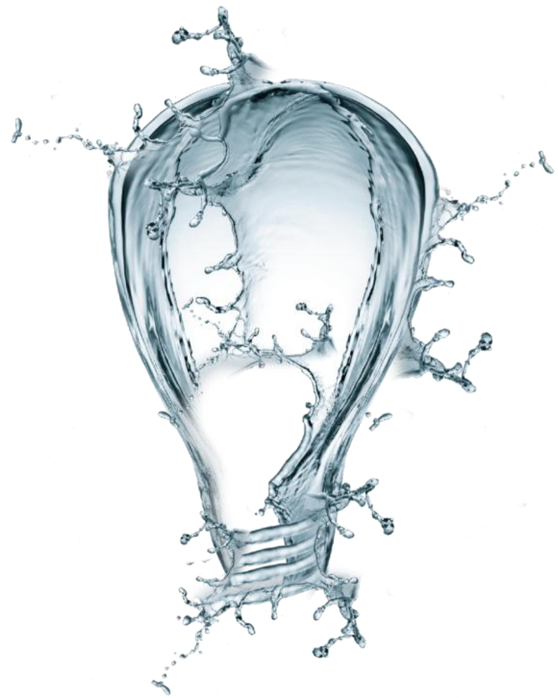

September 26th 2017, Porto

CTRL+SWAN Side meeting

"SWANP: Smart WAter Network Partitioning and Protection"

European Innovation Partnership on Water Action Group CTRL + SWAN

Cloud Technologies & ReaL time monitoring + Smart WAter Network

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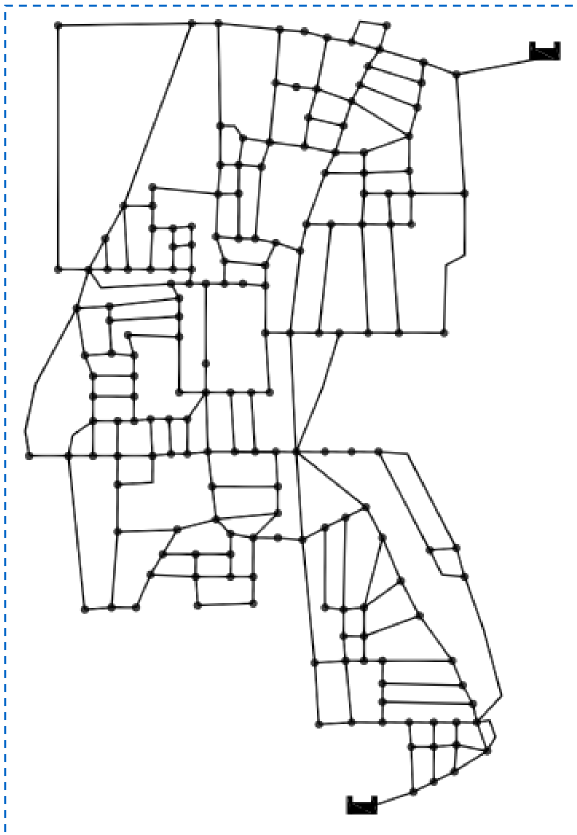
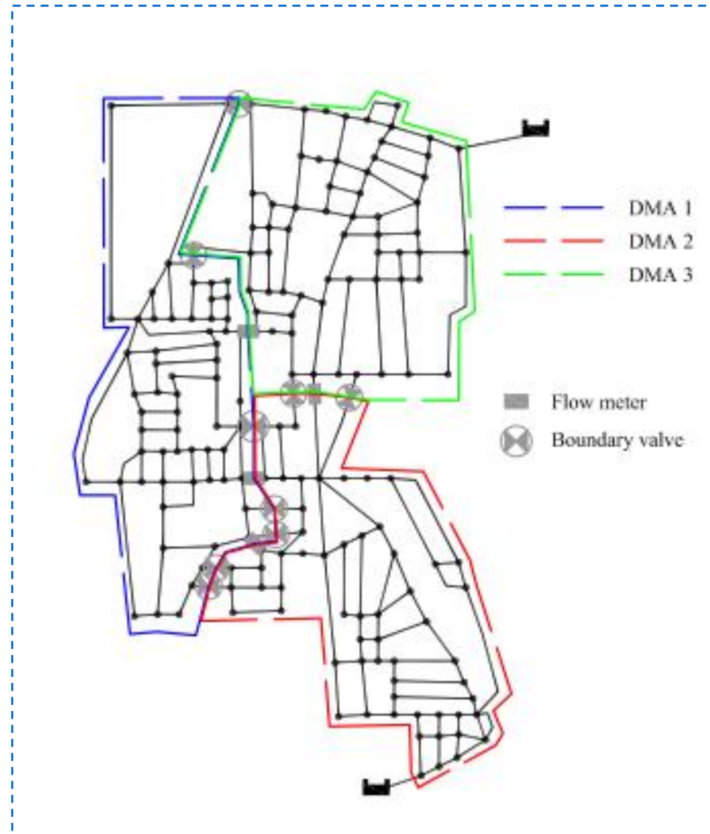
Smart WAter Network – 1. Water Network Partitioning

Water Network Partitioning (WNP) is a methodology that consists in dividing a **Water Distribution System (WDS)** in subsystems or District Meter Areas (DMAs) by using ***flow meters*** and ***gate valve*** (boundary valves), introducing the paradigm of Divide and Conquer



Original Water Distribution Network



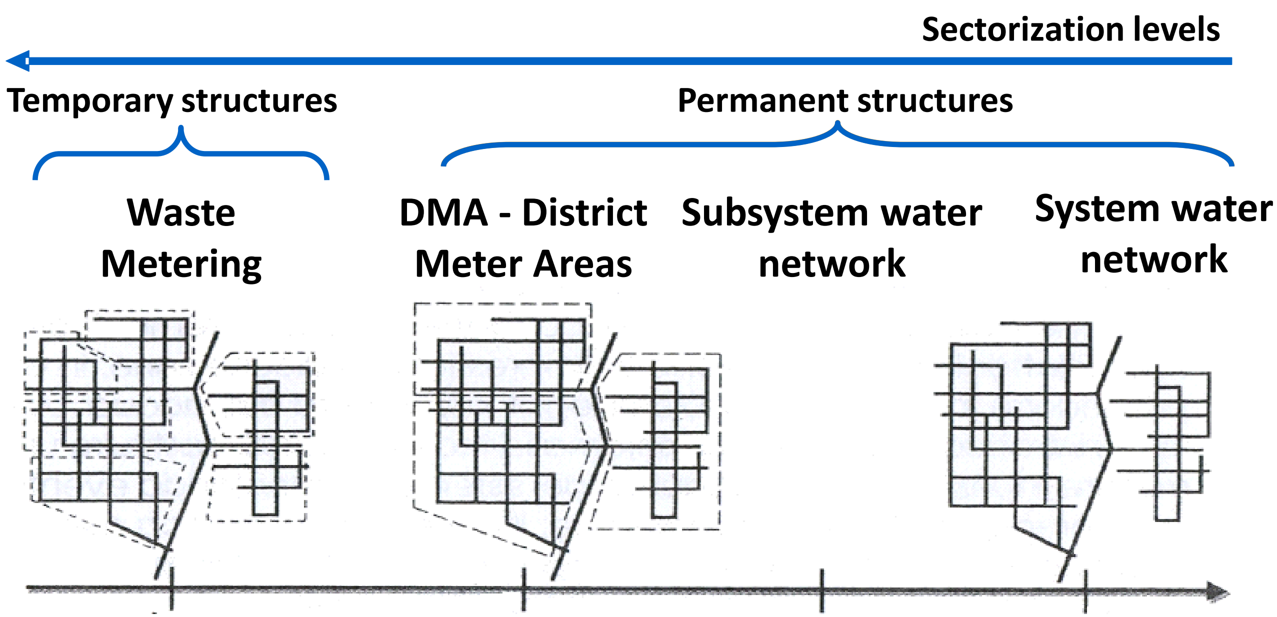
Water network partitioning in DMA

Smart WAter Network – 1. Water Network Partitioning

WNP allows to improve the water network management, in particular to:

- ✓ Evaluation of the **hydraulic balance** in order to recognize network reliability
- ✓ Localization and reduction of **water leakages**
- ✓ **Pressure management** to reduce water losses
- ✓ **Monitoring** network **performances** and water consumption
- ✓ **Protection** from **contamination**

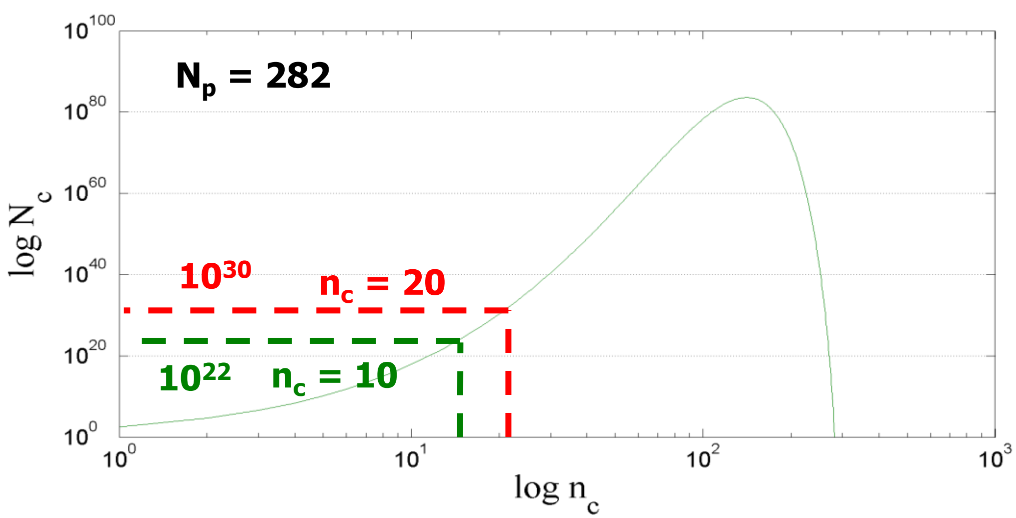
WNP is based on the identification of **District Meter Areas** (**DMA**):



Smart WAter Network – 1. Water Network Partitioning

Main **WNP drawbacks**:

- ✓ **Availability**: the partitioning decreases the network redundancy traditionally used in the design of WDS *(Mays, 2000)*;
- ✓ **Effectiveness**: the partitioning can significantly increase energy dissipations caused by pipe closures *(Di Nardo and Di Natale, 2011)*;
- ✓ **Economy**: it is necessary to contain costs to buy, install and repair flow meters and boundary valves *(Wrc/WSA/WCA Engineering and Operations Committee, 1994)*
- ✓ **Computational complexity**: it is necessary to decrease the number of possible partitioning of a water network that is huge *(Di Nardo and Di Natale, 2011)*



$$N_c = \binom{N_p}{n_c}$$

- *Binomial coefficient*
- N_c= layouts; N_p= pipes; n_c= pipe closed

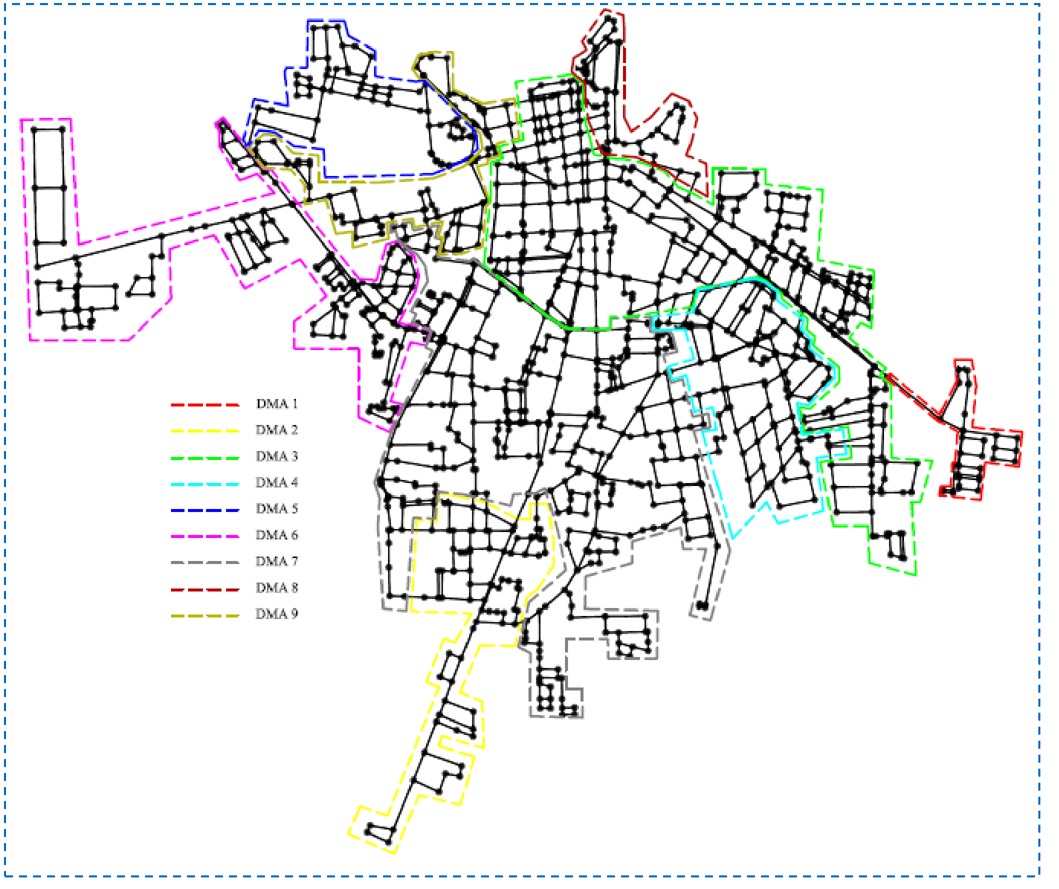
Smart WAter Network – 1. Water Network Partitioning

Our research group has developed a tool for the **automatic definition** of **shape** and **dimension** of **permanent DMAs** or, in other terms, of the number of nodes belonging to each DMA and the **positioning** of **flow meters** and **boundary valves**.

The software has been tested on several case-study real WDNs, among which the WDN of the city of **Matamoros** (Tamaulipas, Mexico) .

