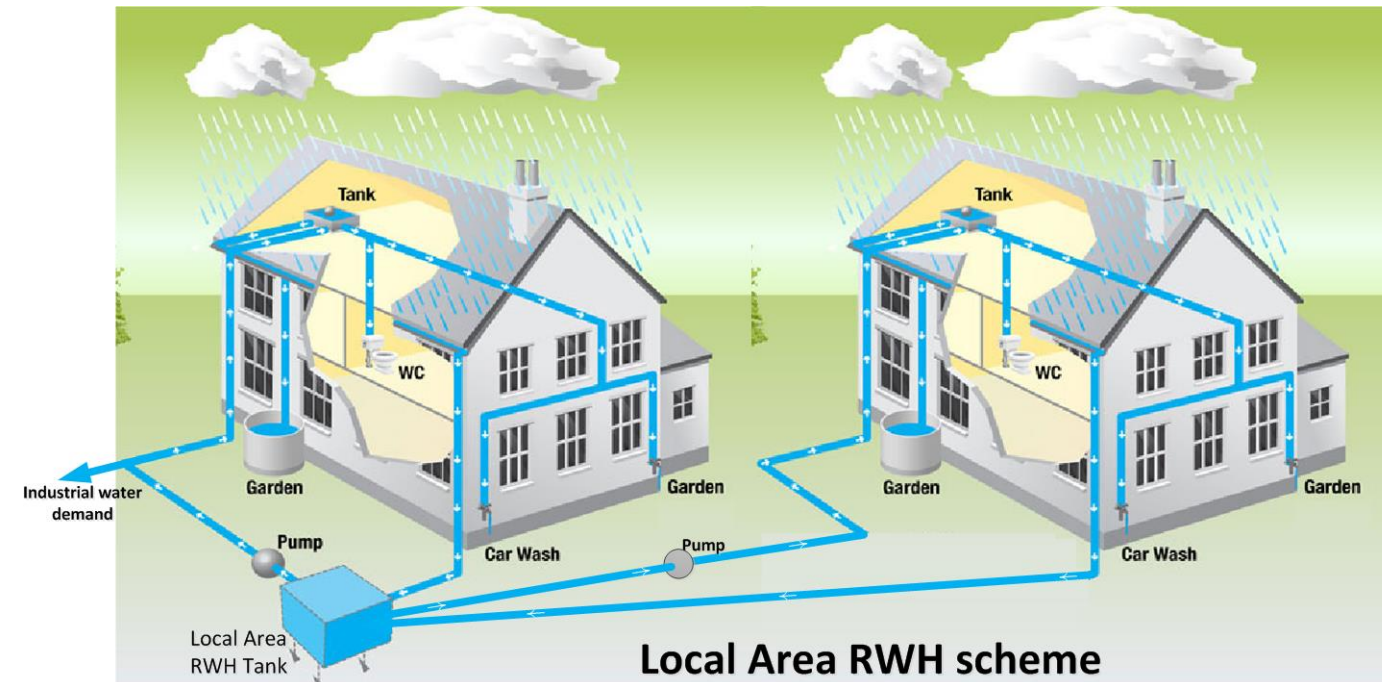
Chart Representation Close

**Graphical Results**

**Tabular Results**

# Water recycling schemes

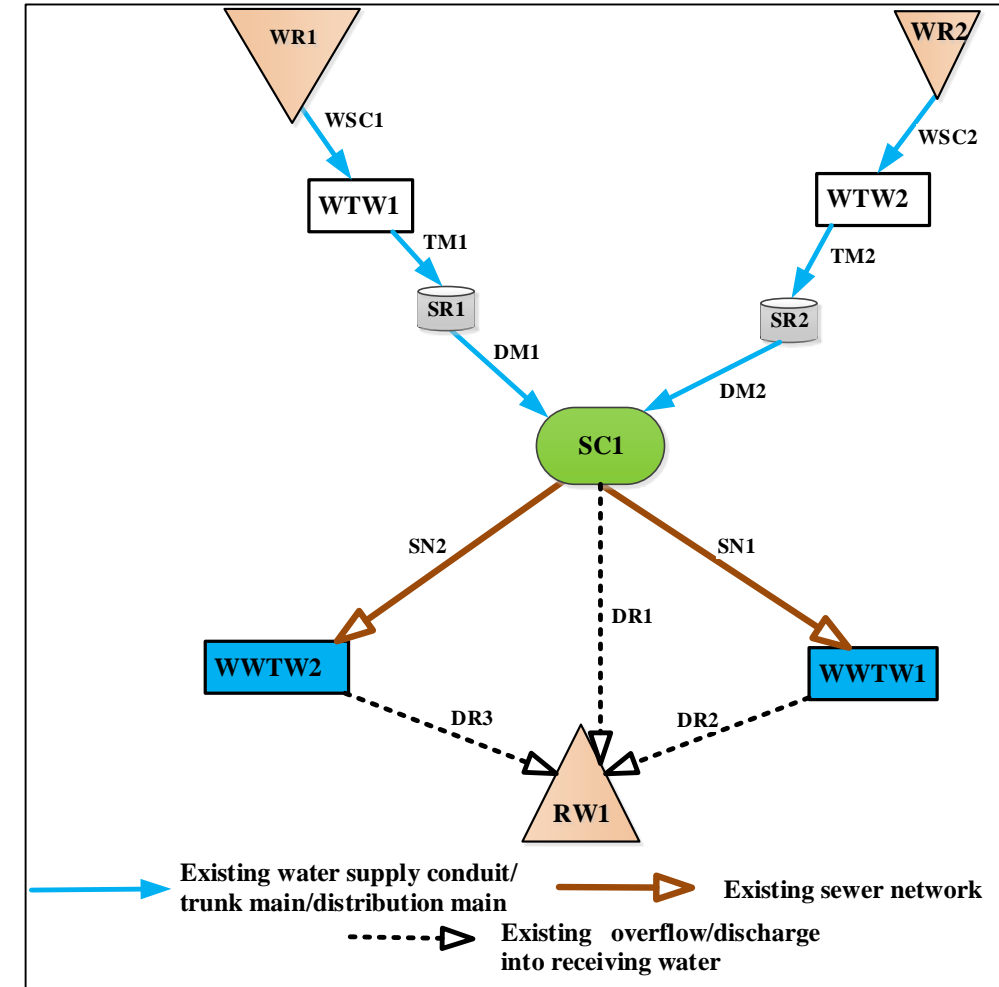
- Two water reuse schemes are analysed:
  - rainwater harvesting (RWH)
  - grey water recycling (GWR)



- 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<sup>3</sup>**
- 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 <sup>3</sup>
25% of full capacity	0.12 MCM	19,500 m <sup>3</sup>
50% of full capacity	0.24 MCM	39,000 m <sup>3</sup>
100% of full capacity	0.48 MCM	78,000 m <sup>3</sup>

