



## RESILIENCE ASSESSMENT TOOLS AND METHODS

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[www.improverproject.eu](http://www.improverproject.eu)

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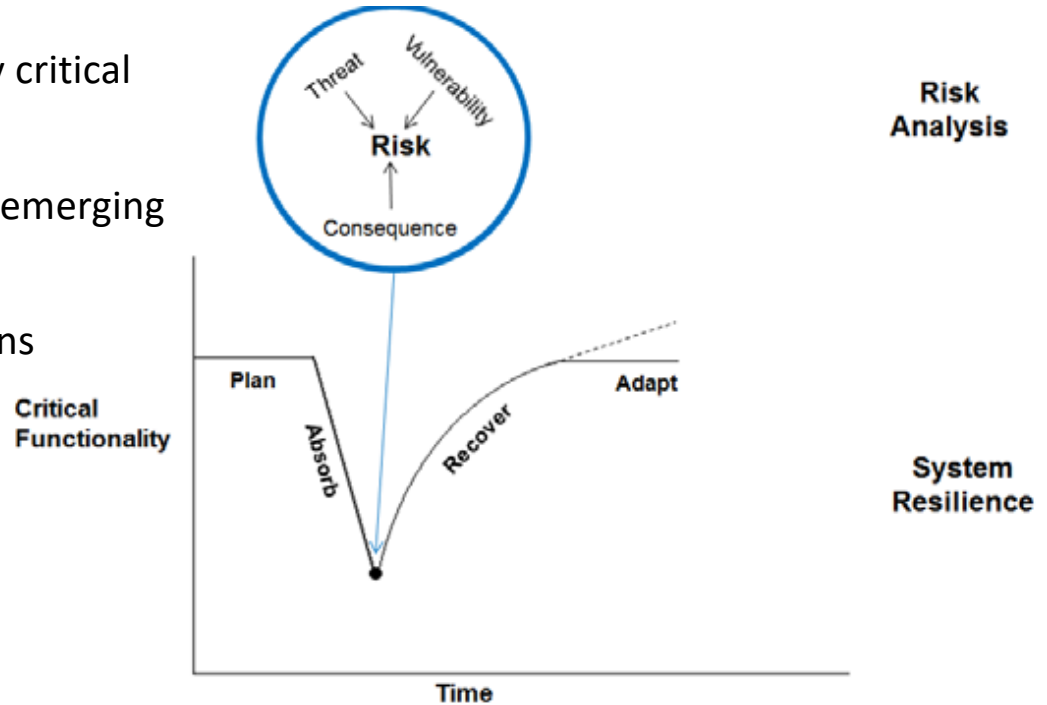


# IMPROVER FRAMEWORK



# From Risk Management to Resilience Management

- Focus on the delivery of **services** by critical infrastructures
- Dealing with **known** and **unknown** emerging risk
- Preservation of key societal functions
  - Resistance
  - Absorption
  - Restoration

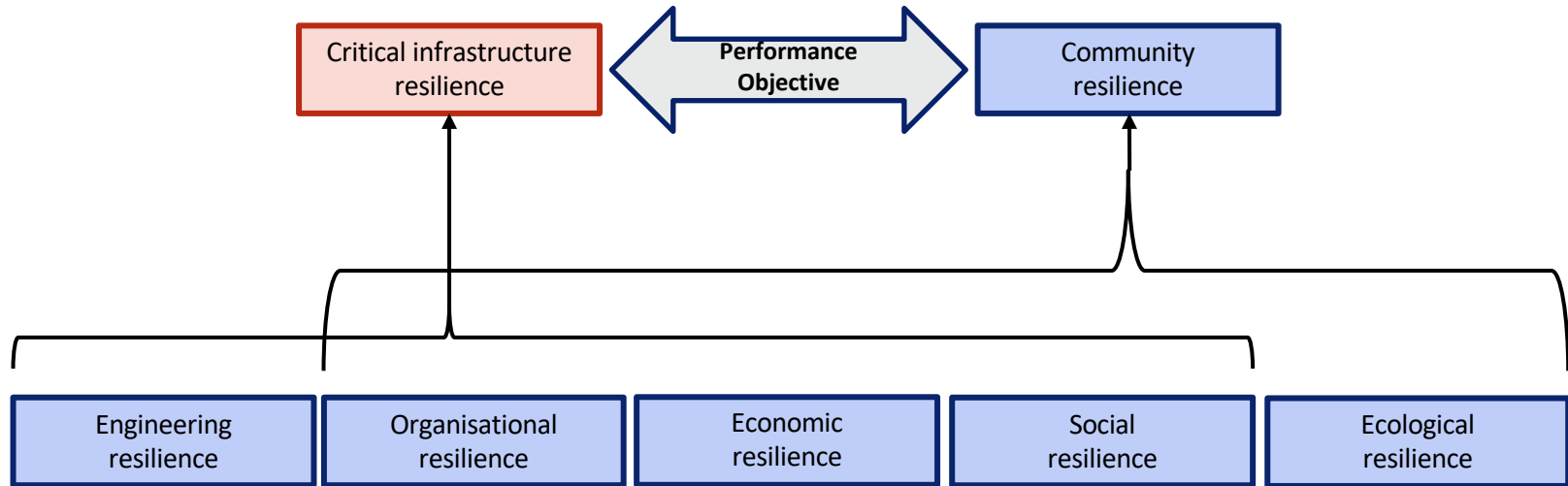


Linkov I. et al. Changing the resilience paradigm  
Nature Climate Change 4, 407–409(2014)



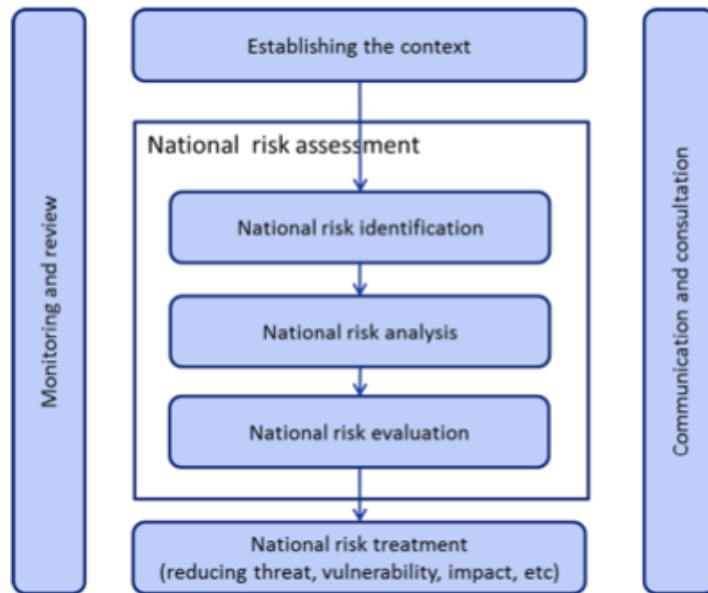
# Balance between CI resilience and community resilience

- *Critical infrastructure is essential for the maintenance of vital societal functions*



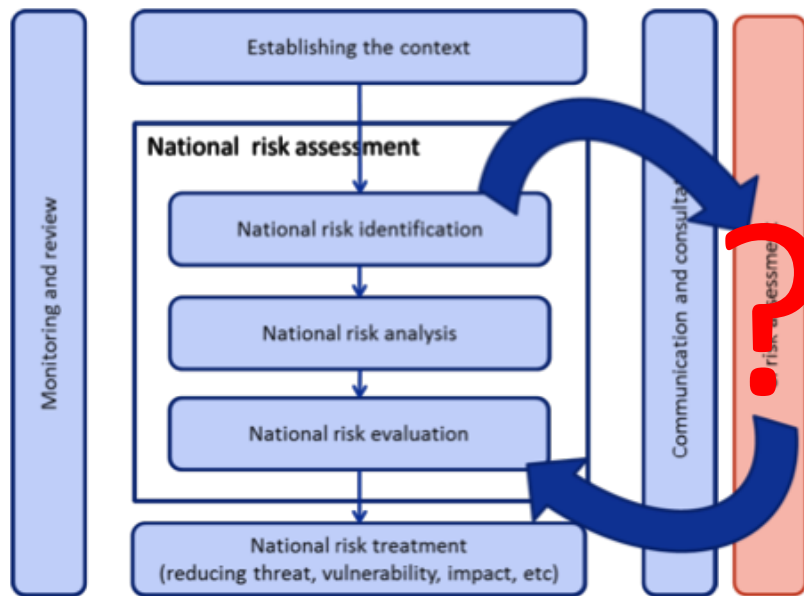
# Implementation alongside National Risk Assessments

- All-hazards, multi-risk, systemic approach
- Focus on major accidents or energy failures
- Infrastructure failure is often identified as a hazard on its own or as the consequence of other hazards
- Similar to the NERAG's here in Australia
- Infrastructure protection is governed by the EPCIP
- A recent review of the EPCIP highlighted two key issues:
  - Interdependencies between CI, and
  - Resilience of CI



# Implementation alongside National Risk Assessments

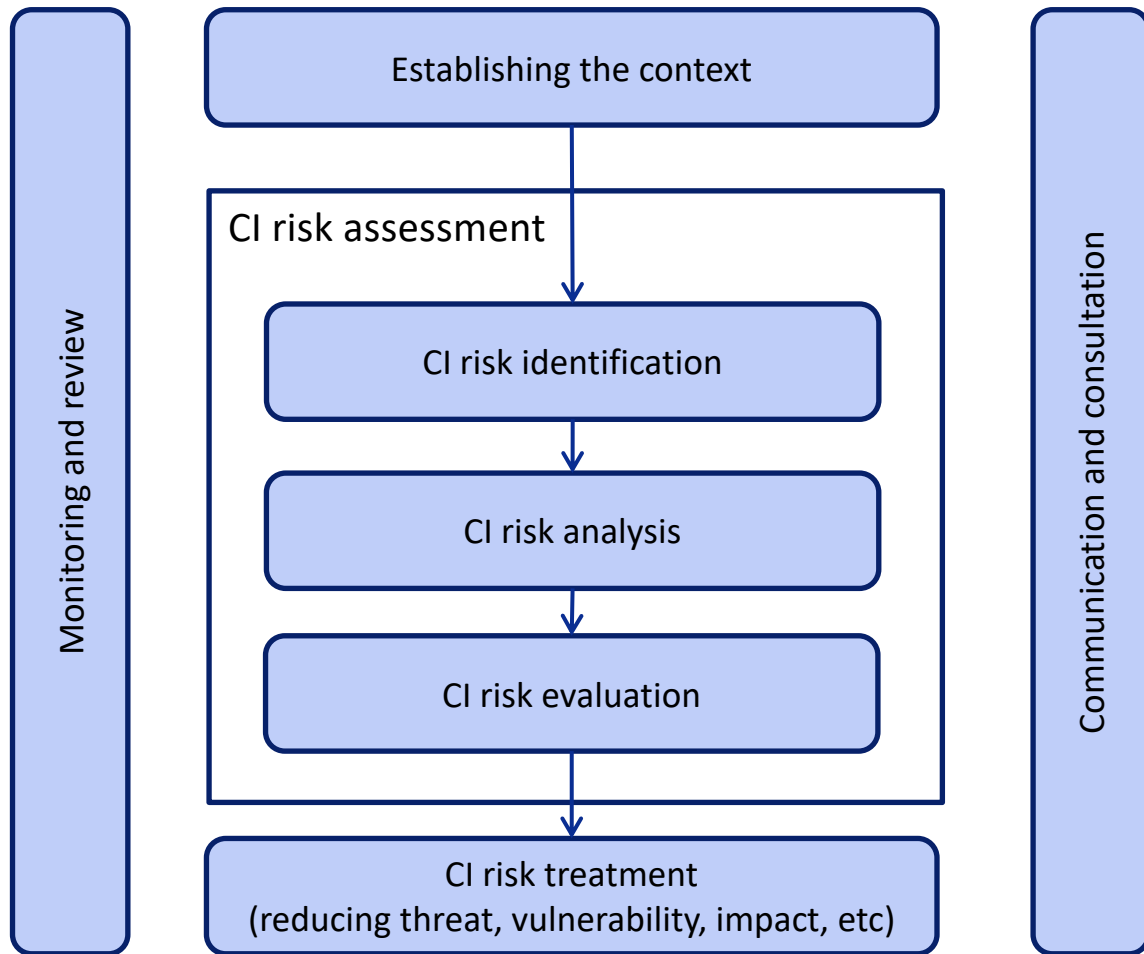
- National risk assessments are usually done by civil protection agencies
- Infrastructure risk assessments are usually done by operators
- There is an opportunity to:
  1. Enrich NRA's with additional information from CI operators, and
  2. Enrich in turn CI Risk management with information about the resilience of CI

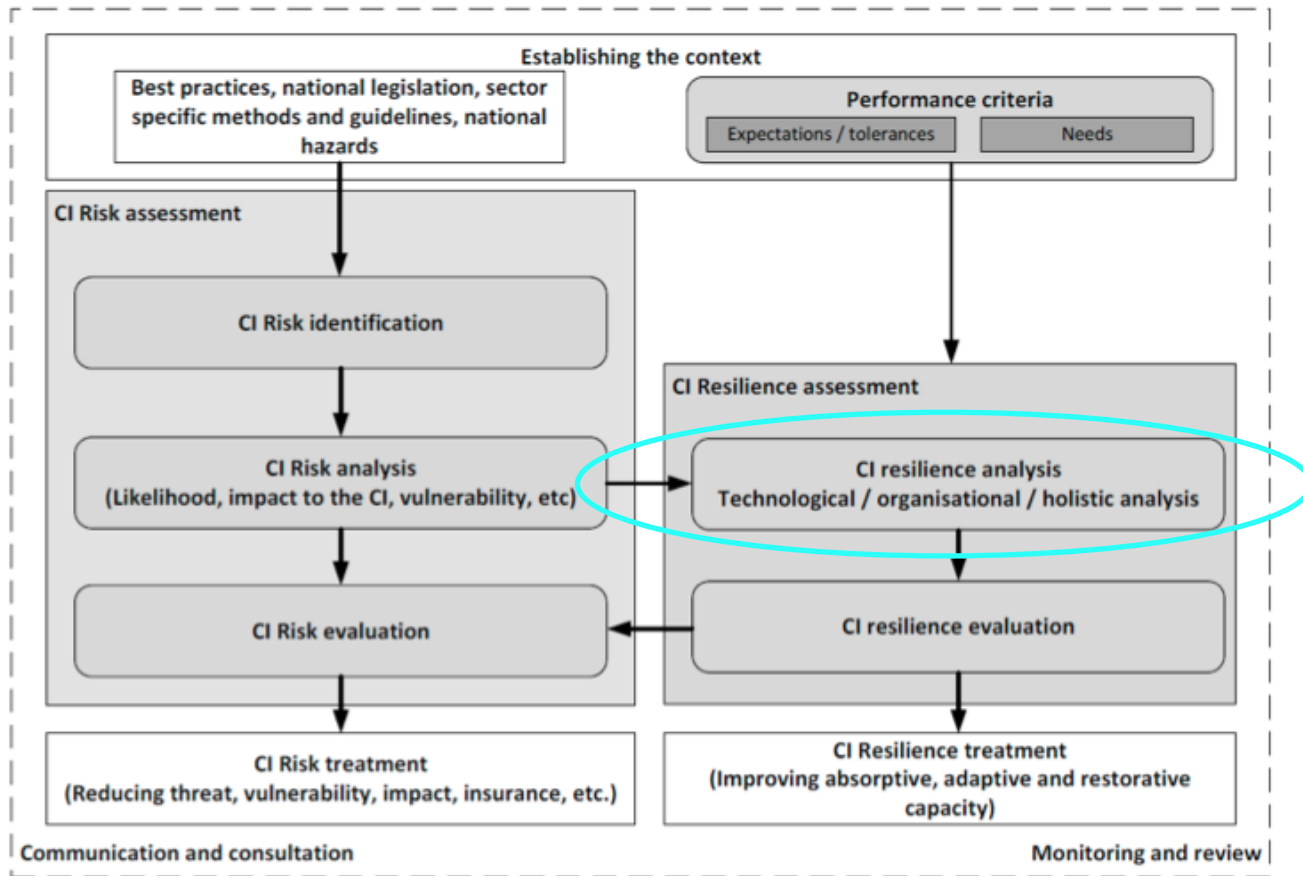


# Governance framework

- We propose a general framework for resilience assessment of CI, which remains compatible with the current guidelines for National Risk Assessments
- Integrates the paradigm of resilience into the Risk Assessment process according to ISO 31000
- Outputs risk and resilience treatment plans on both an asset and a system level
- ***Flexible – neither domain or analysis methodology dependent***

