Exploring Resilience of Community Water Systems

AquaSCALE

A GlobalCities Challenge Project

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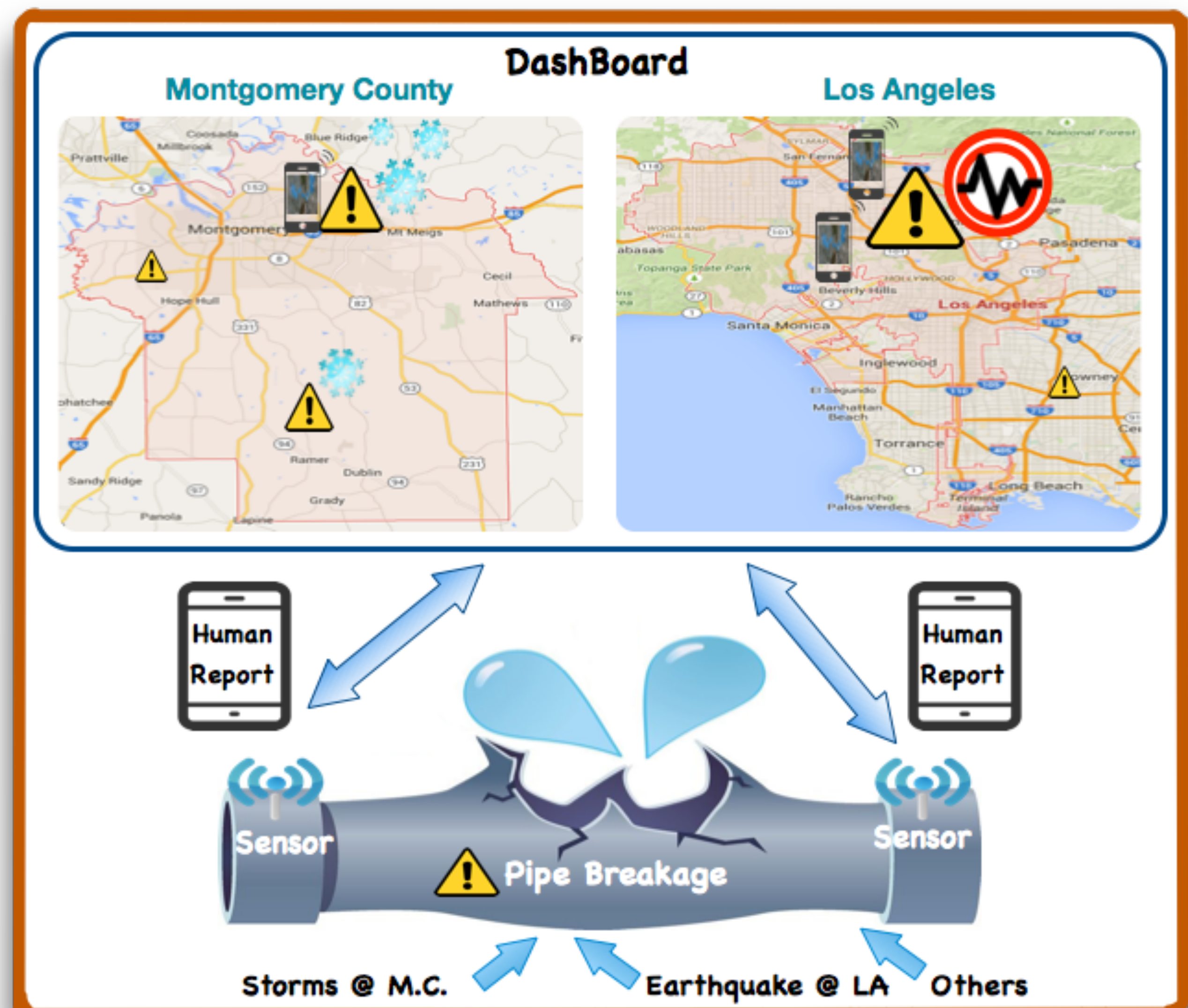
WATER – a precious natural resource

- **A critical resource and lifeline service to communities worldwide .**
- **Water Generation, treatment, storage and distribution infrastructure has been developed over decades (centuries sometimes)**
- **Become large, complex and vulnerable to failures.**

Resilience Concerns - Community Disruptions, Resource Wastage, Contamination, Threat to Public Health