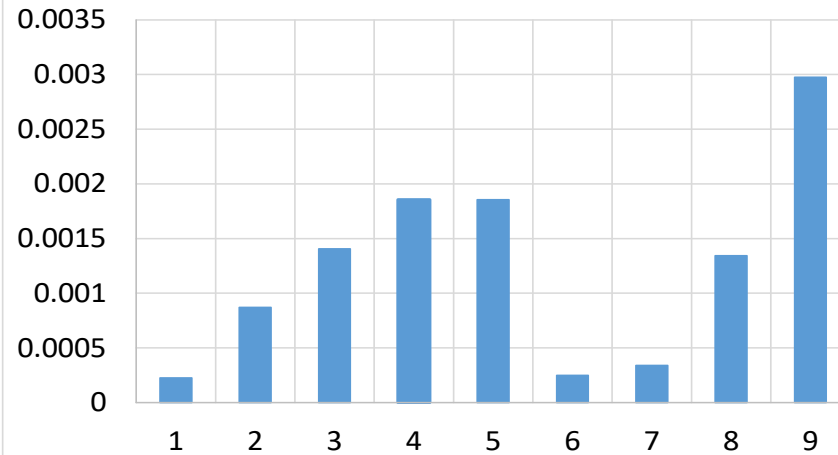


# Results: Recovery rate resilience indicators

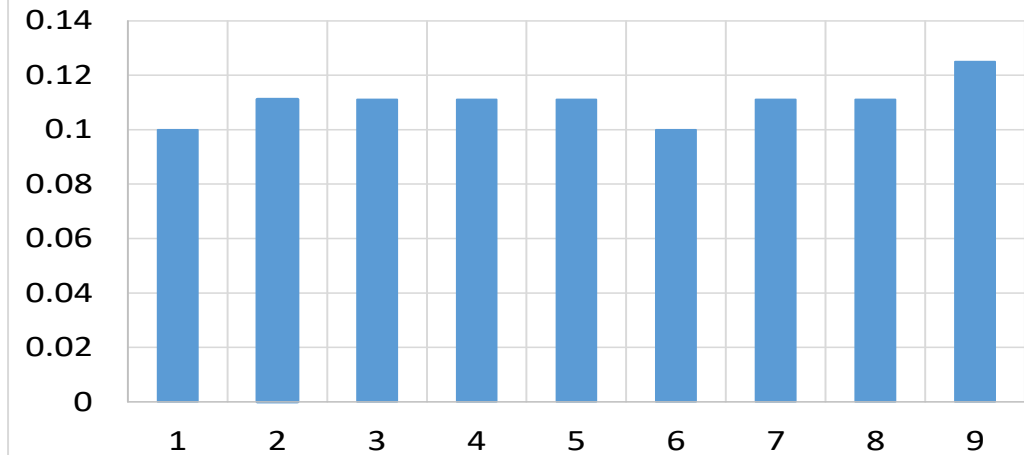
## Strategies:

- 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)

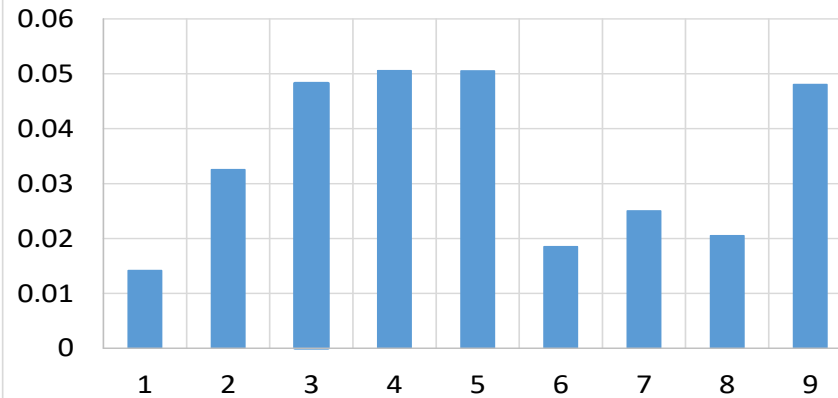
Min Recovery Rate in Water Supply System



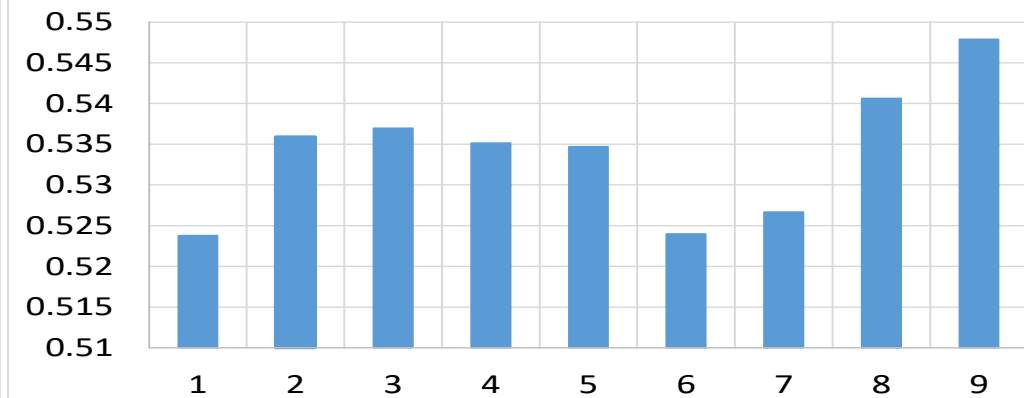
Min Recovery Rate in Sewer System



Average Recovery Rate in Water Supply System



Average Recovery Rate in Sewer System



# Results: Severity-related resilience indicators (%)

## Strategies:

1- BAU

2-RWH(0.048MCM)

3-RWH(0.12MCM)

4-RWH(0.24MCM)

5-RWH(0.48MCM)

