BattLeDIM 2020

Battle of the Leakage Detection and Isolation Methods

Problem Design and Results Evaluation

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BATTLEDIM Organizing Committee

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Organizing committee

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The Challenge

The L-Town water distribution network

- Created based on a real network of a city in **Cyprus**

- ~10000 people
- 42 km pipe length
- Map dimensions:
  2.6 km height, 3 km width
- 782 Junctions, 2 Reservoirs, 1 Tank
- 905 Pipes, 1 Pump, 3 PRVs
- Pipe segments of ~50 meters

Base demands

- Created based on the real network:
  - Each node is assigned a polygon
  - Find Building Area (BA) in polygon from real network (open data)
  - Type of consumer in each building:
    - Residential
    - Commercial
    - Industrial
  - Base demand of node i:

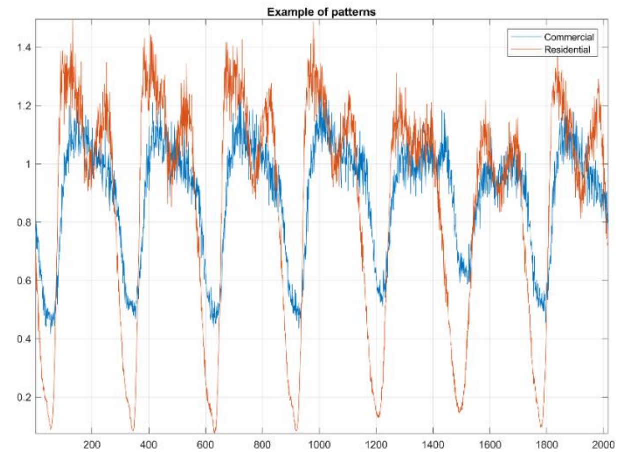
$$d_i^b = \sum_j \left(T_j * CBA_j\right) * BA_i$$

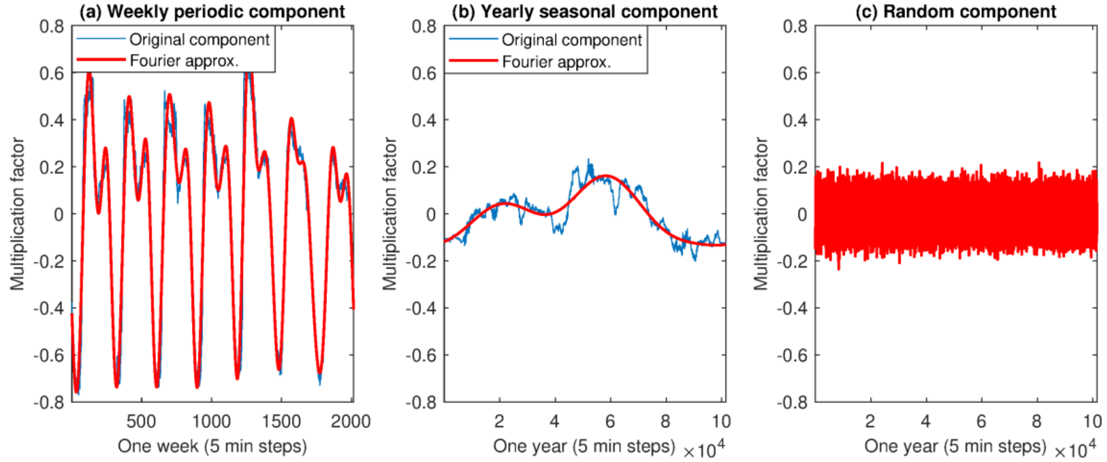
*T_j: Percentage of each consumer type in polygon

*CBA: Consumption per building area for consumer type j

Demand Patterns

- Two **nominal patterns:** Residential and Commercial
- Extracted from **real data**
- Each node is assigned a **unique demand pattern** randomly generated as described in [1]
- **Industrial patterns** based on real AMR data
- Duration: Two years, 5 minute steps
- Seasonal and weekly periodicity
- Peaking factor (MDD/ADD) matching the size of the system
- No special days

