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Supporting water resource resilience through an integrated risk management and collaborative approach: a management model for Water Safety Plans

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Abstract

Water for human consumption is increasingly exposed to new types of hazards that threatenits quantity and quality, due to the emerging triple environmental crisis, population growth and inadequate management. The possible impacts of these phenomena on the final users, companies and farmers, pose challenges for the proper water management, which is one of the unavoidable issues facing today's different types of decision-makers, pursuing a systemic vision.
Water Safety Plans (WSPs), introduced by the World Health Organization (WHO) in 2004, represent the most effective means of ensuring the quality of drinking water and protecting consumer health, as they are based on a proactive and systemic risk assessment and management along the entire drinking water supply system (DWSS). Despite its increasingly application at a global level and the support of international legislation, an absence of studies taking into account the managerial aspects related to WSP implementation, with particular regards to the phase of stakeholder engagement and risk assessment and management, is observed.
Following the principles of the integrated risk assessment and management and the collaborative approach of engaged scholarship, we designed and apply a structured methodology to guarantee the engagement of the most relevant stakeholders in order to provide a comprehensive risk identification, and, hereafter, risk prevention for two DWSSs in Italy. The implications of the two case studies showed that this management protocol was effective in a) fostering participation and collaboration between the key players of water safety management; b) identifying all the potential hazards arising from climatic, natural and anthropogenic sources, and representing a risk on water quality and quantity; c) reducing the correlated risk with effective control measures; d) proactively protecting public health and environmental ecosystems.
The results of this study are particularly relevant since offer insights on managerial aspects of the water safety plans implementation following a systemic perspective and a collaborative approach, that are relevant for both scholars and practitioners. Nonetheless the efficiency of the model

proposed by the authors needs to be further tested and validated in different contexts, in order to broadly evaluate its replicability and flexibility.
Keywords: Water Safety Plan (WSP), climate change, risk assessment, water management.

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1) Introduction

Water security is a fundamental component for long-term social and economic development (Bigas 2012). As a matter of fact, water management is a critical aspect in achieving the majority of the goals of the United Nations Agenda 2030 for the Sustainable Development due to its intrinsic connections with the sphere of social well-being and health, economic growth, global peace and equality (UNWWDR, 2015). Water, indeed, plays a focal role in energy and food security and provisioning, is a key component of ecosystem functioning, provides several ecosystem services and underpins most of our industrial processes (UNWWDR, 2023; Baum and Bartram 2018). Most of all, water is an irreplaceable source of life, which sustains not only the natural environment and the economic system we depend on, but also our livelihood as human beings. Therefore, is it not surprising that water has always been considered as an essential resource for the development of human civilizations and has been one of the main and most persistent sources of conflict between different populations in humankind (Zeitoun et al. 2020). This deep connection between human societies and water also emerges from the tendency of any human society, throughout human history, to charge water with political, social, religious and spiritual meanings, making it a fundamental component of the development of its culture both at the individual and collective level (Hein et al. 2020; Willems and van Schaik 2015).
Unfortunately, nowadays human development is threatened by the emerging global water crisis. Despite obvious differences among the diverse regions of the world, water shortage is rapidly growing at a global level, with impactful consequences on citizens, companies, consumers and farmers (Mishra et al 2021). The increasing demand due to the population growth and the worldwide transversal improvement of living conditions, the climate change impacts and consequences, the industrial exploitation of natural resources and the pervasive degradation of natural ecosystems are stressing the freshwater resources and intensifying the problem of water shortage (Shalamzari and Zhang, 2018; Prochàzka et al. 2018; Khatibi and Arjjumend 2019; Orimoloye et al. 2021). The situation is particularly critical for cities, since the combination of climate change effect and increase in urbanization phenomena is exacerbating water scarcity for urban areas (He et al. 2021).
One of the main concerns about water shortage regards its implications on public health and potable water safety (Salehi 2022). In addition to the obvious issues related to the available water quantity, water shortage also implies a wide range of threats for water quality. The declining freshwater resources, the aging of water infrastructure and the inadequate solutions adopted worldwide by water utilities in order to guarantee water provisioning for civil, industrial and agriculture purpose, pose under risk the microbial and chemical status of the drinking water.
In this context, drinking water management becomes an essential factor to tackle poverty and inequality and to guarantee health protection (Bakir 2020). According to the data collected from the World Health Organization (WHO) water-borne diseases are still one of the main sources of death and diseases both in developing and developed countries, affecting mostly children and vulnerable people. Chemical and biological risks in drinking water arise from a wide range of factors, including climatic, biological, geomorphological, geochemical and anthropogenic drivers (Bakir 2020). It is necessary, thus, to develop new solutions for managing the drinking water supply systems (DWSSs), enhancing the collaboration among several actors, which comprise water utilities, consumers, stakeholders and policy makers, along the entire water supply chain in order to guarantee the access

to adequate sanitation and safe drinking water to all (Kayser et al. 2019; Peden et al. 2021). One of the tools that is gaining momentum and relevance at international level due to the promising results is the adoption of Water safety plans (WSPs) (WHO, 2017b; Gunnarsdottir et al. 2012).

