RESIWATER

INNOVATIVE SECURE SENSOR NETWORKS AND MODEL-BASED ASSESSMENT TOOLS FOR INCREASED RESILIENCE OF WATER INFRASTRUCTURES

PROJET FINANCÉ PAR L'ANR - PROJECT FUNDED BY THE ANR

SPONSORED BY THE Federal Ministry of Education and Research

A Franco-German Project for Augmented Resilience of Water Distribution Systems following Severe Abnormal Events

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Introduction

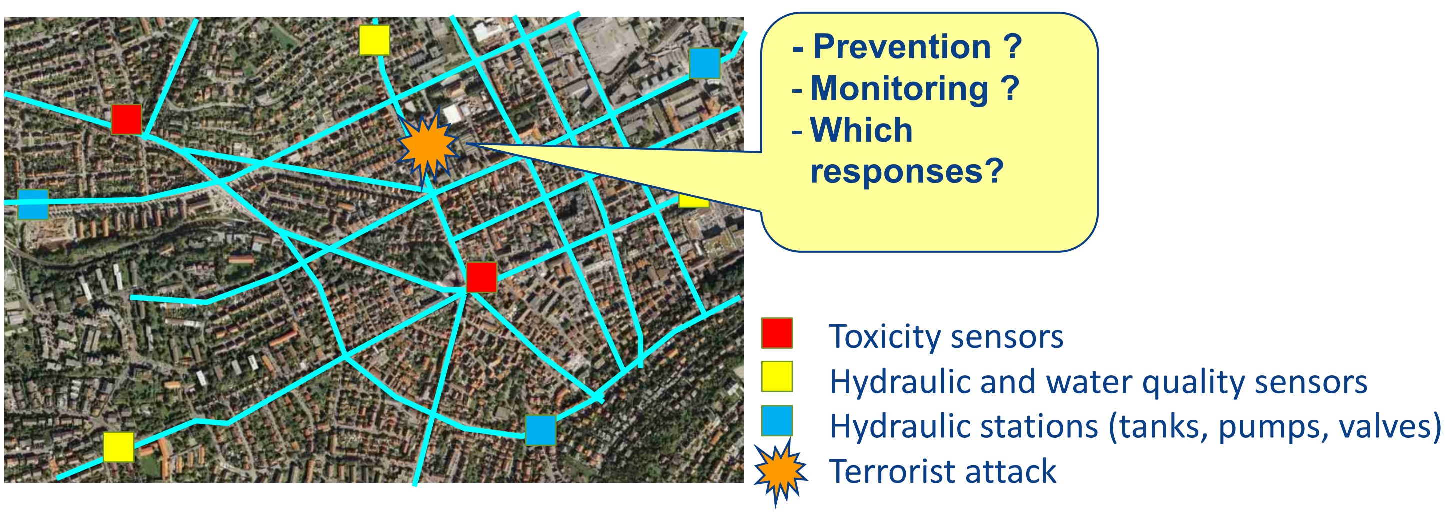
CRITICAL INFRASTRUCTURE PROTECTION

Drinking water distribution networks risk exposure to malicious or accidental contamination or may endure partial or full collapse of the system:

Terrorist attacks, cascade effects, major industrial accidents or natural disasters…

Not only are contaminant warning systems important, but so is water utility preparation, maintenance, training…

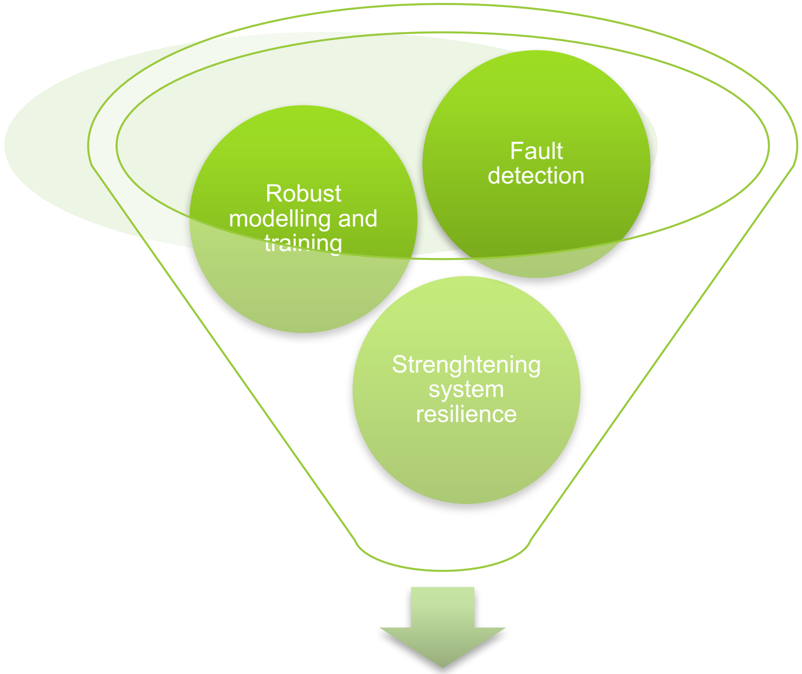
The detection of faults and the capacity to return quickly to a normal state after failures and interruption of services are essential for water utilities.



Introduction

OBJECTIVE

Prepare water utilities to crisis management by improving the system resilience with respect to 3 specific case studies: system failure, water quality deterioration and cascade effects between water, energy and IT infrastructures.



Better crisis management

1. Project consortium and work plan
2. Results M16
3. Main conclusions

Project consortium and work plan

PARTNERS (JULY 2015 – JUNE 2018)

End-users

Berliner Wasserbetriebe (BWB, Germany)

Eurométropole de Strasbourg (EMS, France)

Veolia Eau d'Ile-de-France (VEDIF, France)

Engineering Consulting Company

3S Consult GmbH (Germany)

Laboratories and Research Centers

Irstea (France)

Engees GESTE and ICUBE (France)

DVGW-Technologiezentrum Wasser TZW (Germany)

Fraunhofer Institute IOSB (Germany)

Fraunhofer institute IGB (Germany)

CEA DAM (France)