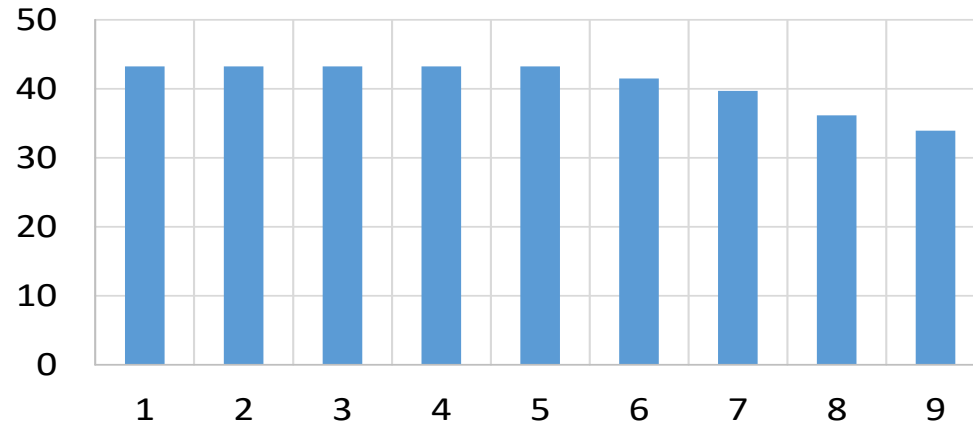
6-GWR(0.00975MCM)

7-GWR(0.0195MCM)

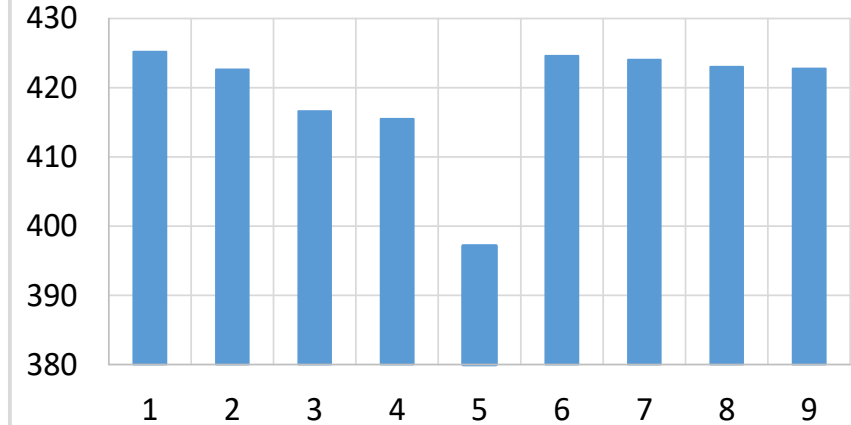
8-GWR(0.039MCM)

9-GWR(0.078MCM)

