Assessment of Flooding Impact on Water Supply Systems: A Comprehensive Approach Based on DSS

Silvia Barbetta[1] · Bianca Bonaccorsi[1] · Stavroula Tsitsifli[2] · Ivana Boljat[3] · Papakonstantinou Argiris[2] · Jasmina Lukač Reberski[3] · Christian Massari[1] · Emanuele Romano[4]

Abstract

The assessment of flood impact on a Water Supply System (WSS) requires a comprehensive approach including several scales of analysis and models and should be managed in the Water Safety Plans (WSP), as recommended in the EU Water Directive 2020/2184. Flooding can affect the quality of groundwater and surface water resources and can cause supply service interruption due to damaged infrastructures. A complete approach to address flood impact on WSS is required but not yet available, while only specific aspects were investigated in details. This work introduces a comprehensive tool named WAter Safety Planning Procedures Decision Support System (WASPP–DSS) developed in the context of MUHA (Multihazard framework for Water Related risks management) project. The tool is mainly addressed to small water utilities (WU) for supporting WSP development and is based on two main premises: 1) a correct approach for WSS risk analysis requires a multi-hazard perspective encompassing all the system components and different hazards; 2) other institutions in addition to WUs have to be involved in WSS risk analyses to harmonize monitoring and response procedures. The tool is here applied on risks associated to flooding and demonstrated for three case studies. The WASPP–DSS, tested by eight WUs, was found a potentially valid support for small WUs that must start drafting the WSP in a comprehensive way and can provide a common shared scheme. Improvements are desirable, as including a specific section to consider the issue of loss of water resources from reservoirs due to overflow.

Keywords Flood hazard · Water supply system · Water safety plan · Decision support system

✉ Silvia Barbetta
s.barbetta@irpi.cnr.it

[1] Research Institute for Geo-Hydrological Protection, National Research Council (CNR), Perugia, Italy

[2] Municipal Water Supply, Sewerage Company of Larissa, Larissa, Greece

[3] Croatian Geological Survey, Zagreb, Croatia

[4] Water Research Institute, National Research Council (CNR), Rome, Italy

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1 Introduction

The Water Supply System (WSS) complexity is related to the dynamic nature of the characteristics influencing it, as climate change and increasing demand due to population (Amarasinghe et al. 2017; Ghandi and Roozbahani 2020).

The water supply, along with the sanitation, is considered a main factor in environmental sustainability, human health, social services and resilience (Luh et al. 2017). The service interruption due to disasters is a scenario that must be considered for WSS design and management. Different hazards could impact the WSS, such as drought and earthquake (Pagano et al. 2021; Amarasinghe et al. 2017), operational losses (Bozorgi et al. 2021), accidental pollution (Di Cristo and Leopardi 2008) and floods (Arrighi et al. 2017; Chau et al. 2021). Assessing the impact of flooding on WSS requires a comprehensive approach able to account for several processes potentially leading to interruption of water supply and/or water quality degradation, which in turns involve several scales of analysis, from the catchment area to the distribution network. The assessment of natural hazards impact on WSS has to be involved and managed in the Water Safety Plans (WSP), whose implementation is supported and advised by the WHO (2017).

During flooding, scarcity of safe drinking water (McCluskey 2001; Bariweni et al. 2012), disruption of water treatment facilities and, as a consequence, disease outbreak (Shimi et al. 2010; Speranza 2010) are the most frequent problems. Moreover, the reduction of groundwater quality can be caused by pollutants transport and flood effect on groundwater recharge (Comte et al. 2018; Alam et al. 2020; Zhang et al. 2017).

Severe flooding can also cause interruption of abstraction from artificial reservoirs and quality deterioration of stored water due to turbidity (Chou and Wu 2010). Flooding can affect well fields and result in pump failure and/or ingress of chemically/microbiologically contaminated flood water into damaged wells (Joannou et al. 2019; Sweya and Wilkinson 2020). It can cause damages also to the treatment component producing interruption of the treatment/water quality control (Hedera 1987; McCluskey 2001; Barnes et al. 2012; Koh et al. 2017). Lastly, flooding can affect the distribution system damaging the infrastructures leading to disruption of the supply service and contamination of the water resources (Arrighi et al. 2017; Joannou et al. 2019).

In this context, the MUHA project, funded by the European INTERREG V-B Adriatic-Ionian ADRION Programme 2014–2020 (https://muha.adrioninterreg.eu/), developed a tool for WAter Safety Planning Procedures Decision Support System (WASPP–DSS). MUHA aims to improve forecasting, prevention and mitigation capacities of different risks in WSSs, strengthening cooperation between civil protection systems and operators at national, European and international levels in the implementation of the WSP.

This process requires common risk analysis tools as basis for sound intervention planning. Some elements of novelty with respect to both the WHO guidelines and the available national guidelines are: 1) the tool is based on a matrix approach that crosses the WSS components with hazards potentially threatening the water safety, as required by the WHO for water safety plans development; 2) the tool allows to fully account for the quantitative aspects impacting on water safety due to climate change and more in general, quantity issues as explicitly mentioned in WHO guidelines.