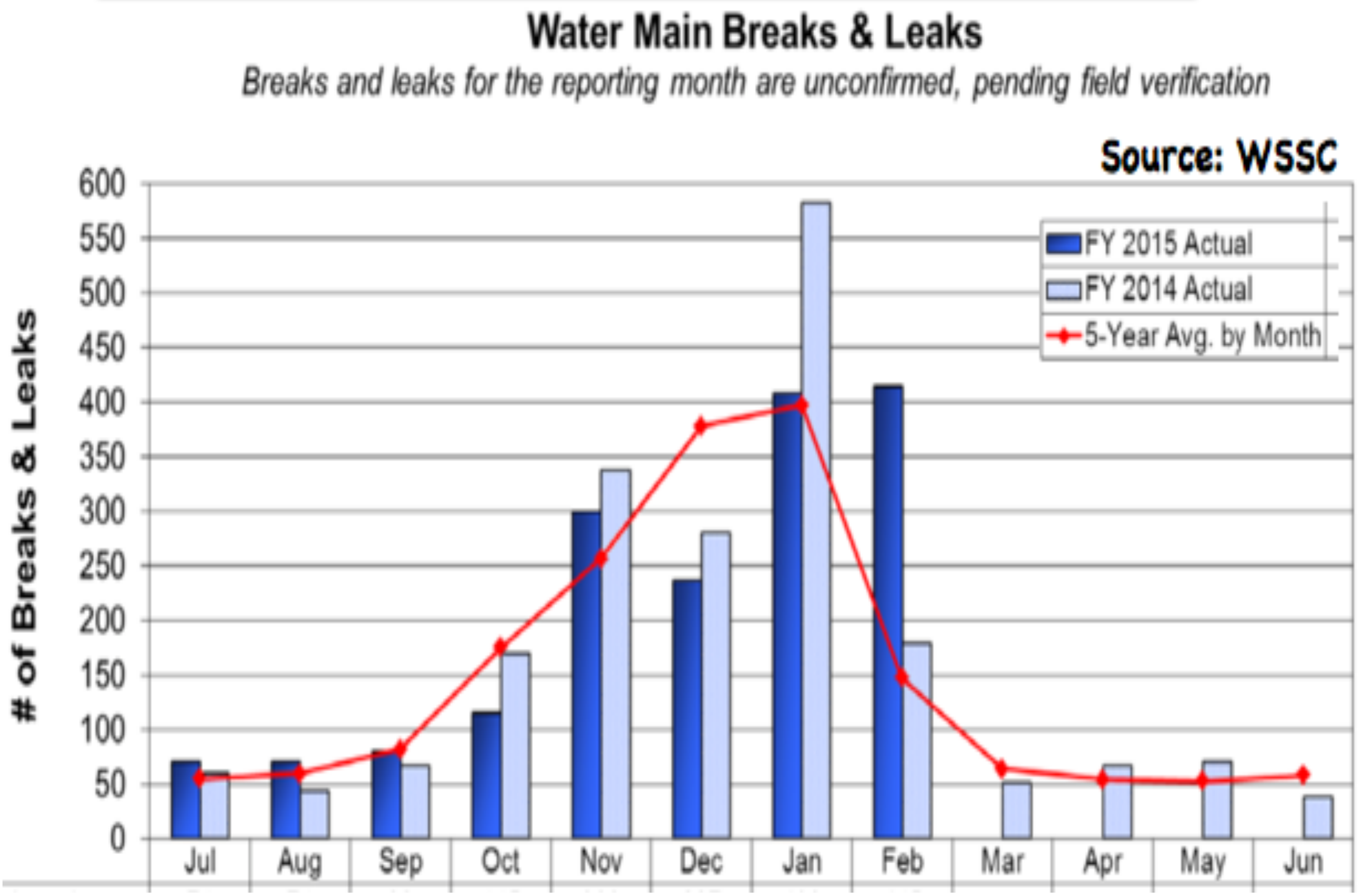


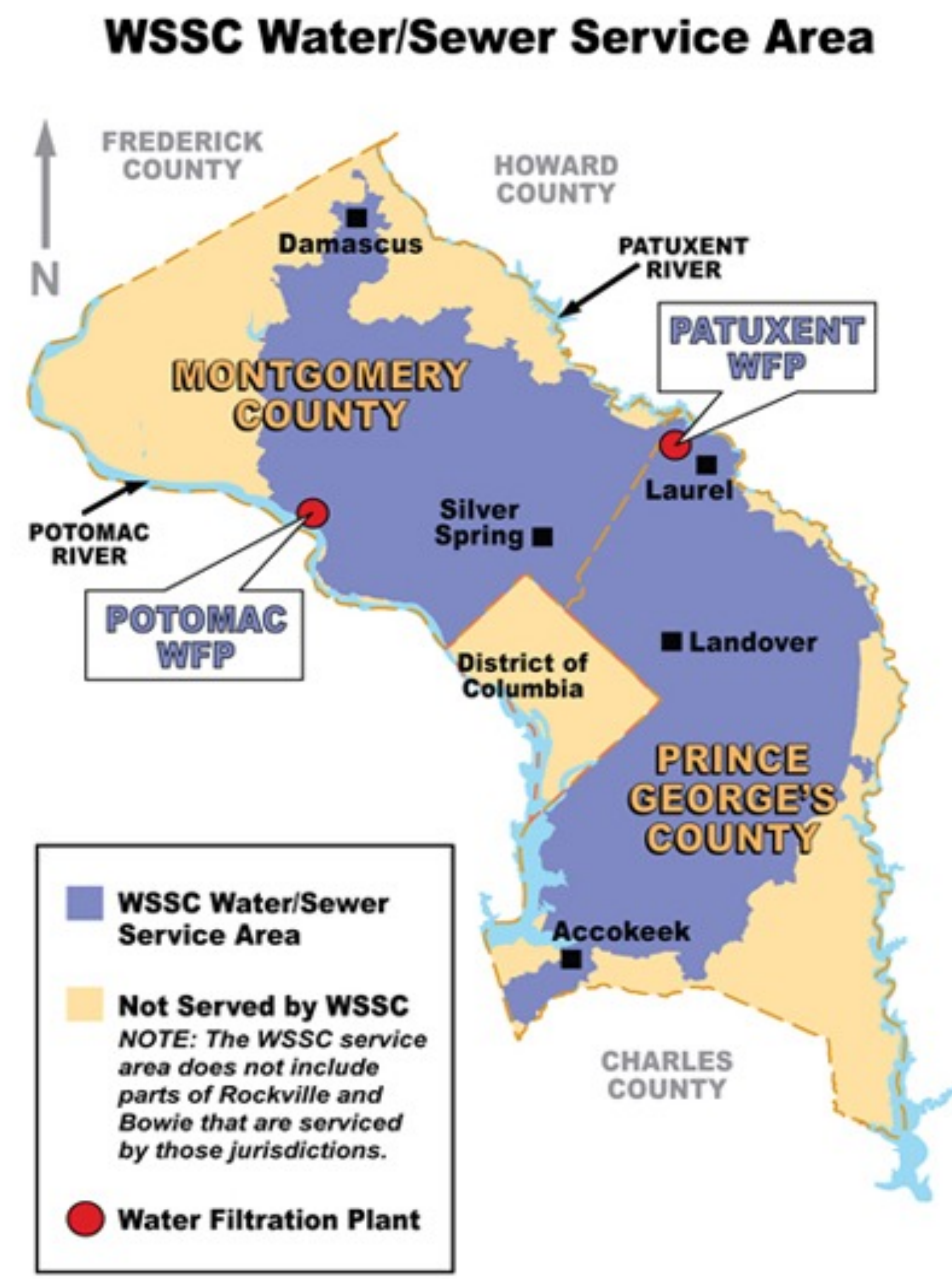
Objectives

- **Develop methodologies to understand resilience issues for real world community water infrastructures in cyberspace before instantiating them into a physical infrastructure.**
- **Prevent water service failures by identifying operational degradation in aging infrastructures.**
- **Improve speed and accuracy of damages estimation in natural disasters and human-made hazards.**
- **Reduce service restoration time in the event of large hazards.**

Why do we care so much?

East Coast – Operational



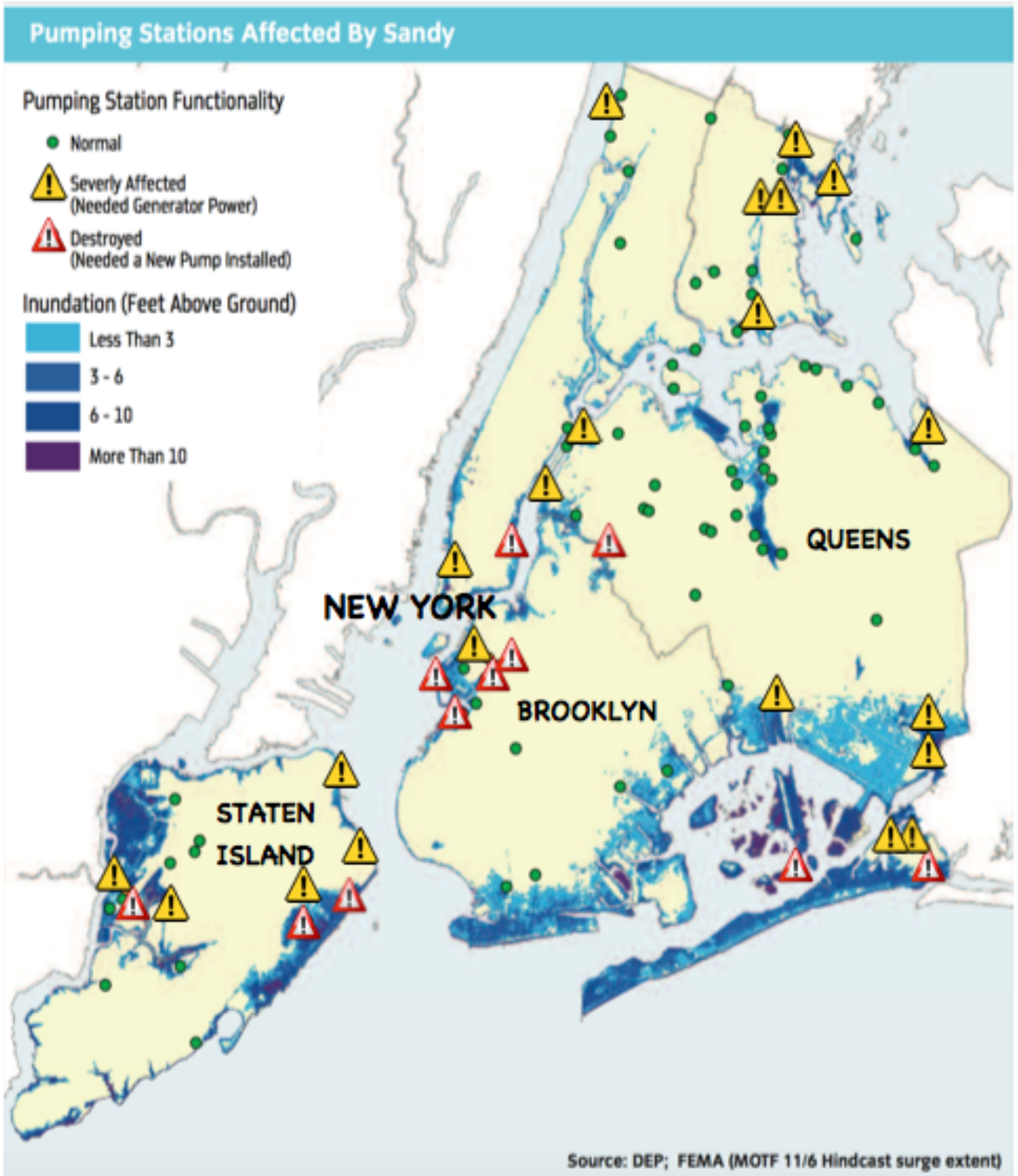


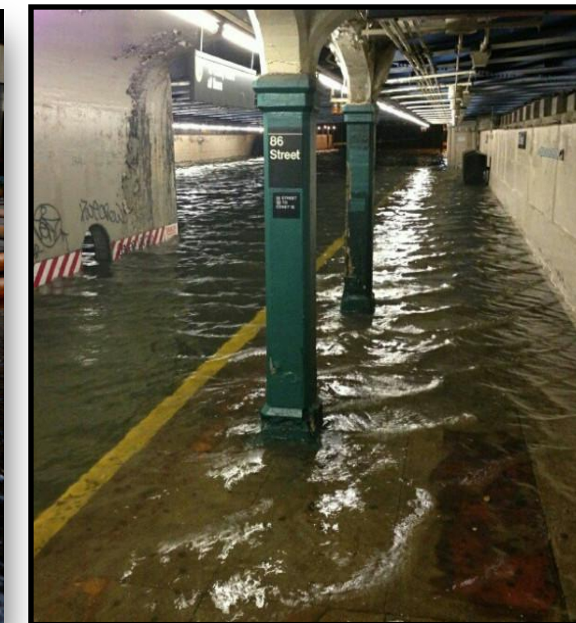
- In February 2015, over **17,000 calls** were received in the ECC (Emergency Contact Center) primarily due to frozen pipes and no water.
- Over **400** water main breaks, resulting in demand increase from an average of **150 million gallons** per day to **188 million gallons** per day.
- **87%** of breaks and leaks resulted from pipes made of cast iron material, **93%** of broken pipes were less than 12 inches in diameter, and **65%** of the breaks occurring in pipes over **50** years old.

Why we care so much?