Although the literature on WSPs is rapidly expanding and national and international bodies on water governance are providing useful guidelines for its implementation, a general shortage of practical information and theoretical background for shaping a framework, that may help practitioners to identify the essential steps for an efficient development of WSPs, may be noted. Thus, this study aims to provide a valuable blueprint for stakeholders and water utilities in the implementation of WSPs in their region. Therefore, this study interprets and discusses the managerial implications, the methodological framework followed and the contributions arose from two parallel and successful case studies of WPS implementation in Italy under the lens of engaged scholarship. The goal of this study is to: a) show and discuss the relevance of WSP in drinking water management; b) identify the main step of a co-creation process of the managerial framework for an effective implementation of WSP under a collaborative approach among scholars and practitioners; c) highlight the potential of a systemic perspective and collaborative approach in achieving an integrated risk assessment and management of drinking water for both human and environmental health.

The paper is structured in the following sections: i) the first section provides a general background on WSPs and outlines the state of art at international level; ii) in the second section the theoretical framework followed to develop the integrated and collaborative risk assessment and management model is presented; iii) the third section explains how this model has been developed through the methodological approach of the engaged scholarship; iv) the fourth section gives a detailed explanation of the model, and main results and implication of the collaboration between scholars and practitioners in WSP implementation.

2) Water Safety Plan: the background

Water Safety Plans, introduced by World Health Organization (WHO) in 2004, constitute a comprehensive risk assessment and management approach in the water sector that is widely recognized, both at a technical-scientific level and in the field of prevention policies, as one of the most effective and reliable means of managing water resources geared towards the highest protection of public health (WHO & IWA, 2009; Gunnarsdottir et al. 2012; Alazaiza et al. 2022). The main goal of the WSP approach is to prevent and reduce the risks related to water safety concerning chemical, physical, microbiological, or radiological threats in order to meet regulatory limits (Bereskiea et al. 2018; Lane et al. 2018; WHO, 2017b). The efficiency of this method is due first because of its holistic or systematic view. Indeed, this approach envisages an overall checks and evaluations along all phases and processes on an ongoing basis. It is also considered preventive and proactive because it goes beyond the controls and interventions downstream, after the detection of problems, and adopts solutions that enable the removal of contamination during water treatment and the prevention of contamination during all stages of the water supply. Moreover, any intervention is informed by rationality of action, based on the analysis of historical and epidemiological data (WHO, 2019). For this reason, the WSP is currently considered an important tool for the achievement of the *SDG 6 Clean Water and Sanitation goal*, with particular regards to the target 6.1 that seeks to achieve access for all to safe drinking water (UNWWDR 2015). Therefore, thanks to the enhancement of policies supporting SDG 6, we are witnessing an intensification of the use of WSPs on a global scale, in particular in the region affected by the most severe water scarcity (Russo 2017). Nonetheless, WSPs have been applied extensively also throughout Europe (Vieira 2011; Setty et al. 2017; Sorlini et al. 2017; Hasan et al. 2021). The region, in fact, is characterized by small-scale water supply systems that present geographical spread and isolation. This situation challenges independent monitoring, which is often limited for such systems. In this context, the application of risk assessment and management methods by water suppliers is essential to complement and support the activities of monitoring agencies. Therefore, WSPs own a strong political support at the international level and national level (Baum and Bartram 2018). In Italy, for instance, the recent *Decreto Legislativo 18/2023*, that implements the Directive (EU) 2020/2184 on the quality of water intended for human consumption, requires water suppliers to adopt the WSP for each DWSS by 2029. For this reason, scholars and practitioners are interested in developing methods to implement efficiently the WSP approach in the national DWSSs, according to the peculiarities of their region under territorial, political and social terms.

3) The theoretical framework

Drinking water safety is a complex issue that is affected by elements of the socioeconomic context, the conditions of natural resources and ecosystems, infrastructural and technical barriers, and climate implications for the DWSS under analysis. Therefore, the assessment and, then, the management of the risks along the entire drinking water supply chain imply a thorough study and analysis, adopting an integrated and collaborative approach that takes into consideration different fields of expertise and knowledge.