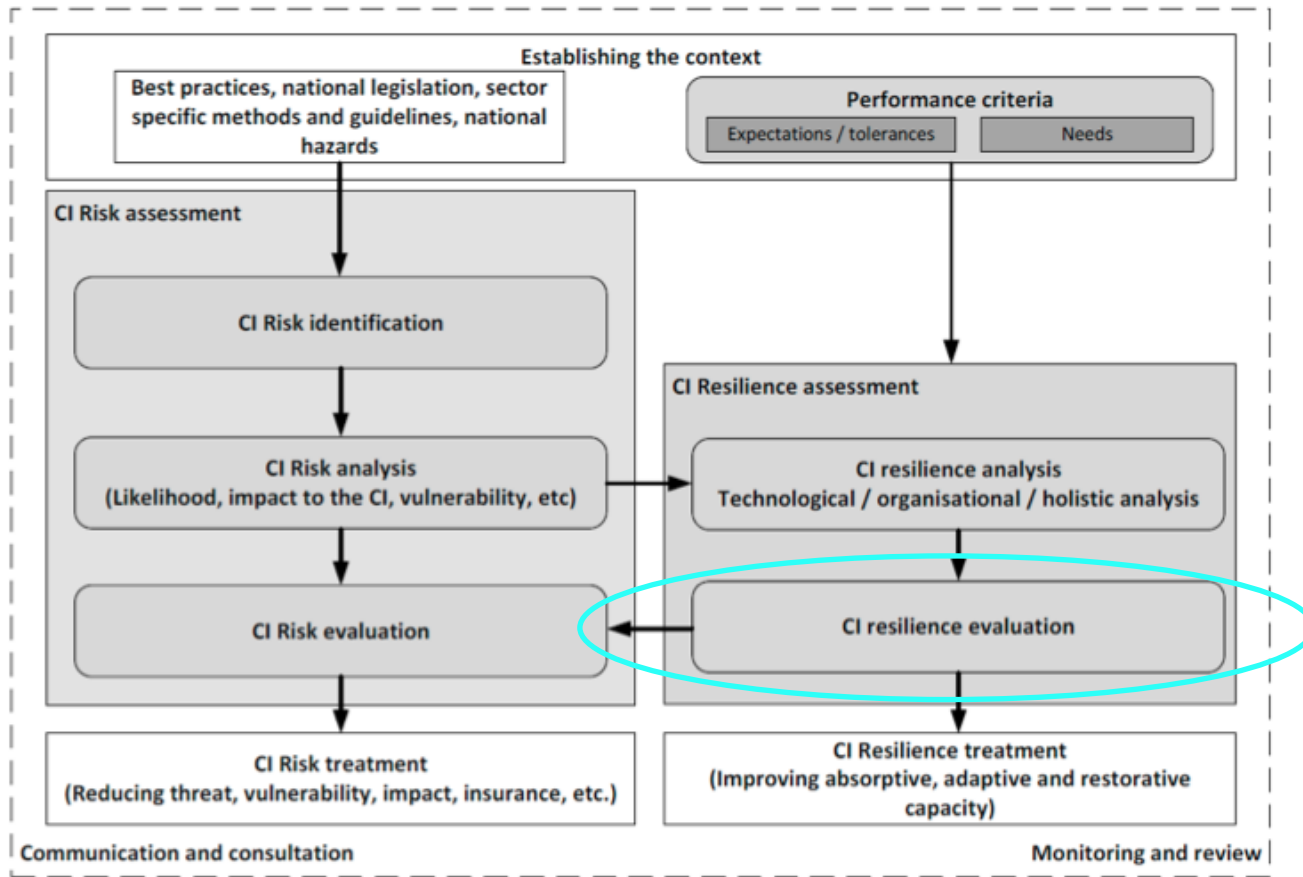




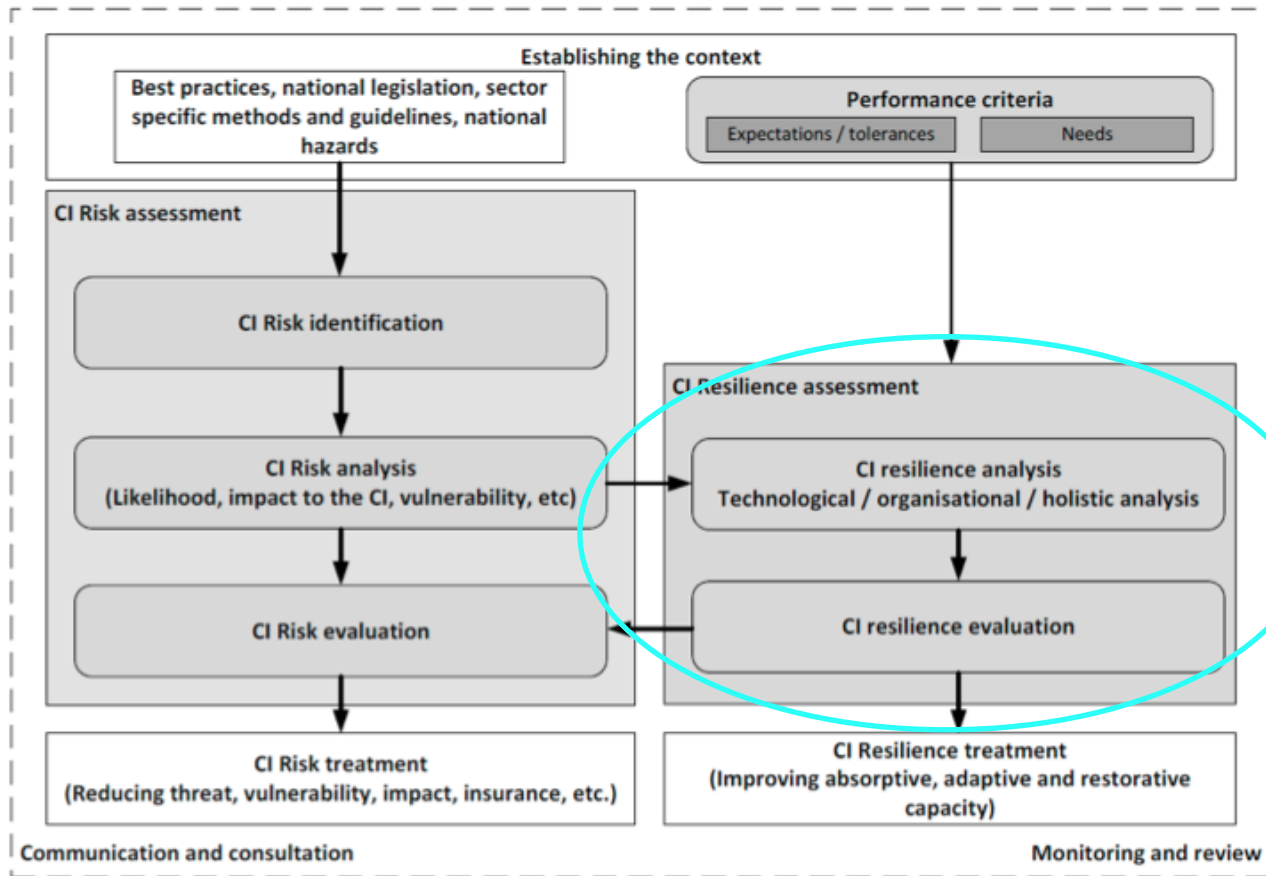


- **Resilience analysis:** Resilience analysis is the process to comprehend and to determine the level of resilience, based on selected resilience indicators

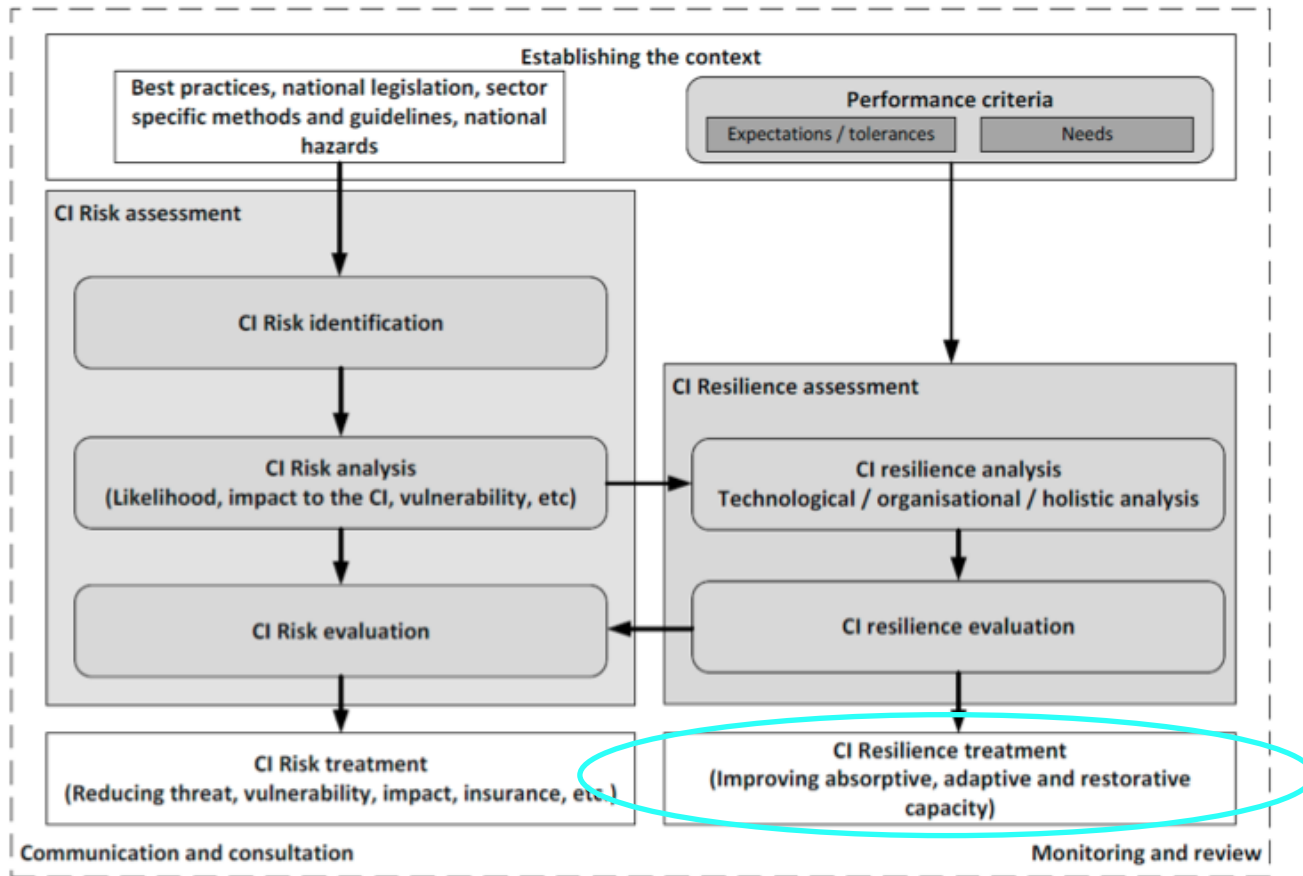




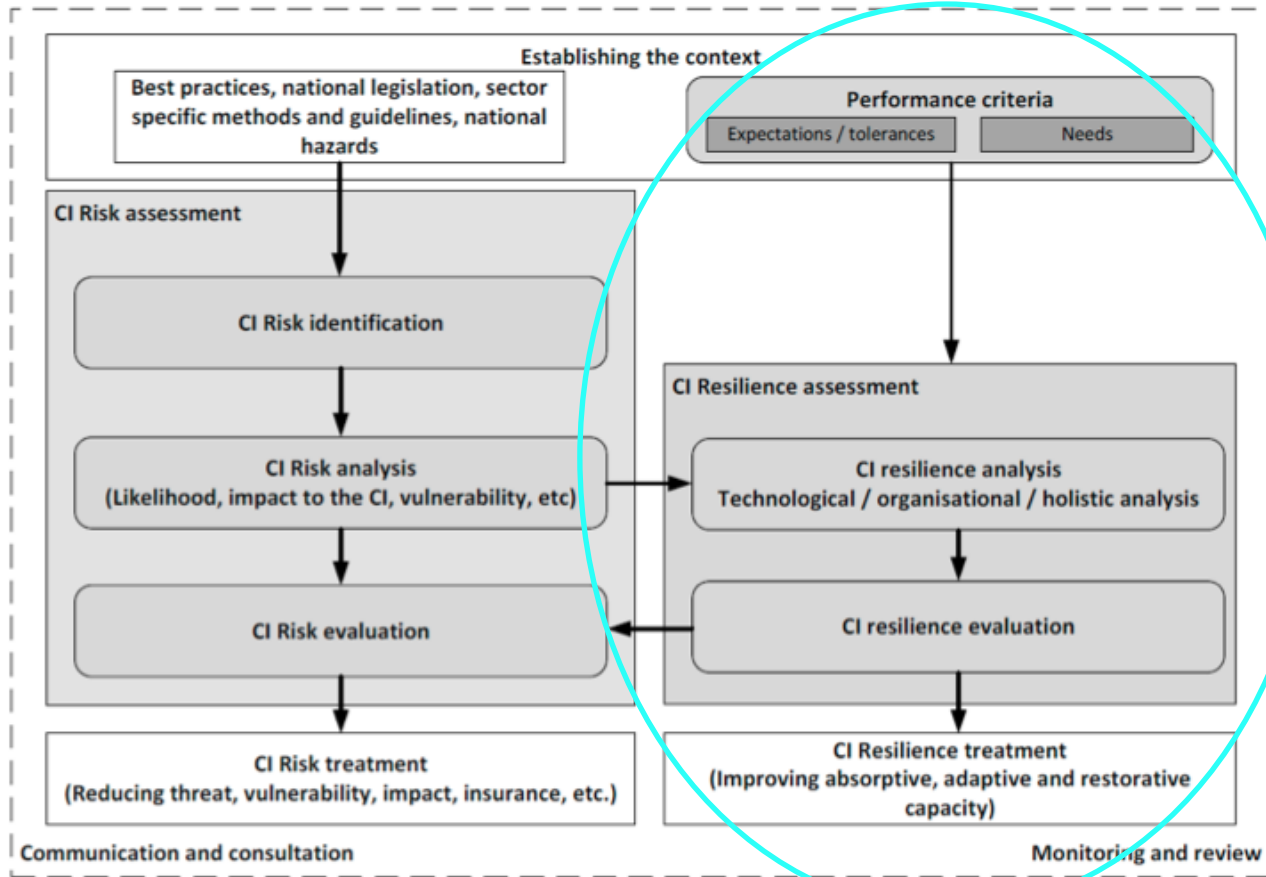
- **Resilience evaluation:** Resilience evaluation is the process of comparing the results of resilience analysis with criteria or objectives to determine whether resilience level is acceptable and identify areas for improvement



- **Resilience assessment:** Resilience assessment is the overall process of resilience analysis and evaluation

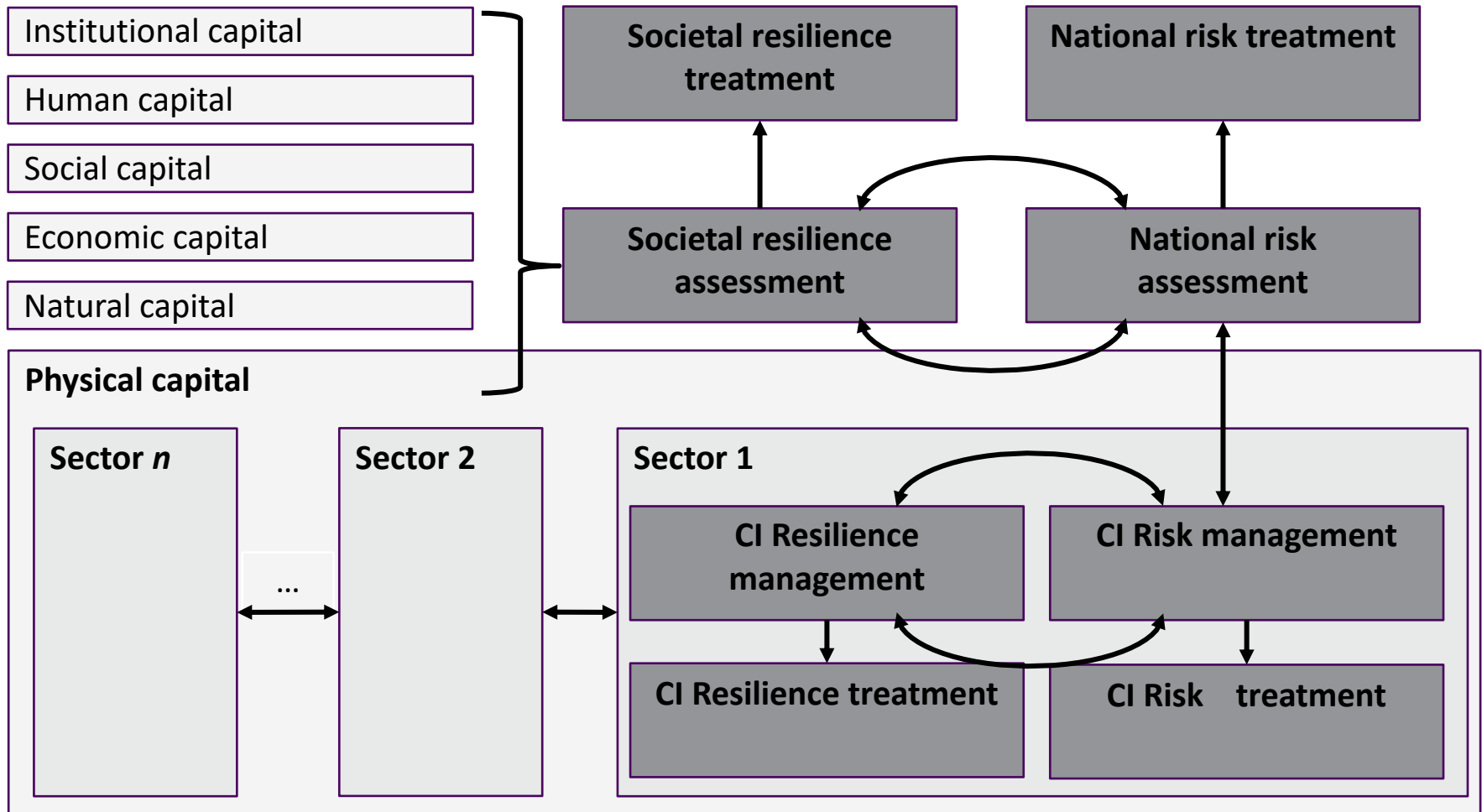


- **Resilience treatment:** the process to modify resilience, focusing on the absorptive, adaptive or restorative capacity



