A Benchmarking Framework for Control of Smart Stormwater Networks

Abhiram Mullapudi[a], S.P. Rimer[b], S.C. Troutman[a], B. Kerkez[a]

a. University of Michigan, Ann Arbor, MI, USA

b. Argonne National Laboratory, Lemont, IL, USA

OPEN-STORM.ORG

Real-Time Water Systems Lab

tinyurl.com/bkerkez

Argonne NATIONAL LABORATORY

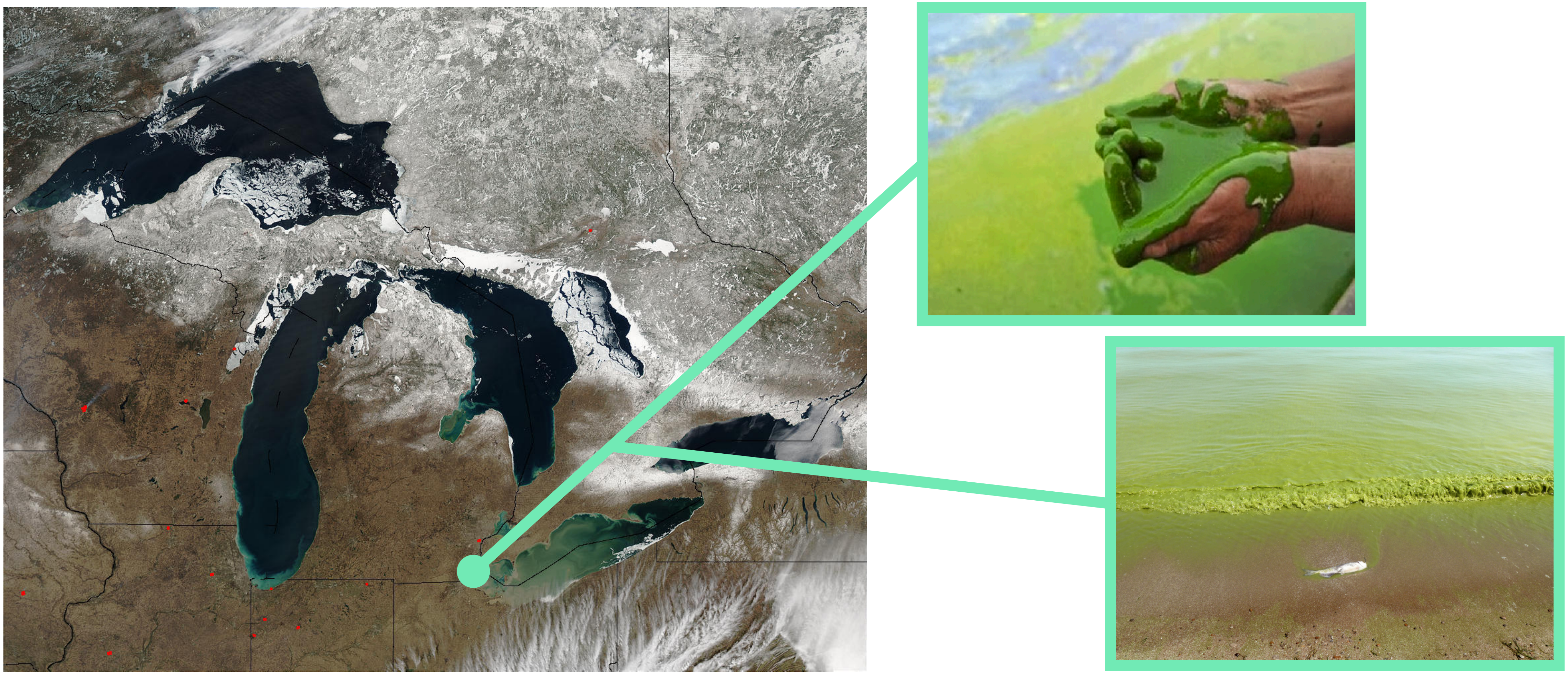
Extreme Storm Events

Duluth, MN, USA 2012

Urban Flooding

Detroit, MI, USA 2014

Water Quality



Five Great Lakes

Algal bloom, Lake Eerie

