Measuring Operational Respose and Resilience of Urban Water Networks

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Aging Infrastructure

Acute & Chronic Stress

Population growth

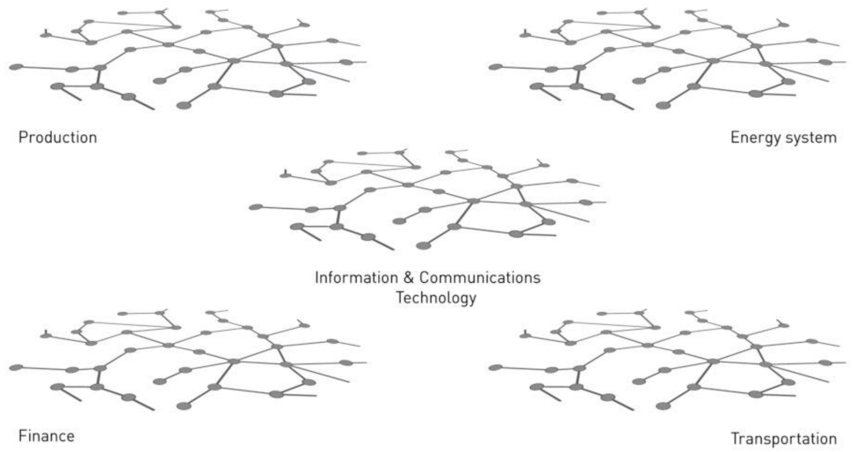
Climate Change

Natural disasters

Limited resources

CRITICAL INFRASTRUCTURE SYSTEMS

Systems which are essential for the maintenance of vital societal functions



National Academy of Sciences

"The ability to prepare and plan for, absorb, recover from, or more successfully adapt to actual or potential adverse events"

The United St

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a fast manner after major disruptions

Questions to assess and build resilience

- What is a system's ability to ***resist*** strain within acceptable limits of degradation?
- What is a system's ability to ***re-stabilize*** its key functions?
- What is a system's ability to ***rebuild*** its functions up to a sufficient level of performance?
- How can a system ***reconfigure*** the flow of services and change its biophysical topology to become more robust and fault-tolerant?
- How can we improve the system's capability to ***cope with*** unexpected disruptions?
- How to acquire and ***remember*** emergency response capabilities that significantly reduce degradation?

National Academy of Sciences (2012). *Disaster Resilience A national Imperative*, The National Academies Press, Washington, D.C.
United States Environmental Protection Agency (2015). "Systems Measures of Water Distribution System Resilience." U.S. Environmental Protection Agency, Washington, DC, USA
https://lrvc.ch/information-design/

Measuring topological and operational resilience and recovery of water networks for planning and management

1

Resilience of water networks

2

Quantitative Assessment of System Response during Disruptions: An Application to Water Distribution Systems

Objective

Simulation-based hydraulic resilience evaluation to investigate systems capability to cope with shocks.

- Topology
- Demand variation
- Pressure performance regimes

Aydin, N. Y. (2018). “Measuring topological and operational resilience and recovery of water networks for planning and management.” World Environmental & Water Resources Congress (EWRI), June 3-7, Minneapolis, Minnesota, USA. DOI: https://doi.org/10.1061/9780784481424.039

Objective

- Capturing the relationship between key factors that influence *performance loss and recovery*
- Identify groups of scenarios that the system exhibits similar response behaviors and that can be easily labeled
- Support decisions to improve WDS resilience before and during a disruption

B. Cassottana, N. Y. Aydin, and L. C. Tang, "Quantitative Assessment of System Response during Disruptions: An Application to Water Distribution Systems," Journal of Water Resources Planning and Management, vol. 147, no. 3, 2021, doi: 10.1061/(asce)wr.1943-5452.0001334.

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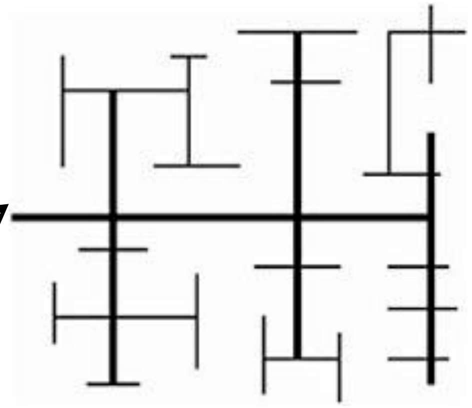
Measuring topological and operational resilience and recovery of water networks for planning and management


Step 1
SELECTING CASE STUDIES & DATA PROCESSING
1
Identifying critical locations
-Centrality
2
Step 2
Step 3
3
Disruption Simulations
-Man-made or natural hazards
-Fire flow
Recovery performance evaluation
4
Step 4

