Stormwater Control Infrastructure: An investigation of four case studies

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INRS
Institut national de la recherche scientifique

Introduction: The need for using Stormwater Control Strategies

Increasing Urbanization and Rapid Urban Development

Increased Impervious Surfaces

- Impact on Stormwater Quantity
- Impact on Water Quality

Stormwater Control strategies

- Source-Control Solutions
- End-of-Pipe Solutions

Pollutant transport to the natural environments

Introduction: Stormwater management Structures

Stormwater Management Structures → Mimicking the natural water cycle and Replicating the predevelopment hydrologic cycle

Stormwater Quantity Control:

- Control flows to prevent stream erosion and flooding

Stormwater Quality Control:

- Remove sediments and various pollutants

MDDEFP & MAMROT (2011)

The 1st Case Study

Objective

1st Case Study

- Stormwater quality performance assessment
- Two types of LID-BMPs
- Located in Quebec, Canada
- Between July 2020 and November 2021

1st Case Study

Introduction to the study site

- Source control infrastructure cover around 60% of the parking area;
- Source control infrastructure captures the surface runoff from approximately 58% of the impermeable surface of the parking lot.
- Located at the intersection of exit ramp 18 of Highway 132 and Montarville Boulevard,
- The site has a total area of 1.20 ha.

Introduction to the study site

1st Case Study

Location of honeycomb permeable pavement (in orange boxes)

Introduction to the study site

1st Case Study

Location of interlocking permeable pavement

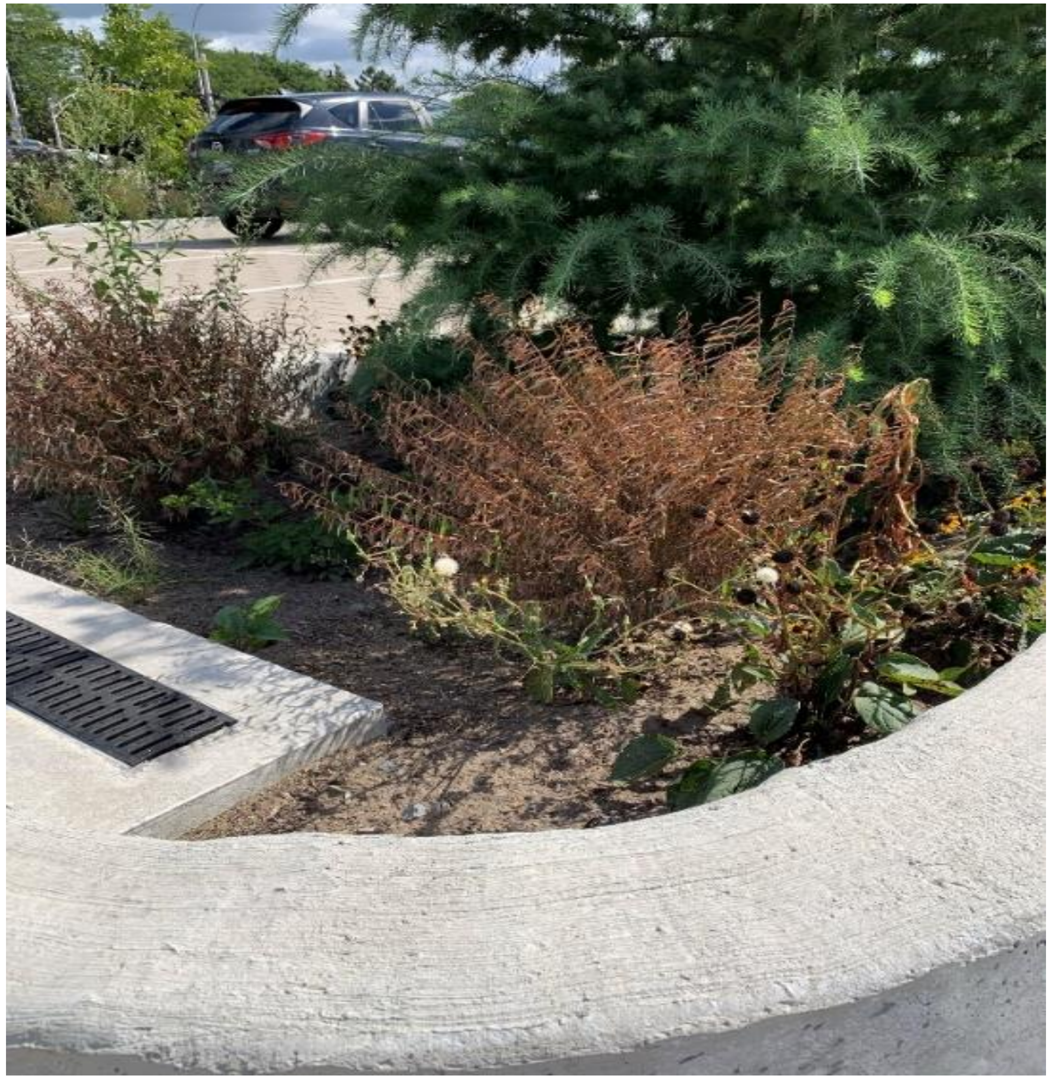
Shown in blue (0.52 ha)

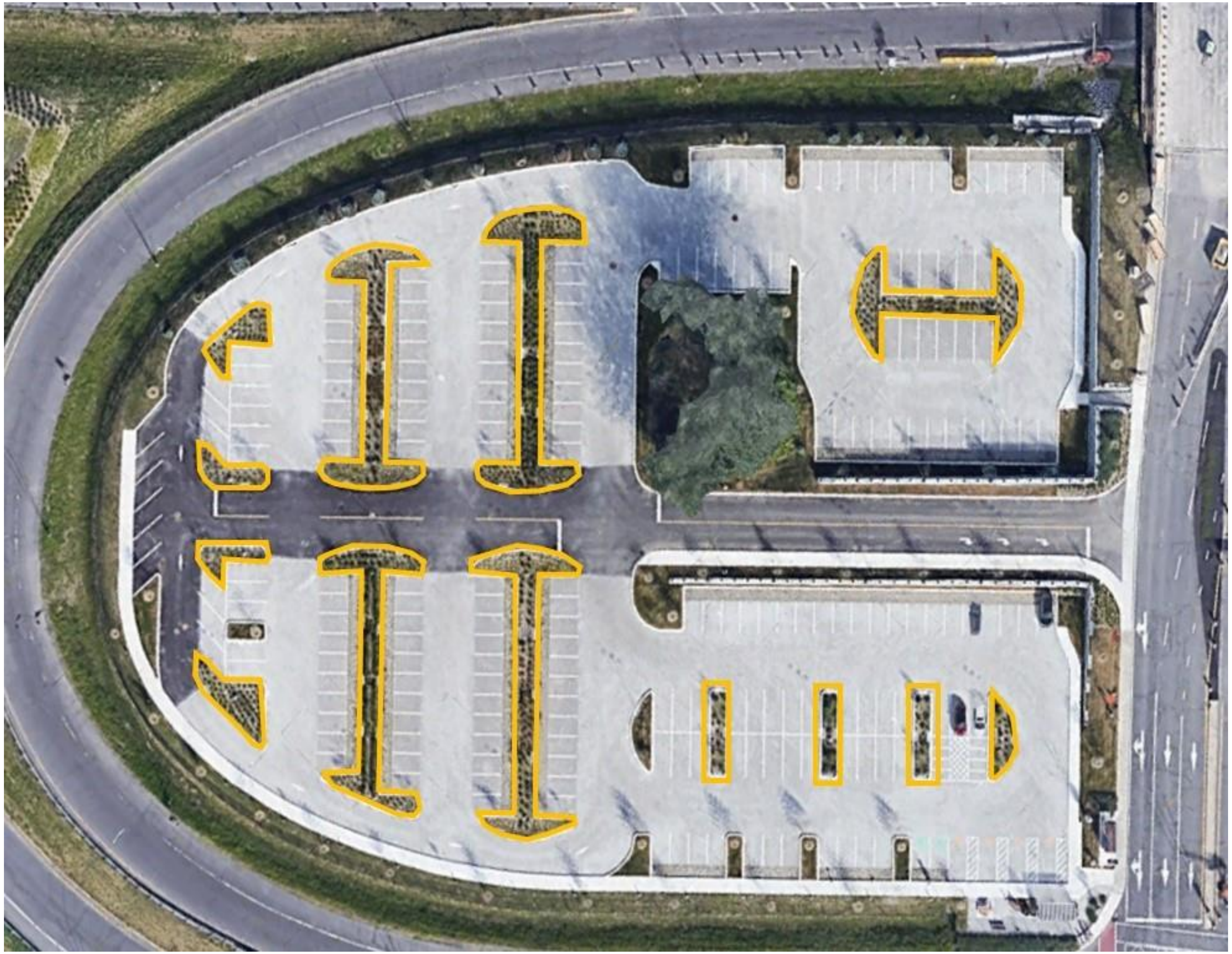
1st Case Study

Introduction to the study site

Location of 13 Bioretention cells

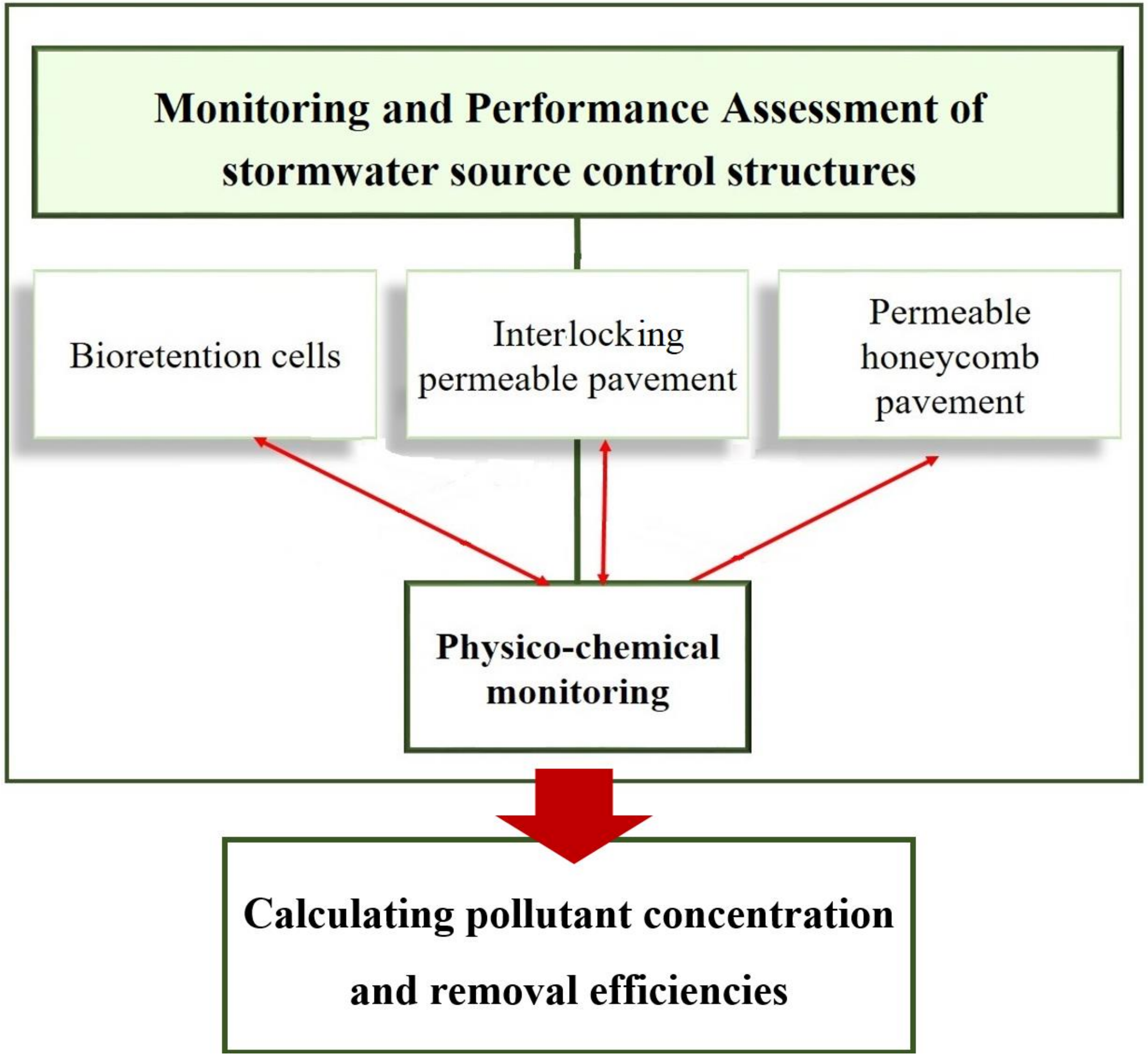
(in yellow boxes)





Materials and Methods:

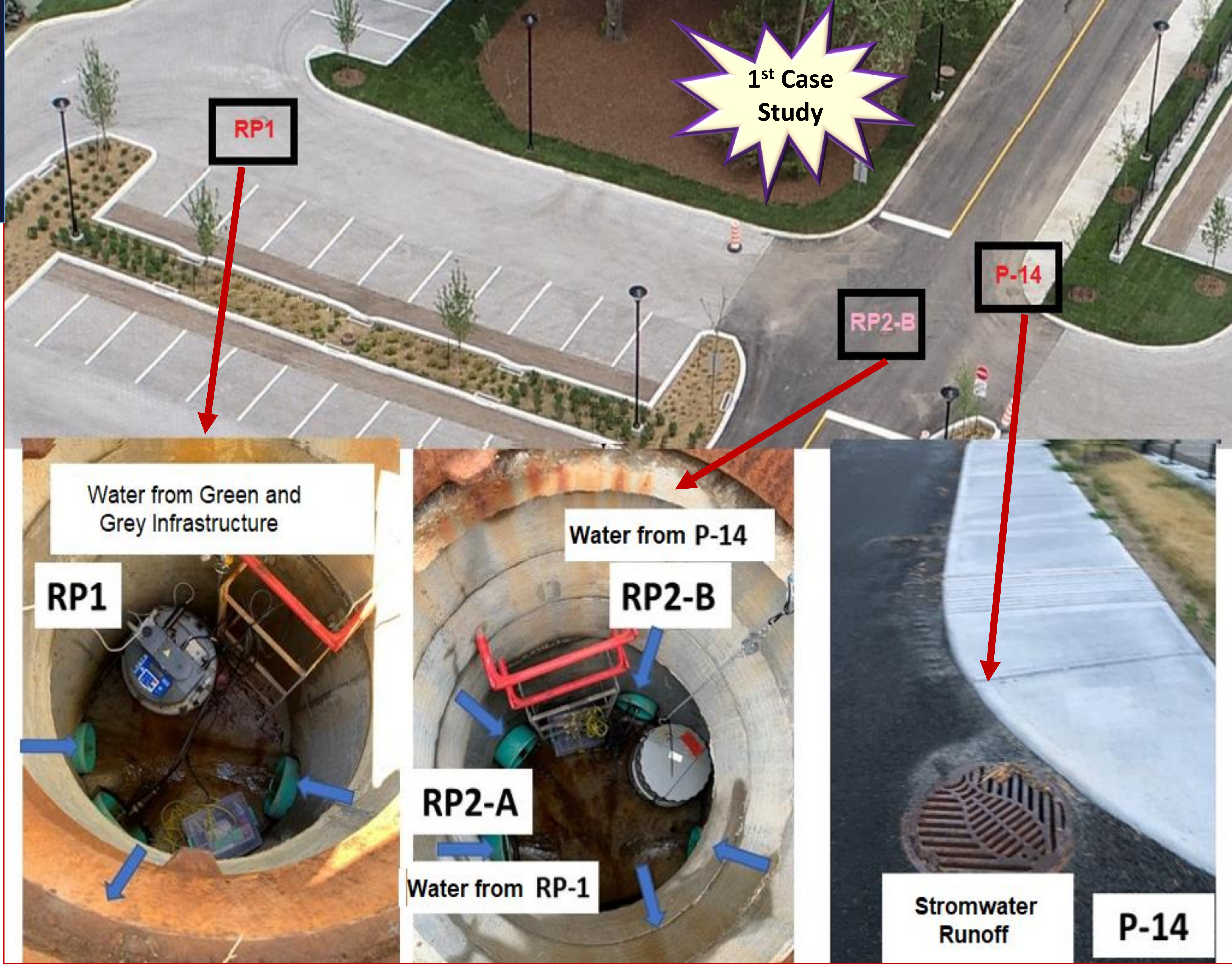
1st Case Study



Materials and Methods: Sampling Techniques

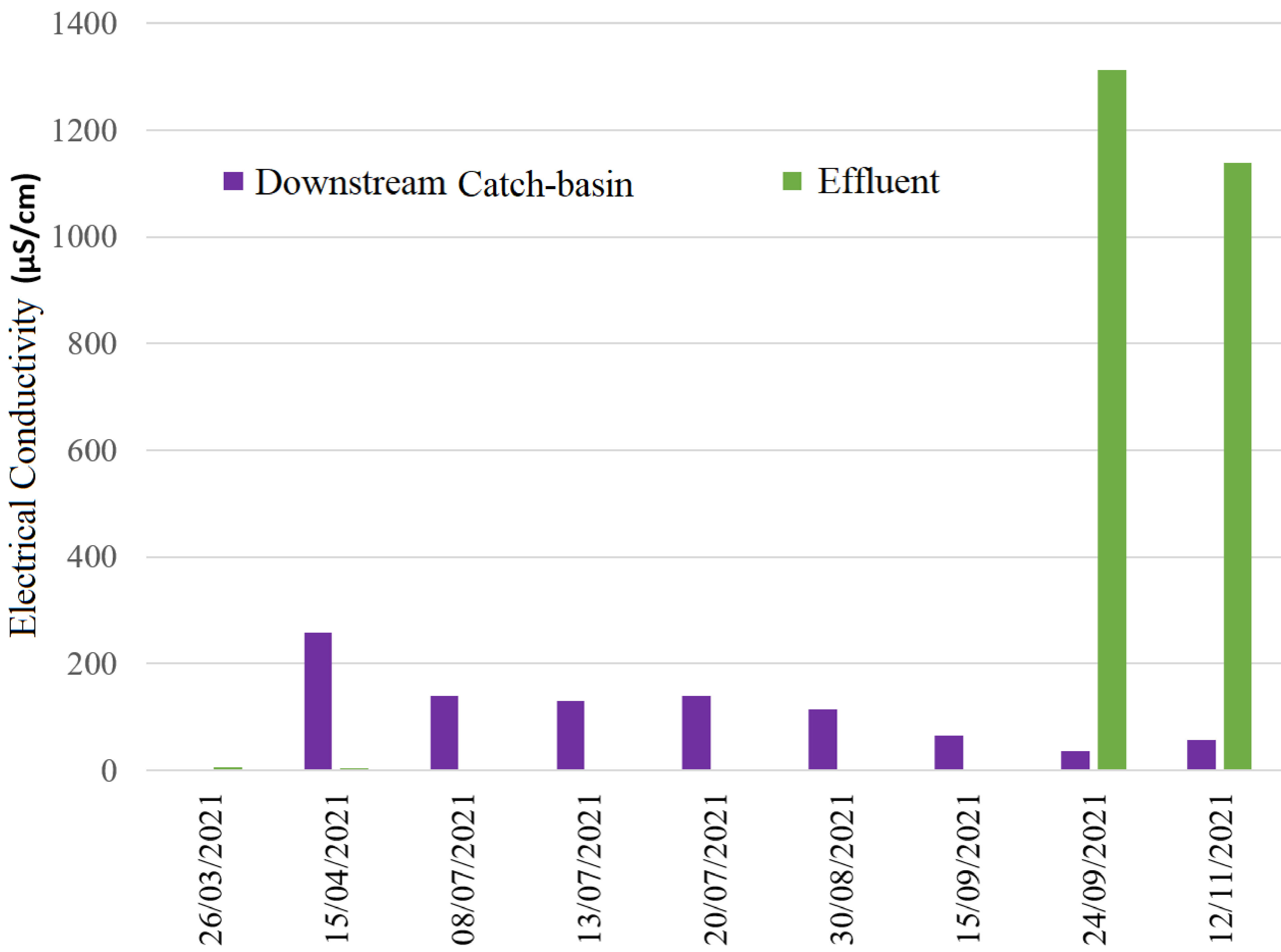
- ❑ Manual sampling (Impermeable parts (P14))

- ❑ Automatic sampling (Storm sewer network (RP1 and RP2-B))



Results: Conductivity

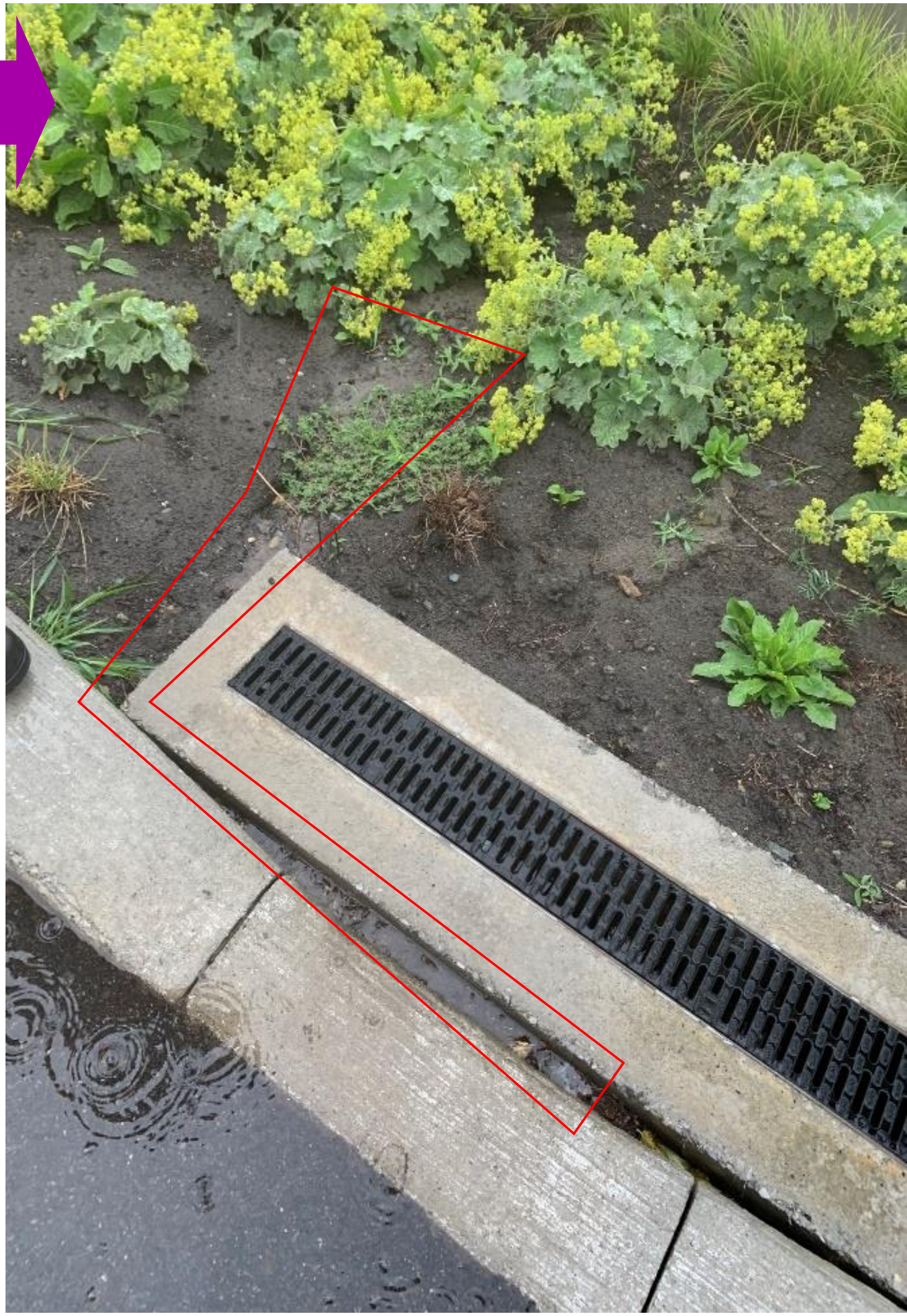
Tracking the Conductivity over time



Limitations: Gaps between the curb and the sedimentation basin

1st Case Study

Bypass of the sediment storage basin by runoff water entering a bioretention cell (the red outline represents the runoff path)



Dug soil at the entrance of a bioretention cell by runoff water

Spacing between the lowered curb at the entrance to a bioretention cell and a sediment storage pond

1st Case Study

Recommendations

To improve the pollutants removal efficiency in the Design of Green Infrastructure:

- Both aerobic and anoxic conditions should be provided to allow for nitrogen removal;

- For phosphorus, the removal rate depends on the Retention Time and the Composition of the Soil (e.g. high percentages of organic matter).