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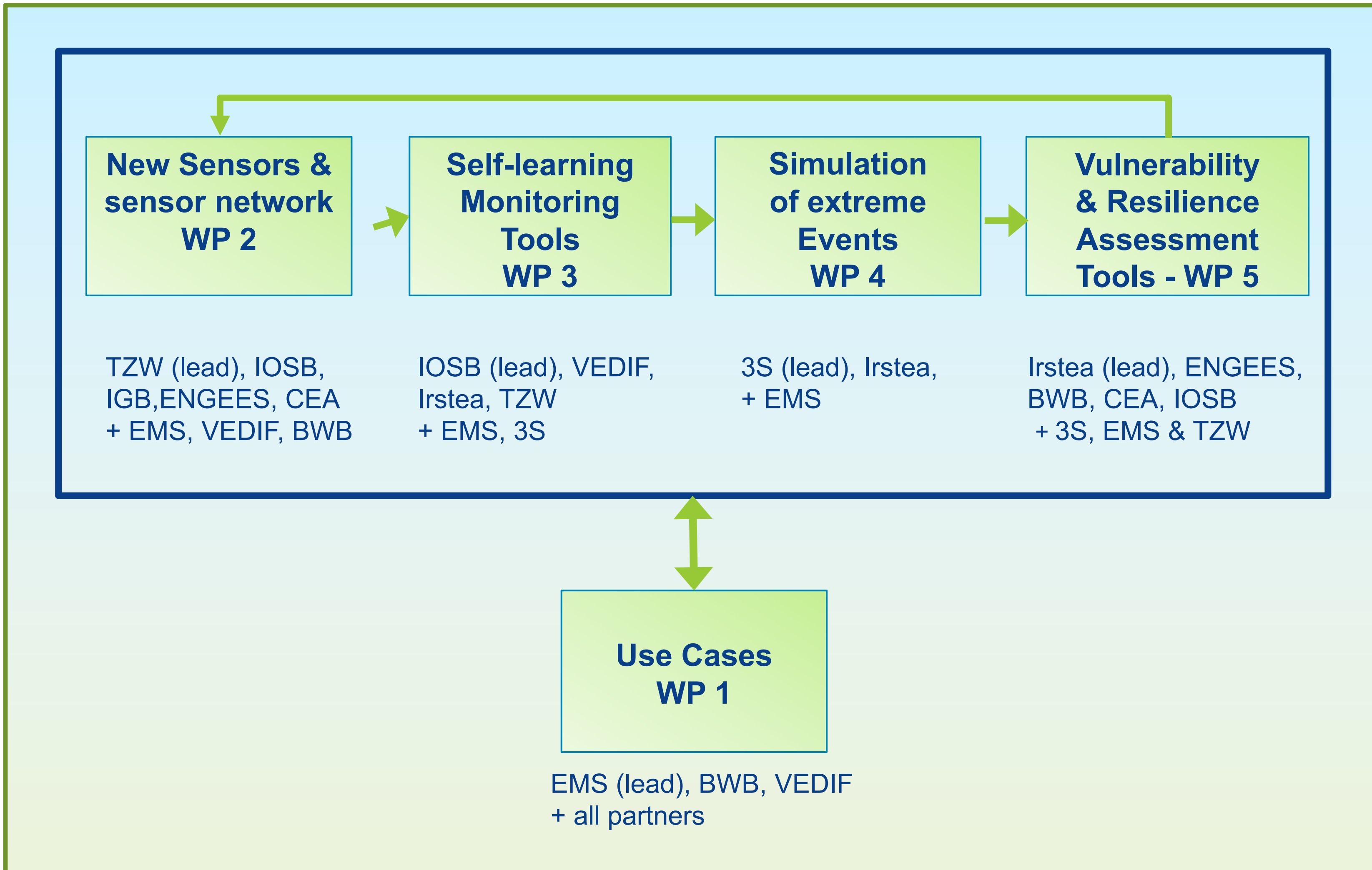
Project consortium and work plan

SCIENTIFIC AND TECHNICAL PROGRAM



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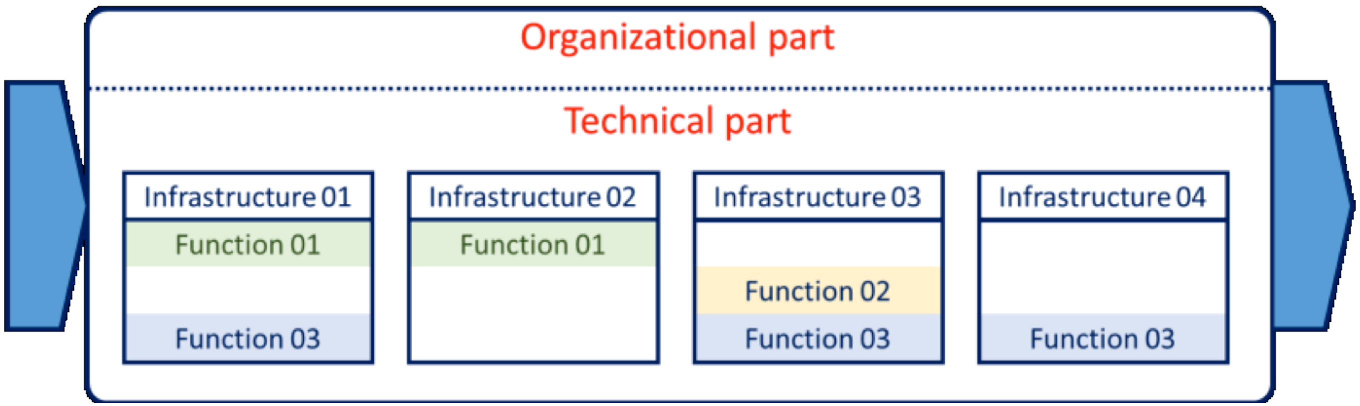
1 VULNERABILITY AND RESILIENCE ASSESSMENT

a WDS is composed of :

- A technical part, described through infrastructures and functions.
- An organizational part (WD utility).



For the present study:

- VULNERABILITY concerns the technical part of the system only.
- RESILIENCE concerns both the technical and the organizational parts of the system.

