D.T.2.2.2. PARTNER-SPECIFIC PILOT ACTION DOCUMENTATION ITALIAN PILOT: RIDRACOLI WATER SUPPLY SYSTEM

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This report describes the activities carried on so far on the Italian pilot of the MUHA project, the Ridracoli water supply system, in relation to the following hazard: flooding, earthquake, drought, accidental pollution (microbiological pollution).
These are specific activities designed on the Italian pilot, to improve the water safety plan of Romagna Acque - Società delle Fonti s.r.l., the water utility in charge for the management of the supply system of Ridracoli. Romagna Acque is part of the Hera group, a multi-utility acting also in the fields of waste management and energy.

1. Activities on flooding hazard.

1.1 Introduction

Within the activities of the MUHA project concerning the flood risk investigation, a study is carried out with the aim of analysing and verifying the lamination of the historical flood events affecting the Ridracoli dam.

To this end, the first phase of the analysis concerns the reconstruction of the inflow discharge hydrographs during the most severe flood events occurred in the last years. Specifically, six major floods are selected for the study in the period 2010-2019.

The lack of level records at a monitoring station located immediately upstream of the reservoir, capable of representing the hydrograph coming into the dam, makes it necessary to proceed with the reconstruction of the incoming hydrographs. These are estimated by applying the LAMINA model (Castorani e Moramarco, 1995) starting from the knowledge of the released flow rate, the variation of the lake level and the reservoir curve, i.e. the lake level-storage volume relationship.

In detail, we first proceed to reconstruct the outflows from the reservoir, known the equations and graphs of the regulating devices, starting from the performed release manoeuvres. Then, based on the recorded lake levels and the available reservoir curve, we reconstruct the incoming discharge hydrographs, which will be used during the second phase of the analysis to investigate possible different scenarios for the dam management.

1.2 Mathematical model for flood events lamination

The LAMINA model (Castorani and Moramarco, 1995) is used to describe the lamination of historic flood events incoming into the reservoir. This model can be used both for the dimensioning of the bottom outlets and the spillways and for the verification of their operation.

In the last case, if the incoming flood wave is known as well as the type and size of each outlet system, the analysis consists in the determination of the maximum level reached in the artificial lake during the lamination phase, considering the constraint related, for instance, to the maximum outflow discharge or to the maximum flood volume that can be released downstream the dam.

The LAMINA model is used to describe the lamination of the flooding hydrographs at the inlet to the reservoir and is based on the continuity equation written in the following form:

$$q_{in}(t) - q_{rel}(t) = \frac{dW(t)}{dt} \qquad (1)$$

where:
q_{in}: inflow to the artificial reservoir;
q_{rel}: outflow from the artificial reservoir;
$W = W_0$ h: storage volume compared to the reference level h;
W_0: unit volume of reservoir, which can be obtained from the lake level-volume reservoir curve
h: water level compared to the adopted reference plan;
t: time.

1.2.1 Numerical solution

The total released discharge from the dam, q_{rel}, is computed as the sum of all the contributions to the downstream outflow from the various outlets and spillways:

$$q_{rel} = q_{rel,sp} + q_{rel,b1} + q_{rel,b2} + q_{rel,der} \quad (2)$$

where $q_{rel,sp}$ is the discharge released from the surface spillway, $q_{rel,b1}$ is the discharge released from the bottom outlet 1, $q_{rel,b2}$ is the discharge released from the bottom outlet 2, and $q_{rel,der}$ is the discharge derived to the drinking water treatment plant.
Equation (1) can be written in a dimensionless form, normalizing the flow rates based on the maximum inlet rate to the dam (associated with the return time of interest or the observed peak), q_{max}, and the times with the relative peak time, t_p, as follows (*Castorani and Moramarco, 1995*):

$$q_{in}^{*}(\tau) - q_{ril}^{*}(\tau) = \frac{dW(\tau)}{d\tau} = F^{*}\frac{dh}{d\tau} \quad (3)$$

with

$$F^{*} = \frac{W_0}{q_{max} \cdot t_p}; \ \tau = \frac{t}{t_p}; \ q_{in}^{*} = \frac{q_a}{q_{max}}; \ q_{ril}^{*} = \frac{q_{ril}}{q_{max}} \quad (4)$$

where h is the water level referred to an identified reference plan, against which the hydraulic head affecting each released system shall be assessed.
The differential equation (3) can be solved by applying the Runge-Kutta criteria that allows to identify four different increments h_{xi} starting from the initial value h_i at time τ_i:

$$h_{x1} = f(\tau_i, h_i, q_{in,i}^{*}) \cdot D\tau \quad (5)$$
$$h_{x2} = f(\tau_i + \frac{D\tau}{2}, h_i + 0.5 \cdot h_{x1}, (q_{in,i}^{*} + q_{in,i+1}^{*})/2) \cdot D\tau \quad (6)$$
$$h_{x3} = f(\tau_i + \frac{D\tau}{2}, h_i + 0.5 \cdot h_{x2}, (q_{in,i}^{*} + q_{in,i+1}^{*})/2) \cdot D\tau \quad (7)$$
$$h_{x4} = f(\tau_i + D\tau, h_i + h_{x3}, q_{in,i+1}^{*}) \cdot D\tau \quad (8)$$

$D\tau$ represents the temporal dimensionless increment.
The total increase in water height with respect to the reference plane, *Dh*, is defined as follows:

$$Dh = 1/6\,(h_{x1} + h_{x2} + h_{x3} + h_{x4}) \quad (9)$$

Therefore, the water level at time i+1 is given by:

$$h_{1+i} = h_i + Dh \quad (10)$$

The function $f(\tau, h, q_{in}^{*})$ is expressed as:

$$f(\tau, h, q_{in}^{*}) = \frac{1}{F}(q_{in}^{*} - q_{rel}^{*}) \quad (11)$$

1.2.2 Dam releases estimation

As concerns the assessment of the outflow released downstream from the dam, it is necessary to know the various types of outlets systems, which can be distinguished in free surface spillways, low bottom outlet and middle bottom outlet. Moreover, the flow rate derived to the drinking water plant has to be considered.
The discharge released from the different outflow systems can be easily derived from the available management curves that allow to estimate the outflow from the bottom outlets starting from the knowledge of the lake level and the opening rate of the gates (see Figure 1 and Figure 2) and the

outflow from the surface spillway starting from the knowledge of the lake level alone (see Figure 3). The official management curves have been provided by Romagna Acque.

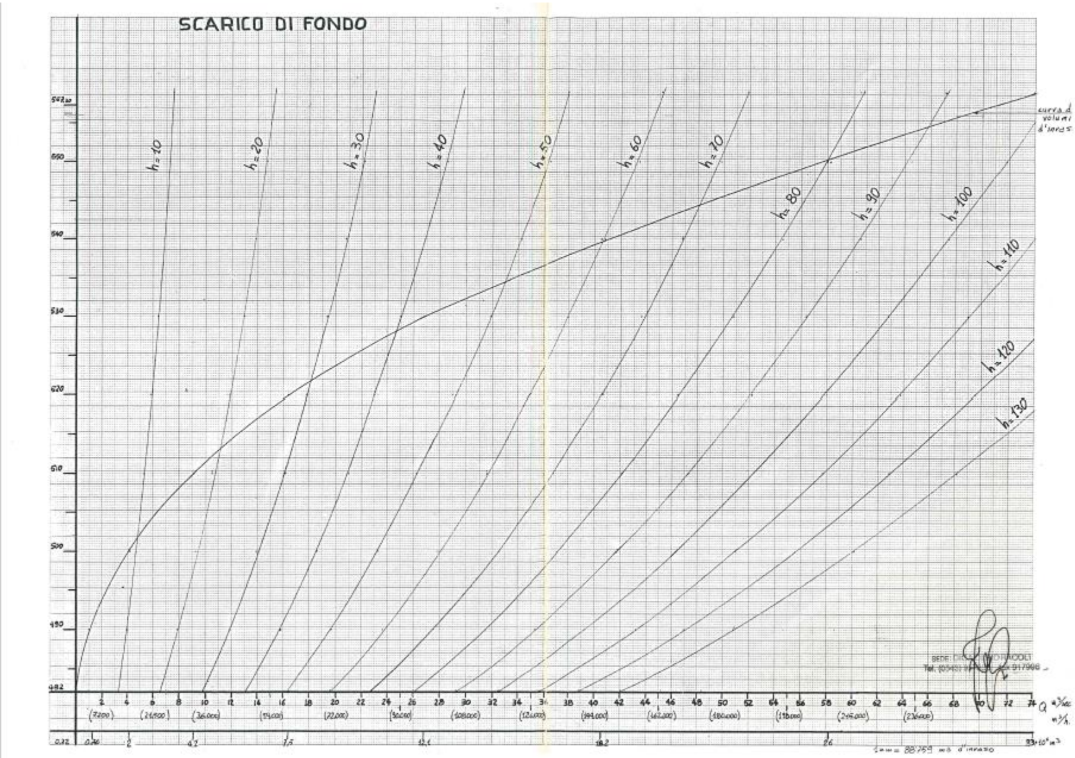


Figure 1. Outflow curves for the low bottom outlet of the Ridracoli dam (source: Romagna Acque).

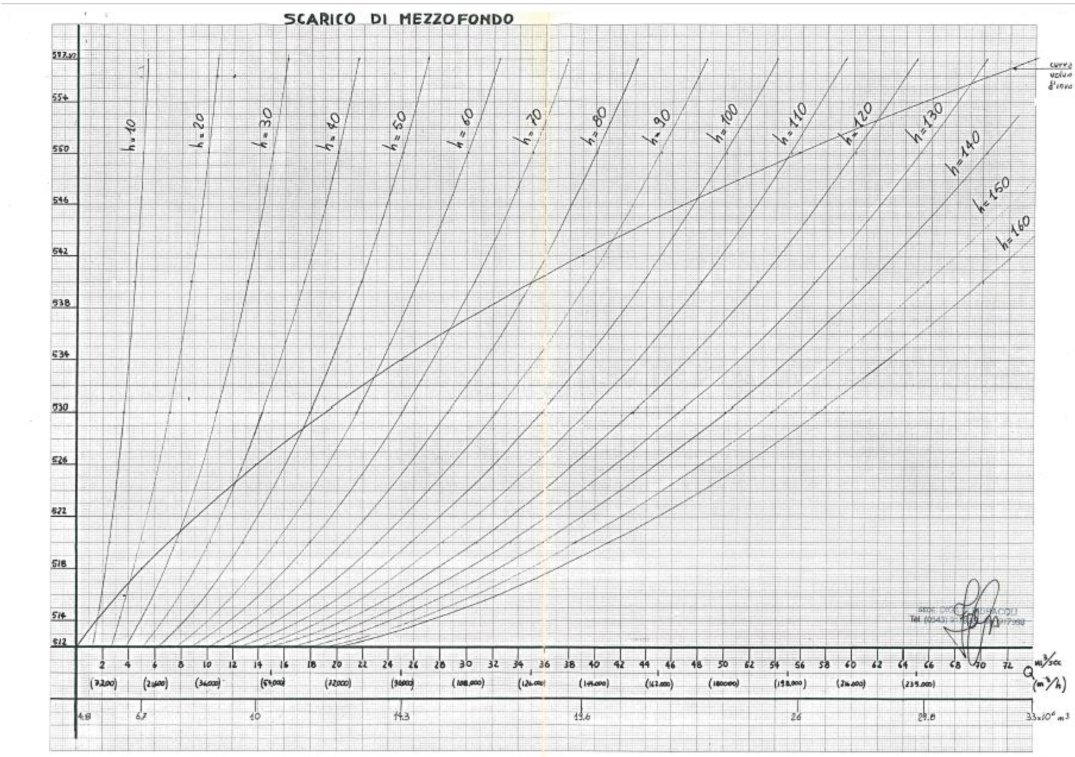


Figure 2. Outflow curves for the middle bottom outlet of the Ridracoli dam (source: Romagna Acque).

Q.I. m.s.m.	Volume Invaso mc.	Lama Sfioro cm.	Portata Sfioro mc/sec
557.31	33,072,667	0	0
557.32	33,082,999	1	0.016
557.33	33,093,334	2	0.087
557.34	33,103,671	3	0.227
557.35	33,114,010	4	0.430
557.36	33,124,351	5	0.724
557.37	33,134,694	6	1.049
557.38	33,145,040	7	1.446
557.39	33,155,387	8	1.884
557.40	33,165,737	9	2.361
557.41	33,176,089	10	2.874
557.42	33,186,443	11	3.430
557.43	33,196,799	12	4.026
557.44	33,207,158	13	4.660
557.45	33,217,518	14	5.333
557.46	33,227,881	15	6.045
557.47	33,238,246	16	6.791
557.48	33,248,613	17	7.580
557.49	33,258,982	18	8.406
557.50	33,269,354	19	9.271
557.51	33,279,727	20	10.174
557.52	33,290,103	21	11.114
557.53	33,300,481	22	12.092
557.54	33,310,861	23	13.100
557.55	33,321,243	24	14.152
557.56	33,331,627	25	15.241
557.57	33,342,014	26	16.366
557.58	33,352,402	27	17.529
557.59	33,362,793	28	18.727
557.60	33,373,186	29	19.954

Q.I. m.s.m.	Volume Invaso mc.	Lama Sfioro cm.	Portata Sfioro mc/sec
557.61	33,383,581	30	21.225
557.62	33,393,979	31	22.531
557.63	33,404,378	32	23.873
557.64	33,414,780	33	25.251
557.65	33,425,184	34	26.664
557.66	33,435,590	35	28.103
557.67	33,445,998	36	29.586
557.68	33,456,408	37	31.103
557.69	33,466,820	38	32.655
557.70	33,477,235	39	34.242
557.71	33,487,652	40	35.863
557.72	33,498,071	41	37.508
557.73	33,508,492	42	39.196
557.74	33,518,915	43	40.919
557.75	33,529,341	44	42.675
557.76	33,539,768	45	44.464
557.77	33,550,198	46	46.287
557.78	33,560,630	47	48.142
557.79	33,571,064	48	50.019
557.80	33,581,501	49	51.940
557.90	33,685,983	59	72.890
558.00	33,790,682	69	96.891
558.10	33,895,598	79	123.775
558.20	34,000,732	89	153.400
558.30	34,106,084	99	185.500
558.40	34,211,653	109	220.000
558.50	34,317,441	119	256.600
558.60	34,423,447	129	295.300
558.70	34,529,672	139	335.800
558.80	34,636,115	149	377.900
558.90	34,742,778	159	421.400
559.00	34,849,660	169	466.300
559.10	34,956,762	179	512.200
559.20	35,064,084	189	559.100

Figure 3. Tables providing the spilled flow from the free surface spillways based on the knowledge of the lake level (source: Romagna Acque).