- **Resilience management:** Coordinated activities to direct and control an organization with regard to its resilience, including the above processes



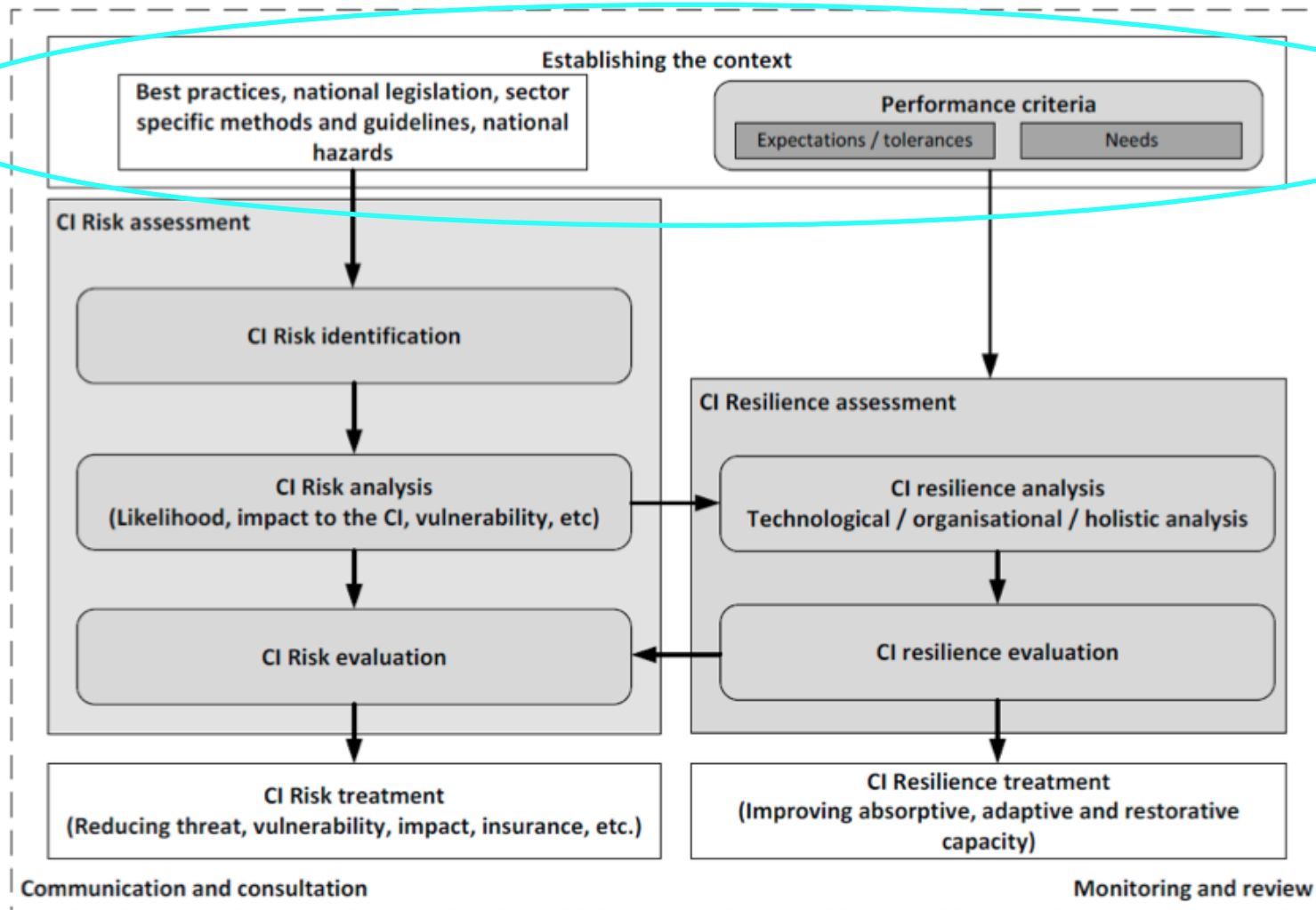


# ESTABLISHING THE CONTEXT



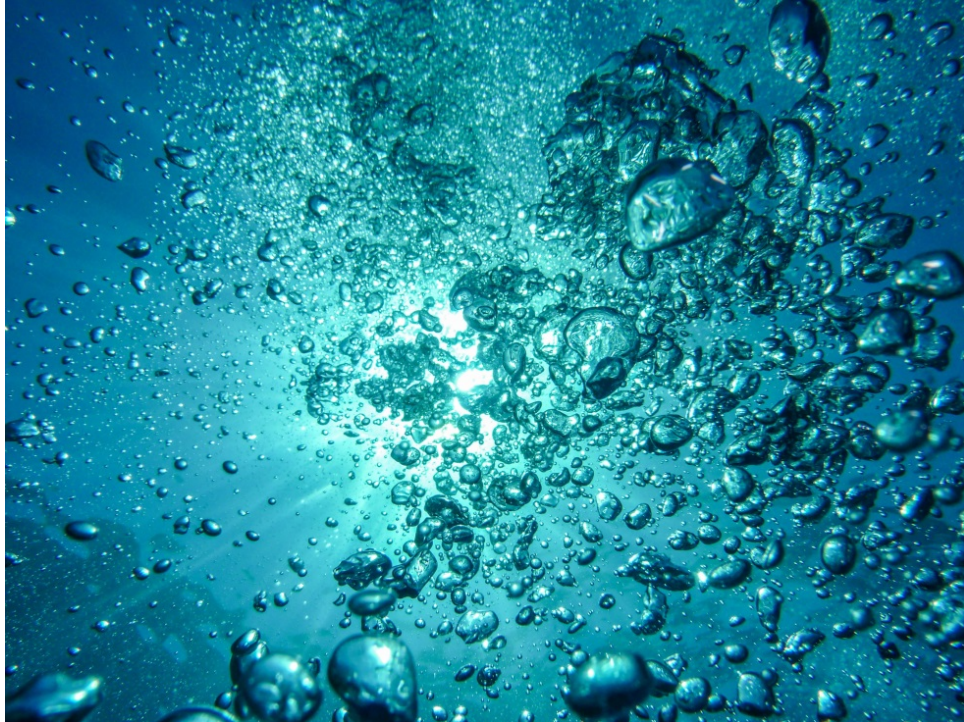








# Performance Criteria



# User Needs

		Service level	Needs met	Level of health concern
		No access (quantity collected often)	Consumption – cannot be assured Hygiene – not possible (unless practiced at source)	Very high
Basic access (average quantity unlikely to exceed 20 l/c/d)	Between 100 and 1000m or 5 to 30 minutes total collection time	Consumption – should be assured Hygiene – handwashing and basic food hygiene possible; laundry/bathing difficult to assure unless carried out at source		High
Intermediate access	Water delivered (average quantity about 50 l/c/d)	Consumption – assured Hygiene – all basic personal and food hygiene assured; laundry and bathing should also be assured		Low
	Optimal access (average quantity 100 l/c/d and above)	Consumption – all needs met Hygiene – all needs should be met		Very low

(World Health Organisation 2003)

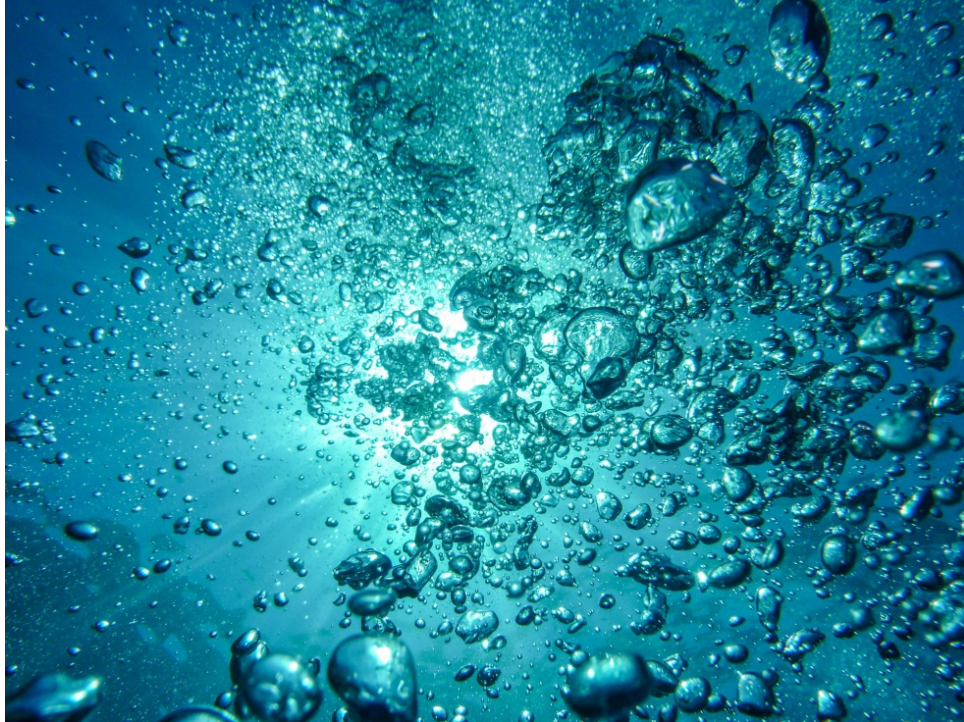


# User Tolerances



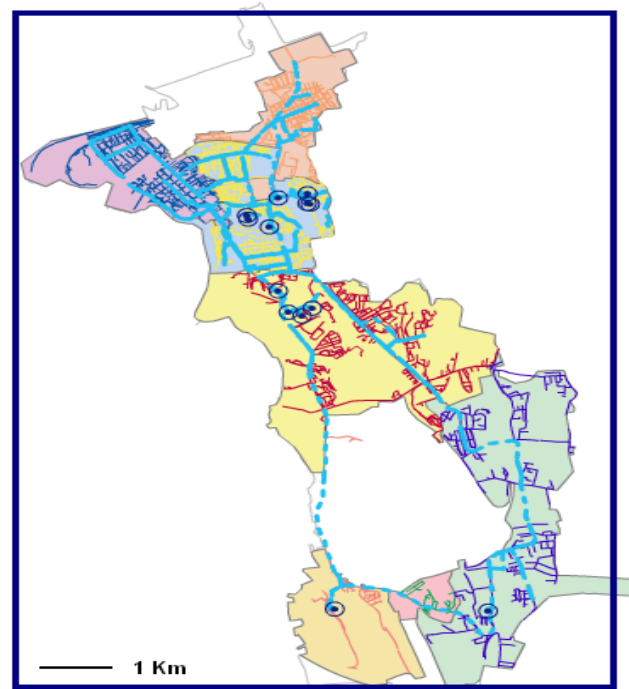
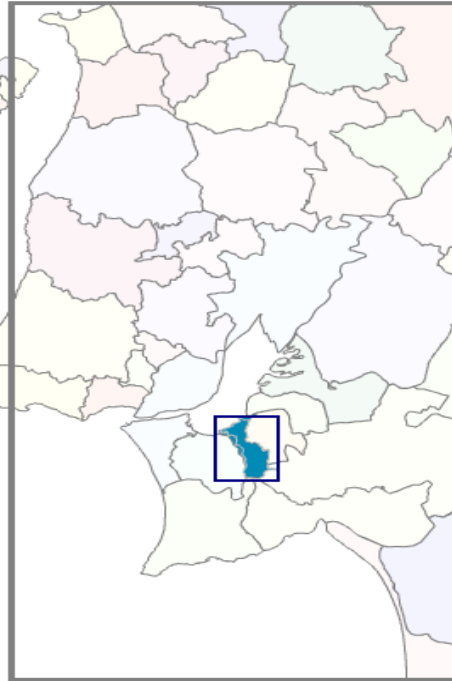
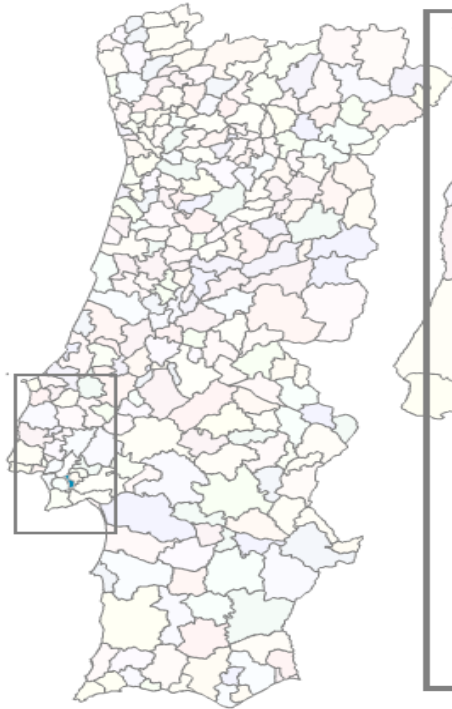
# Performance Criteria