In this work, Sect. 2 describes the procedure to evaluate the flooding impact on WSS and the main characteristics of the tool; in Sect. 3 the application of the tool to three case studies is presented and, lastly, Sects. 4 and 5 outline the discussion and the conclusions.

2 Methodology

2.1 Procedure for Flooding Impact Assessment

The conceptual scheme of the comprehensive approach to evaluate the flood risk impact and consequences on a WSS, as well as adaptation measures, is shown in Fig. 1. The scheme depicts the logic flow to be followed by the WU to estimate flood impacts on the WSS; it considers both surface water bodies and groundwaters as sources for abstraction and it has to be read clockwise starting from the natural hazard occurrence.

Starting from the natural hazard occurrence (1), it has to be considered if severe hydro-meteorological events can produce at basin scale an increase of turbidity, due to the high concentration of suspended sediments caused by a high soil erosion capacity, organic matter load and possible pollutant load in the surface runoff. When the surface flow reaches the river and/or enters into an artificial reservoir, it can affect significantly the surface water body sources quality (2). Similarly, the quality of groundwater (3) can be deteriorated by a polluted surface runoff if it affects damaged wells or springs recharge area. Extreme rainfall can cause inundation with problems related to sediment, organic and pollutant transport potentially affecting surface and groundwater sources. When the abstraction is done from a deteriorated source, the raw water quality (4) entering the treatment plant needs to be analyzed to determine whether it is suitable for a standard treatment, requires a modified treatment or is not appropriate, leading to a temporary interruption of abstraction and distribution. Uncontrolled or particularly polluted source water may directly affect the treatment with possible failures (5) of the process sections and consequences on treatment efficiency (6). Moreover, treatment
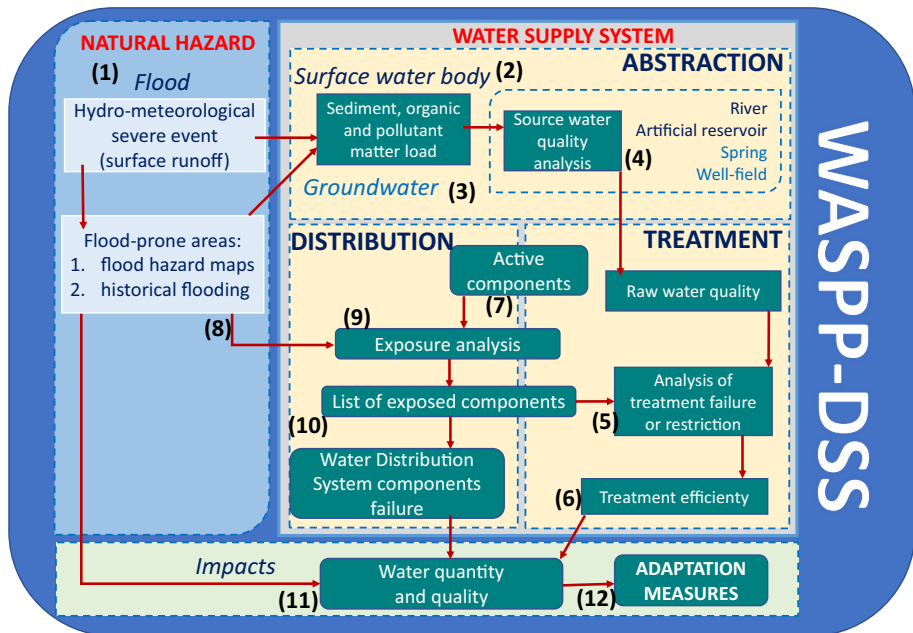

Fig. 1 Conceptual scheme for flood impact assessment on WSSs

plants can be damaged when vulnerable active components (7), powered by electricity, are flooded causing reduction or interruption of the service.

The flood hazard maps (8), generated by a chain of hydrologic and hydraulic models, and/or the delineation of historical flooding (8), identified through the new available high-resolution satellite images that can delineate the boundaries of flooded areas also together with fragmentary ground/remote data, allow to identify exposed elements. The exposure analysis (9) produces a list of exposed components (10), i.e. potentially vulnerable elements of both the distribution and treatment system. The possible failure of these elements during flood events can be foreseen as well as the quantification of effects in terms of quantity and quality of the available resource (11) considering modelling results. When the impact on the efficiency of the water supply service is expected to be not sustainable, adaptation measures (12) to face the possible emergency phase can be identified and planned in details.

The above-described comprehensive approach can be conveniently used to develop WSP and to identify potential flood impacts on the WSS components. The identified information can be organically gathered in the WASPP-DSS tool.

2.2 WASPP-DSS Tool

The MUHA tool (http://muha.apps.vokas.si/home) concept moves from the WHO guidelines (World Health Organization and International Water Association, 2009) that suggests 11 modules in the life-cycle of a WSP to support its implementation.