Chicago TARP : 3 Billion Dollars

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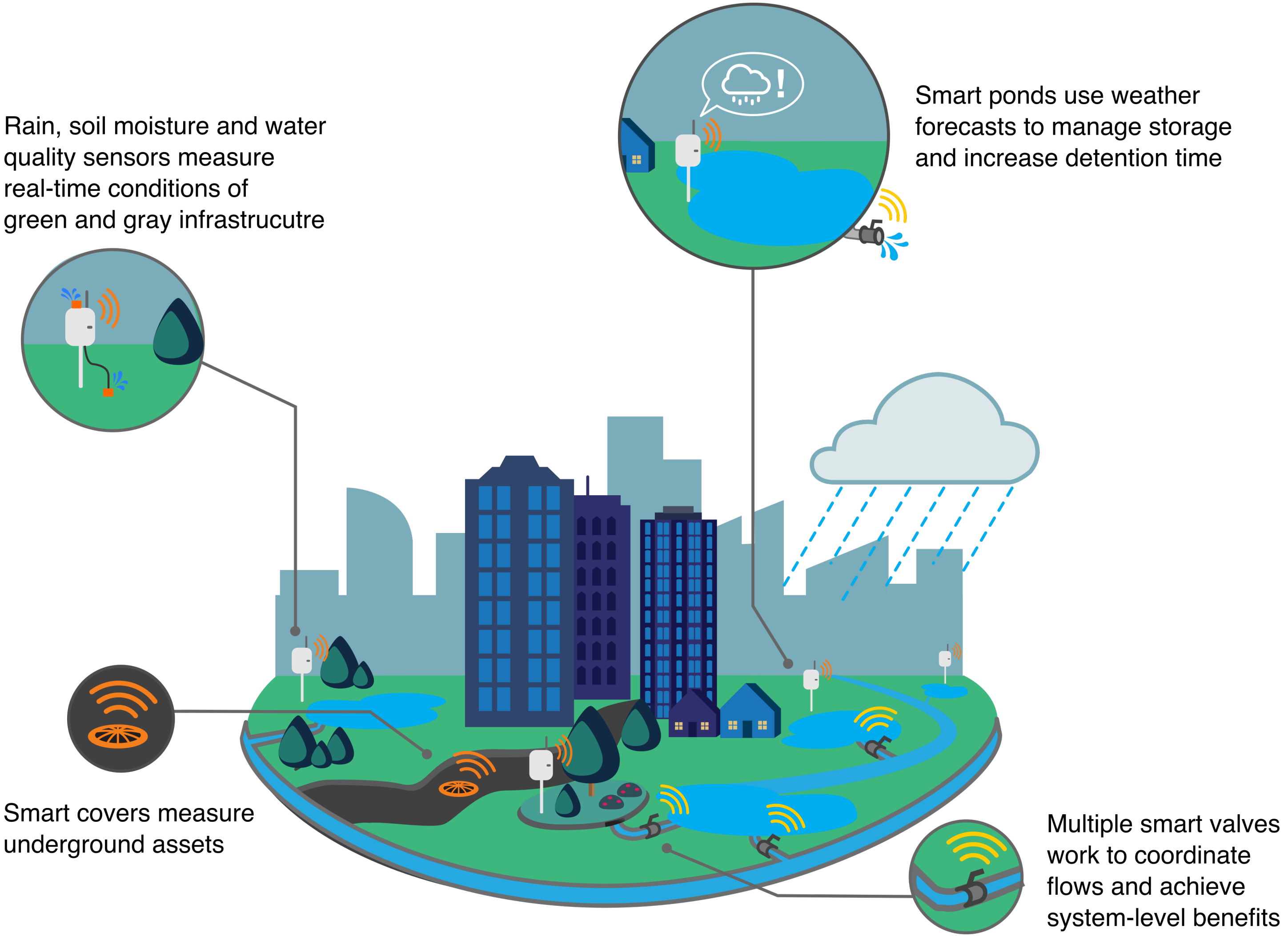
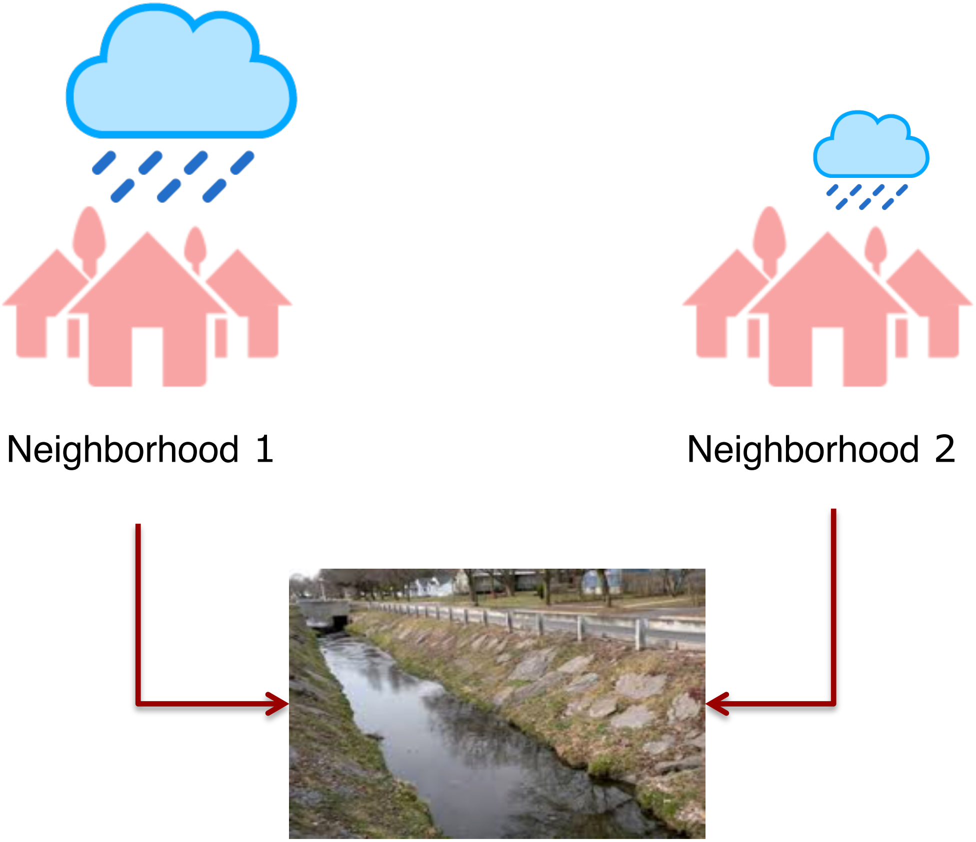
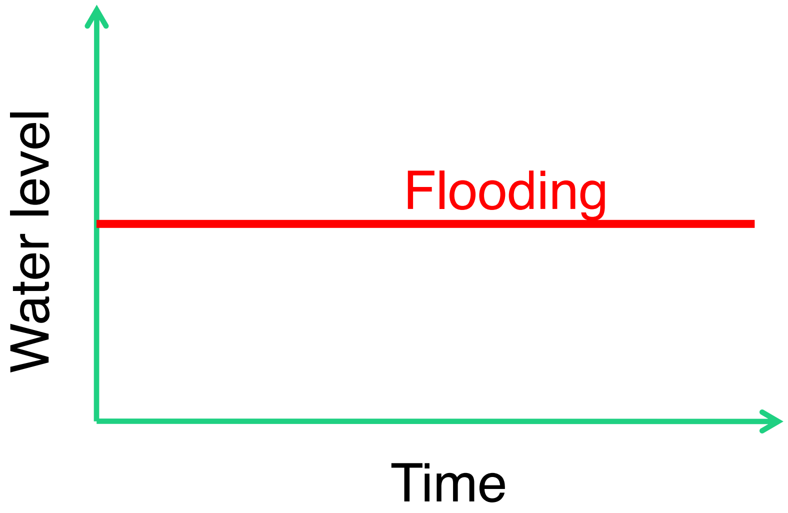
Smarter Stormwater Systems



Kerkez et al. (ES&T, 2016)

Shaping the response of the watershed





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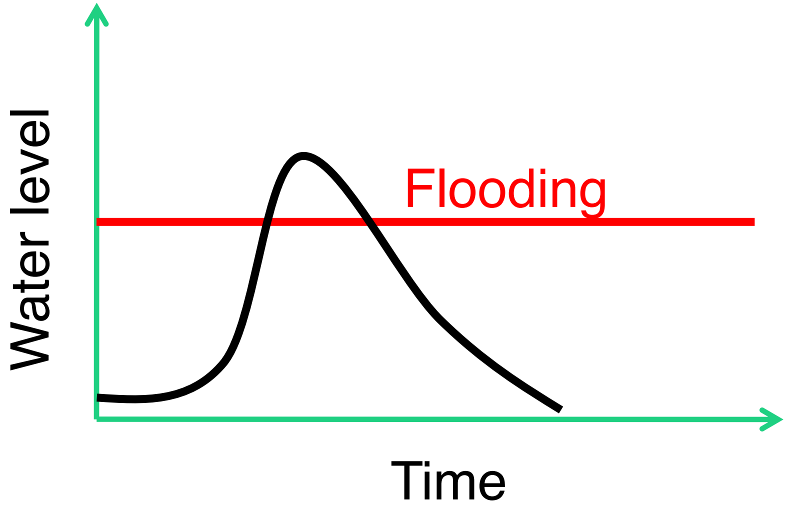
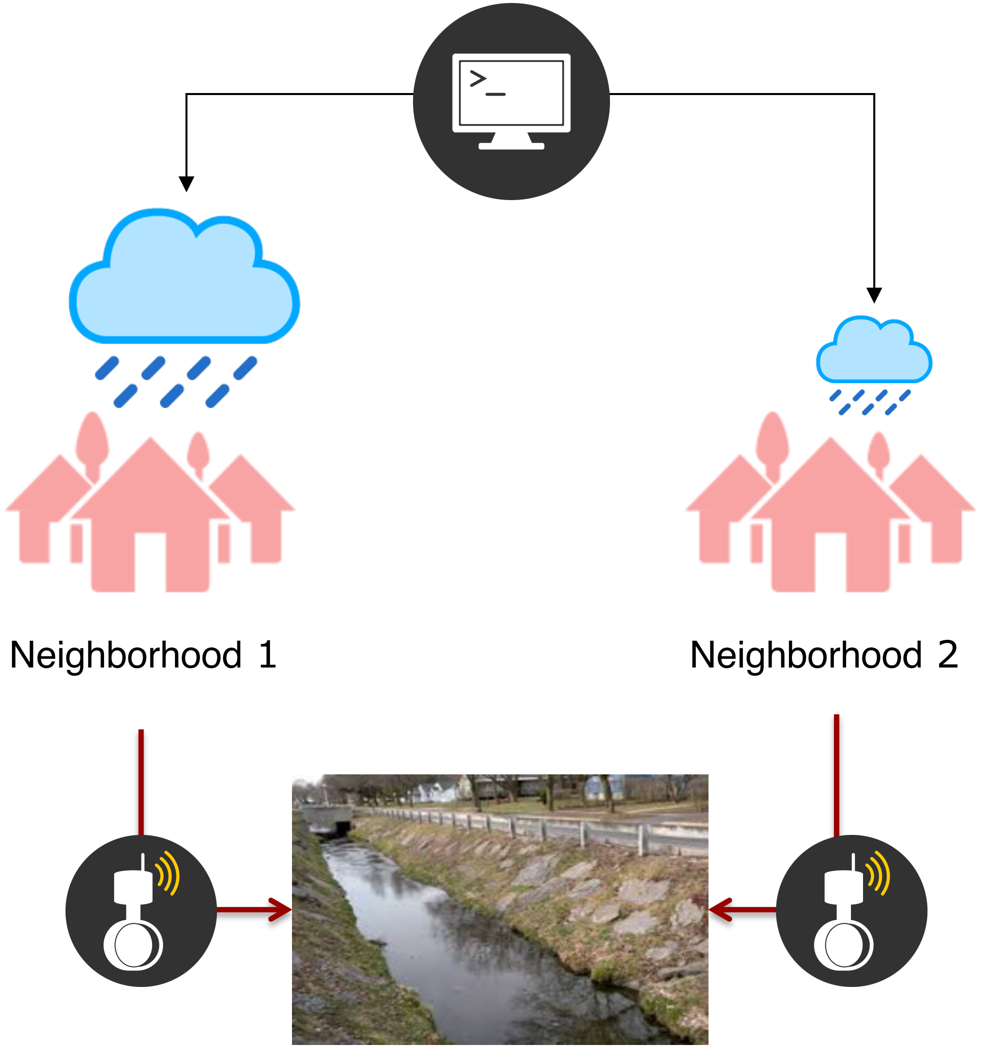
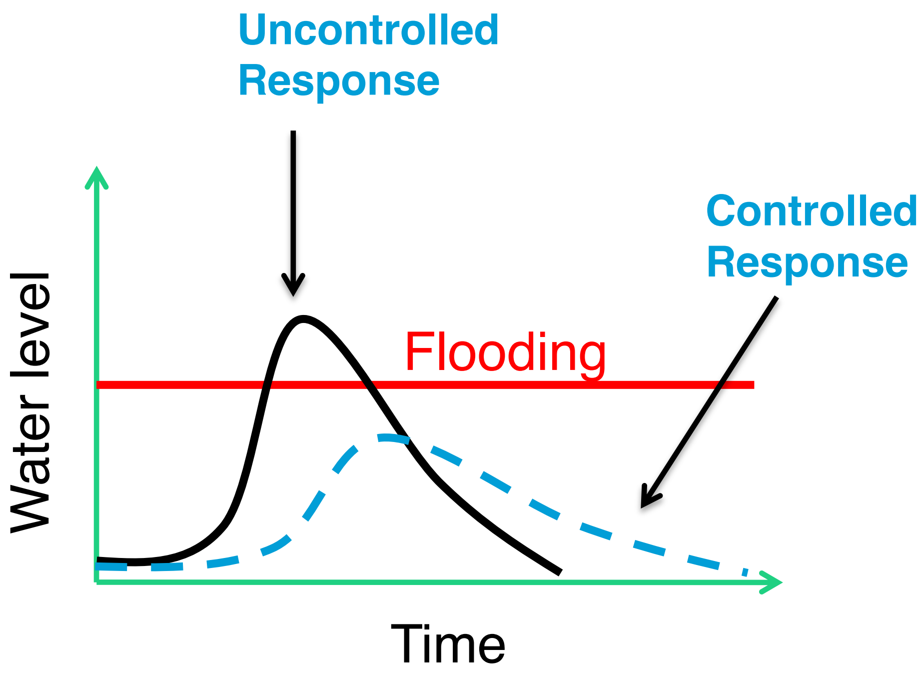
Shaping the response of the watershed