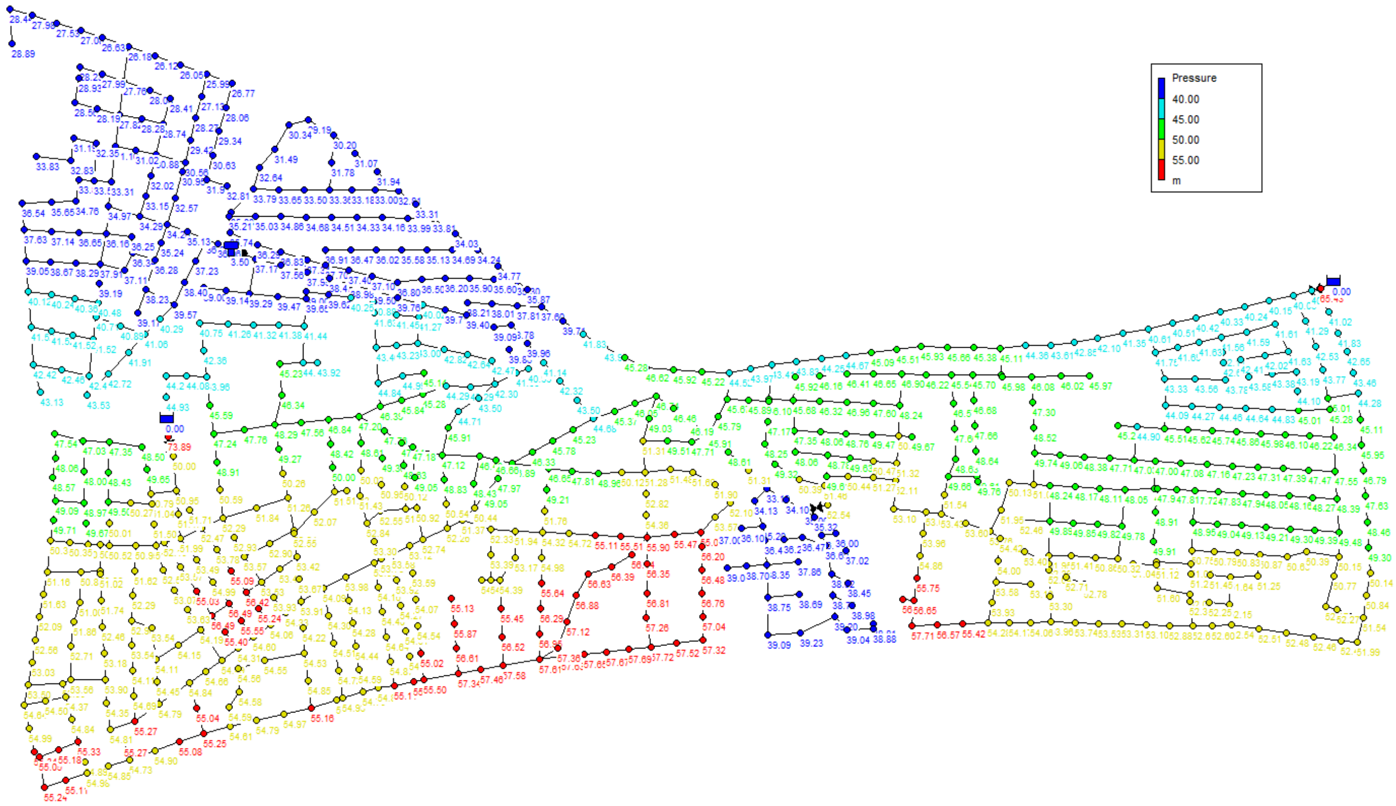




[1] Vrachimis, S. G., Kyriakou, M. S., Eliades, D. G. and Polycarpou, M. M. (2018). LeakDB : A benchmark dataset for leakage diagnosis in water distribution networks. In Proc. of WDSA / CCWI Joint Conference (Vol. 1).

Network behavior

- Different **pressure areas**
- **Normal pressure** during fault-free operation is between 2.5-6 bar.
- **Tank** is typically refilling during night and releasing water during the day.
- ***Pressure-driven* demands** solved using WNTR [2]

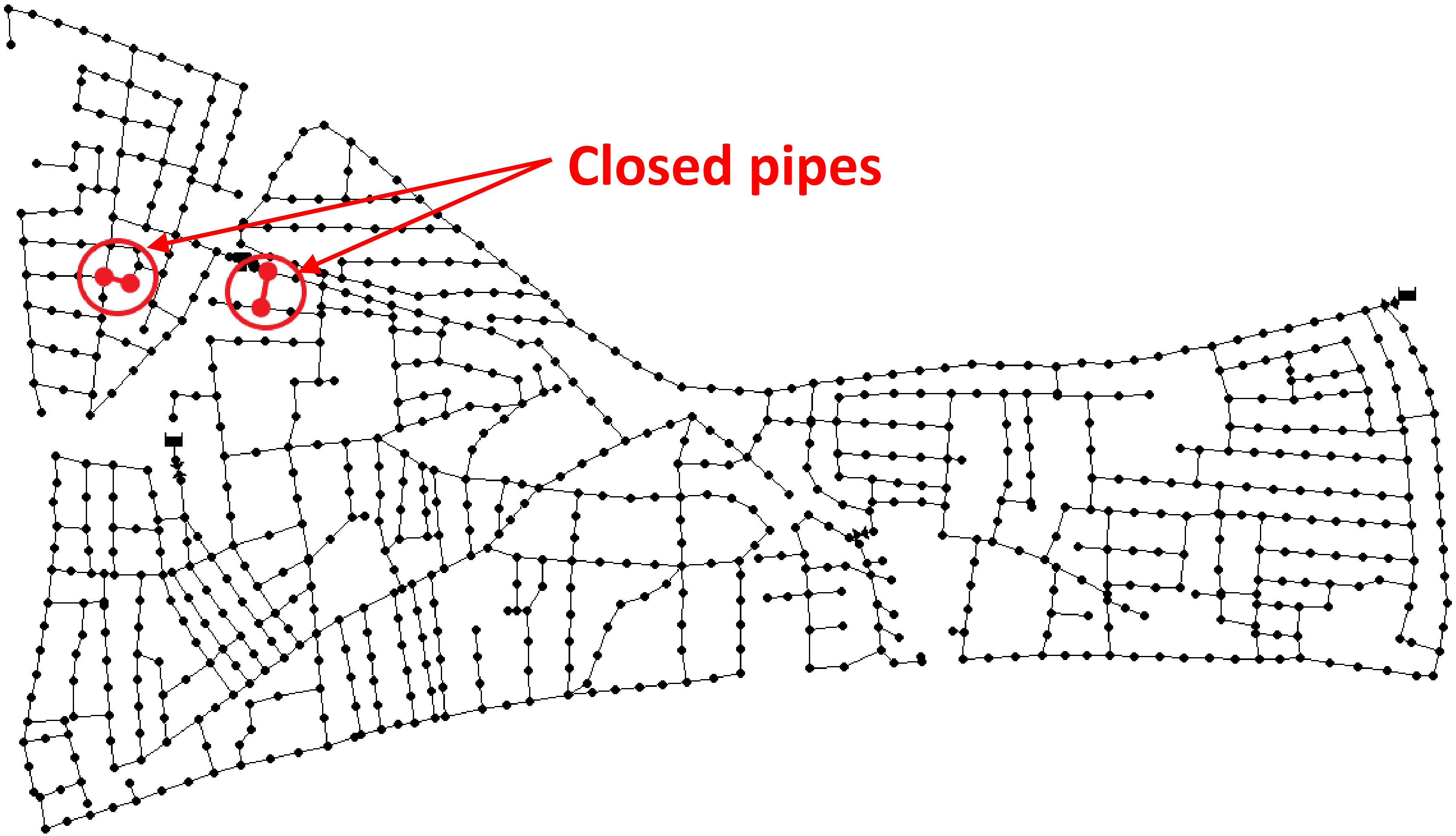


[2] Hart, D., Klise, K.A., Bynum, M.L., Laird, C.D. and Seth, A., (2019). Water Network Tool for Resilience (WNTR) v. 2.0 (No. WNTR). Sandia National Lab (SNL-NM), Albuquerque, NM (United States).

