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ADAPT

*Livorno, 28 giugno 2018*

# **SMART-DEPUR** fognature "smart" per l'ottimizzazione dei sistemi di drenaggio e depurazione dei reflui urbani

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La Cooperazione al cuore del Mediterraneo
La Coopération au coeur de la Méditerranée

# Introduction
# I&I (Infiltration/Inflow)

❑ **Inflow** is stormwater (surface runoff) that enters sanitary sewers at points of direct connection to the systems

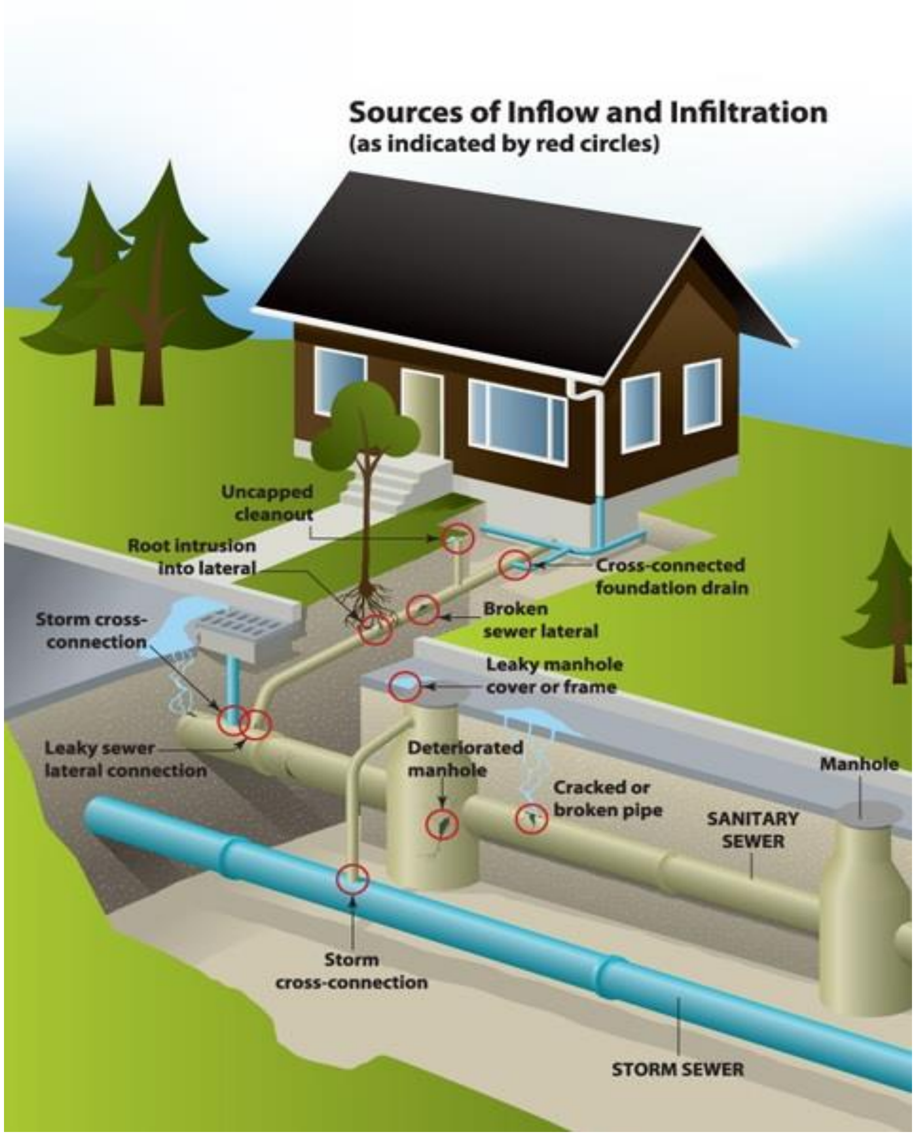
❑ **Inflow sources**: footing/foundation drains, roof drains or leaders, downspouts, drains from window wells, outdoor basement stairwells, drains from driveways, groundwater/basement sump pumps, and illegal/wrong connections to the sanitary sewer system

❑ **Infiltration** is groundwater that enters sewers through pipe cracks and/or leaks

⇩

➢ **Inflow and infiltration** reduce the ability of sanitary sewers and treatment facilities to transport and treat domestic and industrial wastewater

➢ **Higher costs**. e.g., higher amount of reagents, more electrical energy required, environmental impacts, and workforce used to face the emergencies



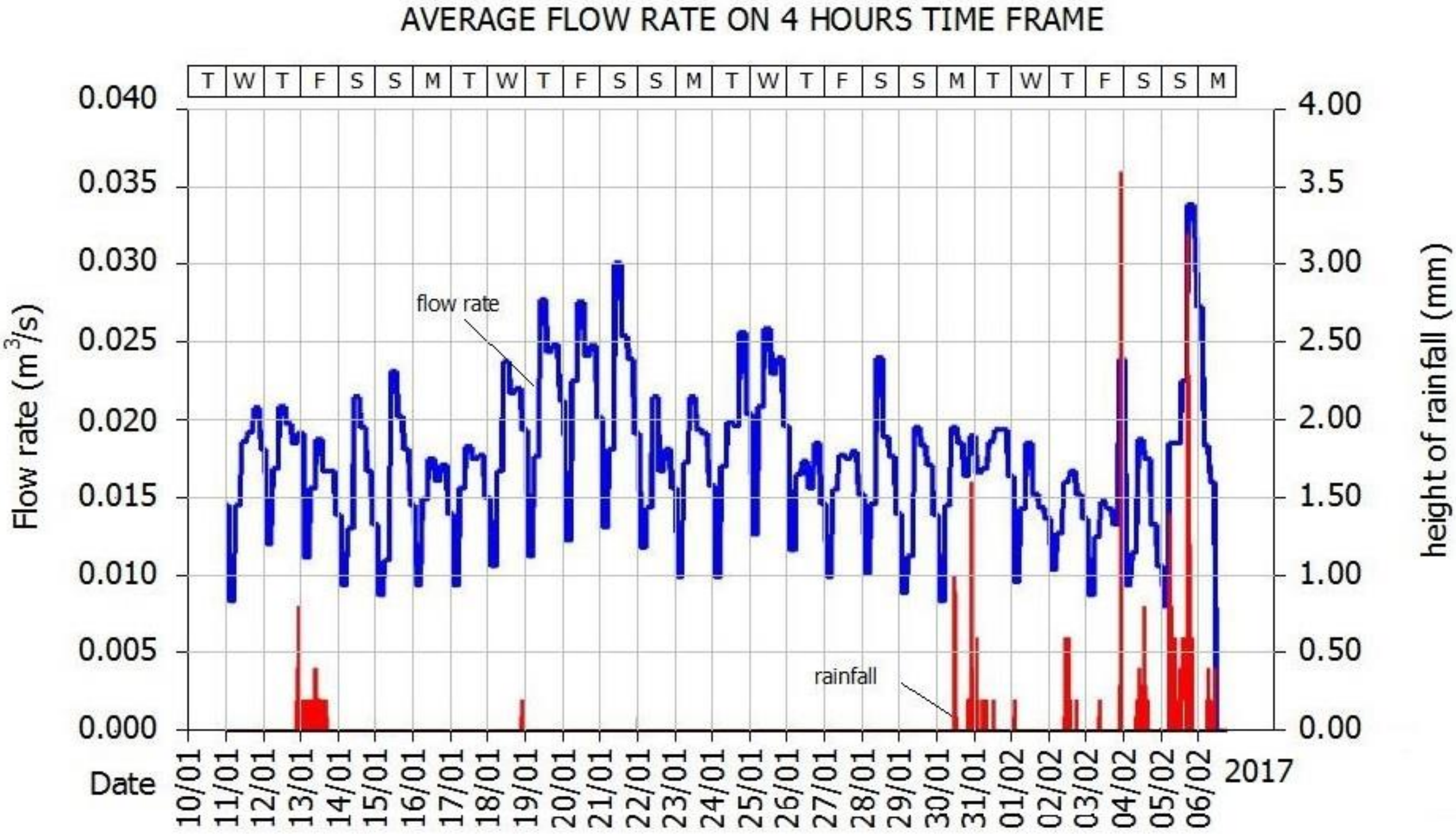
# Case study

# Livorno sewer system

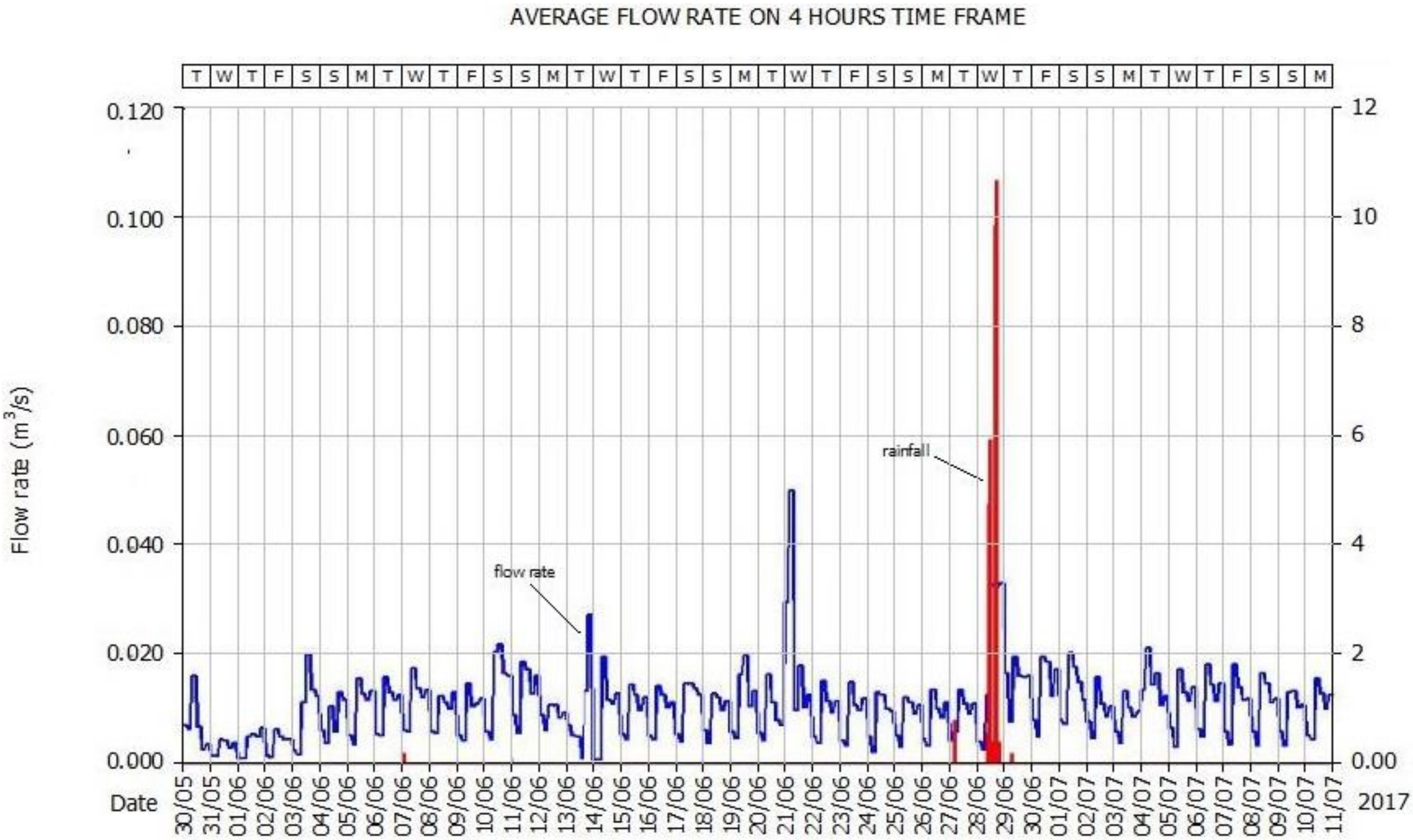
Basin closure section

- ☐ We studied a portion of the sanitary sewer system, located in the city center of Livorno
- ☐ The basin has an area of about **0.6 km$^2$**. It is mainly a residential area, with few commercial activities
- ☐ The basin closure section is located at the intersection of Via Carlo Bini and Via delle Navi.