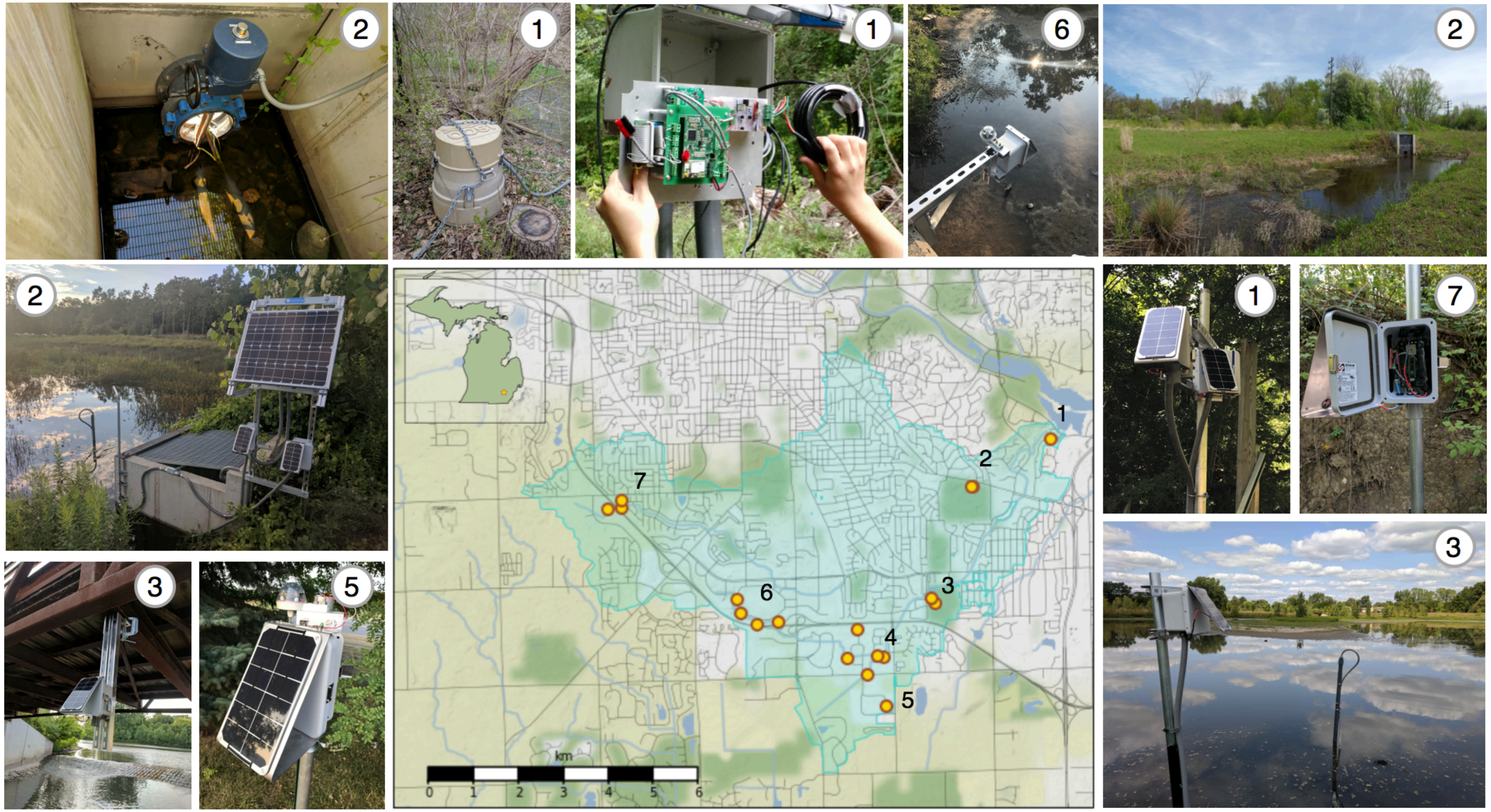


Shaping the response of the watershed



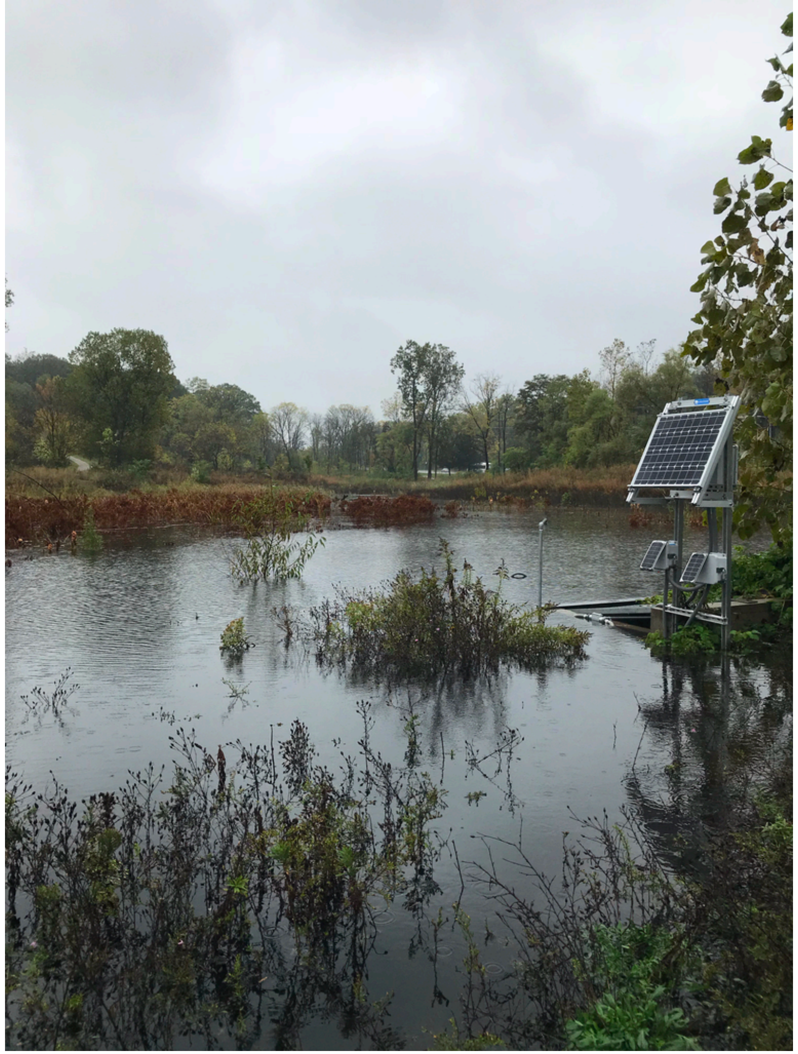


Sensor Deployments – Ann Arbor, USA

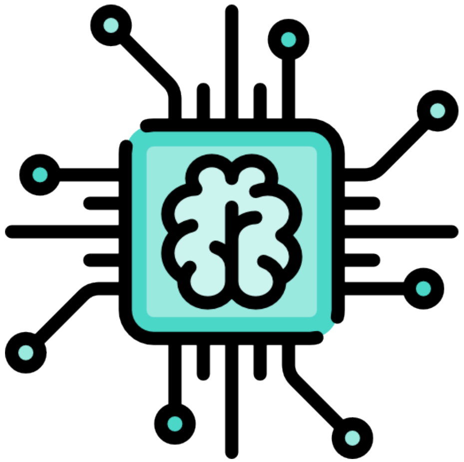


OPEN-STORM.org

Sensor Deployments – Ann Arbor, USA



Control Approaches



Optimization

- Market Based Control
- Non-linear/Linear Optimization

Dynamical Systems

- Linear Quadratic Regulator
- Model-Predictive Control

Artificial Intelligence

- Genetic Algorithms
- Reinforcement Learning

Comparing Control Approaches

REVIEW ARTICLE

Check for updates

Optimization methods applied to stormwater management problems: a review

Shadab Shishegar[a], Sophie Duchesne[a] and Geneviève Pelletier[b]

[a]Centre Eau Terre Environnement, Institut national de la recherche scientifique-INRS, Université du Québec, Québec, G1 K 9A9, Canada; [b]Département de génie civil et de génie des eaux, Université Laval, Québec G1V 0A6, Canada

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ELSEVIER

Performance evaluation of real time control in urban wastewater systems in practice: Review and perspective

CrossMark

Petra van Daal [a, b, *], Günter Gruber [c], Jeroen Langeveld [a, d], Dirk Muschalla [c], François Clemens [a, e]

[a] Delft University of Technology, P.O. Box 5048, 2600 GA Delft, The Netherlands
[b] Witteveen+Bos, P.O. Box 233, 7400 AE Deventer, The Netherlands
[c] Graz University of Technology, Stremayrgasse 10/I, 8010 Graz, Austria
[d] Partners4UrbanWater, Javastraat 104A, 6524 MJ Nijmegen, The Netherlands
[e] Deltares, P.O. Box 177, 2600 MH Delft, The Netherlands