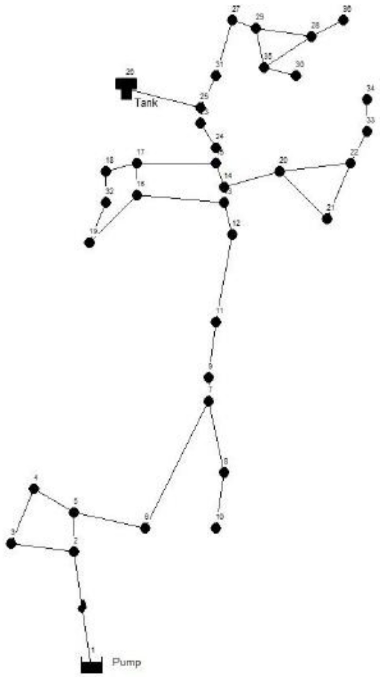
Objective

Simulation-based hydraulic resilience evaluation to investigate systems capability to cope with shocks.

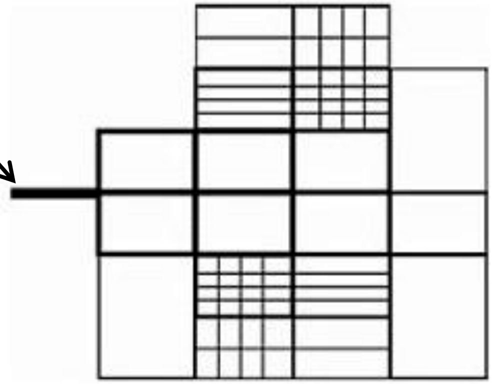
- ➢ Topology
- ➢ Demand variation
- ➢ Pressure performance regimes

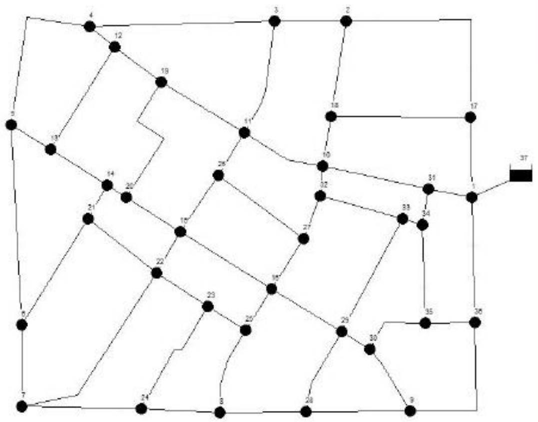


Topology 1



Topology 2





Demand variation and operation range

Simulation-based hydraulic performance evaluation to investigate systems capability to cope with shocks.

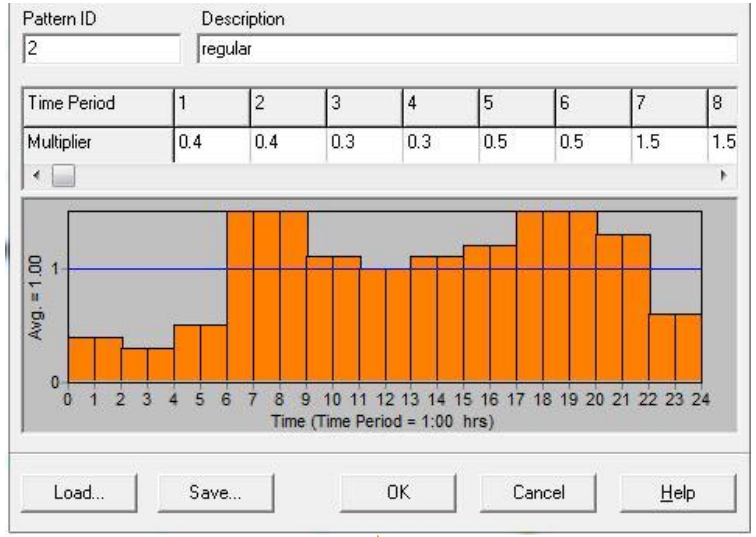
Identify critical locations

Disruption simulation

Excess demand simulation representing fire flow

Performance Evaluation

Demand variation

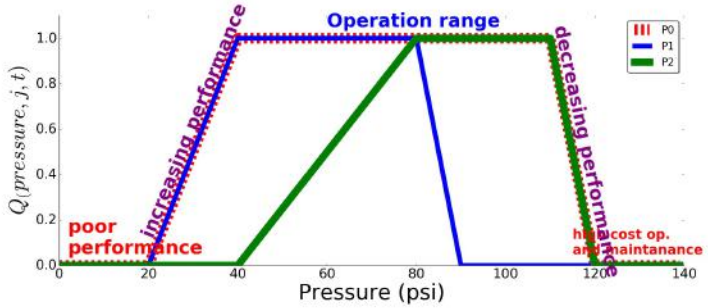


$$Q_{pressure,t} = \sum_{j=1}^{NJ_i} w_{j,t}\, Q_{pressure,j,t}\, \frac{D_{j,t,satisfied}}{D_{j,t}}$$