1.3 Historical flood events analysis: inflow discharge hydrographs reconstruction

The lack of level recordings at a monitoring station immediately upstream of the reservoir does not allow to have a direct instrument able to represent the hydrograph incoming into the reservoir, observed during the event.

For this reason, the events are reconstructed by means of the dimensionless continuity equation (3) and made explicit with respect to the input flow, known for the entire survey period under consideration, the outflow rate and the time pattern of the reservoir levels at hourly intervals.

The flow rate released downstream during the historical floods is determined using the equations, graphs and tables in section 2.2, applied considering the information and data reported in the manoeuvring registers provided by *Romagna Acque*.

Lake level trends were also provided by *Romagna Acque*. Starting from the value of the lake level, it is possible to evaluate the changes in the volume of stored water by means of the reservoir storage curve (see Figure 4).

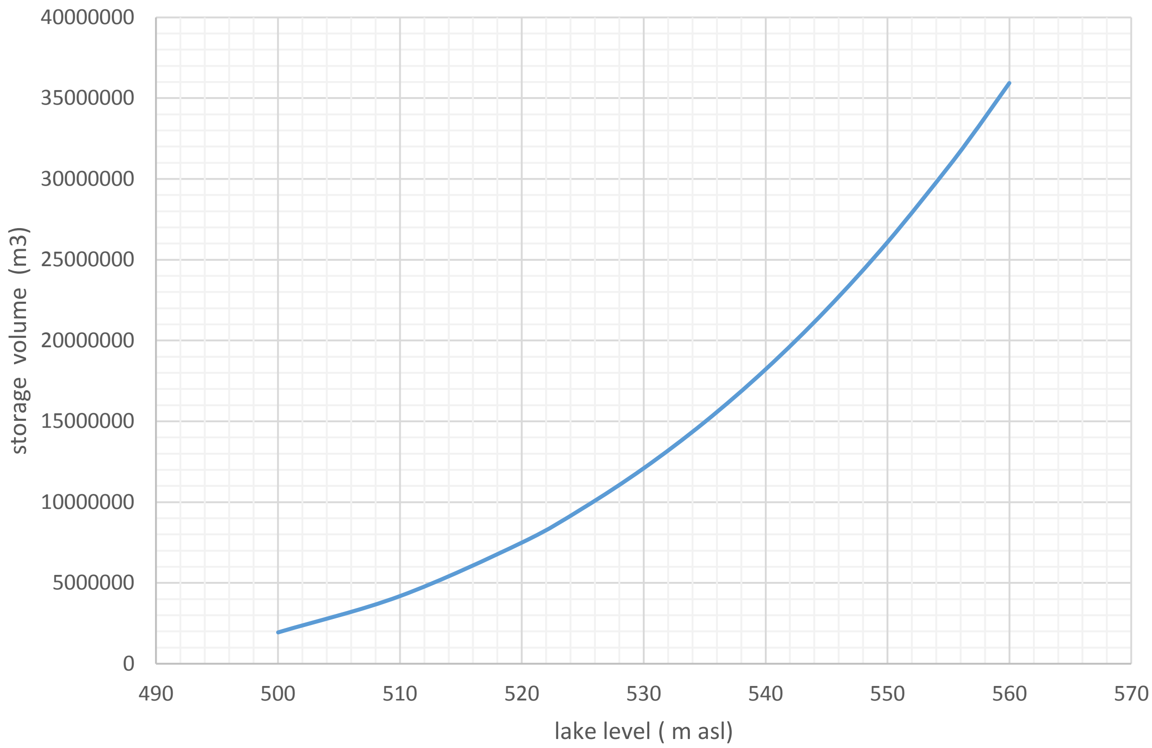


Figure 4. Reservoir storage curve for the Ridracoli dam.

Six main events are identified for the period 2010-2019; these events are selected considering their significance in terms of peak flow rate and total volume.
Figure 5, Figure 6, Figure 7, Figure 8, Figure 9 and Figure 10 show, for the selected flood events, the inflow hydrographs estimated through the LAMINA model, the total outflow released from the dam and the trend of the lake level.
Table *1* summarizes the characteristics of the analysed events: date, total inflow volume W_{inf}, maximum inflow discharge Q_{max}, and maximum lake level H_{max}.

month	year	Starting date	Ending date	W_{inf} (m^3)	Qmax (m^3/s)	Hmax (m asl)
DEC	2010	24/12/10 00:00	24/12/10 23:00	2,001,180	118.2	557.62
MAR	2013	18/03/13 00:00	19/03/13 23:00	4,093,104	75.39	557.53
GEN-FEB	2014	30/01/14 00:00	02/02/14 23:00	3,996,000	130.4	557.59
FEB	2014	10/02/14 00:00	11/02/14 23:00	1,791,060	66.4	557.63
MAR	2018	11/0318 00:00	13/03/818 23:00	2,356,044	53.73	557.61
MAG	2019	12/05/19 00:00	14/05/19 23:00	7,650,900	67.16	557.50

Table 1. Main characteristics of the historical flood events analysed for Ridracoli dam (W_{inf}=total inflow volume; Q_{max}=maximum inflow discharge; H_{max}=maximum lake level)

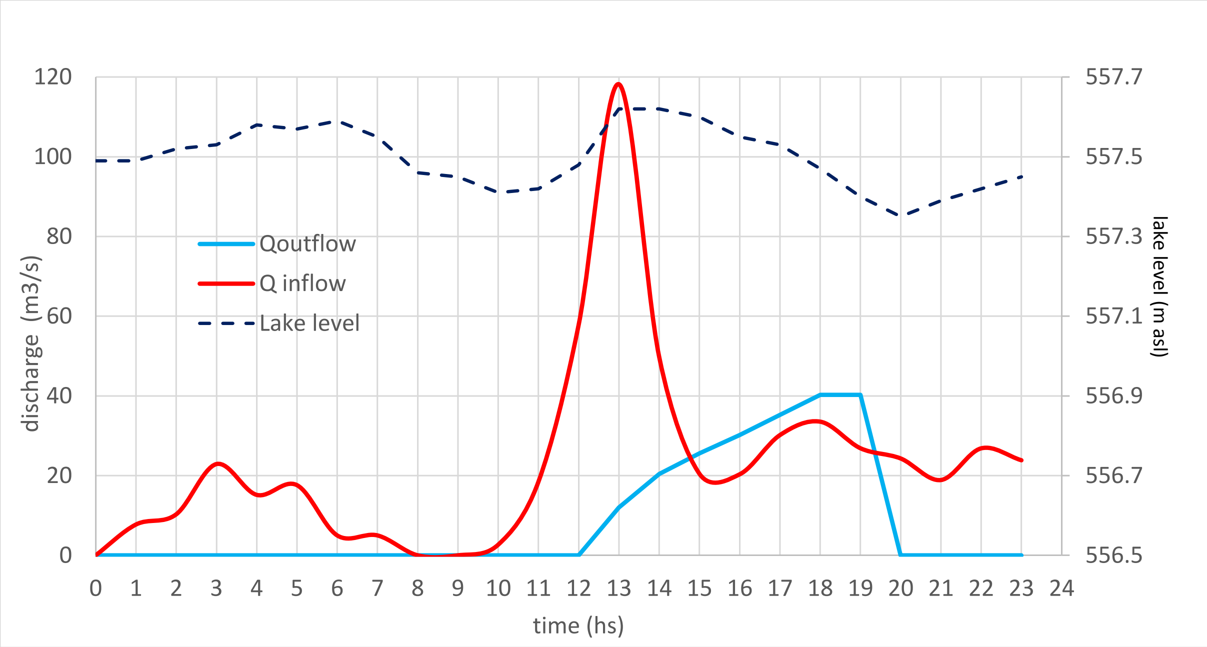


Figure 5. Flood event occurred on December 2010, Ridracoli dam: reconstruction of the inflow hydrograph. The outflow hydrograph and the recorded lake level are also shown.

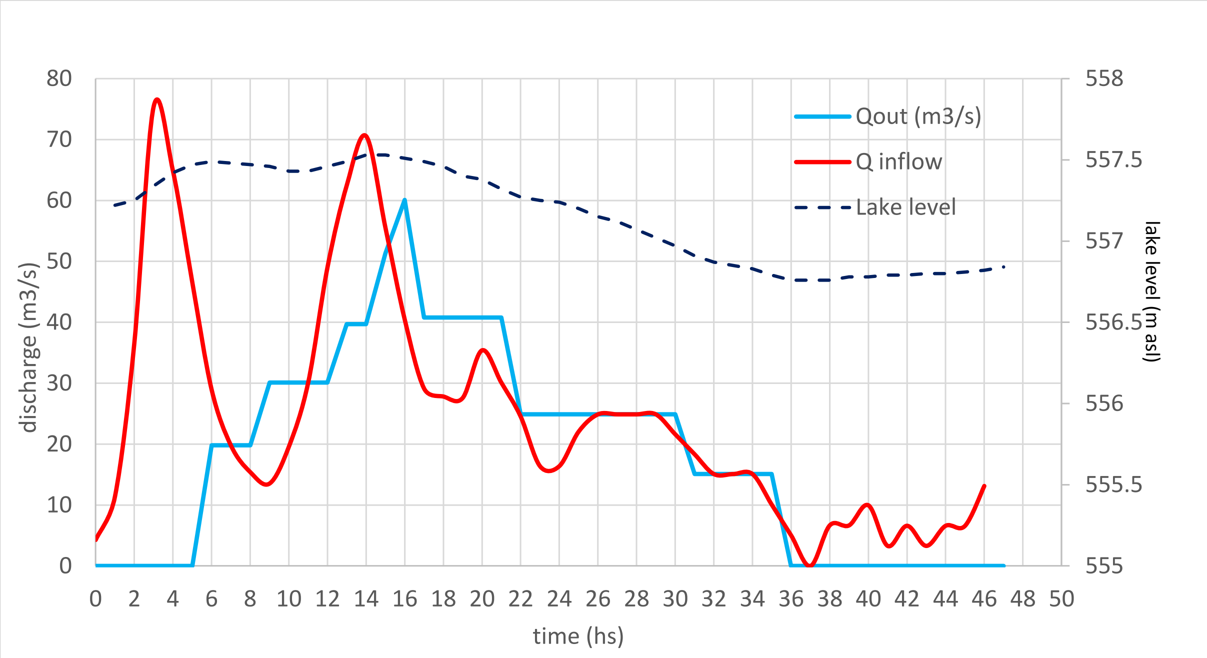


Figure 6. As for Figure 5, but for the flood event occurred on March 2013.

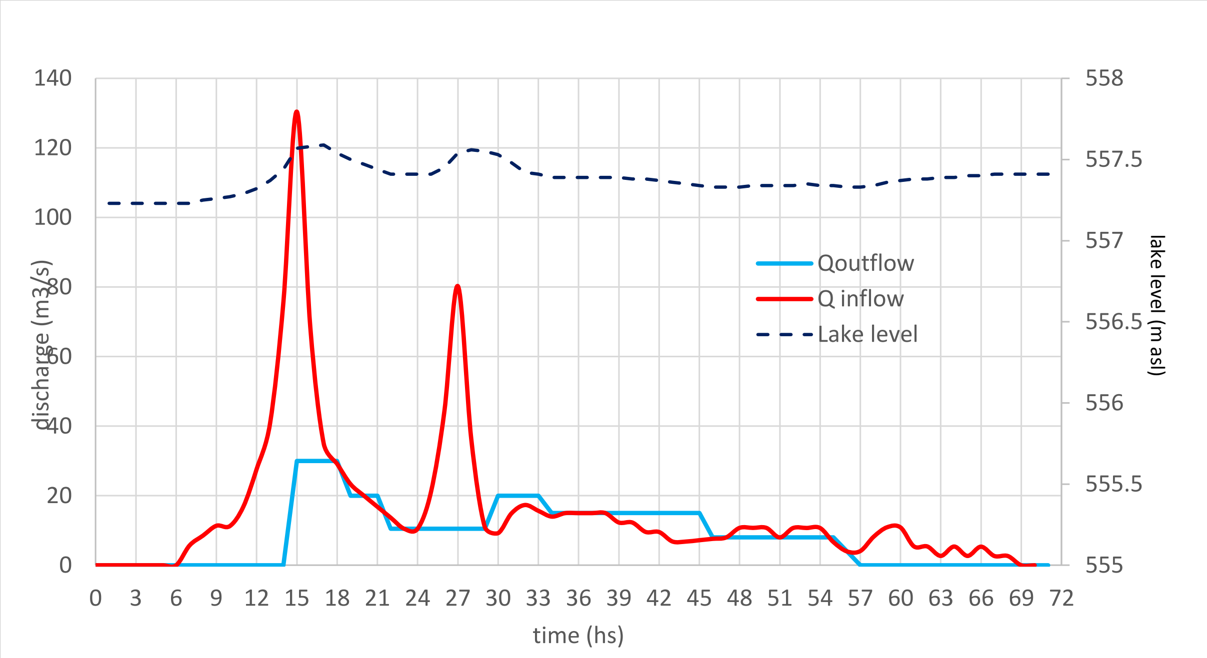


Figure 7. As for Figure 5, but for the flood event occurred on January-February 2014.

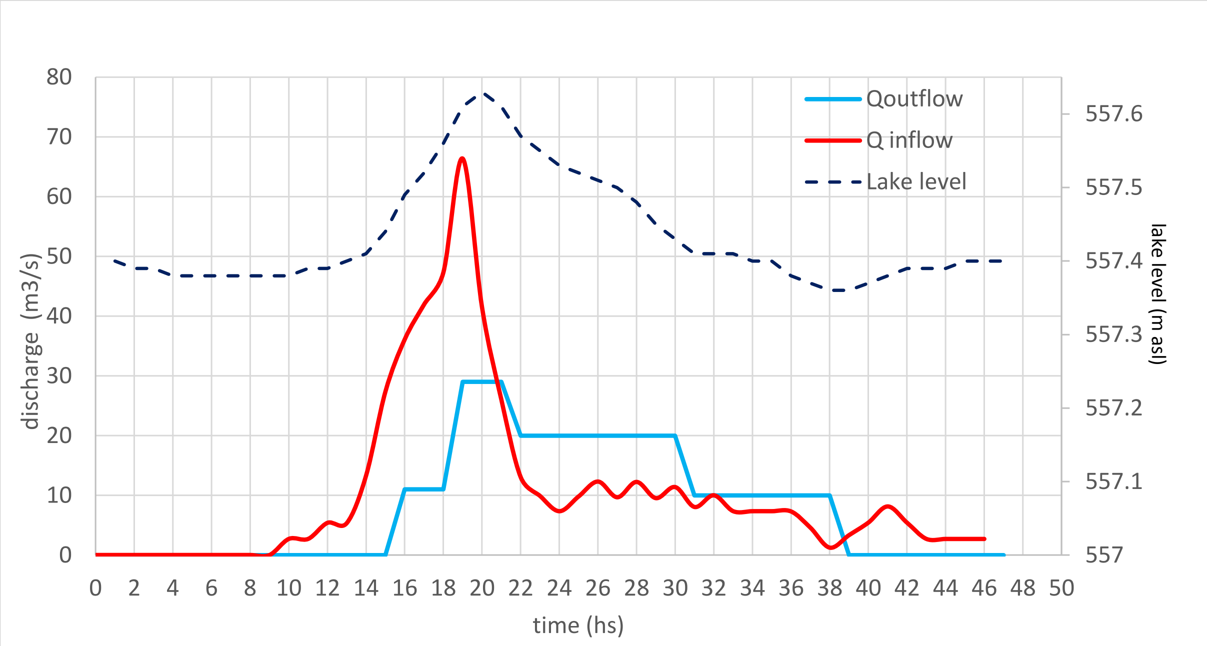


Figure 8. As for Figure 5, but for the flood event occurred on February 2014.