The 2nd Case Study

Objectives

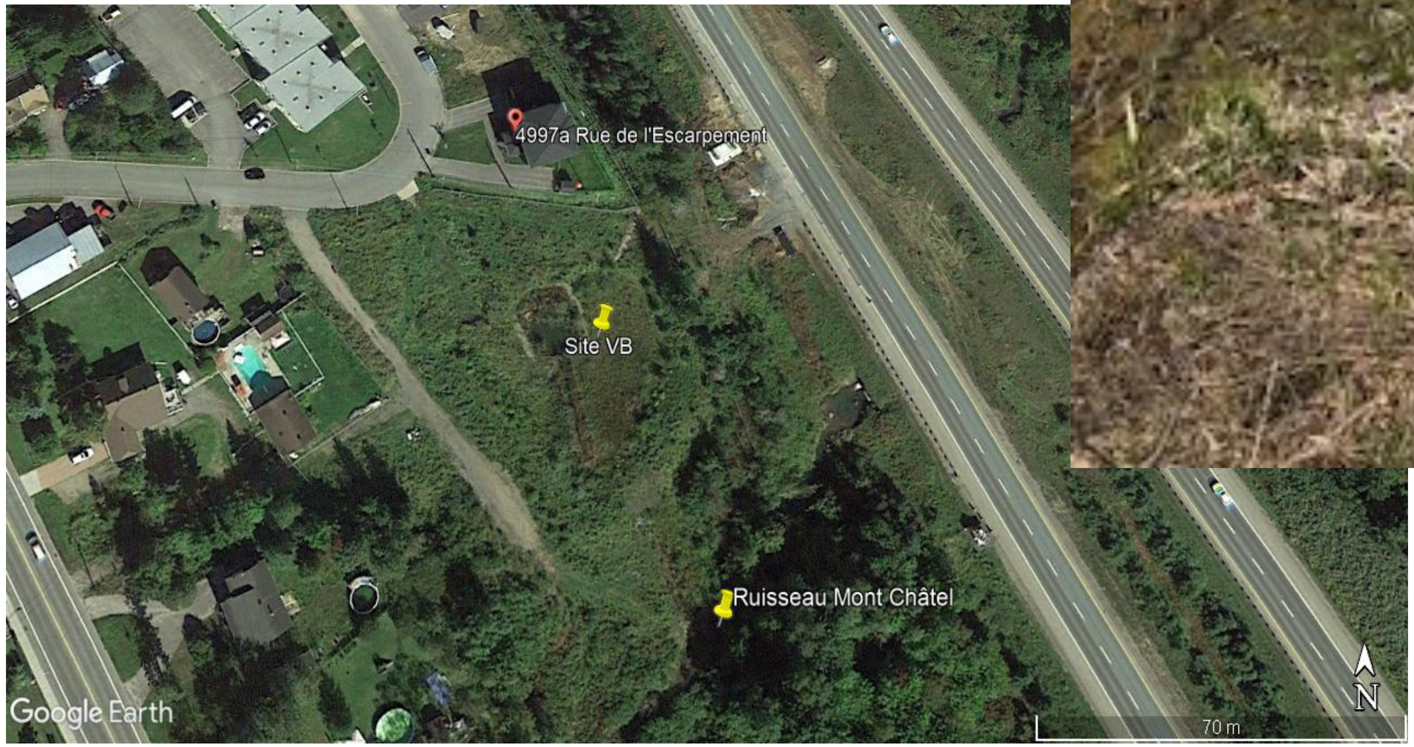
2nd Case Study

- Evaluating the Hydraulic/Hydrological behavior
- Water Quality (pollutant removal) Efficiency
- Three different types of detention basins as End-of-Pipe Stormwater Control Structures
- In Southern Quebec
- June to September 2019 and 2020.

2nd Case Study

Stormwater (End-of-Pipe) Control Structures

Dry detention basin (DDB)



- Quebec city
- Small size (2300 m3)
- Lots of vegetation
- Residential area

Stormwater (End-of-Pipe) Control Structures

2nd Case Study

Dry detention basin with central flow channel (DBC)

- City of Trois-Rivières
- Large size (7800 m3)
- Little vegetation
- Residential area (under development)

2nd Case Study

Stormwater (End-of-Pipe) Control Structures

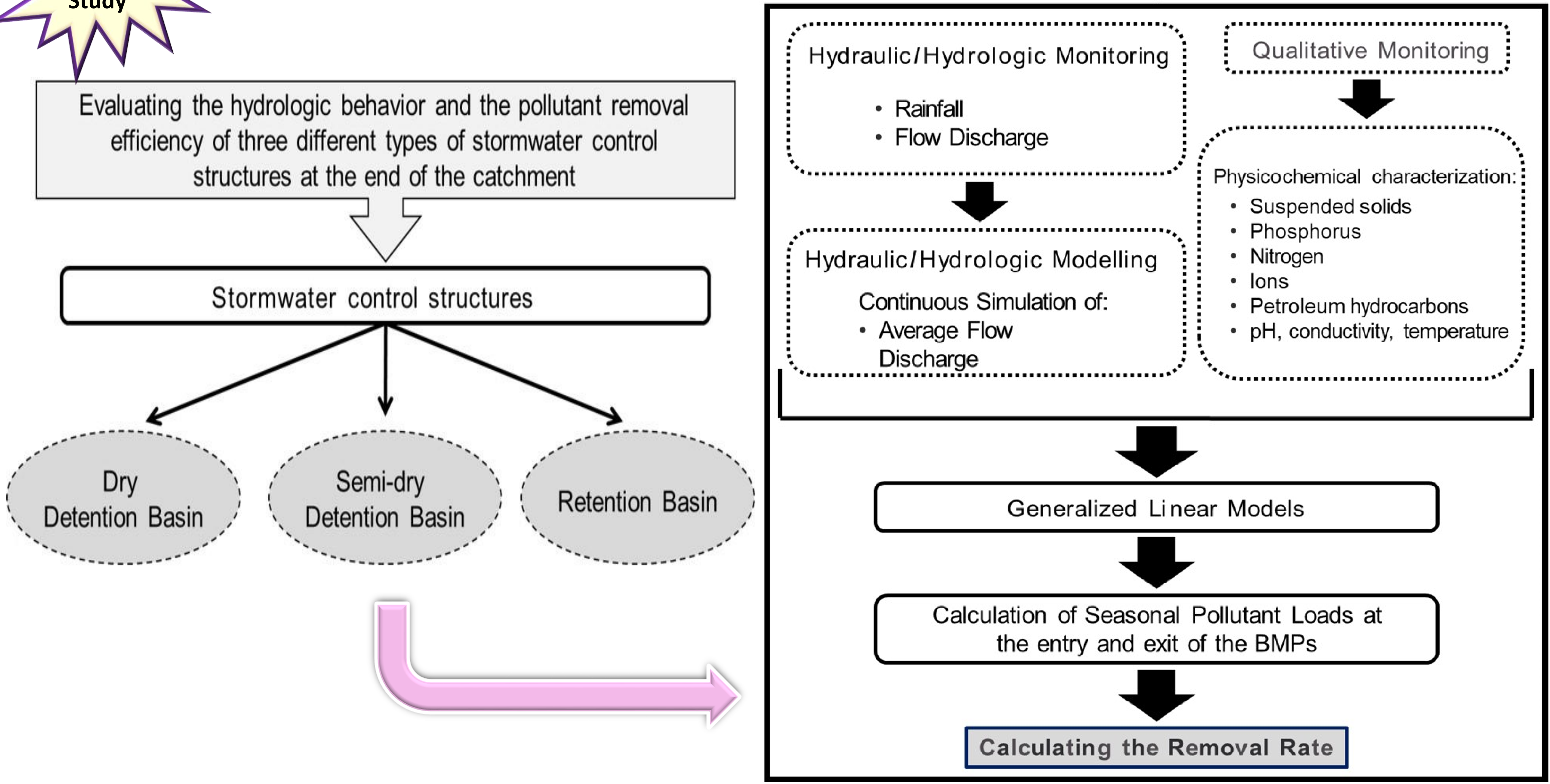
Permanent retention basin

(RB)

- Quebec city
- Large size (23,380 m3)
- Commercial sector, along the highway

Methodology

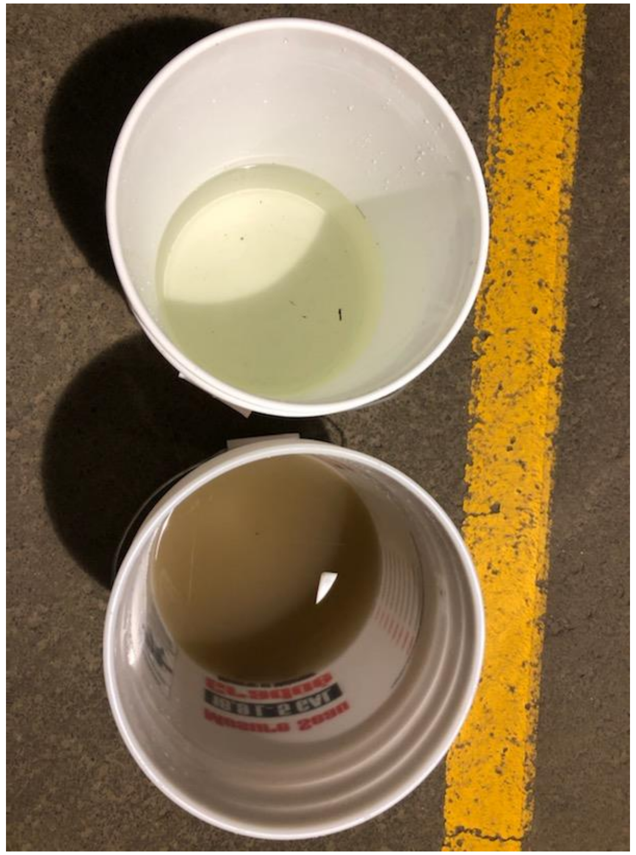
2nd Case Study



2nd Case Study

Methodology: Stormwater Quality Monitoring

- Composite water samples were collected at the inlet and outlet of structures (i.e. Upstream and Downstream of gthe basins)
  to calculate the average concentration of pollutants for each rainfall event)



2nd Case Study

Methodology: Stormwater Hydraulic/Hydrological Monitoring

- Rainfall measurement at the three study sites (using tipping bucket rain gauges)
- Flow measurement (DDB and DBC)
- Ultrasonic probe flow-meter (level and velocity)
- weir
- Pressure sensors (level)

2nd Case Study

Methodology: Qualitative and Quantitative Simulations

Hydrological/hydraulic modeling

- SWMM
- Quantitative data
- Calibration and validation

Generalized linear models

- R software
- Quantitative data + qualitative data
- Relationship between hydrological data (average intensity of rain) and the EMC of pollutants

Rain → SWMM → Flow rate

Rain → Generalized Linear Model → EMC

Methodology: Calculating the Pollutant Load

2nd Case Study

Pollutant Load calculation

- 10-year rainfall time-series (Quebec City)
- Incoming and outgoing load, removal rate

$$L = \sum_{i=1}^{n} \bar{Q}_i \cdot \bar{C}_i \cdot d_i \cdot 0.0036$$

$\bar{L}$ is the pollutant load (kg/season)

$\bar{Q}_i$ is the average discharge of a rainfall event i (L/s)

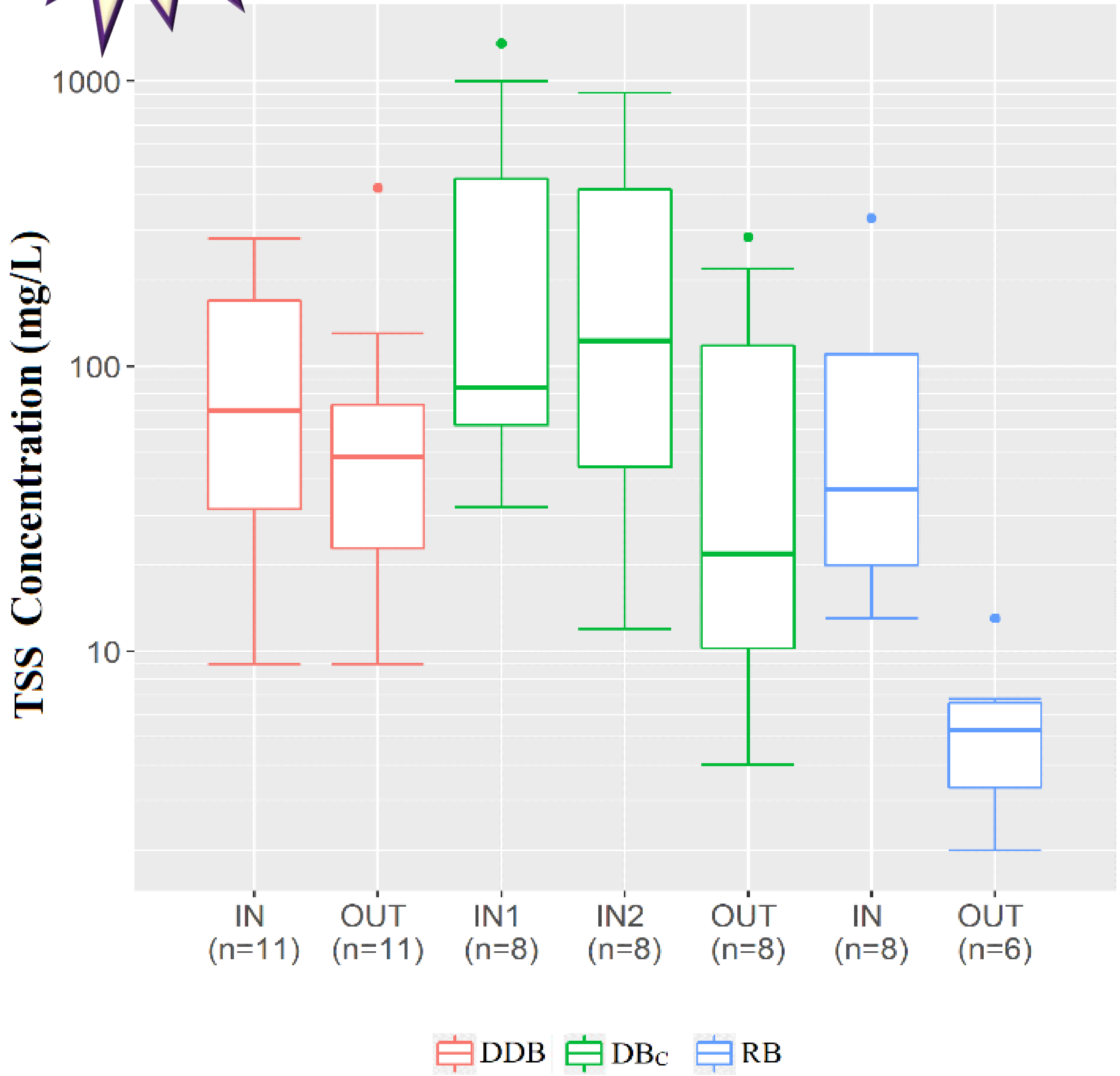
$\bar{C}_i$ is the EMC of the pollutant during a rainfall event i (mg/L)