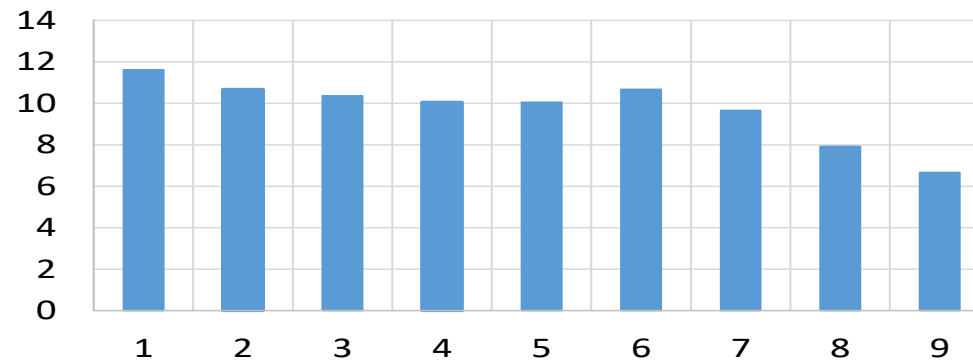
Max Severity in Water Supply System



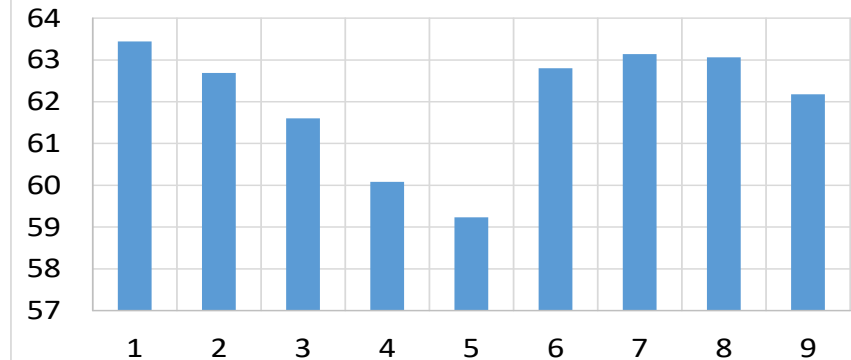
Max Severity in Sewer System



Average Severity in Water Supply System