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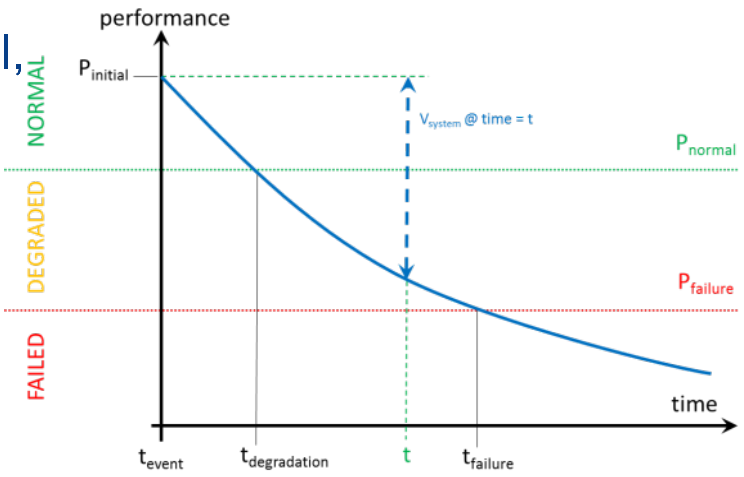
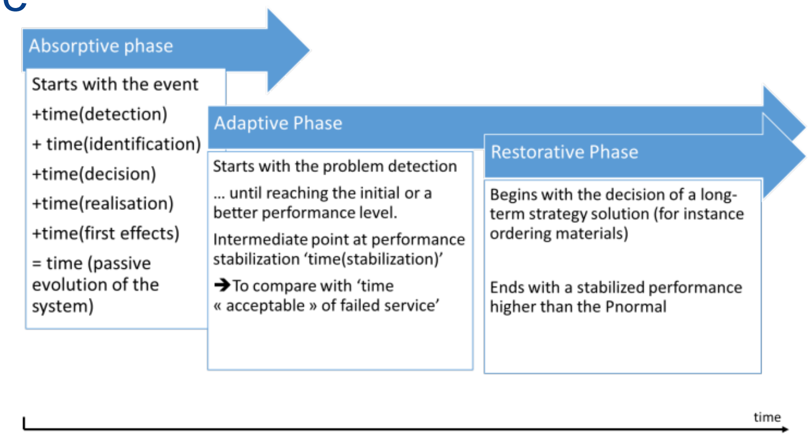
1 VULNERABILITY AND RESILIENCE ASSESSMENT

Four vulnerability components: physical, functional, system, external

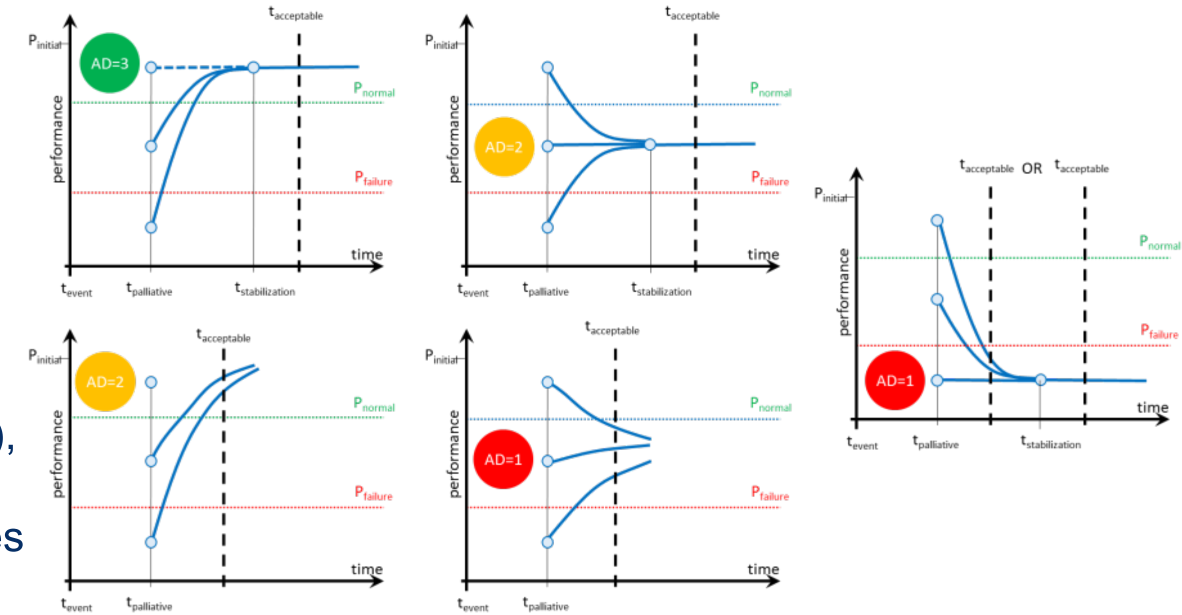
System VULNERABILITY is assessed through the loss of performance of the technical system during the passive phase (before any reaction)



RESILIENCE is composed of three capacities: Absorptive (linked to vulnerability), Adaptive and Restorative



VULNERABILITY and RESILIENCE signatures are also assessed on a simple three-level scale:



VULNERABILITY assessment at system level requires an hydraulic and transport model (Porteau, Sir 3S), given an initial state of perturbed infrastructures and functions.

RESILIENCE can be assessed by:

- Using characteristic times and residual levels of performance (analysis of past events),
- Using simple survey, when no past event is available.

	Question (Not Resilient: 1, Resilient: 3)	1	2	3
a	The first question concerns the ability of detection of system performance degradation (within the system). Given the vignette: • There are detection tools that enable to inform the control room in an instantaneous manner. The detection time is inferior than $t_{failure}$. ➔ $R_{adaptive}$ (Internal Detection)=3 • There are some detection tools but the detection delay is highly variable and difficult to assess ➔ $R_{adaptive}$ (Internal Detection)=2 • There are detection tools but with a detection delay superior of the failure time or there is no detection tool. ➔ $R_{adaptive}$ (Internal Detection)=1			
a*	If the vignette concerns a major natural event that has a slow dynamic (like a flood or heavy rain): • There is an early warning system watching at this threat and the WDS knows from which threshold there will be damages on its infrastructures ➔ $R_{adaptive}$ (External Detection)=3 • There is an early warning system watching at this threat but the WDS doesn't know from which threshold there will be damages on its infrastructures ➔ $R_{adaptive}$ (External Detection)=2 • There is no early warning system. ➔ $R_{adaptive}$ (External Detection)=1			
	If the vignette concerns a major natural event that has a slow dynamic $R_{adaptive}$ (Detection)= MIN [$R_{adaptive}$ (External Detection), $R_{adaptive}$ (Internal Detection)]			

Assessment		Mark
Vulnerability	Initial physical vulnerability	2
	Initial functional vulnerability	2
	System vulnerability	3
	External vulnerability	3
Resilience	Adsorptive capacity	2
	Adaptive capacity - a posteriori	2
	Adaptive capacity - a priori	2
	Restorative capacity	3

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2 END USERS CASE STUDIES

For BWB there are three case studies:

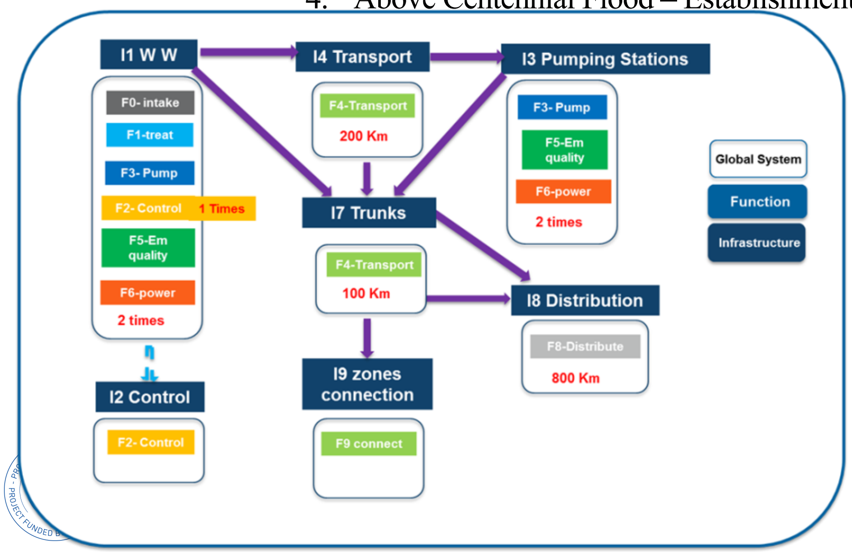
1. Cut off of two waterworks by a regional power cut;
2. Contamination (non-pathogen bacteria) in south east of Berlin;
3. Cyber attack at control systems (stuxnet).

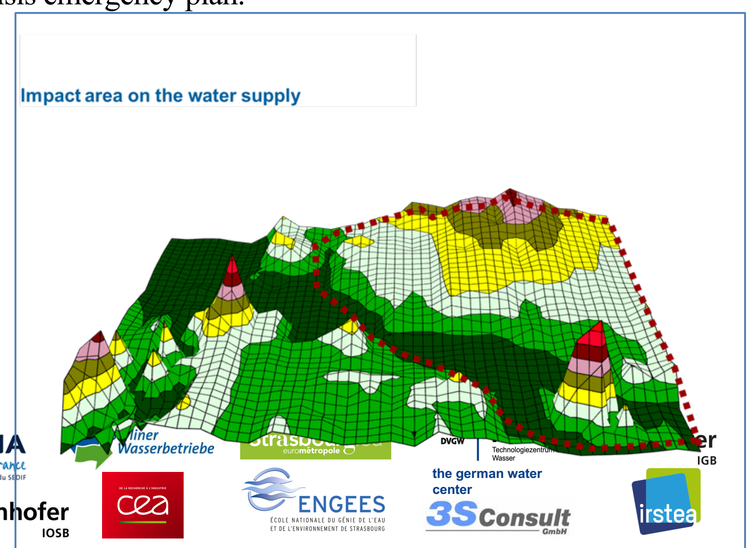
For EMS also three case studies:

1. Main production unit stopped by major flood event;
2. Water quality degradation by intentional network contamination;
3. IT attack Oberhausbergen power plant stopped, event masked by false data (replicated data set).

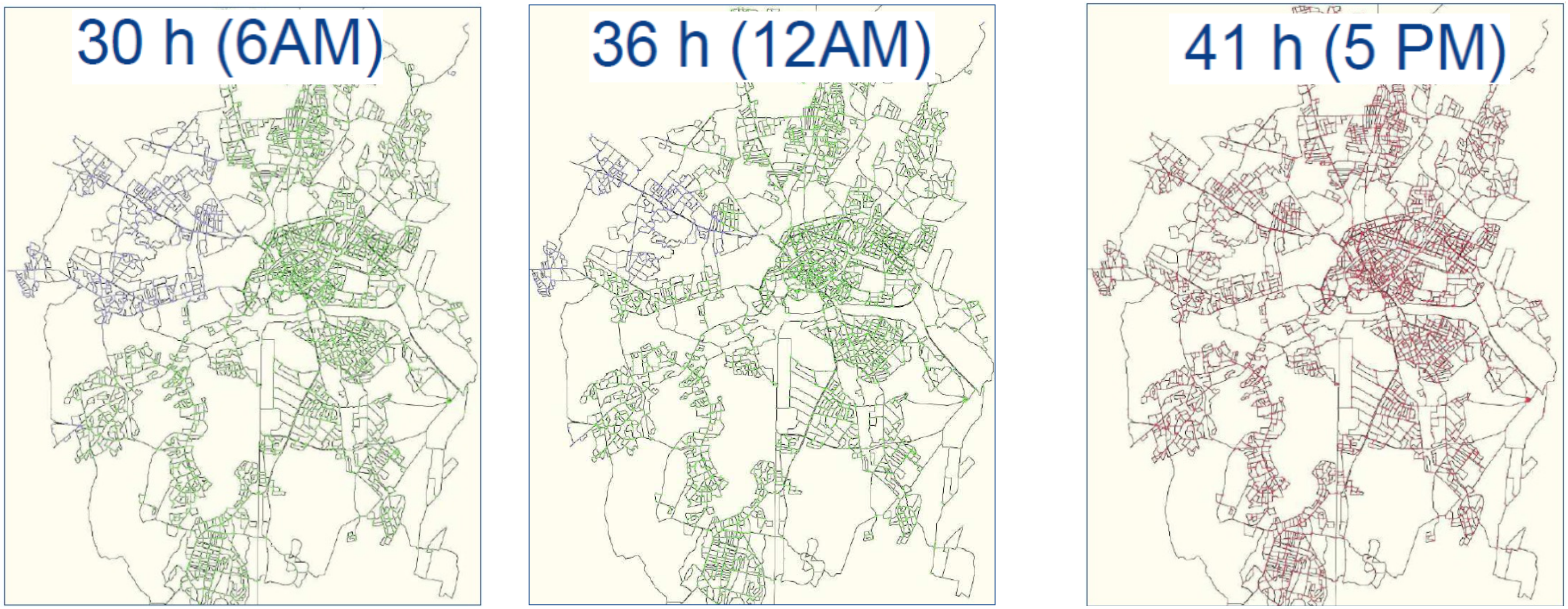
And for VEDIF four case studies:

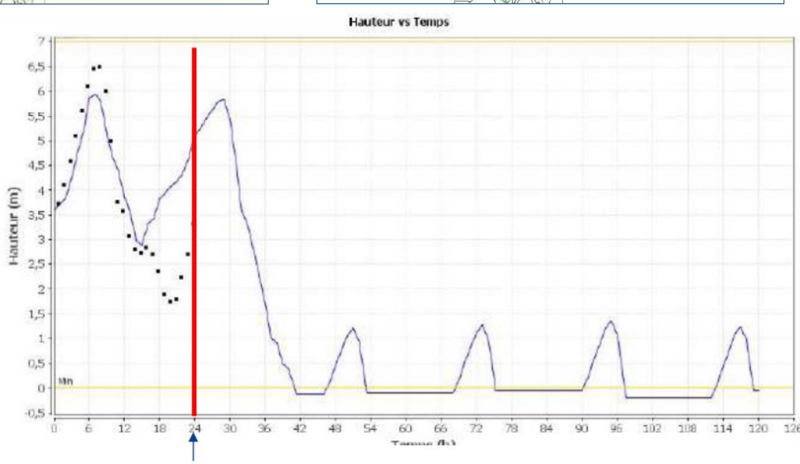
1. Fire Hydrants operation in “Street Pooling” situation;
2. Terrorist attack on network in the situation of a major International Event (COP 21);
3. Centennial Flood;
4. Above Centennial Flood – Establishment of the major crisis emergency plan.