$$w_{j,t} = \frac{D_{j,t}}{\sum_{j=1}^{NJ_i} D_{j,t}}$$

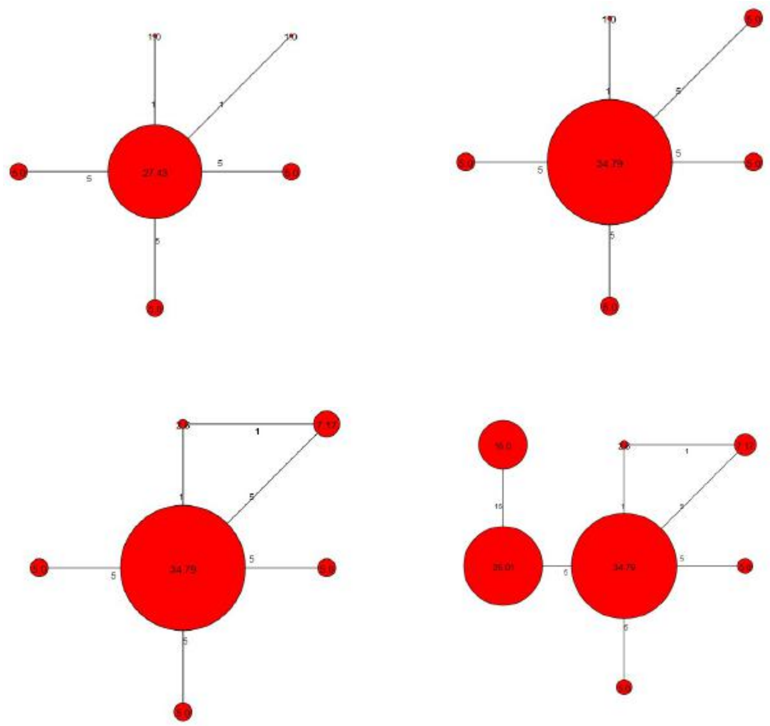
Fire flow (2000 GPM-3 hours)