Number of nodes, *n*	**1,283**
Number of links, *m*	1,651
Number of reservoirs, *r*	9
Hydraulic head of reservoirs [m]	29.0; 31.46; 26.99; 28.14; 36.06; 36.26; 26.12; 30.64; 30.73
Total pipe length, L_{TOT} [km]	376.6
Minimum ground elevation, z_{min} [m]	5.33
Maximum ground elevation, z_{max} [m]	12.9
Pipe materials	PVC and AC
Pipe diameters [mm]	76; 95; 152; 190; 238; 300; 338; 380; 428; 476; 508; 600; 762; 914
Average demand, Q [m^3/s]	0.987
Peak demand, Q [m^3/s]	1.342
Design pressure, h^* [m]	12
h_{FP} [m]	5

AC, asbestos cement; PVC, polyvinyl chloride.



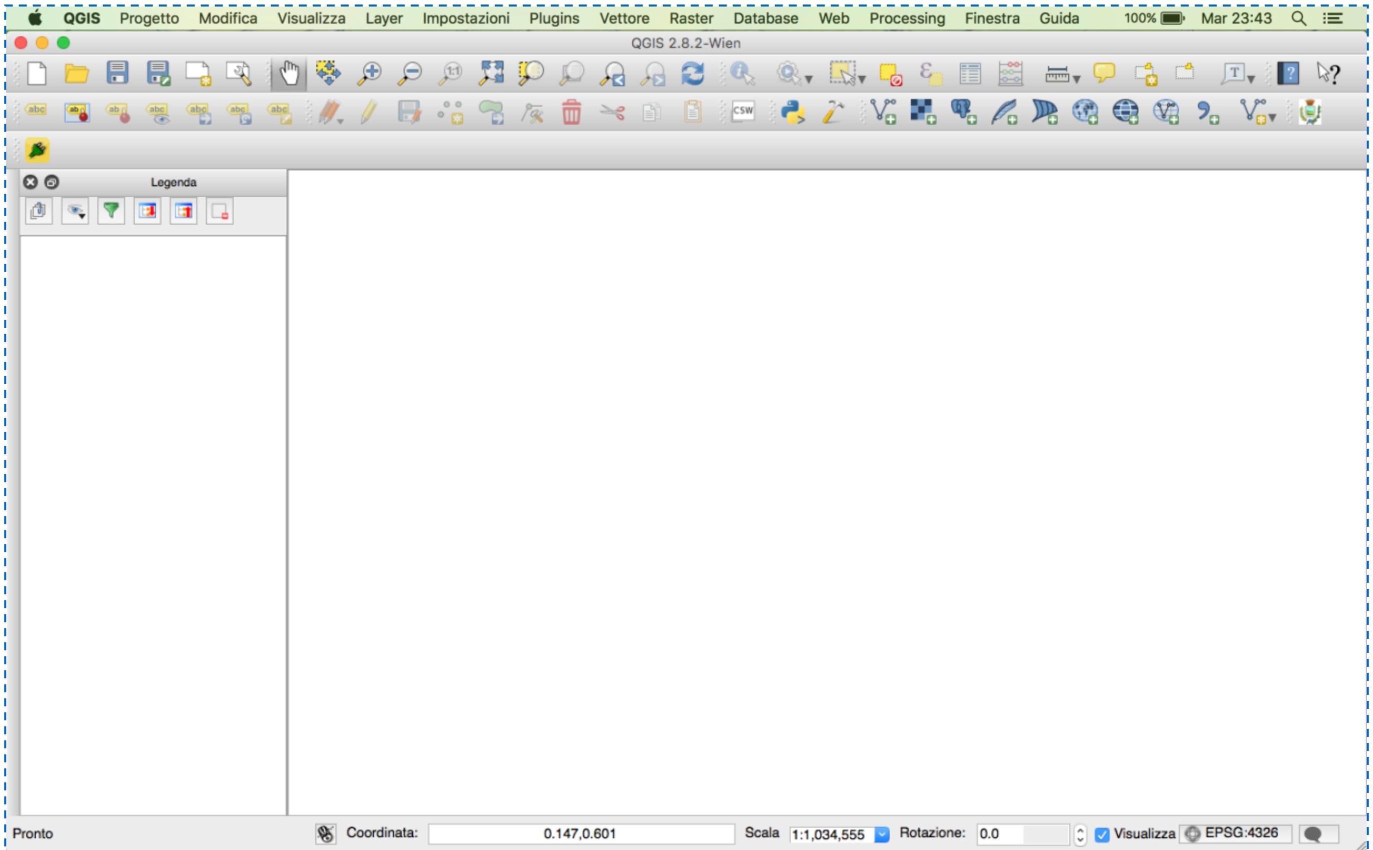
WNP of Matamoros network

SWANP 3.0 is the 3rd release of an hydraulic software devoted to water network modelling, analysing, partitioning and protecting. Its acronym stands for ***Smart WAter Network Partitioning and Protection.***

- ✓ the **decision-maker** that provides different solutions and compares network layouts with some hydraulic and protection performance indices;
- ✓ integrating different algorithms **for water network partitioning**;
- ✓ novel algorithm based on a multi-objective function, for **water network protection** from accidental or intentional contamination.

Smart WAter Network Partitioning and Protection - 1. Introduction

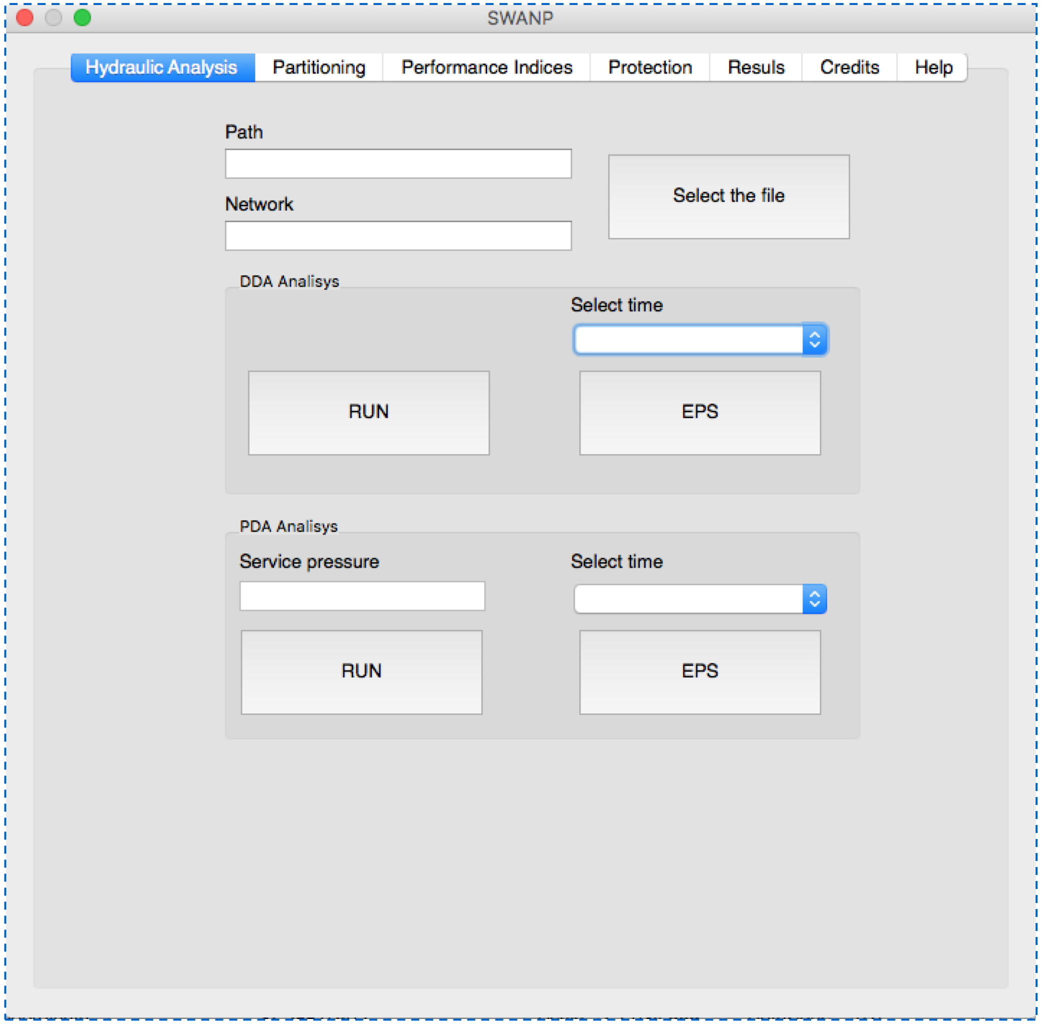
The SWANP software is integrated in a **QGIS software**, which is open source software to manage, visualize, modify and analyse the geographic data. By installing the SWANP plug-in for QGIS it is possible use all SWANP functions and, simultaneously, all analysis and visualization instruments provided by the QGIS. The GUI (graphic user interface) of SWANP tools for QGIS uses the QT4 graphic libraries while the functions of the SWANP are developed in Python 2.7.