Nominal model and Real network

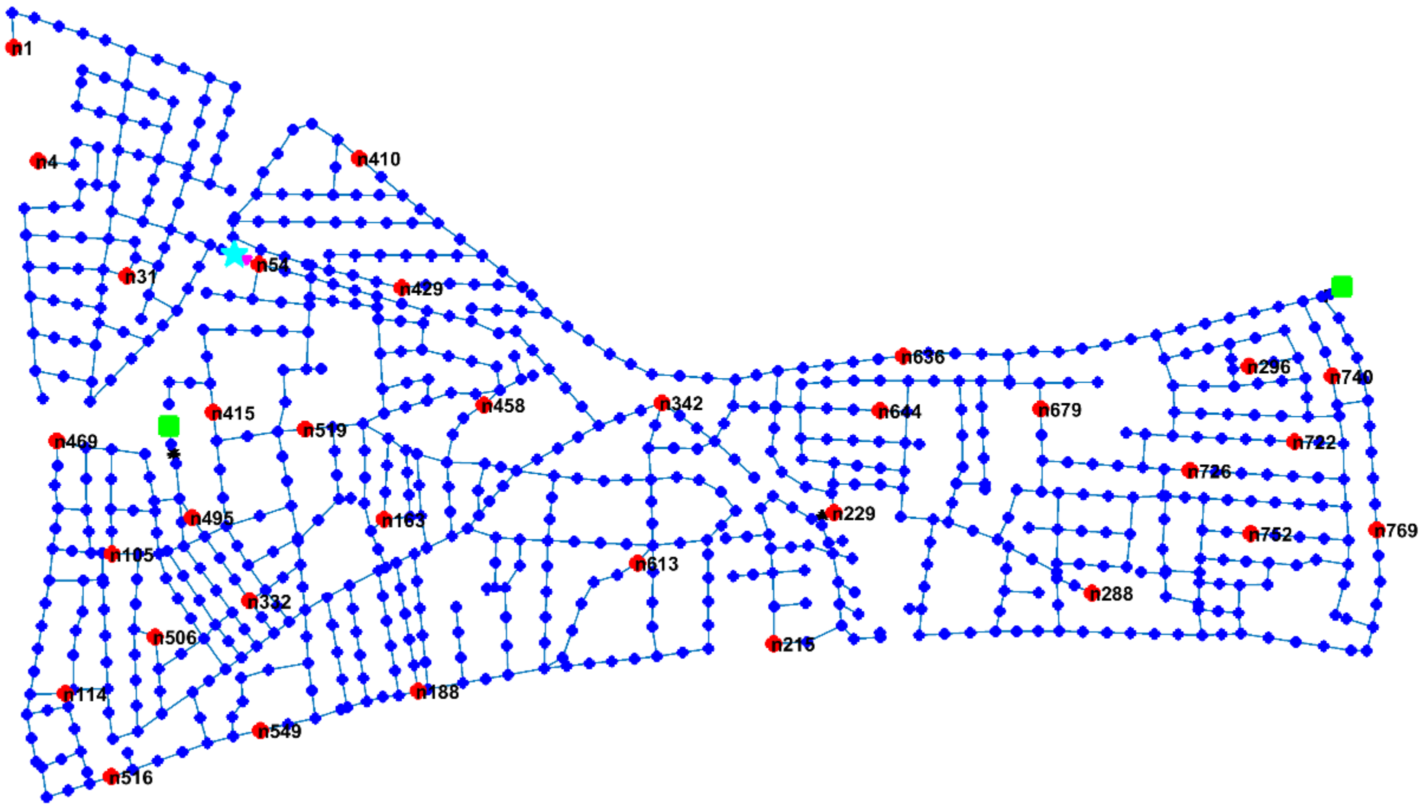
- **“Real” network** is used for generating the data
- **Nominal model** contains the “available” network information (provided as an EPANET input file (.inp))
- Differences of nominal model compared to real network:
  - **Base demands:** randomized uniformly between $\pm 10\%$ of real value
  - **Demand patterns:** Nominal residential and commercial patterns available. Industrial patterns not available.
  - **Pipe parameters:** randomized uniformly $\pm 10\%$ of real value (Elevation and pump curve uncertainty were omitted to reduce problem complexity)
  - **Topology:** “p37” and “p251” closed in real network

Nominal model and Real model



Sensors

- One (1) tank water level sensor
- Three (3) flow sensors (Pump and DMA entrances)
- Thirty-three (33) pressure sensors
  - Placed using a sensitivity matrix method
- Automatic Meter Reading devices (AMRs) in “Area C” (red)
- Industrial consumers (green)



The datasets

- Sensors give accurate readings with no time-delay (reduce problem complexity)
- Readings rounded to **2 decimal points**

➢ Historical dataset:
  - One year **(2018)** of sensor data
  - The **time and repair location** of pipe bursts that have been fixed are provided