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Petra van D

François Cl

[a] Delft University o

[b] Witteveen+Bos, I

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[e] Deltares, P.O. Box

395

Modelling real-time control options on virtual sewer systems

Péter Borsányi, Lorenzo Benedetti, Geert Dirckx, Webbey De Keyser, Dirk Muschalla, Anne-Marie Solvi, Veronique Vandenberghe, Michael Weyand, and Peter A. Vanrolleghem

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Dirk Musch
Peter A. Va

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Modeling and real-time control of urban drainage systems: A review☆

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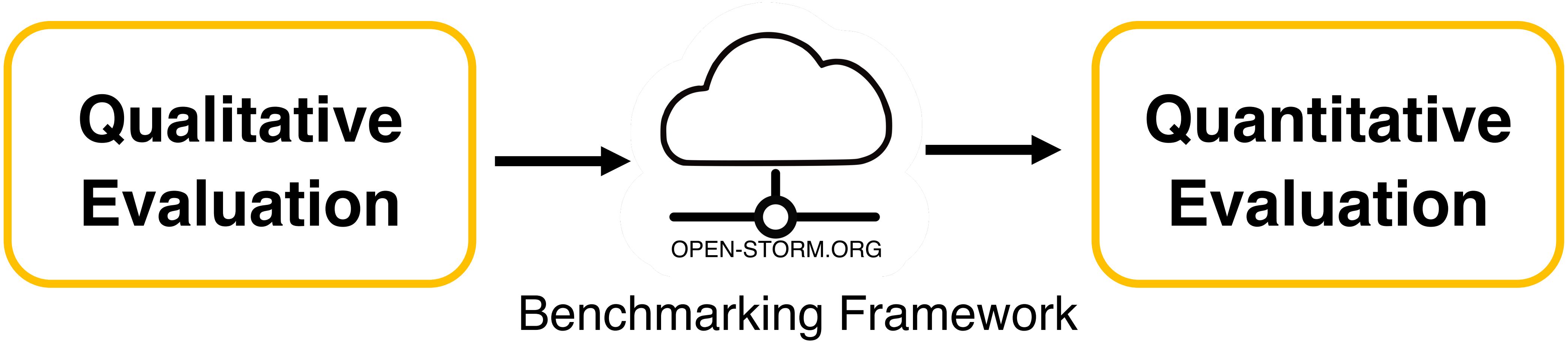
L. García[a], J. Barreiro-Gomez[a,b], E. Escobar[a], D. Téllez[a], N. Quijano[a], C. Ocampo-Martinez[b,*]

[a] Departamento de Ingeniería Eléctrica y Electrónica, Universidad de los Andes, Carrera 1A No 18A-10, Colombia
[b] Automatic Control Department, Universitat Politècnica de Catalunya, Institut de Robòtica i Informàtica Industrial (CSIC-UPC), Llorens i Artigas, 4-6, Barcelona 08028, Spain


Qualitative Evaluation
OPEN-STORM.ORG
Benchmarking Framework
Quantitative Evaluation

Motivation

Systematic Quantitative Evaluation : Drinking Water, Electric Grid

Motivation

Systematic Quantitative Evaluation : Drinking Water

Battle of the Water Networks II

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The Battle of the Water Sensor Networks (BWSN): A Design Challenge for Engineers and Algorithms

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BATTLE OF THE NETWORK MODELS: EPILOGUE