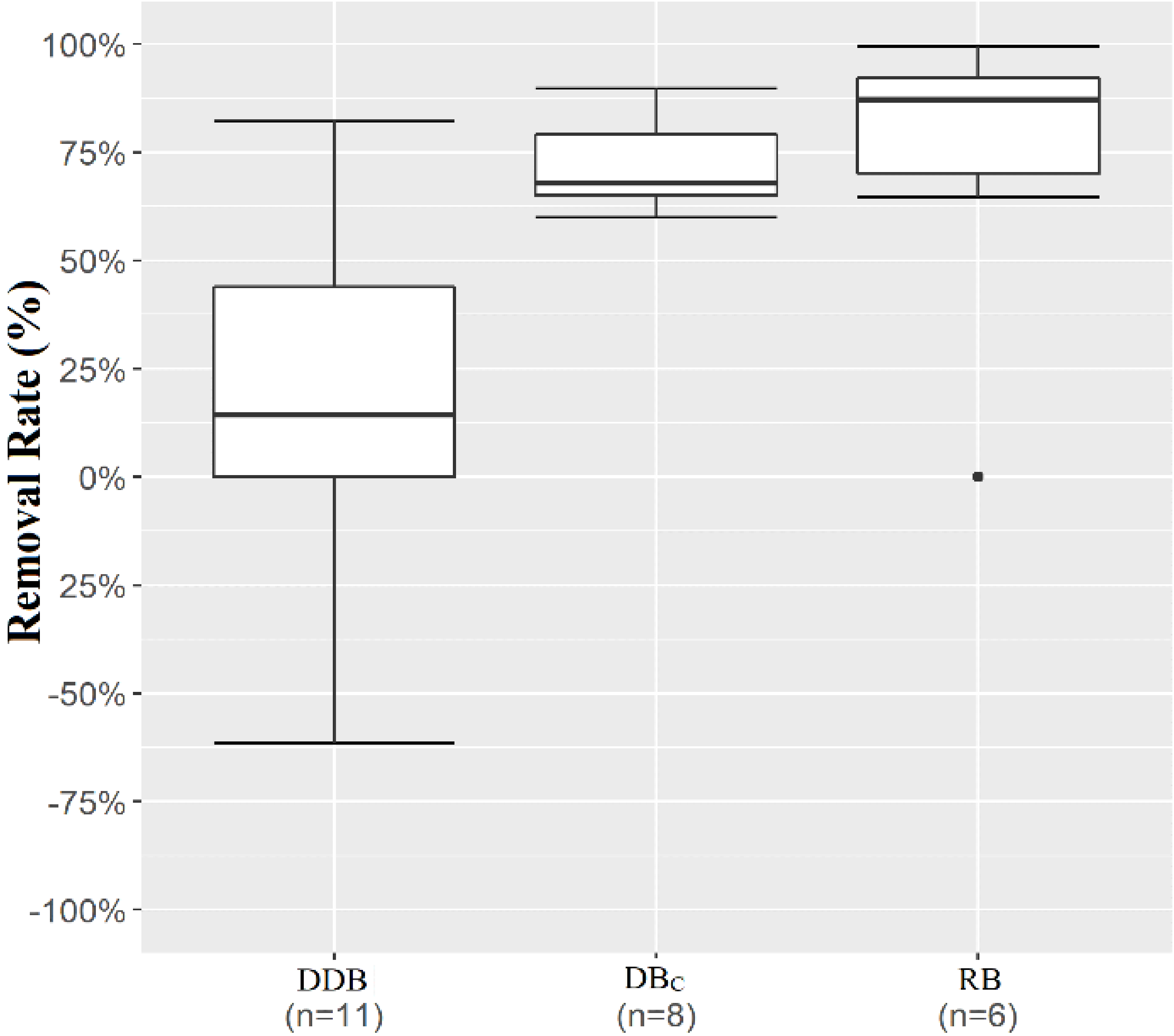
d_i is the duration of event i (h)

n is the number of events in a season (June to October)

Results: Total Suspended solids (TSS)

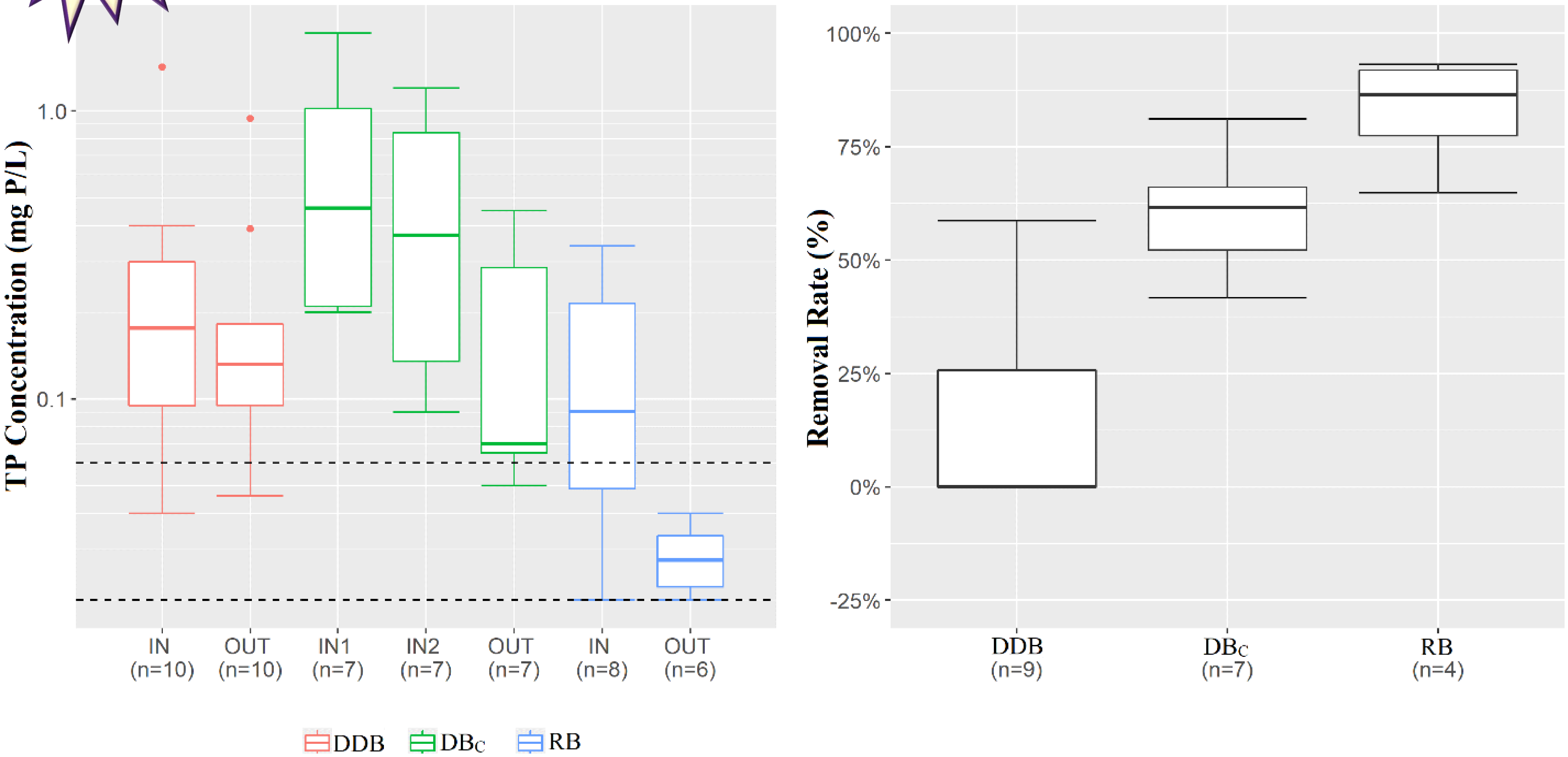
2nd Case Study





2nd Case Study

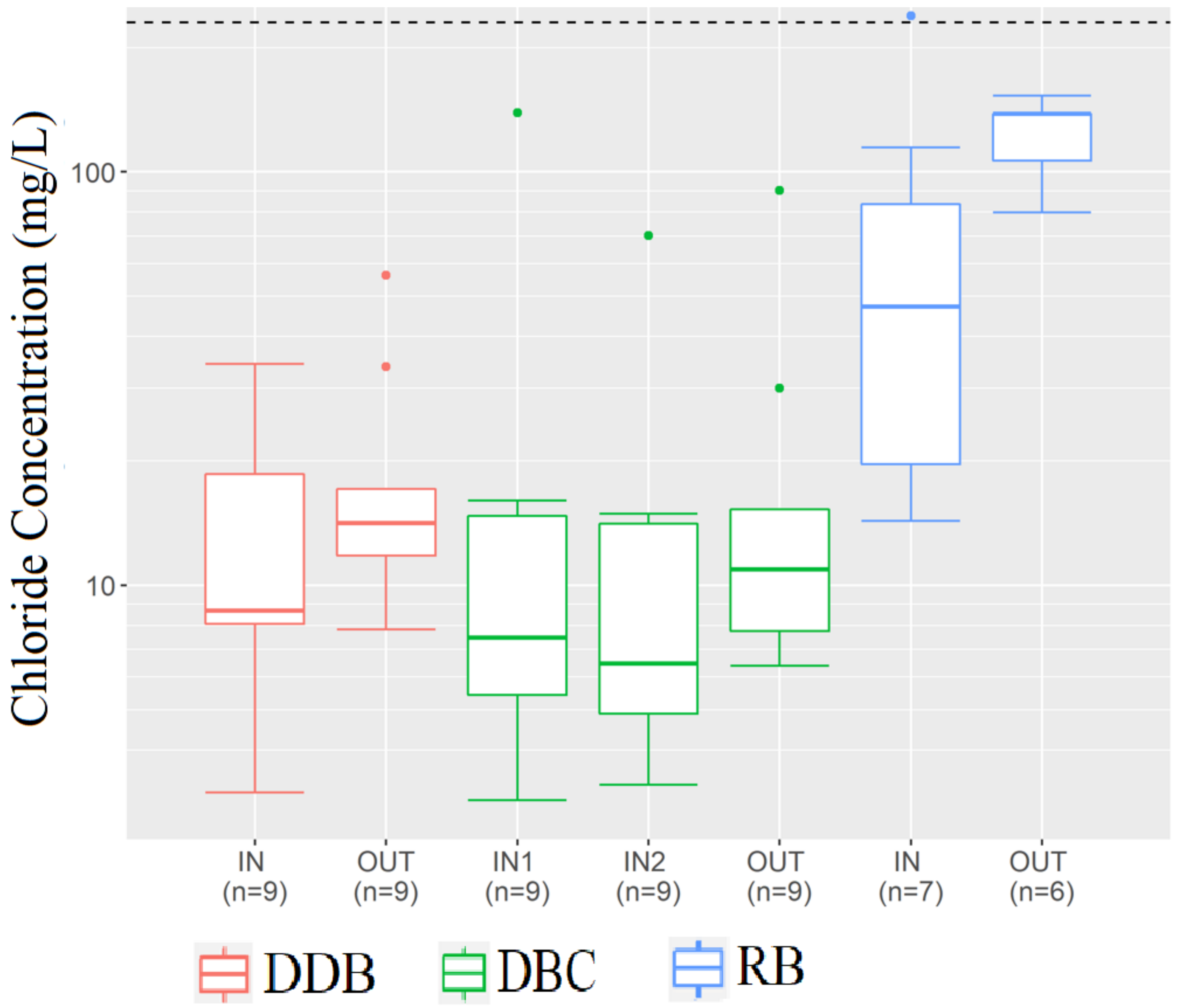
Results: Total Phosphorus (TP)



2nd Case Study

Results: Ions (road salts)