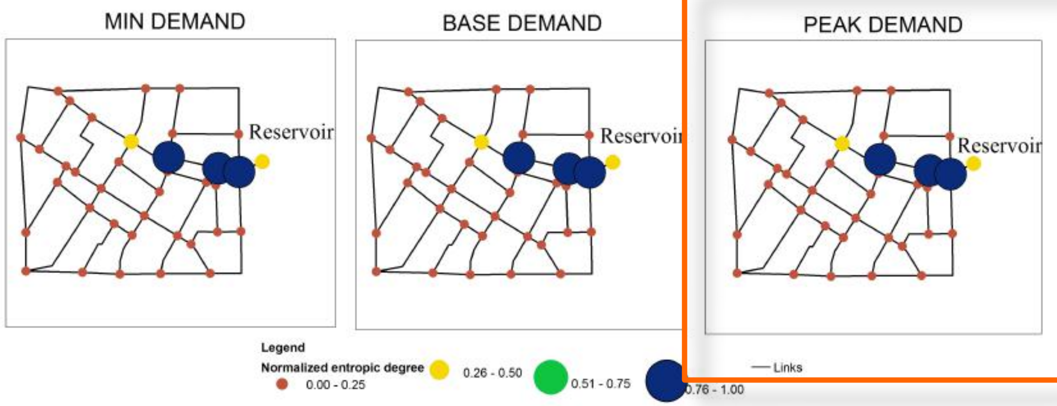
Operation range

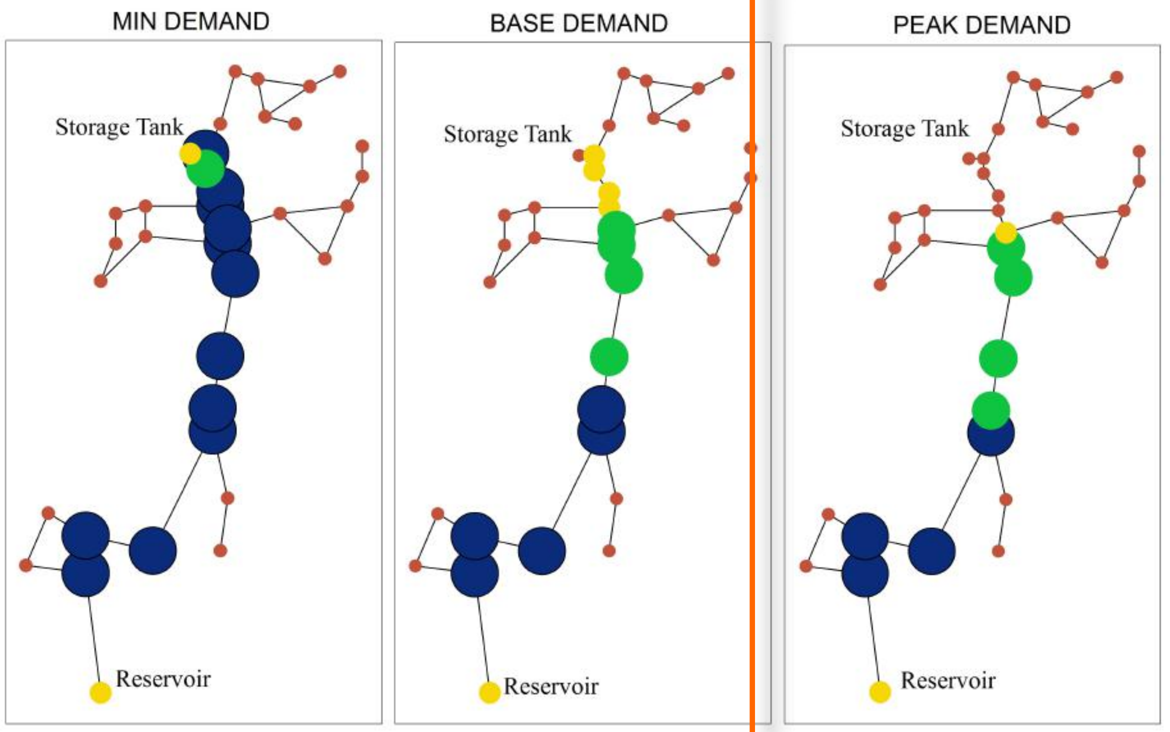


Pressure Performance (psi)	P0	P1	P2
P_{min}	20	20	40
P_{max}	120	90	120
Operation range	40-110	40-80	80-110

Entropic Degree







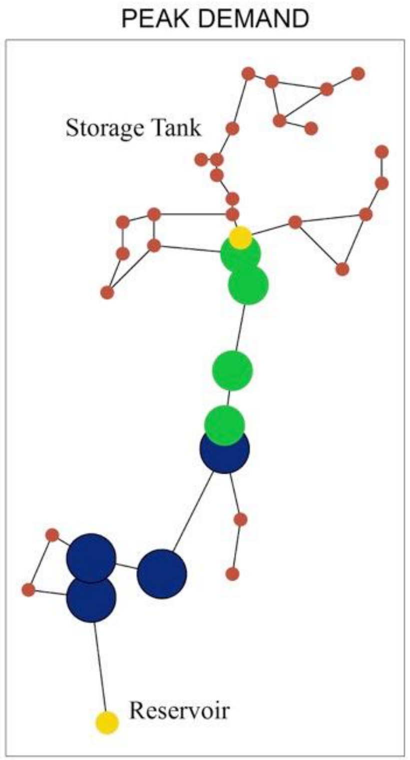
$$k_i^w = (1-\sum_{j=1}^{N_B} p_{ij} logp_{ij})\sum_{j=1}^{N_B} w_{ij}$$