QGIS Software

The GUI (Graphic User Interface) of SWANP is composed by 5 main sections:

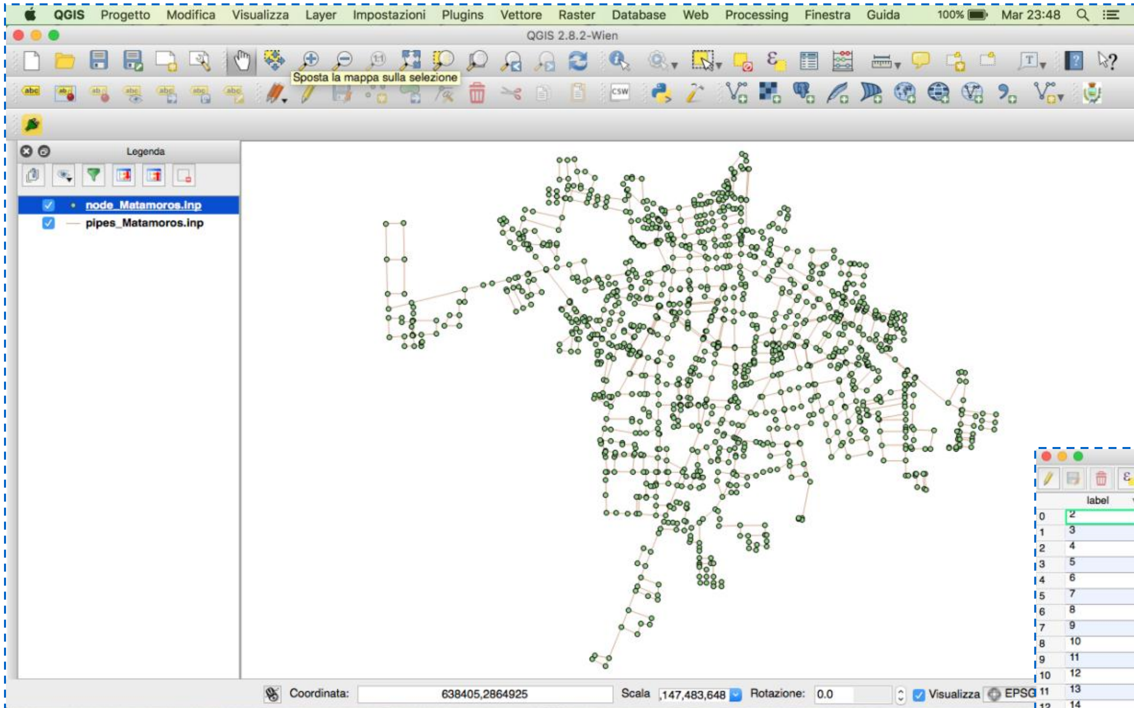
- ✓ **Hydraulic analysis**
- ✓ **Partitioning**
- ✓ **Protection**
- ✓ **Results**
- ✓ **Performance Indices**



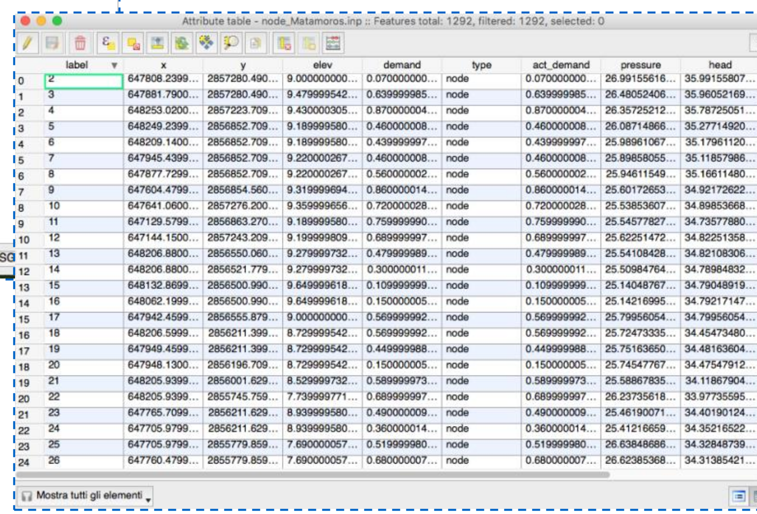
SWNP GUI: Hydraulic analysis section

SWANP 3.0 can performs the steady-state simulation of a Water Network Distribution by integrating the dynamic library of the EPANET 2.0 software.

It is possible using a **Demand Driven Analysis (DDA)** or **Pressure Driven Analysis (PDA)** approach in which, starting from topologic and hydraulic and water demand INPUTs, pressure nodes and pipe flow are provided.