➢ Evaluation dataset:
  - One year **(2019)** of sensor data

	A	B	C	D	E	
1	Timestamp	n1	n4	n31	n54	n
2	1/1/2019 0:00	28,63	33,72	37	36,93	
3	1/1/2019 0:05	28,66	33,75	37,02	37,05	
4	1/1/2019 0:10	28,67	33,76	37,04	37,03	
5	1/1/2019 0:15	28,69	33,78	37,05	37,09	
6	1/1/2019 0:20	28,68	33,77	37,05	36,95	
7	1/1/2019 0:25	28,72	33,8	37,07	37,08	
8	1/1/2019 0:30	28,74	33,82	37,09	37,18	
9	1/1/2019 0:35	28,73	33,82	37,09	37,09	
10	1/1/2019 0:40	28,76	33,84	37,12	37,15	
11	1/1/2019 0:45	28,76	33,85	37,13	37,14	
12	1/1/2019 0:50	28,8	33,88	37,15	37,22	
13	1/1/2019 0:55	28,82	33,9	37,17	37,27	
14	1/1/2019 1:00	28,83	33,91	37,18	37,22	
15	1/1/2019 1:05	28,85	33,93	37,2	37,27	
16	1/1/2019 1:10	28,86	33,94	37,21	37,26	
17	1/1/2019 1:15	28,89	33,96	37,23	37,32	
18	1/1/2019 1:20	28,89	33,97	37,24	37,32	
19	1/1/2019 1:25	28,91	33,98	37,25	37,39	
20	1/1/2019 1:30	28,93	34	37,27	37,38	
21	1/1/2019 1:35	28,93	34,01	37,28	37,36	
22	1/1/2019 1:40	28,95	34,02	37,29	37,41	
23	1/1/2019 1:45	28,97	34,04	37,3	37,41	

The Leakages

Leakages are assumed **the only faults** that exist in L-Town.

(Pipe bursts as well as background leakages)

Leakage modeling

- Leakages are modeled **on pipes** as described by Crowl and Louvar [3]:

$$d_{leak}(t) = C_d A(t) p^a(t) \sqrt{2/\rho}$$

- In *BattLeDIM*:
  - Leak demand $d_{leak}(t)$ $(\frac{m^3}{h})$
  - Leak hole area $A(t)$ (m^2)
  - Pressure $p(t)$ (m)
  - Discharge coefficient $C_d = 0.75$ (assuming turbulent flow)
  - Discharge exponent $\alpha = 0.5$ for steel pipes and $\alpha = 2.5$ for plastic pipes

[3] Crowl, D.A., and Louvar, J.F. (2002). Chemical Process Safety: Fundamentals with Applications, 3rd edition. Upper Saddle River, NJ: Prentice Hall, 720p.

Leakage types

Three types of leaks categorized depending on their magnitude:

1. **Background leaks**: Small leaks with size of 1-5% of the average inflow.
2. **Medium pipe bursts**: Pipe breaks with size of 5-10% of the average inflow.
3. **Large pipe bursts**: Pipe breaks with size above 10% of the average inflow.

❖ Average system inflow $\sim 180 m^3/h$

Large and some medium leakages (above $15\ m^3/h$) are **fixed by the water utility** after a reasonable amount of time selected in random (max 2 months)

Leakage time profile

1. **Abrupt leakages** (pipe bursts):

$$A(t) = \begin{cases} 0 & t < t_{start}, t > t_{end} \\ A_{max} & t_{start} \leq t \leq t_{end} \end{cases}$$

2. **Incipient leakages** (background leakages which can evolve into bursts):

$$A(t) = \begin{cases} 0 & t < t_{start}, t > t_{end} \\ A_{max}\left(\dfrac{t - t_{start}}{t_{peak} - t_{start}}\right) & t_{start} \leq t < t_{peak} \\ A_{max} & t_{peak} \leq t \leq t_{end} \end{cases}$$

Leakage placement

- An algorithm places the leakages **randomly, with constraints**:
  - Maximum number of leakages in a year (20)
  - Minimum time (2 weeks) between leakages with overlapping detection radius to ensure separability
  - Detection radius (300 meters)

- Leakage characteristics are **selected randomly, with constraints**:
  - Predetermined number of background, medium and large leakages
  - Predetermined number of abrupt and incipient leakages
  - Incipient peak time selected based on the leakage type and magnitude