East Coast – Extreme event

Community Disruptions, Resource Wastage, Contamination, Threat to Public Health





Hurricane Sandy (Oct. 25, 2012)

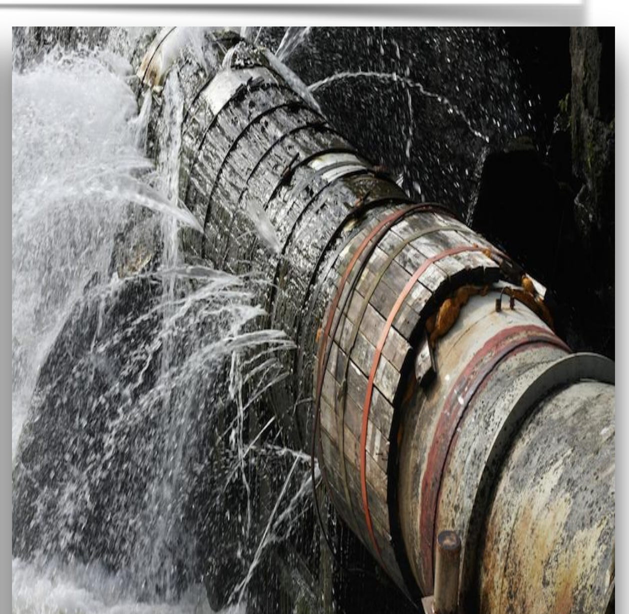
- **High winds caused erosion on the reservoir's edge, sending natural materials into the reservoir.**
- **44% of pumping stations were damaged.**
- **2.75 billion gallons of untreated waste flowed into the nearby homes, causing a significant health concern in Baldwin and East Rockaway, New York.**
- **DEP (Department of Environmental Protection) crews cleaned more than 3,500 catch basins and flushed more than 190,000 linear feet of sewer lines in the three weeks following the storm.**

Why we care so much?

West Coast – Operational

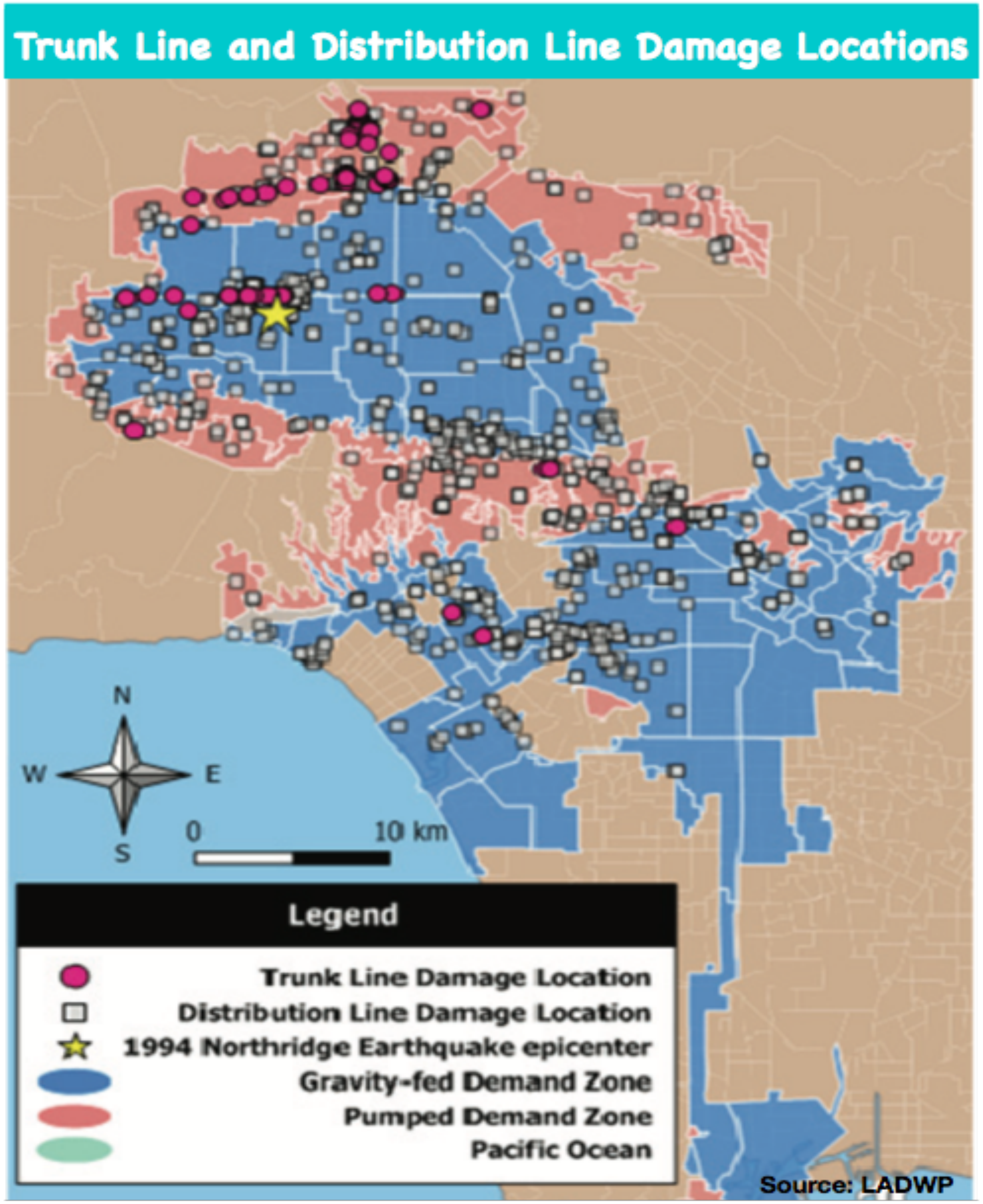
Water Pipe Burst Under Sunset Boulevard in L.A. (July 30, 2014)

- The juncture of a **93-year-old 30-inch** water pipe and a **58-year-old 36-inch** pipe burst.
- Open a **20 feet wide**, **10 feet deep** sinkhole and send a geyser **30 feet** into the air, causing a flood of troubles over the UCLA campus.
- **20 million** gallons of freshwater, around **35,000** gallons a minute, wasted in the middle of the worst drought in California history.
- **Hundreds** of vehicles were waterlogged.
- Tap water for **half a million** people unsafe to drink.



Why we care so much?