The tool focuses on the sub-group "System Assessment", specifically on Modules 2 ('Describe the water supply system'), 3 ('Identify the hazards and assess the risks') and 4 ('Determine and validate control measures, reassess and prioritize').

A detailed survey of the current status of implementation of WSPs in the ADRION area performed in the MUHA project highlighted the need for a common scheme, shared by all WUs and institutions, for the analysis of the possible hazardous events affecting the components of WSS. It was also found that although large WUs generally have in their own skills and knowledge to develop robust WSP, small and medium ones have to face several internal issues. On this basis, MUHA identified as first support for WUs who need to start the development of WSP, a tool able to individuate the WSS components prone to specific hazards and to rank hazards and related risks to deliver initial risk matrices, according to WHO guidelines (World Health Organization and International Water Association, 2009).The WASSP-DSS is constituted by a catalogue of possible hazardous events affecting the different components of the WSS listed in Fig. 2a, from 'surface water resources' to 'governance and future hazards'.

Each possible foreseen hazardous event is described in a specific box (Fig. 2b) where the user is requested to evaluate the probability and severity of occurrence. The two components are combined for a risk estimation categorized as very low, low, medium, high and very high.

Once the "catalogue of events" is completed, the overall risk assessment is given in terms of number of hazardous events completed (Fig. 3a), number of hazardous events per component and hazard category (Fig. 3b), severity of consequences by component and by hazard (Fig. 3c, d, respectively) and the risk category by component and by hazard (Fig. 3e, f, respectively).

Fig. 2 **a** Categories of components of WSS in the WASSP-DSS (basic window) and **b** detailed view on the component with the description of the hazard, consequences and measures

Fig. 3 Overall representation of the hazard analysis performed on a generic water supply system through ▶
the WASSP-DSS tool: **a**) overview of completion; **b**) overview of hazards; **c**) severity of consequences; **d**)
severity of consequences by hazards; **e**) risk evaluation: **f**) risk category by hazard

3 Application and Results

In the MUHA project the WASPP-DSS was tested on the six pilot areas of the ADRION
region considering four hazards: drought, flooding, accidental pollution and damage to
infrastructure due to earthquakes.

In this work, the tool is demonstrated for flooding impact analysis in three pilot areas:
the Ridracoli reservoir in Italy and two municipalities (Larissa in Greece and Zadar in
Croatia).

In the following, for each case study the main outcomes of the tool application are
presented. It is worth stressing that some analyses need to be performed out of the tool:
e.g., for the Ridracoli dam, previous studies on the water volume loss due to overflow
process were available and can be included as important indications in the tool.

3.1 Ridracoli Pilot Area (Italy)

The Ridracoli dam, located in northern Italy, is managed by Romagna Acque company.
The reservoir can store a maximum of 33 million cubic meters of water. The water is
made drinkable by passing through a water treatment plant and supplies 50 municipali-
ties serving 950,000 inhabitants and millions of tourists in summer. No severe issues
were experienced in the last years due to flood events; however, floods could affect the
dam in the future due to climate change that is expected to exacerbate extreme events
both in terms of drought periods and flood waves. When dealing with flood impact on
artificial dams, the loss of water for overflow process and the increased sediment trans-
port are recognized as important issues. The first process occurs when extreme precipi-
tation events produce large amounts of water entering into the reservoir rapidly with an
available volume not sufficient to store it. The second issue is caused by the increased
sediment transport that affects water quality and leads to sedimentation with a reservoir
storage reduction.

3.1.1 WASPP-DSS Application

The main statistics and risk assessment derived by the tool application are shown in
Fig. 4 where the total number of hazardous events (not only the ones due to flooding) are
summarized.

For the sixth category of the WSS components (i.e. Treatment), nearly all the hazard-
ous event sections were filled (Fig. 4a). For this category, the severity of consequences is
mostly indicated causing minimal effects (Fig. 4b) with a risk category mainly classified as
very low (Fig. 4c).