- Water Quality
- Water Quantity
- Water Delivery

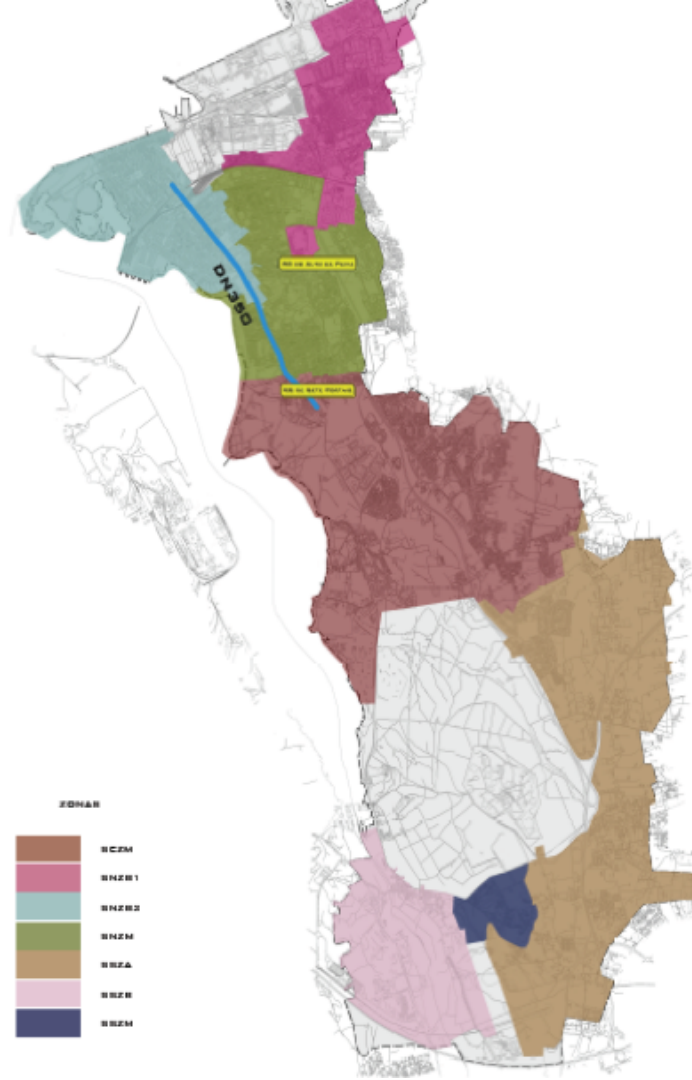




# Area Description



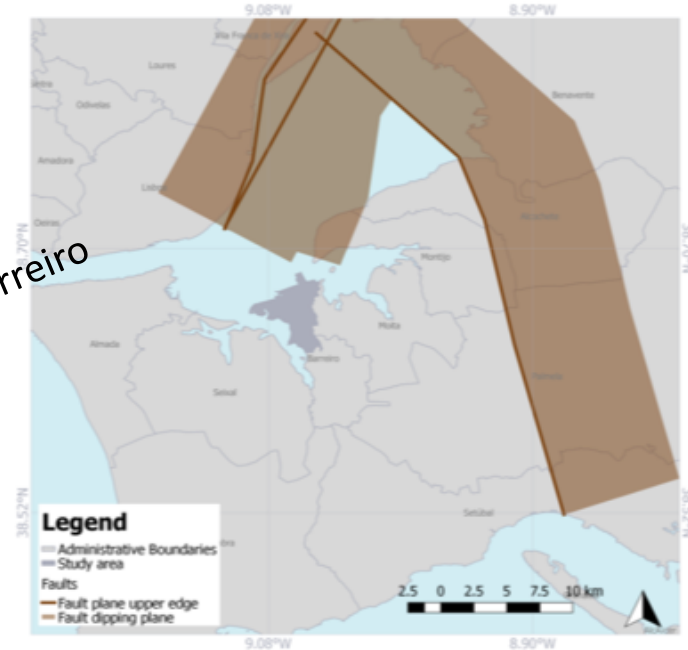
# System Description



# Seismic area

- Prone to liquefaction

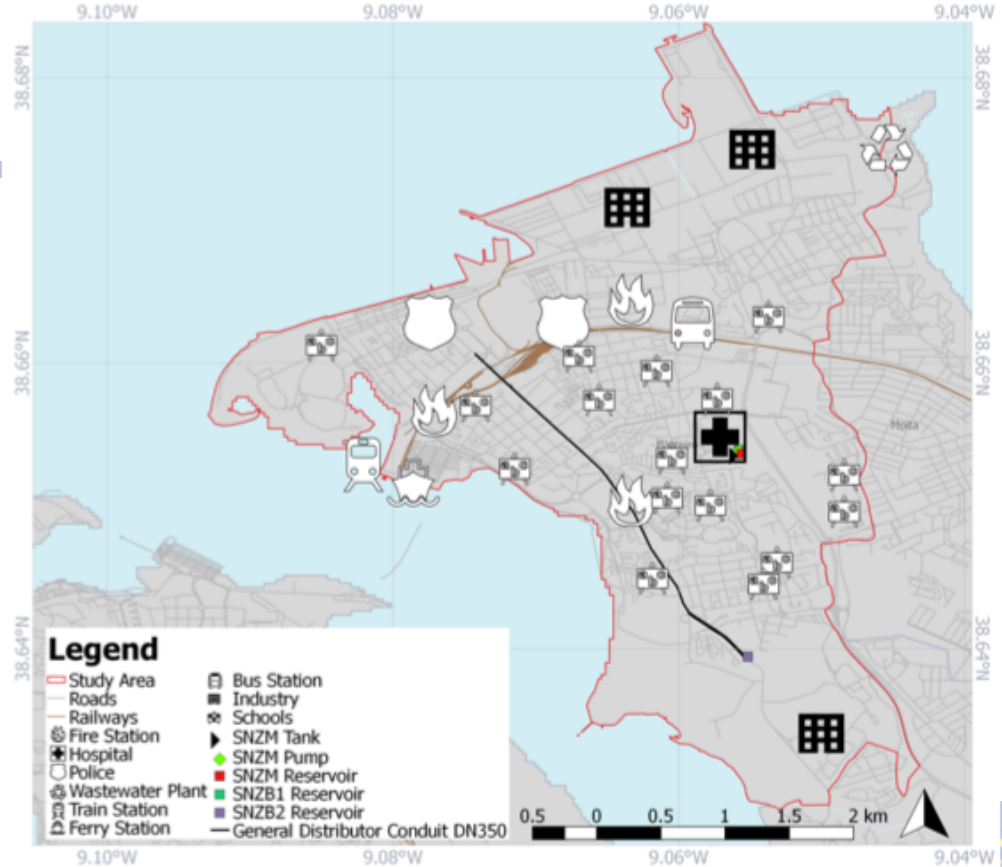
No fault lines in Barreiro



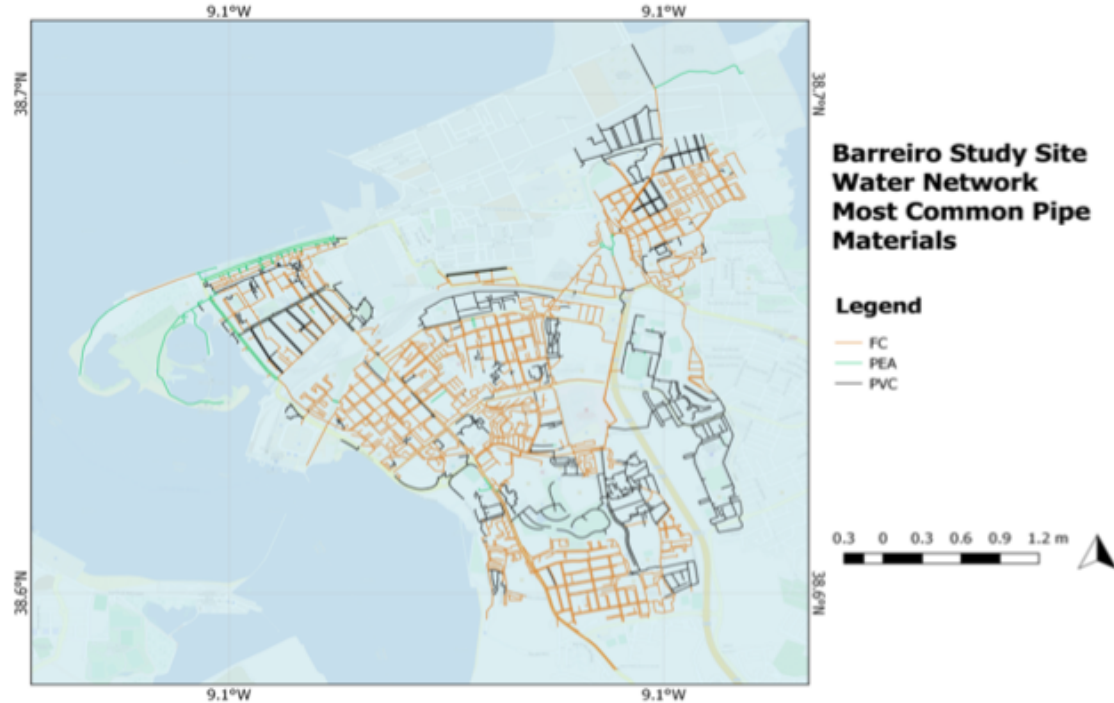




# System Description



# System Description



# Water Safety Plan – Hazardous Events in the Water Supply System

- Seismic ground shaking, liquefaction and tsunami;
- Wildfire;
- Heatwave leading to water shortage;
- Storm surge;
- Low temperatures and ice;
- Hydrocarbons plastic pipes migration;
- Use of not certified materials for contact with drinking water;
- Improper links;
- Aging network;
- ...



# HAZARD IDENTIFICATION



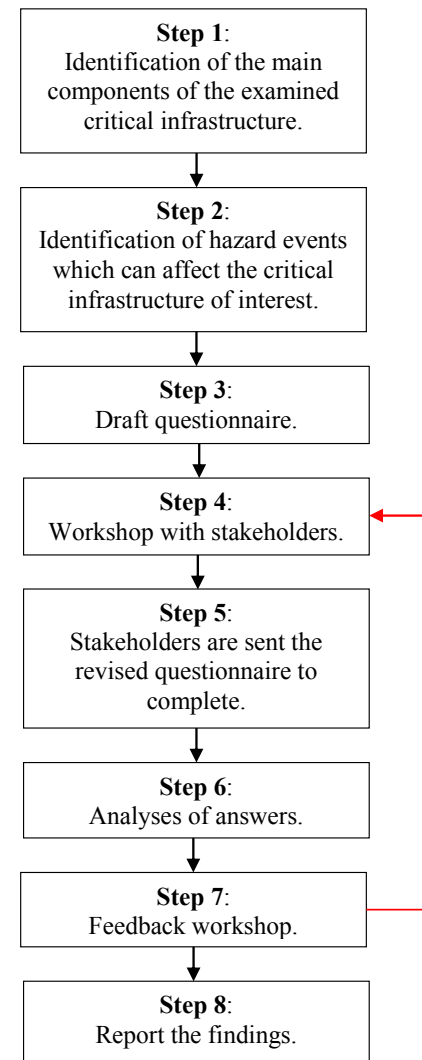
# Risk identification

- Assessment of resilience typically relies on the determination of one or more hazard scenarios against which this can be evaluated
- One of the challenges that an analyst has is how they can determine a suitable hazard scenario for use in the assessment of infrastructure resilience

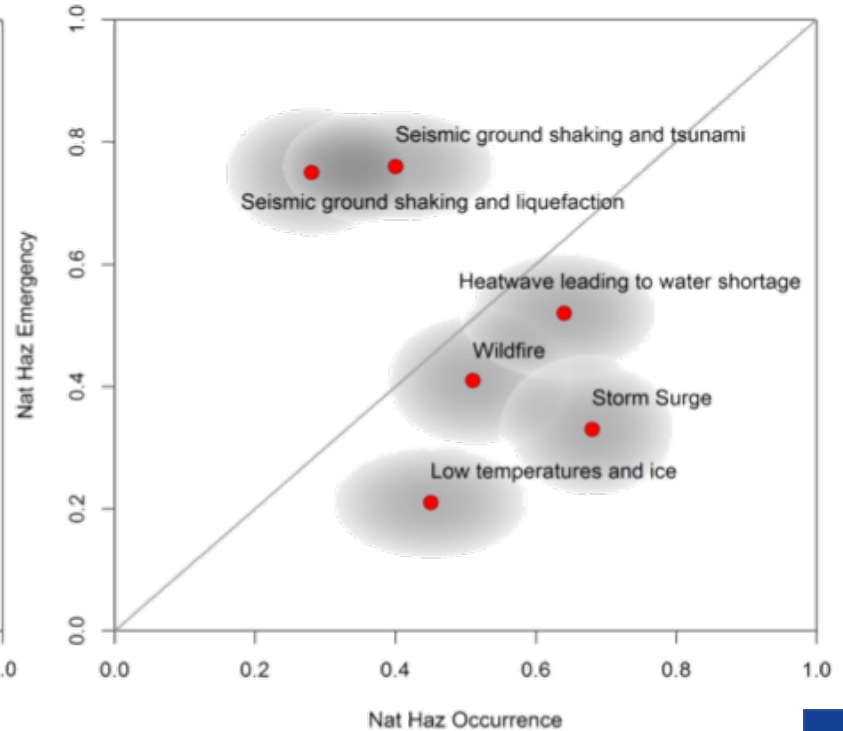
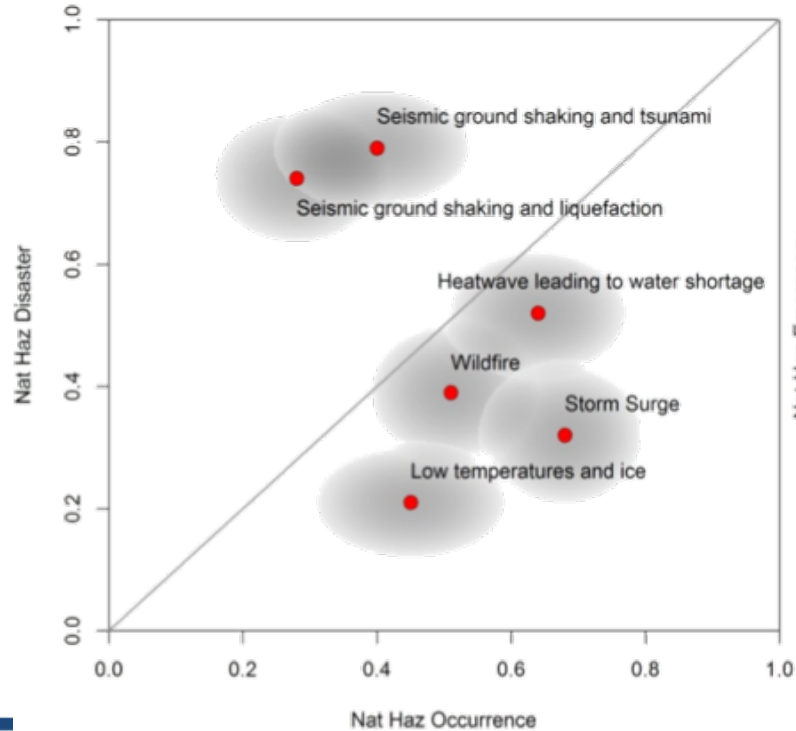


# Methodology

- Novel methodology based on Structured Expert Judgment (SEJ) elicitation
  - determine a rational consensus among subject-matter experts
- Stakeholders are invited to use their judgement
- This method is:
  - Reproducible
  - Accountable
  - Neutral
  - And finally, this approach reduces the potential bias of dominant personalities who may sway the opinions of the group in the direction they consider as more appropriate.



# CI risk identification



# OVERVIEW OF ANALYSIS METHODOLOGIES





# Implementing the IMPROVER framework

Application complexity	Summary	Supporting tool	Required expertise
Low	Self assessment or holistic resilience assessment	CIRI	Internal
High	Organisational resilience assessment	IORA	External expertise likely required
High	Technological resilience assessment	ITRA	

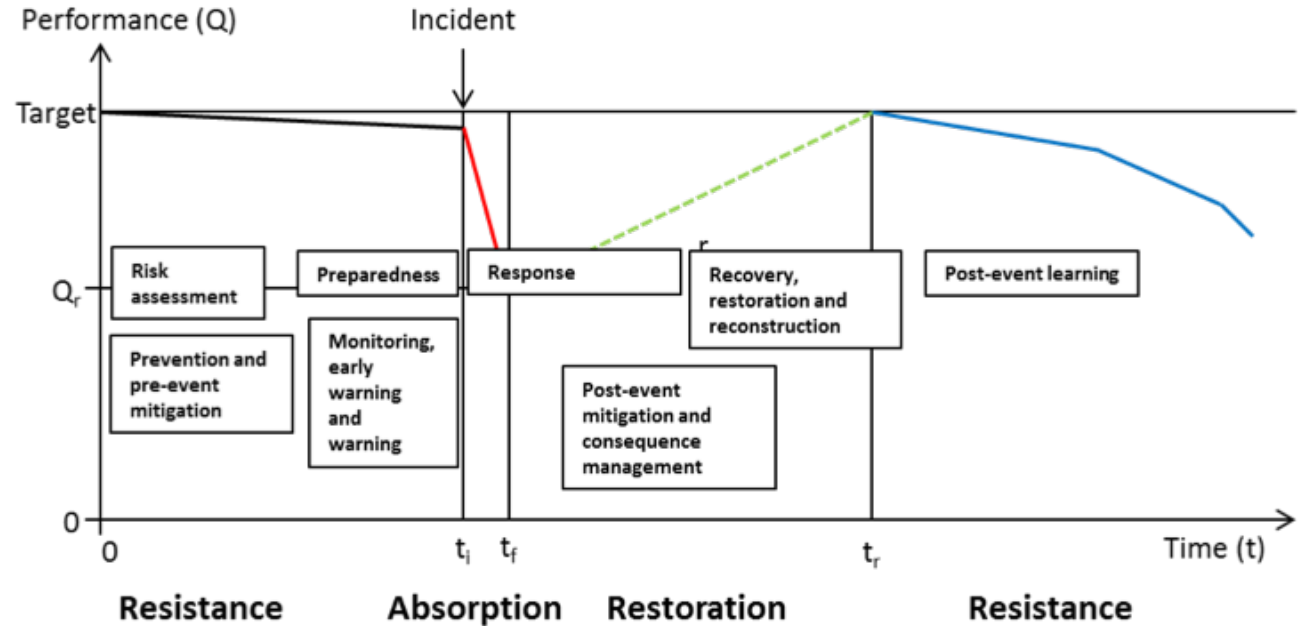


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# The crisis management cycle - the basis of CIRI



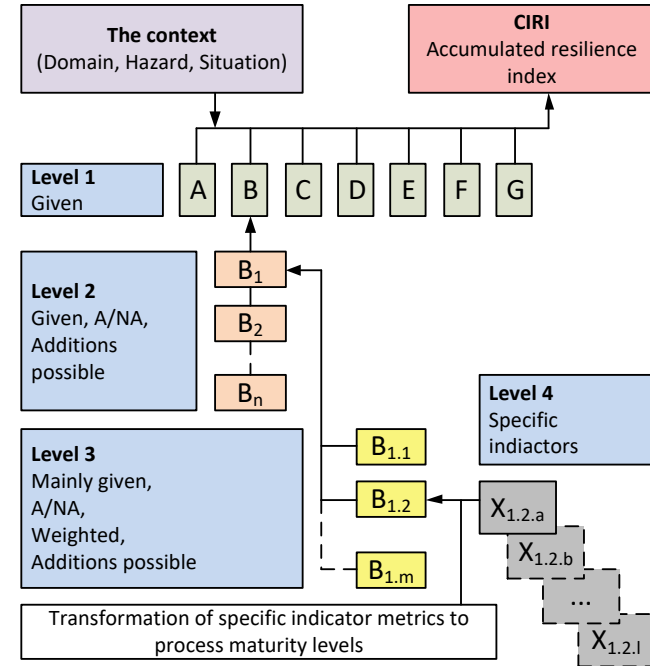
# Critical Infrastructure Resilience Index (CIRI)

**LEVEL 1:** ‘The phases of resilience’, corresponding to the Crisis Management Cycle, reflecting the temporal nature of resilience.

**LEVEL 2:** Components (if technological) or structures/processes (if organisational/social), limited to ‘very’ generic components / processes / structures.

