An approach to measuring resilience to manage water supply systems

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Normal provision of water service

DURATION AND SEVERITY
| TOOLS                        | MODELS                             |
|------------------------------|------------------------------------|
| Raise awareness              | Water quantity                     |
| (Travers, 2010)             | X                                  |
| Climate change               | Water quality                      |
| (EPA, 2012)                 | X                                  |
| Contamination warning systems| Water demand                       |
| (Murray et al., 2010)       | X                                  |
| Risk management              | Other variables                     |
| (Brashear y Jones, 2010)    | X                                  |

| INDICATORS                   | MODELS                             |
|------------------------------|------------------------------------|
| Argonne National Laboratory Resilience Index | Functionality of the system |
| (Petit et al., 2013)        | X                                  |
| Resilience Index            | Time to recover                     |
| (Todini, 2000)              | X                                  |
| Modified Resilience Index   | Magnitude of events                 |
| (Jayaram y Srinivasan, 2008)| X                                  |
| Network Resilience Index    | Duration of events                  |
| (Prasad y Park, 2004)       | X                                  |

| MODELS                       | DEFINITION                    |
|------------------------------|-------------------------------|
| Water discontinuity         | (White House, 2013)           |
| Loss of service level       | (Henry y Ramírez, 2012)       |
| Preparedness                | (Petit et al., 2013)          |
| Anticipate risk             | (Fitzgerald, 2009)            |
| Absorb energy               | (EPA, 2015)                   |
| Mitigation                  |                               |
| Adaptation                  |                               |
| Assessment of vulnerability |                               |
| Limit impact                |                               |
| Response capacity           |                               |
| Risk management             |                               |
| Support                     |                               |
| Recovery                    |                               |
«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

Protocols, technologies and resources change

RESILIENCE should be updated after a disruptive event

Level of service

Time

Disruption period

$te$ $tf$
FAILURE THRESHOLDS

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

\[
\begin{align*}
\left( R_{fn} \right)_A &= \left( R_{fn1} \right)_A + \left( R_{fn2} \right)_A = \int_{t_{s1}}^{t_{n1}} \left( F_{SA}(t) - F_A(t) \right) \cdot dt + \int_{t_{n2}}^{t_{s2}} \left( F_{SA}(t) - F_A(t) \right) \cdot dt \\
\left( R_{fa} \right)_A &= \left( R_{fa1} \right)_A + \left( R_{fa2} \right)_A = \int_{t_{n1}}^{t_{a1}} \left( F_{NA}(t) - F_A(t) \right) \cdot dt + \int_{t_{a2}}^{t_{n2}} \left( F_{NA}(t) - F_A(t) \right) \cdot dt \\
\left( R_{fc} \right)_A &= \int_{t_{a1}}^{t_{a2}} \left( F_{aA}(t) - F_A(t) \right) \cdot dt \\
\left( R_f \right)_A &= P_{nA} \cdot \left( R_{fn} \right)_A + P_{aA} \cdot \left( R_{fa} \right)_A + P_{cA} \cdot \left( R_{fc} \right)_A
\end{align*}
\]

\[
R_f = R_f_A \cdot P_A + R_f_B \cdot P_B + R_f_C \cdot P_C + R_f_D \cdot P_D
\]
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
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

No. properties vs. Time

No. people with health problems vs. Time

Water quality damages

- FATAL
- SEVERE
- LOW

Awareness time
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: Ductil 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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