Focusing on flood impact, the results of the analysis are summarized in Table 1. Con-
cerning the 'Surface water sources', floods could lead to water quality degradation due to
significant surface runoff causing erosion and consequent high-load sediment transport.
The probability of occurrence cannot be estimated because it requires investigations not
yet developed. The consequences were classified as moderate because the impact would be
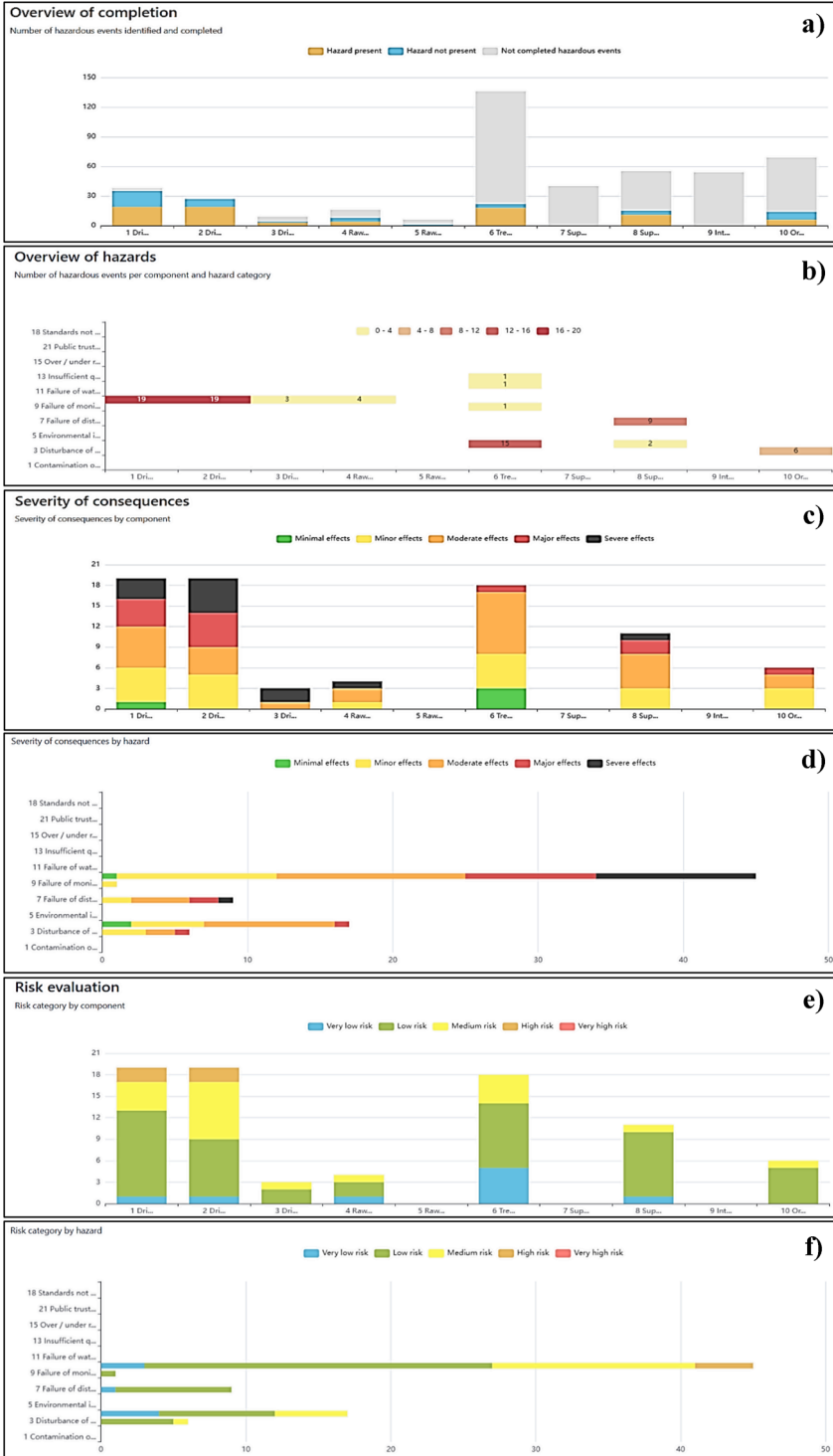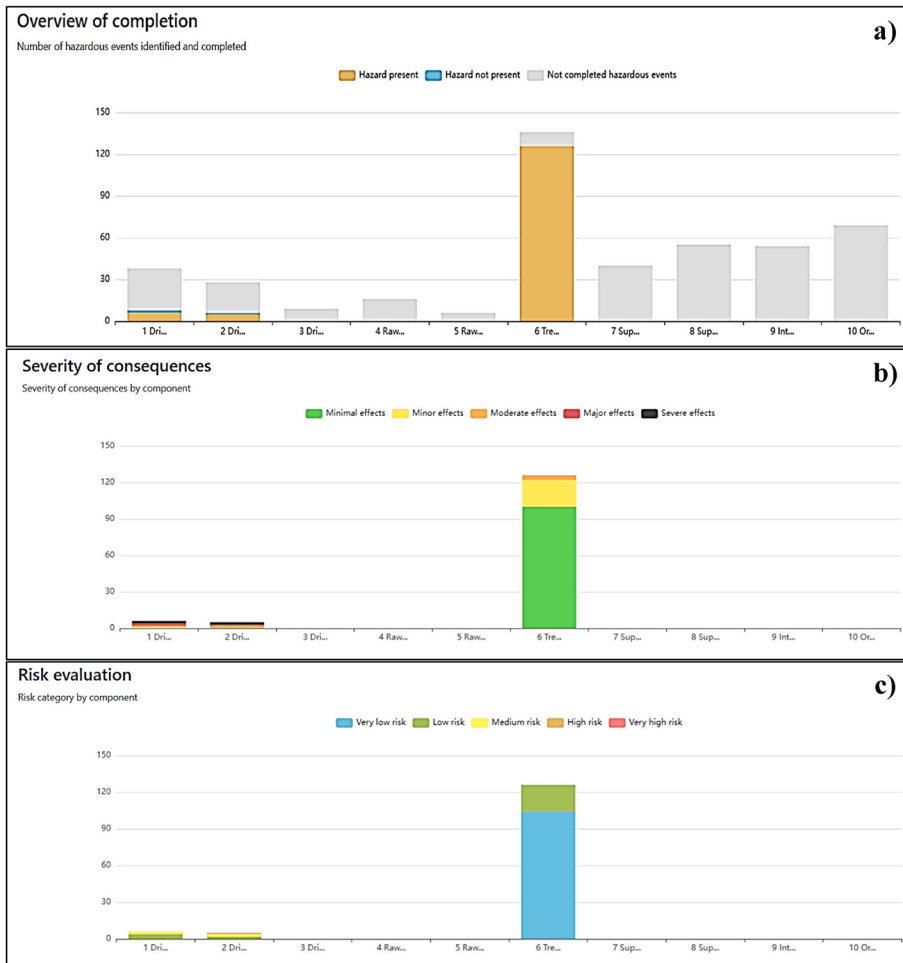
Fig. 4 WASPP-DSS: main overall statistics and risk assessment outcomes for the Italian pilot area for all hazards; **a**) overview of completion, **b**) severity of consequences and **c**) risk evaluation