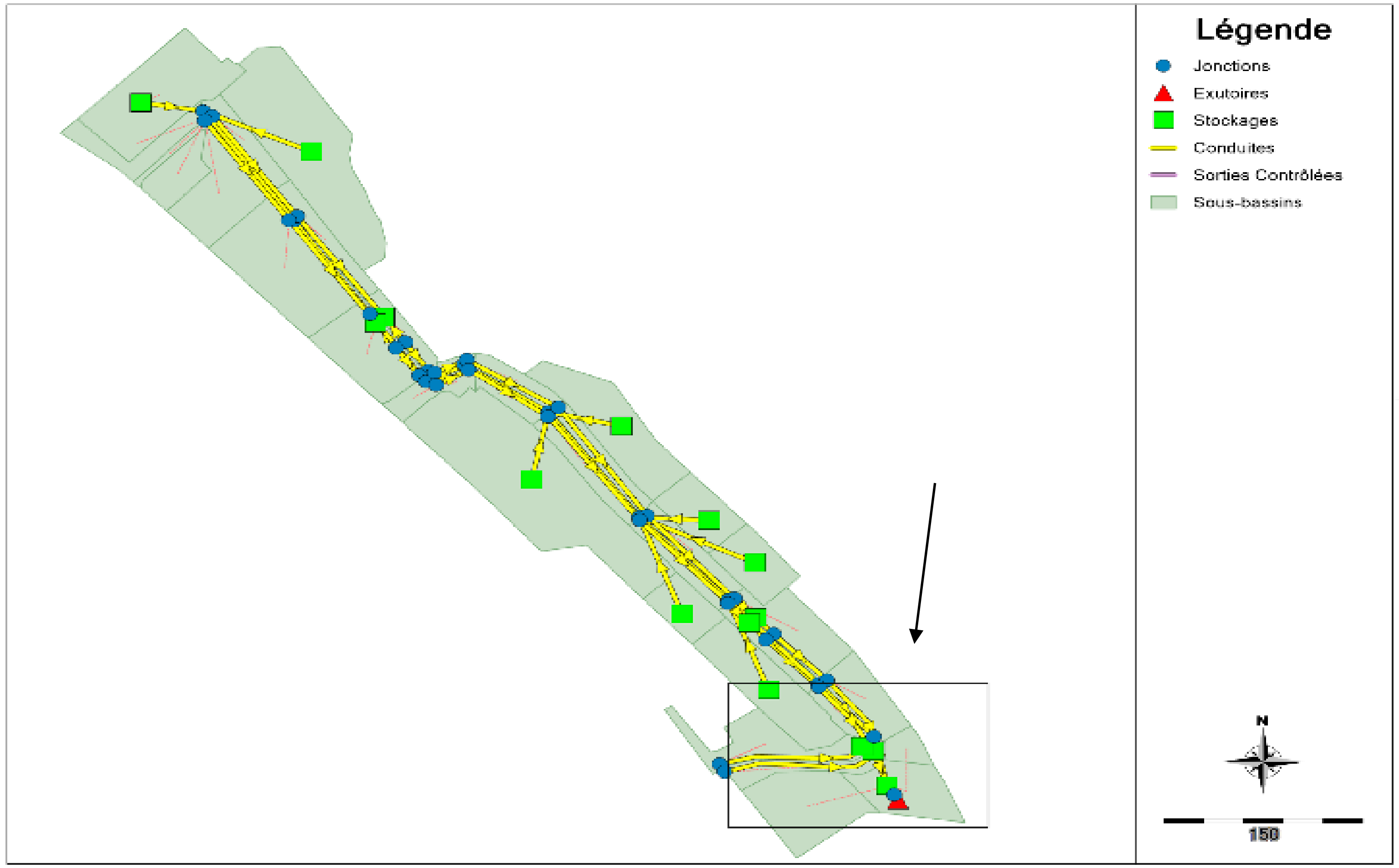
Basin	Removal rate (+) or increase (-) (median)				
	Cl^-	Na^+	Ca^{2+}	K^+	Mg^{2+}
DDB (n=9)	-64%	-59%	-29%	-36%	-53%
DBC (n=8)	-28%	-57%	-2%	-12%	-29%
RB (n=6)	-244%	-155%	41%	37%	-81%

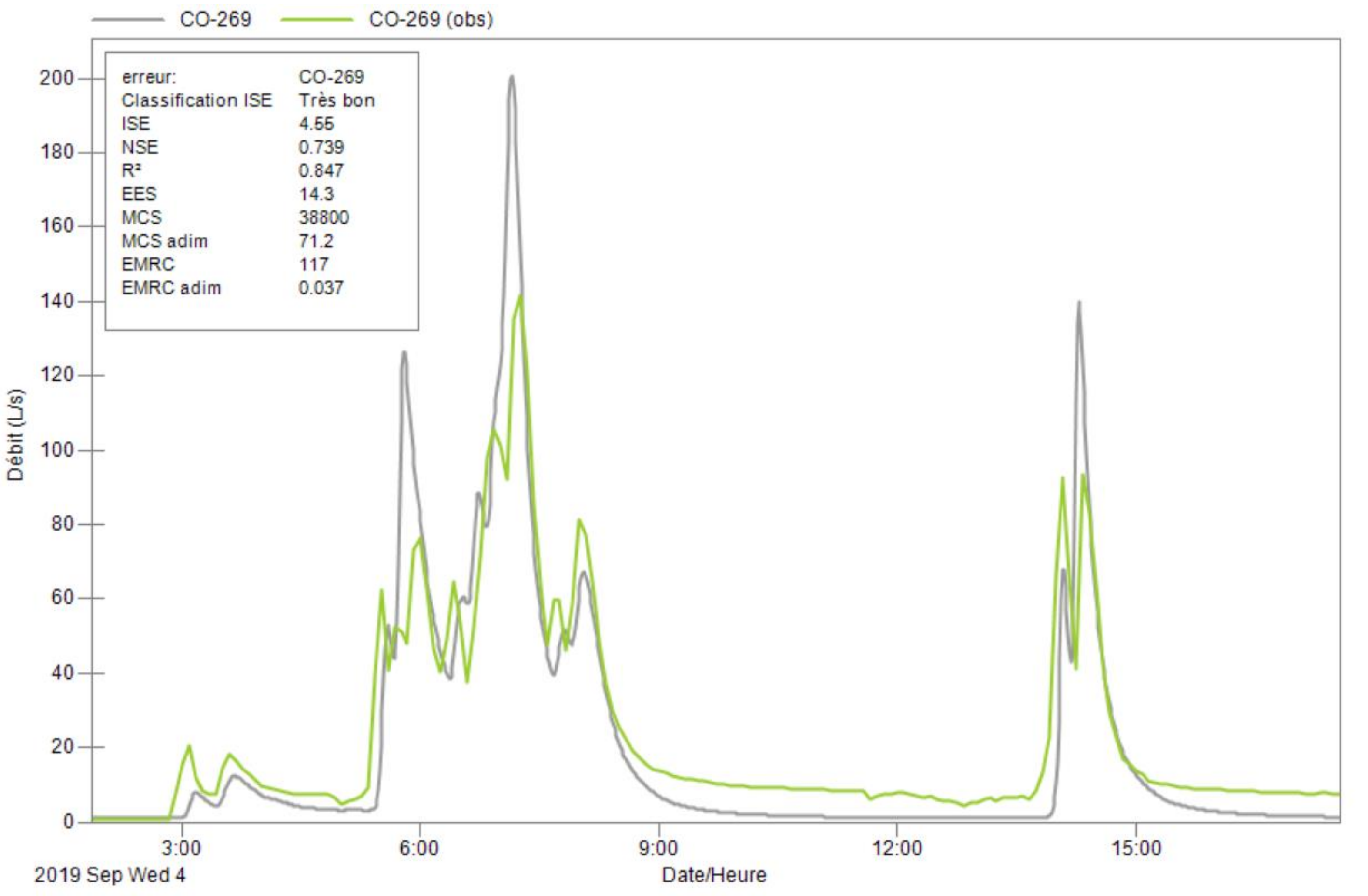


2nd Case Study

Results: Hydrological/hydraulic modeling (SWMM)

- Characteristics of sub-watersheds (impermeability, area, roughness, etc.)
- Characteristics of the stormwater network





Example:

- Calibration
- Event of September 4, 2019
- Inflows (simulated and observed)

2nd Case Study

Results: Pollutant Loads

Simulated Summer Loads (June to September), over 10 years (2010 to 2019):

Parameter	Basin	Incoming load (kg/season)		Outgoing load (kg/season)		Load retained (kg/season)		Load removal rate (%)	
		Median	IQR	Median	IQR	Median	IQR	Median	IQR
TSS	DDB	674	187	470	131	204	58	30	1
	DBC	1849	461	459	103	1369	392	74	1
TP	DDB	1.8	0.5	1.5	0.4	0.3	0.1	18	1
	DBC	2.6	0.6	1.3	0.3	1.3	0.4	47	3

Conclusion

2nd Case Study

- ❑ Water Quality Efficiency for TSS and TP → RB > DBC > DDB

(Even when considering uncertainties)

- ❑ RB: Longer retention time in the basins with permanent pool → Particle Settlement

- ❑ DDB: The lowest and most variable median removal rates

- ❑ DBC:
  - The water volume permanently flowing in the central channel
  - And High length to width ratio

  } Increased Particle settling

Advantage → Management of rainfalls with Lower Volume

Recommandations

2nd Case Study

- Road Salt Accumulation (RB) was significant

Monitoring the conductivity or chloride concentration in the effluent from this basin over the next few years is recommended;

The 3rd Case Study

3rd Case Study

Introduction to the Case Study

Objective

- ❑ Reducing the Sewer Surcharge and Local Flooding

The Basin and its tributary areas

- Mostly single-family residential buildings
- Impermeability: 42%

Study area

The main and contributory basins

Methodology

3rd Case Study

Source control solutions are selected by spatial analysis taking into account the built environment and vulnerable locations.

3rd Case Study

Summary of Results

- *Source Control Solutions are required to prevent inundation in the local street level.*

The 4th Case Study

4th Case Study

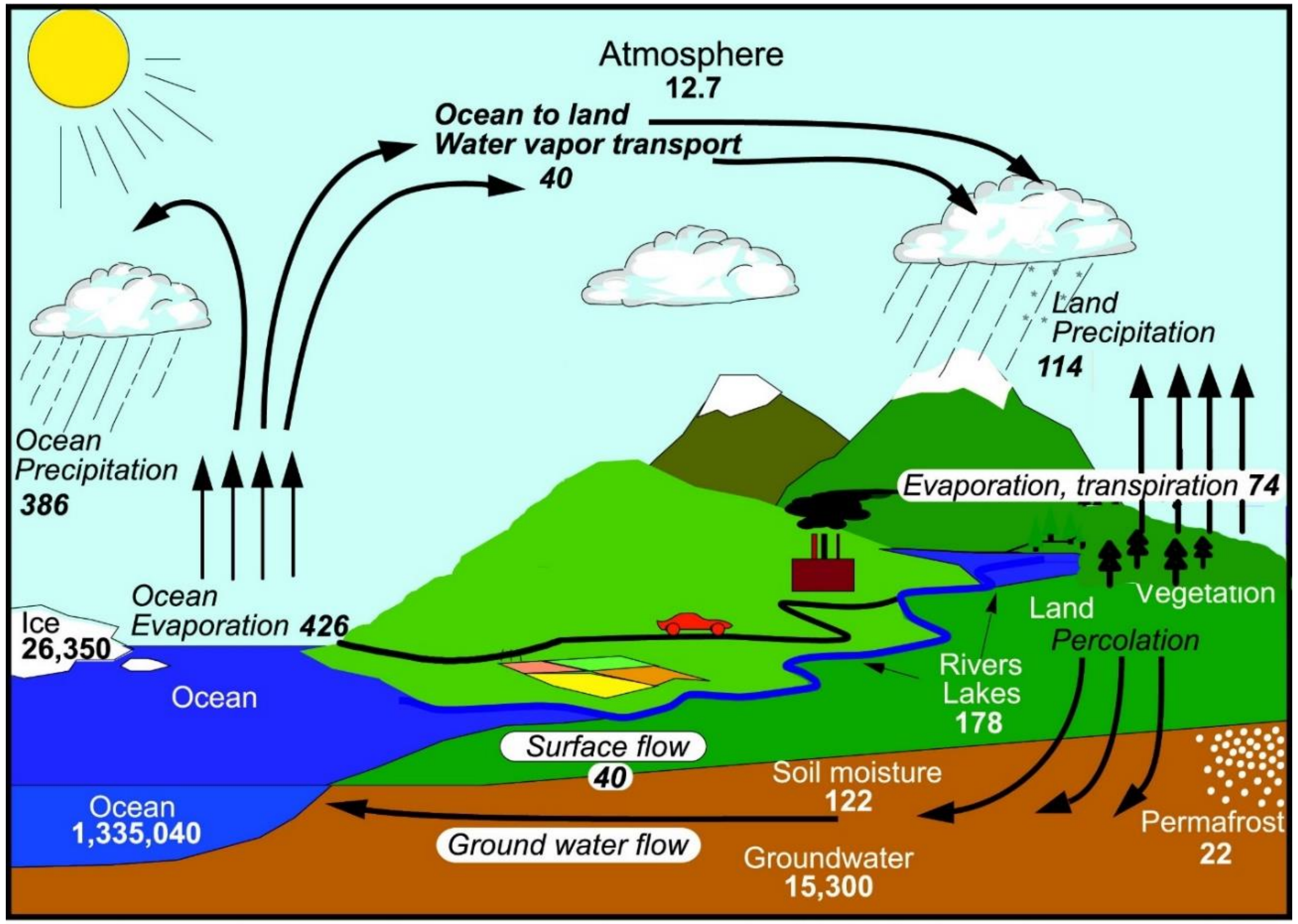
Introduction: Climate Change as a major challenge

Climate Change → ***Change in precipitation Patterns*** → ***Exacerbating Flood Risk***

- Spatio-Temporal trends
- Rainfall Amount
- Rainfall Intensity
- Rainfall Frequency

❖ Adverse impacts of climate change on Urban Draiange Systems (UDS)