$$p_{ij} = w_{ij} \Big/ \sum_{j=1}^{N_B} w_{ij}$$

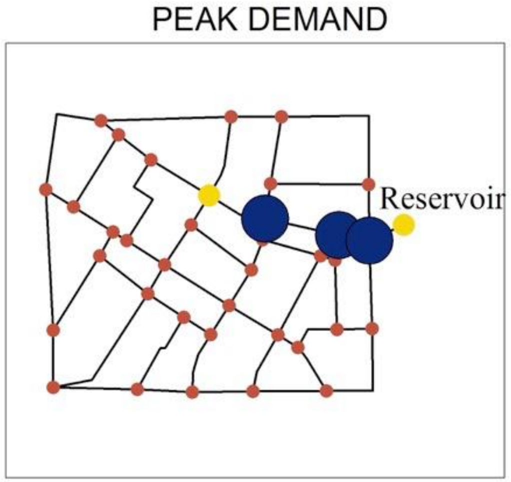
$$p_{ij} = normalized\ weight$$

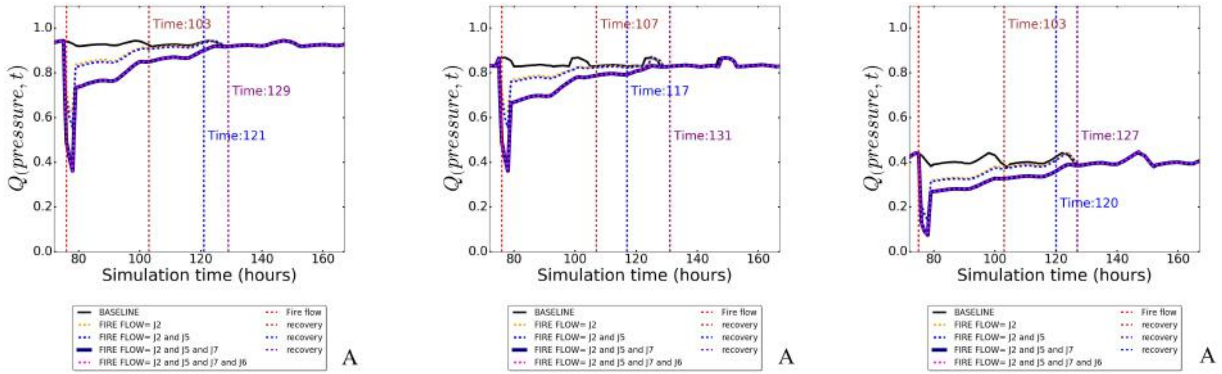
Results

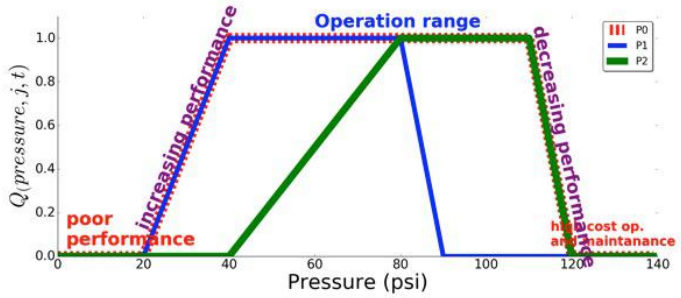
Topology 1

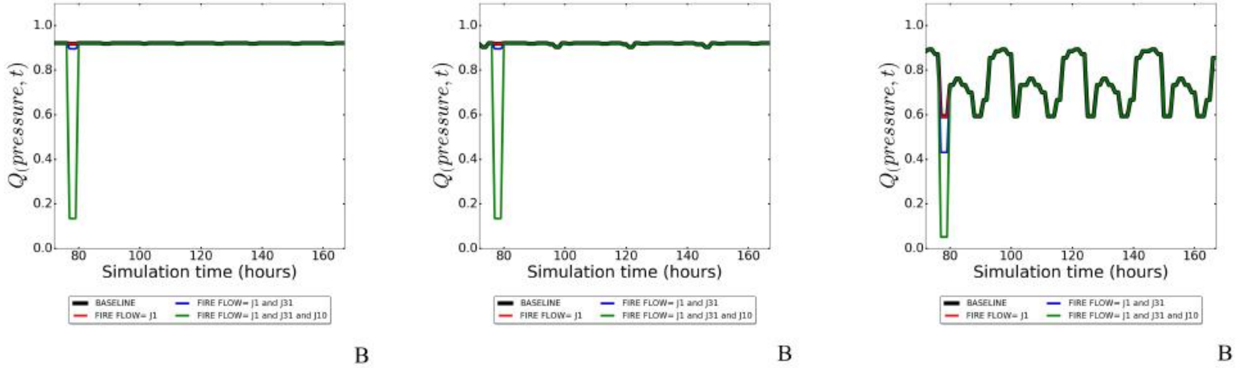


Topology 2









Recovery performance under different operation regimes

Quantitative Assessment of System Response During Disruptions: An Application to Water Distribution Systems

Objective

- Capturing the relationship between key factors that influence *performance loss and recovery*
- Identify groups of scenarios that the system exhibits similar response behaviors and that can be easily labeled
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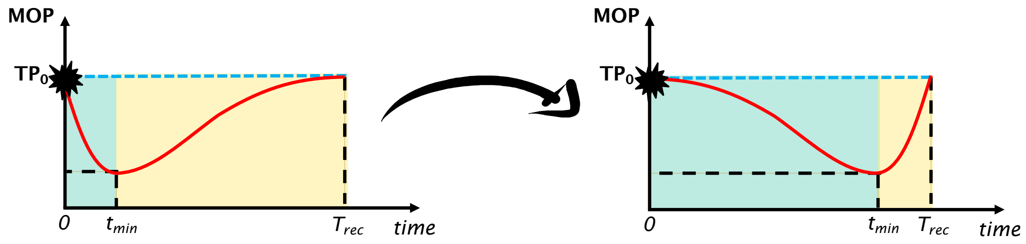
Recovery Modelling for Water Distribution Systems

- Two benchmark water networks are considered: **Net3 and C-Town**
- An **n-1 analysis** is conducted, where one node at a time is disrupted by simulating a water leakage
- Systems dynamics are simulated and the **average satisfied demand calculated as MOP**

- **Beta family of recovery** functions with **enhanced versatility** is developed to identify critical components of a WDS



$$\mathrm{MOP}(t) = \mathrm{TP}_0 - a\,\frac{(b+c)^{b+c}}{b^b c^c}\left(\frac{t}{\nu}\right)^b\left(1-\frac{t}{\nu}\right)^b$$

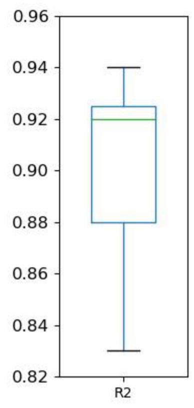
with $0 \leq t \leq \nu$

- ✓ ***a*** characterizes the max performance loss
- ✓ ***b*** the time to strain
- ✓ ***ν*** the time to recovery