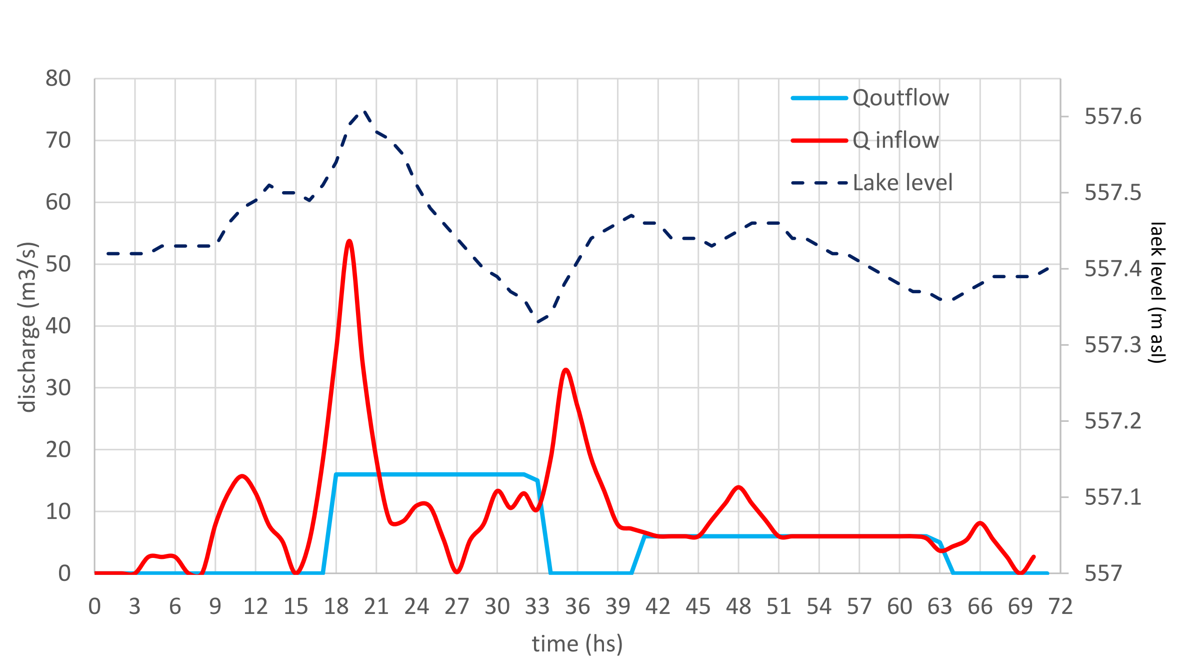


Figure 9. As for Figure 5, but for the flood event occurred on March 2018.

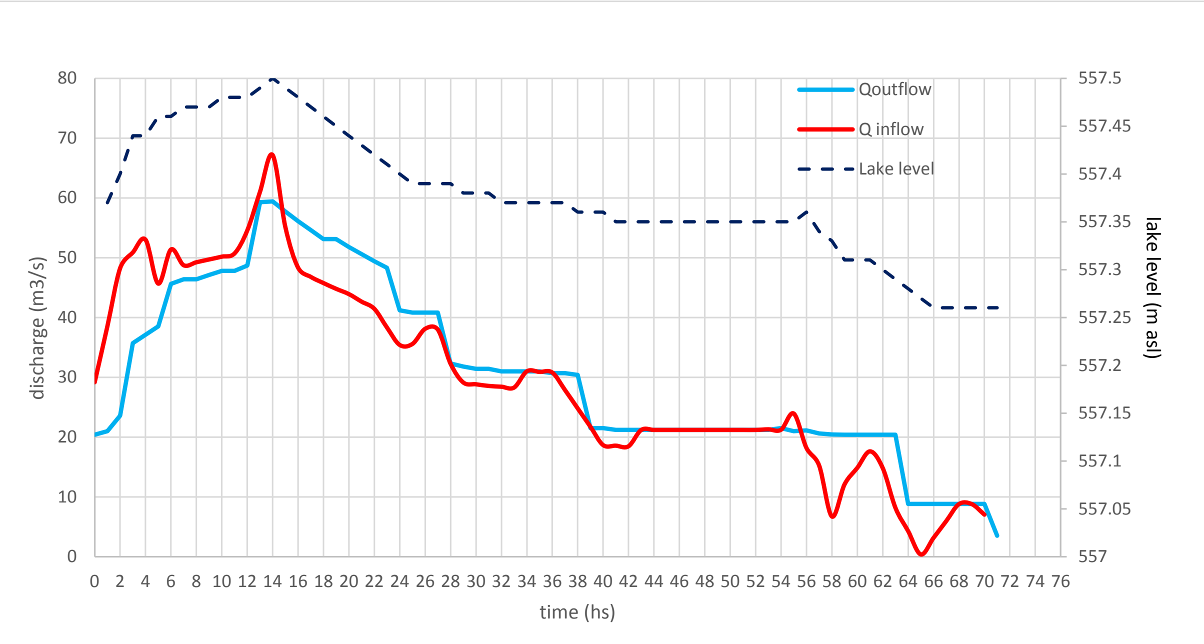


Figure 10. As for Figure 5, but for the flood event occurred on May 2019.

month	year	Starting date	Ending date	Qmax inflow (m³/s)	Qmax outflow (m³/s)	reduction (%)
DEC	2010	24/12/10 00:00	24/12/10 23:00	118.2	40.3	65.9
MAR	2013	18/03/13 00:00	19/03/13 23:00	75.39	60.1	20.3
GEN-FEB	2014	30/01/14 00:00	02/02/14 23:00	130.4	29.2	77.6
FEB	2014	10/02/14 00:00	11/02/14 23:00	66.4	29.0	56.3
MAR	2018	11/0318 00:00	13/03/818 23:00	53.73	16.0	70.2
MAG	2019	12/05/19 00:00	14/05/19 23:00	67.16	59.4	11.6

Table 2. Flood peak reduction for the historical flood events analysed for Ridracoli dam (Q_{max} inflow=maximum inflow discharge; Q_{max} outflow=maximum outflow discharge); reduction=percentage reduction of peak value).

By inspecting the figures 5-10 and Table 2, the lamination effect of the Ridracoli dam on the flood peak entering into the artificial reservoir is evident. Specifically, the maximum inflow discharge has been decreased on average by 50%, with a maximum reduction observed during the flood event occurred in January-February 2014 equal to 77%. This lamination effect is really beneficial for the downstream territory.

2. Activities on earthquake hazard.

2.1 Introduction

The present work aims at providing a summary of the methodological approach being used and of the preliminary activities undertaken at pilot level, with specific reference to the Romagna Acque case. Particularly, this section aims to provide an overview of the activities that are being performed to support the analysis of the drinking water supply infrastructure, focusing on the assessment of the impacts potentially associated to earthquakes. As will be discussed in the following, the approach is not hazard specific, and can therefore be potentially used for a multi-hazard analysis.

The key objective is to develop a straightforward tool that could be used for easily identifying and modeling the impacts of extreme events (including, but not limited to earthquakes) on a generic water supply system, as well as to aid decision-makers in the identification of potential solutions for improving system resilience. Starting from an overview of the most relevant approaches and methods used in the scientific literature, and based on the background and the previous experiences of the research group, a novel methodology based on the integration of multiple topological metrics through Bayesian Belief Networks is proposed and is currently being tested.

The main added value associated with the proposed model can be summarized as follows:

- it provides a simple yet effective approach to support a risk assessment of drinking water supply systems without using detailed hydraulic simulations or complex models. In principle, a topological scheme of the water distribution network (WDN) to be investigated, and only a few general information (e.g. pipe diameter and length) is needed to perform the analysis.
- It supports the analysis of the water supply system independent on the specific hazard under investigation, thus being in principle useful for a real multi-hazard assessment.
- It may be used both for the purpose of risk assessment (e.g. to analyze the impacts of failure scenarios) and for supporting the planning phase (e.g. to test and compare multiple resilience enhancing measures).

2.2 Rationale

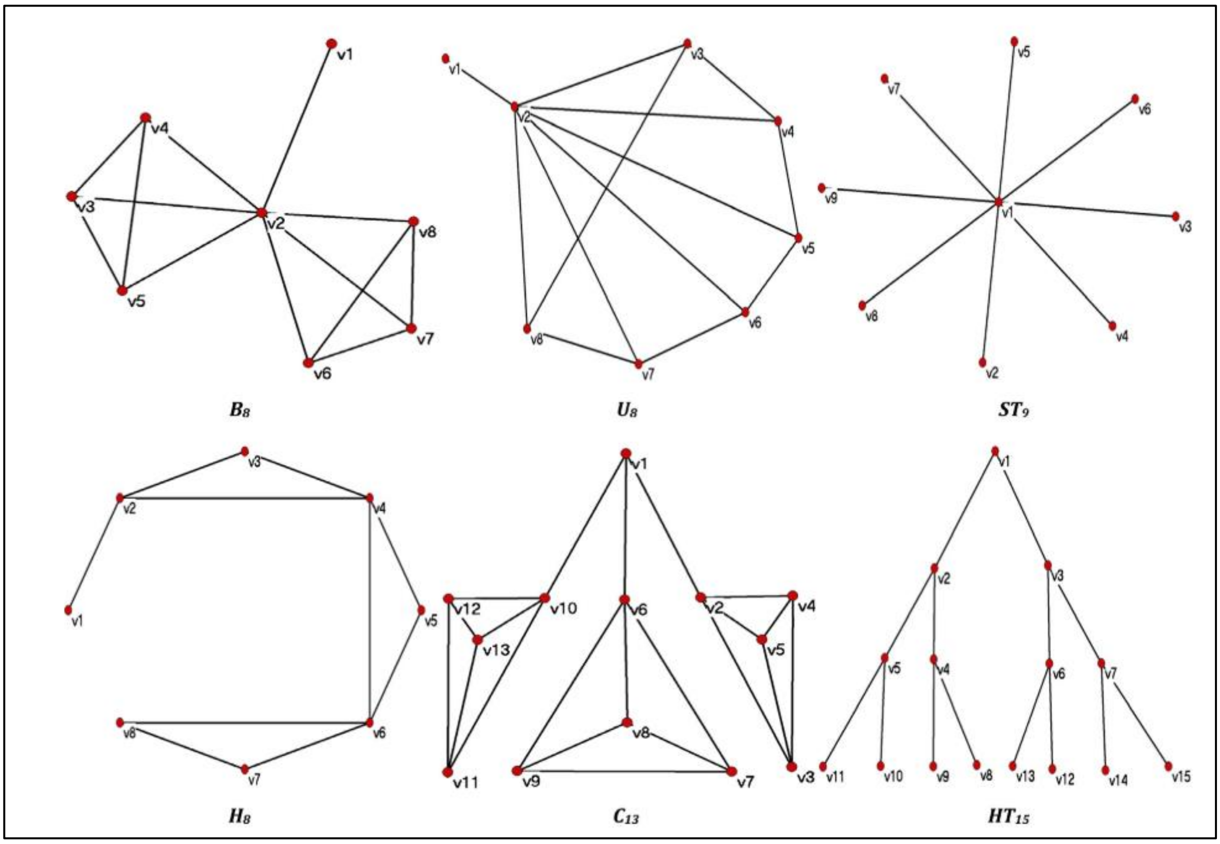
The present report describes a modelling approach that is being developed and tested in the Ridracoli pilot area, but is general and replicable elsewhere. It aims to provide a straightforward analysis of the main features of a water supply system, specifically focusing on its resilience and on the impact that a single pipe failure (due to external causes) may cause on the overall system operation. For the purpose of the present work, *resilience* can be defined – following what has been specifically proposed for water supply infrastructural systems - as “the degree to which the system minimizes level of service failure magnitude and duration over its design life when subject to exceptional conditions” (Butler et al. 2016).

More specifically, **the rationale of the work is to use well-known graph-theory (GT) metrics to describe some topological properties of the system which may (to some extent) describe its resilience to single pipe failure events, independent from the hazard**. Advancing on the current scientific literature on this topic, the main element of innovation of the proposed approach is to aggregate multiple graph-theory metrics through a Bayesian Belief Network (BBN), in order to improve the saliency and accuracy of results. The selected metrics are both used to characterize the infrastructural network in ordinary operating conditions and to perform a network *degradation analysis*, i.e. an assessment of network performances under different conditions of component failure. Similarly, the model can be also used for a scenario analysis oriented to better understanding and quantifying the effectiveness of different resilience-enhancing measures.

The approach is mainly oriented to perform a preliminary analysis on the ‘importance’ of single pipe branches on the entire network resilience, without using detailed hydraulic models, thus specifically supporting either a global screening of the key elements for network operation or a decision-support for driving emergency operations. One of the key advantages of the proposed approach, as already mentioned, is that it is not meant to be ‘hazard-specific’. i.e. it does not explicitly take into account the specificities of the hazard, since it is focused on the impacts on the infrastructural system.