# Example – 1

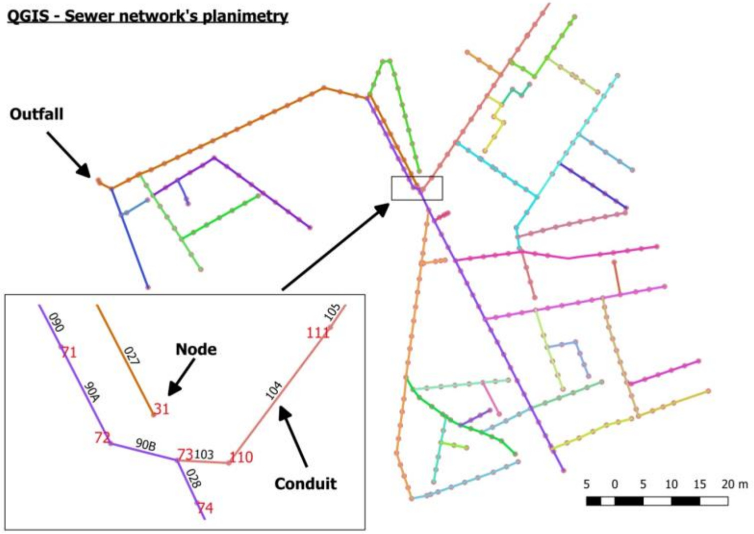

AVERAGE FLOW RATE ON 4 HOURS TIME FRAME
T W T F S S M T W T F S S M T W T F S S M T W T F S S M
Flow rate ($m^3/s$)
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
height of rainfall (mm)
4.00
3.5
3.00
2.50
2.00
1.50
1.00
0.50
0.00
flow rate
rainfall
Date
10/01 11/01 12/01 13/01 14/01 15/01 16/01 17/01 18/01 19/01 20/01 21/01 22/01 23/01 24/01 25/01 26/01 27/01 28/01 29/01 30/01 31/01 01/02 02/02 03/02 04/02 05/02 06/02
2017

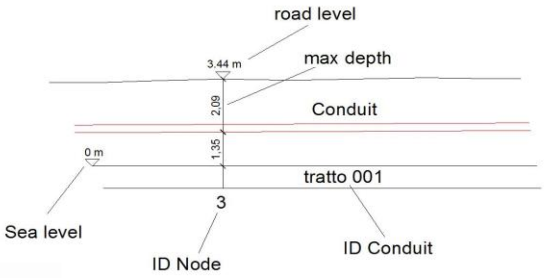
# Example – 2


AVERAGE FLOW RATE ON 4 HOURS TIME FRAME
T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S M T W T F S S M
Flow rate (m³/s)
0.120
0.100
0.080
0.060
0.040
0.020
0.000
12
10
8
6
4
2
0.00
flow rate
rainfall
Date
30/05 31/05 01/06 02/06 03/06 04/06 05/06 06/06 07/06 08/06 09/06 10/06 11/06 12/06 13/06 14/06 15/06 16/06 17/06 18/06 19/06 20/06 21/06 22/06 23/06 24/06 25/06 26/06 27/06 28/06 29/06 30/06 01/07 02/07 03/07 04/07 05/07 06/07 07/07 08/07 09/07 10/07 11/07
2017

# Our approach to the I&I identification

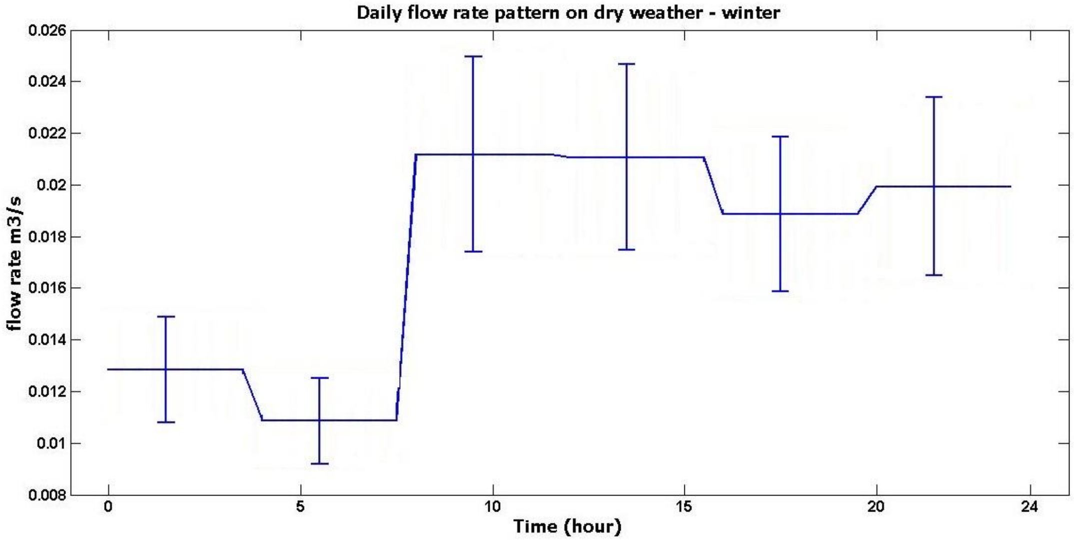
- We developed a **SWMM model** of the analyzed network in order to simulate the real behavior of the basin in the presence of rainfall.
- The adopted modelling approach required:
  - Definition of the network geometry;
  - Collection of flow data measured at the closing section by a combined level-speed flow meter;
  - Collection of rainfall data;
  - Analysis and processing of collected data;
  - Checking the hydraulic network in dry weather;
  - Modeling by EPA SWMM software of the network behavior in case of rain;
  - Determination of critical rain and associated return time;
  - Assessments and considerations, based on the results obtained, about the extent of the parasitic waters (in terms of quantity and location).


QGIS - Sewer network's planimetry

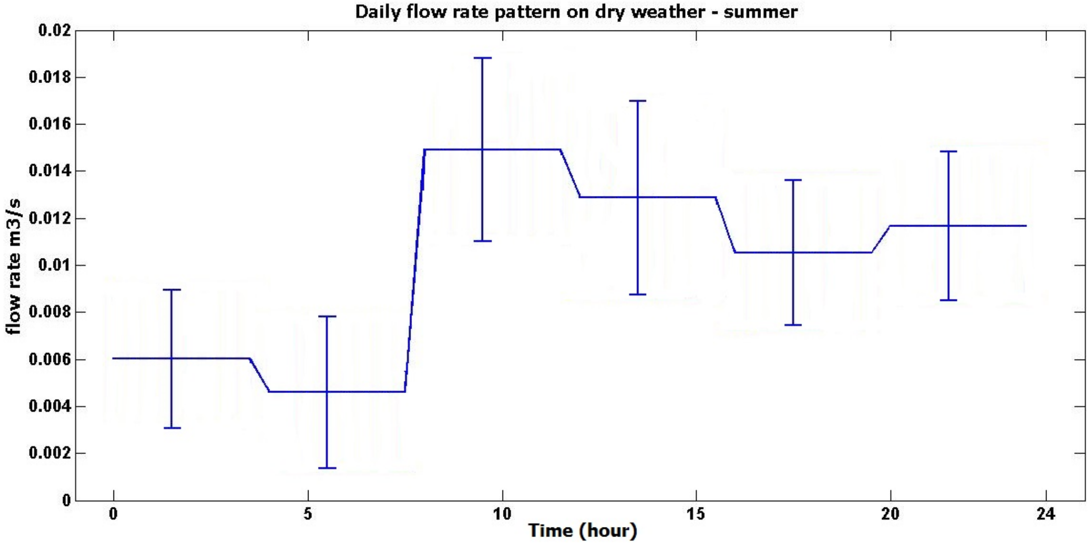


# Daily mean dry-weather flow rate patterns

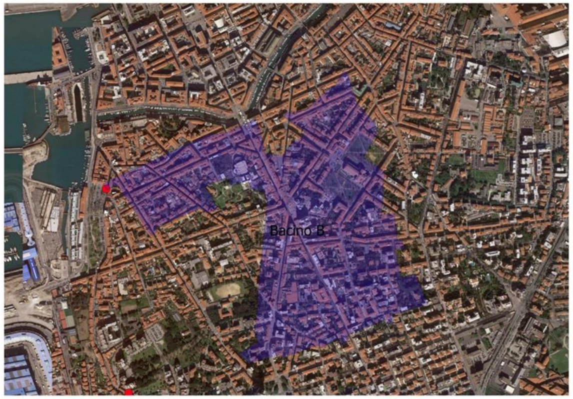
- ➢ WINTER



- ➢ SUMMER



# Case study



**Data from ASA database of water main users:**

☐ Resident population: 10,500 units

☐ Total water consumption: 485,639 $m^3/y$

☐ Average water supply per capita: **127 L/(unit·d)**

**Data from flow measurements carried out at the closing section:**

- Mean dry weather flowrate = 0.013 $m^3/s$
- Maximum dry weather flowrate = 0.037 $m^3/s$

⇨ Peak coeff. = 2.85

- Annual volume discharged (total) = 409,968 $m^3/y$
- Annual volume per capita = 39.04 $m^3/(unit·y)$
- Daily volume per capita = **107 L/(unit·d)**

⇨ Inflow coeff. = 0.83

# Uniform flow NETWORK verification (Dry weather)

The dry-weather capacity of each individual pipe of the network was verified by comparing its estimated peak flow ($Q_n$) with its maximum hydraulic capacity ($Q_{max}$)