EMS (1): Main production unit stopped by major flood event





Polygone plant stopped

0 bar
1 bar
2.5 bar
4 bar

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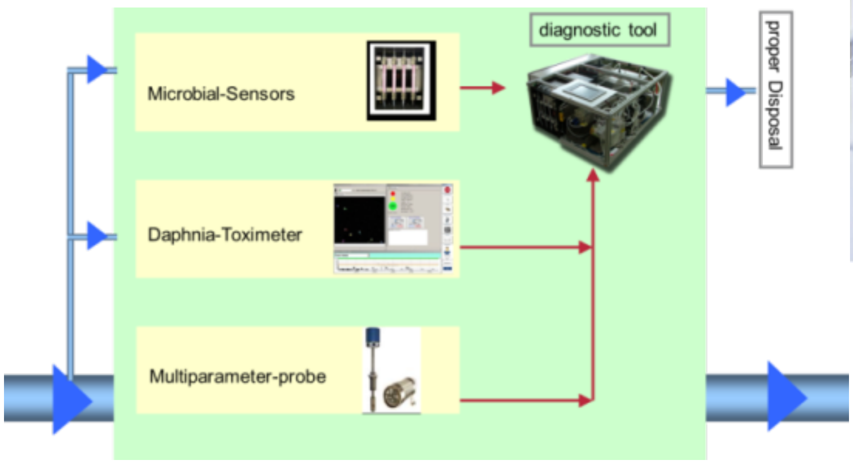
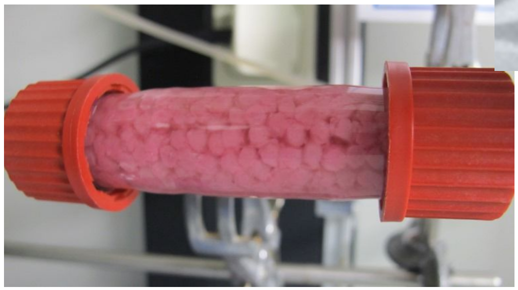
3 NEW SENSORS

Investigation and partly development of new sensors for online-Monitoring

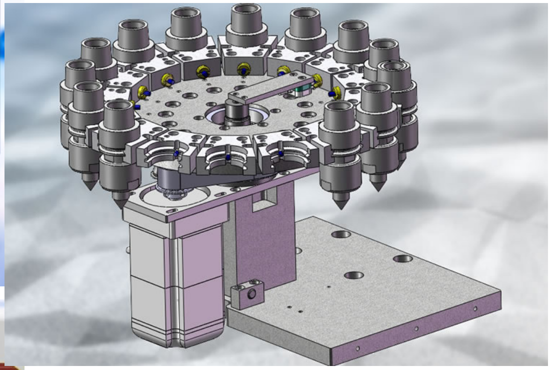
- Biological Sensor system « AquaBioTox »
- Spectroscopic sensors
- Low-Cost through-flow measurement system

Development of a concept for integrated and secure sensor networks





Red colonies of the biosensors cultivated on agar medium



Revolving cartridge system for several biological reactors

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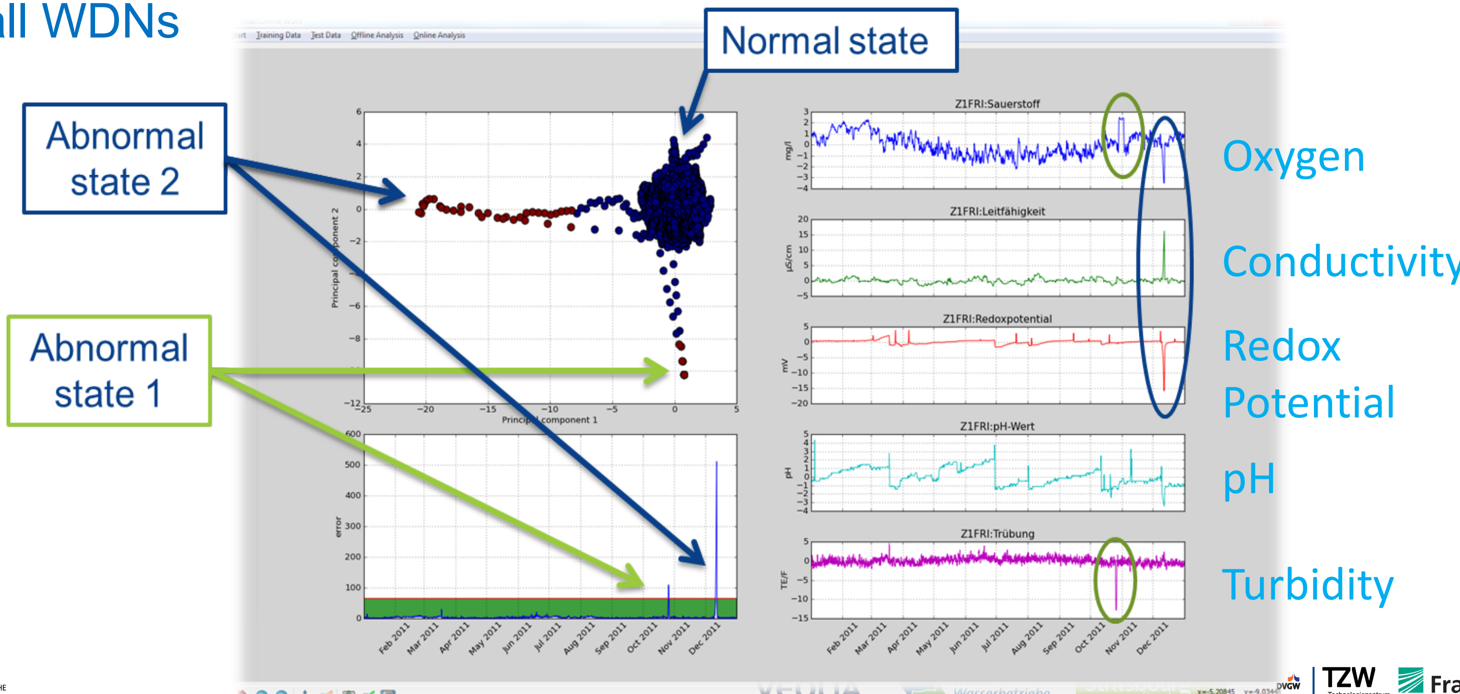
4 SELF-LEARNING MONITORING