**LEVEL 3:** Indicator expressed on an appropriate and uniform maturity scale.

**LEVEL 4:** Indicator measured. Transition to Level 3 through the developed indicator cards.



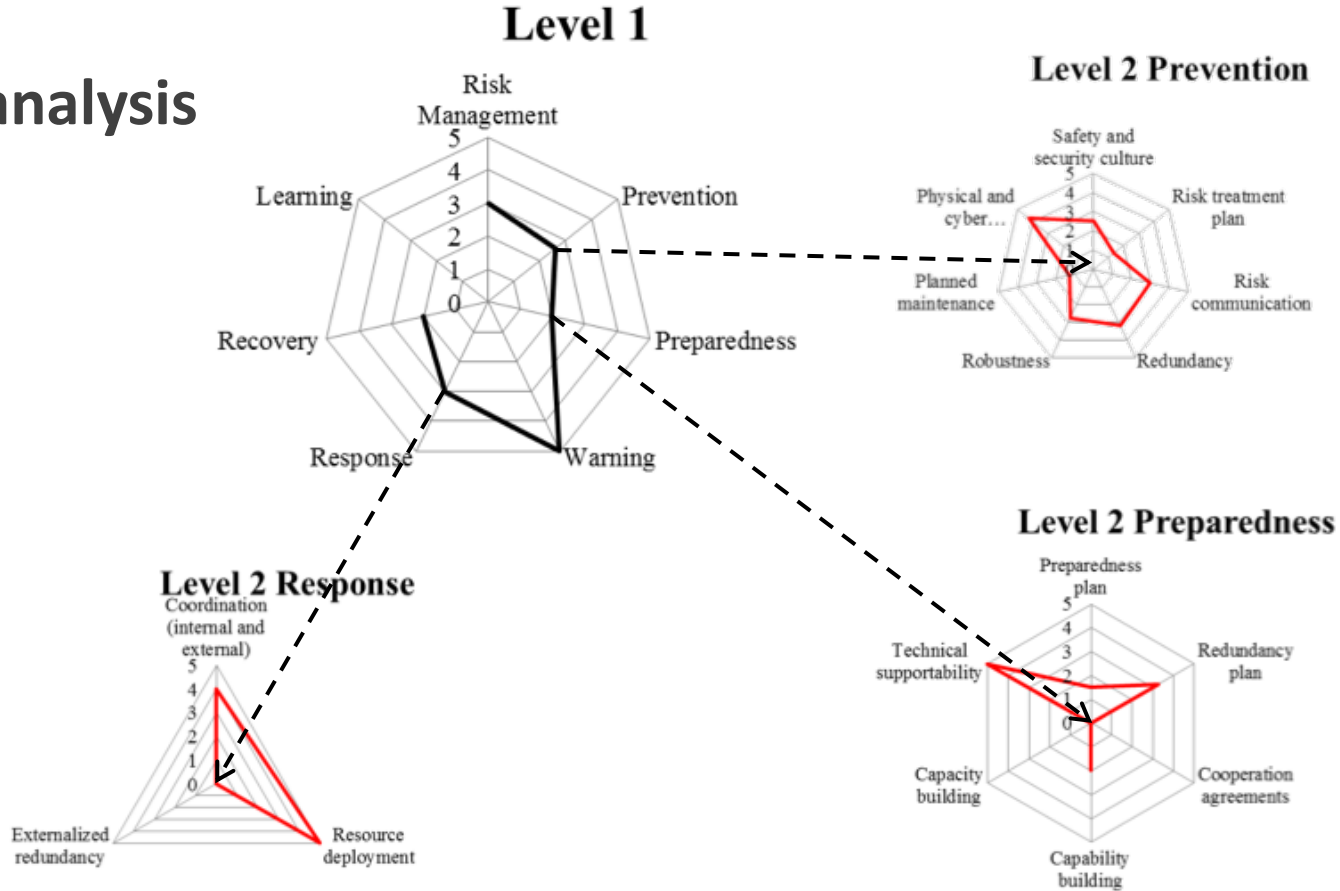
# Constructing the overall measure

- CIRI – Critical Infrastructure Resilience Index
- Self assessment / audit tool
- ca. 200 indicator ‘cards’ from different resilience domains

$$CIRI = \frac{1}{\sum_{k=1}^7 u_k} \sum_{k=1}^7 u_k \left[ \frac{1}{\sum_{j=1}^n v_j} \sum_{j=1}^n v_j \left[ \frac{\sum_{i=1}^m w_i X_{k,j,i}}{\sum_{i=1}^m w_i} \right] \right]$$



# CIRI analysis



# Implementing the IMPROVER framework

Application complexity	Summary	Supporting tool	Required expertise
Low	Self assessment or holistic resilience assessment	CIRI	Internal
High	<b>Organisational resilience assessment</b>	<b>IORA</b>	<b>External expertise likely required</b>
High	Technological resilience assessment	ITRA	



# Organisational Resilience

*"The ability to adapt and succeed under varying conditions and circumstances"*

Taking into account...

- **A Systems Perspective** – A system of people and technology
- **Variability** – The system will not always behave in the same way
- **Complexity** – We are sometimes subjected to unforeseen events

**"Organisational"**

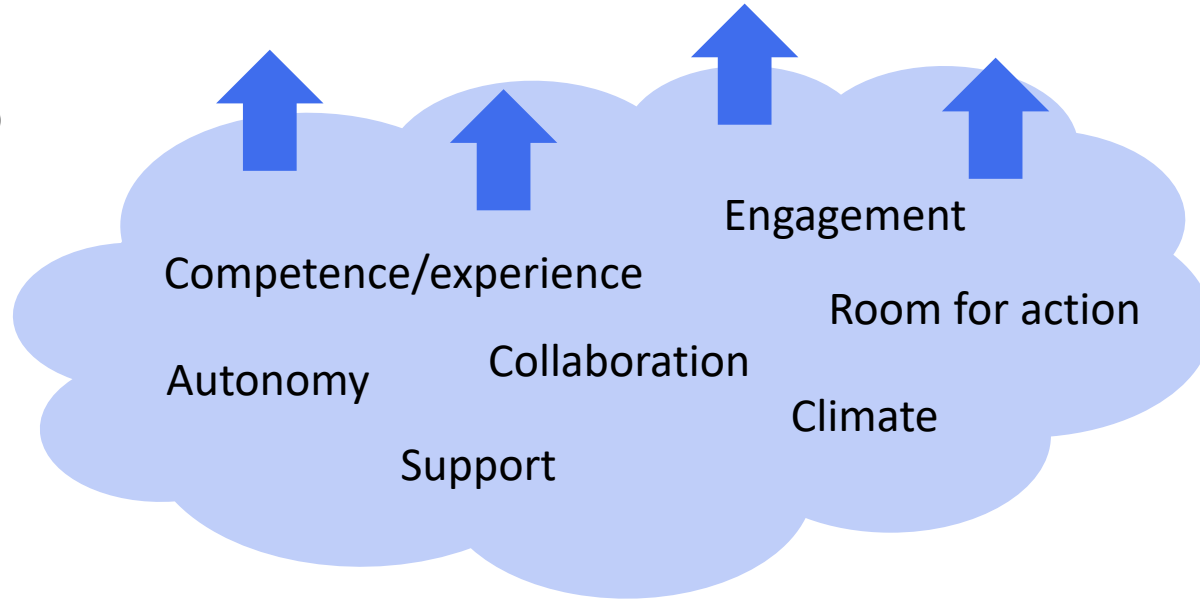
- What can organisations do to enable resilient action?



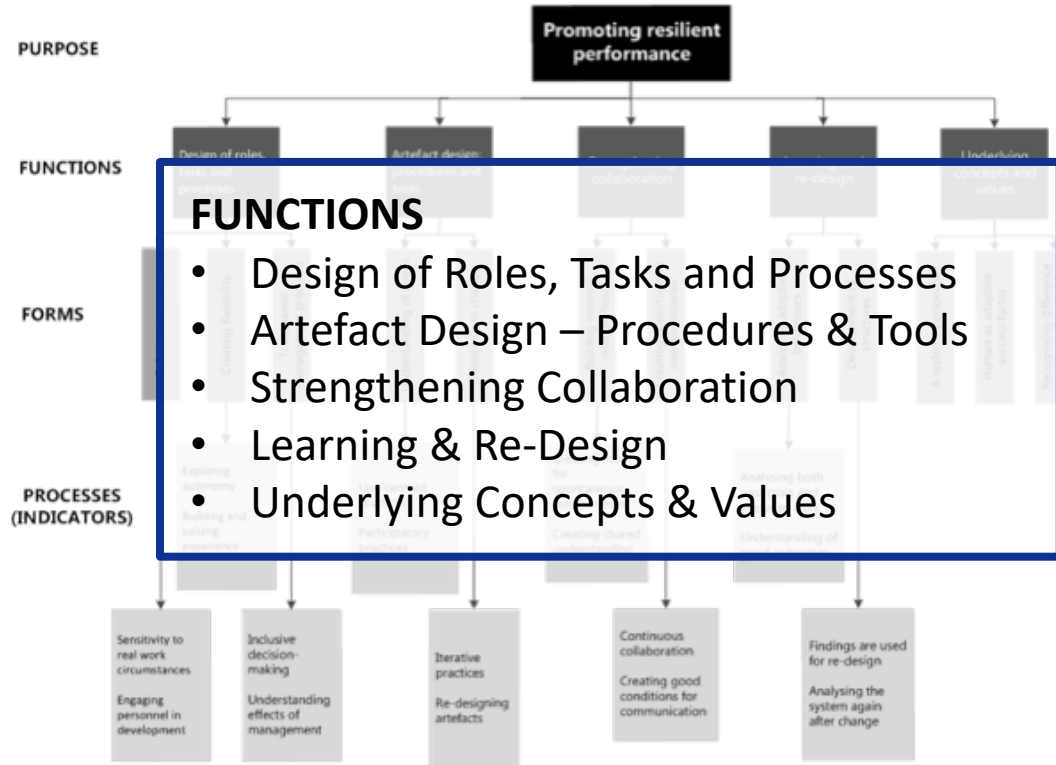


# What are some marks of resilient action?

- Flexibility in operations: actions, methods, roles, relations...
- Creativity
- Initiative
- Ownership



# The Organisational Resilience Framework



# Barreiro Workshop Case – 2014 Salt Water Intrusion

- Call from dialysis clinic – very high conductivity
- Response time from the lab was one week
- No existing procedures or direct experience
- The analysis took two days – situation awareness and problem-solving
- CCTV exposed cavities and saline intrusion



A diagram consisting of four large, overlapping circles arranged in a diamond shape. The top circle is green and labeled 'COLLABORATION'. The bottom circle is red and labeled 'PROBLEM-SOLVING'. The left circle is blue and labeled 'PROBLEM IDENTIFICATION'. The right circle is orange and labeled 'AFTER-ACTION'. All text is in white, bold, uppercase letters.

**PROBLEM  
IDENTIFICATION**

**COLLABORATION**

**AFTER-ACTION**

**PROBLEM-  
SOLVING**



## PROBLEM IDENTIFICATION

- Quickly established contacts with clinic
- Coordination between management and field
- Familiarity

ATION

AFTER-ACTION

PROBLEM-  
SOLVING

## COLLABORATION

- Swift confirmation from the administration
- Strong authority
- Small gap between management and operations
- Good preconditions for DM, economic and technical

AFTER-ACTION

PROB  
IDENTIFI





**PROBLEM  
IDENTIFICATION**

**COL**

## **PROBLEM-SOLVING**

- A process supported by collaboration, competence and technology
- Resilient use of the environment

**ACTION**

**PROBLEM  
IDENTIFICATION**

**COLLABORATION**

## **AFTER-ACTION**

- Experience and competence were key
- Initiatives to anchor new procedures
- Some resistance has been seen



# APPLICATION OF ITRA



# Implementing the IMPROVER framework

Application complexity	Summary	Supporting tool	Required expertise
Low	Self assessment or holistic resilience assessment	CIRI	Internal
High	Organisational resilience assessment	IORA	<b>External expertise likely required</b>
<b>High</b>	<b>Technological resilience assessment</b>	<b>ITRA</b>	



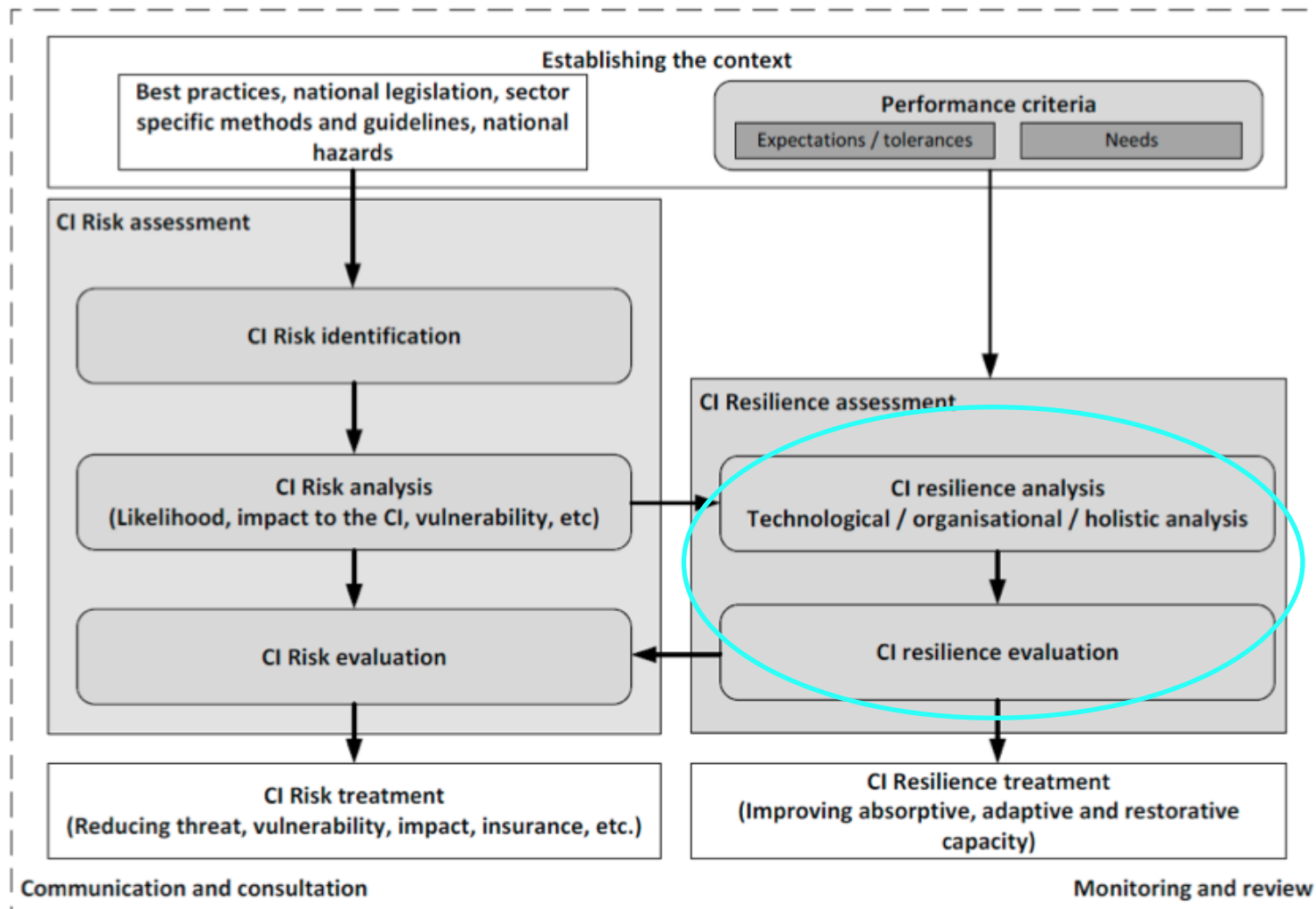
**APPLICATION OF ITRA AND EVALUATION USING ITRA  
–IMPROVER TECHNOLOGICAL RESILIENCE  
ASSESSMENT  
(30 MIN)**

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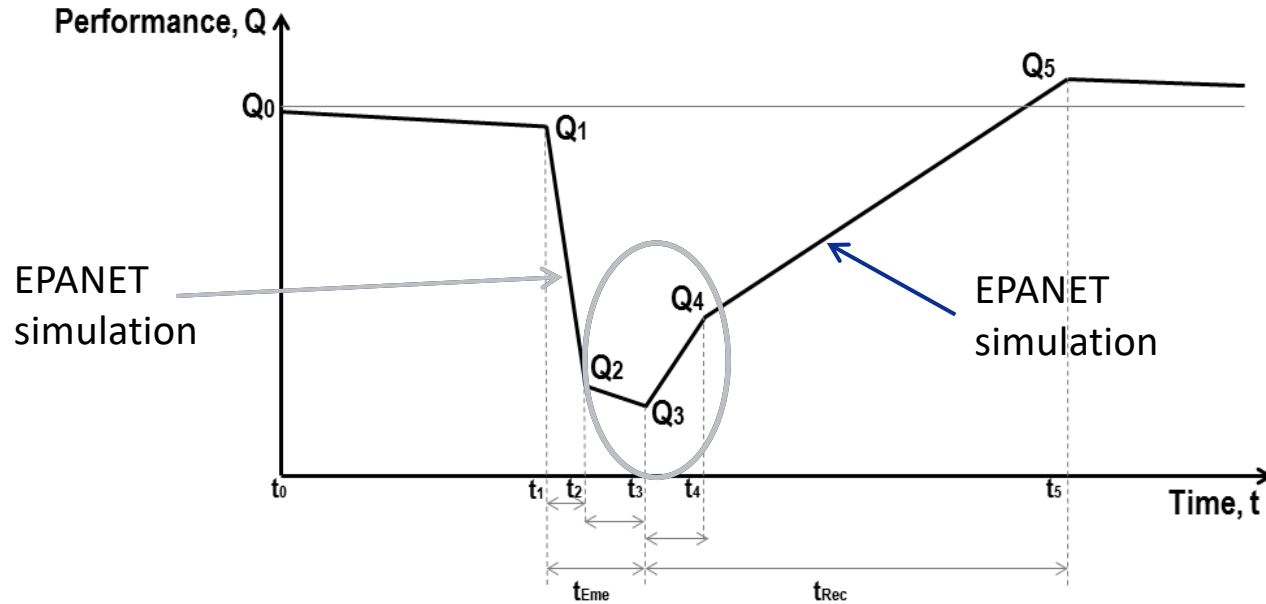
@improverproject