Leakage Locations - Historical Dataset 2018

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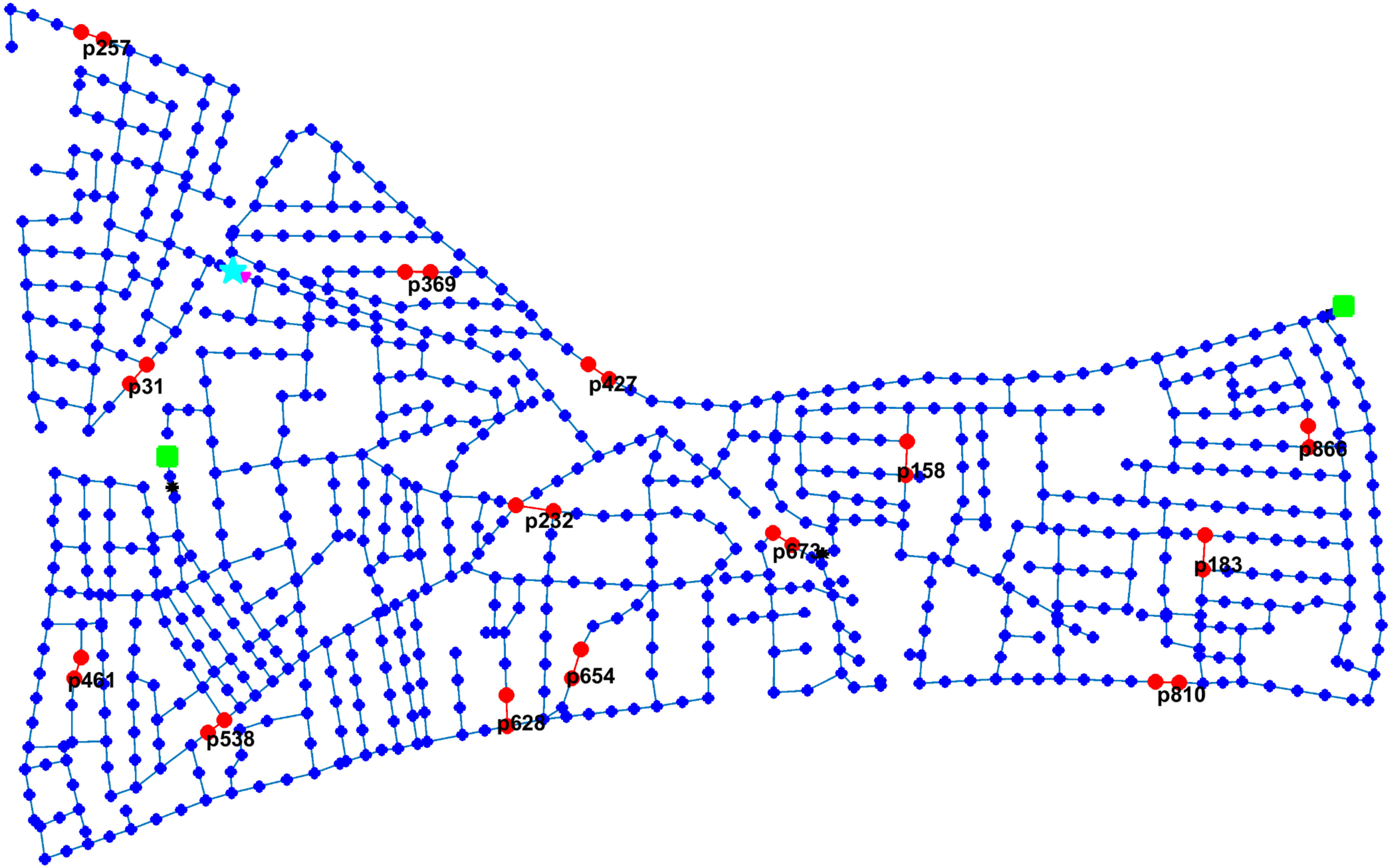

- 14 Leakages total
- 10 are fixed (given)
- 4 background leakages are not fixed and continue into 2019 on pipes p257, p427, p810, p654