- Training from historical data (method: Principal Component Analysis). Dynamic PCA detect events in oscillating data + incremental PCA can be used to learn drifting sensor data.
- Development of a standardized platform for data acquisition and analysis for all WDNs



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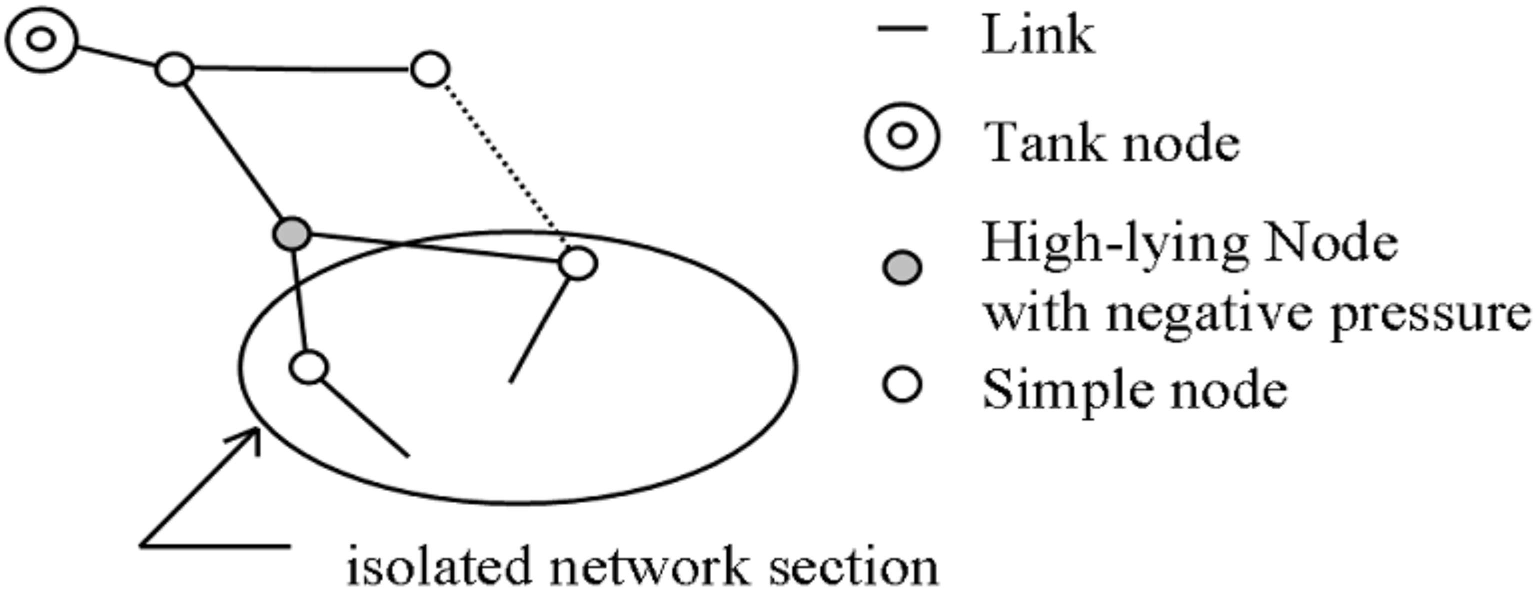
Braun et al., CCWI 2016, session 6, room A

LIMITATIONS OF DEMAND- AND PRESSURE-DRIVEN MODELING FOR LARGE DEFICIENT NETWORKS



- Non realistic solutions may be obtained after solving of previous system
- One main pipe has broken or is closed (the dotted line)
- There is only one path for water to supply a specific network section even if the pressure at the high-lying node is negative

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5 ROBUST MODELING - CONTENT MINIMIZATION

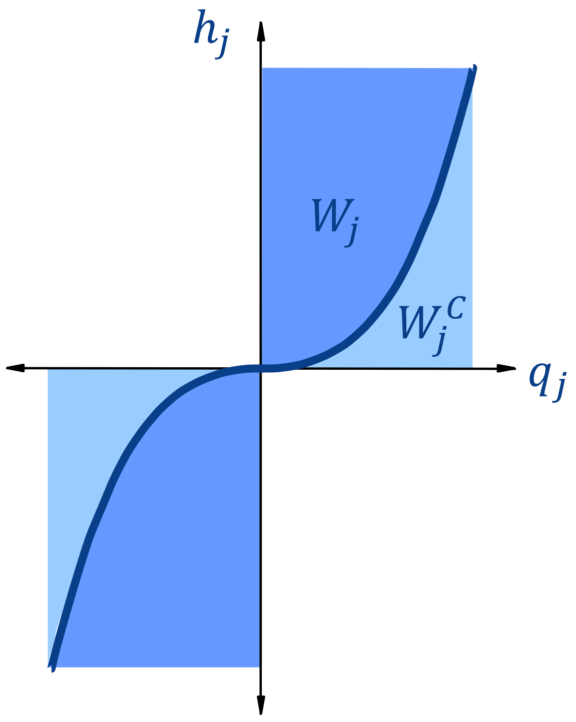
Content Model:

$$\min_{\mathbf{q}\in R^{np}} C(\mathbf{q}) = \sum_{j=1}^{np} W_j - \mathbf{q}^T \mathbf{A}_0 \boldsymbol{h}_0$$

$$s.t.\ -\mathbf{A}_1^T\mathbf{q} - \mathbf{d} = \mathbf{0}_{nj}$$

Content of a pipe (including minor loss):