mainly the necessity of a deeper treatment in the purification plant. Thus, the risk was classified as medium.

Floods could cause interruption of water supply due to damages to reservoir; the dam could be compromised until the extreme consequence of total or partial failure. This hazard was considered potentially present with severe consequences and with a probability of occurrence higher than 30 years; therefore, the risk was classified as low. Moreover, the sediments coming into the reservoir during floods can accumulate reducing the storage volume storage. The consequences were assessed as major, with a probability of occurrence that cannot be assessed with the available information and the risk was classified as medium.

The last row in Table 1 is related to the '*Loss of resource (water volume released through overflow process)',* not currently included in the tool for the lack of appropriate section. The results of a previous analysis, presented below, allowed to fill this section.

Table 1 WASPP-DSS application for the Ridracoli pilot area: data on flooding hazard impact on the different components of the tool identified as potentially affected by flood events. The last row contains results not included in the tool due to the lack of the appropriate section in the present version of the DSS

Component	Hazard	Probability of occurrence	Severity of consequences	Risk
Drinking water source – surface water (1)	Contamination of catchment zone (1.12)	Hazard is present but probability cannot be assessed	Moderate effects	Medium
Supply System –Reservoirs and pumps (either directly after treatment or in the distribution system) (7)	No water supply / contamination of water (134.1)	Every 30 years or more	Severe effects	Low
Supply System –Reservoirs and pumps (either directly after treatment or in the distribution system) (7)	Water quality deterioration (140.1)	Hazard is present but probability cannot be assessed	Major effects	Medium
Supply System –Reservoirs and pumps (either directly after treatment or in the distribution system) (7)	Loss of resource (water volume released through overflow process)	Every 10 years	Moderate effects	Low

3.1.2 Historical Flood Events Analysis

For the Ridracoli dam, a study of historical floods was developed to analyze possible flood management scenarios.

First, the main floods entering into the reservoir during the last years were reconstructed by exploiting the outflows from the reservoir (assessed through equations and graphs of the regulating devices), the recorded lake levels and available reservoir curve.

Second, the reconstructed flood hydrographs were used as input to the reservoir to investigate different scenarios for dam management by assuming different initial lake levels.

The study exploited a lamination model (Castorani and Moramarco 1995) based on the continuity equation:

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

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 = volume of reservoir derived from the lake level-volume curve; h = water level compared to the reference plan; t = time.

The total release, q_{rel}, is the sum of all the contributions to the downstream outflow from the various outlets and spillways (free surface spillway, bottom and middle outlet; discharge derived to treatment plant). Equation (1) allows to compute q_{in} from the knowledge of the total outflow and time modification of the stored water volume.

Similarly, the outflow and the lake level variation can be estimated when the incoming hydrograph is known.

3.1.2.1 Historical Inflow Hydrographs Reconstruction
The lack of a monitoring station upstream the dam prevents from having a direct observation of reservoir inflows. Therefore, the events were reconstructed using Eq. (1) starting from the known outflows and time pattern of the reservoir levels at hourly intervals. The inflow hydrograph was assessed for six main floods in the period 2010–2019. Table 2 summarizes the events characteristics and Fig. 5 shows the estimated inflow hydrograph, Q_{in}, the total outflow released from the dam, Q_{out}, and the trend of the lake level for the flood event occurred on January–February 2014, characterized by the highest flood peak.