Water network imported in SWANP

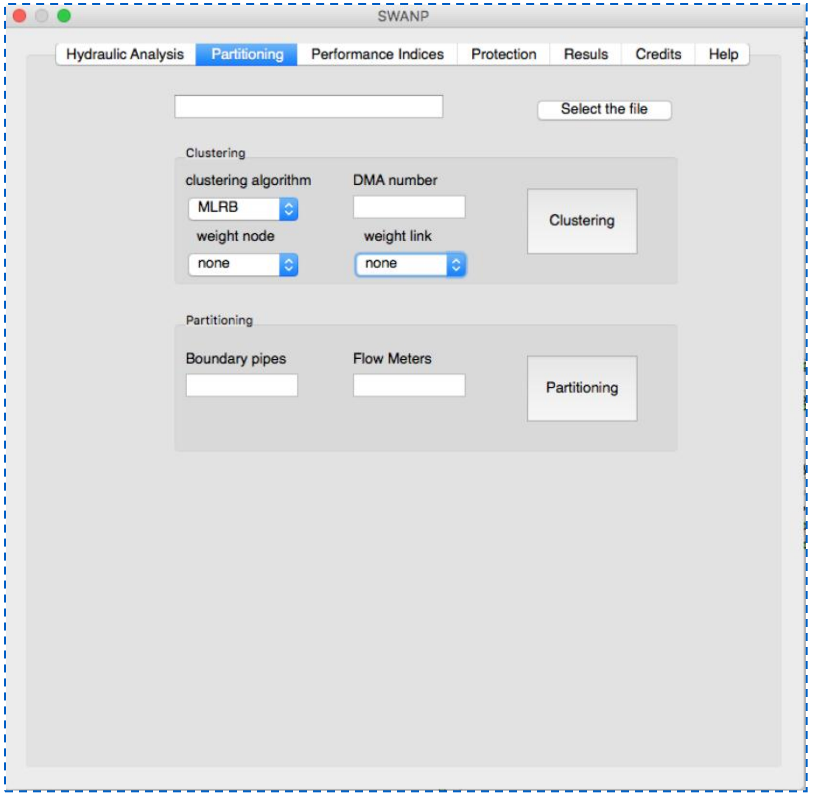


	label	x	y	elev	demand	type	act_demand	pressure	head
0	2	647808.2399...	2857280.490...	9.000000000...	0.070000000...	node	0.070000000...	26.99155616...	35.99155807...
1	3	647881.7900...	2857280.490...	9.479999542...	0.639999985...	node	0.639999985...	26.48052406...	35.96052169...
2	4	648253.0200...	2857223.709...	9.430000305...	0.870000004...	node	0.870000004...	26.35725212...	35.78725051...
3	5	648249.2399...	2856852.709...	9.189999580...	0.460000008...	node	0.460000008...	26.08714866...	35.27714920...
4	6	648209.1400...	2856852.709...	9.189999580...	0.439999997...	node	0.439999997...	25.98961067...	35.17961120...
5	7	647945.4399...	2856852.709...	9.220000267...	0.460000008...	node	0.460000008...	25.89858055...	35.11857986...
6	8	647877.7299...	2856852.709...	9.220000267...	0.560000002...	node	0.560000002...	25.94611549...	35.16611480...
7	9	647604.4799...	2856854.560...	9.319999694...	0.860000014...	node	0.860000014...	25.60172653...	34.92172622...
8	10	647641.0600...	2857276.200...	9.359999656...	0.720000028...	node	0.720000028...	25.53853607...	34.89853668...
9	11	647129.5799...	2856863.270...	9.189999580...	0.759999990...	node	0.759999990...	25.54577827...	34.73577880...
10	12	647144.1500...	2857243.209...	9.199999809...	0.689999997...	node	0.689999997...	25.62251472...	34.82251358...
11	13	648206.8800...	2856550.060...	9.279999732...	0.479999989...	node	0.479999989...	25.54108428...	34.82108306...
12	14	648206.8800...	2856521.779...	9.279999732...	0.300000011...	node	0.300000011...	25.50984764...	34.78984832...
13	15	648132.8699...	2856500.990...	9.649999618...	0.109999999...	node	0.109999999...	25.14048767...	34.79048919...
14	16	648062.1999...	2856500.990...	9.649999618...	0.150000005...	node	0.150000005...	25.14216995...	34.79217147...
15	17	647942.4599...	2856555.879...	9.000000000...	0.569999992...	node	0.569999992...	25.79956054...	34.79956054...
16	18	648206.5999...	2856211.399...	8.729999542...	0.569999992...	node	0.569999992...	25.72473335...	34.45473480...
17	19	647949.4599...	2856211.399...	8.729999542...	0.449999988...	node	0.449999988...	25.75163650...	34.48163604...
18	20	647948.1300...	2856196.709...	8.729999542...	0.150000005...	node	0.150000005...	25.74547767...	34.47547912...
19	21	648205.9399...	2856001.629...	8.529999732...	0.589999973...	node	0.589999973...	25.58867835...	34.11867904...
20	22	648205.9399...	2855745.759...	7.739999771...	0.689999997...	node	0.689999997...	26.23735618...	33.97735595...
21	23	647765.7099...	2856211.629...	8.939999580...	0.490000009...	node	0.490000009...	25.46190071...	34.40190124...
22	24	647705.9799...	2856211.629...	8.939999580...	0.360000014...	node	0.360000014...	25.41216659...	34.35216522...
23	25	647705.9799...	2855779.859...	7.690000057...	0.519999980...	node	0.519999980...	26.63848686...	34.32848739...
24	26	647760.4799...	2855779.859...	7.690000057...	0.680000007...	node	0.680000007...	26.62385368...	34.31385421...

SWANP 3.0 allows defining automatically an optimal partitioning of a water network (**WNP**) using different algorithms. The proposed procedure is subdivided in two phases:

a) the **clustering**, aimed to define the shape and dimension of network subsets based on graph theory;

b) The **dividing** that consists in the definition of the best position of the flow meters and the boundary (or gate) valves.



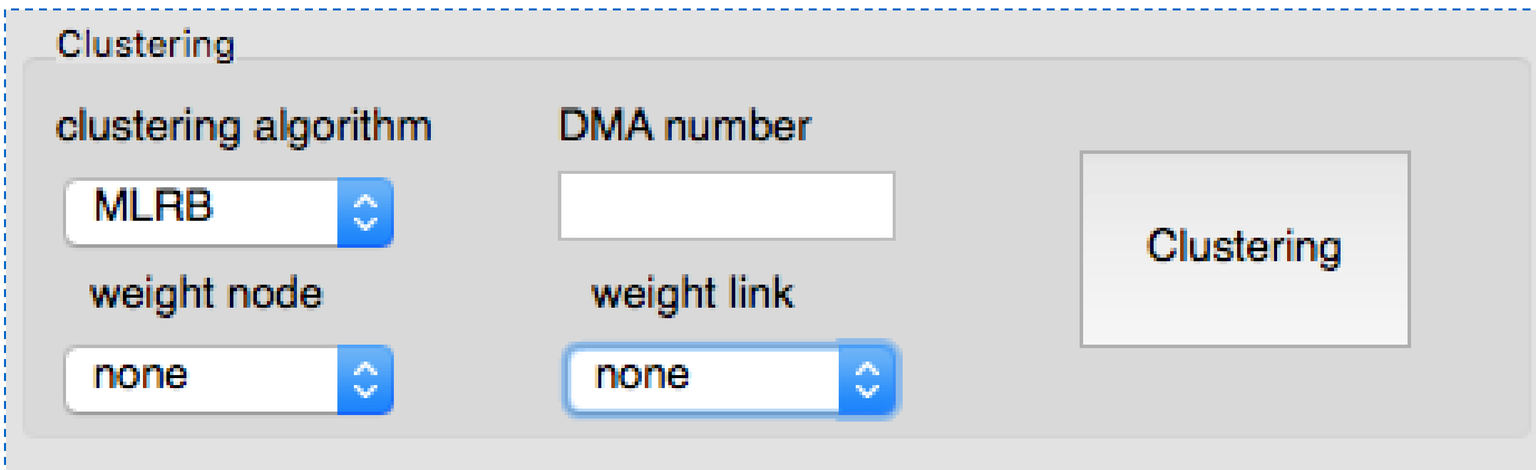
SWNP GUI: Partitioning section

To perform the **clustering** phases, three different algorithms are proposed based on **graph partitioning**, **community structure** and **spectral clustering**

1) MLRB (MultiLevel Recursive Bisection)