# Emergency Response and Recovery

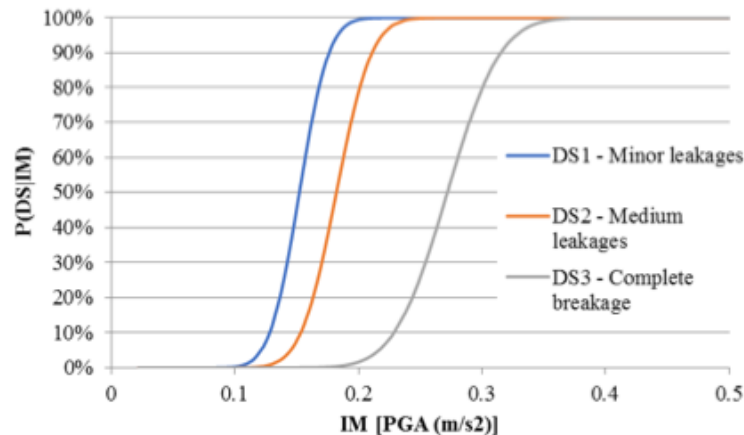
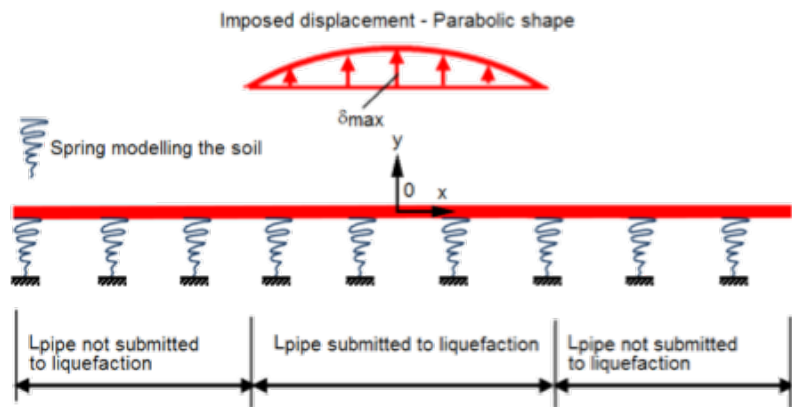


# Pipe fragilities

- Based on PGV / PGA
  - For different materials
- Based on liquefaction
  - We use historical lit. data
- Each pipe with a certain material and length is assigned a probability for breaking



# Pipe fragility based on calculation (DN350)

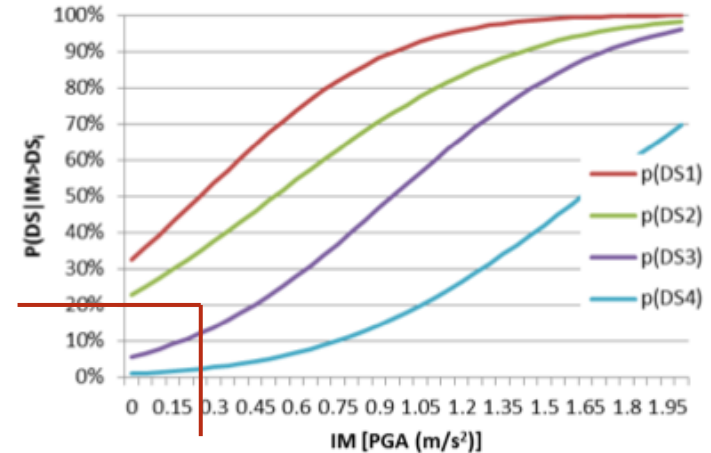




# Reservoir fragilities

- The reservoir currently included is assumed to be an 'on ground anchored concrete tank'

Damage State	Description	Functionality
DS1 (Slight / minor damage)	defined by the tank suffering minor damage without loss of its contents or functionality.	97%
DS2 (Moderate damage)	defined by the tank being considerably damaged, but only minor loss of content.	95%
DS3 (Extensive damage)	defined by the tank being severely damaged and going out of service.	20%
DS4 (Complete damage)	defined by the tank collapsing and losing all of its content	10%



# Failure simulations

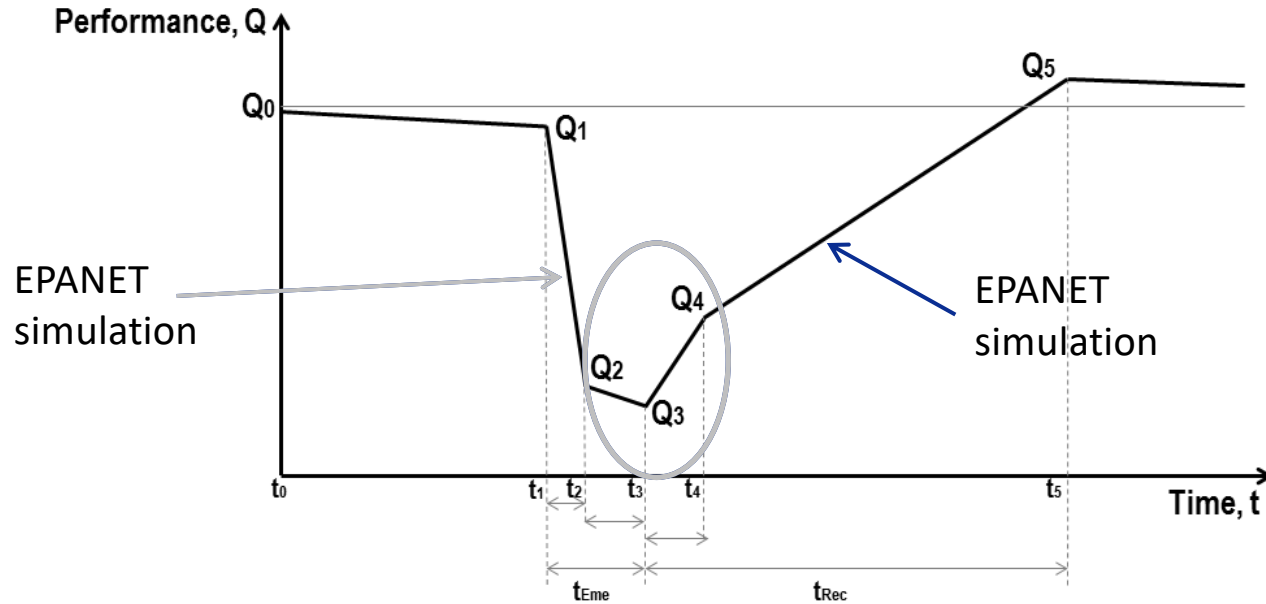


# Emergency Response

- E.g.: East Bay Municipal Utility District
  - Via truck within 3 days – for pick up
  - Via distribution system within 10 days – minimum service to 70%



# Emergency Response and Recovery



# Emergency Response

TARGET STATES OF RECOVERY: WATER & WASTEWATER SECTOR (COAST)											
	Event occurs	0-24 hours	1-3 days	3-7 days	1-2 weeks	2 weeks - 1 month	1-3 months	3-6 months	6 months - 1 year	1-3 years	3+ years
Domestic Water Supply											
Potable water available at supply source (WTP, wells, impoundment)				R		Y		G		X	
Main transmission facilities, pipes, pump stations, and reservoirs (backbone) operational			R	Y	G					X	
Water supply to critical facilities available				R		Y		G		X	
Water for fire suppression—at key supply points			R		Y			G		X	
Water for fire suppression—at fire hydrants						R	Y	G		X	
Water available at community distribution centers/points				R	Y	G	X				
Distribution system operational					R		Y	G			X

## The Oregon Resilience Plan

Reducing Risk and Improving Recovery  
for the Next Cascadia Earthquake and Tsunami

Report to the  
77<sup>th</sup> Legislative Assembly

from  
Oregon Seismic Safety Policy  
Advisory Commission (OSSPAC)



Salem, Oregon  
February 2013

### KEY TO THE TABLE

#### TARGET TIMEFRAME FOR RECOVERY:

Desired time to restore component to 80–90% operational

Desired time to restore component to 50–60% operational

Desired time to restore component to 20–30% operational

Current State (90% operational)



# Barreiro Context

	Barreiro context	unit
<b>Number of inhabitants</b>	78764	Persons
<b>Inhabitant average water usage</b>	200	litre / person
City / residential storage available for consumption	5	litre / person
Inhabitant average water usage in crisis	20	litre / person
Reserve water sources at hospital	yes	yes/no
Number of pumping stations	3	N
<b>Pumping station top capacity</b>	20000000	l/day
Number of critical water lines	30	N



# The network

Scenario damages	Societal damage [%]	Daily repair rate [% point]	Required work days
Electricity network damage	100%	5%	20
Cellphone network damage	100%	100%	1
Road access to Barreiro	60%	30%	2
System damages	System damage [%]	Daily repair rate [% point]	Required work days
Water distribution network breakdown	93%	3%	30
Pumpstation breakdown	80%	6%	14
Reservoir damage	17%	0%	93
Backbone transmission lines, water system breakage	21%	21%	1
Damage of critical sewage system	50%	10%	5
Critical users water supply damage, hospitals etc.	100%	100%	1
Capacity to construct community supply points	100%	20%	5



# Organisation

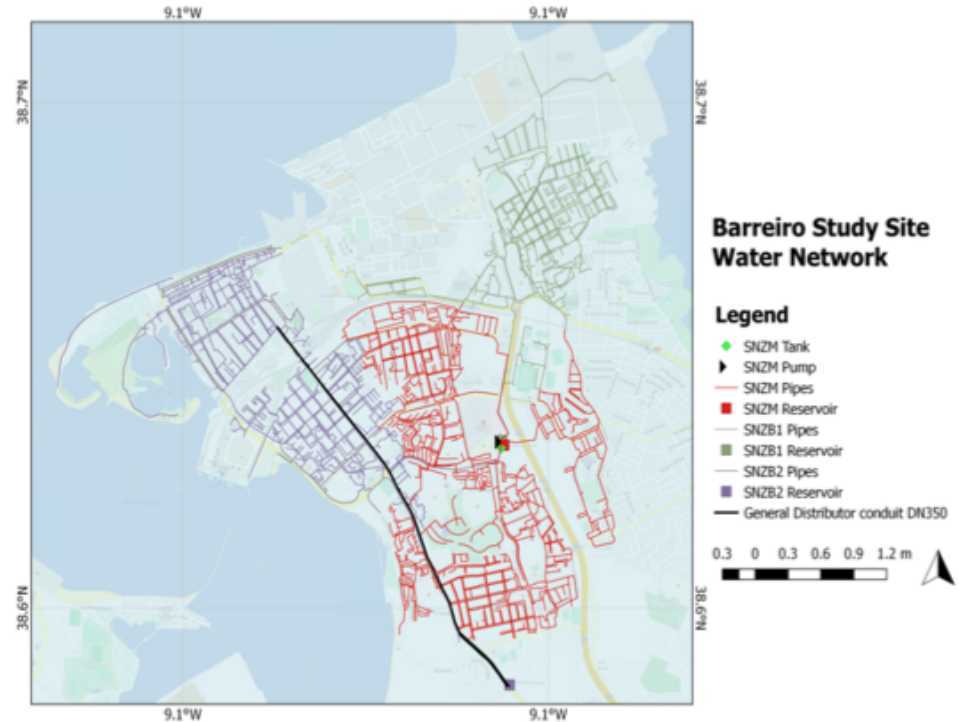
Priority level	Actions	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7	Day 8	Day 9	Day 10	Day 11	Day 12	Day 13	Day 14	Day 15
1	Period when search and rescue is the priority	1	1	1	0	0	0	0	0	0	0	0	0	0	0	0
1	Road access	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
2	Pumping station repairs	0	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Reservoir repairs	0	0	1	1	1	1	1	1	1	1	1	1	1	1	1
2	Backbone transmission lines	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
3	Time to repair critical infrastructure sewage system with threat to public health	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0
3	Time to repair critical infrastructure: hospitals etc.	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
4	Community water supply points	0	0	0	0	0	0	0	0	0	0	1	1	1	1	0
5	Repair the remaining pipes	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1





# Recovery model

- Hydraulic calculation of pipe performance at different stages of recovery



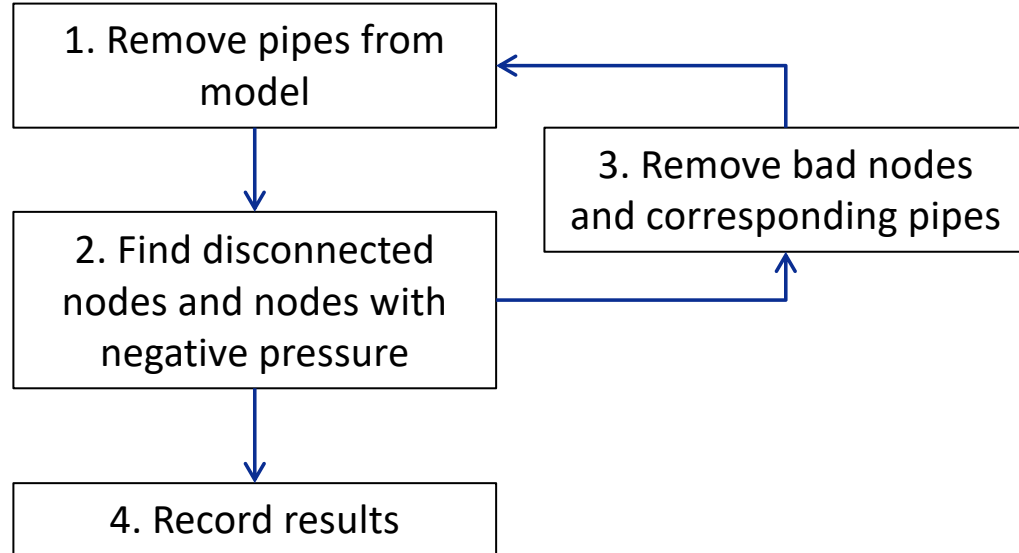
# Solving hydraulics in a water system with damaged pipes

- **Problem:**

*EPANET cannot solve a damaged system*

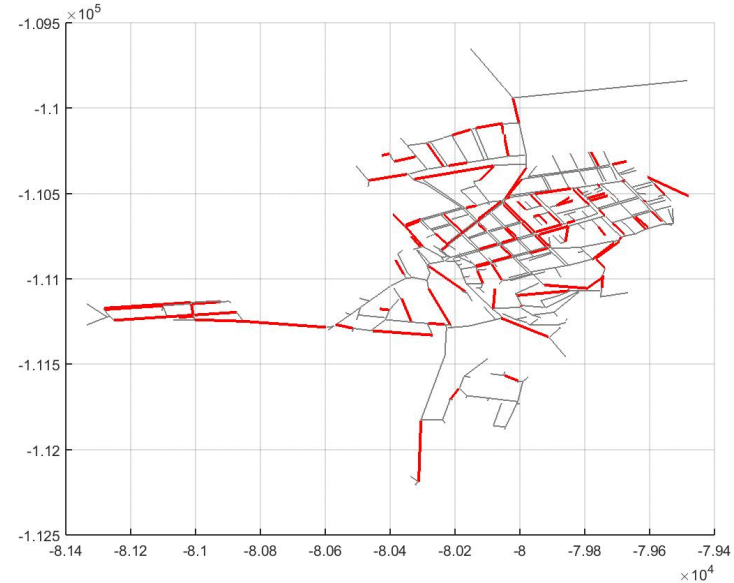
- **Solution:**

*Developed a methodology for resolving the damaged EPANET model*



# Recovery algorithm

- The recovery of pipes depends on a prioritisation of pipes for repair
  - Different prioritization schemes can be applied
- At each recovery step, repaired pipes are replaced in the model and the analysis is rerun



# Repair priorities

- We have studied 5 different prioritization schemes:

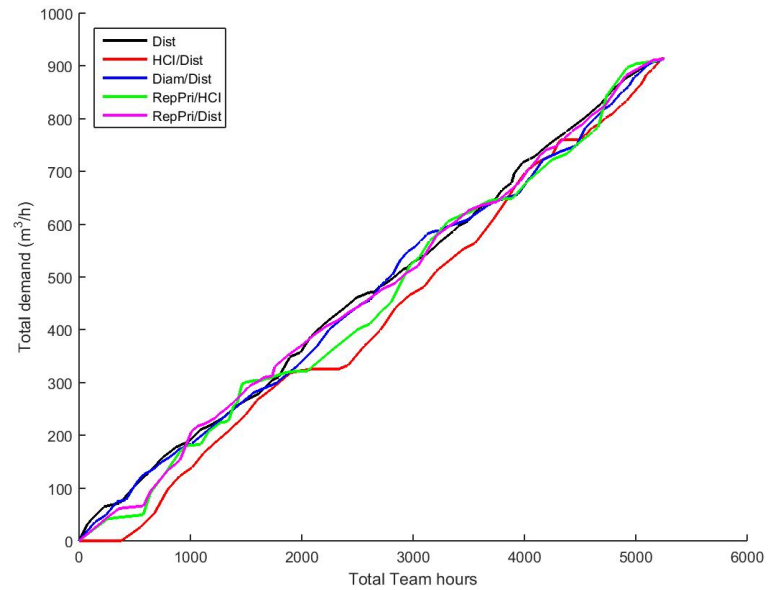
- Repair strategy 1: distance to the reservoir
- Repair strategy 2: hydraulic critical index (HCI)
- Repair strategy 3: pipe diameter and then distance to reservoir
- Repair strategy 4: operator provided and then HCI

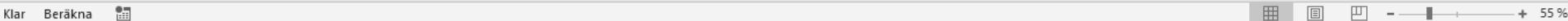
*The operator provided repair strategy prioritises backbone lines and community supply points*