West Coast – Extreme Event

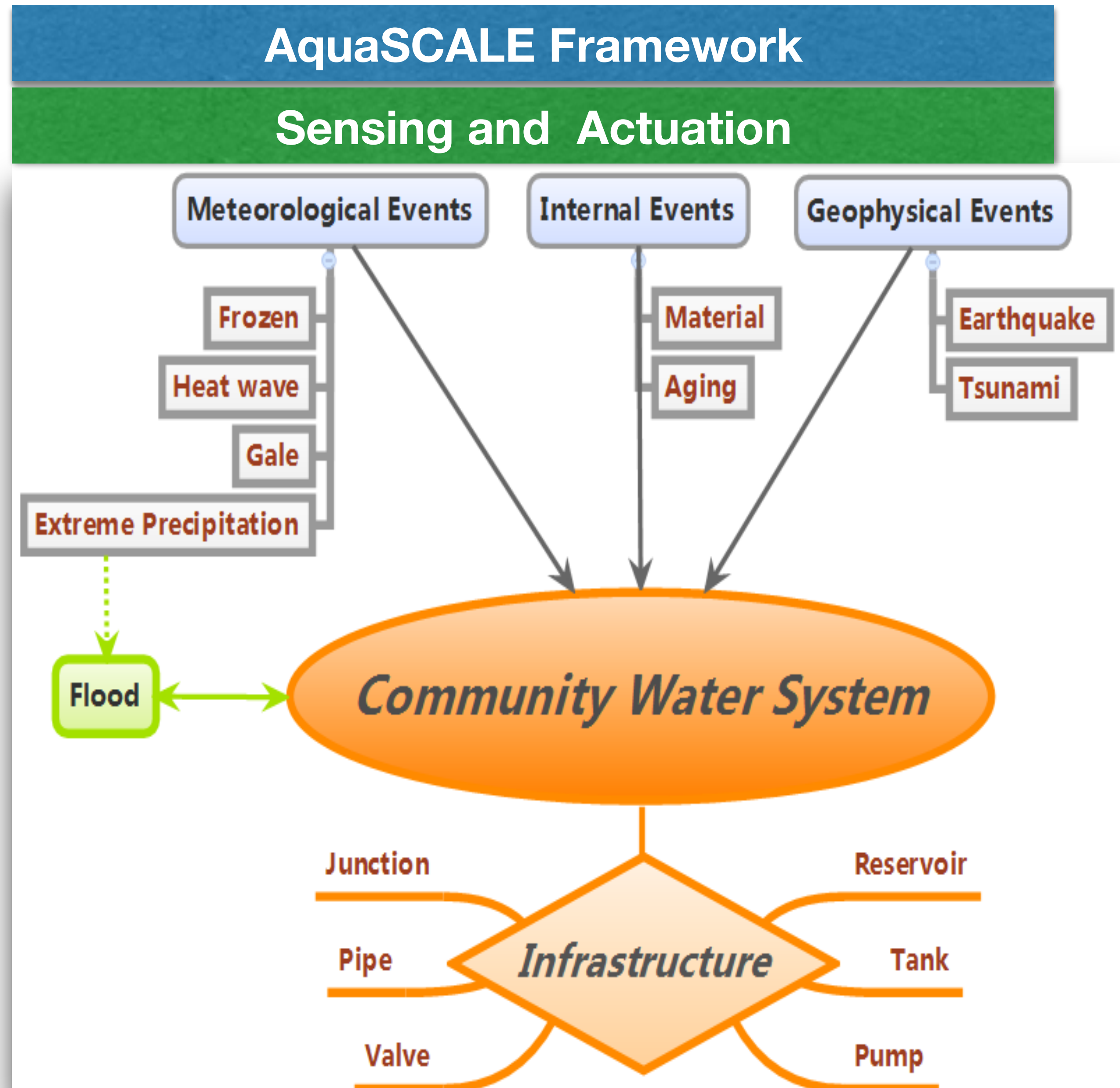


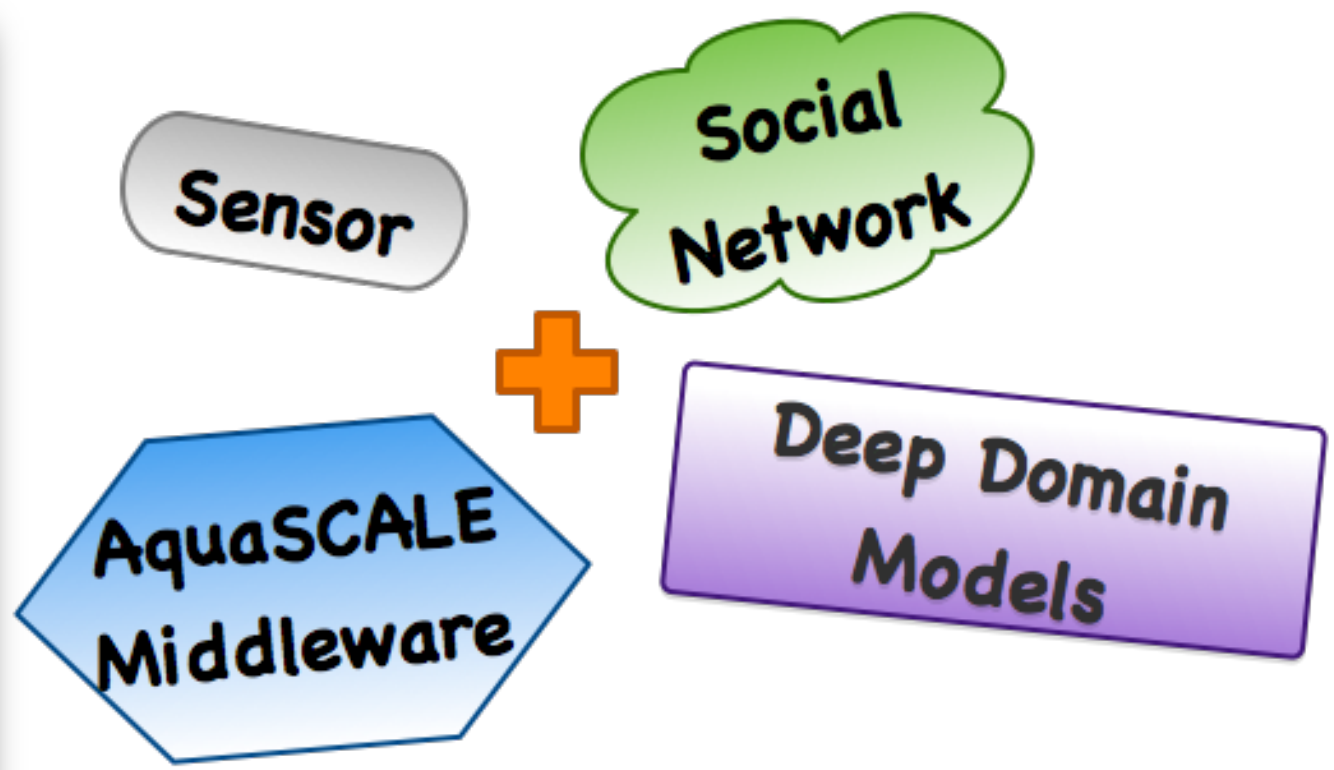
Northridge Earthquake (Jan. 17, 1994)

- More than 70 incidents of damage to trunk lines, 1,013 incidents of damage to distribution lines, and damage to 5 out of 110 water tanks.
- Approximately 500,000 people (14% of those served by LADWP, Los Angeles Department of Water and Power) lost water service.
- It took five days to restore water, costing about $41 million.
- About 18% of surveyed businesses closed due to loss of water.
- Water purification lasted for up to 12 days in some areas.

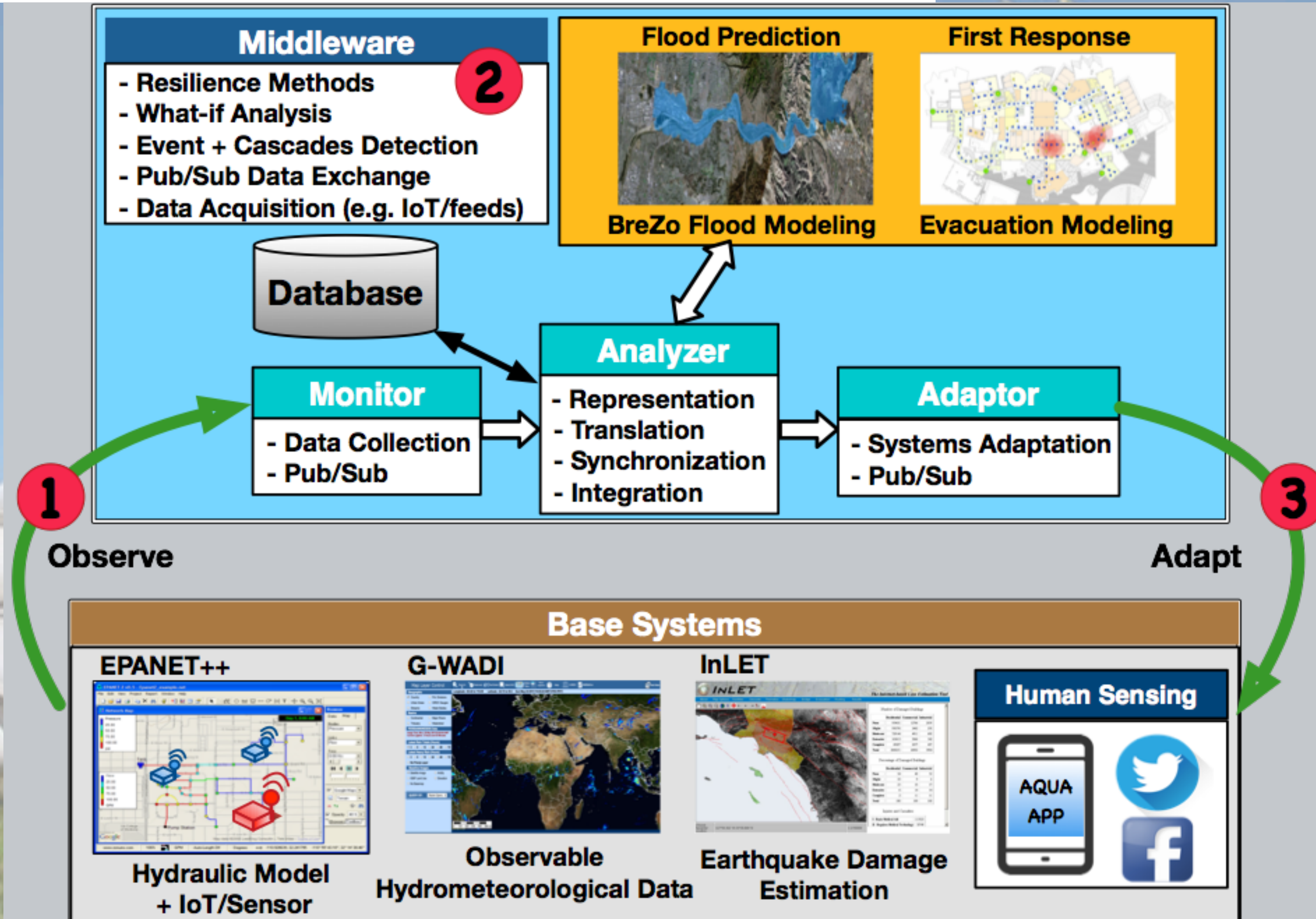
AquaSCALE- A CPHS Enabled Platform

A framework for integrating new and emerging sensor technologies into simulation modeling to improve the resilience of community water supply systems in sudden and prolonged events.