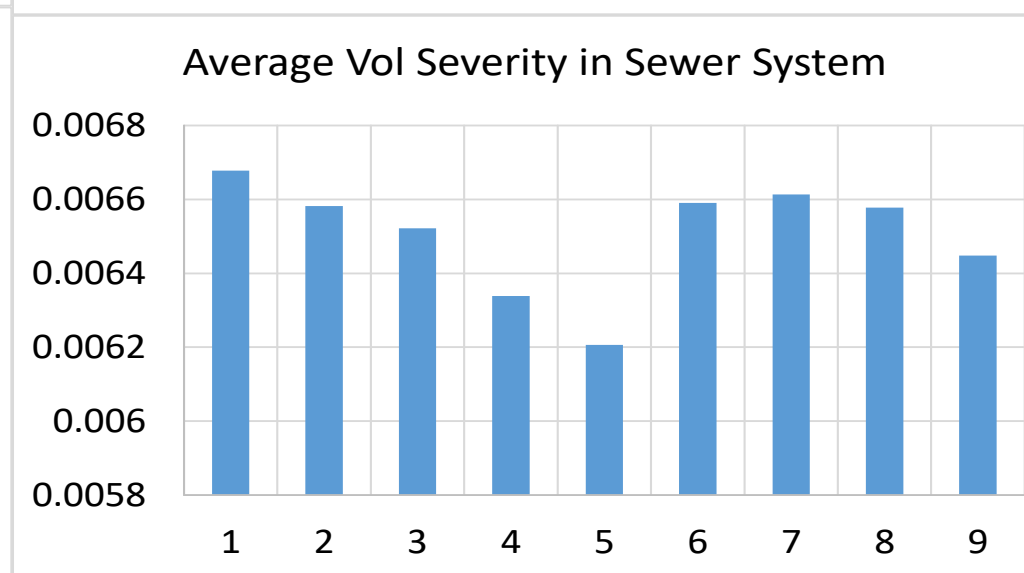
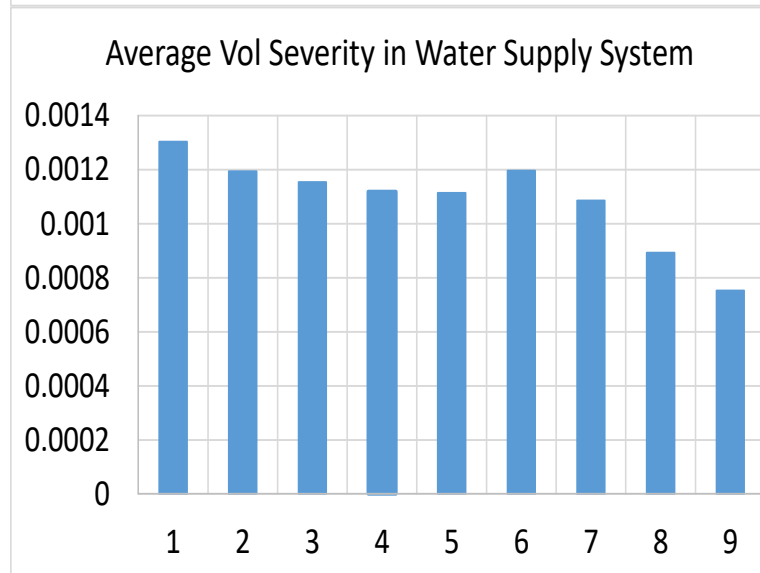
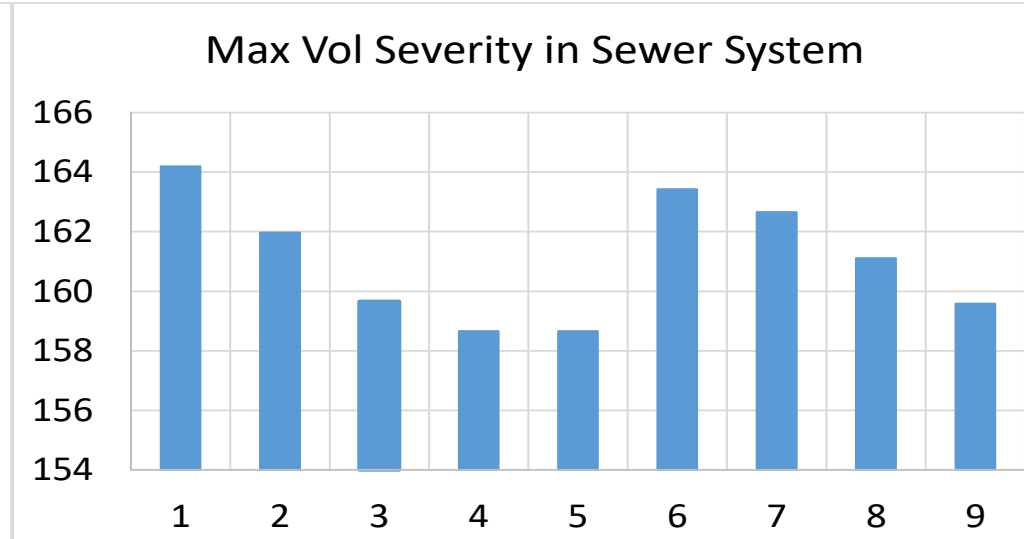
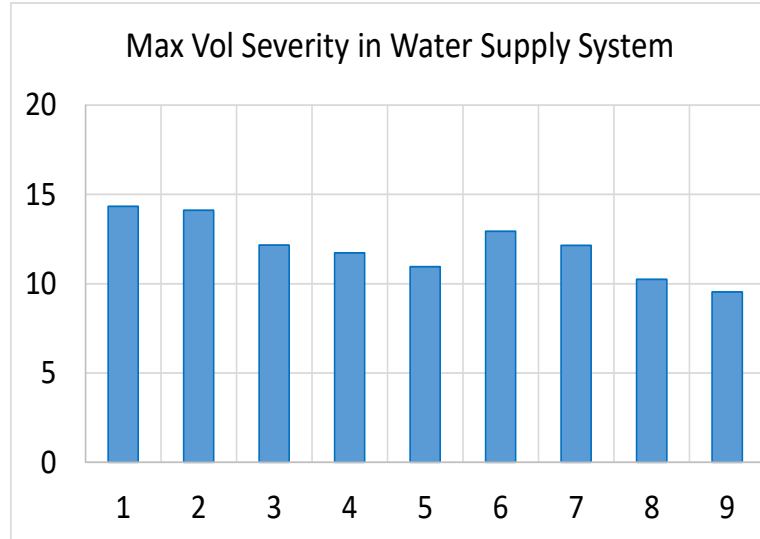
Average Severity in Sewer System