2.3 Background

The available approaches for WDN resilience can be broadly classified as either 'property-based' or 'performance-based'. With the aim of giving a rather generic characterization, '*Performance-based*' approaches typically require that system performance (i.e. the ability to maintain the level of service) under multiple failure scenarios is computed using hydraulic models. Both single component failure analysis (i.e. the targeted or random failure of specific elements of the network) and global resilience analysis (i.e. the systematic analysis of the level of service provision under any possible magnitude of a given system failure mode, irrespective of the threat, as in (Diao et al., 2016) can be used. Such approach results in the generation of response curves which can be used to describe how resilient the system is.
'*Property-based*' approaches investigate the susceptibility to failure, focusing on the link between system performance and its inherent properties such as robustness, diversity, connectivity and redundancy (Yazdani and Jeffrey, 2012; Butler et al., 2017). According to GT, a water supply system can be represented as a *graph*, which comprises a set of *n* nodes and *m* edges (pipes), with the peculiarity that every target node (T) has at least one path of edges connecting to a source node S (Herrera et al., 2016). GT metrics have been recently used in the analysis of such networks with a threefold purpose: (1) to define network size, (2) to describe network-level properties, and (3) to identify important nodes and links (Porse and Lund, 2016). A specific target of such analyses is WDN resilience assessment: metrics can be used both to analyze network topology independent of the potential disruption scenario, and to assess system performances under disruption (Lorenz and Pelz, 2020). A simple example is proposed in the following Figure 11, to highlight the potential relevance of network topological properties on the description of its behavior (Yazdani et al., 2013).



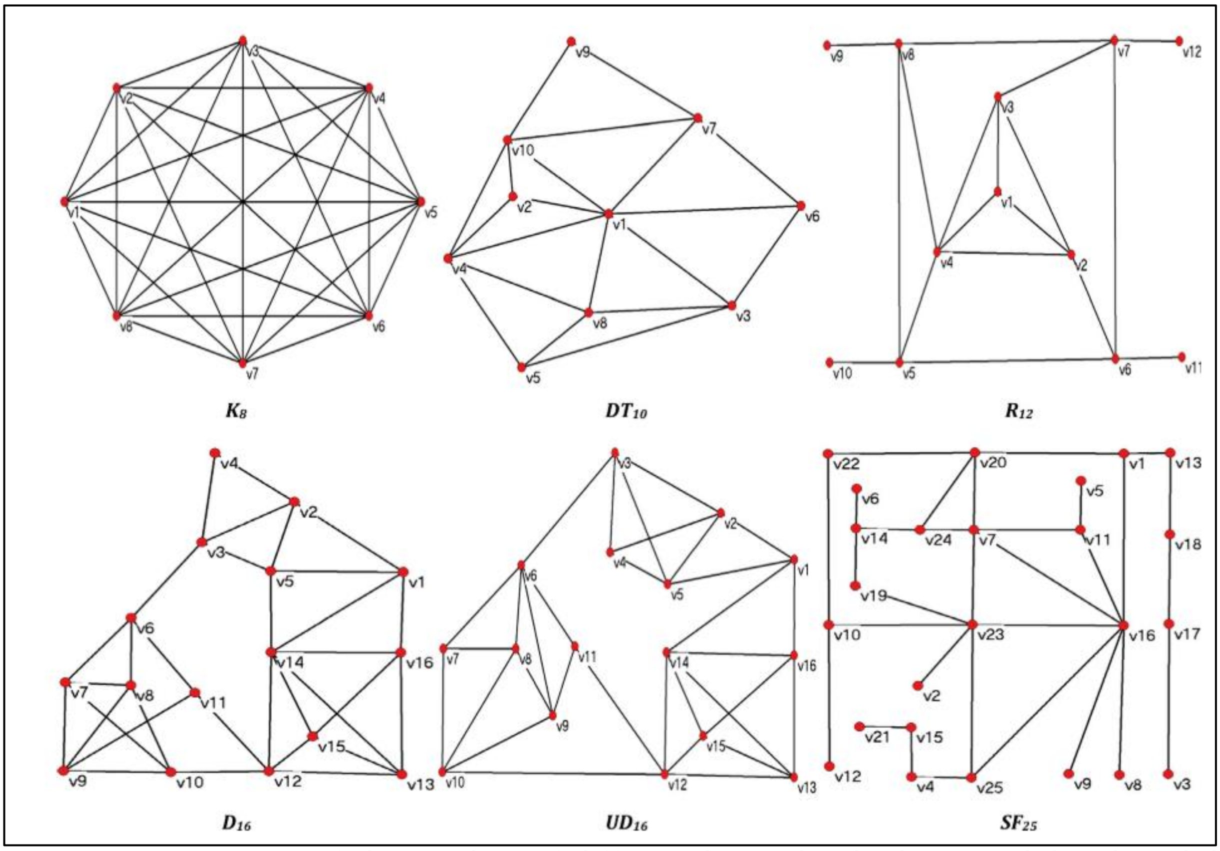


Figure 11. Comparison of the topology of different hierarchical (above) and distributed (below networks (Yazdani et al., 2013)

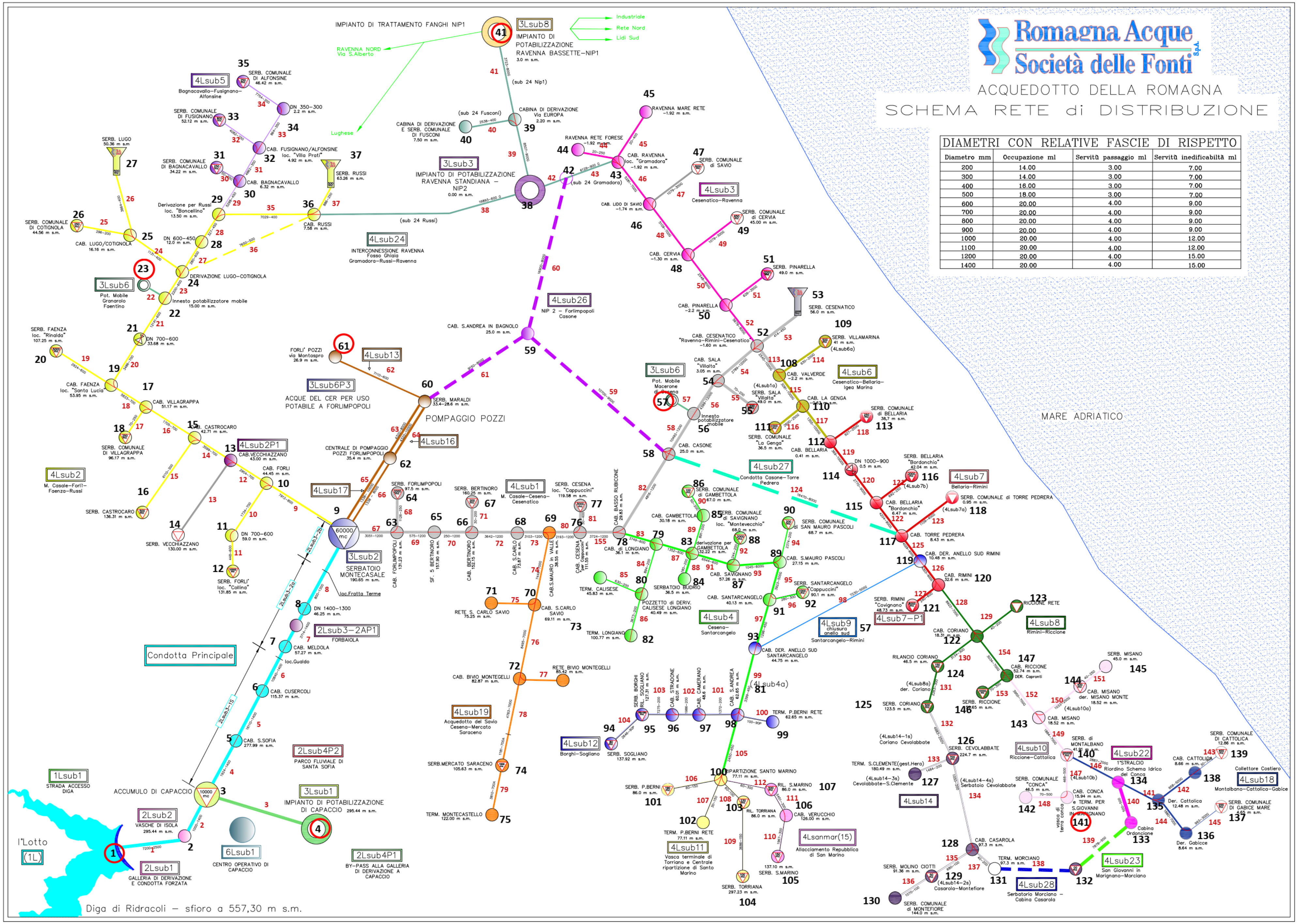
Recently, network analysis approaches have been also widely used to describe the structural properties of water networks, with a specific focus on failures, and a few correlations were identified between network theory metrics and specific properties such as redundancy, robustness and, particularly, resilience (Porse and Lund, 2016). Among the others, (Yazdani and Jeffrey, 2011) used network topology and connectivity to analyze system functionality following perturbations such as single or multiple component removals, due to either random or targeted failures. Yazdani and Jeffrey (2012) used weighted and directed network measures to analyze WDN topology, vulnerability, and robustness against failures, proposing an innovative hybrid metric which combines topological and physical information to define a pipe criticality rank. Porse and Lund (2015, 2016) tested the relevance of network analysis approaches to support large-scale water infrastructure network assessment, focusing both on current system properties and on potential changes in terms e.g. of connectivity, ultimately suggesting decision-makers and managers how to improve the capability of the system to be resilient and quickly adapt to changing conditions. Meng et al. (2018) identified, based on a literature review, a set of attributes which represent key topological properties of WDNs. All such attributes might be described using one (or more) representative metric(s). The authors highlighted that a strong correlation exists between certain metrics of resilience (especially the spatial and temporal scales of failure impacts) and topological attributes (connectivity, network efficiency and modularity).

A review of the such works highlighted that pipe network topology is highly relevant to characterize system performance (Torres et al., 2016), but that several measures need to be taken jointly into account, since no single GT metric can adequately capture the behavior of complex networks. Some studies have specifically discussed the correlation between GT metrics and network performance (Meng et al., 2018; Pagano et al., 2019) finding that significant information can be provided by GT metrics as well, although with some limitations still exist mainly due to the high level of complexity and interconnection in water systems

2.4 Overview of the case study

The water supply infrastructure managed by Romagna Acque is represented schematically in the following Figure 12. It basically comprises two main interconnected gravity supply systems, with an overall length of approximately 400 km. The system is globally characterized by a significant level of complexity and by interconnected subsystems. Both steel (mainly upstream) and cast-iron (mainly downstream) pipes are used, with diameters ranging between 100 mm and 1400 mm.

The system has been preliminary analyzed to identify nodes (both sources and targets) and edges, pipe diameters and lengths. No additional information (e.g. hydraulic data) has been considered intentionally, since the proposed approach aims at providing a simplified analysis relying on topological network information only.



DIAMETRI CON RELATIVE FASCIE DI RISPETTO			
Diametro mm	Occupazione ml	Servitù passaggio ml	Servitù inedificabilità ml
200	14.00	3.00	7.00
300	14.00	3.00	7.00
400	16.00	3.00	7.00
500	18.00	3.00	7.00
600	20.00	4.00	9.00
700	20.00	4.00	9.00
800	20.00	4.00	9.00
900	20.00	4.00	9.00
1000	20.00	4.00	12.00
1100	20.00	4.00	12.00
1200	20.00	4.00	15.00
1400	20.00	4.00	15.00

Figure 12. Topological Scheme of the drinking water supply system managed by Romagna Acque

2.5 Description of the proposed approach

The proposed approach basically requires that a set of topological measures for WDN analysis (details are provided in the following) is computed for the network under investigation, firstly to provide a characterization of the network under 'normal' conditions, and then to perform a network degradation analysis. The results of the latter are then aggregated using a Bayesian Network, and used to define a pipe ranking which aims to reflect the individual pipe contribution to WDN resilience to single pipe failure.

2.5.1 Selection of GT measures

The literature review proposed in the Section 2.3 suggests the relevance of some topological properties to analyze the performances of water supply networks and to describe some specific characteristics of their behavior. Particularly, a few authors highlighted a strong correlation between topological measures and network resilience properties, corroborated also by the analysis of the results of hydraulic models.

In the proposed approach, three network properties are mainly considered to be adequately described by topological indicators, namely: i) *vulnerability to failures*; ii) *efficiency*; iii) *robustness*. The vulnerability is related to the WDN tolerance to faults and to its resilience against efforts to isolate parts (Yazdani and Jeffrey, 2012; Di Nardo et al., 2018). Efficiency refers to the water flow following the shortest paths for a network. Robustness represents the ability of the system to withstand perturbations while providing water to customers with an acceptable quantity and quality (Mazumder et al., 2018; Meng et al., 2018; Jung et al., 2019).

Such properties are described using a set of limited and non-redundant graph-theory metrics, whose relevance to describe the resilience of WDNs through hydraulic simulation had been already proven in the scientific literature. The *selected* metrics are described further into details in the following.

- The algebraic connectivity λ_2 is widely used to describe network behavior against isolation of parts and fault tolerance. The comparison with hydraulic models highlighted a good correlation between time to strain/failure duration and algebraic connectivity (Meng et al., 2018).
- The central point dominance C_b defines the average difference in node betweenness centrality of most central point $C_{b,max}$ and all other n nodes $C_{b,j}$. It basically measures the concentration of the network topology around a central location, and ranges between 0 (regular or 'localized' network) and 1 ('centralized', e.g. star network) (Yazdani et al., 2011, 2013; Porse and Lund, 2016; Pagano et al., 2019).
- The average path length l_m is the average distance along the shortest paths between any two pairs of nodes $d_{i,j}$, compared to all possible pairs of network nodes (Yazdani et al. 2011; Yazdani and Jeffrey 2012; Yazdani et al. 2013; Porse and Lund 2016). Instead of the average path length, an index of network efficiency $E[G]$ is often used, which defines the sum of all the reciprocals of path lengths between two nodes (Porse and Lund, 2016; Balekelayi and Tesfamariam, 2019).
- The contribution of each link to system robustness is estimated considering whether its failure/removal causes a disconnection between sources S and targets T or an increase of the shortest path(s) between them. The shortest paths are weighted based on a simple hydraulic surrogate of flow resistance (reference is made to the Darcy-Weisbach formula as in (Herrera et al., 2016; Pagano et al., 2019; Sitzenfrei et al., 2020))

2.5.2 Network degradation analysis

This project is supported by the Interreg ADRION Programme, funded under the European Regional Development Fund and IPA II fund.