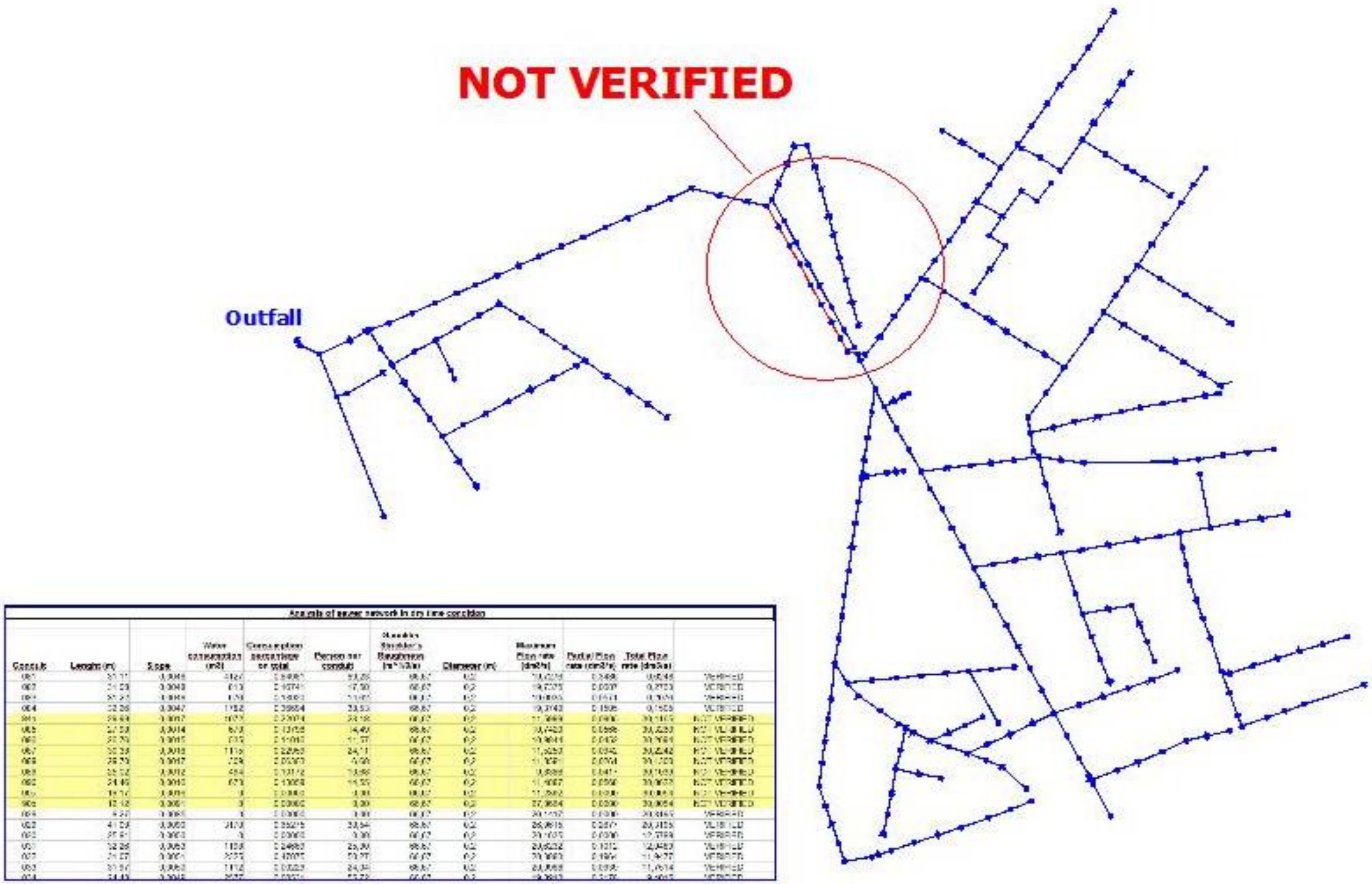
Estimated peak flow ($\mathbf{Q_n}$): $$Q_n = \alpha \psi \frac{N q}{86400}$$

where:
$Q_n$ = conduit peak flow (L/s)
N = population units served by the conduit
q = water supply per capita ($L \cdot unit^{-1} \cdot d^{-1}$)
α = peak flow coefficient
Ψ = Inflow coefficient

The maximum hydraulic capacity ($\mathbf{Q_{max}}$) of each conduit was estimated in uniform flow conditions using the Gauckler-Strickler equation at a maximum filling ratio of 83%

# Uniform flow NETWORK validation: Results

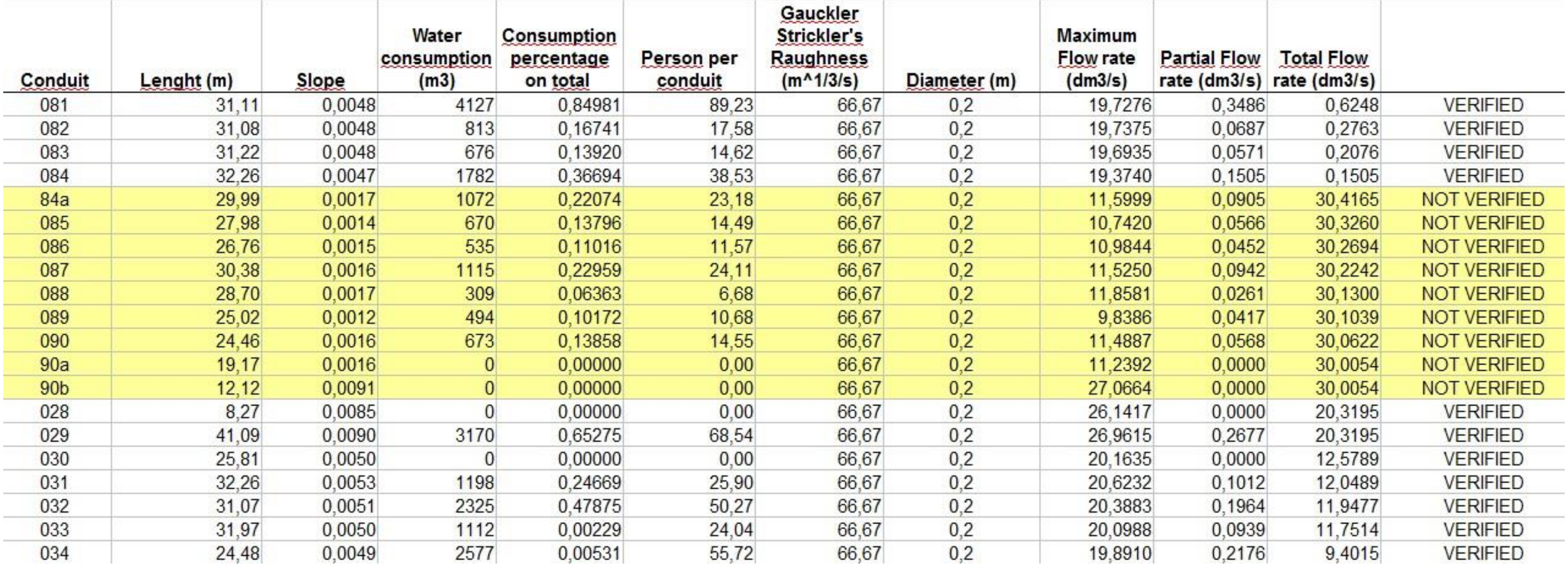
## Analysis of sewer network in dry time condition