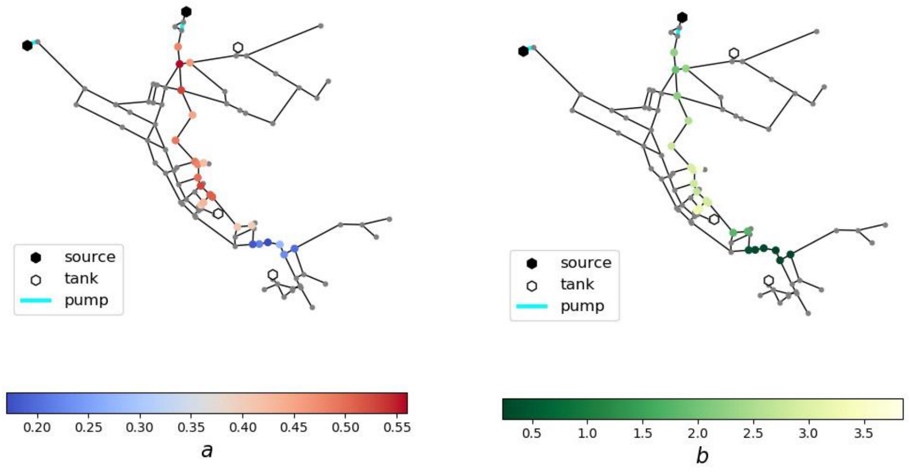
Results

- Some degree of correlation is observed between parameters *a* and *b*
- Two characteristic recovery processes are identified

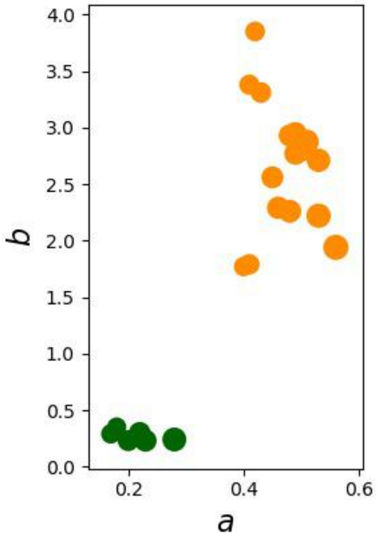
(1)



(2)



(3)



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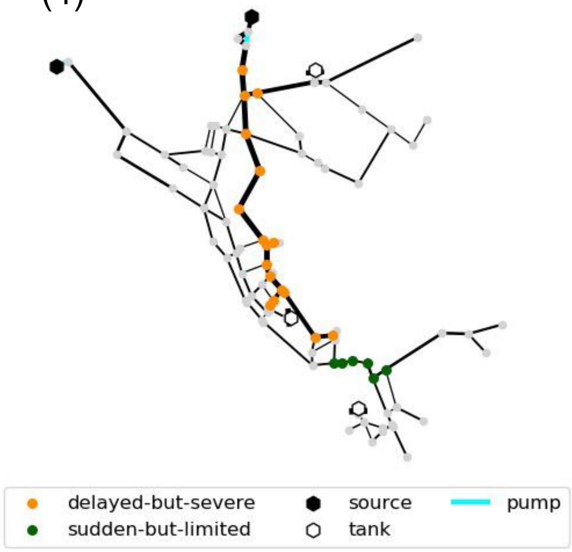

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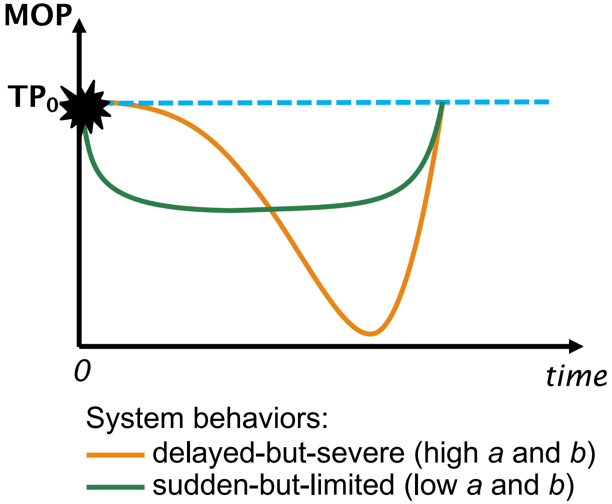