The analysis of network topology provides useful insights for the analysis of the network, specifically supporting an improved understanding of the role of individual elements. Network analysis with respect to random failures can be performed through the degradation analysis, which is based on the selective removal of either nodes or links (Porse and Lund, 2016). The proposed methodology, which aims to be general and replicable as well as able to provide a comprehensive knowledge on system response to external stresses, is based on a systematic assessment of the effect of single edge removal. This ultimately relies on analyzing network connectivity before and after edge removal (Porse and Lund, 2016; Pagano et al., 2019).
The network degradation analysis basically requires the comparison between the value of each metric in case of ordinary operation and under (single) pipe failure. A normalization should be also performed in order to support the comparison of results. The metrics identified in the previous Section should be considered in the degradation analysis:

2.5.3 Aggregation of results using BBN

BBNs are DAGs (i.e. Directed Acyclic Graphs) combining graph theory principles and probability theory through the joint probability distribution (Pearl, 1988). Variables (representing graph nodes) are connected through edges, which define conditional dependencies whose strength is represented by conditional probabilities. BBNs therefore allow a probabilistic representation of interactions between variables, integrating a qualitative (graphical) and a quantitative (probabilistic) component. Full technical details on BBN building and use can be found e.g. in (Pearl, 1988).
BBNs are used, for the purpose of the proposed method, as a tool for aggregating the information provided by multiple GT metrics, following e.g. the approach proposed by Balekelayi and Tesfamariam (2019). Particularly, BBNs help describing the relationships between selected GT metrics and specific network resilience properties.
More specifically, the causal chain of the BBN relies on the following structure which comprises three levels: input variables (i.e. the variation of the selected GT metrics obtained through the degradation analysis) → influence on the resilience properties (i.e. vulnerability to failures, efficiency, robustness) → individual pipe contribution to network resilience. In other words, given the variation of the selected GT metrics in the degradation analysis and the influence of such metrics on well-known network resilience properties, the influence of single pipe failure on global resilience is estimated. A structure of the BBN that is being built for the purpose, is proposed in Figure 13.

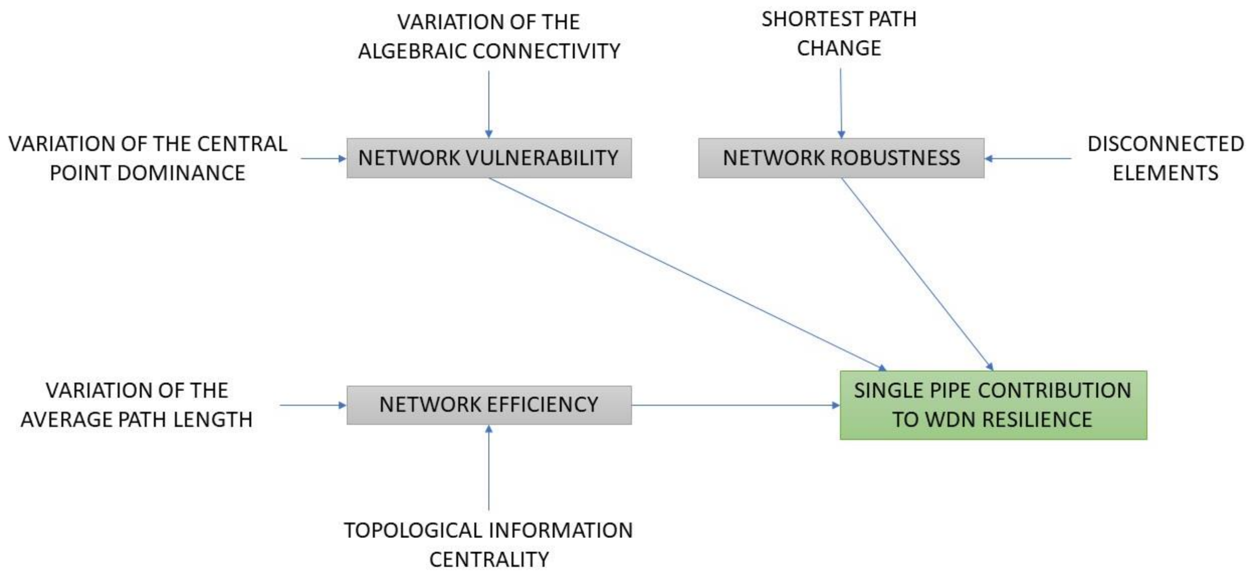


Figure 13. Structure of the aggregation of the GT metrics for assessing the individual pipe contribution to WDN resilience, to be performed using BBN.

The final definition of the BBN requires that the state of the variables included in the degradation analysis are translated into linguistic values (e.g. ‘High’, ‘Average’, ‘Low’, ‘Null’), based on expert knowledge about WDN operation. Furthermore the CPTs, i.e. the probabilistic ‘engine’ of the BBN need to be defined to quantify the causal relationships in the causal chain.

2.6 Preliminary results

A basic characterization of the WDN under investigation has been performed considering some of the metrics described in the Section 2.5.1 and integrating the information with data provided by (Meng et al., 2018). In the cited work, the Authors provided a range of values of such metrics (the extreme values are identified as Min and Max in the following Figure 14) obtained from the analysis of 80 virtual network (i.e. it does not represent a theoretical range). This is highly useful to compare the behavior of the network under investigation with other networks.

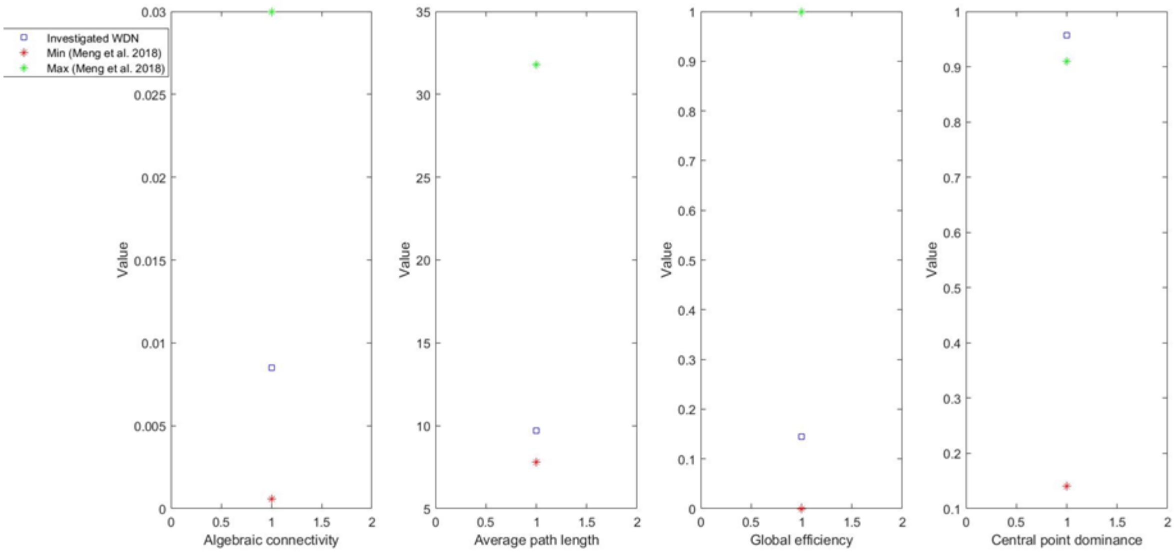


Figure 14. Comparison (over a set of metrics) between the investigated WDN and the values provided by (Meng et al. 2018)

2.7 Overview of next steps

The methodological approach has been conceptualized and is currently being developed, implemented and fine-tuned in the pilot area. Particularly, the following steps will be completed in the next few months:

- Finalization of the procedure for the network degradation analysis, with the definition of the parameters and their normalization.
- Definition of the CPTs for the BBN, based on expert judgement (with the contribution of both experts such as researchers and academics, and the Romagna Acque technical staff).
- Model testing and validation of the results with the water utility.
- Insights on the analyzed network: identification of potential vulnerabilities, pipe prioritization and definition of potential resilience-enhancing strategies, mainly with respect to pipe failure as a consequence of natural hazards
- Preparation or guidelines for the development of this GT analysis in other WDN.

3. Activities on drought hazard.

3.1 Context of the MUHA activities

The Ridracoli water supply system is prone to water shortage crisis during periods of precipitation significantly under the mean. Significant drought events occurred in 2003, 2007 and 2017. It is worth stressing that in 2017 the Council of Ministers declared the “state of emergency” for water crisis after the request of the Emilia-Romagna region for the provinces of Parma, Piacenza, Bologna, Modena, Reggio Emilia, Ravenna, Forlì-Cesena, Rimini, the last three being supplied by the water supplied system connected to Ridracoli. More details on the description of the water supply system can be found in the previous deliverable T2.1.3. *Descriptive documentation of pilot actions and related issues addressing drinking water supply resilience – Italy*.

During the emergency phase, in 2007 the commissioner structure for the national level was set up at the Civil Protection Department, which had the task of adopting measures aimed at managing the water crisis, from the regulation of water resources to the adoption of decrees aimed at saving water, from the suppression of illegal water withdrawals to the coordination of interventions and provisional measures aimed at emergency water supply, and so on.

Following the aforementioned water crisis, monitoring has been set up on the main Emilia-Romagna reservoirs, such as the Ridracoli dam, for which the Water Utility produces and sends a weekly report to the Civil Protection Regional Agency informing on the levels and volumes of the reservoir, in addition to the quantity of drinking water and a report with the withdrawals from all resources exploited in the area (wells, reservoirs, withdrawals from the river Po); since 2007, a monitoring of the water table of the Marecchia river cone in the Rimini area has also been performed. Data collected on the reservoir (volume, height, etc.) are available on-line at institutional web site of Romagna Acque www.romagnacque.it

At the national level, the Civil Protection Department has followed and facilitated monitoring activities carried out by the Managing Authority and the Emilia-Romagna Region. To date, this activity is carried on in the framework of the *Observatories for Water Uses* established at the District Basin Authorities by the Ministry of the Environment on July 2016. These observatories aim at collecting, analyzing and sharing meteorological and water availability data to provide technical support for decisions by the bodies in charge and in particular to activate measures to mitigate the water crisis with due timeliness. The Water Use Observatories are a measure of the Water Management Plans, which in turn are excerpts from the District Basin Plans. The Water Use Observatories are made up of representatives of the District Basin Authorities, the Department of Civil Protection, the Regions and the various stakeholders. A more detailed description of the Water Uses Observatories structure, as well as on their role, is reported in the deliverable DT1.1.4 (report at country level). In addition, the Department of Civil Protection, periodically, convenes the Technical Group for monthly and seasonal forecasts, made up of experts from research bodies (ISPRA, CNR-IBIMET, CNR-ISAC, CREA, ARPA Emilia-Romagna) and from the Air Force, with the task of (i) providing forecasting scenarios on a monthly and seasonal scale; (ii) providing technical support for decisions, especially about the management of water resources, the fight against forest fires and the prevention of the effects of heat waves on public health.

As far as the water manager concerns, Romagna Acque has adopted since 2019 a “management model” of the reservoir, developed by the University of Bologna - Department of Civil, Chemical, Environmental, and Materials Engineering. The model simulates the mass balance of the water supply system at weekly scale, taking into account:

- Inflow to the reservoir. A specific hydrological model has been set up, calibrated and validated to simulate the inflow to the reservoir as a function of the precipitation and temperature on the recharge area

- The monthly water needs of the seven “supply areas” presented above. The amount of water needs for each month and area have been assessed considering the maximum consumptions over the period 2009-2016
- The limits (min and max) of water that can be supplied to each area from the reservoir and from each of the local sources and purification plant (NIP2).

The model implemented by the University of Bologna - Department of Civil, Chemical, Environmental, and Materials Engineering is adopted for different purposes:

- To assess the vulnerability of the water supply system of Ridracoli to drought events and related resilience;
- To assess early warning indicators for possible forthcoming conditions of water shortage to short-medium terms;
- To identify possible allocation schemes able to decrease the vulnerability of the system to water scarcity conditions and increase its resilience
- To evaluate changes of the vulnerability and resilience of the system under climate change.

However, it is worth noting that such model has been developed in five years with significant associated costs. In the framework of the *Observatories for Water Uses* as well as during the preparation water safety plans, such an investment appears to be not feasible for most of the water utilities, especially the smallest ones.
A common tool, accessible for everyone, able to quantify the risk of shortage considering both the specific infrastructure, management capacity and meteorological variability is still missing.
The Water Research Institute of the National Research Council of Italy (LP of MUHA) has been actively collaborated for years with the Italian civil protection department (PP10) to address such issue (e.g. Romano et al. 2017; Guyennon et al. 2017; Romano et al. 2018), creating a user-friendly open source tool, able to adapt to any water supply system scheme and specificity in a relative short time.
In the frame of the MUHA WPT2 activities, the Water Research institute, in collaboration with PP10 (DPC) and the water utility in charge of the management of the Ridracoli water supply system (Romagna Acque), is testing and developing the user friendly tool *INOPIA^{QGIS}* on the Ridracoli water supply system. The proposed methodology (implemented as plugin in a software developed on a GIS open source platform) is based on a guided procedure aiming at individuating the climatic conditions that can potentially lead to a significant decrease of the exploited water resources and to possible water shortages, considering both the existing infrastructure and the management options for multiresources-multiusers water supply systems. The Ridracoli pilot will be used as a benchmark of *INOPIA^{QGIS}* by comparison with the existing model with the aim of extending its use to other water supply systems of the ADRION area.

3.2 INOPIA^{Qgis}, a tool accessible for everyone

As previously introduced, the main issue to address regarding models able to quantify the risk of shortage associated to drought conditions is to improve their transportability and accessibility. If INOPIA^{Qgis} has already been developed adopting an open source approach (i.e. the plugin is based on the open source python 3 technology and hosted by the open source Qgis software) and a native user-friendly philosophy, both aspects can be improved. Within the MUHA project, the LP (CNR) has dedicated resources to overcome the limits previously identified:

(i) Migrate from a local “homemade” programming to a professional programming hosted on GITLAB, easy to install, available everywhere at any time, able to handle user errors, to improve the software stability and ready for further multi-developer integrations by the open source community (as illustrated in Figure 15). For such purpose a collaboration between CNR and Faunalia, open Source and GIS Specialists (https://www.faunalia.eu/en/), has been activated through external expertise.