Analysis of sewer network in dry time condition

# Uniform flow NETWORK validation: Results

**Analysis of sewer network in dry time condition**

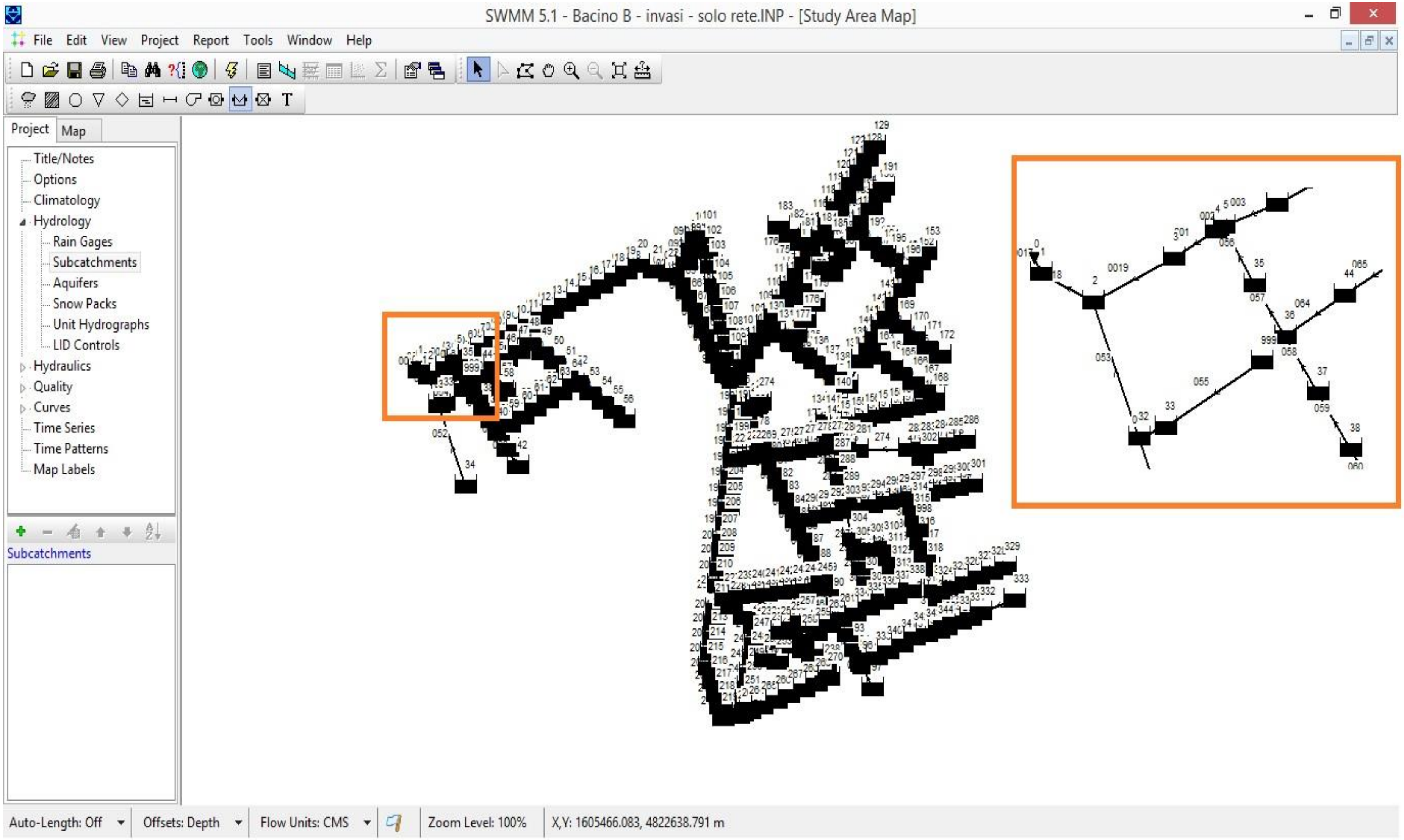


Analysis of sewer network in dry time condition

| Conduit | Lenght (m) | Slope | Water consumption (m3) | Consumption percentage on total | Person per conduit | Gauckler Strickler's Raughness (m^1/3/s) | Diameter (m) | Maximum Flow rate (dm3/s) | Partial Flow rate (dm3/s) | Total Flow rate (dm3/s) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 081 | 31,11 | 0,0048 | 4127 | 0,84981 | 89,23 | 66,67 | 0,2 | 19,7276 | 0,3486 | 0,6248 | VERIFIED |
| 082 | 31,08 | 0,0048 | 813 | 0,16741 | 17,58 | 66,67 | 0,2 | 19,7375 | 0,0687 | 0,2763 | VERIFIED |
| 083 | 31,22 | 0,0048 | 676 | 0,13920 | 14,62 | 66,67 | 0,2 | 19,6935 | 0,0571 | 0,2076 | VERIFIED |
| 084 | 32,26 | 0,0047 | 1782 | 0,36694 | 38,53 | 66,67 | 0,2 | 19,3740 | 0,1505 | 0,1505 | VERIFIED |
| 84a | 29,99 | 0,0017 | 1072 | 0,22074 | 23,18 | 66,67 | 0,2 | 11,5999 | 0,0905 | 30,4165 | NOT VERIFIED |
| 085 | 27,98 | 0,0014 | 670 | 0,13796 | 14,49 | 66,67 | 0,2 | 10,7420 | 0,0566 | 30,3260 | NOT VERIFIED |
| 086 | 26,76 | 0,0015 | 535 | 0,11016 | 11,57 | 66,67 | 0,2 | 10,9844 | 0,0452 | 30,2694 | NOT VERIFIED |
| 087 | 30,38 | 0,0016 | 1115 | 0,22959 | 24,11 | 66,67 | 0,2 | 11,5250 | 0,0942 | 30,2242 | NOT VERIFIED |
| 088 | 28,70 | 0,0017 | 309 | 0,06363 | 6,68 | 66,67 | 0,2 | 11,8581 | 0,0261 | 30,1300 | NOT VERIFIED |
| 089 | 25,02 | 0,0012 | 494 | 0,10172 | 10,68 | 66,67 | 0,2 | 9,8386 | 0,0417 | 30,1039 | NOT VERIFIED |
| 090 | 24,46 | 0,0016 | 673 | 0,13858 | 14,55 | 66,67 | 0,2 | 11,4887 | 0,0568 | 30,0622 | NOT VERIFIED |
| 90a | 19,17 | 0,0016 | 0 | 0,00000 | 0,00 | 66,67 | 0,2 | 11,2392 | 0,0000 | 30,0054 | NOT VERIFIED |
| 90b | 12,12 | 0,0091 | 0 | 0,00000 | 0,00 | 66,67 | 0,2 | 27,0664 | 0,0000 | 30,0054 | NOT VERIFIED |
| 028 | 8,27 | 0,0085 | 0 | 0,00000 | 0,00 | 66,67 | 0,2 | 26,1417 | 0,0000 | 20,3195 | VERIFIED |
| 029 | 41,09 | 0,0090 | 3170 | 0,65275 | 68,54 | 66,67 | 0,2 | 26,9615 | 0,2677 | 20,3195 | VERIFIED |
| 030 | 25,81 | 0,0050 | 0 | 0,00000 | 0,00 | 66,67 | 0,2 | 20,1635 | 0,0000 | 12,5789 | VERIFIED |
| 031 | 32,26 | 0,0053 | 1198 | 0,24669 | 25,90 | 66,67 | 0,2 | 20,6232 | 0,1012 | 12,0489 | VERIFIED |
| 032 | 31,07 | 0,0051 | 2325 | 0,47875 | 50,27 | 66,67 | 0,2 | 20,3883 | 0,1964 | 11,9477 | VERIFIED |
| 033 | 31,97 | 0,0050 | 1112 | 0,00229 | 24,04 | 66,67 | 0,2 | 20,0988 | 0,0939 | 11,7514 | VERIFIED |
| 034 | 24,48 | 0,0049 | 2577 | 0,00531 | 55,72 | 66,67 | 0,2 | 19,8910 | 0,2176 | 9,4015 | VERIFIED |

# U.S. E.P.A. SWMM 5.1

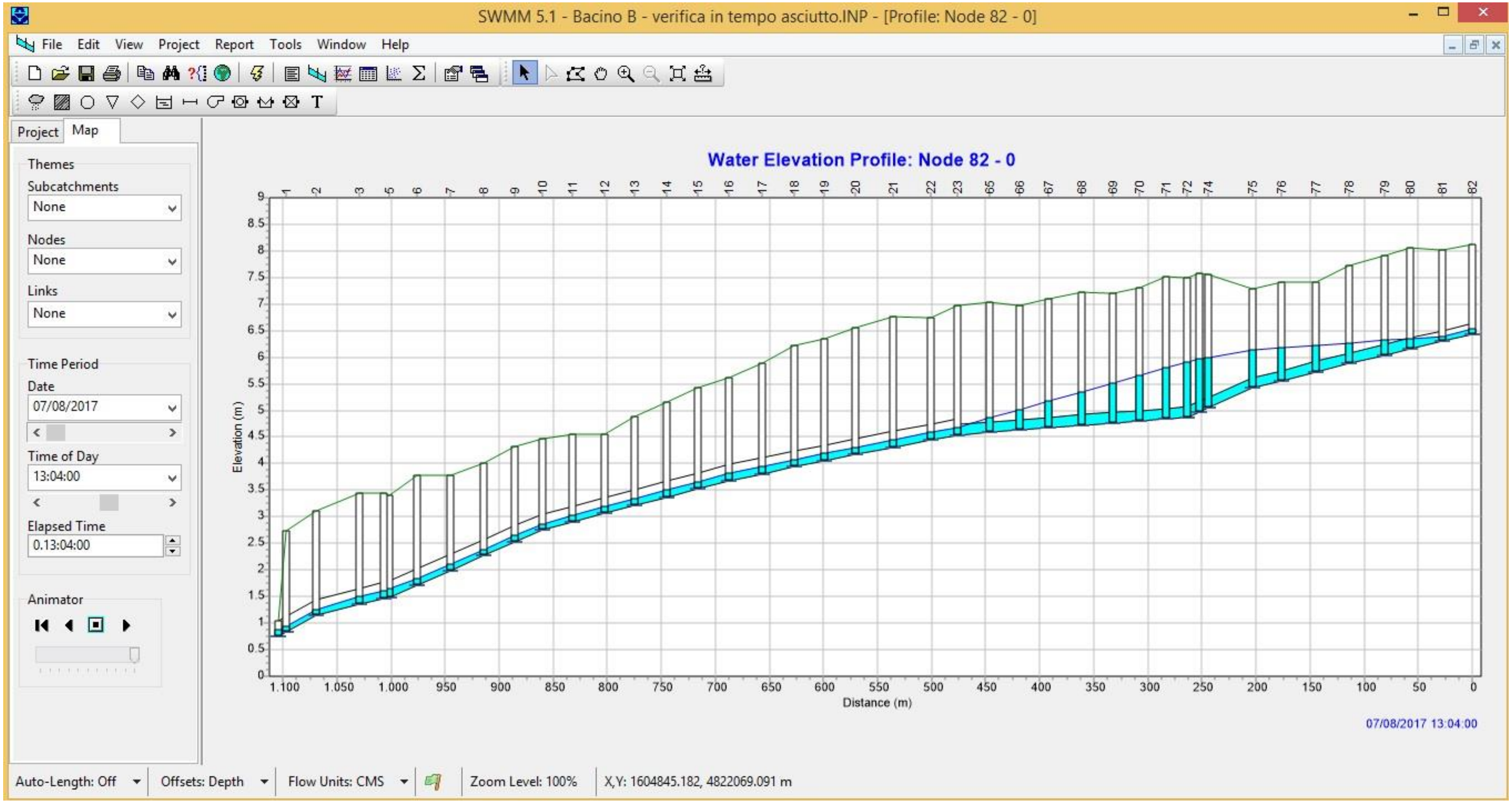
## (Storm Water Management Model)



SWMM 5.1 - Bacino B - invasi - solo rete.INP - [Study Area Map]

Auto-Length: Off
Offsets: Depth
Flow Units: CMS
Zoom Level: 100%
X,Y: 1605466.083, 4822638.791 m

# Model results



SWMM 5.1 - Bacino B - verifica in tempo asciutto.INP - [Profile: Node 82 - 0]

Themes
Subcatchments: None
Nodes: None
Links: None

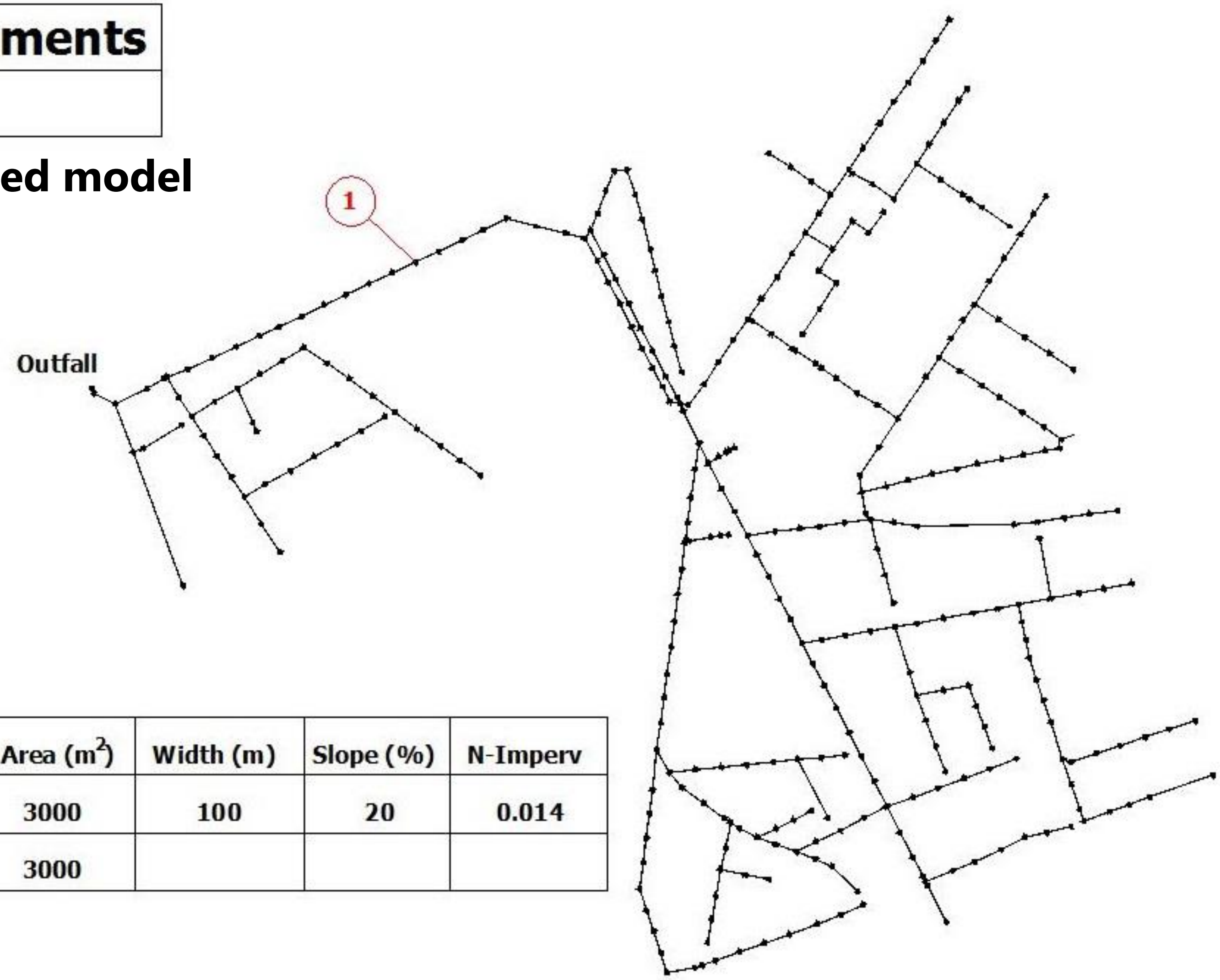
Time Period
Date: 07/08/2017
Time of Day: 13:04:00
Elapsed Time: 0.13:04:00