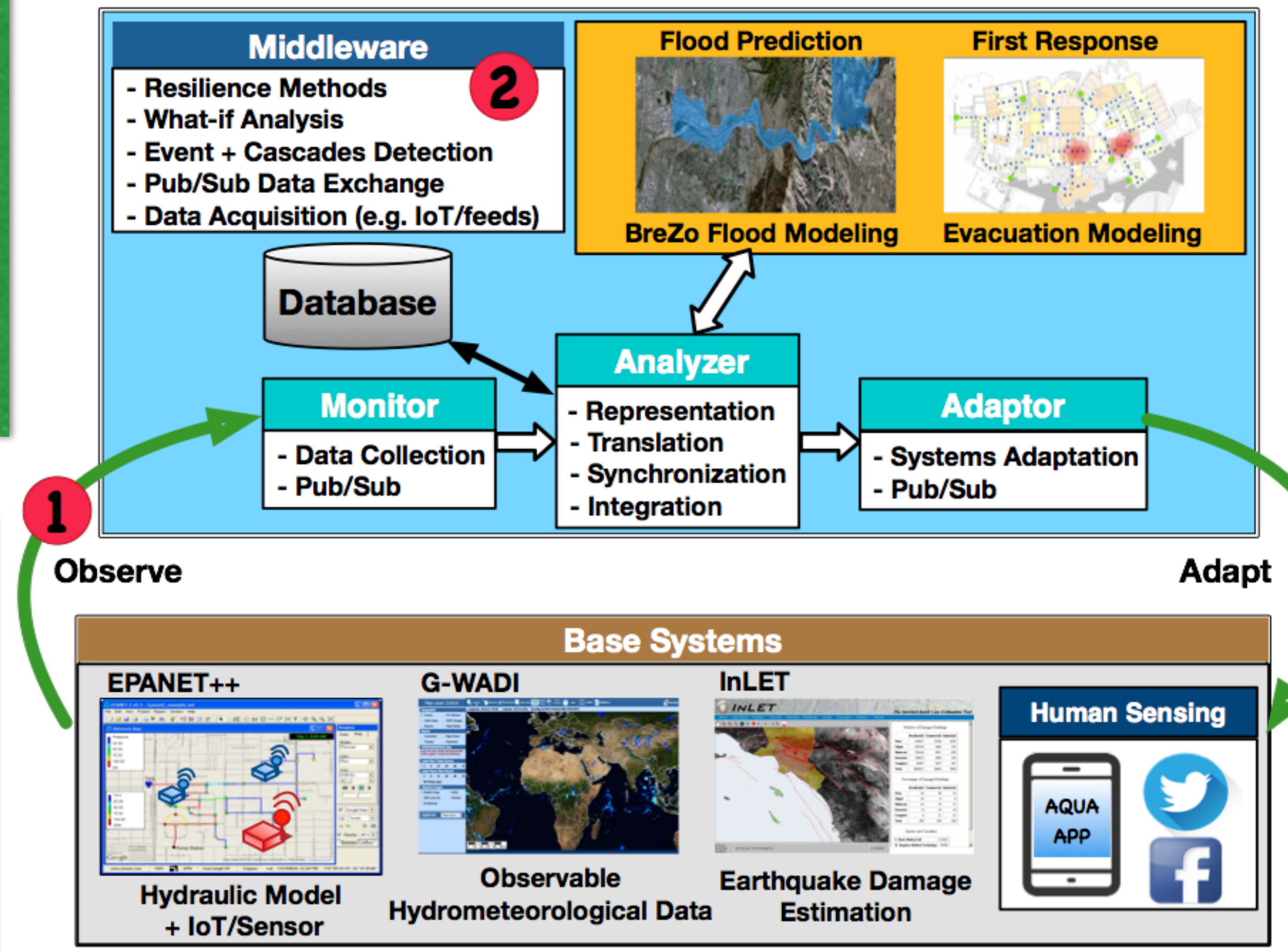
AquaSCALE Framework



AquaSCALE Framework

1. IoT/Sensor Data Acquisition Module

Gather real-time field information, identify effects of new information, and project the effects, with updates from the field on a simulation outcomes.



2. Integrated Analytics Modules

Explore the use of available deep-domain software to identify regions of higher vulnerability and qualify the potential extent of damage using what-if analysis.

3. Decision Support Module

Leverage dashboards and user interface platforms available within the team for Human-in-the-loop visualization to trigger mitigation mechanisms, including intelligent sensor placement, distribution and flows rerouting, and supply shutdown.

Sample Problem: Leak Detection

Complex and Large Infrastructure

- LADWP: 300 regulator stations, 73 pump stations, 110 tanks and numerous small reservoirs, 7,142 mi. of pipe line—5,635 mi. up to 12 in. in diameter, 972 mi. 12 to 16 in. in diameter, and 535 mi. larger than 16 in. in diameter.

Damaged to underground pipelines is often hidden

- 237,600 breaks per year in the US leading to approximately $2.8 billion lost in yearly revenue (AWWA).

Expensive (High Cost Equipment, Many Operators, Operator Training)

Location Dependent

Weather Dependent

Interference Sensitive

Risk of contamination

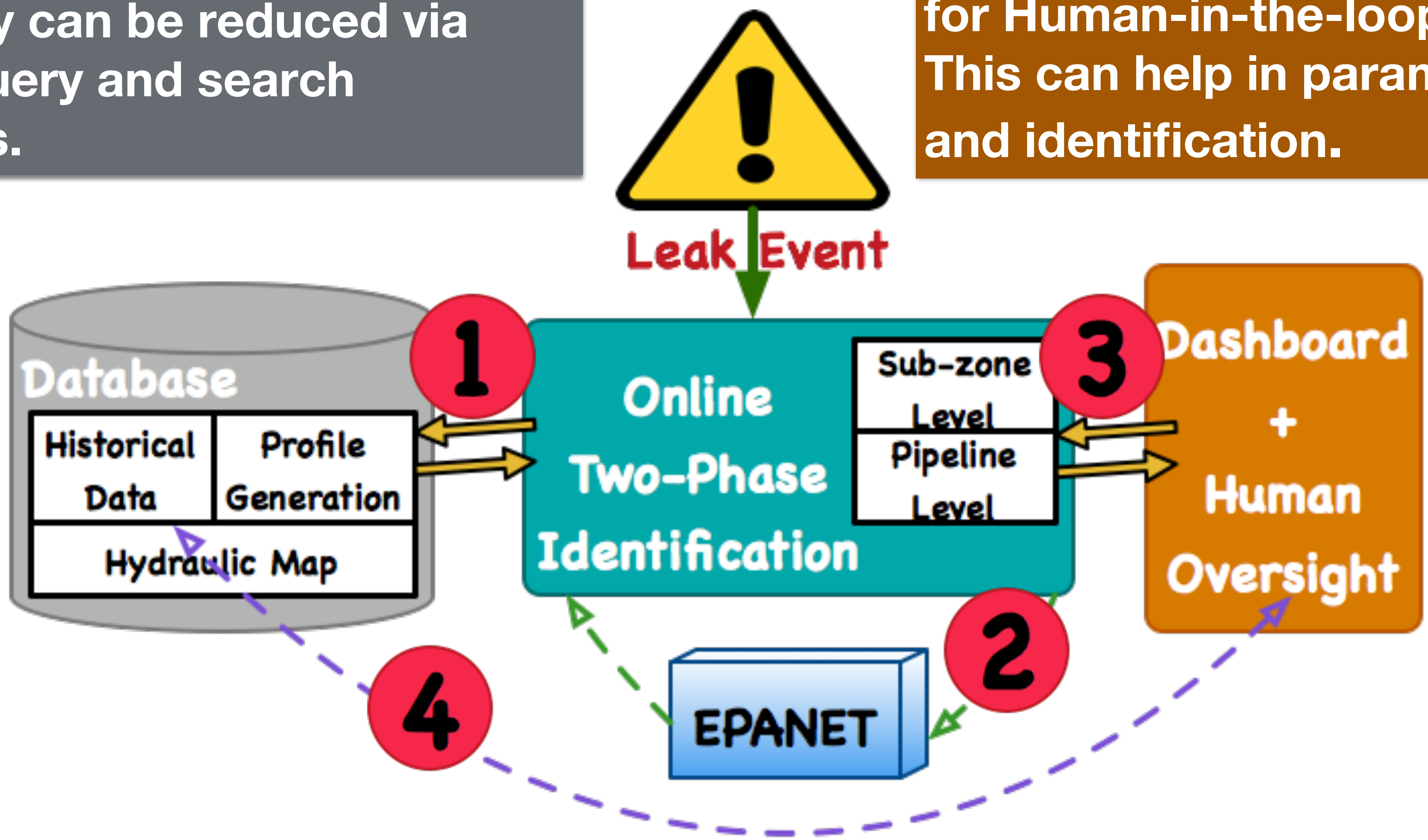
Hours to Days

Leak Detection Today

IoT Driven Leak Detection Methodology

1. Access database for identifying the hotspot of damaged regions. Complexity can be reduced via efficient query and search techniques.

3. Leverage dashboards and user interface platforms within the team for Human-in-the-loop visualization. This can help in parameter setting and identification.



4. Trigger corresponding adaptations (e.g. actuation and control of water infrastructure elements). Update database to refine sensor selection and placement, pipeline distribution and replacement etc.

2. Update hydraulic simulators with observations to iterate to a most likely solution. Complexity depends on the number of potential nodes identified by 1.

IoT Driven Leak Detection Methodology

- Assumptions

1. The existence of leakage, thus estimate leak events without diagnosis of the occurrence of the damage.
2. Pressure measurements can be accessed at certain locations where the sensors are deployed.

- Problem Definition

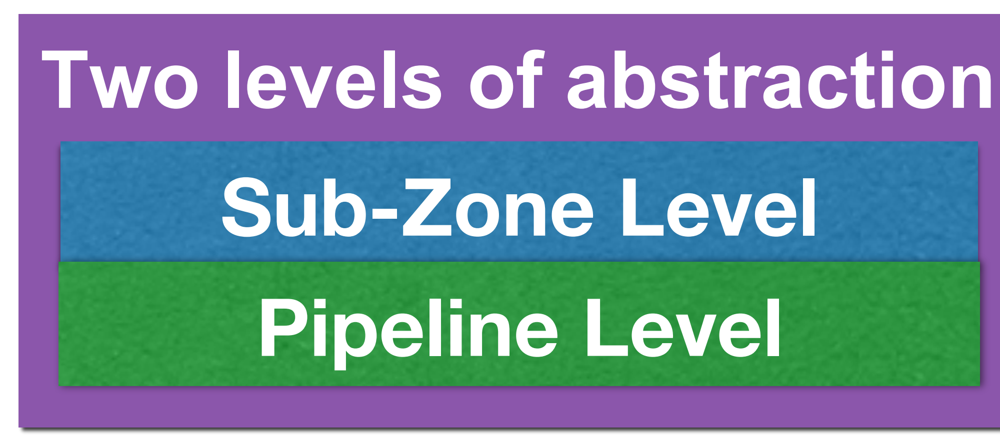
To identify potential broken pipelines in a water network and assign them corresponding confidence intervals. A higher probability is more likely to be damaged.