2) EBC (Edge Betweenness Community)

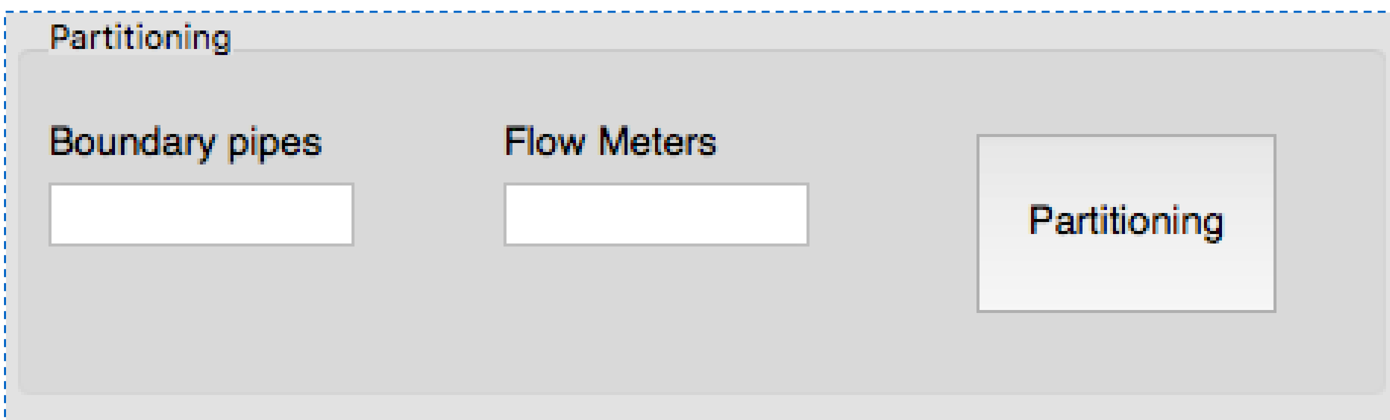
3) NCut algorithm (spectral clustering)



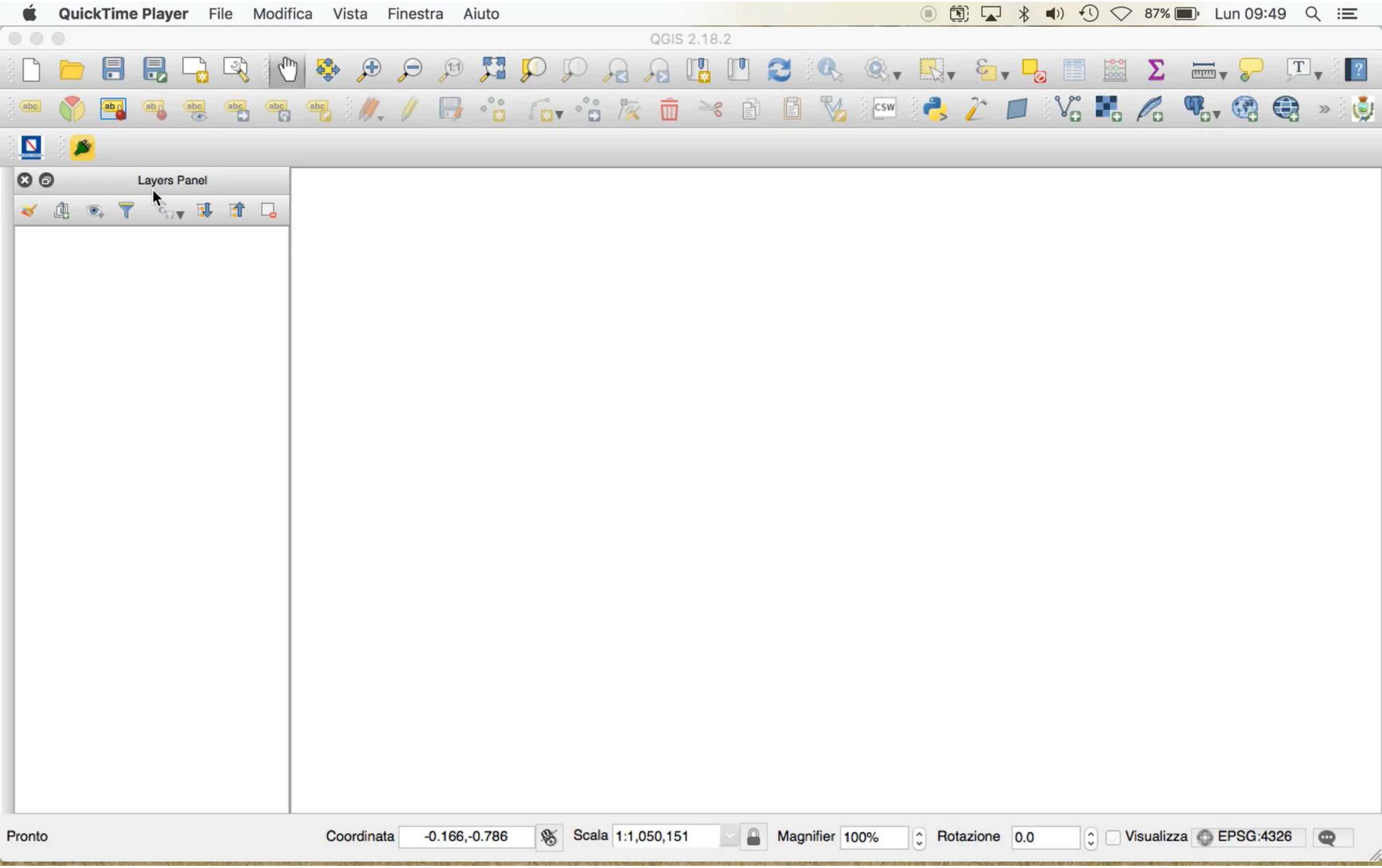
Clustering tab of Partitioning section

The **dividing** phase consists in to define the best position of the **flow meters** and **boundary (or gate valves)** to insert in the boundary pipes (or edge-cuts) between DMAs previously obtained by clustering algorithms. This goal is obtained by using a heuristic optimization method based on a Genetic Algorithm (GA), it is used maximizing the total node power of the network.

$$FO = \max\left(\gamma \sum_{i=1}^{n} Q_i H_i \right)$$



Dividing tab of Partitioning section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Scala
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Magnifier
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Rotazione
0.0
Visualizza
EPSG:4326