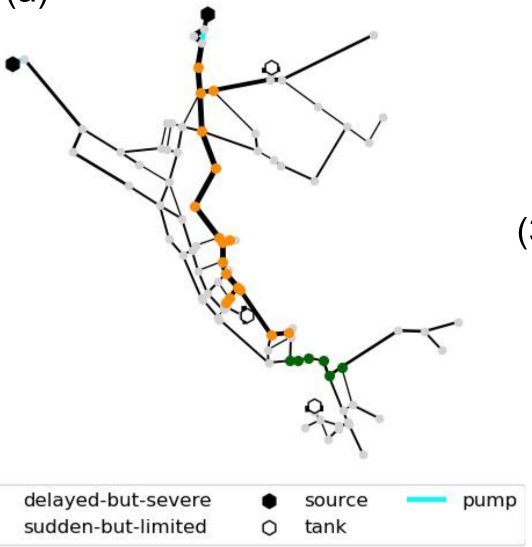
Figure 1: Goodness of fit (R^2)
Figure 2: Topology of *Net3*, nodes are coloured according to *a, b*, and Δ
Figure 3: Results of the *k-means* algorithm
Figure 4: Topology of *Net3*, nodes are coloured according to *cluster*
Figure 5: Identified characteristic recovery processes

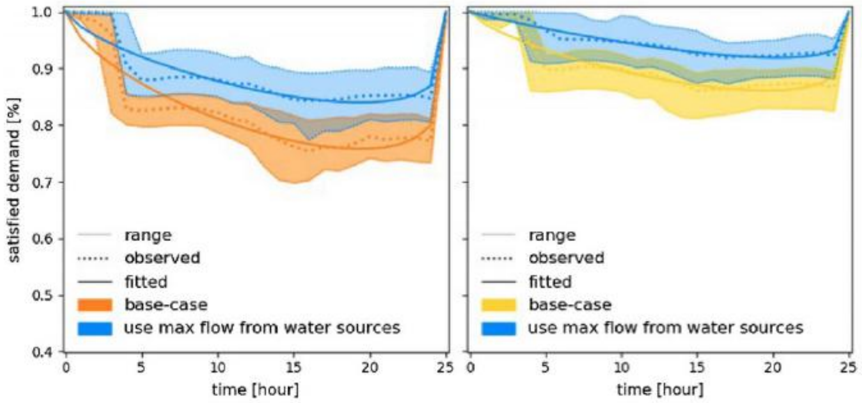
Results

Resilience strategies

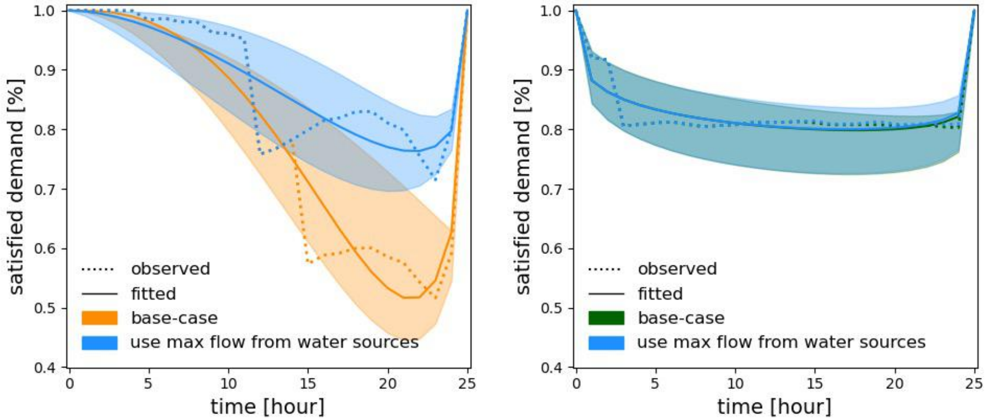
- Two strategies are implemented, namely using the max available flow from (i) water sources or (ii) water tanks
- Their effects is evaluated on the two identified clusters using the beta recovery functions fitted to the MOP associated to the min, max, and median Δ of a cluster

(a)





(1) (2)



(3) (4)