- Performance Metrics

Accurately and quickly locate the leakage.

- Algorithms

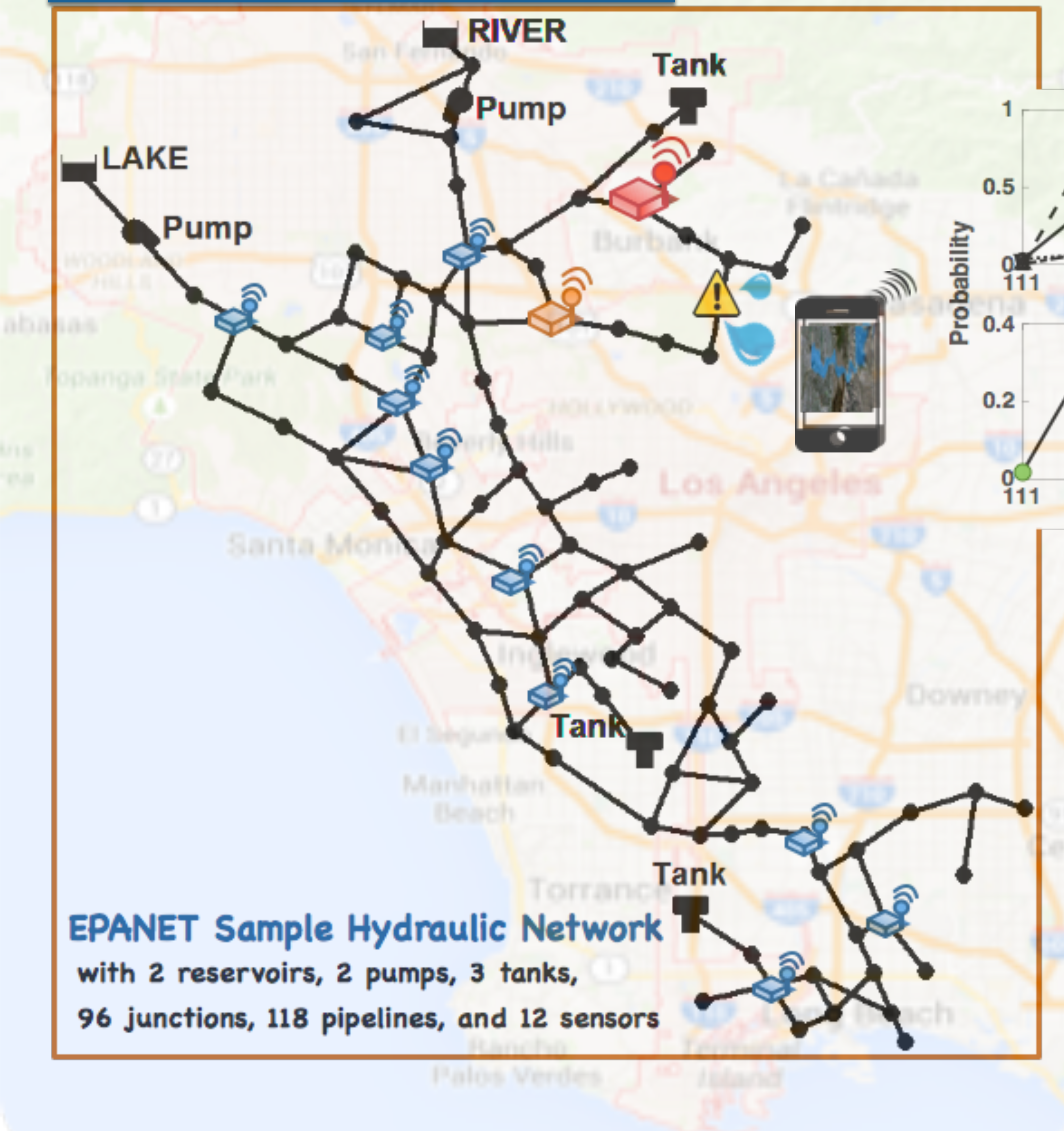
1. Sub-zone level: detect leakage within a zone via Pattern Match but unable to specify the exact position of the leak. Complexity can be reduced by efficient querying techniques.

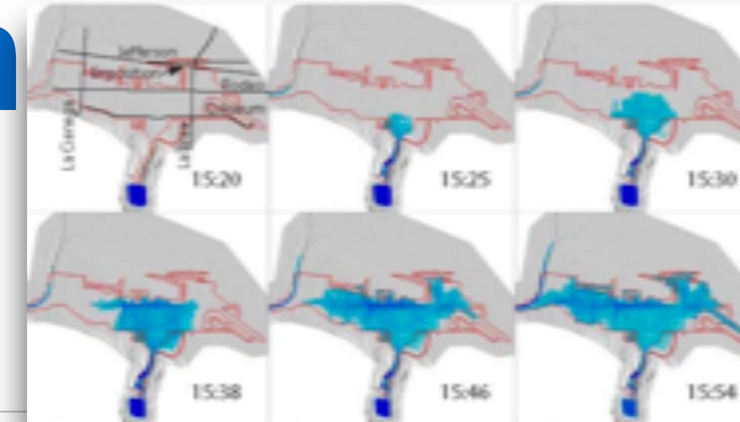


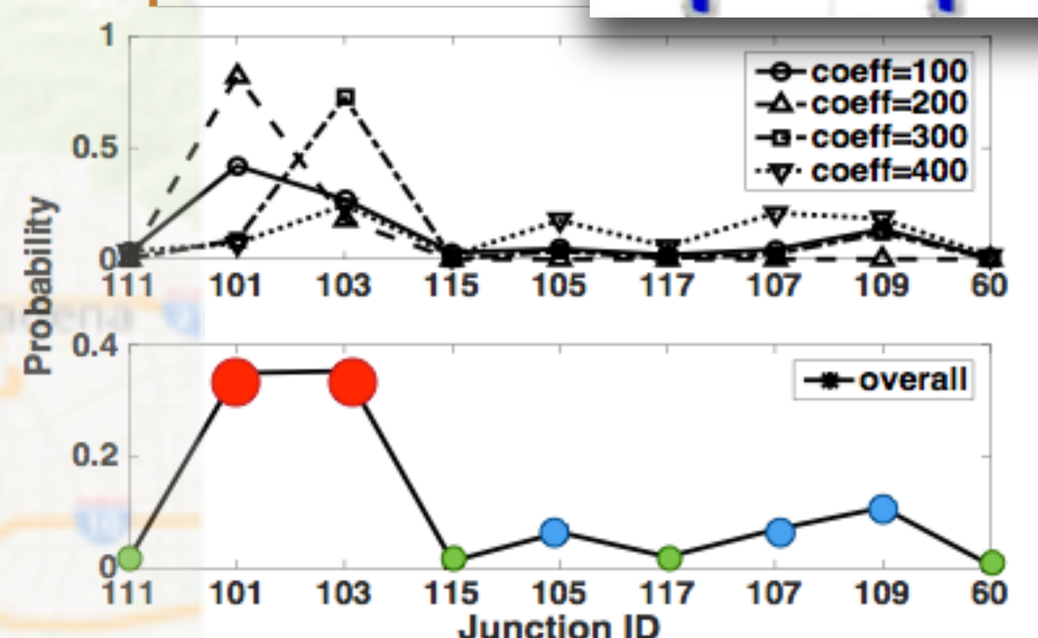
2. Pipeline level: update EPANET with observations of pressures to iterate to a solution where likely leak events that could be tied to observed pressures via Bayesian Probabilistic Network. Complexity depends on the number of potential broken pipes identified by level 1.