Leakage Evolution - Historical Dataset 2018

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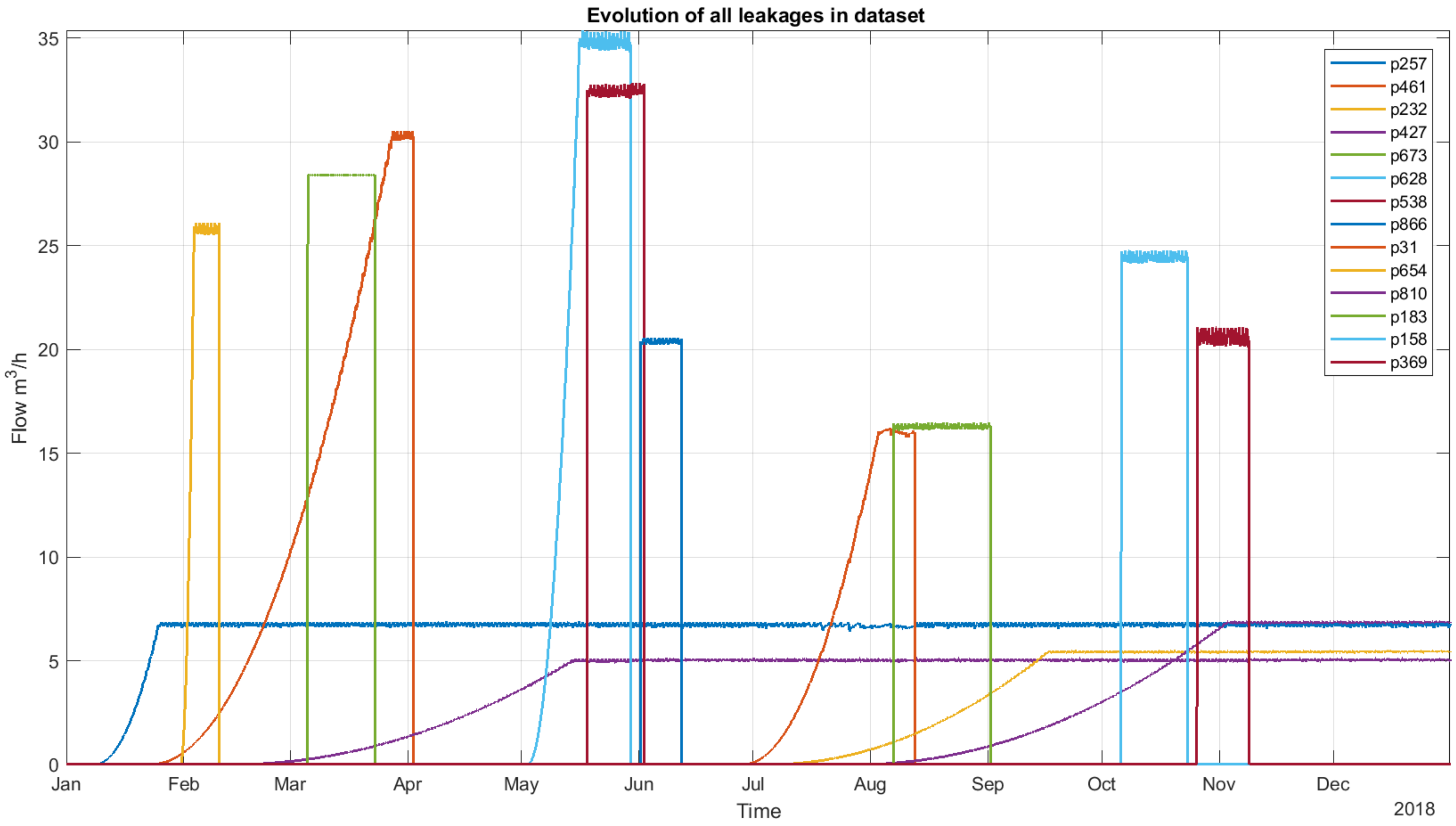
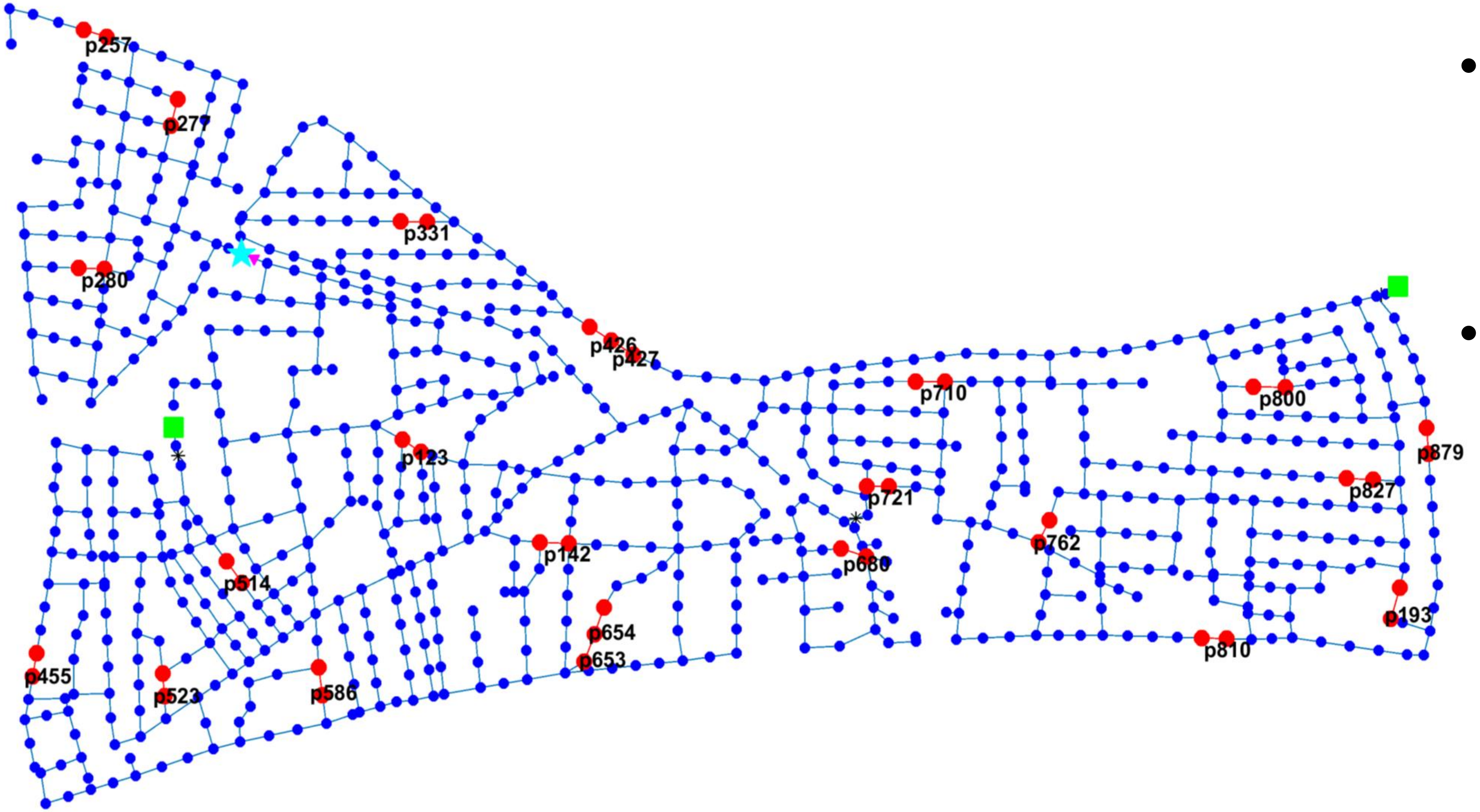


- Abrupt and incipient leakages
- Mainly large leakages (above $15\ m^3/h$
- Background leakages smaller than $8\ m^3/h$

Leakage Locations - Evaluation Dataset 2019



- 23 Leakages total:
  - 4 begin in 2018
  - 19 begin in 2019
- All the leakages present in the 2019 dataset are evaluated