Auto-Length: Off
Offsets: Depth
Flow Units: CMS
Zoom Level: 100%
X,Y: 1604845.182, 4822069.091 m

# Modelling of infiltration/Inflow

| **Subcatchments** |
|---|
| **Test 1** |

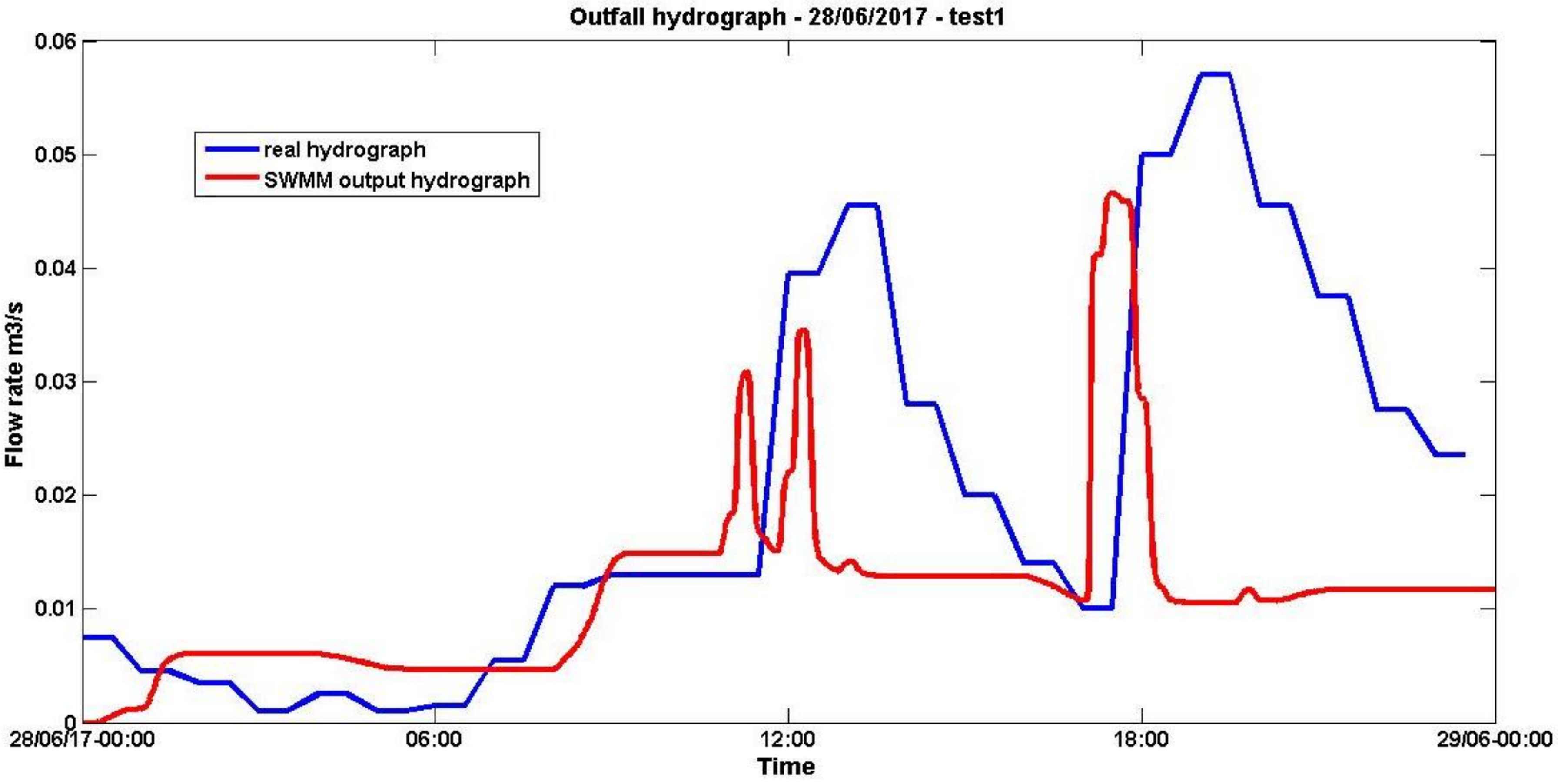
**Un-calibrated model**



| Subcatchment | Area ($m^2$) | Width (m) | Slope (%) | N-Imperv |
|---|---|---|---|---|
| ① | 3000 | 100 | 20 | 0.014 |
| Total area | 3000 | | | |