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Motivation

Systematic Quantitative Evaluation : Drinking Water

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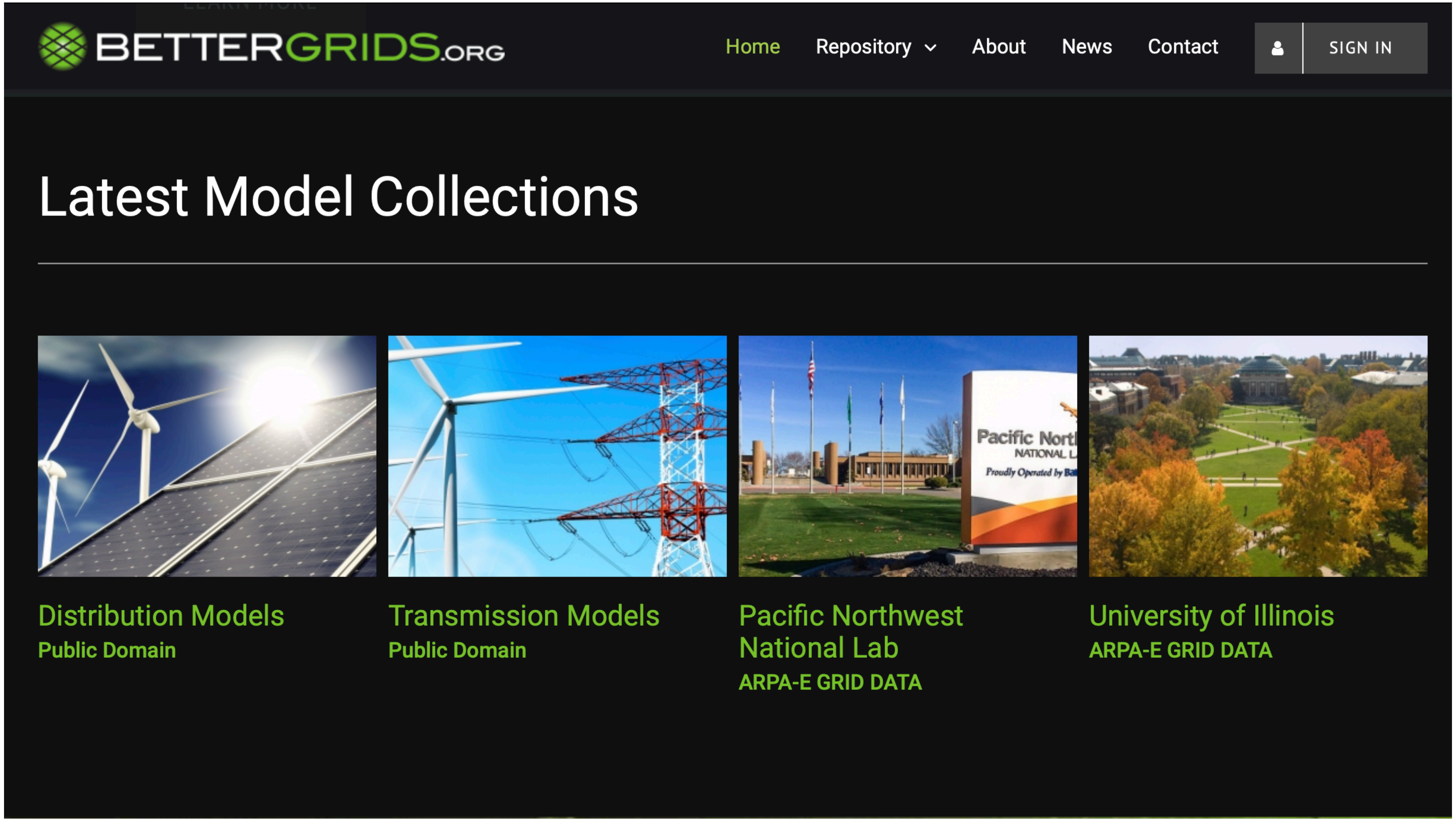
Battle of the Water Networks District Metered Areas

Juan Saldarriaga, A.M.ASCE[1]; Jessica Bohorquez[2]; David Celeita[3]; Laura Vega[4]; Diego Paez[5]; Dragan Savic, A.M.ASCE[6]; Graeme Dandy, M.ASCE[7]; Yves Filion[8];

Motivation

Systematic Quantitative Evaluation : Electricity Networks



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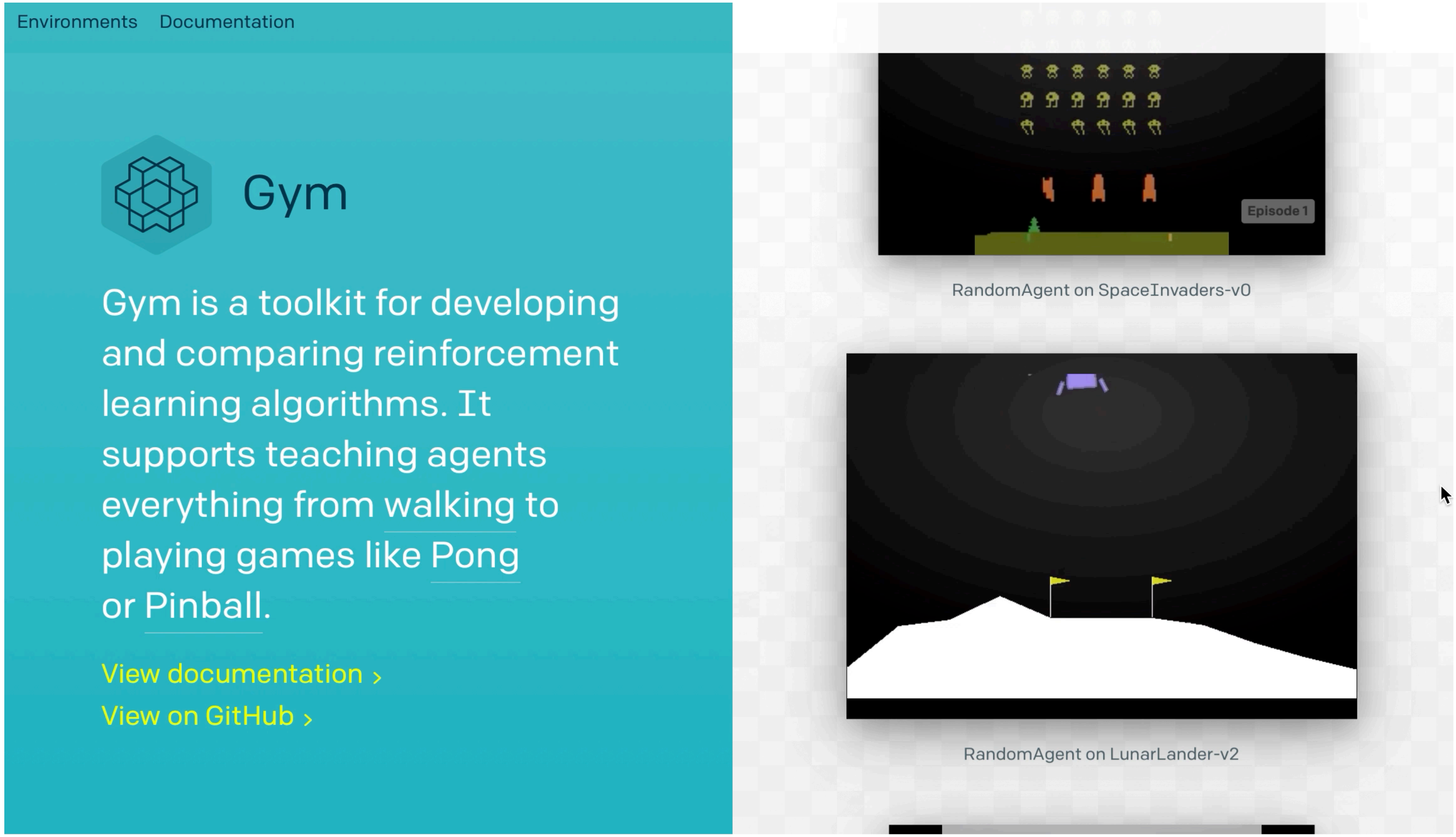
Motivation

Systematic Quantitative Evaluation : Reinforcement Learning



Benchmarking Framework

1. Anonymized stormwater networks and corresponding delineated benchmarking scenarios (alpha, beta, gamma, delta, and epsilon)