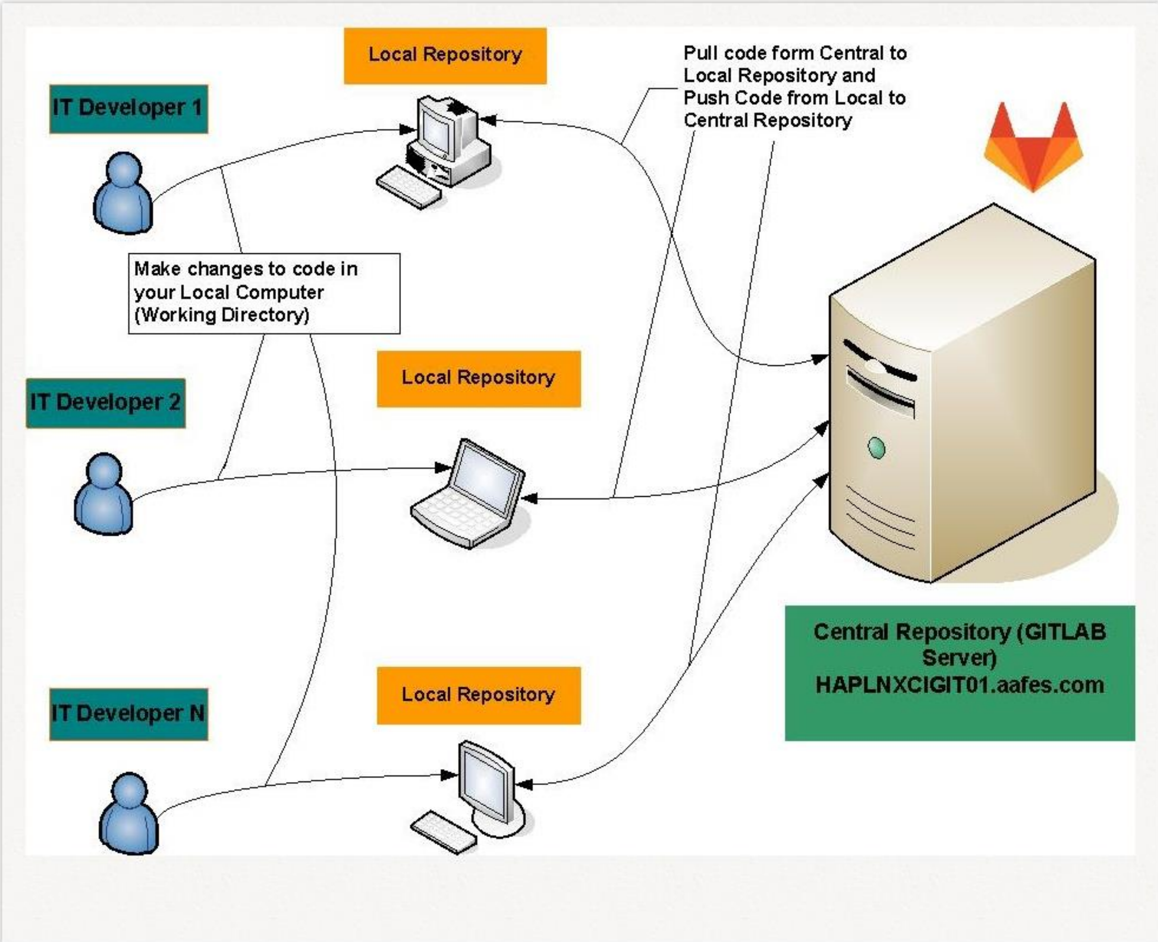


Figure 15. Multi-developer capacity offered by the GITLAB technology

(ii) Create a visual brand identity and an intuitive set of icons to make the use of INOPIA^{Qgis} actually user friendly. For such purpose a collaboration between CNR and the professional designer D. Togninelli, has been activated through external expertise.

The current level of implementation of both aspects are further detailed and illustrated in the following.

3.3 Switching to the open source community

Thanks to the active collaboration with Faunalia (contract 9531/2021) the INOPIA^{Qgis} code has migrate from a local homemade programming to a community cloud professional programming hosted by the open source GITLAB technology (https://about.gitlab.com/) on the LP servers. Such migration is illustrated in Figure 16.

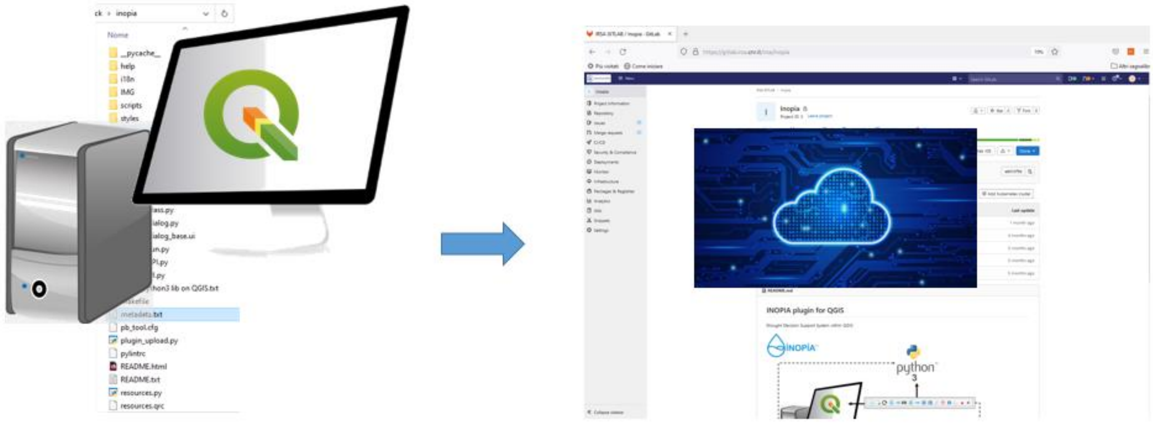


Figure 16. Migration from local programming to a professional GITLAB programming

Together with such migration, opening the possibility of multi-developer integration by the open source community, the code has been refactorised (as illustrated in Figure 17) and integrated with exception handling by professional the programmer from the Faunalia, open Source and GIS Specialists. Code refactoring is defined as the process of restructuring computer code without changing or adding something to its external behaviour and functionality. The goal of code refactoring is to turn “dirty” code into “clean” code, which reduces a project’s overall technical debt. “Dirty” code is an informal term that refers to any code that is hard to maintain and update, and even more difficult to understand and translate. The idea behind technical debt is that if the code is as clean as possible, it is much easier to change and improve in later iterations – so that your future self and other future programmers who work with the code can take advantage from its organization. Refactoring may seem unimportant when compared to higher priority tasks, but the cumulative effect from such changes is significant and can lead to a better-functioning team and approach to programming. Such efforts significantly improved both the transportability and the user-friendly approach of the tool, and allowed for an easier integration of the open source community, giving to anyone the possibility to propose possible new integrations to the plugin (e.g. unforeseen water sources, unforeseen technical limitation for water distribution, new management rules, ect …), to better adapt to any situation. The productive collaboration with Faunalia is still under progress.

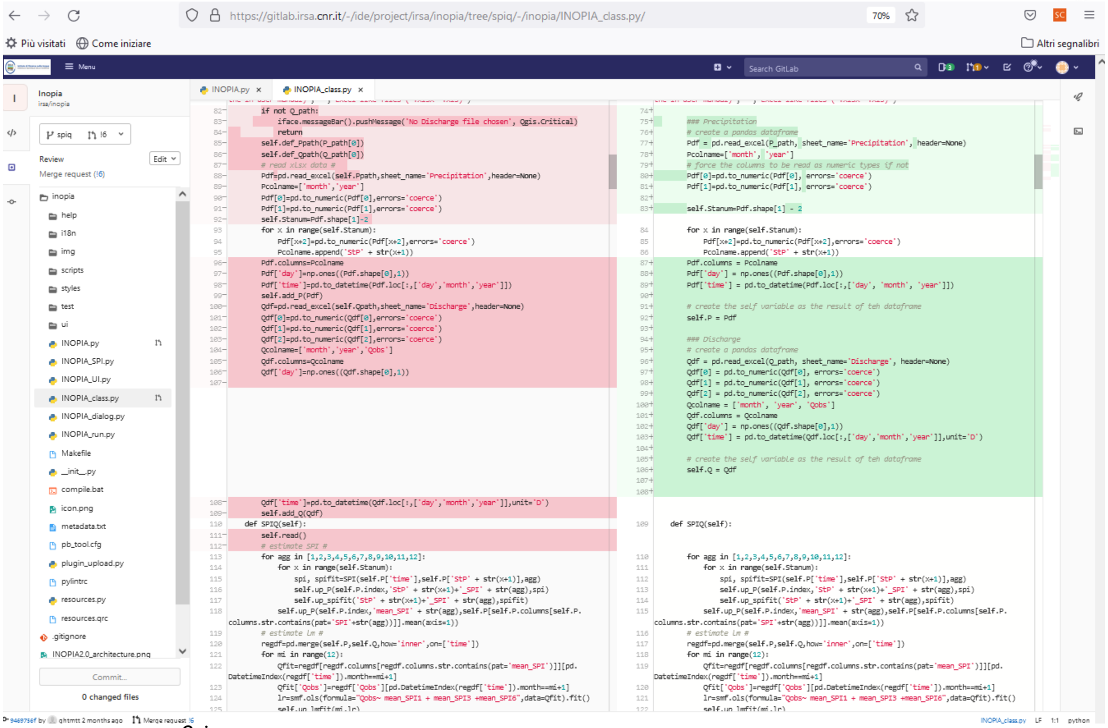


Figure 17. INOPIA^{Qgis} refactorisation on GITLAB

3.4 User friendly and brand identity

Thanks to the collaboration with the professional designer D. Togninelli within the framework of MUHA (contract 9531/2021), a full brand identity (Figure 18) and a user-friendly intuitive set of icons has been developed to further improve the accessibility for everyone to the tool. The visual result is a compromise between the logo and the illustration approach, resulting of the balance between simplifications and scientific exigence.

Figure 18. INOPIA Brand identity guideline (annex D1)

Such aspect of the tool should not be under evaluated. In fact, the success of the overall attempt to overcome the issue highlighted in the context of MUHA activities regarding the

drought hazard, depends on the acceptation and diffusion of the tool among the stakeholders (from high specialised technical staff available for the larger water utilities to the reduced team of the small ones, which cannot afford for specific formation). The easiest to use and the more user friendly is the tool, the wider is the expected diffusion, making the proposed tool more pertinent and efficient for the decision makers (e.g. water utilities, water agencies, district basin authorities, national civil protection …).
The INOPIA brand identity guideline is available in annex (annex 1) and the main elements are reported in the following

- Logo INOPIA

Figure 19. INOPIA logo with payoff

- Resources, distribution and project management set of icons

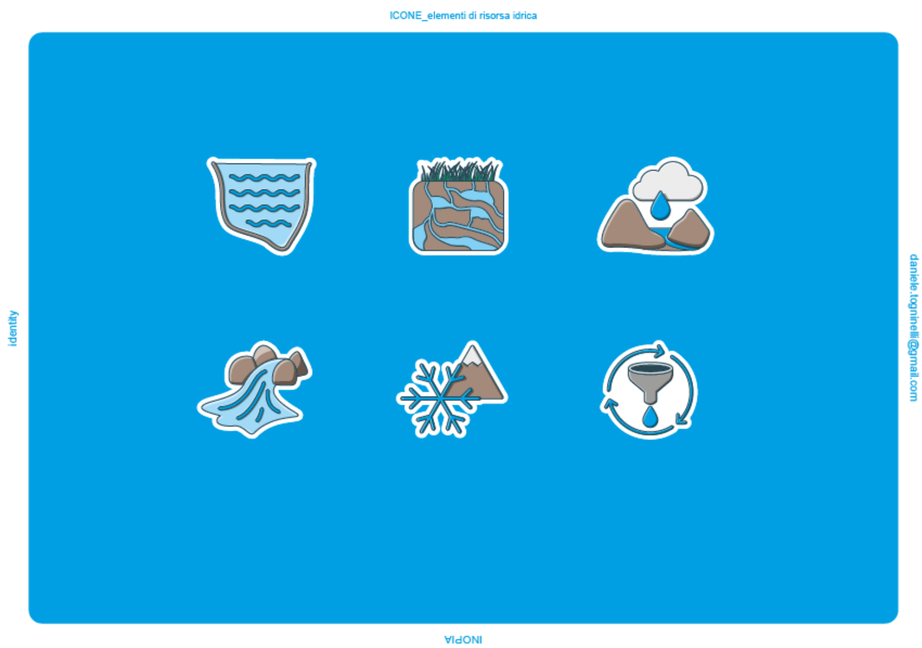


Figure 20. INOPIA^{Qgis} resources set of icons

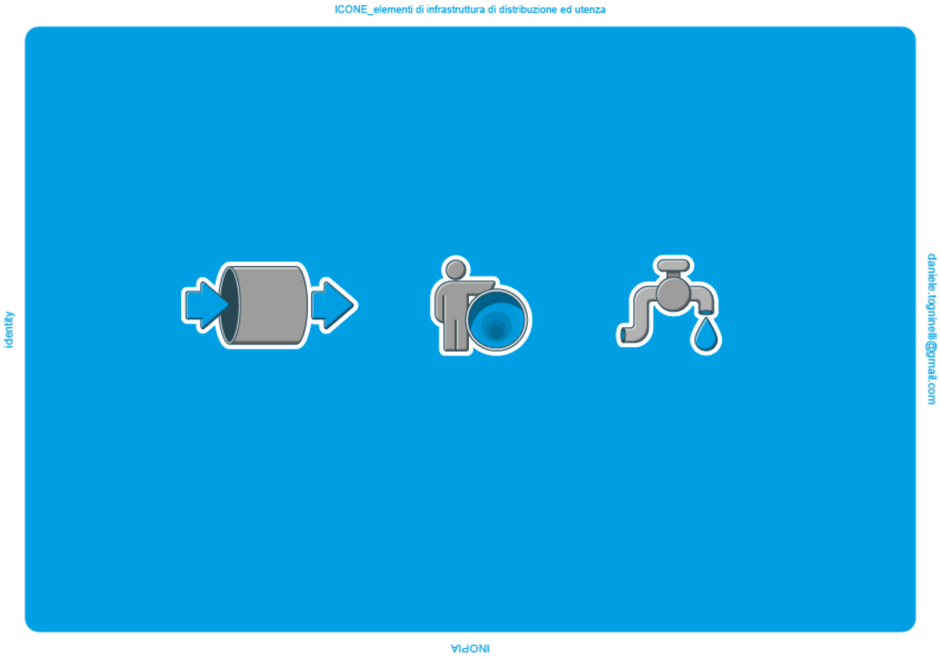


Figure 21. INOPIA^{Qgis} distribution set of icons

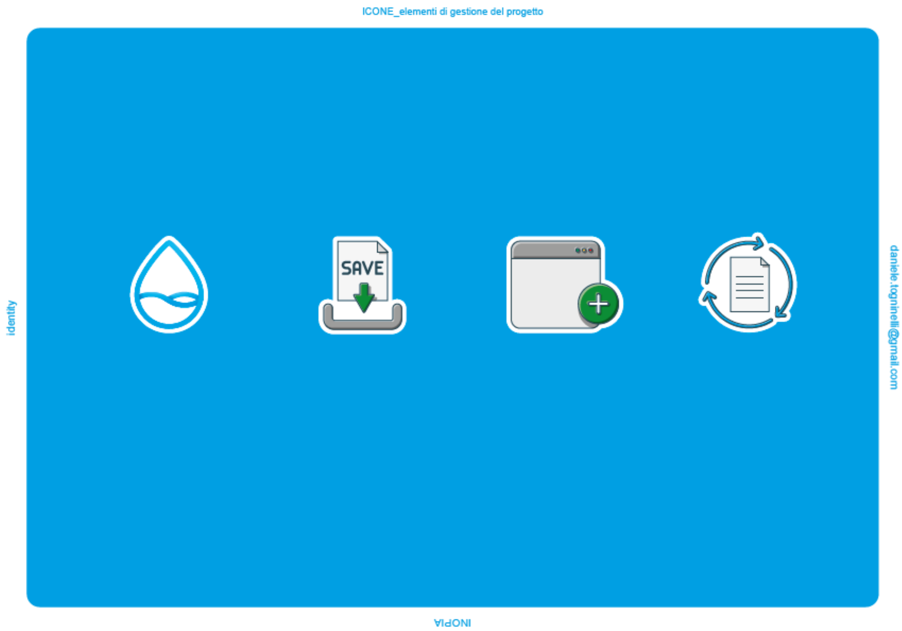


Figure 22. INOPIA^{Qgis} project management set of icons

3.5 Adapting INOPIA^{Qgis} to the Ridracoli WSS management specificities

In the framework of the MUHA project, the current version of the tool has been further developed and implemented in the Italian pilot action developing a specific routine able to meet the different water user needs by dynamically addressing the available water resources depending on the status of the different resources exploited (reservoir, wells, purification plants, etc.).