# Modelling of infiltration/Inflow

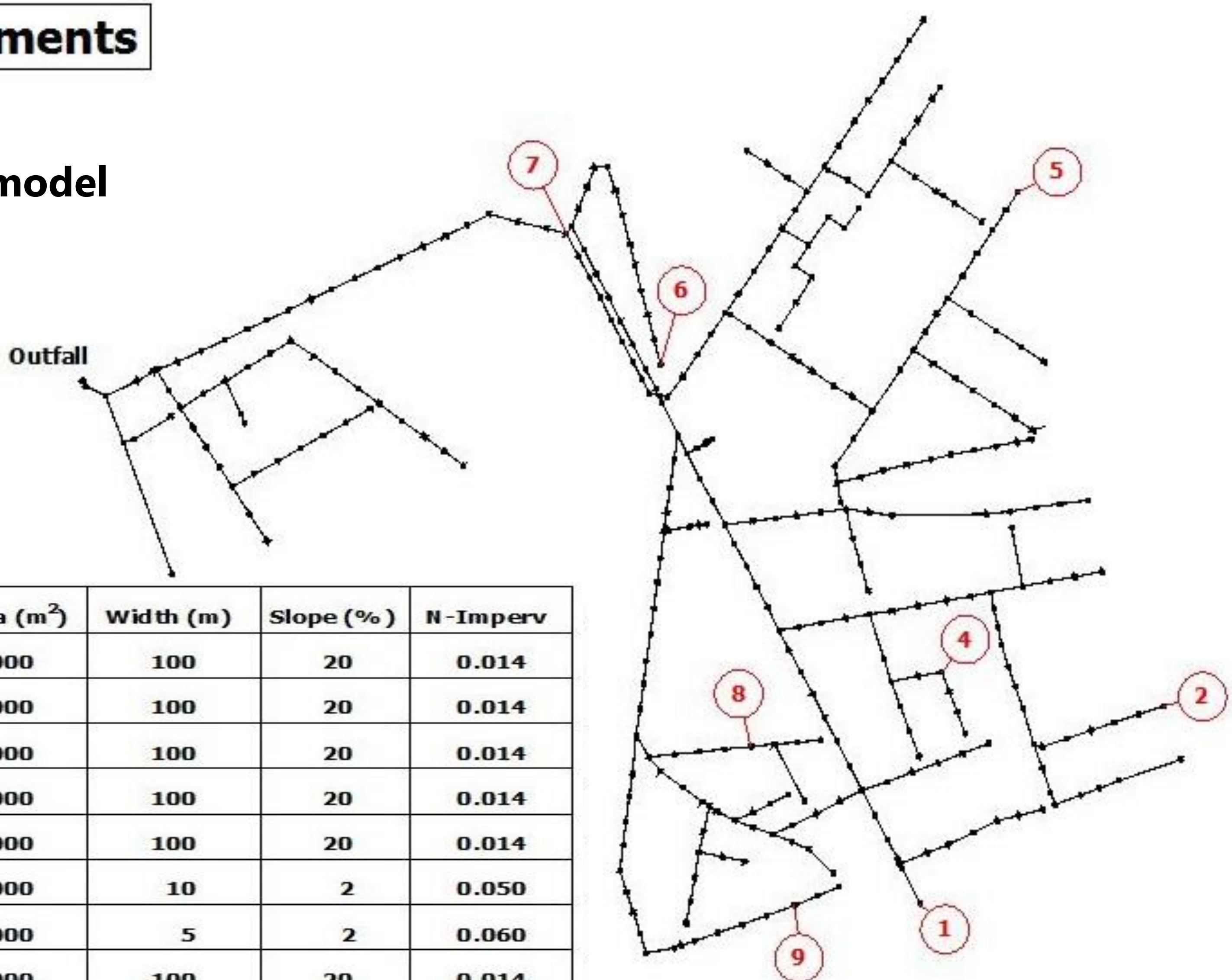
## Un-calibrated model



# Model calibration

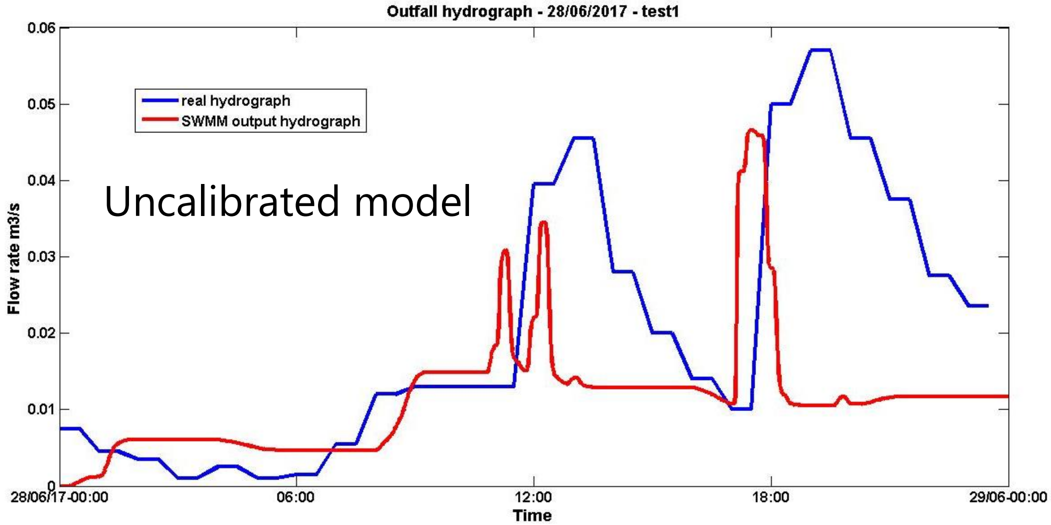
**Subcatchments**

**Calibrated model**

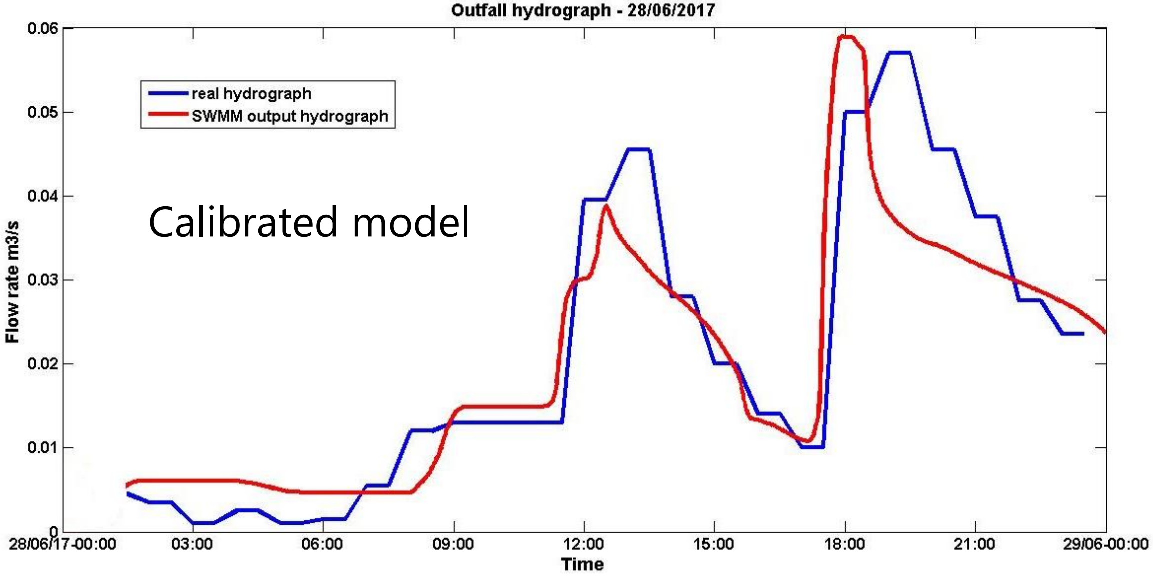


| Subcatchment | Area (m$^2$) | Width (m) | Slope (%) | N-Imperv |
|---|---|---|---|---|
| ① | 2000 | 100 | 20 | 0.014 |
| ② | 2000 | 100 | 20 | 0.014 |
| ③ | 2000 | 100 | 20 | 0.014 |
| ④ | 1000 | 100 | 20 | 0.014 |
| ⑤ | 2000 | 100 | 20 | 0.014 |
| ⑥ | 3000 | 10 | 2 | 0.050 |
| ⑦ | 1000 | 5 | 2 | 0.060 |
| ⑧ | 1000 | 100 | 20 | 0.014 |
| ⑨ | 2000 | 100 | 20 | 0.014 |
| Total area | 16000 | | | |