2. A streamlined programming interface with hydraulic simulator

3. Online leader board with solutions and tutorials

Scenarios

Scenario

Physical network components

Network

System driver
e.g., storm event, tidal fluctuations

Control problem components

Controllable assets

Observable states

Control objectives

Scenarios

Scenario

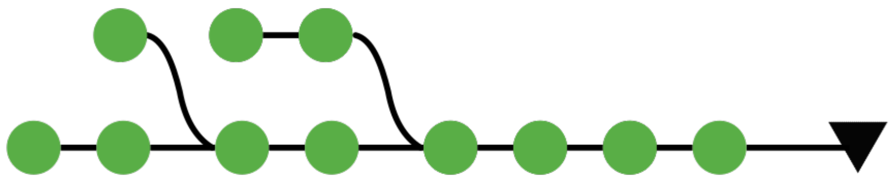
Physical network components

- **Network**
- **System driver**
  e.g., storm event, tidal fluctuations

Control problem components

- **Controllable assets**
- **Observable states**
- **Control objectives**

Scenario Gamma



Scenarios

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e.g., storm event, tidal fluctuations

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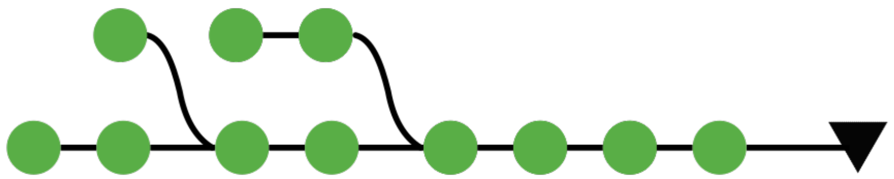
Scenario Gamma



25 year 6 hour event

Scenarios

Scenario

Physical network components

Network

System driver
e.g., storm event, tidal fluctuations

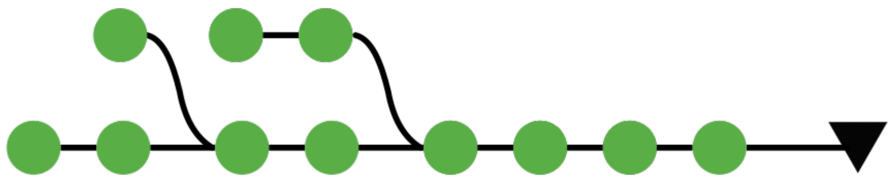
Control problem components

Controllable assets

Observable states

Control objectives

Scenario Gamma



25 year 6 hour event

All the 11 basins in the networks

Scenarios

Scenario

Physical network components

Network

System driver
e.g., storm event, tidal fluctuations

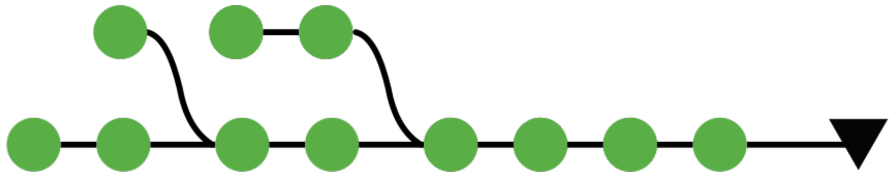
Control problem components

Controllable assets

Observable states

Control objectives

Scenario Gamma



25 year 6 hour event

All the 11 basins in the networks

Water levels in 11 basins

Scenarios

Scenario

Physical network components

Network

System driver
e.g., storm event, tidal fluctuations

Control problem components

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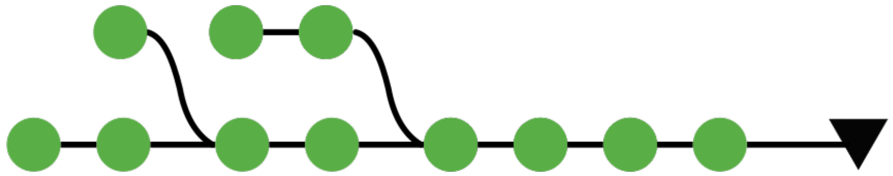
Scenario Gamma



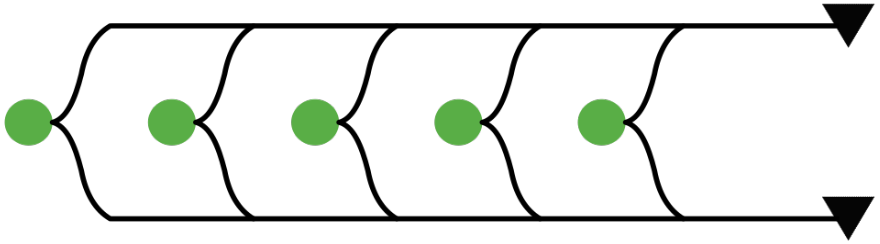
25 year 6 hour event

All the 11 basins in the networks

Water levels in 11 basins

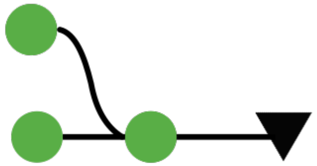
Maintain the flows and water levels in the network below a desired threshold.

Scenarios – Diverse Objectives



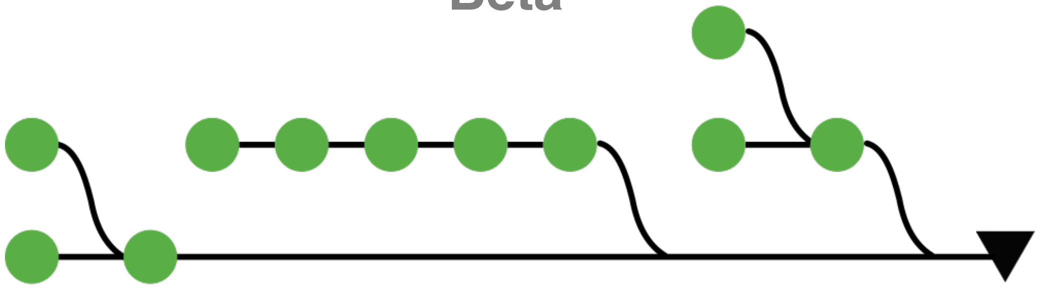
Alpha

A combined sewer network of 0.12 km^2 aiming to minimize combined sewer overflows



Beta

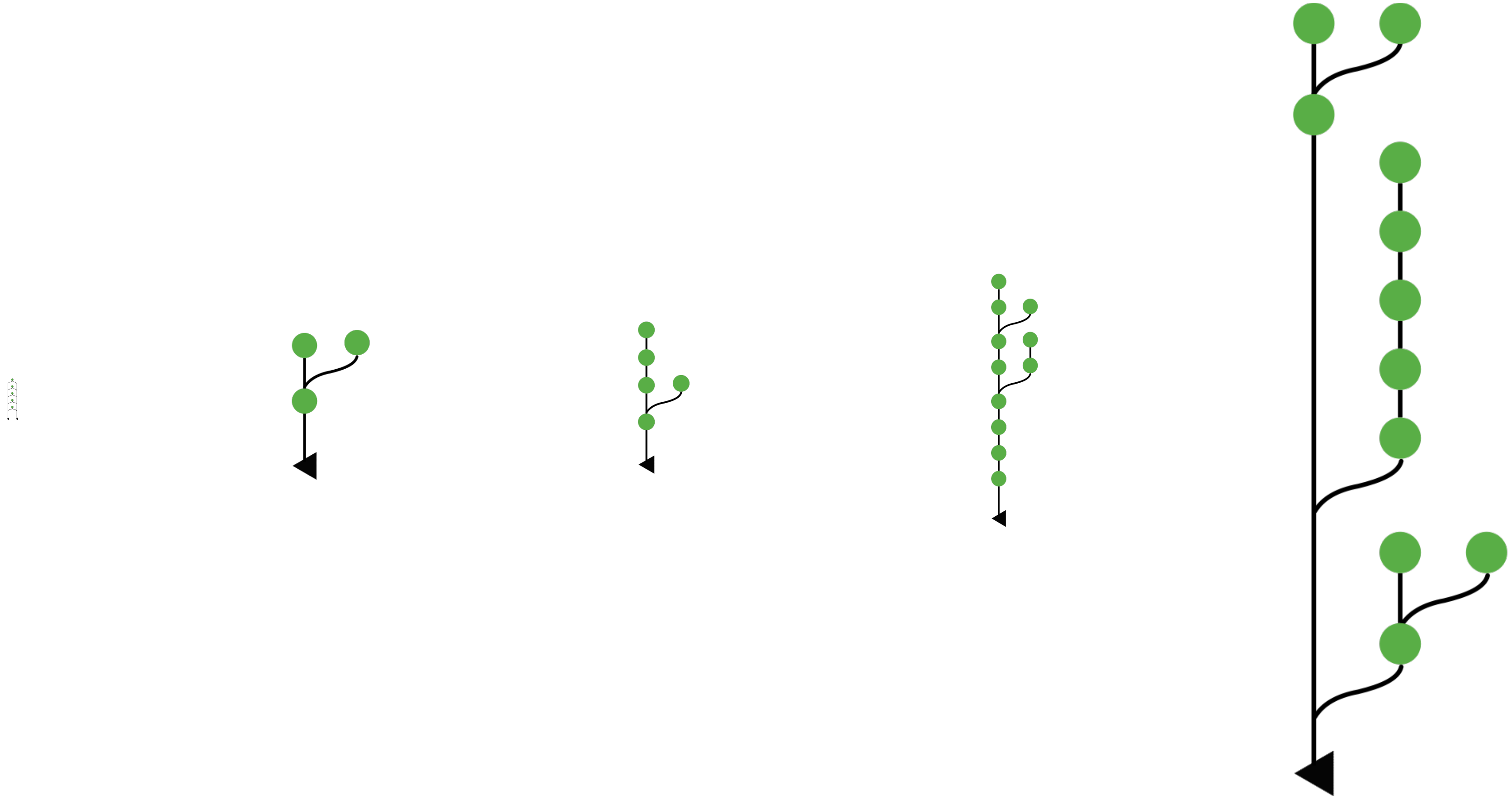
A separated sewer network (1.3 km^2) with a tidally-influenced receiving river.