IoT Driven Leak Detection

Single Leak Case



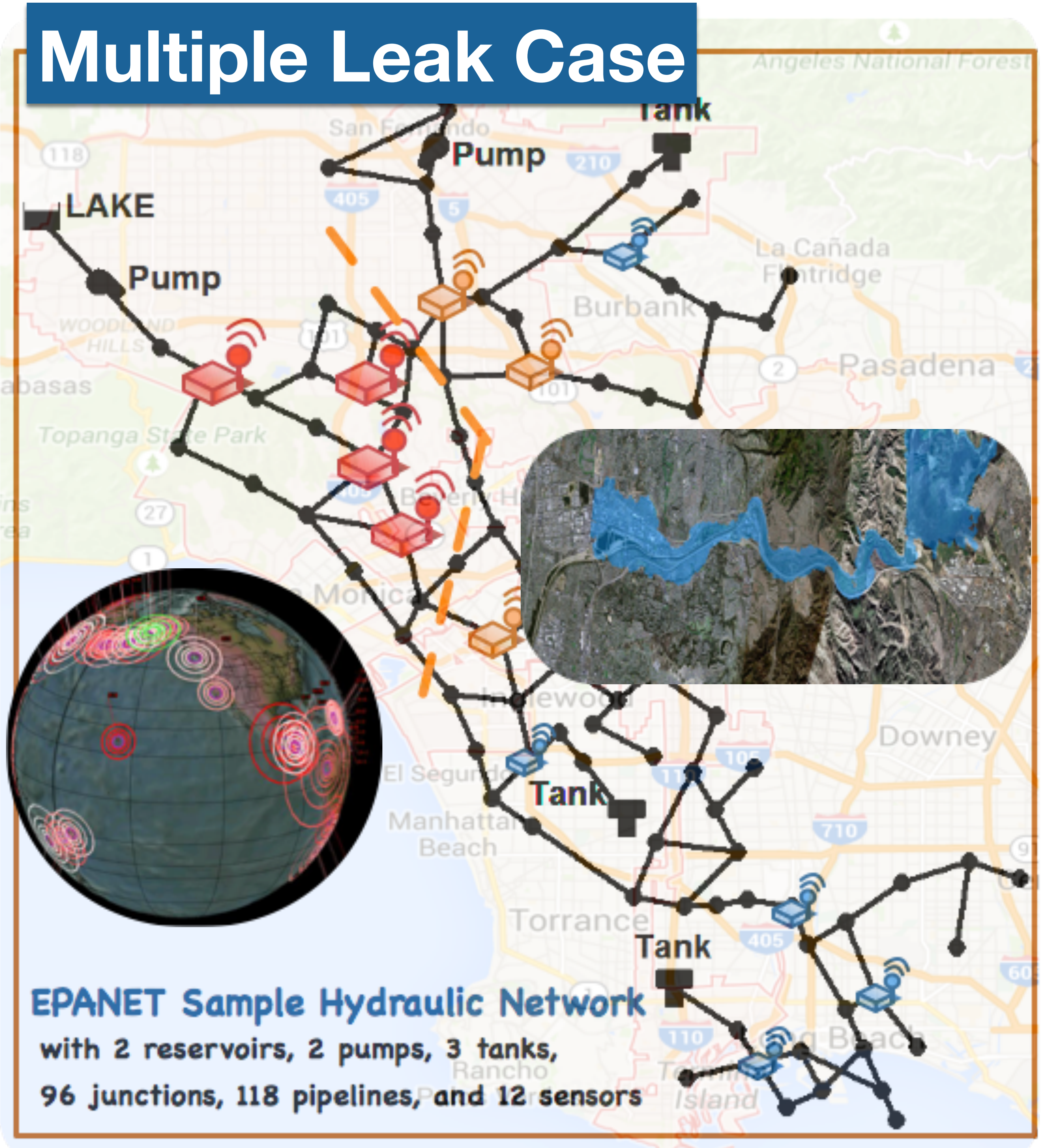




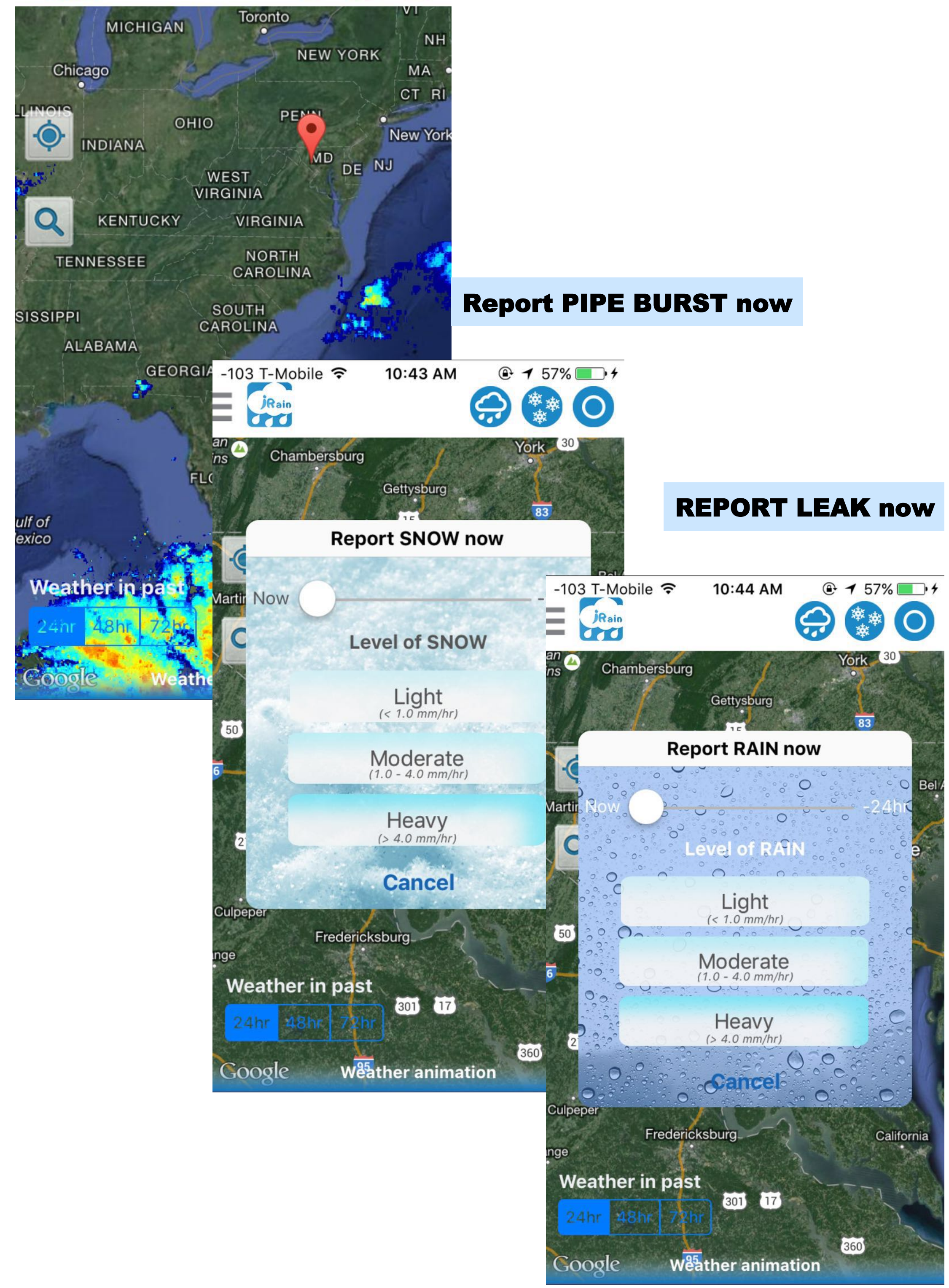
- By extending extending hydraulic simulator **EPANET** and flood model **BreZo**.
- By integrating decoupling **deep domain models** and **sensor** technologies using **pub/sub** mechanisms .

IoT Driven Leak Detection

Multiple Leak Case



Incorporation of human input



Interesting Research Challenges

Developing Generalized resilience techniques is complicated

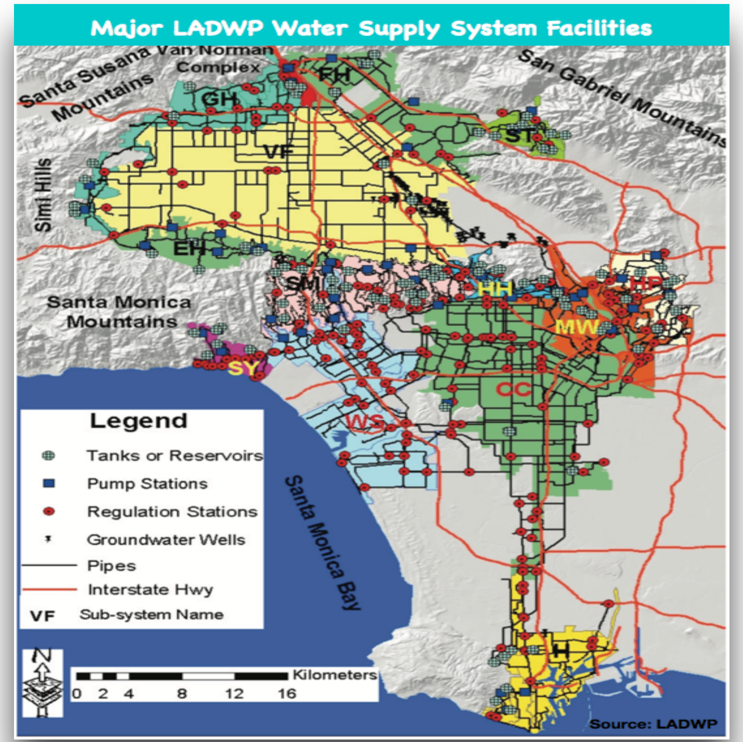
Heterogeneity of structure and scale of urban water infrastructures

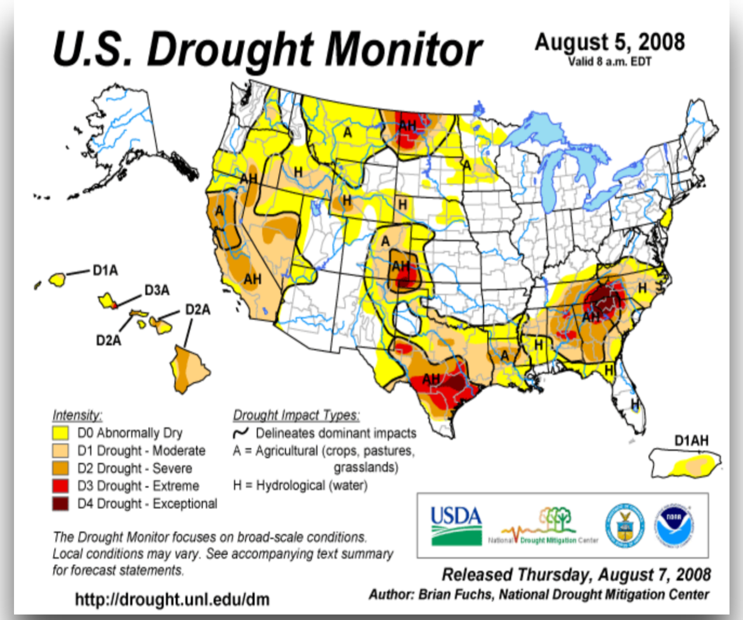
Scalable execution in near real-time for rapid response

Abstractions to Bridge Semantic Gap
- user service level view to operator hydraulic level view

Modeling and reasoning about Interdependencies with other infrastructures enery/water nexus, communication networks

Diversity of Concerns:
e.g. Period of drought increases water demand and adds strain to water supply .