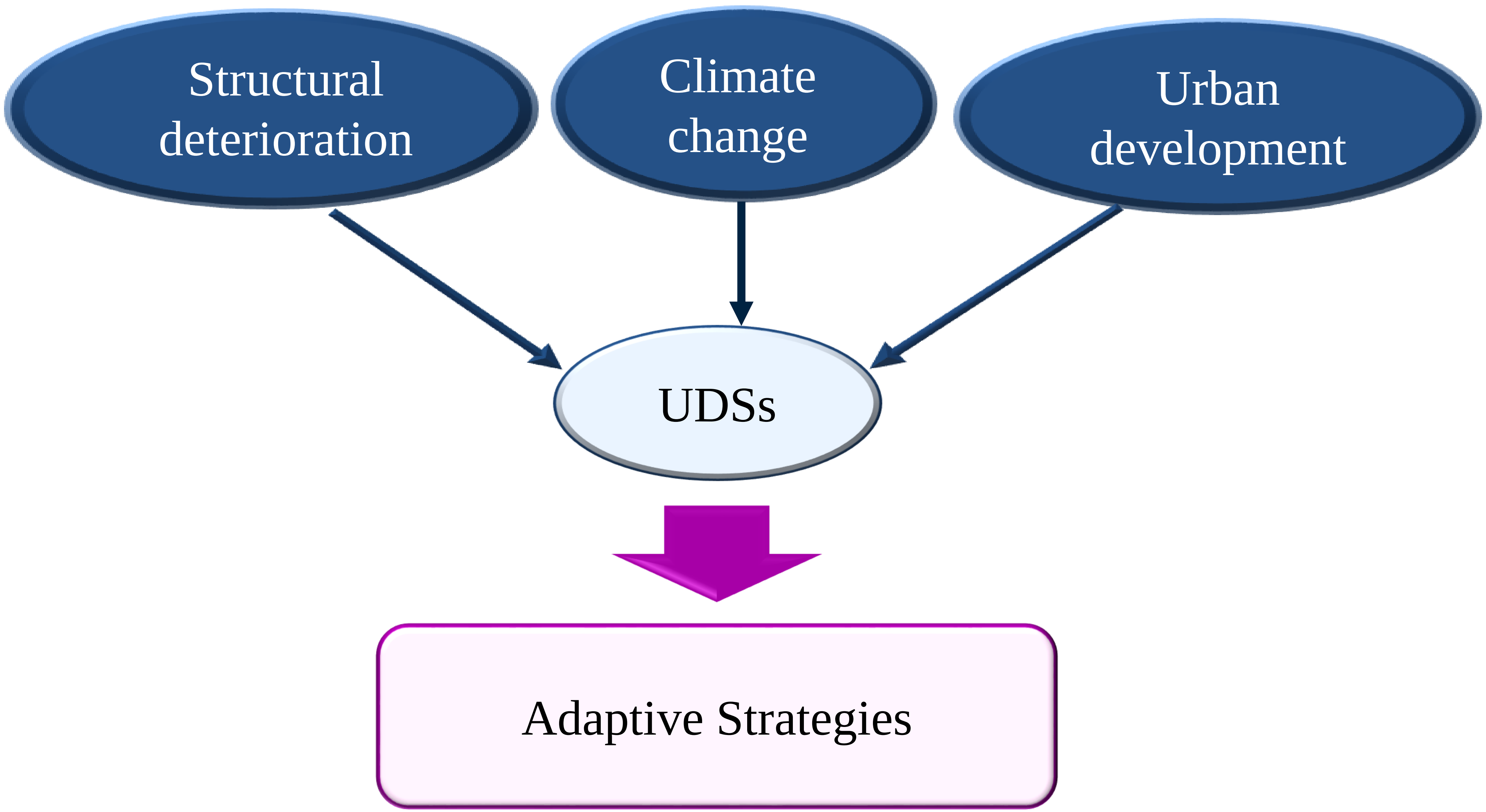
❖ UDS is a Key Infrastructure in response to flash floods in Cities.



Units: Thousand cubic km for storage, and *thousand cubic km/yr* for exchanges *1990s

4th Case Study

Introduction: Climate Change as a major challenge



4th Case Study

Objectives

- Investigatiung the Impcat of Climate Change on the Urban Drainage Performance (i.e. Resilience, Reliability, Vulnerability)

- Adaptation to Climate Change

4th Case Study

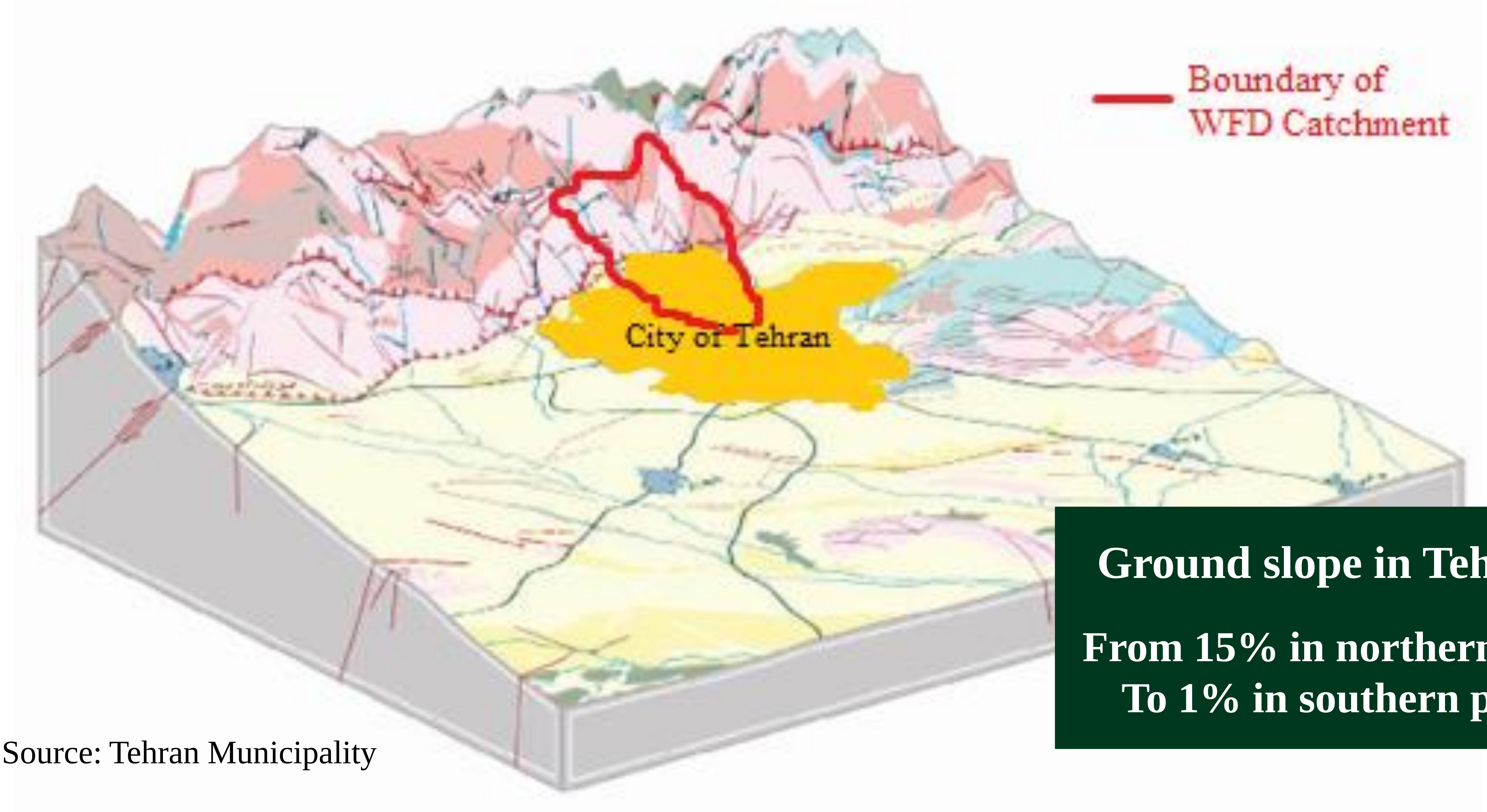
Introduction to the Study Area: City of Tehran

- Located in a semi-arid region in south of Alborz mountains.
- A population of around 9 million, with an area more that 700 Km^2.

- Covered by dense buildings, streets, and impermeable surfaces and a few parks.

Introduction to the Study Area: West Flood-Diversion (WFD) Catchment

Tehran Topography and Slope



Ground slope in Tehran:

From 15% in northern parts
To 1% in southern parts

Source: Tehran Municipality

4th Case Study

Predicting Future Climatic Condition (rainfall)

- Daily future projections of the model obtained from World Data Center (WDCC) Climate website (AR5);
- Under three Representative Concentration Pathways (RCP2.6, RCP4.5, and RCP8.5) scenarios;
- GIS was used for data extraction from the specific computational cell where the catchment is located in.
- Change Factor (CF) method was also used to downscale and correct the future projections.

4th Case Study

Rainfall-Runoff Simulation

SWMM *(Version 5)*

Simulating a network composed of both open-channels and covered channels

with rectangular and horseshoe-shaped cross-sections

- Width of channels from 1.4 m to 30 m
- Channels' height from 1.4 m to 6 m.

System configuration in SWMM:

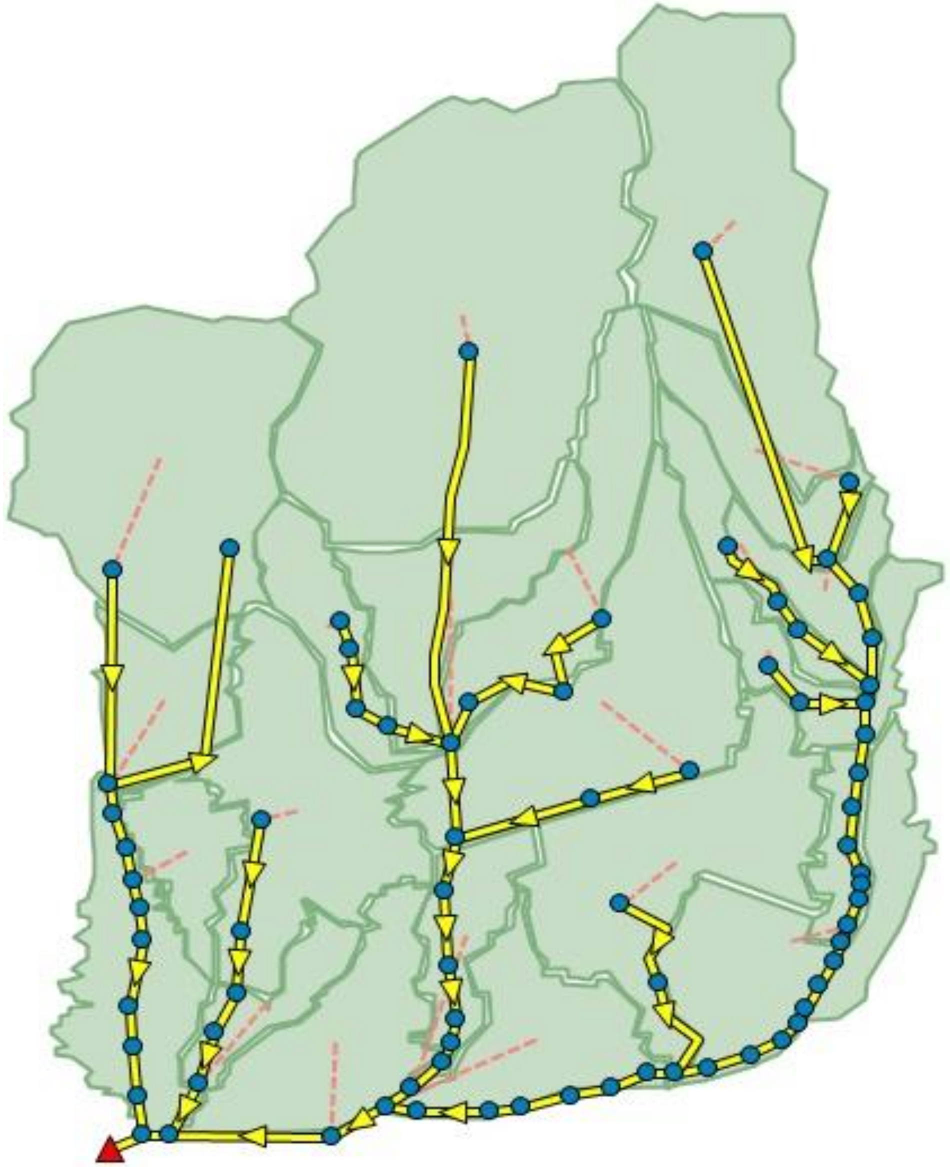
73 nodes plus an outlet, 74 links as drainage channels,

Around 67 Km drainage channel was modeled.