Epsilon

A combined sewer network (67 km^2) with a focus on water quality objectives.

Scenarios – Scale



Alpha (0.1 sq.km)

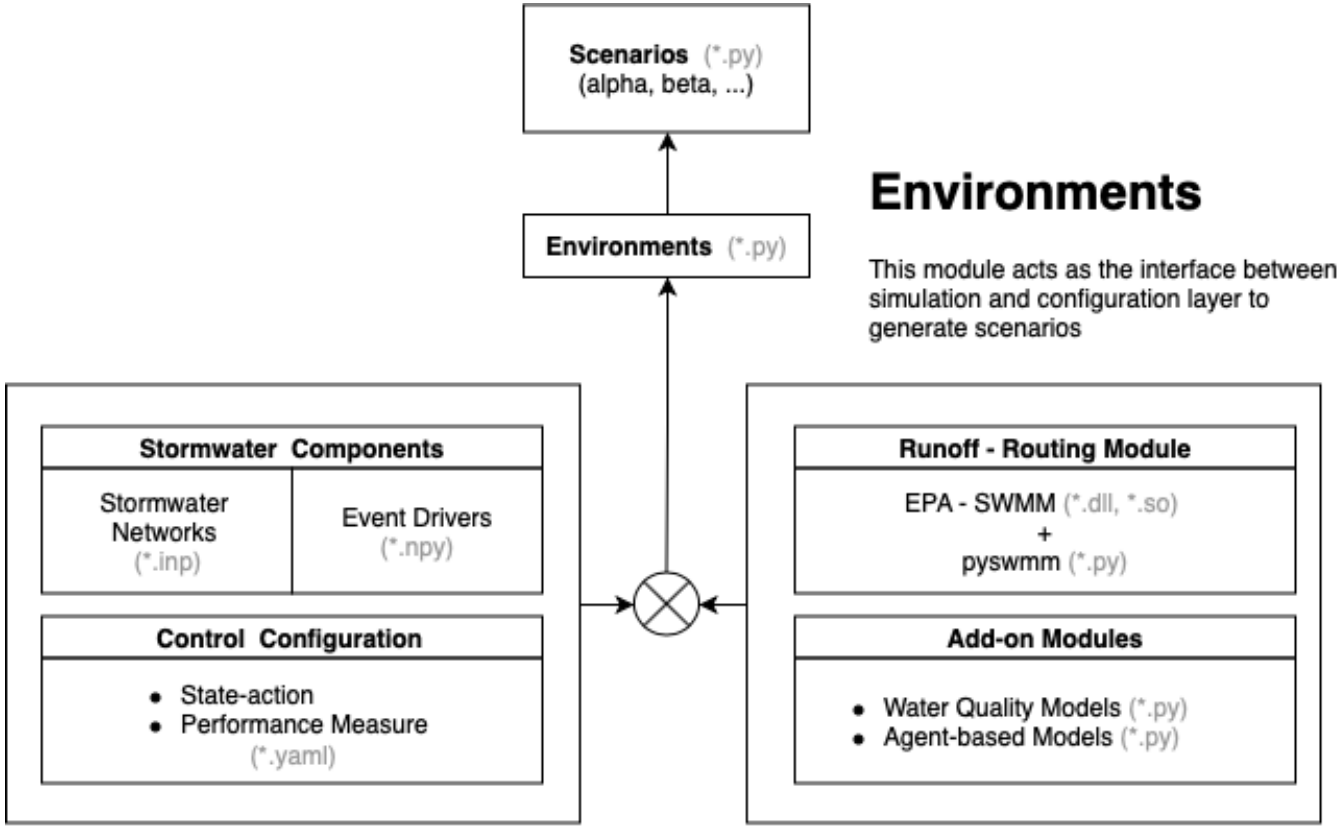
Beta (1.3 sq.km)

Delta (1.7 sq.km)

Gamma (4 sq.km)

Epsilon (67 sq.km)

Library Architecture



Environments

This module acts as the interface between simulation and configuration layer to generate scenarios

Configuration layer

Data structures encapsulating stormwater network topology, control objectives, state-action space and performance measures.

Simulation layer

Modules for modeling the flow of runoff, and its interactions with pollutants in the watershed are embedded in this layer.

Example

```python
import benchmarking

scenario = bechmarking.scenarios.gamma()
done = False

while not done:
  # Query the state

  # Decide actions

  # Implement the action

  # Repeat
```

Example : state

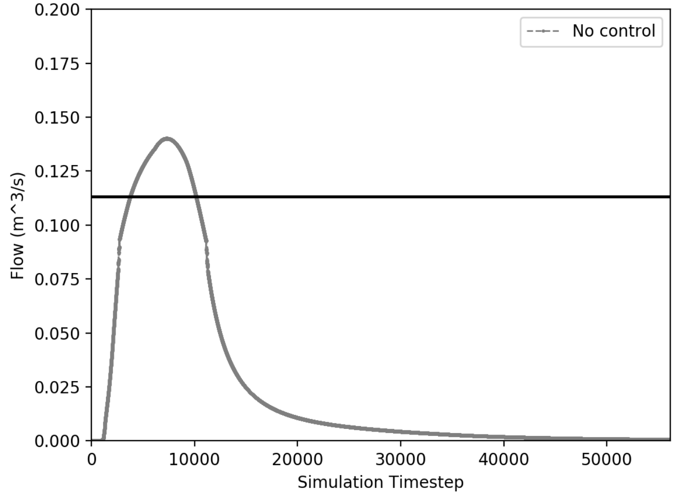
```python
import benchmarking

scenario = bechmarking.scenarios.gamma()
done = False

while not done:
    # Query the state
    state = scenario.state()
    # Decide actions

    # Implement the action

    # Repeat
```