Leakage Evolution - Evaluation Dataset 2019

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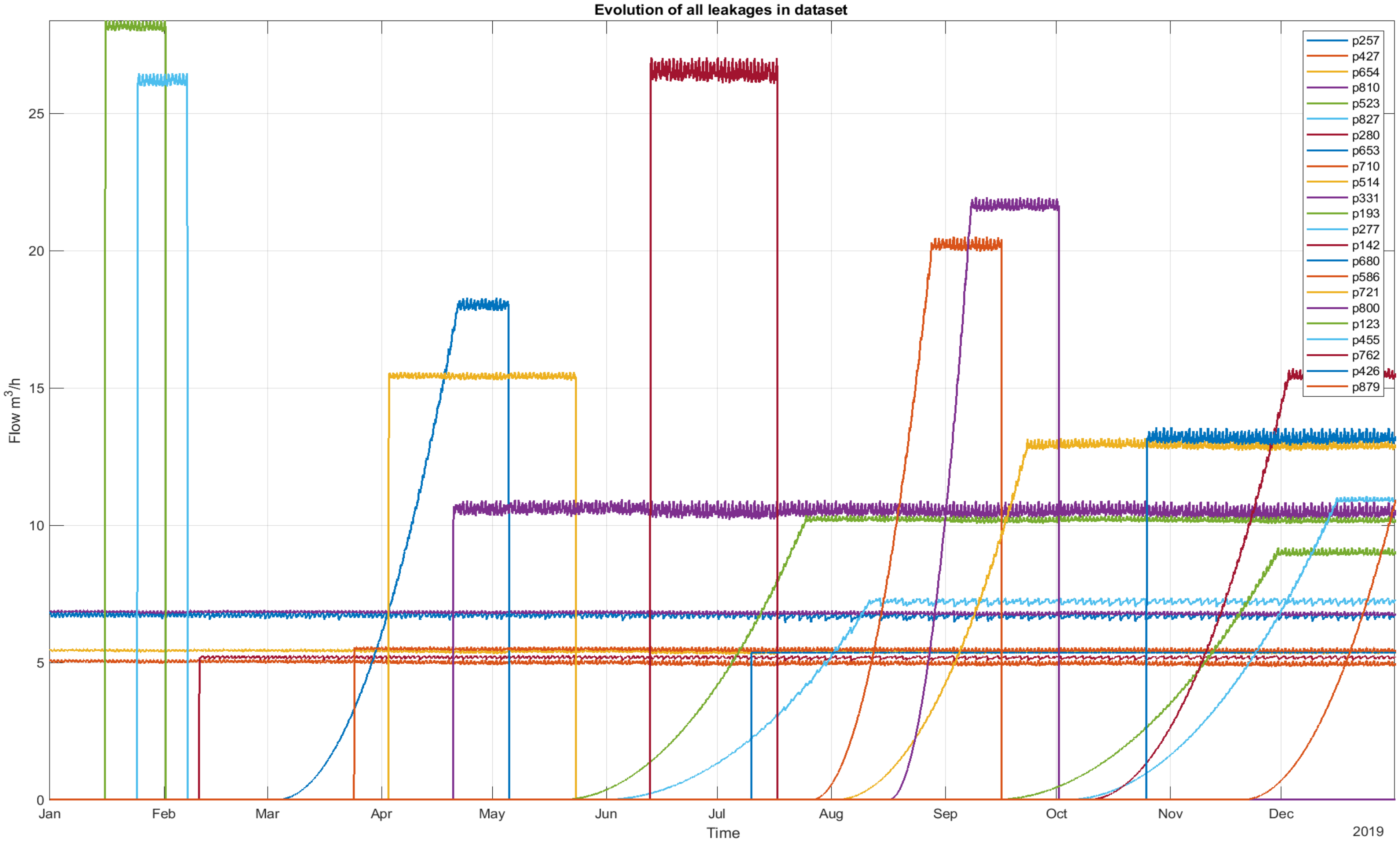


Leakage Size:

- **Background leaks**
  Count: 3+4
  Max diameter: 1.2 cm
- **Medium pipe bursts**
  Count: 10
  Max diameter: 1.8 cm
- **Large pipe bursts**
  Count: 6
  Max diameter: 2.4 cm

Time profile:

- 10 incipient leaks
- 9 abrupt leaks
- 4 continuing from 2018

Evaluation methodology

Evaluation approach

Evaluation of participant results follows a **pure economic approach**:

1. The water utility of L-Town calculates the **profit from water saved** from successful detections.
2. The utility also considers the **cost of the repair crew** every time it is sent to search for a leakage.

❖ **Note:** The selected methodology has been chosen by the organizing committee as the most suitable for this competition. Alternative evaluation methodologies have also been considered and will be described in a future journal paper.

Evaluation procedure (1/4)

Set of rules are applied to each result to **calculate the score**:

1. True detection (**True Positive**) condition:
   - A detection pointing at a **time during the lifetime of a leakage** and within a **predefined pipe length distance** from the leak location
2. False detection (**False Positive**) condition:
   - Detections which do not satisfy the *True detection condition* (1.) above.
3. Missed detection (**False Negative**) condition:
   - Leakages in 2019 dataset which have not been detected

Evaluation procedure (2/4)

4. Detections are evaluated in **chronological order**, i.e., from the earliest detection to the latest detection given.
5. Detections **outside 2019** are **ignored** (not penalized).
6. **Repeated detections** of the same leakage are **ignored.**
7. A single detection may **detect only one leakage**, even if more than one leakage is in the detection area. In the case of multiple detections, only **the leakage closest to the detected link** is considered to be detected successfully.

Evaluation procedure (3/4)

8. The **profit from water saved** p_w^i (euro) by a detection i, for a detected leakage j, given leakage flow rate $q^j(t)$, and cost of water per cubic meter c_w (euro), is calculated as follows:

$$p_w^i = \left(\sum_{k=t_d^i}^{t_{end}^j} q^j(k) * \Delta t \right) * c_w,$$

9. The **utility repair crew cost** c_r^i for a given detection i, detection distance from leakage x_{ij}, maximum detection distance x_{max}, and maximum repair crew cost c_r is calculated as follows:

$$c_r^i = \begin{cases} -\left(\frac{x_{ij}}{x_{max}}\right) c_r & x_{ij} < x_{max} \\ -c_r & x_{ij} \geq x_{max} \end{cases},$$

