An approach to measuring resilience to manage water supply systems

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Normal provision of water service

DURATION AND SEVERITY
### TOOLS

<table>
<thead>
<tr>
<th></th>
<th>Raise awareness</th>
<th>Climate change</th>
<th>Contamination warning systems</th>
<th>Risk management</th>
<th>Argonne National Laboratory Resilience Index</th>
<th>Resilience Index</th>
<th>Modified Resilience Index</th>
<th>Network Resilience Index</th>
<th>Resilience factor</th>
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### DEFINITION

<table>
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<tr>
<th>Preparedness</th>
<th>Anticipate risk</th>
<th>Absorb energy</th>
<th>Mitigation</th>
<th>Adaptation</th>
<th>Assessment of vulnerability</th>
<th>Limit impact</th>
<th>Response capacity</th>
<th>Risk management</th>
<th>Support</th>
<th>Recovery</th>
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<tbody>
<tr>
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### INDICATORS

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### MODELS

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<th>Water quantity</th>
<th>Water quality</th>
<th>Water demand</th>
<th>Other variables (pressure, etc.)</th>
<th>Functionality of the system</th>
<th>Time to recover</th>
<th>Magnitude of events</th>
<th>Duration of events</th>
<th>Water discontinuity</th>
<th>Loss of service level</th>
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### Models

- Water quantity
- Water quality
- Water demand
- Other variables (pressure, etc.)
- Functionality of the system
- Time to recover
- Magnitude of events
- Duration of events
«We define RESILIENCE as the set of system CAPACITIES TO DELIMIT IMPACTS»
METHODOLOGY
We have defined

THREATS

A. Water scarcity
B. Water supply discontinuity
C. Discontinuity of drinking water quality conditions
D. Discontinuity of hydraulic conditions
Disruption period

Loss of service level

Level of service

Protocols, technologies and resources change

RESILIENCE should be updated after a disruptive event

RESILIENCE

Time

Disruption period
FAILURE THRESHOLDS

\[ t_e, t_f, t_s, n, a_{1\&2} \]: occurrence time, final recovery time, intersection time with thresholds
RESILIENCE FACTOR

\[
\begin{align*}
\left( R_{fn} \right)_A &= \left( R_{fn1} \right)_A + \left( R_{fn2} \right)_A = \int_{t_{s1}}^{t_{n1}} \left( F_{SA} (t) - F_A (t) \right) \cdot dt \\
\left( R_{fa} \right)_A &= \left( R_{fa1} \right)_A + \left( R_{fa2} \right)_A = \int_{t_{n1}}^{t_{a1}} \left( F_{NA} (t) - F_A (t) \right) \cdot dt \\
\left( R_{fc} \right)_A &= \int_{t_{a1}}^{t_{a2}} \left( F_{CA} (t) - F_A (t) \right) \cdot dt \\
\left( R_f \right)_A &= P_{nA} \cdot \left( R_{fn} \right)_A + P_{aA} \cdot \left( R_{fa} \right)_A + P_{cA} \cdot \left( R_{fc} \right)_A \\
R_f &= R_{fA} \cdot P_A + R_{fB} \cdot P_B + R_{fC} \cdot P_C + R_{fD} \cdot P_D
\end{align*}
\]
CASE STUDY
Public water company that manages the water cycle in the Autonomous Region of Madrid (Spain)

6,238,000 end-users
17,500 km pipes
179 municipalities
Water scarcity

DROUGHTS

hm$^3$/year

Water supply discontinuity

DUE TO PIPE BREAKS (2011-2014)

Average time of discontinuity (hours)

Maximum number of affected properties by the same break
Discontinuity of drinking water quality conditions

![Graph showing the relationship between awareness time, number of properties, water quality damages, and number of people with health problems over time.](image)

- **No. properties**
- **Time**
- **Water quality damages**
  - FATAL
  - SEVERE
  - LOW
- **No. people with health problems**
- **Time**

Awareness time:

- LOW
- SEVERE
- FATAL
- FATAL

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RESULTS
DROUGHT
\[ R_{fn} A = 9.4\% \cdot 12 \text{ months} = 112.8\% \cdot \text{ month} = 9.4\% \cdot 1 \text{ year} = 9.4\% \cdot \text{ year} \]
PROTOCOLS FOR CONTINGENCIES
PIPE BREAKS
No. affected properties: 103. Disruption time: 4.43h
Material: Fibrecement. Diameter: 100 mm

456.63 properties-hour
No. affected properties: 262. Disruption time: 15.83h
Material: Grey iron. Diameter: 150 mm

4148.33 properties-hour
No. affected properties: 114. Disruption time: 9.83h
Material: Ductile iron. Diameter: 150 mm

1121 properties-hour
PROTOCOLS FOR CONTINGENCIES
WATER QUALITY FAILURES
No. affected properties: 144. Disruption time: 168h

24192 properties-hour
No. affected properties: 124. Disruption time: 312h

38688 properties-hour
No. affected properties: 104. Disruption time: 576h

59904 properties-hour
CONCLUSIONS
A new METHODOLOGY to measure RESILIENCE is developed

THREATS

FAILURE

THRESHOLDS
The METHODOLOGY is applied to the water supply system of Canal Gestión water utility

DROUGHTS

PIPE BREAKS

WATER QUALITY FAILURES
The METHODOLOGY allows:

Measuring RESILIENCE
Assessing PROTOCOLS
Planning INVESTMENTS
It is possible to quantify RESILIENCE of a water supply system

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