- Repair strategy 5: operator provided and then distance to reservoir

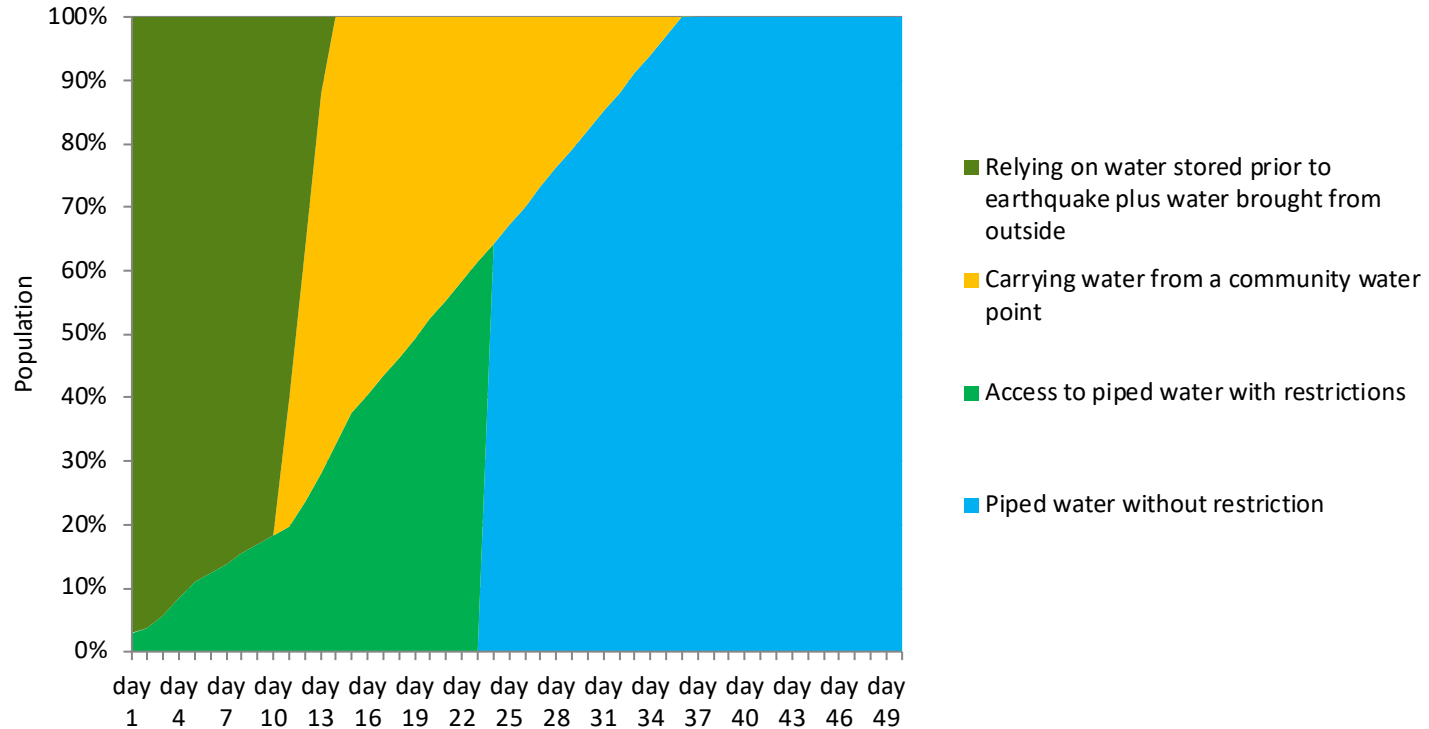


# Results





# ITRA – recovery model





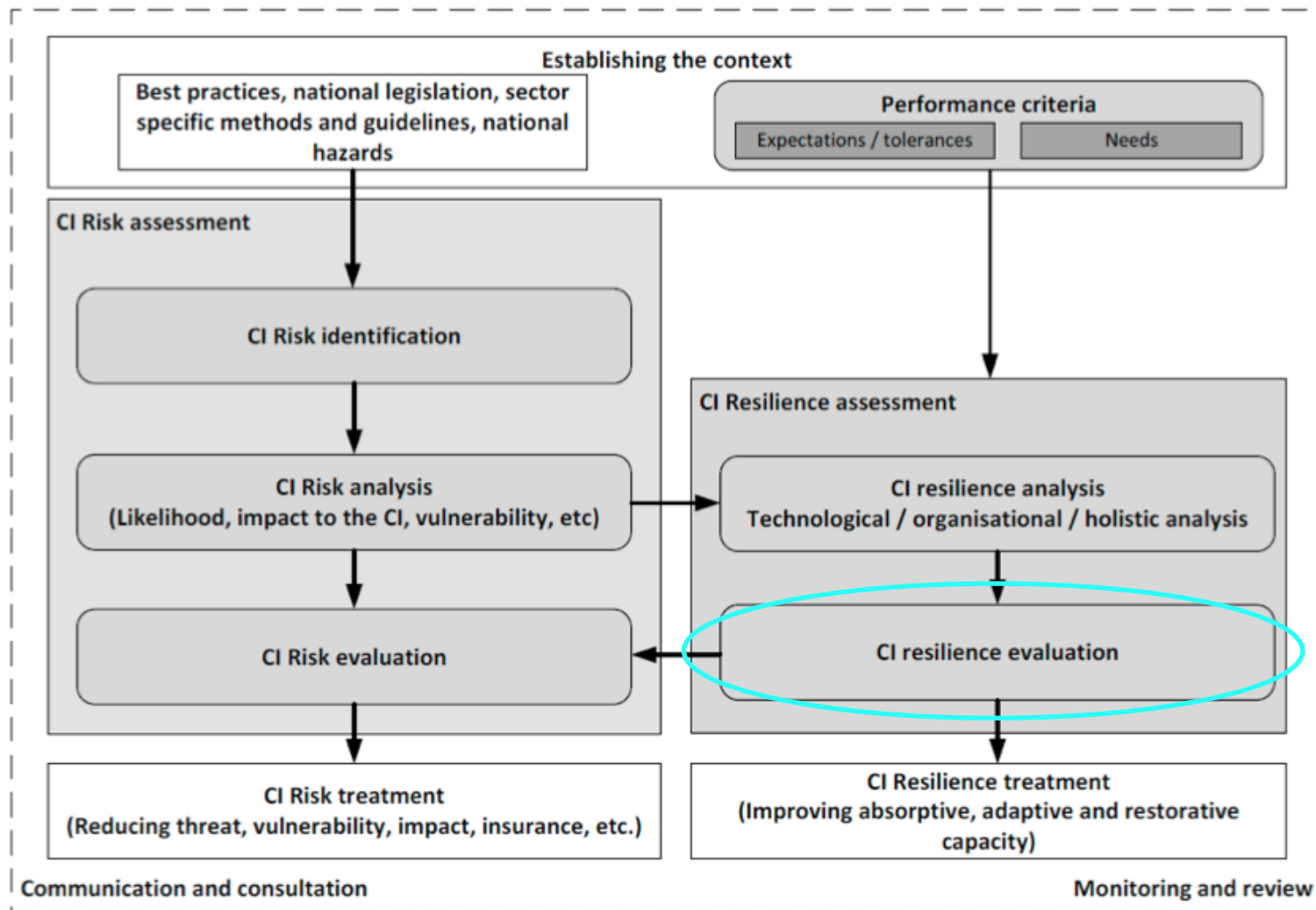
## EVALUATION

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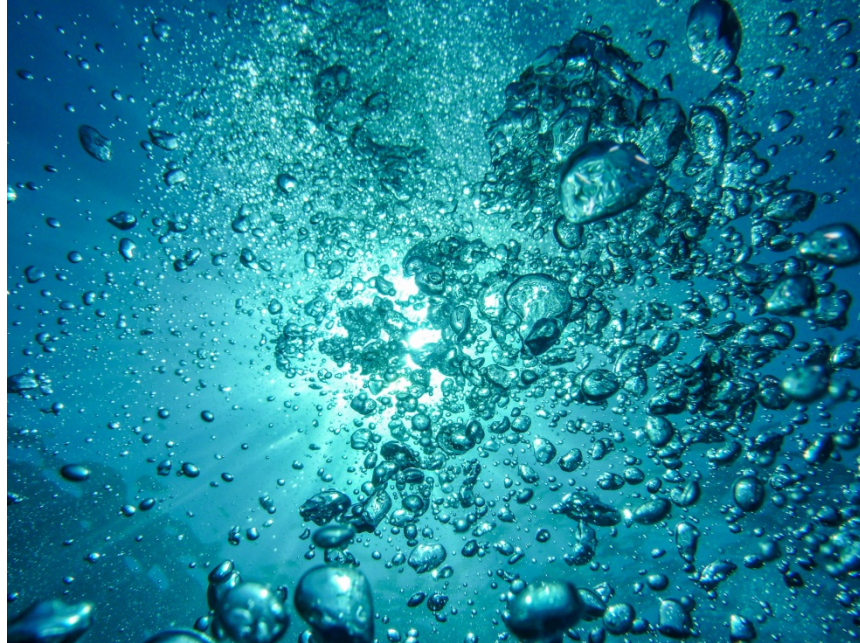




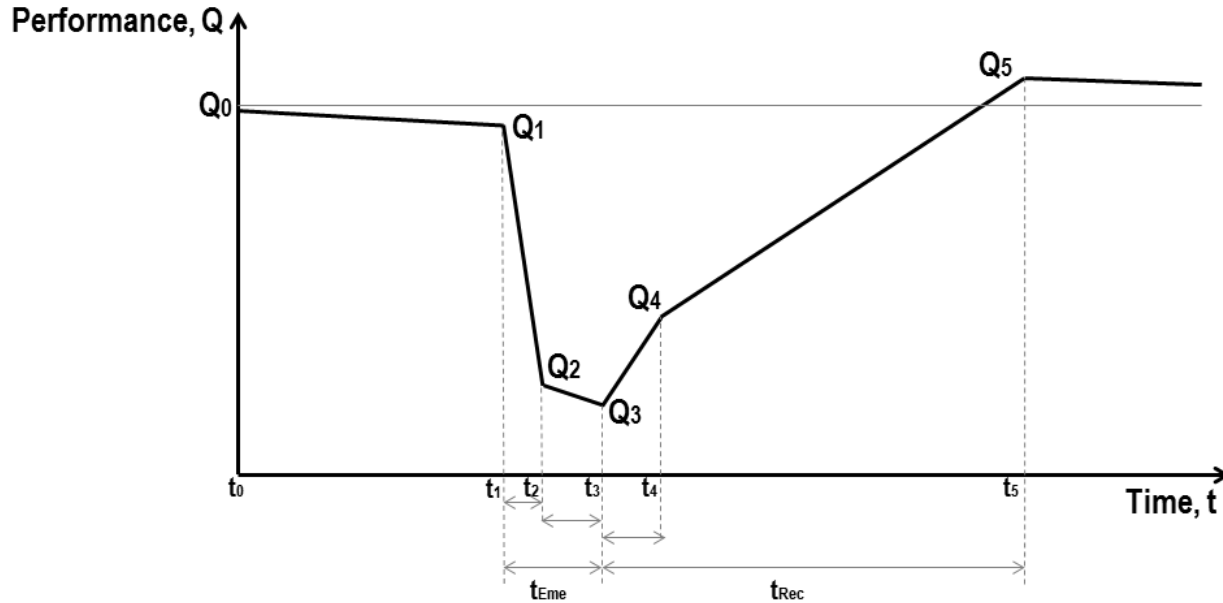


# Performance Criteria

- Water Delivery
- Water Quantity
- Water Quality



# Emergency Response and Recovery



# Development of a survey

- The function of the infrastructure is to provide clean, safe drinking water to the public.
- Created to be comparable to the performance measures
- Based on real world performance capabilities of operators
- Asks about factors affecting expectations
  - satisfaction levels with the current water service
  - previous disaster experience
  - risk perception

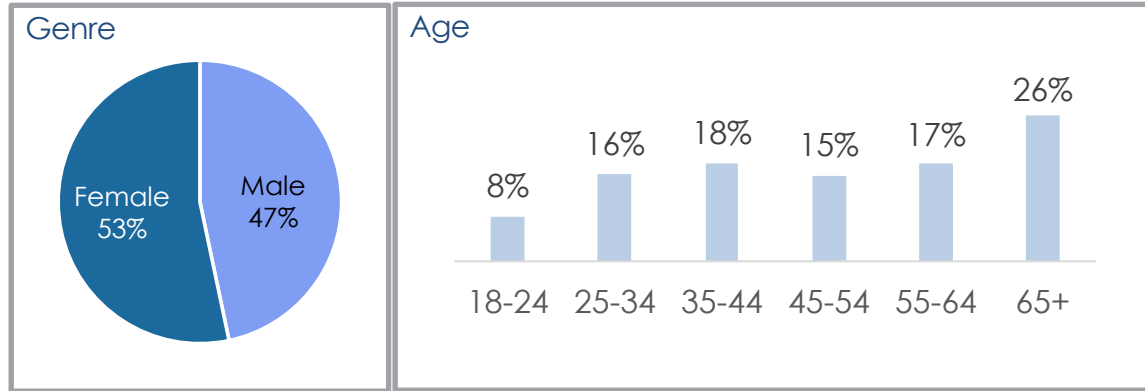


# The Sample


1005 respondents

Residents in the Municipality of Barreiro with a minimum age of 18 years old.

Oct. 10- Nov 5, 2017.





A close-up photograph of parched, cracked soil. The ground is a light tan color, heavily textured with small clumps and deep, irregular fissures that run across the frame. Some dry, brown plant matter is scattered on the surface.

Imagine that a high magnitude earthquake occurs, where a large part of the population is left without access to potable water on tap without any previous warning.

**Scenario**

## **Tolerance levels:**

**Delivery – How long would you tolerate water being delivered in tanks?**

**Quality – How long would you tolerate having to boil water before drinking it?**

**How long will you tolerate having only the following amount of water per person per day? 10, 20, 50, 51-100 l/p, day**



## Scenario - evaluated

Scenario	
Repstrat	4
Damage	0,2
EQ intensity (MMI 6 - 12)	7

Not unreasonable damage  
4-10 % likelihood / 50 years



Arkiv Start Infoga Rita Sidlayout Formler Data Granska Visa Berätta vad du vill göra

Klistra in Urklipp Tecken Justering Tal Villkorsstyrd formatering Formatera Cellformat Infoga Ta bort Format Autosumma Fyll Radera Sortera och filtrera Sök och markera Redigering