Table 2 Ridracoli dam: main characteristics of the historical flood events

month	year	Starting date	Ending date	V_{inf} (m³)	Q_{max} (m³/s)	H_{max} (m asl)	Q_{out_max} (m³/s)
Dec	2010	24/12/10 00:00	24/12/10 23:00	1,104,892	56.58	557.62	40
Mar	2013	18/03/13 00:00	19/03/13 23:00	2,810,778	53.72	557.53	60
Jan-Feb	2014	30/01/14 00:00	02/02/14 23:00	2,546,940	71.46	557.59	30
Feb	2014	10/02/14 00:00	11/02/14 23:00	1,491,564	44.92	557.63	29
Mar	2018	11/0318 00:00	13/03/818 23:00	1,577,280	31.94	557.61	16
May	2019	12/05/19 00:00	14/05/19 23:00	7,841,736	62.59	557.50	59.3

V_{inf} total estimated inflow volume, Q_{max} maximum estimated inflow discharge, H_{max} maximum observed lake level, Q_{out_max} maximum released discharge
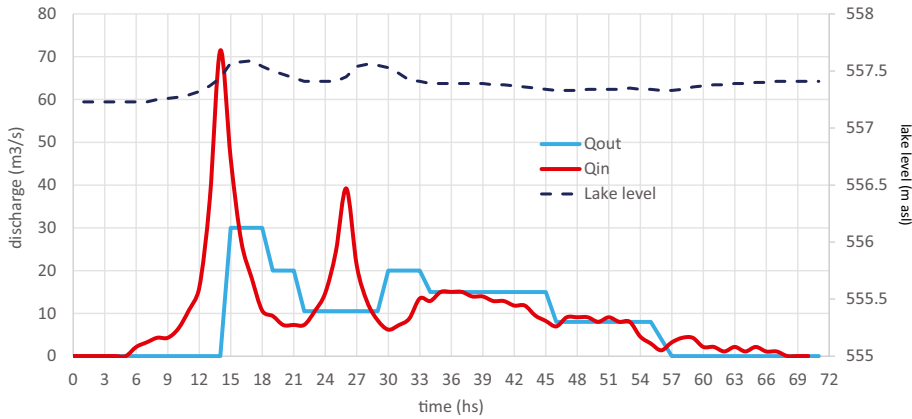
Fig. 5 January–February 2014 flood, Ridracoli dam: reconstruction of the inflow hydrograph, Q_{in} The outflow hydrograph, Q_{out} and the recorded lake level are also shown

3.1.2.2 Historical Floods Lamination Scenario The six reconstructed floods were considered as inflows to the reservoir during a second step of analysis. Moreover, a flood characterized by 100-years return period was considered with a peak flow of 140 m³/s. The analysis aimed to identify, for each flood, the maximum initial lake level that could be allowed in order to have a maximum discharge released not exceeding 50 m³/s. In this way, we wanted to assure the maximum water volume stored in the reservoir and, at the same time, to guarantee a safe condition for the downstream territory where no negative impacts are expected with a release lower than 50 m³/s. The analysis was carried out assuming the middle and bottom outlets closed, no water derived to the treatment plant and the discharge released only by the free surface spillway, which is described by a known discharge-lake level relationship.

First, we identified the maximum initial lake level that would allow to not release water downstream from the free spillways, storing the maximum water volume during the flood.

Second, we optimized the maximum initial lake level to allow a release from the free spillways not exceeding 50 m³/s, to avoid flooding problems. The results, summarized in Table 3, show that with an initial lake level equal to the crest of the surface spillways (557.3 m asl) and without other releases, all the flood events would produce an outflow lower than 50 m³/s, except for the May 2019 flood. This was the one characterized by the highest volume and, hence, for it we estimated the lowest optimal initial lake level (552.1 m asl). The results can address planning measures to reduce the water loss for overflow process and should be included in the tool once an appropriate section will be developed.

3.2 Municipality of Larissa Pilot Area (Greece)

The municipal water supply and sewerage company of Larissa (DEYAL) supplies water to the municipality of Larissa (Greece) and other local districts. The pilot area covers 335.12 Km² and supplies approximately 230,000 people through 1,110 km pipeline network and 84,126 water meters. The WSS of DEYAL consists of 11 water supply zones abstracting water through 28 active boreholes. Water is transferred to water tanks and from there it is distributed to the consumers. The daily water volume supplied is 33,888 m³.