The current implementation of INOPIA^{Qgis} to the MUHA Italian case study is presented in Figure 23. Such implementation consider:

- the different resources available: the monthly inflow to the dam based on monthly precipitation anomalies; the dam properties; the maximum seasonal mean extractable water from each well fields; the maximum available water for each macro users from the purification plant (NIP2);

- The monthly water needs of the seven macro users, considering the maximum consumptions over the period 2009-2016
- The distribution facilities from the different resources to each supplied macro users
- A management node between each macro users and its connected resources

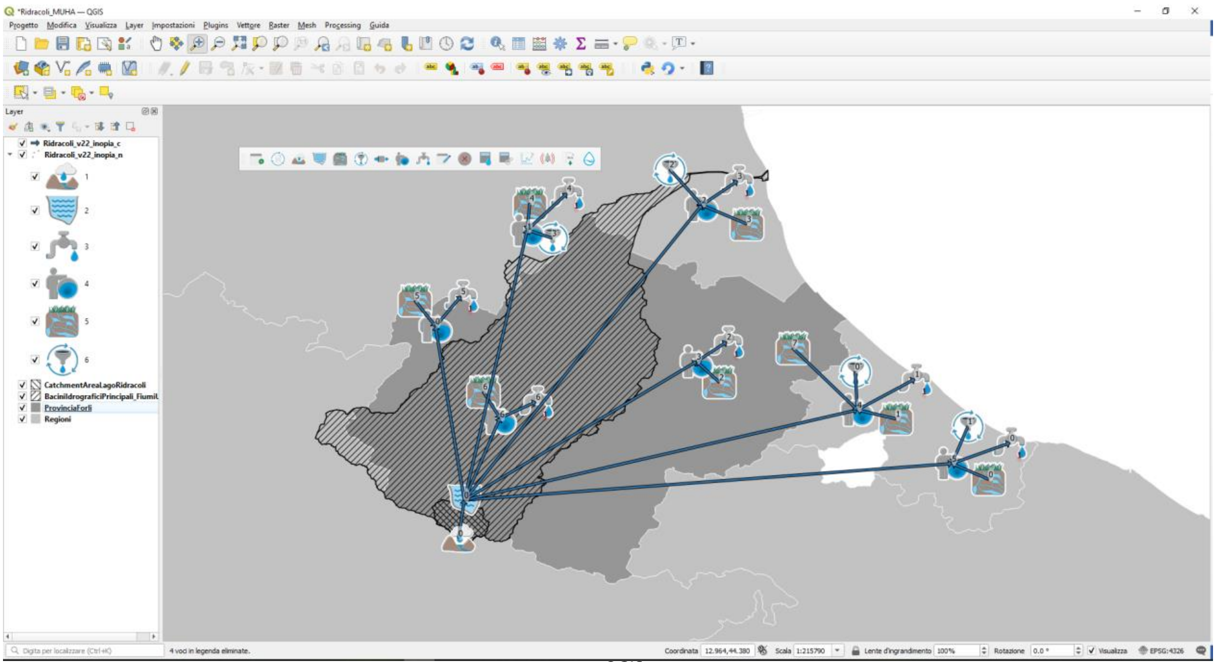


Figure 23. Current implementation of INOPIA^{QGIS} on the Ridracoli water supply system

It is worth stressing that in the Emilia-Romagna region specific “civil protection plans” on the territory related to drought hazard are not available. Drought and water scarcity events, possibly leading to water shortage conditions, are managed after the water crisis of 2007 at regional level through specific operational procedures involving different institution (public health services, environmental agency, regional civil protection, water manager, etc.).
During the emergency phase, in 2007 the commissioner structure for the national level was set up at the Civil Protection Department, which had the task of adopting measures aimed at managing the water crisis, from the regulation of water resources to the adoption of decrees aimed at saving water, from the suppression of illegal water withdrawals to the coordination of interventions and provisional measures aimed at emergency water supply, and so on.
The measures or action agreed during the emergency phase in 2007 are triggered below specific “threshold levels” of the Ridracoli reservoir. To such levels correspond not only an increasing reduction of the withdrawals, but also an increasing deterioration of the quality of the water resource.
According to the thresholds for triggering measures set at regional level (see also section 3.3 of DT2.1.3-Italy) reported here in Table 2, warning and pre-alert conditions have been reached in winter 1993-1994, summer 2007 and autumn 2011. However, it is worth stressing that almost every year the level of the reservoir below approximately 50% of its total capacity obliges Romagna Acque to tune the ordinary management rules decreasing the amount of water supplied by the reservoir and increasing that one from the alternative resources (wells, purification plants). In other words, prevention of water crises relies on a wise management of the resource significantly before that warning or pre-alert conditions

have been reached. Such pre-warning management can be set as a pre-established allocation of the different macro users to their connected resources, even considering seasonality variation in the rules, or can be estimated on the basis of the availability of each resource, in particular that of the Ridracoli Dam.

LEVEL	STORED VOLUME [m^3] (max volume = 33 Mm^3; death volume = 5 Mm^3)	MEASURES/ACTIONS
warning	6,000,000 < V < 7,000,000	Information campaign to save water resource Ordinance issued at the municipality level (Mayor Ordinance) to save water resource Assessment of the water needs of the "big" users and progressive reduction measures
pre-alert	5,300,00 < V < 6,000,000	Activation of the Regional Operational Committee for emergency (COREM ex art. 23 Regional law 1/2005) Intensification of the information campaign to save water resource Ordinance issued at the municipality level (Mayor decree) to save water resource Possible reduction of water supplied to "big" users Possible declaration of the "regional state of emergency" (Regional Law 1/2005, art. 8) and/or declaration of the "national state of emergency", depending of the meteorological conditions Possible derogation to the actual parameters for water intended for human consumption
Alarm ("Allarme")	Less than 5.300.000	Water rationing measures; Delivery limitation to production users; Civil protection interventions to guarantee the supply through tankers, mobile water purifiers and other provisional measures.

Table 2. Level below which Romagna Acque change the management rules decreasing the amount of water supplied by the reservoir and increasing that one from the alternative resources

To reach such level of management to be tested through INOPIA^{Qgis} within the MUHA project on the Italian case study, a dynamic management rule (i.e. for which the allocation rules of a given macro user at a given time step depends on the connected resources availability) has been developed and is currently under testing. Such parametrization is based on a logistic curve, making possible to switch from a maximum to a minimum allocation of the addressed demand (from 0 to 100%) at a given threshold introducing a wide range of possible non-linearity (from abrupt decision to linear reduction) through a shape coefficient. Such decision has been motivated by both the "universality" and the relative simplicity of the logistic curve, to better adapt to any situation. An illustration of such parametrization applied to the Ridracoli dam is reported in Figure 24, for which the allocation of the demand to the dam from 100 to 50% as the availed volume in the dam decreases, with a smooth decision centered at 15 Mm^3 (obtained with a shape parameter of 0.5).

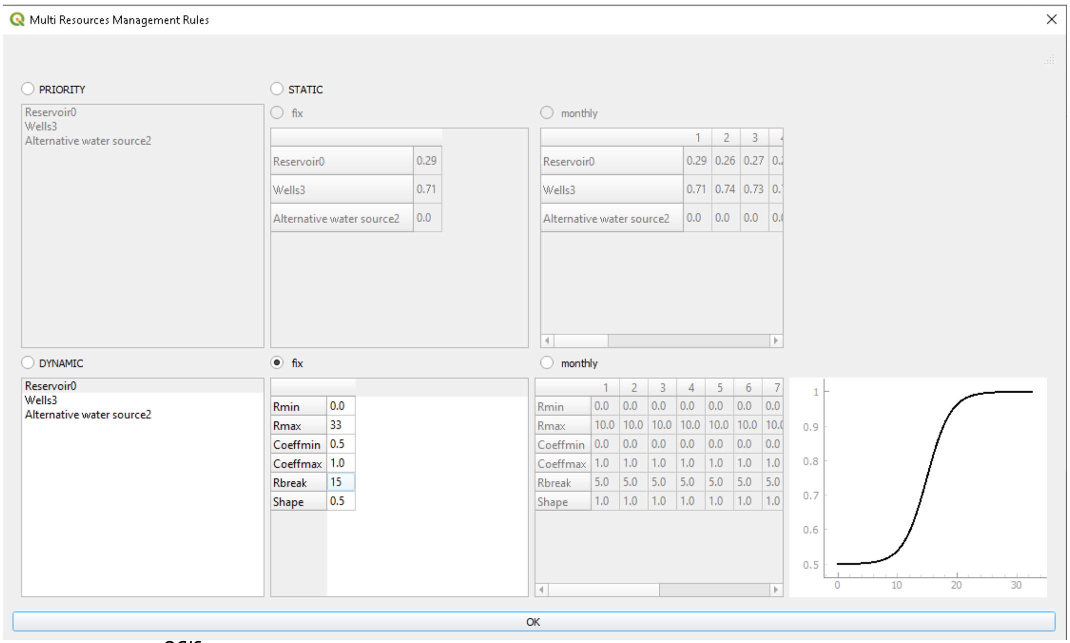


Figure 24. INOPIA^{QGIS} dynamic allocation rules

3.6 Early warning: learning from rare events

While the calibration of pre-established (or fixed, by opposition to dynamic) allocation schemes of the different macro users to their connected resources can be done (through the *INOPIA* management nodes) learning from the water utilities experience (see 3.5 for more details), dynamical allocation setting may require more advance decision support tools.

One of possibility offered by INOPIA^{Qgis} is to use the results of a simulation to search for relations between the past precipitation anomalies, the availability of the water resource and the futures shortages of a given superficial reservoir at each time step. Such relation can support a shortage early-warning as a response to meteorological drought for a given infrastructure and management setup (Romano et al. 2017, Romano et al. 2018). Such early warning can then support the parametrization to search for the managing rules *tuning* minimizing the impact of meteorological droughts to the users.

One limit of such approach is the limited availability of the observation time series (of both precipitation and inflow to the reservoir). Although the INOPIA approach can overcome limited hydrological observation availability (i.e. discharge to the surface reservoir) and be robust to precipitation missing data thanks to a simple rainfall-runoff model based on a linear combination of monthly precipitation anomalies at different time-scales, failure events may remain rare during to the infrastructure lifetime.

To address such issue, CNR had implemented in INOPIA^{Qgis} a stochastic weather generator based on an autoregressive integrated moving average (ARIMA) model applied to precipitation anomalies able to feed the WSS during 500 years (Figure 25), with the aim of answering to the question "what would occurred to my water supply system during 500 years of current climatic conditions". The early-warning decision support can then be supplied with such "*stochastic run*", increasing the statistic robustness of that obtained with the historical or "*hindcast run*" as illustrated in *Figure 25*.