G31

## Change only these numbers

**Number of inhabitants**

**Inhabitant average water usage**

City / residential storage available for consumption

Inhabitant average water usage in crisis

Reserve water sources at hospital

Number of pumping stations

**Pumping station top capacity**

Number of critical water lines

**Workforce availability**

Number of teams

Shift length

**Scenario damages**

Electricity network damage

Cellphone network damage

Road access to Barreiro

**System damages**

**Water distribution network breakdown**

**Pumpstation breakdown**

**Reservoir damage**

**Backbone transmission lines, water system breakage (Main transmission)**

**Damage of critical sewage system**

**Critical users water supply damage, hospitals etc.**

**Capacity to construct community supply points**

**Quality recovery stages**

Increment

Flush period

**Actions**

Period when search and rescue is the priority

Road access

**Scenario**

Repstrat 4

Damage 0,2

EQ intensity (MMI) 6 7

**Barreiro context**

unit

78764 Persons

200 litre / person

5 litre / person

20 litre / person

yes yes/no

3 N

200000000 l/day

30 N

**Number**

unit

13 teams

8 hours per day

**Societal damage** Daily / Required work days

100%	5%	20
100%	100%	1
60%	30%	2

**System damage** Daily / Required work days

33%	3%	30
80%	6%	14
17%	0%	33
21%	21%	1,00
50%	10%	5
100%	100%	1
100%	20%	5

**Number**

unit

20%

14,00 days

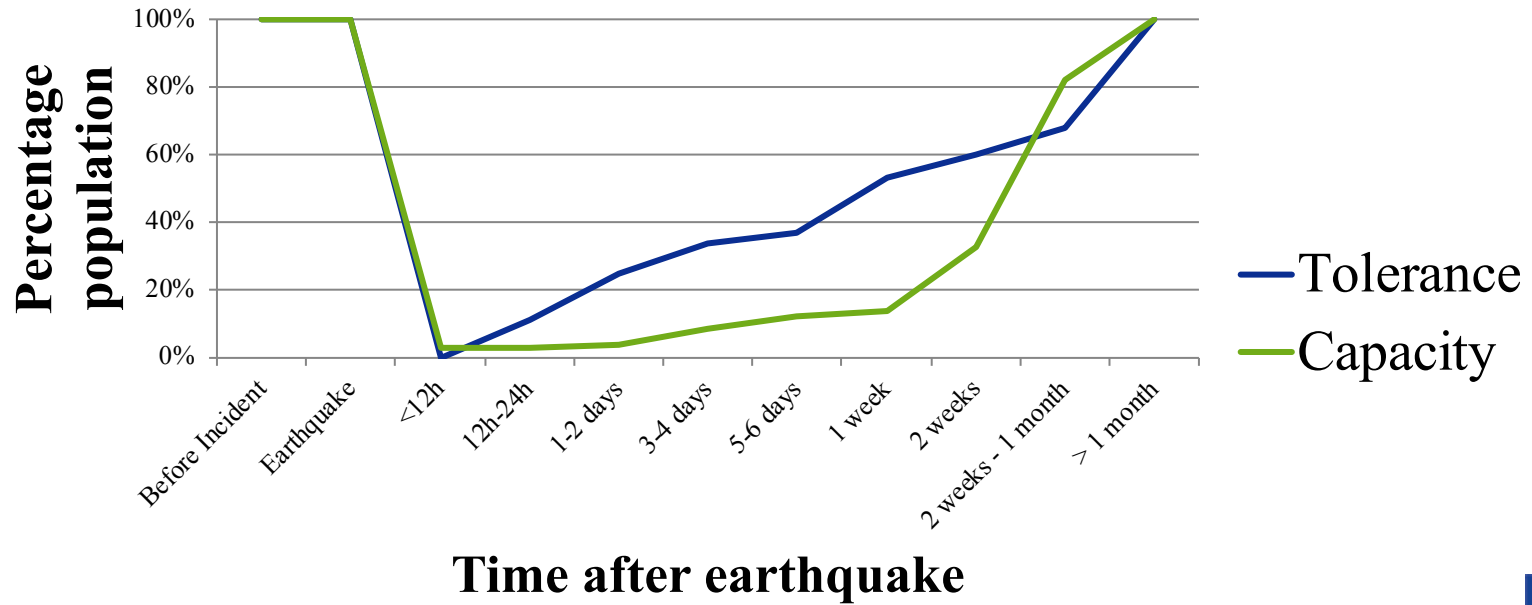
**Resilience evaluation - delivery**

**Resilience evaluation - quality**

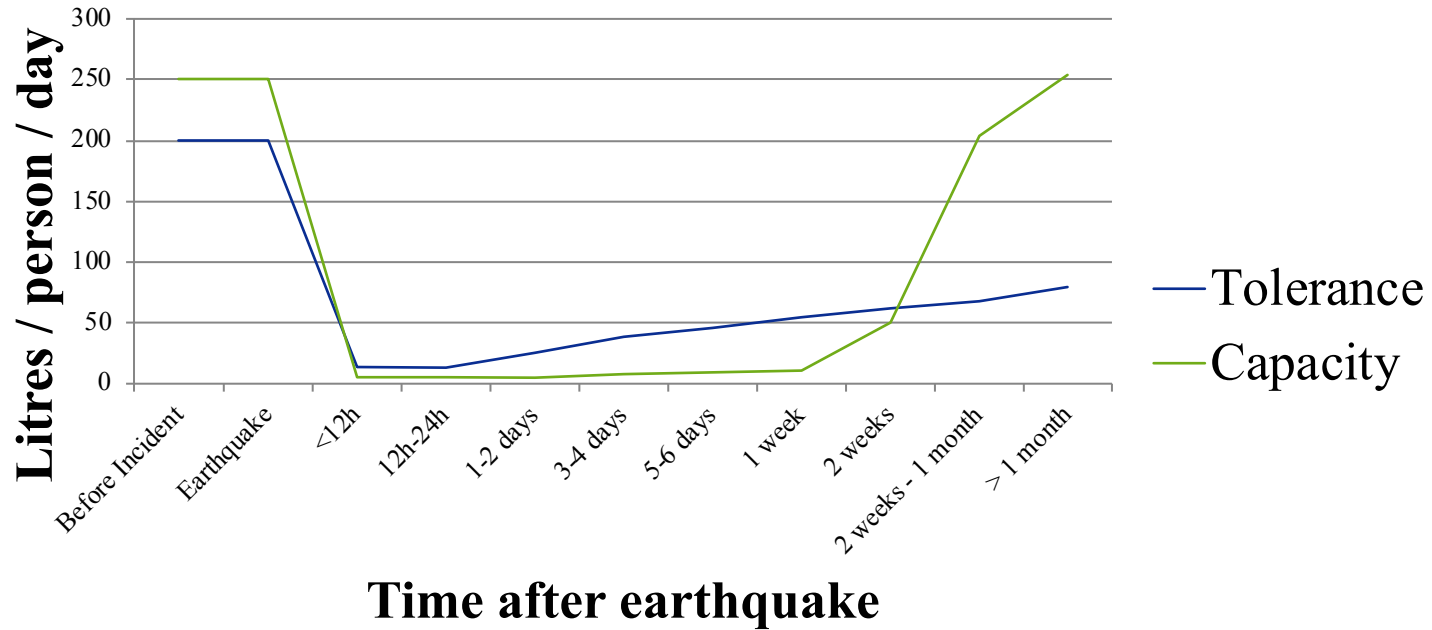
**Resilience evaluation - quantity**

**Population recovery over time**

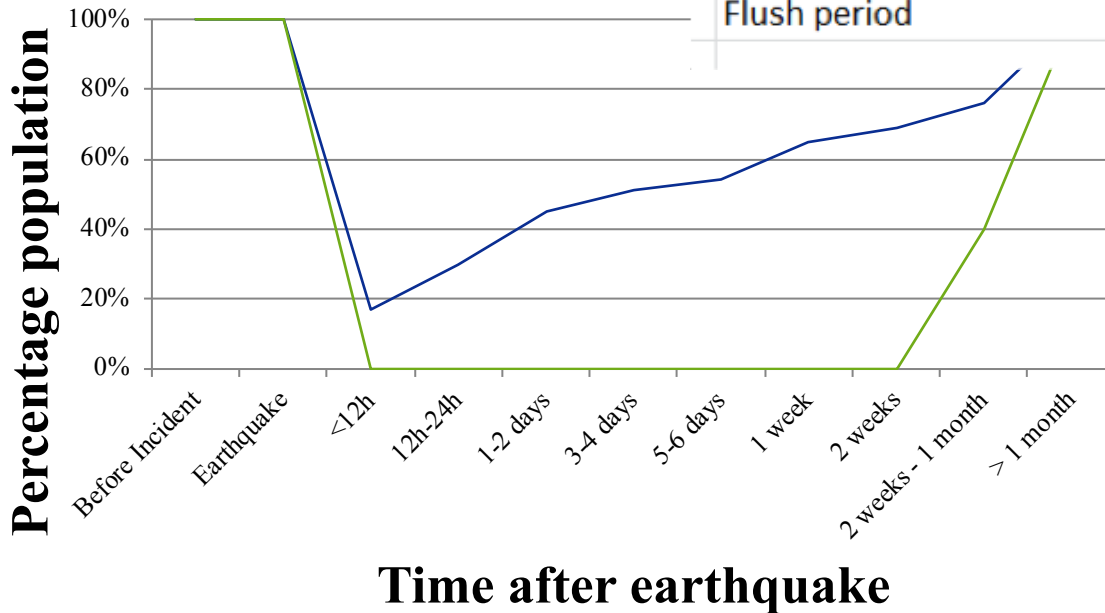
# Evaluation - Delivery



# Evaluation - Quantity



# Evaluation - Quality



## Quality recovery stages

Increment

Flush period

Number

unit

20%

%

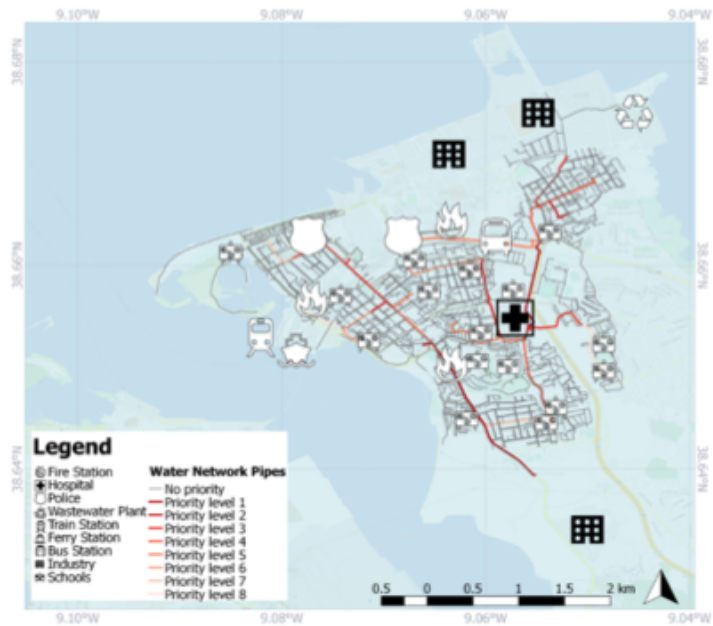
14,00

days

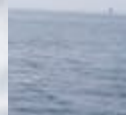
— Tolerance

— Capacity





# Emergency Response



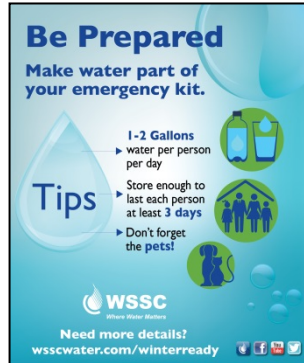
# Resilience Treatment: Communication

- Information provision leads to more realistic performance expectations
- AESOP: Communication Guidelines in brief
  - Use both social and traditional media to communicate with the public about the time needed to fully restore critical services during incidents
  - Communicate with the public at all stages of a disaster i.e. not just in the response phase
  - Ensure message consistency across all media platforms (for both social and traditional media)
  - Post-disaster learning to enhance and develop future communication strategies



# Communication: Preparedness campaign

- Increase citizen tolerance for water quantity via preparedness campaigns





# Communication: boil water

- Increase citizen tolerance for quality via communication
- Ahead of the crisis
  - promote/explain why it is necessary to wait “so long” before removing the boiling advisory (public health and safety, etc.)
- During the crisis
  - Use AESOP guidelines
    - keep public informed with estimated recovery times



# Antiseptic tanks

- Decrease recovery time for quality by investing in antiseptic tanks



# EVALUATION USING ITRA



# RESILIENCE TREATMENT PLANNING



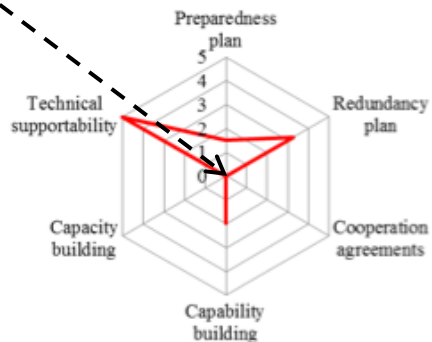
# Level 1



## Level 2 Prevention



## Level 2 Preparedness



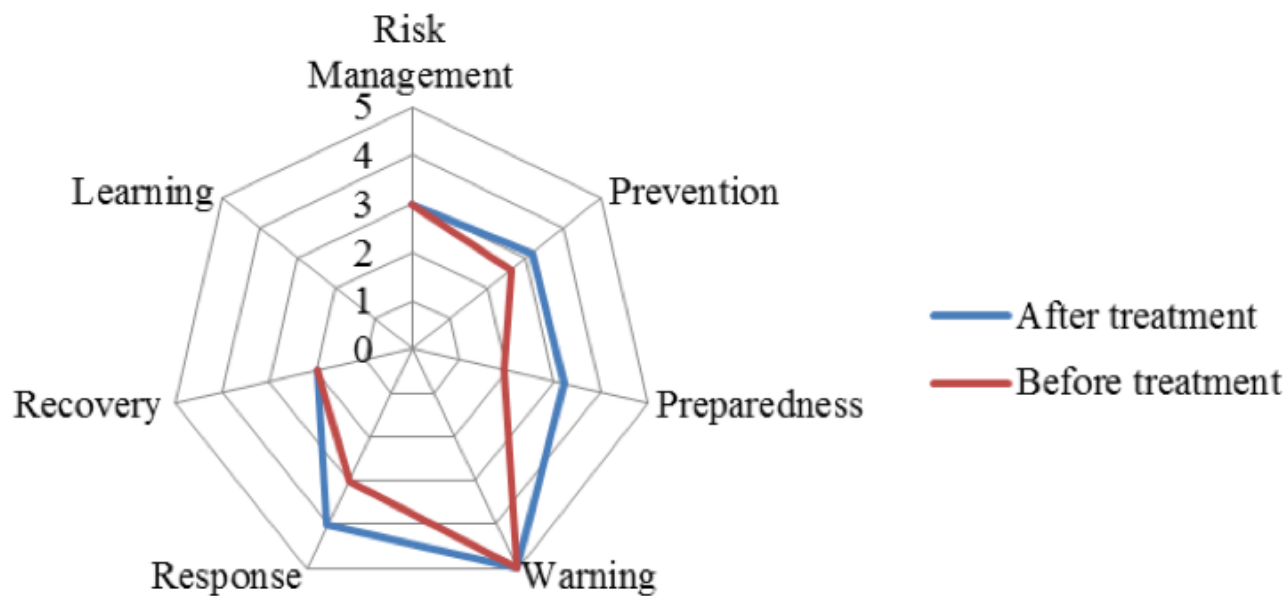
## Level 2 Response



<b>Level 1</b>	<b>Level 2</b>	<b>Proposed treatment</b>	<b>Indicator</b>
<b>Prevention</b>	<b>Safety and security culture</b>	<b>Storage in private containers</b>	<b>2.1.1.2</b>
		<b>Storage in the critical facilities (CF) in terms of tanks</b>	<b>2.1.1.3</b>
	<b>Risk treatment plan</b>	<b>Increase monitoring points</b>	<b>2.2.1.1</b>
		<b>Increase flexibility of the system</b>	<b>2.2.2.2</b>
	<b>Planned maintenance</b>	<b>Cleaning the pipe network as needed</b>	<b>2.6.1.1</b>
		<b>Inspection of manholes and valves</b>	<b>2.6.1.2</b>
		<b>Maintaining or replacement of the old pipes in the network</b>	<b>2.6.2.1</b>
<b>Preparedness</b>	<b>Preparedness plan</b>	<b>Staff duties and authorisation</b>	<b>3.1.2.1</b>
		<b>Decision makers duties and responsibilities</b>	<b>3.1.2.2</b>
		<b>Measures in place to prevent silos</b>	<b>3.1.2.3</b>
	<b>Cooperation agreements</b>	<b>Priorities agreements</b>	<b>3.3.2.1</b>
		<b>Cooperation for minimum system performance</b>	<b>3.3.2.2</b>
	<b>Capacity building</b>	<b>Internal training</b>	<b>3.5.1.1</b>
		<b>External training</b>	<b>3.5.1.2</b>
<b>Response</b>	<b>Externalised redundancy</b>	<b>Financing plan</b>	<b>5.8.1.2</b>



# Level 1



# Communication: Preparedness campaign

- Increase citizen tolerance for water quantity via preparedness campaigns



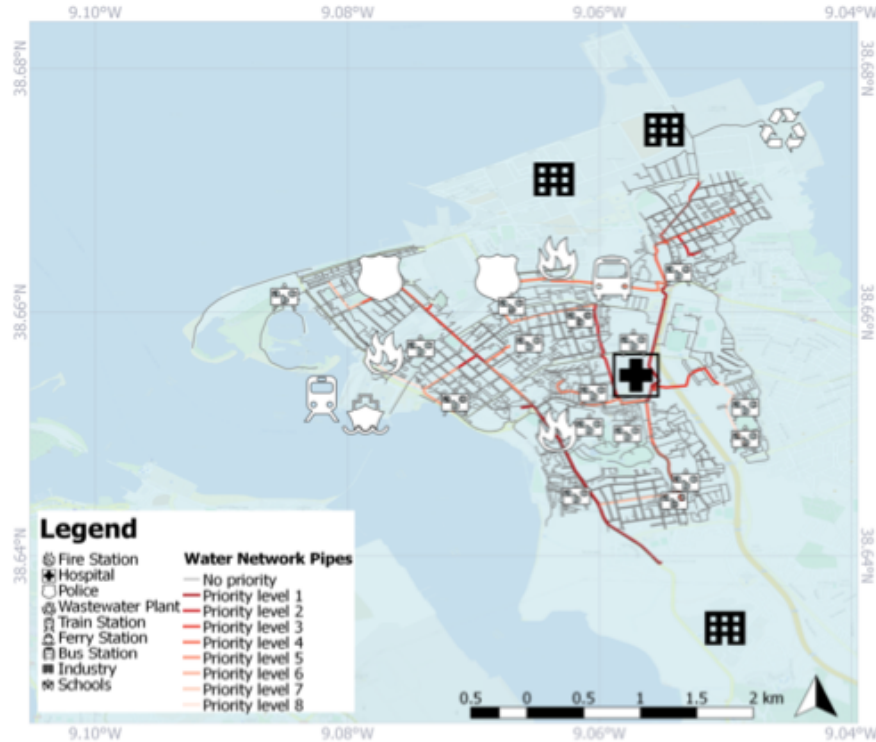


# Communication: boil water

- Increase citizen tolerance for quality via communication
- Ahead of the crisis
  - promote/explain why it is necessary to wait “so long” before removing the boiling advisory (public health and safety, etc.)
- During the crisis
  - Use AESOP guidelines
    - Keep public informed with estimated recovery times



# Decrease pipe fragility – earthquake safe pipes and connections



# Resilience Treatment

- Decrease recovery time for quality by investing in antiseptic tanks
- Redundancy in critical connections
- Pipe repair prioritisation scheme
- Information sharing
  - Critical users
  - First responders
  - Up and downstream CI
  - Mutual aid agreements
- Demonstrable impact on recovery and preservation of service



## The Oregon Resilience Plan

Reducing Risk and Improving Recovery  
for the Next Cascadia Earthquake and Tsunami

Report to the  
77<sup>th</sup> Legislative Assembly

from  
Oregon Seismic Safety Policy  
Advisory Commission (OSSPAC)



Salem, Oregon  
February 2013