$$W_j = \int_0^{q_j} \left(r_j |x_j|^{\alpha-1} + K_j |x_j| \right) x_j dx_j.$$



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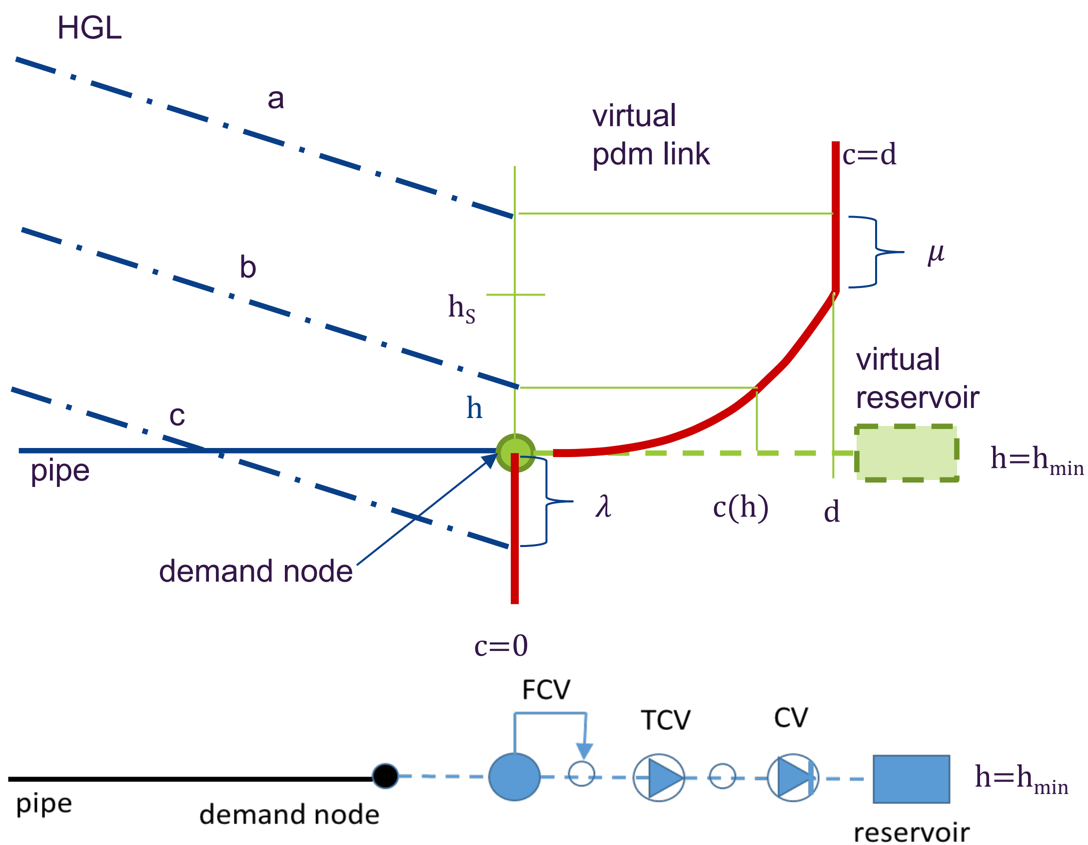
5 ROBUST MODELING – PDM ANALOGOUS SYSTEM



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5 ROBUST MODELING - CONTENT MINIMIZATION

$$\min_{[\mathbf{q},\mathbf{c}]\in R^{np+nj}} C(\mathbf{q},\mathbf{c}) = \sum_{j=1}^{np} W_j(q_j) + \sum_{i=1}^{nj} \widehat{W}_i(c_i) - \mathbf{q}^T \mathbf{A}_0 \boldsymbol{h}_0$$

$$s.t.\ -\mathbf{A}_1^T\mathbf{q} - \mathbf{c} = \mathbf{0}_{nj}$$

$$\mathbf{0}_{nj} \leq \mathbf{c}$$

$$\mathbf{c} \leq \mathbf{d}$$

PDM

1. Elhay, S., et al.(2015). "A Robust, Rapidly Convergent Method That Solves the Water Distribution Equations for Pressure-Dependent Models." Journal of Water Resources Planning and Management, 142(2), 04015047-1 - 04015047-12.
2. Piller, O., et al. (2016). "Local Sensitivity of Pressure-Driven Modeling and Demand-Driven Modeling Steady-State Solutions to Variations in Parameters." Journal of Water Resources Planning and Management, 04016074, 12 pages.
3. Deuerlein et al. (2016). “Sensitivity Analysis of Topological Subgraphs within Water Distribution Systems.”, WDSA 2016, 8 pages.

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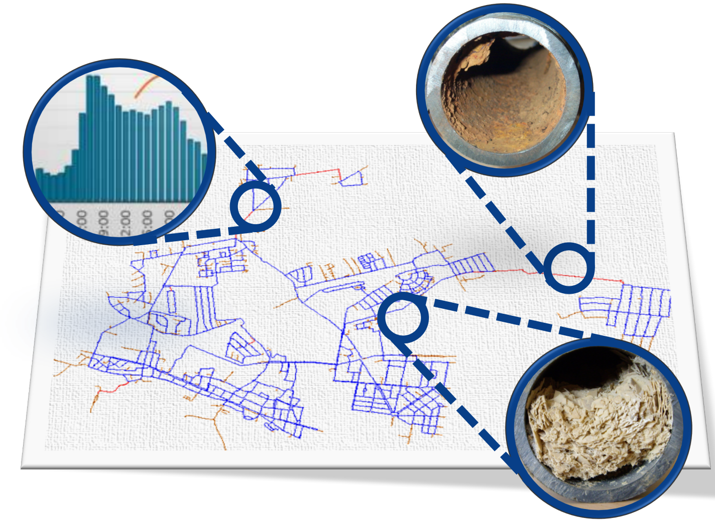
6 UNCERTAINTY PROPAGATION

➢ Why Uncertainty Analysis

- Complex Network Models with many Parameters
- Hydraulic Solution for deterministic Parameters
- Parameter Values are inherently uncertain



How do Parameter Uncertainties influence the results?