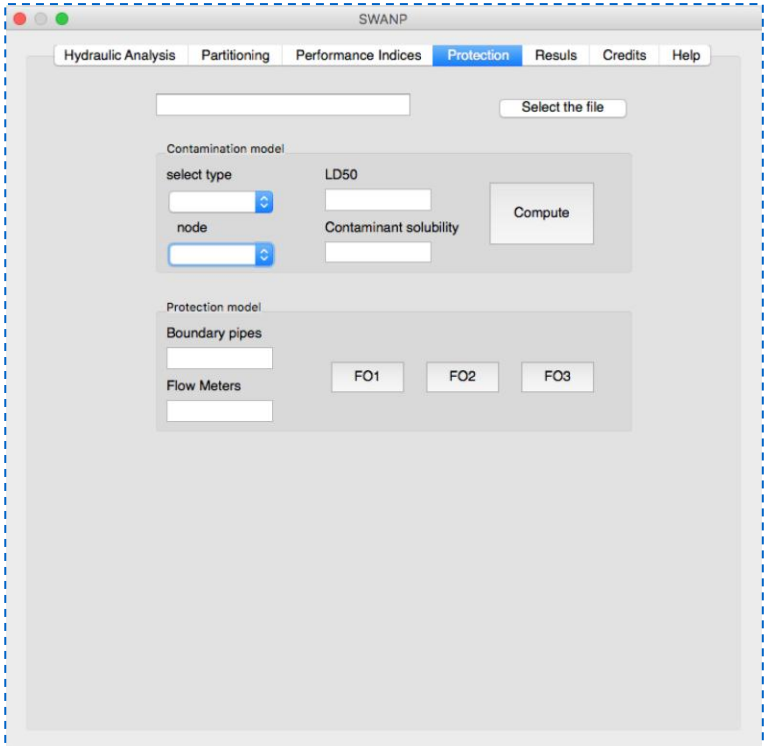
Water distribution networks are exposed to different potential sources of accidental and intentional contamination. There are myriad of ways in which a contaminant can be introduced into a water distribution system and preventing all such contamination accidents is generally not possible. Consequently, **the overall goal of sensor placement is to minimize contamination risks.**

Accidental contamination

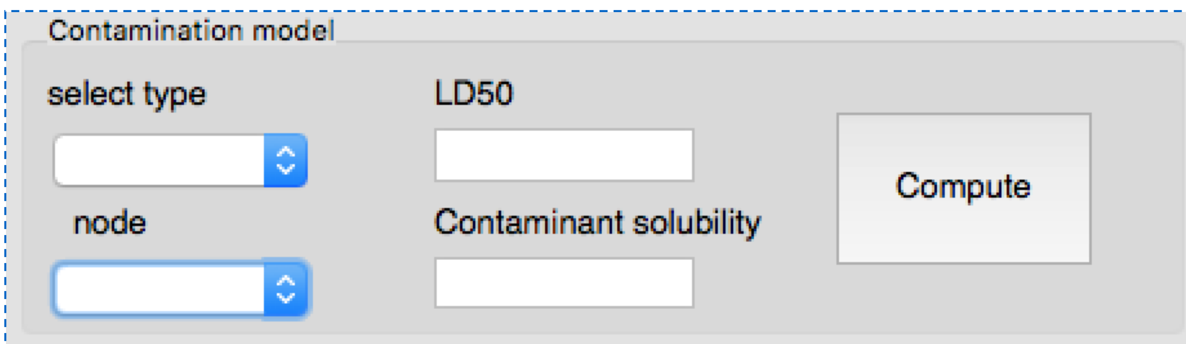
- ✓ occasional bad source water quality
- ✓ dysfunction of chlorine stations
- ✓ pipe breaks
- ✓ etc.

Malicious attack

- ✓ intentional introduction of a contaminant at the network sources
- ✓ backflow attack (injection of a contaminant in a network pipe through a pump system that allows to overcome the pressure gradient of network pipes)



SWANP GUI: protection section

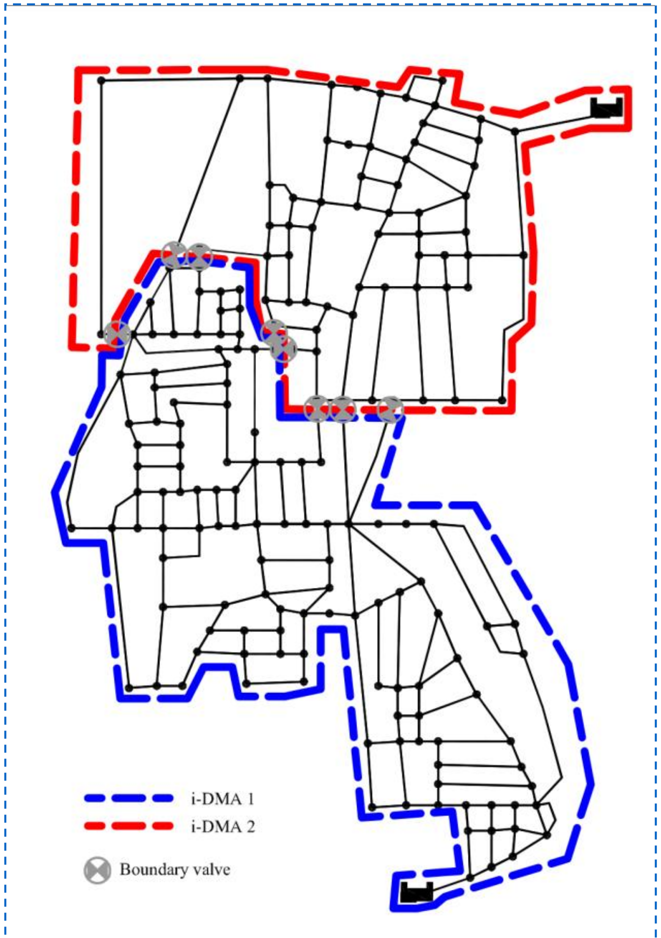


SWANP provides a simulation tools able to perform extended-period simulation of the hydraulic and water quality. This model can evaluate the expected flow in water distribution systems, and compute the transport of contaminants and related chemical interactions.
In this way it is possible to asses different contamination scenarios.

The contamination impact is measured by some Protection Performance Indices:

- ✓ **the total number of exposed users** (**Neu**),
- ✓ **the number of exposed users that consumed more than the LD50** (**Neu50**);
- ✓ **length of the contaminated pipes** (**Lep**).

SWANP can reduce the risk of contamination in a water supply network using the technique of Water Network Sectorization (WNS). Sectorization is achieved by closing gate valves in the network pipes that link the DMAs.



Water Networks Sectorization

The protection of water network with WNS showed that:

a) DMA isolation is more effective than only water network partitioning,
b) the higher the number of DMAs in a WNP, improve the protection for the users;
c) WNP reduces the extent of risk because several introduction points are needed to have a wide negative impact on the network;
d) WNP allows to activate easier protection measures because it is possible to disconnect a small part of the network;
e) the methodology respects the criteria of dual-use value.

The optimal network sensor design is a big challenging not only for the researches but also for the real word application, Water Utility, etc..
SWANP provides a tool for **optimal sensor placement:** after the clustering phase the user can chose a Multi Objective Function, for the dividing phase, in order to minimize the alteration of hydraulic performance and decrease the disastrous effects of contamination:

$$\min\left(MOF = I_{rd} + \sum_{p=1}^{k} \alpha_p \frac{N_{eu,p}}{N^*_{eu,p}} + \sum_{p=1}^{k} \alpha_p \frac{N_{eu50,p}}{N^*_{eu50,p}} \right)$$

$$I_{rd} = \left(1 - \frac{I_r^*}{I_r}\right)100 = \left(\frac{P_D^* - P_D}{P_{D\max} - P_D}\right)100$$

the **Resilience deviation index** between the original network and of WNP (*)

$$\frac{N_{eu,p}}{N^*_{eu,p}} \qquad \frac{N_{eu50,p}}{N^*_{eu50,p}}$$

the deviation of the Number of Exposed User Number (N_{eu}) and the total Number of Exposed Users that consumed more than the lethal dose (N_{eu50}) of the original network and WNP