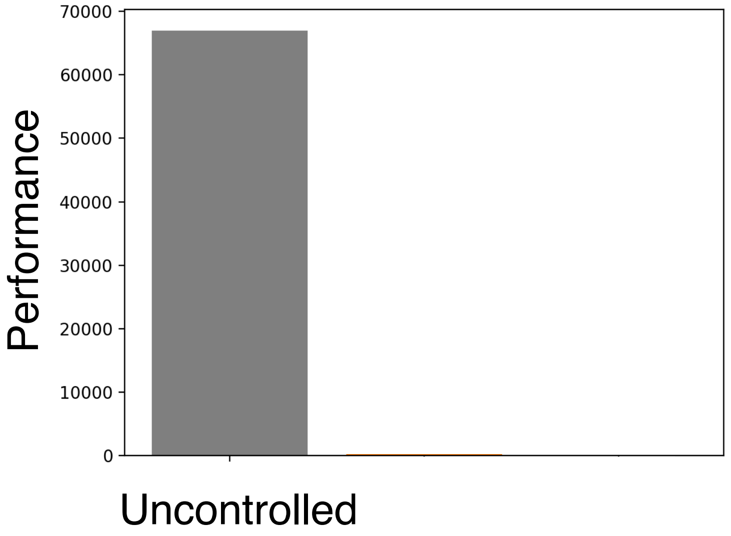
Water levels in the 11 basins

```
In [5]: state

Out[5]: array([0., 0., 0., 0., 0., 0.,
0., 0., 0., 0., 0.])
```

Example : Uncontrolled

```python
import benchmarking

scenario = bechmarking.scenarios.gamma()
done = False

while not done:
    # Query the state
    state = scenario.state()
    # Decide actions
    actions = np.ones(11)
    # Implement the action
    done = scenario.step(actions)
```





Example : Rule based control

```python
import benchmarking
import numpy as np
scenario = bechmarking.scenarios.gamma()
done = False

while not done:
  # Query the state
  state = scenario.state()
  # Decide actions
  actions = np.ones(11)
  for i in range(0, 11):
    if state[i] < 0.5:
      action[i] = 0.25
    elif state[i] < 1.0:
      action[i] = 0.50
    elif state[i] < 1.5:
      action[i] = 0.75
    else:
      action[i] = 1.0
  # Implement the action
  done = scenario.step(actions)
```

Control Algorithm

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Example : Rule based control

```python
import benchmarking
import numpy as np
scenario = bechmarking.scenarios.gamma()
done = False

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  # Query the state
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      action[i] = 0.50
    elif state[i] < 1.5:
      action[i] = 0.75
    else:
      action[i] = 1.0
  # Implement the action
  done = scenario.step(actions)
```
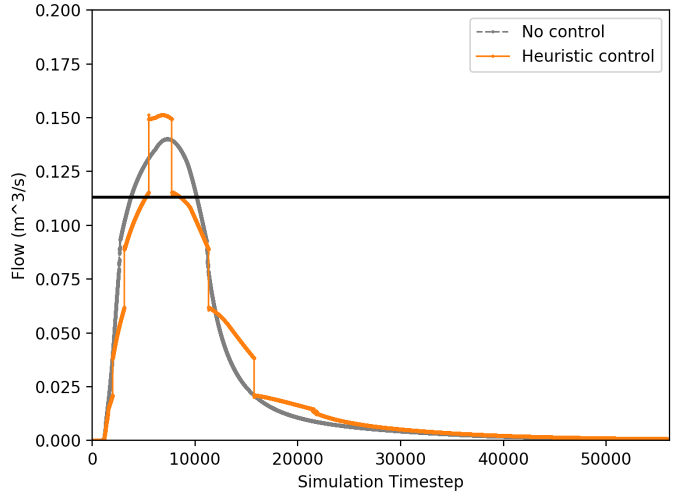
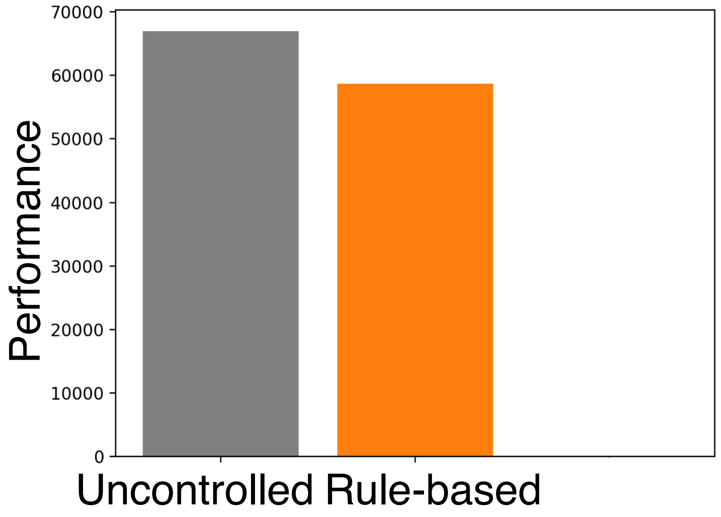
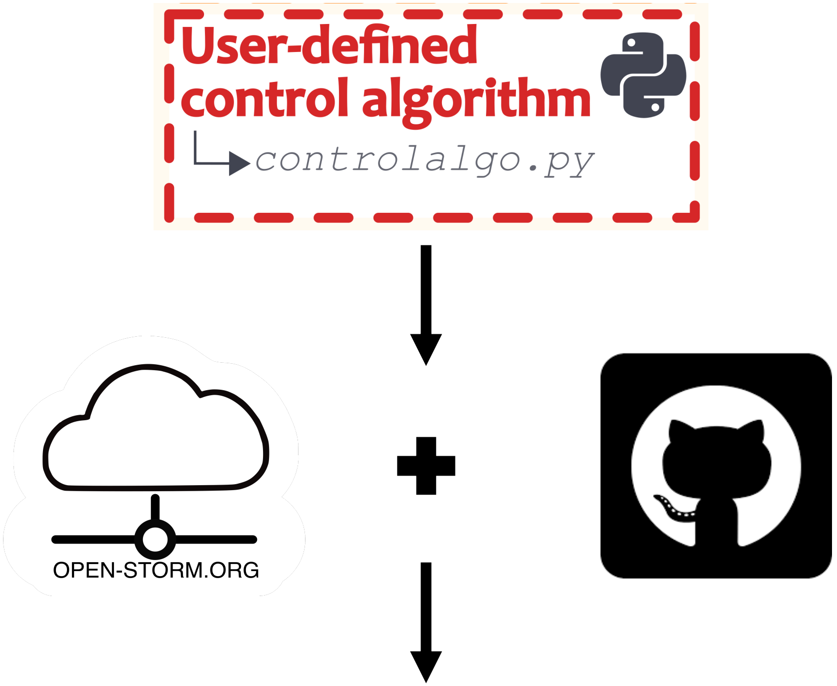





Community Building

Online friendly competition



Scenarios	Control Algorithm		
	Uncontrolled	Bayesian Optimization	Genetic Algorithm
Scenario gamma	1.000	0.626	0.611
Scenario delta	1.000	0.218	0.224

Community Building

Webpage with tutorials

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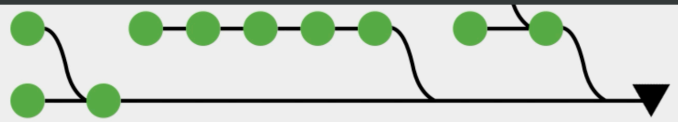

Scenario epsilon

A combined sewer network (67 sq km) with a focus on water quality objectives.

Welcome! We have built this benchmarking toolbox to encourage more researchers to have access to smart stormwater control problems. We want these problems accessible to all populations of researchers — those with experience in controls, but not stormwater; those with experience in stormwater, but not controls; and those without prior experience in either! We have streamlined all of the backend details of running a smart stormwater control problem so that all you have to do is focus on the control algorithm (see below for an example).

Getting Started

To try out how exactly to interact with stormwater networks using our benchmarking toolbox, we encourage you to first begin with our "toy control problem" which you can access **here**. Once you feel comfortable with how our toolbox works, we then encourage you really begin to have some fun by interacting with our five benchmarking scenarios: **`alpha`**, **`beta`**, **`gamma`**, **`delta`**, and **`epsilon`**. These benchmarking scenarios are built using real-world inspired stormwater networks, driving events, and control assets.

To learn more about this work, check out our github repository:

To install and begin working, use:

```
pip install git+https://github.com/kLabUM/Benchmarking
```

This is how one would go about running a scenario ...

```
import benchmarking

def controller(state):
    """
```

Great Lakes Protection Fund

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U.S. DEPARTMENT OF ENERGY

Thank you !

open-storm.org/benchmarking

emnet

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