Rainfall-Runoff Simulation

SWMM Calibration and Validation

Type of analysis	Given variable at the outlet	MAE	RMSE
Calibration	*depth*	0.0081	0.0130
	velocity	0.0455	0.0614
Validation	*depth*	0.0106	0.0156
	velocity	0.0606	0.0744



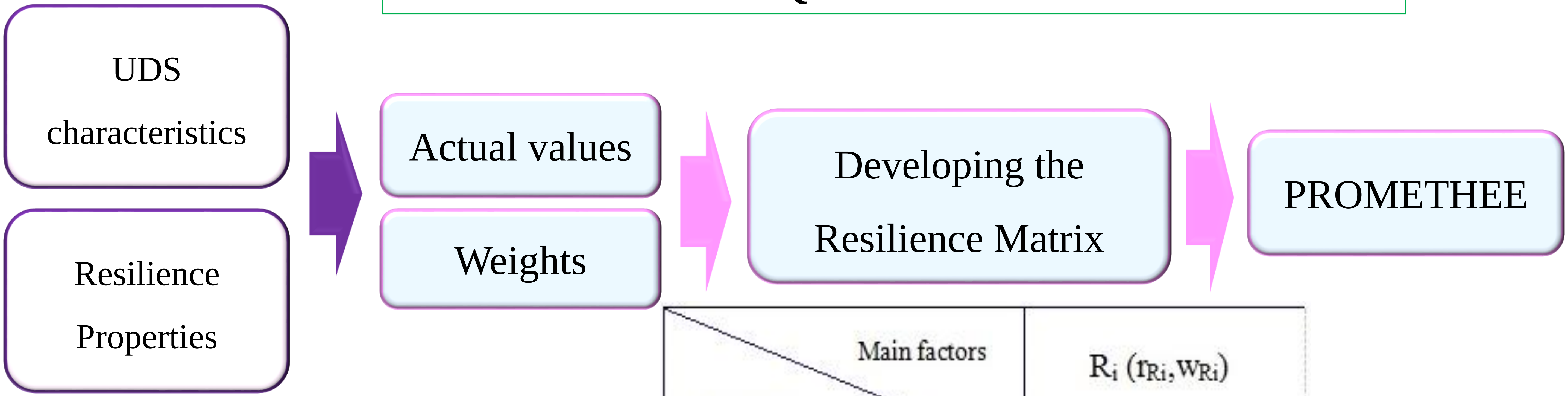
4th Case Study

Reliability

The probability that a system will perform its intended function (without any failure) for a specified period of time.

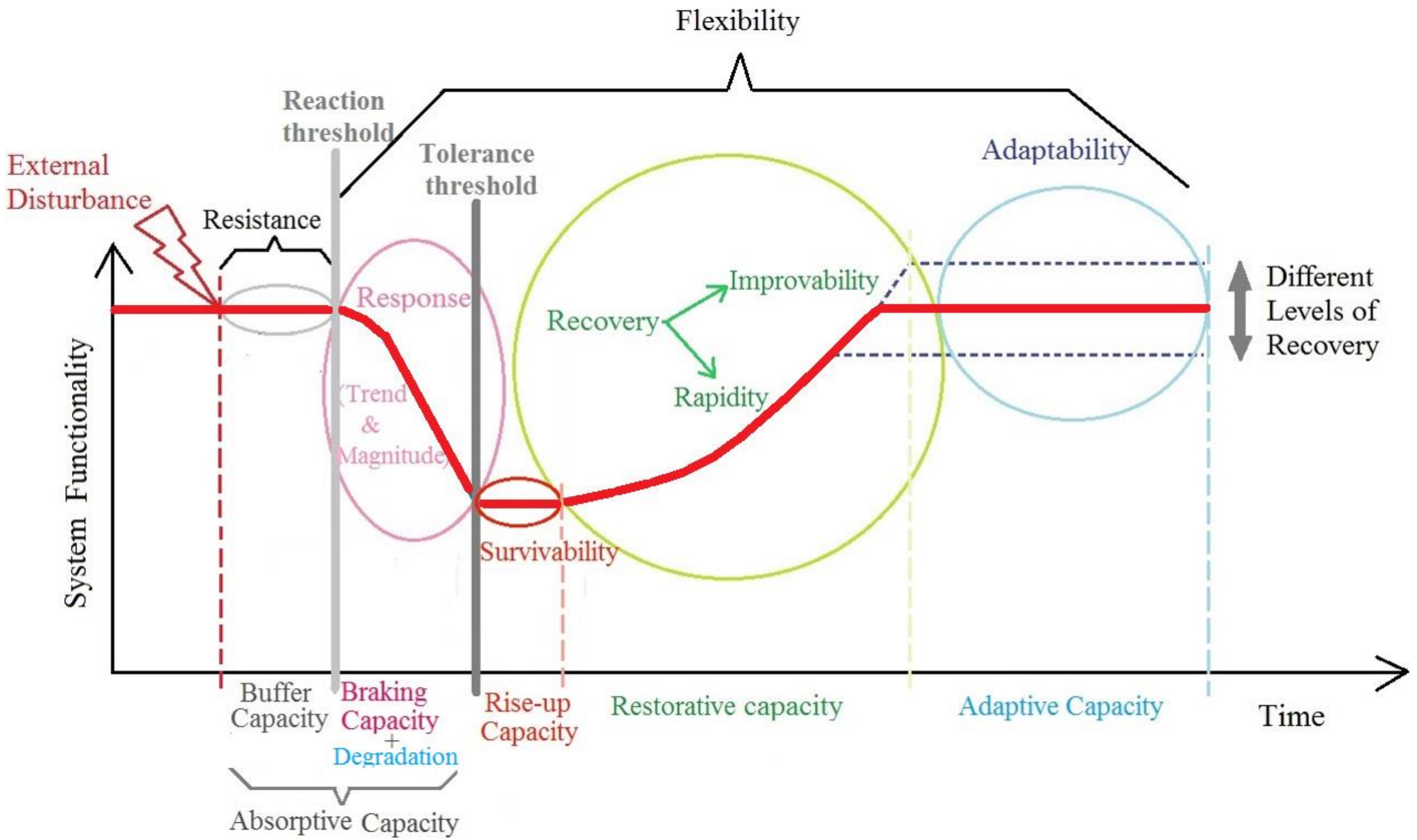
The number of times the system succeeds to the total number of times it operates.

Parametric-based Quantification of Resilience



Main factors / Domains	R_i (r_{Ri}, w_{Ri})
D_j (r_{Dj}, w_{Dj})	$r_{(Dj,Ri,1)} \times w_{(Dj,Ri,1)}$ $r_{(Dj,Ri,2)} \times w_{(Dj,Ri,2)}$ $\vdots$ $r_{(Dj,Ri,k)} \times w_{(Dj,Ri,k)}$

The system behavior in response to a disturbance



4th Case Study

Choosing the Appropriate BMPs for WFD Catchment

The study by:
Tahmasebi Birgani et al. (2013) → For a region near WFD catchment

Based on:

Technical → Flood volume; Time duration for recovery

Environmental → TSS Removal

Economic → Construction/maintenance costs

→

- **Permeable pavement**
- **Detention Basin**

Implementing Best Management Practices (BMPs)

4th Case Study

Not every location is appropriate for installing the Best Management Practices.

↓

BMPs' effectiveness is highly dependent on geographic situation they are installed.

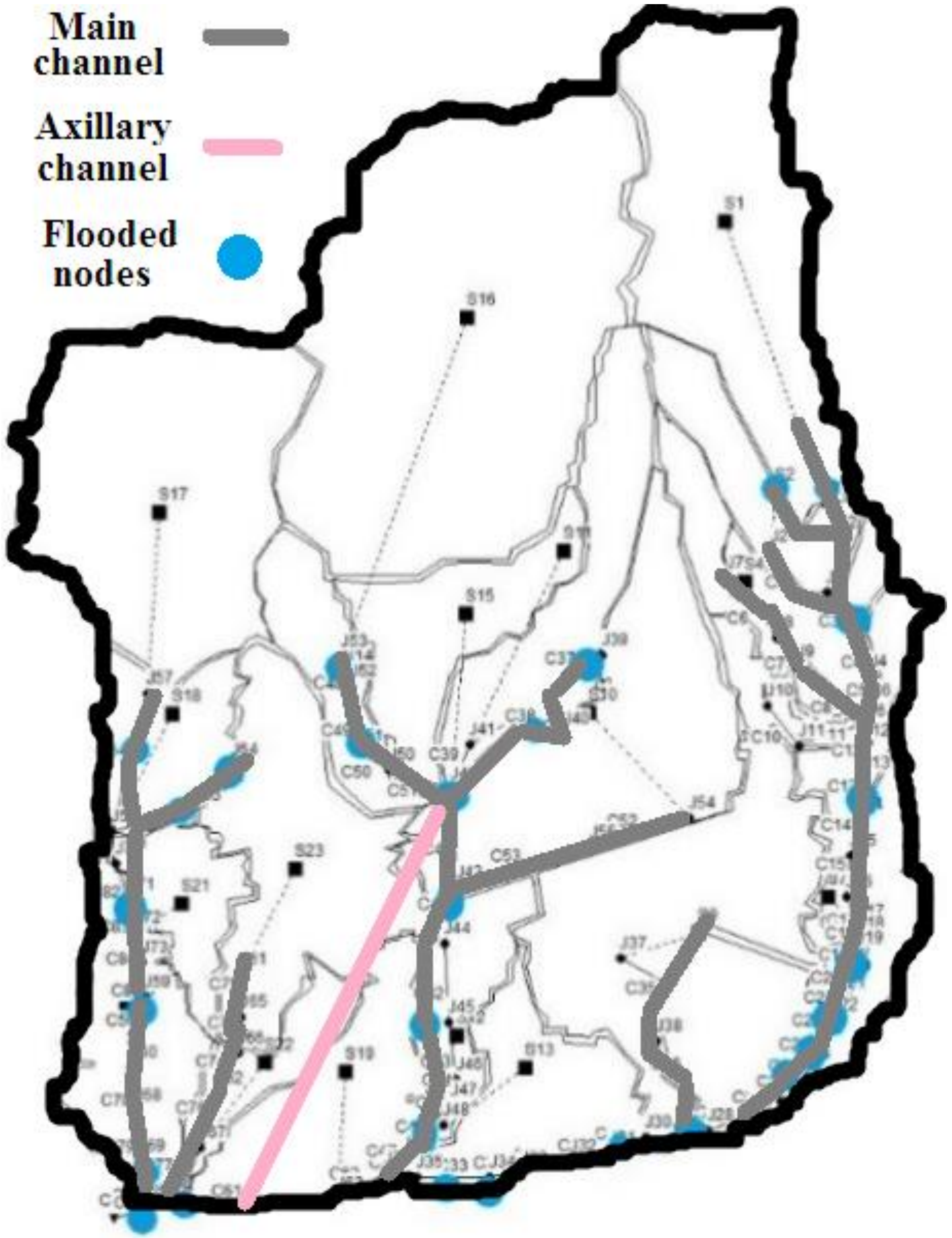
↓

Multi-dimensional nature of BMPs

4th Case Study

Scenarios for Solving the UDS problems

- ❑ Increasing the UDS capacity up to 30%
- ❑ Using auxiliary channels (parallel channels)
- ❑ BMP implementation alongside the drainage system Only in Urban areas
- ❑ BMP implementation alongside the drainage system both in Urbanized and Upstream suburbs



4th Case Study

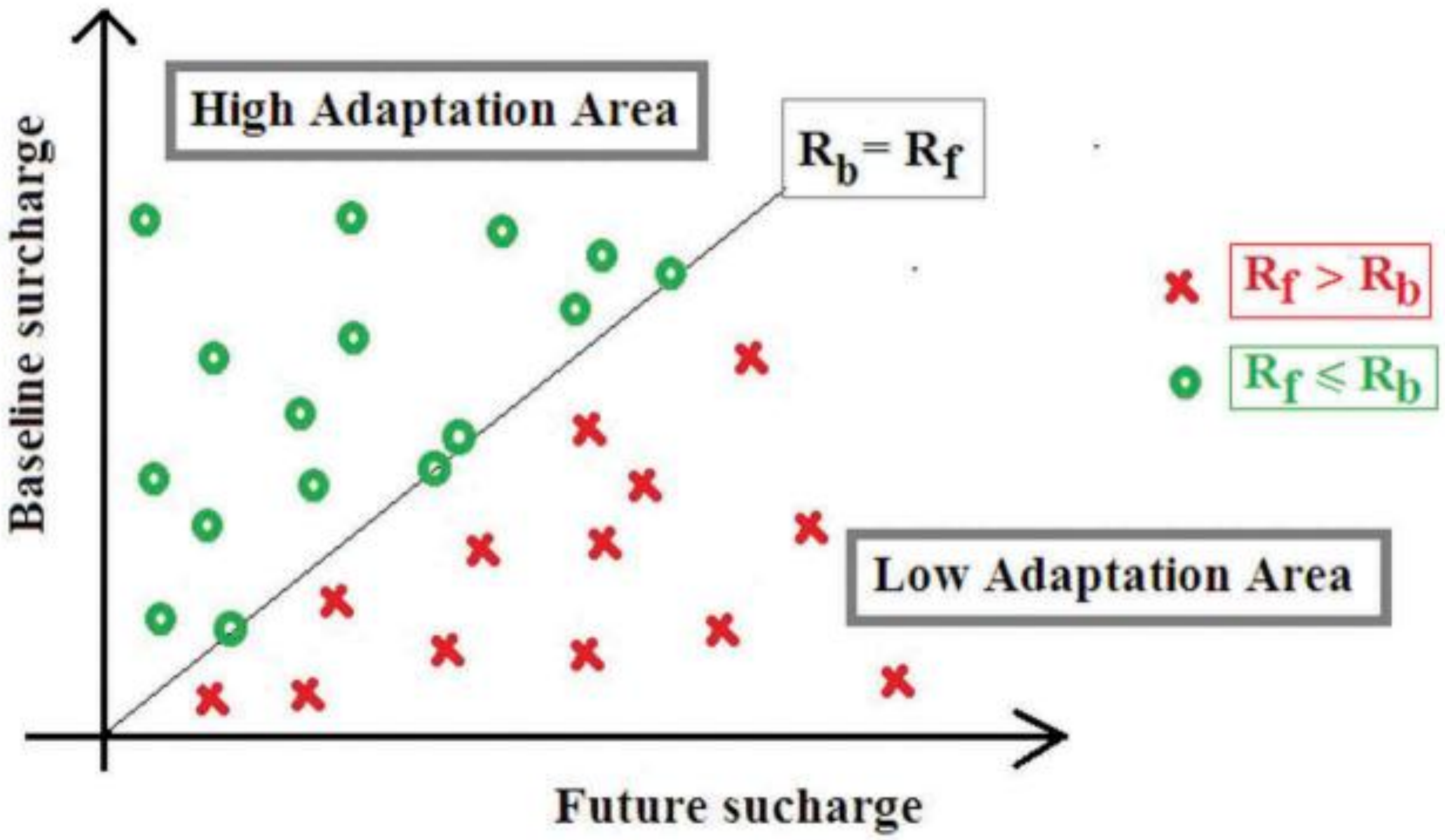
Climate change adaptability index (CCAI)

$$CCAI = P(R_f \le R_b) = \frac{\text{The number of times when } R_f \le R_b}{T}$$