a_p a weight to differentiate the importance of each DMA

p the district label

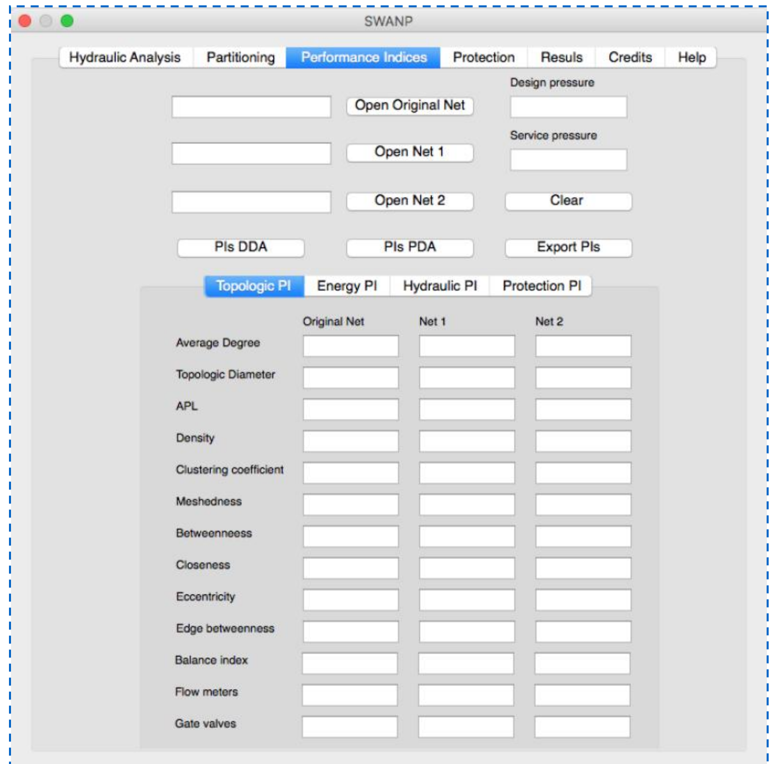
The protection tool was tested on the WDN of the city of **Matamoros** (Tamaulipas, Mexico) in collaboration with the Mexican Institute of Water Technology.

Comparison of exposed users (Neu) between original network and three partitioning layout with different weights.

Network	Neu [%]	Neu50 [%]	Lep [%]
a	65.83	12.20	45.88
b	58.03	5.32	54.58
c	58.02	16.67	54.24

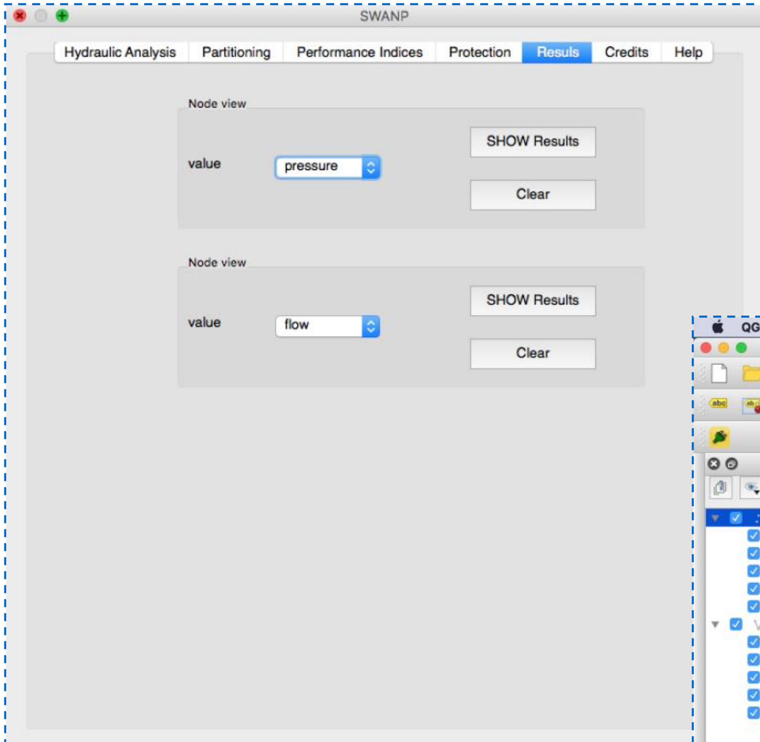
SWANP 3.0 allows to compute some traditional and innovative Performance Indices (PI) that provide information both on the whole network and on a sub-system or DMA. PI are organized in four category and tested in different publications:

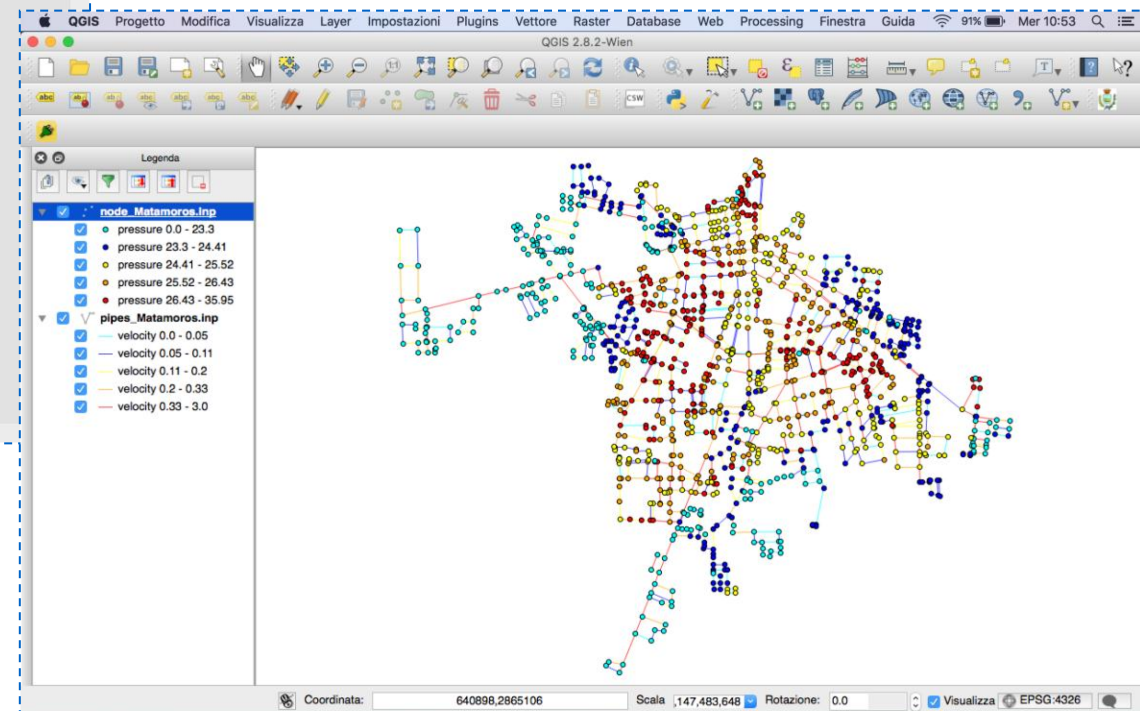
1) Topological PI
2) Energy PI
3) Hydraulic PI
4) Protection PI



SWANP GUI: Performance Indices section

SWANP 3.0 uses also the visualization instruments provided by the QGIS, to plot the result of hydraulic analisys, partitiong etc.





SWANP GUI: Results section

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EIP Water Action Group

Pooling resources – Innovating water

Thank you for your attention