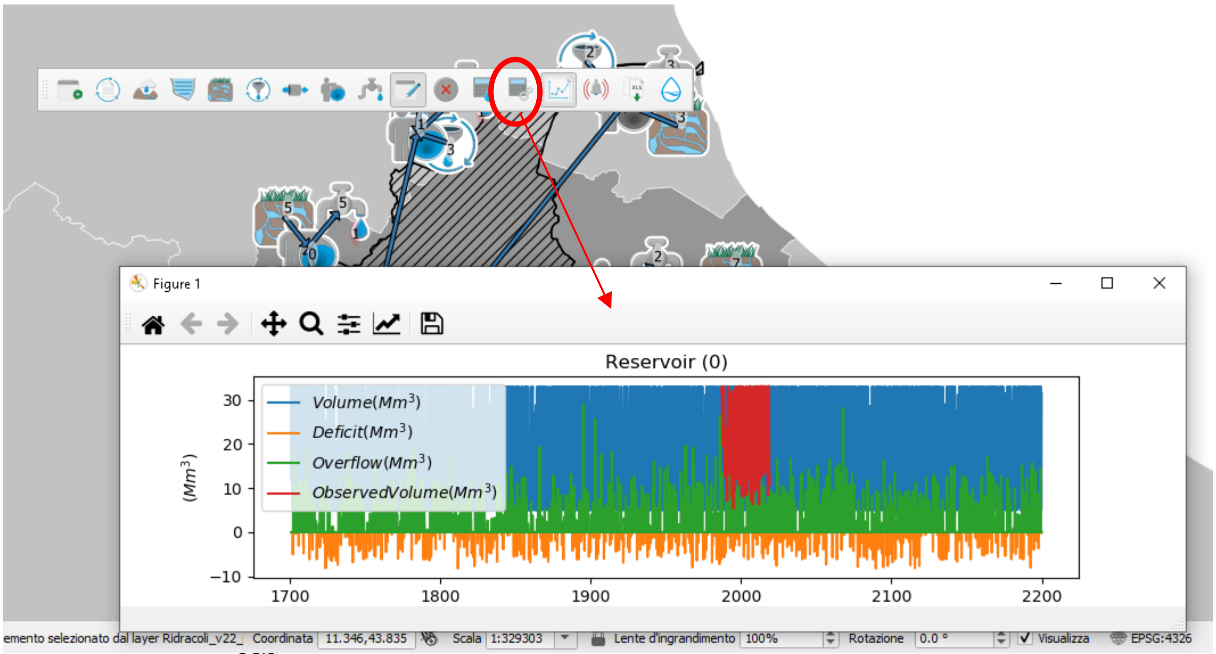


Figure 25. INOPIA^{QGIS} stochastic weather generator

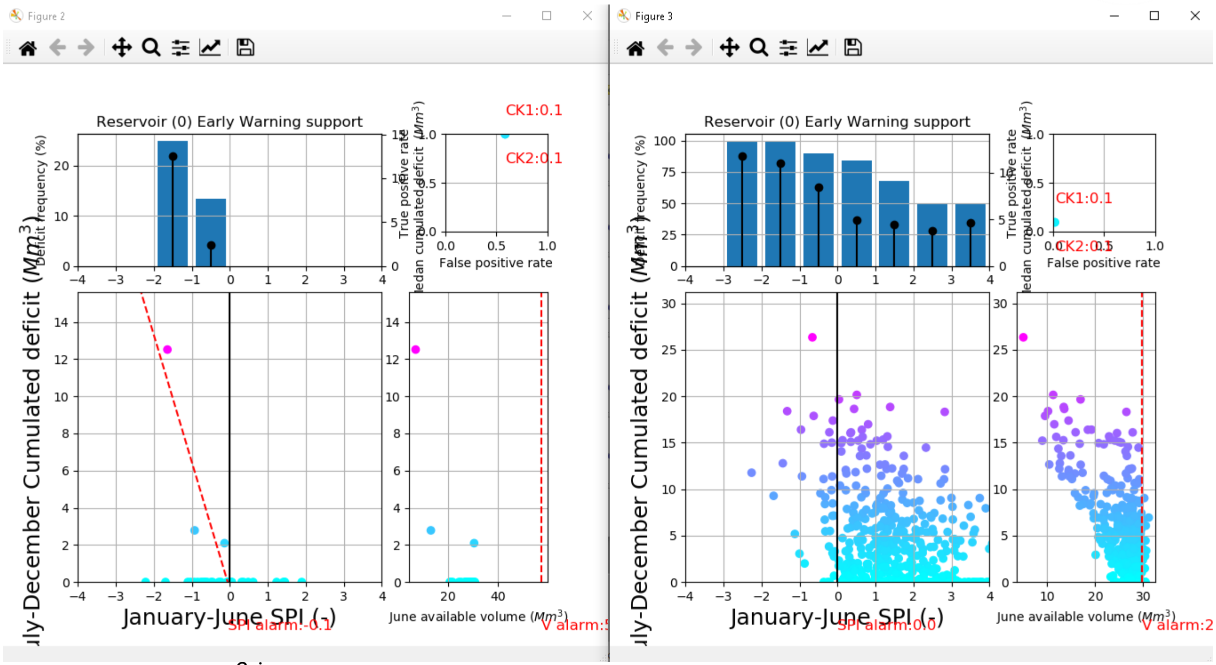


Figure 26. INOPIA^{Qgis} early warning decision support supplied by hindcast *and* stochastic *run (left and right panel respectively)*

3.7 Preliminary results

The implementation of the MUHA Italian case study has been validated against the observed Ridracoli water level variation, using a monthly static allocation scheme, based on the Romagna Acque water utility experience: in fact the water manager is already implementing a management scheme in ordinary conditions based for each month on a fixed partition (water addressing) of the seven main distribution points of the Ridracoli water supply system to the available resources (Ridracoli dam, pumping stations, purification plants and springs). The result of the *hindcast* run over the past 30 years are presented in Figure 27.

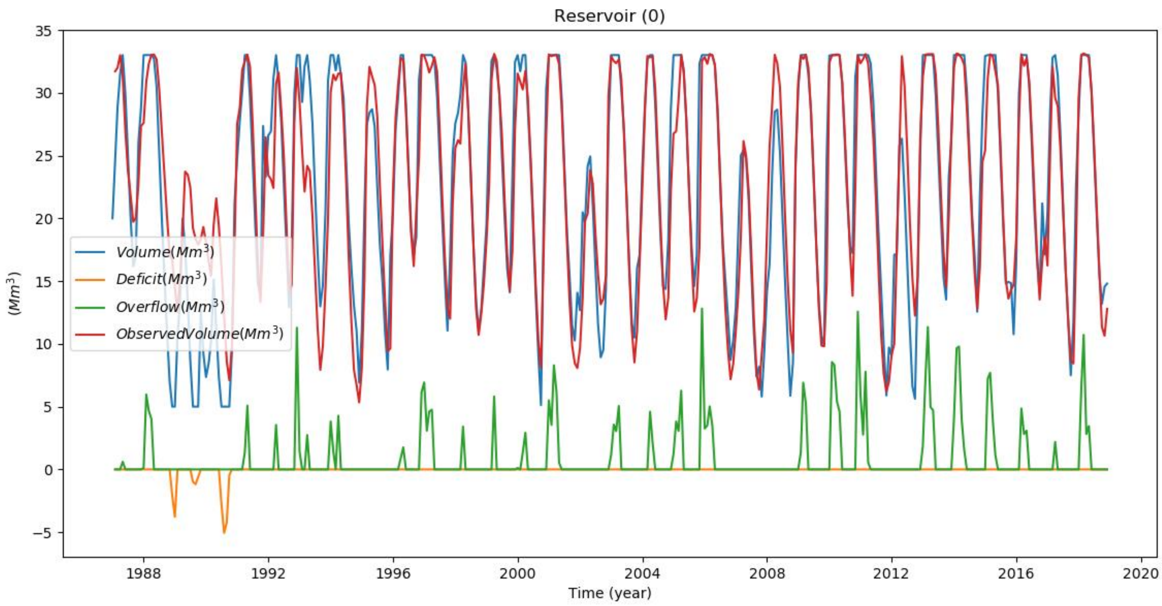


Figure 27. Validation of the current implementation of INOPIA^{Qgis} to the MUHA Italian pilot.

The impact of the historical (1993-1994) and recent (2003, 2007, 2011 and 2017) drought episodes are well caught by the INOPIA implementation.

Such results can be compared with a scenario of management in which the water utilities did not implement a pre-alert management, allocating users demand in priority to the Ridracoli dam.

4. Activities on accidental contamination hazard.

4.1 Background and rationale of the research activity

The accidental pollution of drinking waters is mostly owed to either the poor quality of the influent water or malfunctioning which may occur along the potabilization treatment train. The microbiologial contamination levels following accidental contamination events are of great concern, since contaminated waters could be distributed and consumed before a microbial hazard is detected by the current cultivation-based monitoring approach.

The objective of this research activity was to explore the use of innovative parameters for the real-time monitoring of water microbial quality to complement the current assessments of microbiological contamination. We hypothesized that varying treatment and supply schemes will result in different microbial removal performances following the quality of the influent raw water (as affected by seasonal fluctuations), and the efficacy of water filtration steps.

4.2 Sampling strategy

Two sampling surveys were performed in selected locations across the drinking water supply system managed by Romagna Acque. In particular, three treatment plants were targeted since fed with surface waters of different origin and based on different water filtration settings.

The drinking water treatment plant (DWTP) at Capaccio (UA-Capaccio) directly receives waters from the reservoir of Ridracoli, collected at a depth of -30m. Two lines of sand and carbon-based filtration systems are used to remove the excess of suspended solids and microbial biomass from the influent water.

The DWTP at Bassette-Ravenna (NIP) receives surface waters from surrounding streams and rivers and seven carbon-activated units are kept operating continuously for the in-line water filtration.

The DWTP at Standiana (NIP2) receives surface waters for a stream channel of the River Po (Channel Emiliano-Romagnolo). The water filtration system is relatively new and based on an advanced technological treatment system, also including ultrafiltration units.

Samples were collected from the three selected DWTPs in spring (21-22/04/2021) and summer (07-08/07/2021), by including the influent raw waters, treated waters after the filtration units and chlorinated waters before distribution.

4.3 Methodological approach

All major physical-chemical parameters were assessed by team members of Romagna Acque and by the use of a field probe on-site by CNR. The complete set of microbiological analyses was assessed on all samples either on-site or within 24h from sampling. Plating and cultivation-based analyses were performed by Romagna Acque following ISO protocols as required by the adopted guidelines.

Supportive parameters for the microbiological characterization of sampled waters were obtained through a biomolecular and quantitative approach for a fast detection and a high specificity of water microbial contamination.

For the nucleic acid extraction, water samples (1-2 L) were filtered with 0.2 µm pore-size polycarbonate filters (type GTTP; diameter, 47 mm; Millipore, Eschborn, Germany) either soon after sampling at the laboratory facility of Romagna Acque or within 24 h from sampling at the laboratory of IRSA-CNR. All filters are stored at −20 °C at IRSA-CNR.

DNA has been extracted and the qPCR Sybr Green assay was utilized to measure the 16S rDNA gene copy number in 25 µL of sample using the CFX96 Touch Real Time PCR Detection System (Bio-Rad, United States). Triplicates samples and no template controls (NTCs) were analyzed. The *E. coli* 16S rDNA was used as positive control, and standard curves were produced with gene copy numbers from 10^2 to 10^6 genes per reaction tube. The concentration of the amplified DNA was determined using NanoDrop spectrophotometer. The gene copy number per µL of solution was calculated with results reported as the mean of measurements of triplicates analysis with standard deviations. Data were analyzed with the CFX ManagerTM software v3.1 (Bio-Rad, Italy) (Amalfitano et al., 2018). Further phylogenetic analyses for the assessment of the microbial community composition (16S rRNA high-throughput gene sequencing) will be performed on the extracted DNA once all samples from the four seasons will be collected.
Flow cytometry (FCM) in combination with nucleic-acid-targeted dyes was used as a candidate technology for high-throughput and real-time microbial cell quantification in the targeted DWTP. FCM analyses were performed on-site immediately after sampling and within 24 h, by using a compact flow cytometer (A50-Micro; Apogee Flow Systems, Hertfordshire, UK), equipped with a solid state laser set at 20 mV and tuned to an excitation wave length of 488 nm. With an approximate weight of 30 kg, the machine is portable and suitable for field applications owing to specifically developments to preserve a precise optical alignment after transportation. The Total Cell Counts (TCC) were determined in SYBR-stained samples by the signatures of the prokaryotic cells in the density plots of the forward and side scatter vs the green fluorescence signals. Formaldehyde-fixed water samples (2%, final concentration) were stained for 10 min in the dark at room temperature by SYBR Green I (1:10000 dilution; Life Technologies, code S7563). The intensity of green fluorescence emitted by SYBR-positive prokaryotic cells allowed for the discrimination among cell groups exhibiting Low and High Nucleic Acid content (hereafter named LNA and HNA cells, respectively). Eukaryotic cells were discriminated according to their relatively higher intensities of forward scatter and green fluorescence signals in comparison to prokaryotic cells. The gate settings were determined through the use of negative controls and validated on pure microbial cultures. The occurrence of suspended particulate was assessed in a plot of green vs red fluorescence according to the relatively higher intensity of red auto-fluorescence signals in comparison to microbial cells. The live/dead cell ratio was assessed by double staining with SYBR Green I and Propidium Iodide (10 µg/mL, final concentration) on a plot of green vs red fluorescence, in order to verify whether microbial cell viability was affected by the treatment steps. Membrane-intact prokaryotic cells showed higher green fluorescence signals than the membrane-compromised dead cells selectively marked in red by propidium. Since fixation was reported to alter the cell membrane integrity, this analysis was performed on-site only on unfixed samples. The same settings and gates were applied to all samples. Data were analyzed by the Apogee Histogram Software (v89.0) (Vergine et al., 2018).

4.4 Preliminary results

The preliminary results showed clear differences in major physical-chemical parameters of waters collected in spring and summer (Figure 28 and *Table 3*).

a) Spring 2021 b) Summer 2021

Figure 28. Influent raw water collected in spring (a - April 2021) and summer (b – July 2021) at the selected sampling location within the NIP DWTP in Bassette-Ravenna.

DWTP	Sample	Water type	T	EC	DO	DO	pH	ORP
			°C	uS/cm	mg/L	%		mV
Bassette	220-NIP	Raw	14.3	630	8.55	86.8	7.92	218.4
Bassette	227-NIP	Filtered	14.6	639	8.00	81.9	7.85	230.4
Bassette	228-NIP	Cl+	14.7	626	8.83	89.6	7.91	255.7
Standiana	P01-NIP2	Raw	15.1	515	7.88	79.2	7.71	236.8
Standiana	P06- NIP2	Filtered	14.9	530	8.82	86.6	7.27	187.8
Standiana	P08-NIP2	Cl+	14.7	526	9.24	90.4	7.43	326.0
Capaccio	00-G	Raw	10.8	359	9.67	92.3	7.54	295.5
Capaccio	00-F	Filtered	10.1	372	10.33	92.6	7.40	307.9
Capaccio	00-U	Cl+	10.4	374	10.30	93.7	7.64	324.8

Table 3 – Major physical-chemical parameters assessed by the field probe in spring 2021.

Preliminary results are available from the sampling event performed in spring 2021 (Table 4). As assessed by qPCR and FCM, the total microbial abundance was higher in the raw waters and showed lowest values after chlorination, particularly at Capaccio. In the three DWTPs, filtration reduced the total microbial contamination value by approximately 1 log unit.
The great majority of the microbial biomass was composed by heterotrophic non-pigment cells. Photosynthetic pigmented cells (mainly belonging to Cyanobacteria) were mostly found in raw waters and lowered below the detection limit after treatment.

Sample	16S rDNA copies/ml	TCC cells/ml	Cyanobact cells/ml	PicoEuk cells/ml	NanoEuk cells/ml	MicroEuk cells/ml
220-NIP	1.30E+11	4.03E+06	5.65E+03	4.27E+03	9.96E+02	1.01E+03
227-NIP	1.18E+10	2.75E+05	2.19E+02	<LOD	6.50E+03	<LOD
228-NIP	5.42E+08	3.27E+05	<LOD	<LOD	2.18E+03	<LOD
P01-NIP2	5.41E+10	1.82E+06	1.75E+03	9.67E+02	1.56E+04	<LOD
P06- NIP2	2.04E+09	1.63E+05	1.49E+02	<LOD	6.78E+03	<LOD
P08-NIP2	8.83E+08	2.23E+05	1.23E+02	<LOD	5.24E+03	<LOD
00-G	3.41E+10	1.16E+06	1.28E+03	1.55E+02	2.72E+03	<LOD
00-F	9.71E+08	1.34E+05	<LOD	<LOD	3.20E+03	<LOD
00-U	8.71E+08	1.23E+05	<LOD	<LOD	2.75E+03	<LOD

Table 4 – Microbial community structure as assessed by qPCR and flow cytometry in samples collected at spring 2021.

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