Table 3 Lamination of floods for the Ridracoli dam

Date	H_{init_op} (m asl)	V_{init} (m³)	V_{out} (m³)	V_{sto} (m³)	Q_{out_max} (m³/s)	H_{max} (m asl)
Dec 2010	556.55	32,303,855	0	1,104,892	0	≈557.3
Dec 2010	557.30	33,321,243	1,104,892	≈0	22	557.55
Mar 2013	555.40	31,148,333	0	2,810,778	0	≈557.3
Mar 2013	557.30	33,321,243	2,810,778	≈0	45	558
Jan-Feb 2014	555.70	31,437,079	0	2,546,940	0	≈557.3
Jan-Feb 2014	557.30	33,321,243	2,546,940	≈0	22	557.92
Feb 2014	556.35	32,090,747	0	1,491,564	0	≈557.3
Feb 2014	557.30	33,321,243	1,491,564	≈0	25	557.88
Mar 2018	556.20	31,939,103	0	1,577,280	0	≈557.3
Mar 2018	557.30	33,321,243	1,577,280	≈0	16	557.50
May 2019	552.10	27,976,978	0	7,841,736	0	≈557.3
May 2019	557.30	33,321,243	7,841,736	≈0	57	557.77
Flood Tr≈100 years	555.95	31,687,427	0	2,095,452	0	≈557.3
Flood Tr≈100 years	557.30	33,321,243	2,095,452	≈0	71	557.83

H_{init_op} maximum initial optimized lake level, V_{init} initial stored volume, V_{out} total volume released from the dam, V_{sto} water volume stored during the flood, Q_{out_max} maximum flow rate released from the dam, H_{max} maximum lake level reached

The WSS of DEYAL is located in the potential high-risk flood zone of Pinios (3,353 Km²).

Five flood events took place in the area of Larissa municipality in the period 2012–2018, however, none of these affected the WSS.

3.2.1 WASPP-DSS Application for Flooding Risk

The flooding risk assessment using the WASPP-DSS resulted in the outcomes summarized in Table 4.

Concerning the 'Groundwater sources', floods could lead to water contamination due to agricultural runoff during flooding events. This hazard is present, but its probability of occurrence could not be estimated (never experienced in the past), and the consequences were assessed as major due to pollutants and pathogens from the manure spread present in such contamination events. Thus, the risk was classified as medium.

Moreover, floods could lead to water contamination due to wastewater overflows. This hazard was estimated as potentially occurring every 30 years and more, since there are no wastewater facilities very close to the water intake points, and the consequences were assessed as severe due to pathogens present in such contamination events. Thus, the risk was classified as low.

When the 'Raw water source' is of interest, floods have been considered able to cause contamination phenomena which were assessed as a potential hazard whose probability of occurrence could not be estimated, while the consequences were assessed as major. Thus, the risk was classified as medium. Considering the 'Reservoirs' in the supply system, the

Table 4 WASPP-DSS application for the municipality of Larissa pilot area: data on flooding hazard impact on the different components of the tool identified as potentially affected by flood events

Component	Hazard	Probability of occurrence	Severity of consequences	Risk
Drinking water source – groundwater (2)	Contamination of aquifers (9.11)	Hazard is present but probability cannot be assessed	Major effects	**Medium**
Drinking water source – groundwater (2)	Contamination of aquifers (9.3)	Every 30 years or more	Severe effects	**Low**
Raw water intake (4)	Contamination through openings (e.g. well-head, ventilation pipe, grit chamber, stilling basin, overflow pipe, doors…) (23.1)	Hazard is present but probability cannot be assessed	Major effects	**Medium**
Supply System -Reservoirs and pumps (either directly after treatment or in the distribution system) (7)	No water supply / contamination of water (134.1)	Hazard is present but probability cannot be assessed	Major effects	**Medium**
Supply System -Reservoirs and pumps (either directly after treatment or in the distribution system) (7)	No/low pressure/flow in network water. Network water contamination (141.1)	Hazard is present but probability cannot be assessed	Major effects	**Medium**

floods could cause contamination or destruction of water supply due to failures to reservoirs. This hazard was considered potentially present with major consequences, but the probability was not quantifiable. Thus, the risk was classified as medium.

Analyzing 'Pumps' in the system, floods can cause contamination or destruction of water supply due to failures of pumping stations. The hazard was considered potentially present causing major consequences and with a not quantifiable probability of occurrence leading to a medium risk.

3.3 Pilot Area Managed by Zadar Water Supply Company (Croatia)

The WSS managed by Vodovod d.o.o. Zadar is situated in the coastal area of northern Dalmatia in Croatia, and it is a typical karst system with numerous karst phenomena. It covers an area of about 2152.50 km^2 and supplies about 115,000 consumers in three cities and 16 municipalities.

The WSS consists of 16 extraction sites, 35 reservoirs, and break chambers with a daily capacity of 37,240 m^3 and about 1,000 km of pipelines. Average water supply amounts are around 500–600 l/s, and in the summer, around 800 l/s.

From 2000 to 2018, 27 flood events were registered in the area; the most significant flood was in September 2017, when buildings, cattle, agricultural land, and equipment were heavily damaged by a torrential flood. The pilot area is susceptible to climate change that is causing more frequent extreme precipitation and severe floods.

3.3.1 WASPP-DSS Application for Flooding Risk

The results of the analysis are summarized in Table 5.