# Model calibration: Results

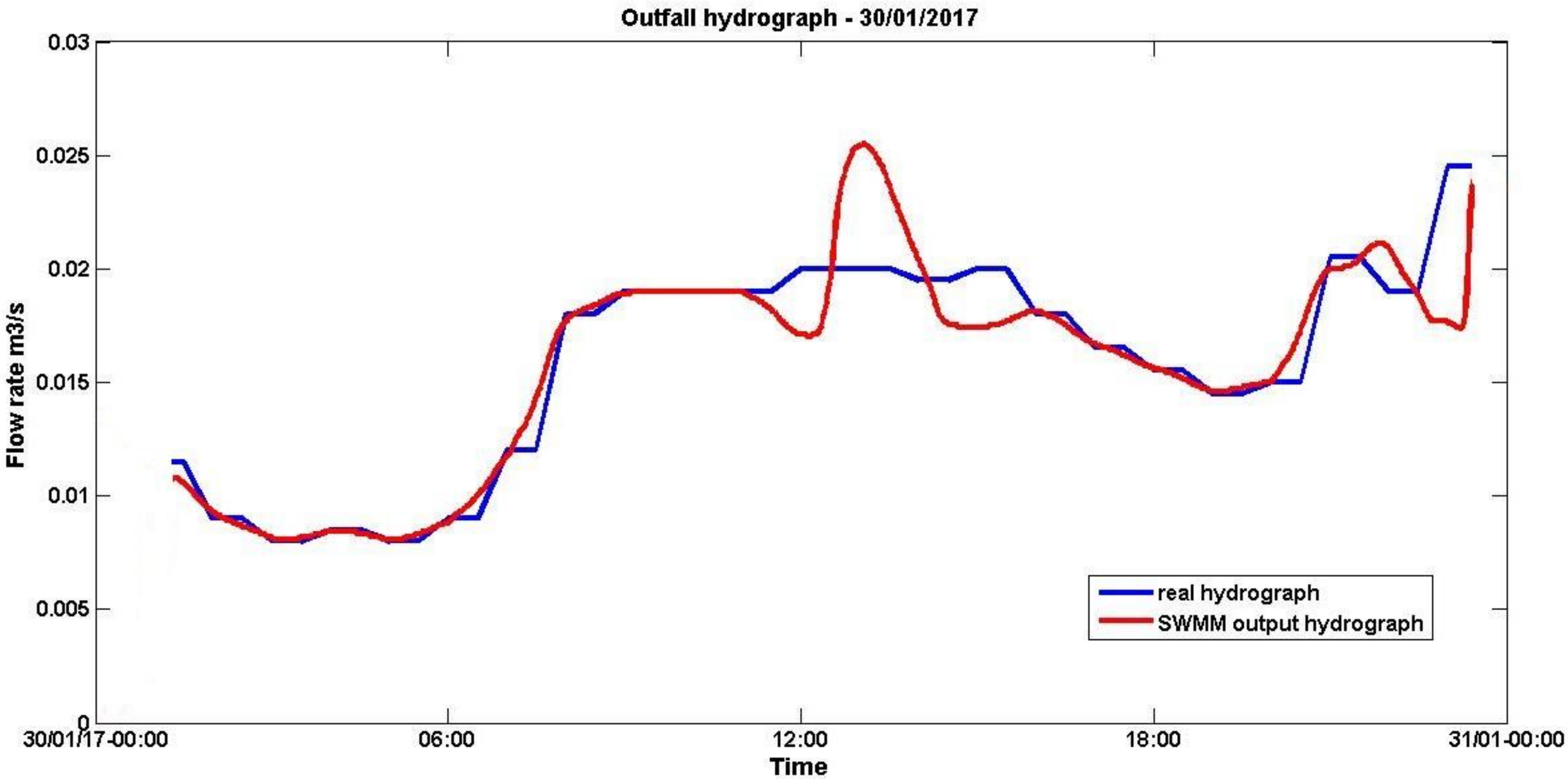


Uncalibrated model

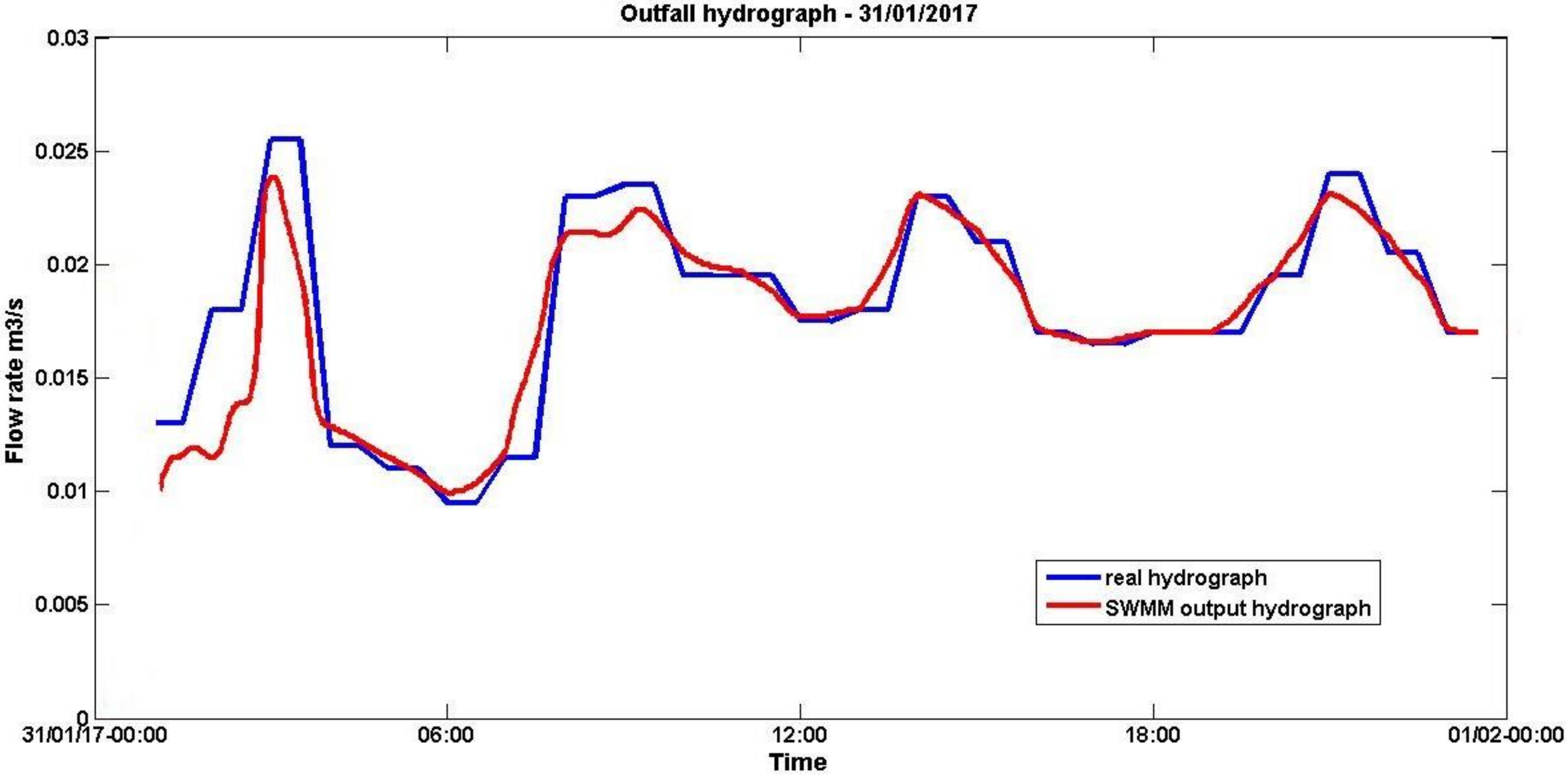


Calibrated model

# Model Validation – 1

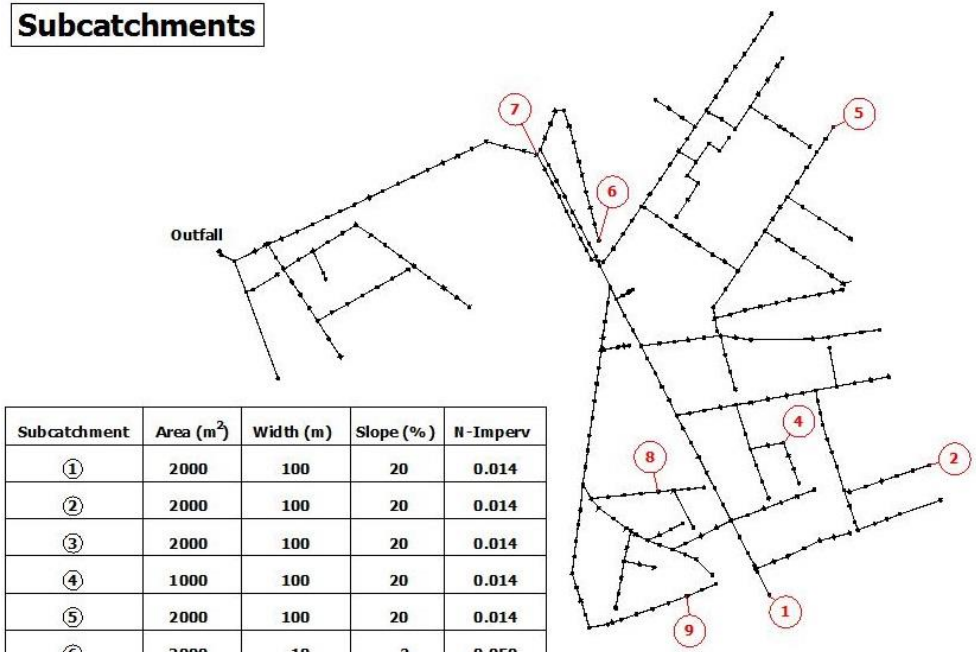


# Model Validation – 2



# Discussion

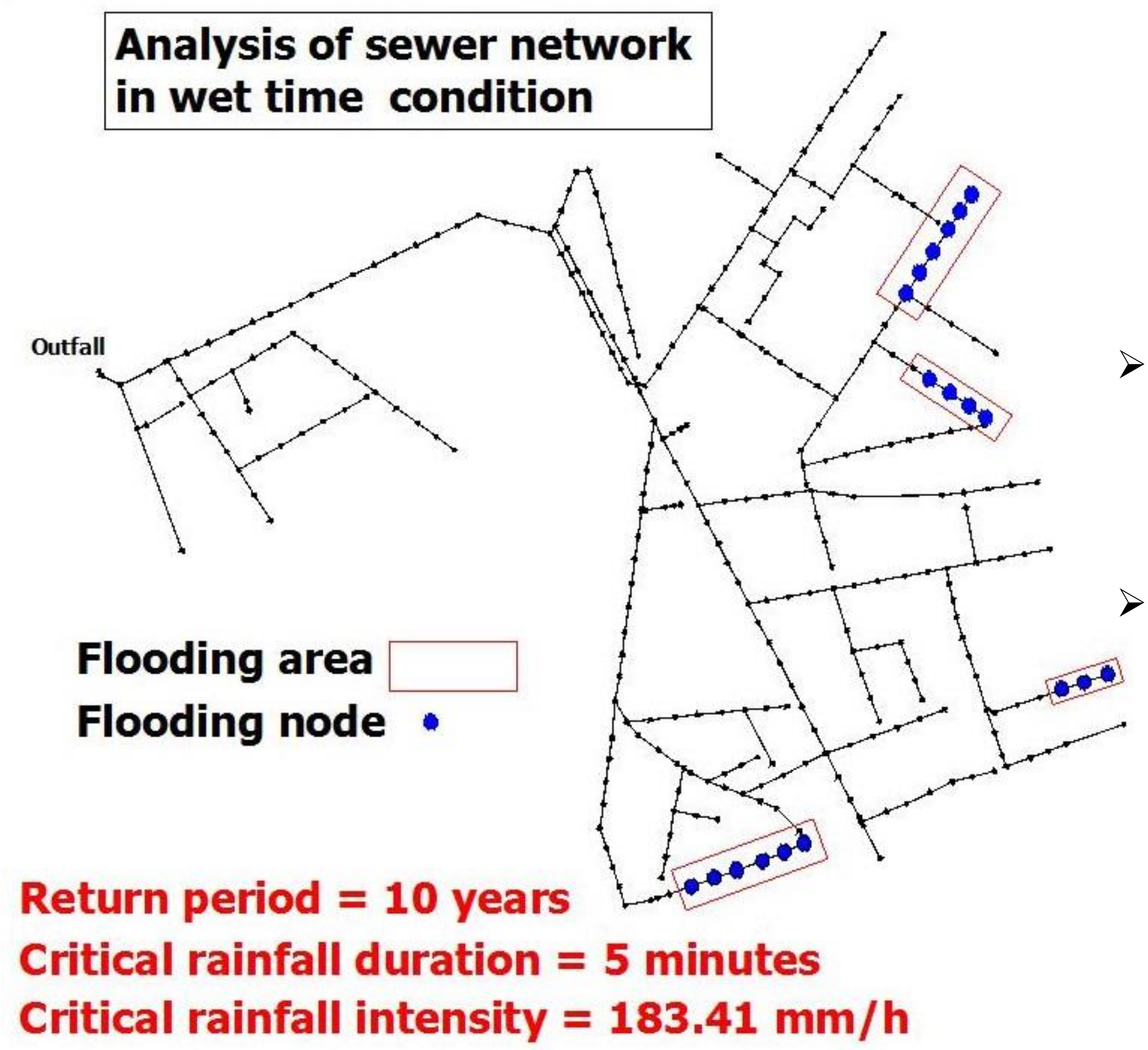
- Infiltration is originated from a ~**16000 $m^2$** surface, corresponding to **2.8%** of the total surface of the basin
- The model calibration allowed us to find the **spatial distribution** of those surfaces / inlet points contributing to inflow
- The model validation was successful. Further refinement is possible by improving the quality of the **input data** (e.g., field surveys)


**Subcatchments**

| Subcatchment | Area ($m^2$) | Width (m) | Slope (%) | N-Imperv |
|---|---|---|---|---|
| ① | 2000 | 100 | 20 | 0.014 |
| ② | 2000 | 100 | 20 | 0.014 |
| ③ | 2000 | 100 | 20 | 0.014 |
| ④ | 1000 | 100 | 20 | 0.014 |
| ⑤ | 2000 | 100 | 20 | 0.014 |
| ⑥ | 3000 | 10 | 2 | 0.050 |
| ⑦ | 1000 | 5 | 2 | 0.060 |
| ⑧ | 1000 | 100 | 20 | 0.014 |
| ⑨ | 2000 | 100 | 20 | 0.014 |
| Total area | 16000 | | | |

- the different parameters used (width, slope and roughness) indicate different **inflow/infiltration mechanisms**. While sub-basins 1,2,3,4,4,5,8,9 may represent direct drainage connections of impermeable surfaces to the sewer (e.g., roofs), sub-basins 6 and 7 may be due to slower rainwater inlet into the network (e. g. broken pipelines or wells).

# Critical rainfall



**Analysis of sewer network in wet time condition**

**Return period = 10 years**

**Critical rainfall duration = 5 minutes**

**Critical rainfall intensity = 183.41 mm/h**

- In **critical conditions** there is an increase in flow rate of **20 L/s**, equal to the average flow rate multiplied by 1.54
- The drainage areas are mostly located in the network sections that are far from the closing section

# Water quality monitoring and modelling

**Aims:**

- Confirming the infiltration/inflow points identified with the flow model;
- Improving the management practices of wastewater treatments plants to reach water quality standards.

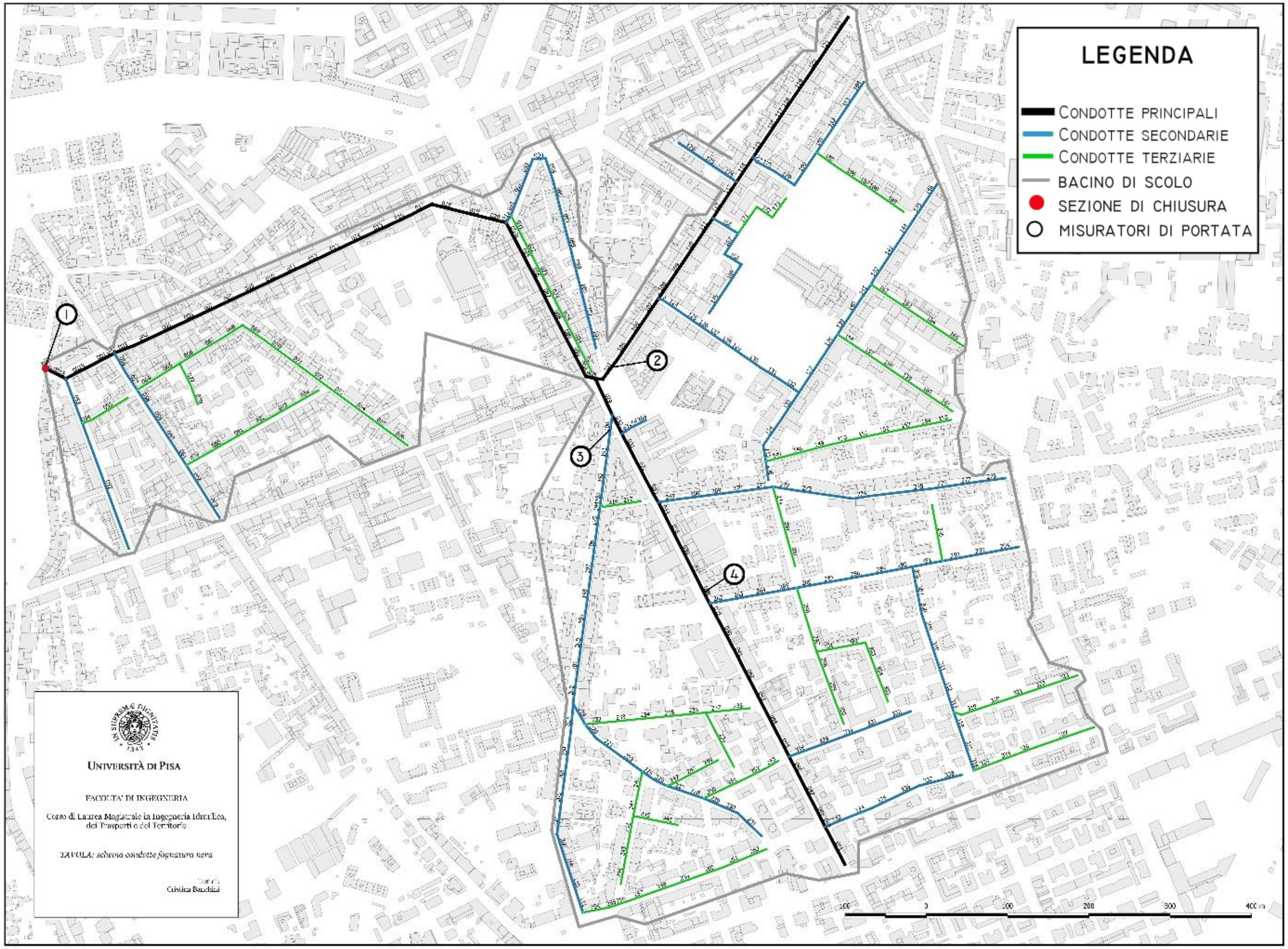
**The adopted approach:**

- Definition of the monitoring points in the network;
- Measurement of flow and *chemical-physical* parameters data;
- Collection of wastewater samples;
- Analysis and processing of collected data;
- Coupled modeling by SWMM of flow and transport process in dry weather and rain conditions.