# Results: Severity-related resilience indicators (%)

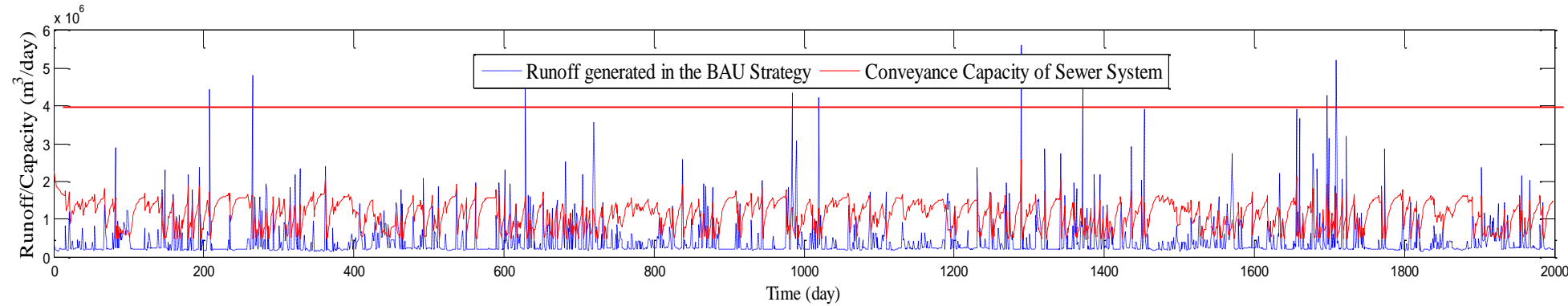
## Strategies:

- 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)

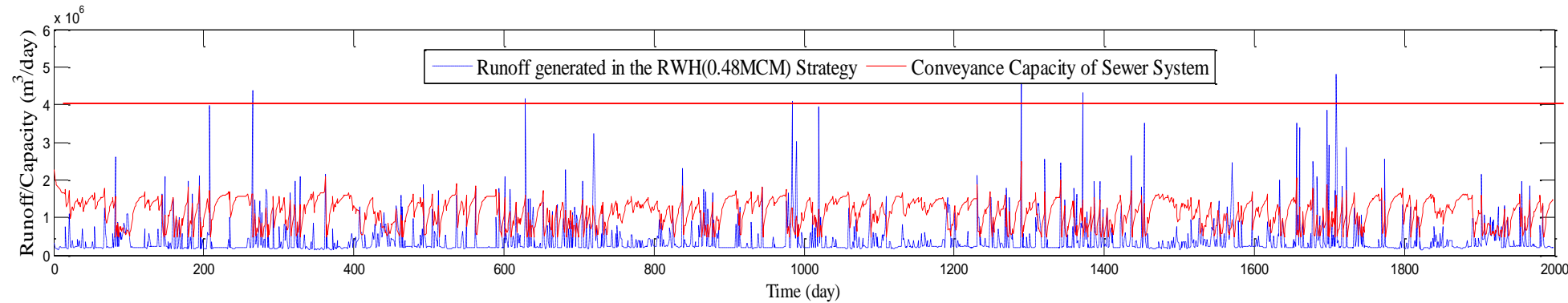


# Variations of runoff generated/conveyance capacity of sewer system

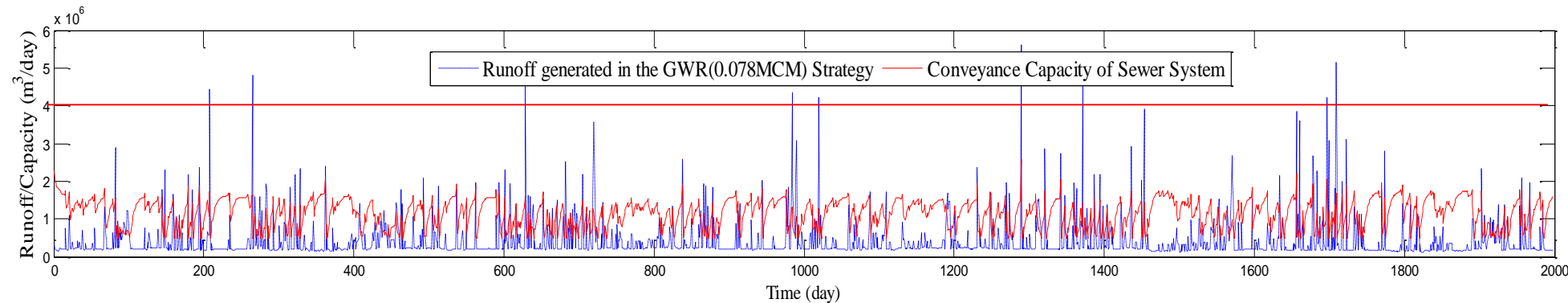
## 1- Business as usual (BAU)