Concerning the 'Groundwater sources', the hazardous event due to the process of leaching of contaminates from waste disposal sites and material storage as a result of failed safety features due to floods (first row in Table 5) is considered characterized by a quite low probability (every 10 years). Moreover, in the past the pollution events at water supply facilities was not recorded and, hence, the consequences can be considered as moderate leading to a risk classified as low. During floods, the agricultural runoff can produce increment of the pesticide and nitrate concentrations (second row in Table 5). Past observations indicated that the maximum allowable concentrations for drinking water were not exceeded. Moreover, water pollution can happen if the flood occurred at the time of the maximum pesticides' concentration. The available data indicate that this hazard can be characterized by a return period of 10 years with minor consequences and, hence, the risk was classified as low.

Table 5 WASPP-DSS application for the Croatian pilot area: data on flooding hazard impact on the different components of the tool identified as potentially affected by flood events

Component	Hazard	Probability of occurrence	Severity of consequences	Risk
Drinking water source – groundwater (2)	Contamination of aquifers (9.5)	Every 10 years	Moderate effects	**Low**
Drinking water source – groundwater (2)	Contamination of aquifers (9.11)	Every 10 years	Minor effects	**Low**

4 Discussion

The first version of WASPP-DSS was tested by eight WUs in the context of the MUHA project; it was found to be a potentially useful tool to gather and compare all the available information on the WSS components and the possible issues caused by different hazards. The tool has been evaluated useful for the early-stage development of the WSP mainly for small water utilities that typically do not have in their own necessary skills and knowledge. It allows the description of the WSS components and links, the hazards identification and risk assessment providing overall outcomes in terms of number of hazardous events, severity of consequences and risk category classification.

The possibility to choose from a predefined list of hazards would make easier the classification and also the selective extraction of results based on the type of hazard, e.g. flooding. Moreover, having a shared scheme of analysis may booster comparison among different WSP, promoting collaboration among water utilities acting in close territories or, in some cases, having interconnections.

In this work, we focused on flooding hazards, testing the WASSP-DSS on three case studies. The Ridracoli dam is an artificial reservoir feeding a drinking water distribution network. Therefore, the loss of water volume during floods from surface spillways is an issue that was investigated and the relevant results are shown in this work even if no related specific section is currently available in the tool.

Further developments are necessary to also account for: a) the multi-hazard dimension, when effects of different hazards overlap; b) the propagation of impacts through the whole chain from resource(s) to tap. In fact, the tool does not allow to consider the spatial dimension of water infrastructures. Adding spatial data (e.g. maps with the location of infrastructures and assets, flooding maps) would provide more detailed and distributed information on risk level over a complex infrastructural system, and help directly identifying suitable mitigation measures. When dealing with flood hazard, the main limit is the lack of a GIS section that would allow the user to import flood hazard maps and other geodata (e.g., historical flooded areas, high-resolution satellite data) really important to figure out the location and overlap of flood-prone/flooded areas and WSS components.

5 Conclusions

The assessment of flood impact on WSSs needs different scales of analysis and is fundamental to ensure safe drinkable water distribution. Floods can impact the quality of the water resources in multiple ways, and can cause the interruption of supply service. A comprehensive approach to address the issue of flood impact on WSS is here presented based on the WASPP–DSS tool developed in the context of the MUHA project. The tool provides a shared scheme of analysis among different WSPs, promoting collaboration among WUs acting in close territories. It is based on a matrix approach that crosses the WSS components with hazards potentially threatening the water safety and allows to fully account for the quantitative aspects impacting on water safety due to climate change.

The tool, applied for some pilot areas, has proven to be a valid support for the development of the WSP allowing the description of the WSS components and links, the hazards identification and risk assessment. It was found particularly useful for small WUs activities, when the WSP development and implementation is still at an early stage. Specifically,

the tool provides an overview of the main statistics and risk assessment outcomes allowing to identify the most important issues to be addressed by identifying appropriate mitigation measures. The first version of the WASPP–DSS can be surely improved also including an appropriate hazardous event section to take the possible water volume loss during floods into consideration and a GIS interface. Further developments are also necessary to account for the multi-hazard dimension, when effects of different hazards overlap, and the propagation of impacts through the whole chain from resource(s) to tap.

Authors Contributions S. Barbetta carried out the analysis for Ridracoli dam, wrote the paper and coordinated the research. B. Bonaccorsi applied the DSS to the Italian case study and developed the scientific literature review. S. Tsitsifli and P. Argiris applied the DSS for the Greek case study and developed the results material. I. Boljat and J. L. Reberski applied the DSS for the Croatian case study and developed the results material. C. Massari supported the research development coordination and the paper writing. E. Romano coordinated the research, wrote the section of DSS description. All the authors revised the paper and improved it with their experience and knowledge.

Availability of Data and Materials Authors agree with data transparency.

Declarations

Ethical Approval The authors undertake that this article has not been published in any other journal and that no plagiarism has occurred.

Consent to Participate The authors agree to participate in the journal.

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