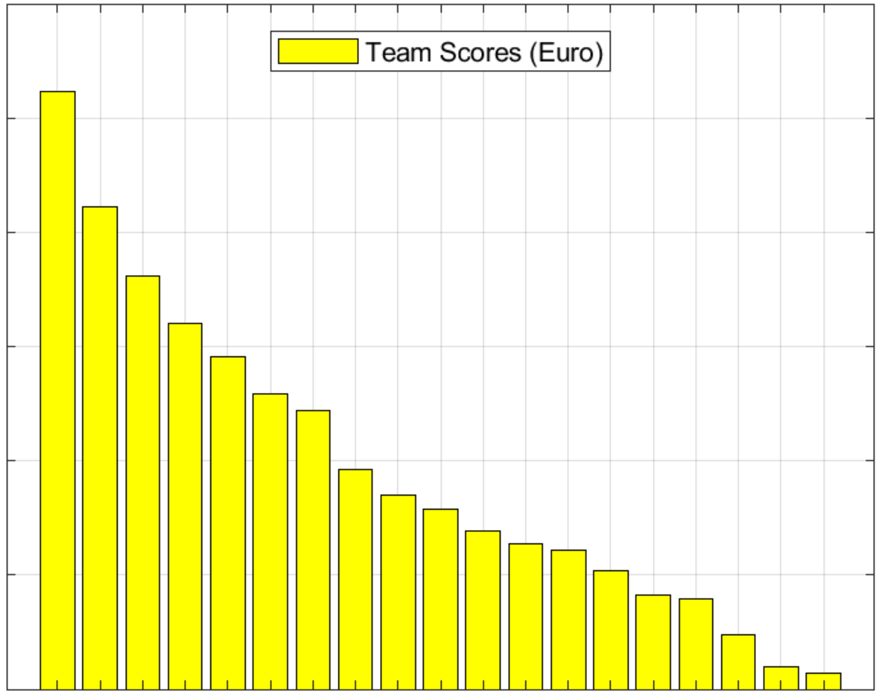
Evaluation procedure (4/4)

10. The **score per detection** for a given detection i is given by adding the profit and cost:

$$s^i = p_w^i + c_r^i$$

11. The **total score** S for a given set of detections is given by:

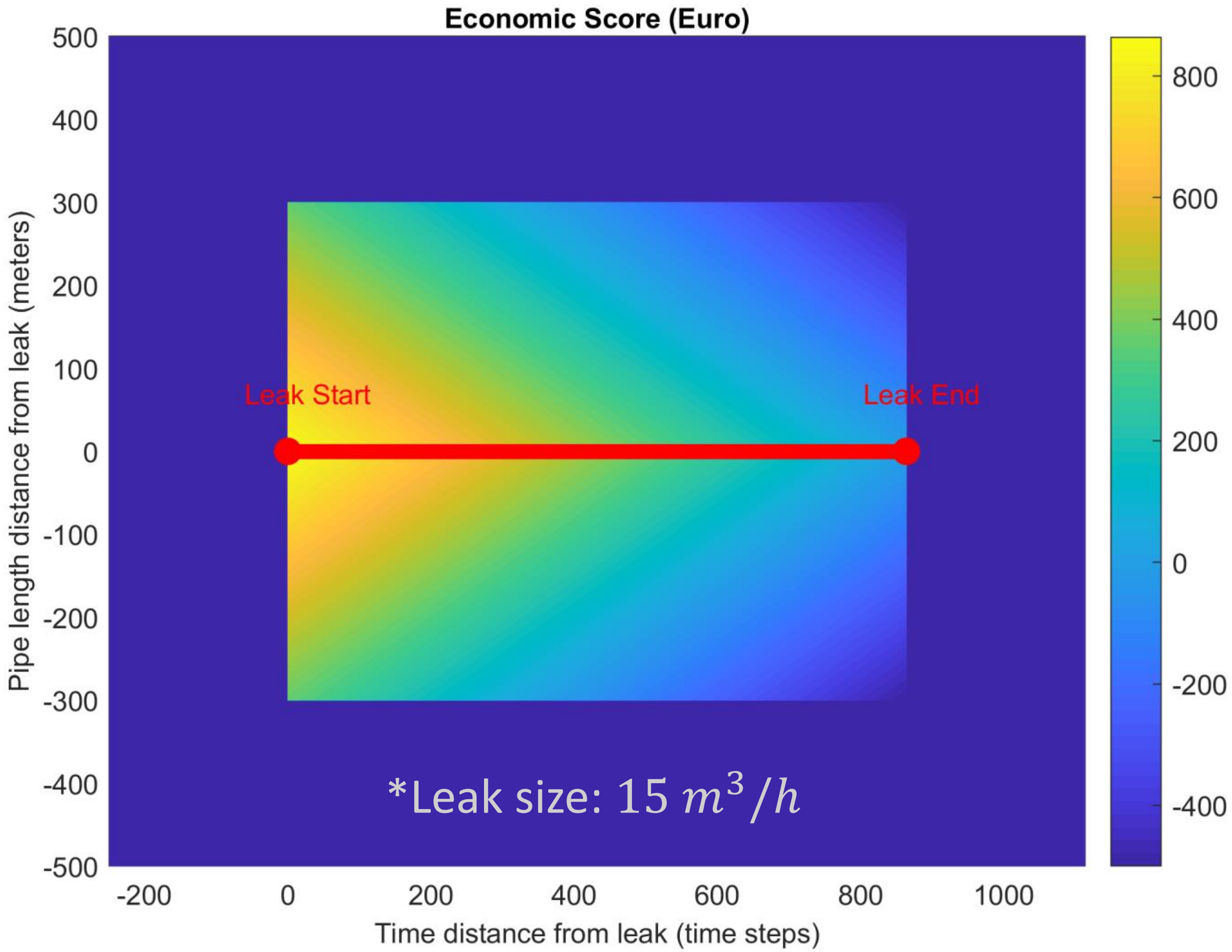
$$S = \sum_i s^i$$



Scoring function

BattLeDIM evaluation parameters:

Max detection distance (x_{max}):	300 (meters)
Cost of water per m^3 (c_w):	0.80 (Euro)
Maximum repair crew cost (c_r):	500 (Euro)



Evaluation code

Openly available on GitHub:
https://github.com/KIOS-Research/BattLeDIM

*Instructions are provided on how to score your results file

Run online using CodeOcean:
https://codeocean.com/capsule/8332511

- Pending approval

More code, available shortly:

1. Generation of BattLeDIM network code
2. Sensor placement code
3. Leakage placement code