## 2-RWH with 0.48 MCM capacity

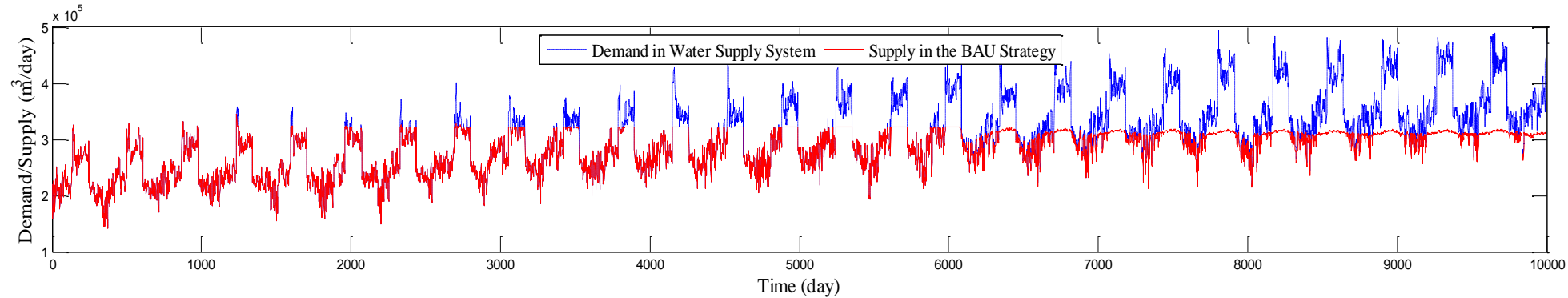


## 3-GWR with 0.078 MCM capacity

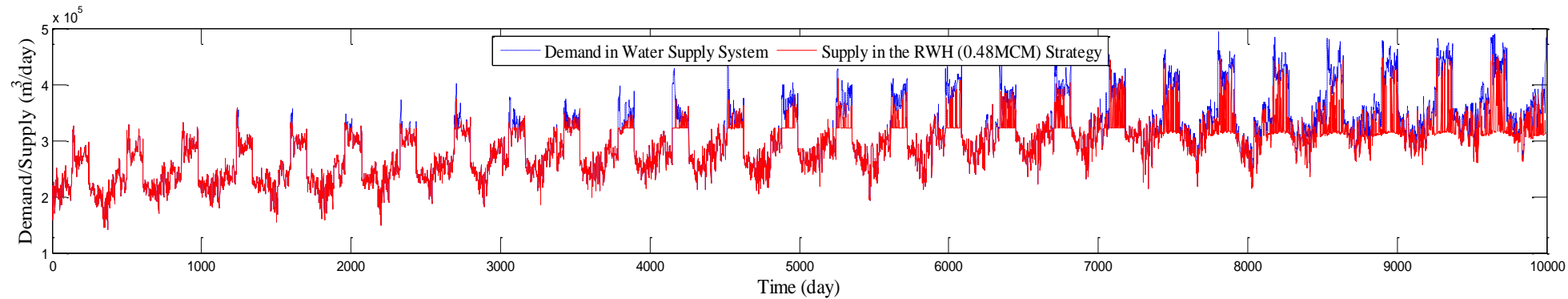


# Variations of water demand and supply in three strategies

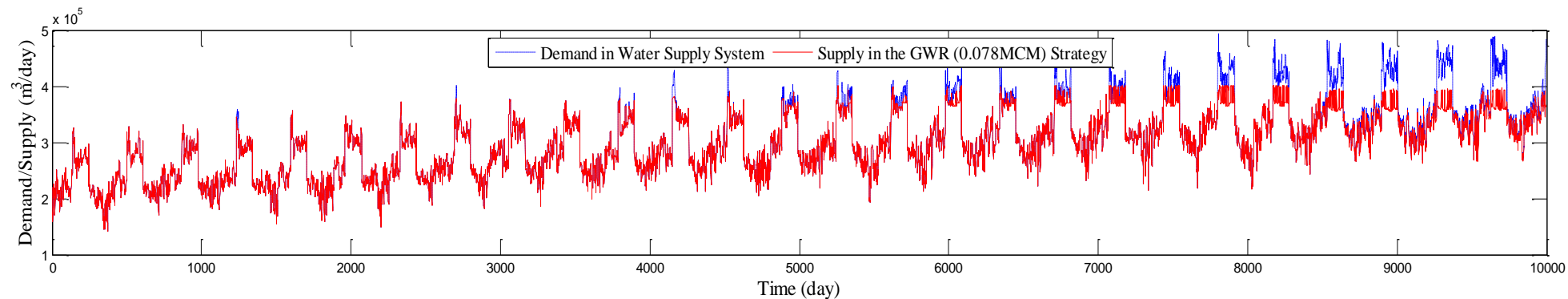
## 1- Business as usual (BAU)



## 2-RWH with 0.48 MCM capacity



## 3-GWR with 0.078 MCM capacity





# Conclusions

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- **Metabolism based** approach (WaterMet<sup>2</sup> ) 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!

Contact:  
[kourosh.behzadian@uwl.ac.uk](mailto:kourosh.behzadian@uwl.ac.uk)