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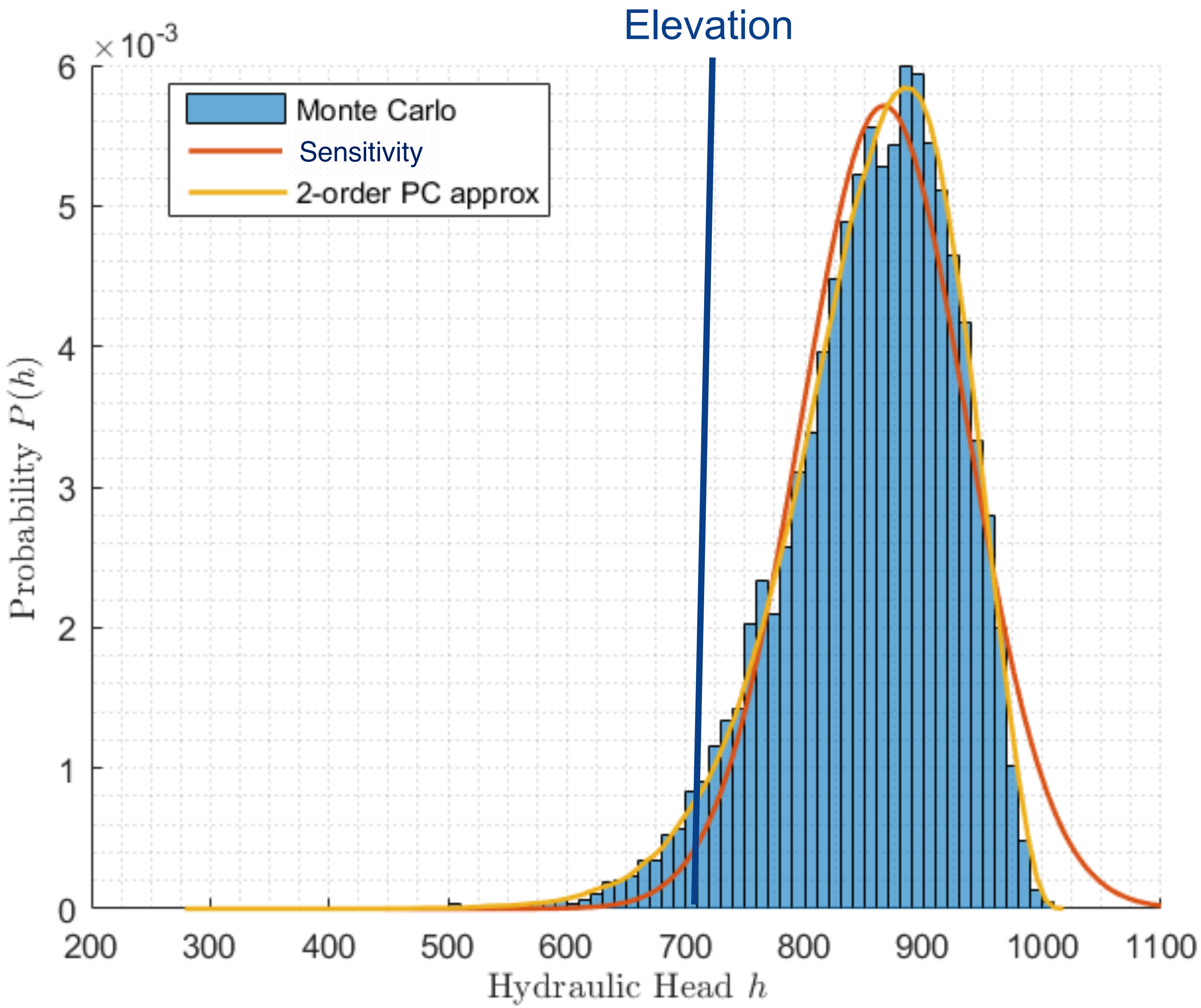

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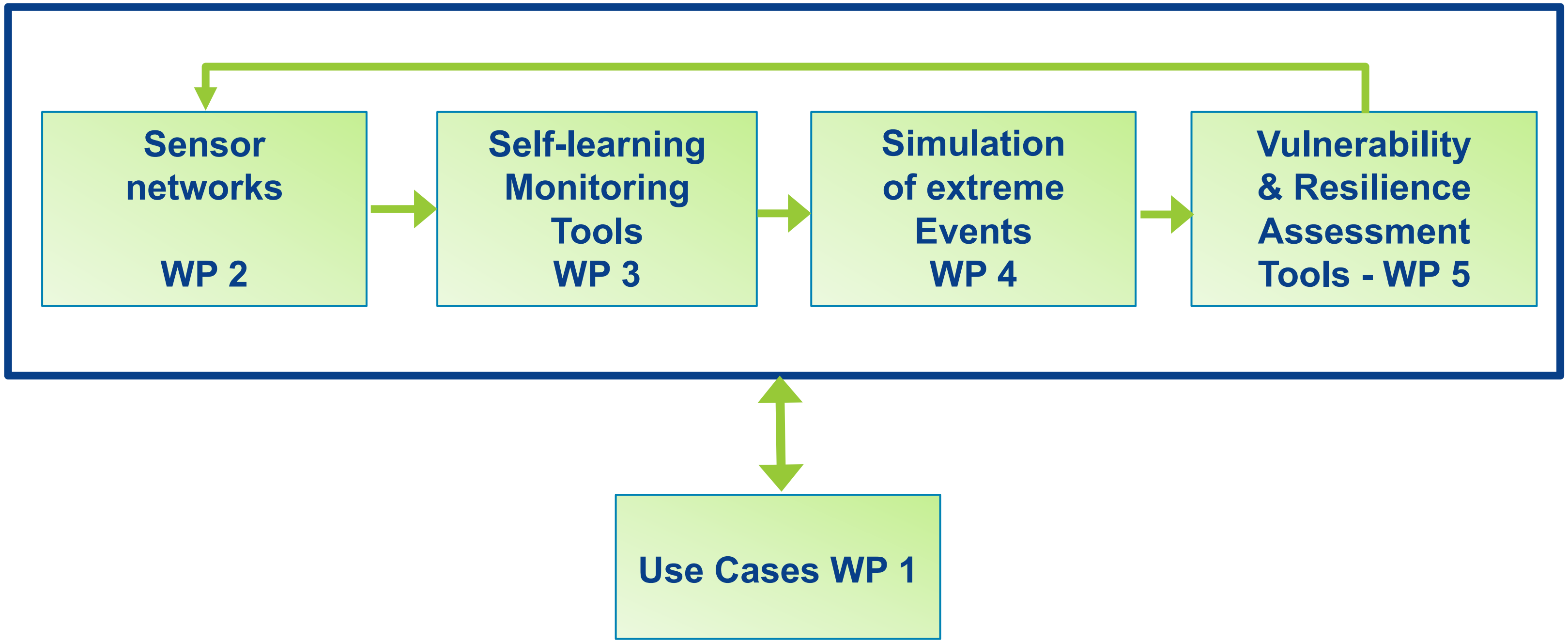
Conclusions

OBJECTIVE AND METHOD

Prepare water utilities to crisis management by improving the system resilience with respect to 3 specific case studies: system failure, water quality deterioration and cascade effects between water, energy and IT infrastructures.



Conclusions

MAIN RESULTS

✓An assessment method is adopted for the vulnerability and resilience assessments of the three project end users.

✓Three use cases per water utility: Collapse of WDS, Water Quality Deterioration and Cascade Events are specified in details.

✓A first software solution was delivered for alarm generation that is based on the developed methods Dynamic and Incremental Principal Component Analysis.

✓An optimisation framework was developed that enables the fast and robust solving of a range of algorithms for the pressure-driven modelling (PDM) system of equations

✓The chaos polynomial method looks adapted to the uncertainty propagation

Thank you for your attention!
Any questions?

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7 DIRECT COST VALUATION ON 4 CRISIS CASES EMS-BWB