The total number of time steps in the simulated period

$$0 \le CCAI \le 1$$

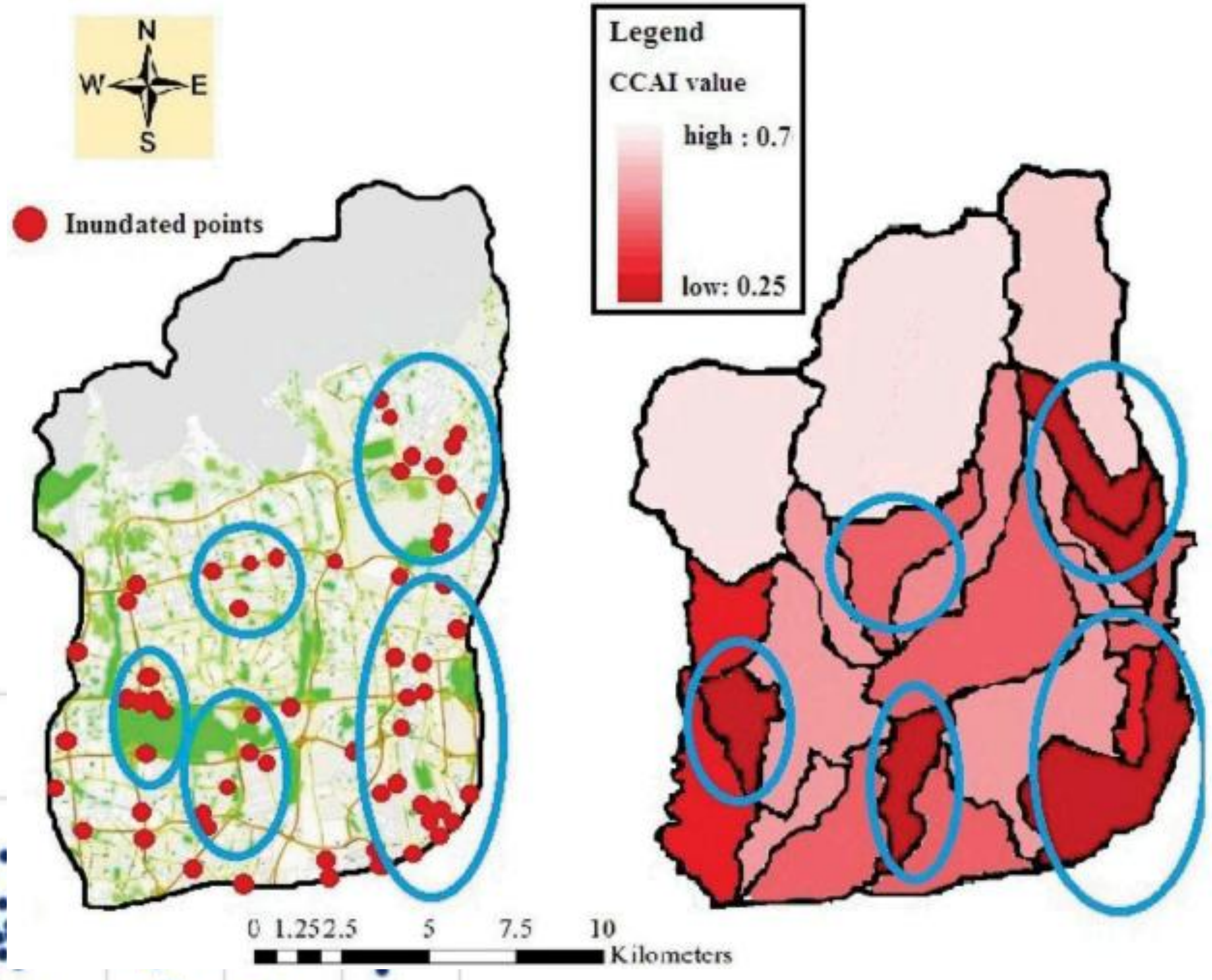
Zero Adaptability — Full Adaptability



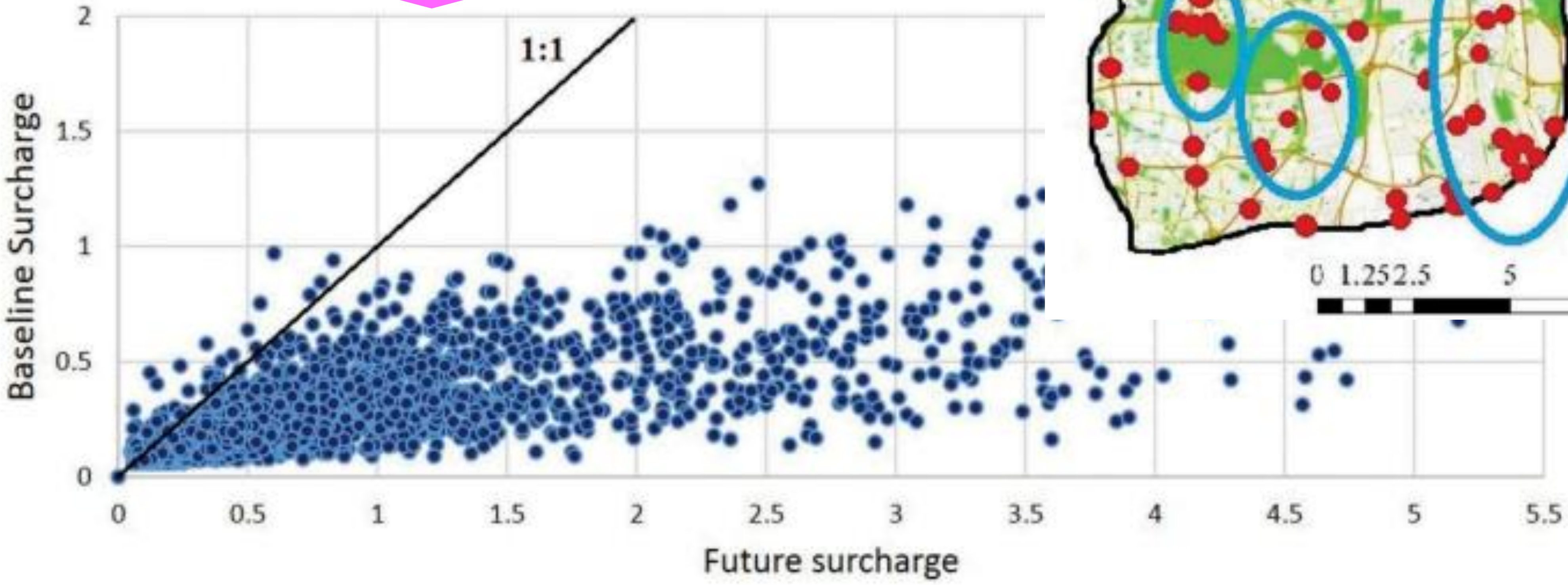
Rb: The simulated surcharged runoff volume in base-line climatic conditions

Rf: The simulated surcharged volume from the system in a future climate condition

CCAI Results’ Validation



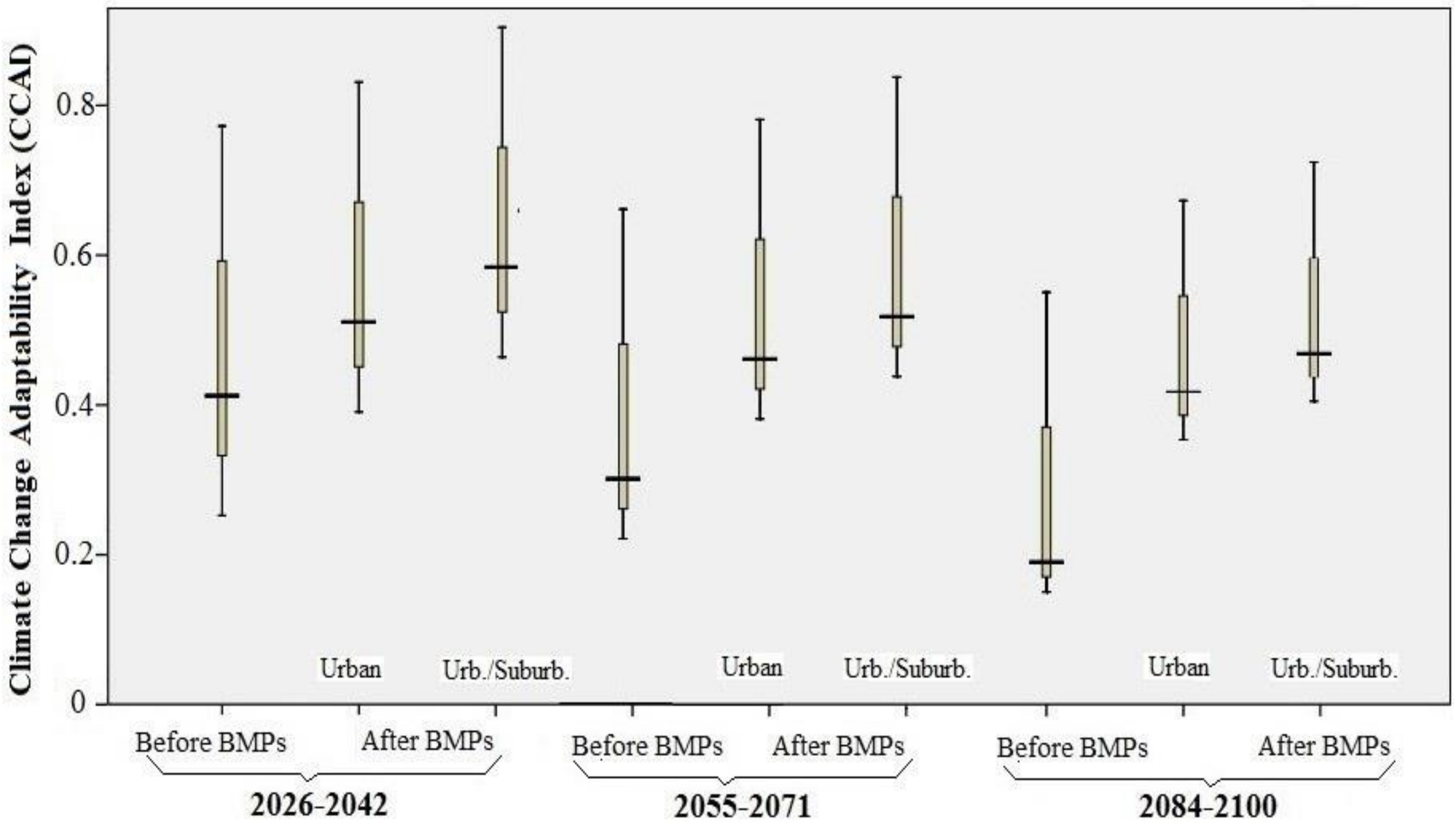
Rate of change in surcharge from the UDS under the 2084–2100 scenario compared to 1990–2006 with no BMP implementation.



Climate change adaptability index (CCAI)

4th Case Study

The extent of CCAI in different nodes of the UDS before and after BMP implementation



4th Case Study

Summary of Results

Increase in the amount and intensity and frequency of in the extreme-rainfall in the future for the studied region.

Increase in the number of Surcharge Points and Flooded Nodes of the drainage system in the future.

Designing the Critical Infrastructures’ capacity based on Future (predicted) changes.

The advantages of utilizing the BMPs in appropriate areas was confirmed.

Thank you for your attention!