Exploring Resilience of Community Water System

AquaSCALE

Thank You

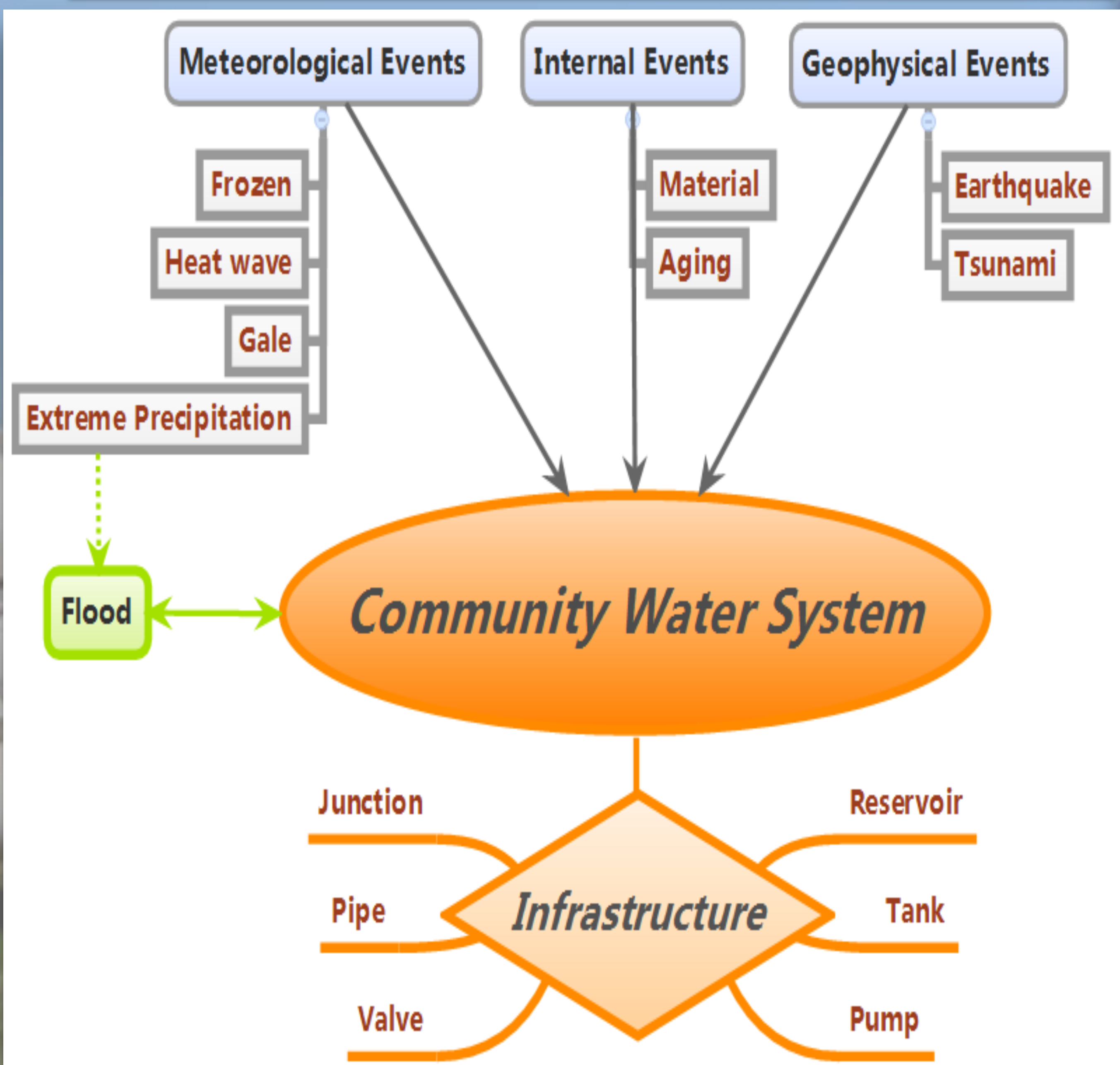
AquaSCALE Goals

Actuation

AquaSCALE Framework

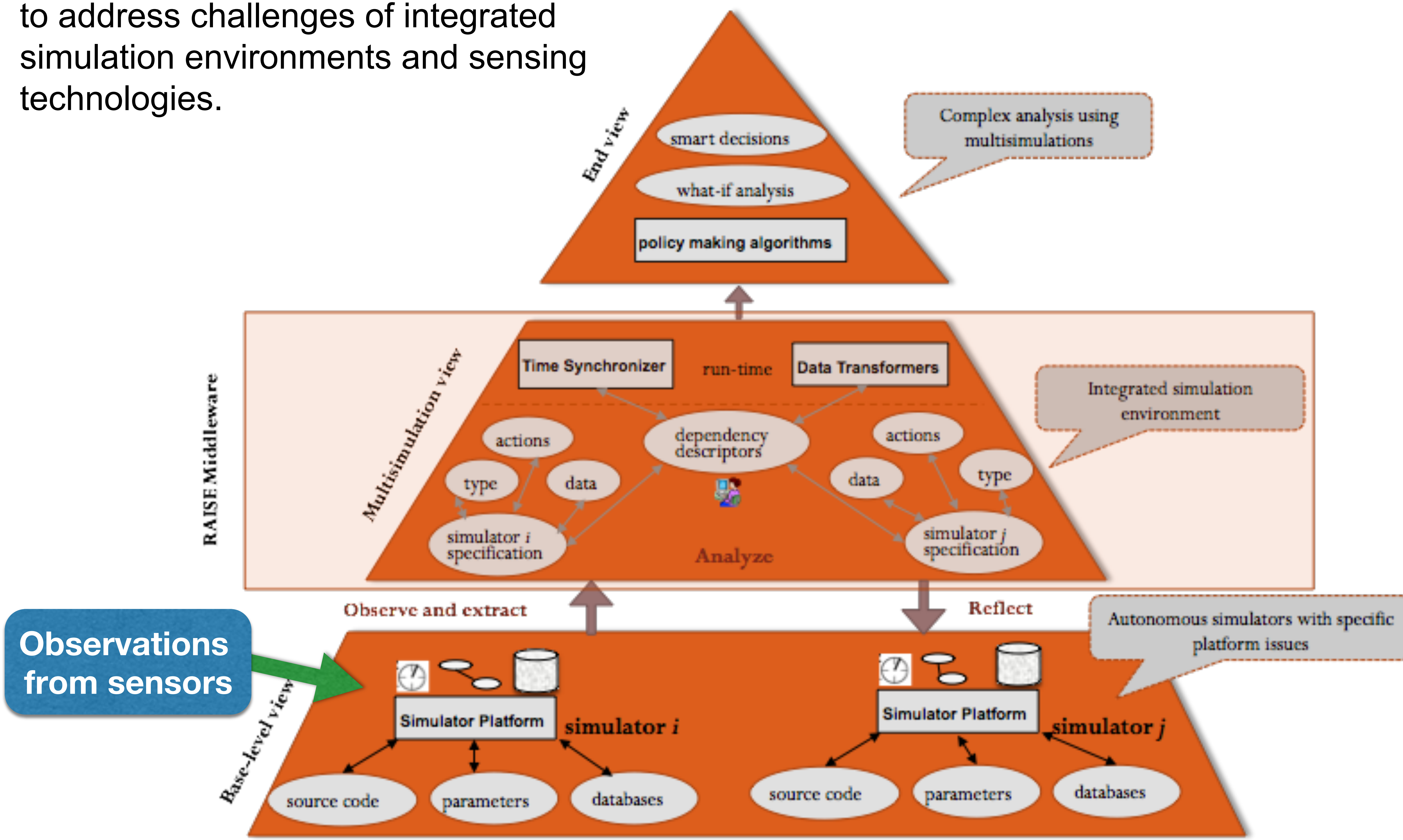
Hardware Sensing, Human Sensing

Storm; Flood; Earthquake; Aging



Reflective Middleware Architecture

Utilise reflective middleware solutions to address challenges of integrated simulation environments and sensing technologies.



Source: Leila Jalali