# Water quality monitoring

- Definition of the monitoring points based on conduits ranking

- 3-level ranking of conduits;
- 4 monitoring points (including the closing section)

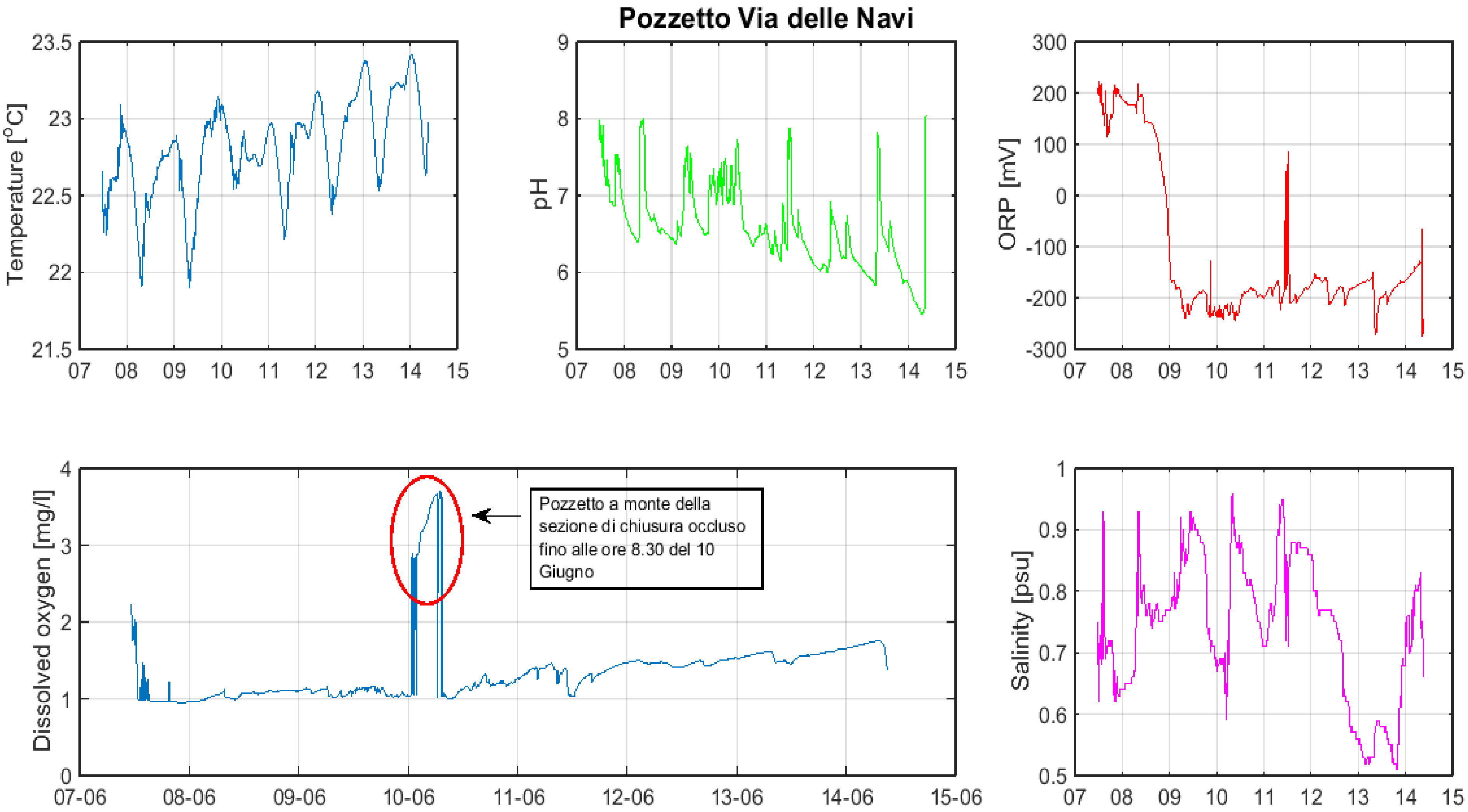


# Water quality monitoring

- Flow meter and multi-parametric probes installation in monitoring points
- Wastewater samples collection in in monitoring points

# Water quality monitoring

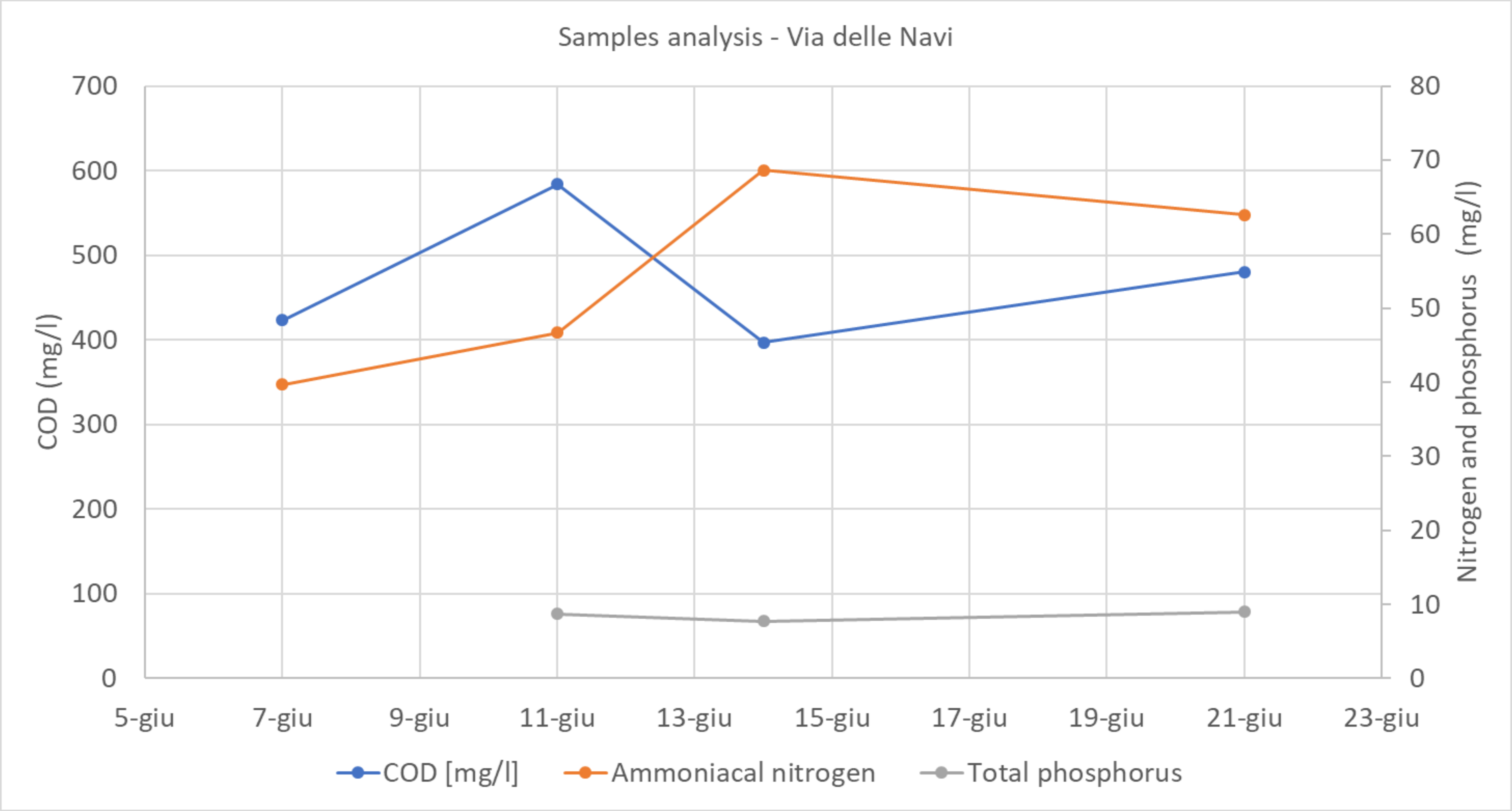
- First results



Pozzetto a monte della sezione di chiusura occluso fino alle ore 8.30 del 10 Giugno

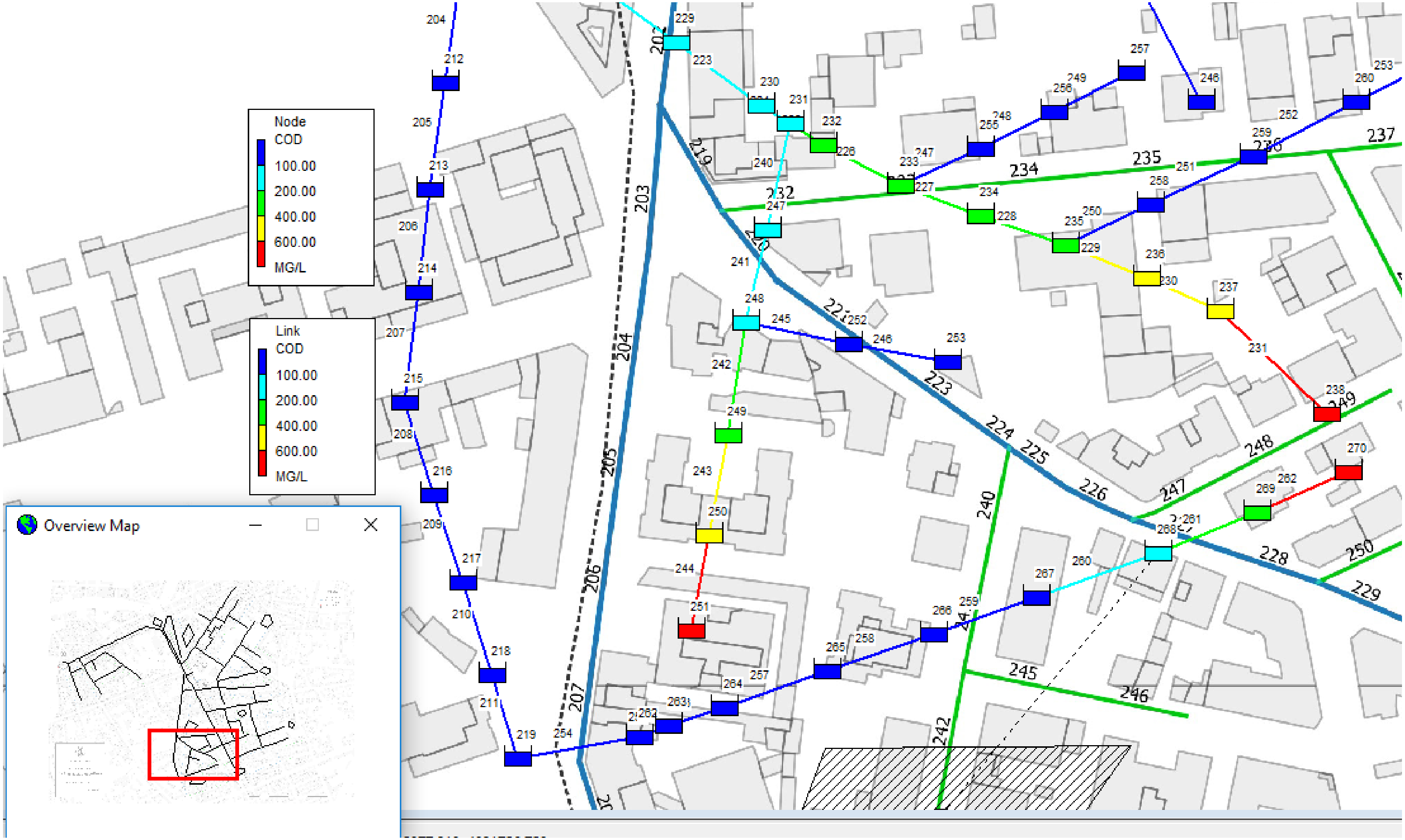
# Water quality monitoring

- First results



# Water quality modelling

- Concentration results



# Conclusions

- We developed an approach, based on modelling, to identify and locate the possible infiltration/inflow points in the network
- We applied the model to a portion of the sanitary sewer network of Livorno
- We calibrated the model with flow measurements at the closing section of the studied basin
- The model was successfully validated

# Future steps

- Extend the study area, possibly to the entire sewer network
- Develop algorithms to automatically identify the most critical sections of the network
- Define network maintenance and adaptation, and suggesting wastewater treatment management rules
- Define a priority scale that takes into account the costs and benefits of the possible interventions

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# Merci pour l’attention

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