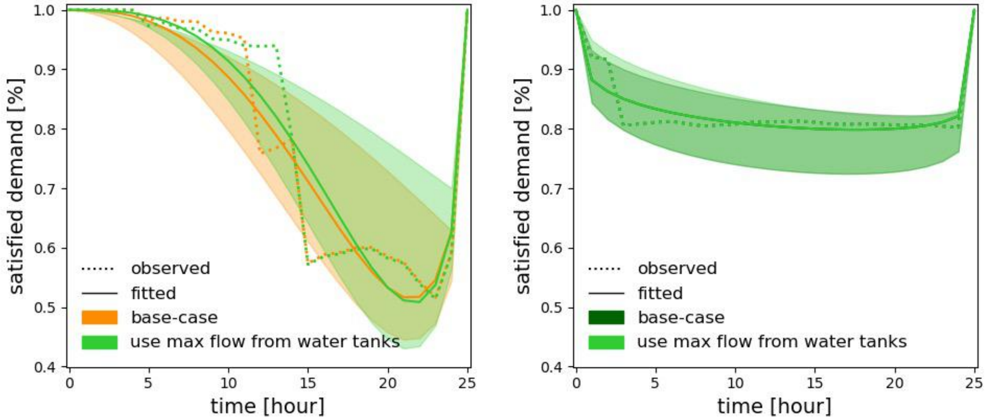


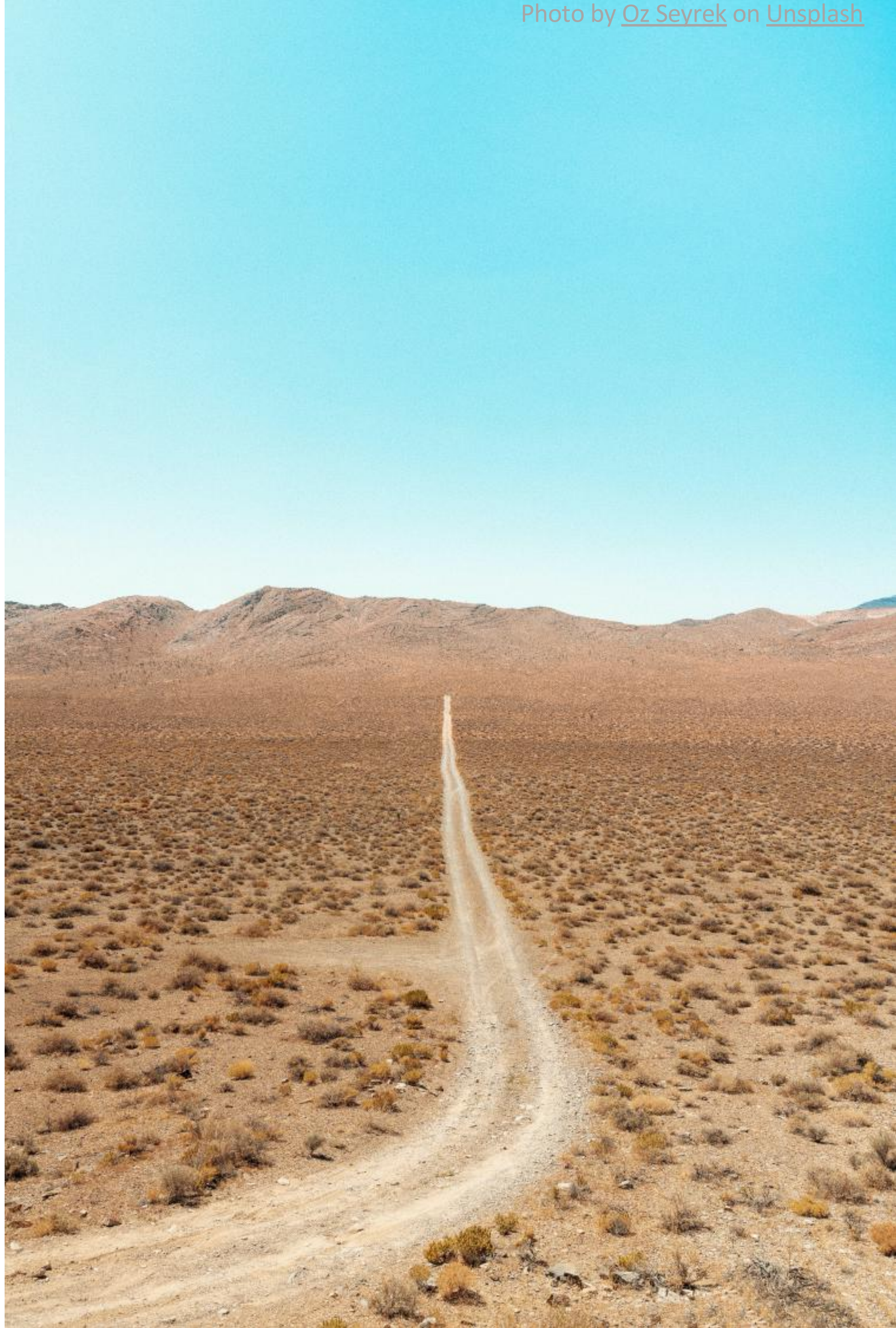
Figure a: Topology of *Net3*, nodes are coloured according to *cluster*
Figure 1: Fitted functions, strategy (i), cluster ‘delayed-but-severe’
Figure 2: Fitted functions, strategy (i), cluster ‘sudden-but-limited’
Figure 3: Fitted functions, strategy (ii), cluster ‘delayed-but-severe’
Figure 4: Fitted functions, strategy (ii), cluster ‘sudden-but-limited’

Concluding Remarks

- Robustness vs. Resilience:
    - What is necessary to move from being robust to become resilient? What do we need for a concrete road map towards resilience?

- MOPs, Resilience functions and Metrics:
    - How do you choose metrics given that number of metrics are available now as well as models, algorithms, or data. What is the determinant factor when we select or exclude variables?

- Extreme events, emerging response:
    - Resilience against what, when, whom?



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