3.1 Integrated Risk Assessment and Management and Water Safety Plans

As stated before, WSP is "*a comprehensive risk assessment and risk management approach to help ensure the safety of a drinking-water supply"* (WHO, 2004). The risk-based approach along the entire supply chain is underlined also in the recently revised European Directive 2020/2184 on the quality of water intended for human consumption, which aimed to improve the overall quality standard of the drinking water through an overall risk identification and management (Dettori et al. 2022). Several authors agree that water governance is affected by factor that arose not only from the technical and economic feasibility of control strategies but more generally from the environmental status of the natural resource, the climate implications, and the socio-economic context that creates determined conditions that exert pression on the water-related ecosystems (Ganoulis 2004; Doll et al 2014; Rosèn et al.2008). For this reason, the identification of risks that affect the entire drinking water supply chain shouldn't be reduced to technical and infrastructural analysis but need to embrace a broader and holistic view that takes into account the entire system that allow the provisioning of high-quality water (Berg et al. 2019), not only to protect human health, but respecting natural environment boundaries and meeting the needs of the industry, agriculture, and the entire society.
Integrated Risk Assessment and Management approach, in accordance to the WSP framework, aims at identifying a strategy that allows to a) map, evaluate and prioritize the existing risks that comes from diverse sources and different phase of the supply chain; b) identify and plan solutions to mitigate the risks; c) monitor the results and implementation of the assessment and management phases; d) communicate efficiently the process to all the relevant stakeholders (Rosén et al. 2008).

3.2 Stakeholder Engagement and Water Safety Plans

According to McKie et al. (2006), the WSP approach requires a team of stakeholders to share their knowledge and know-how in order to map efficiently all risks related to the resource, the infrastructure and the status of the environmental context, and to reach consensus on their prioritization and adaptation or control strategies. As explained in the previous paragraph, the integrated risk assessment and management approach, implies competences that comes from different field of study as political and social sciences, economics, engineering, environmental sciences and climate studies (Ganoulis 2004). In addition to that it is becoming more and more relevant, the importance of engaging local communities in the water governance and protection process (Lane et al. 2022). That's because, first of all, they are the final beneficiaries of the implementation strategies, and it is necessary to understand what their needs are and how to properly address them. Moreover, several authors point out that WSPs, in addition to the protection of public health, may have positive repercussions for environmental protection (Roeger et al., 2018, Almeida et. al 2014, Hubbard et al. 2013), which affect the entire society. The stakeholder engagement in WSPs results, thus, to be a fundamental prerequisite for the protection of the ecosystems and the water resource. Recent literature on the experiences of WSP implementation (Roeger et al., 2018; Baum and 2018) has pointed out, that the involvement of working groups and collaborations between health and environmental protection agencies are key aspects in determining the success of WSPs, along with factors such as governance, leadership and managerial commitment, and technical knowledge (Summeril et al. 2010). In addition to that, Jalba et al. (2010) showed how communication and experience sharing between water service managers and other stakeholders such as public safety and environmental agencies are critical aspects in joint emergency management.

4) Methodology

4.1 The Engaged Scholarship Methodological Process

Authors utilized the Engaged Scholarship Methodological Process to develop an integrated and collaborative risk management model for implementing Water Safety Plans. This approach facilitated the identification and thorough study of issues and solutions within the realm of safe water management. The engaged scholarship approach is particularly relevant when it comes to analyses complex problems that involve social, economic and environmental aspects and that require, therefore, the interactions between skills, knowledge and competencies that arise from different fields of study (Van de Ven 2007.) Engaged scholarship and stakeholder engagement, thus, have been widely and successfully applied in a wide range of case studies related to risk management and common good governance, in order to create a new knowledge based on local experience and expertise from scientific researchers, policymakers and all relevant actors potentially involved. This approach has been show to support risk assessment and reduction related to emerging issues such as climate change (Jenewein & Hummel 2022), social media use (Elbanna et al. 2019) and urban pollution (Godsman & Rother 2019) , to address efficiently public health inequalities and concerns (Ortiz et al., 2020), to inform the policy making process and foster the public-private partnership (McIsaac & Riley, 2020), to promote an effective water management for safe drinking water and disaster prevention (Ricart 2016; Lacroix & Megdal 2016; Chingombe et al. 2015; Challies et al. 2016).
The theoretical framework of Engaged scholarship, represented in Fig.1, allowed the research group to a) ground the problem of water governance for health protection in a real context, according to the peculiar features of each case study and considering all the relevant elements (problem formulation); b) investigate plausible theories to address efficiently the problem (theory building); c) design the research and its practical application and test it in different settings (research design); and e) apply the research findings to each DWSS in order to empirically evaluate its functioning (problem solving). This entire process required the collaboration of all the relevant actors involved in order to collect the necessary information and elaborate feasible solutions, thanks to the contributions of different expertise and know-how.

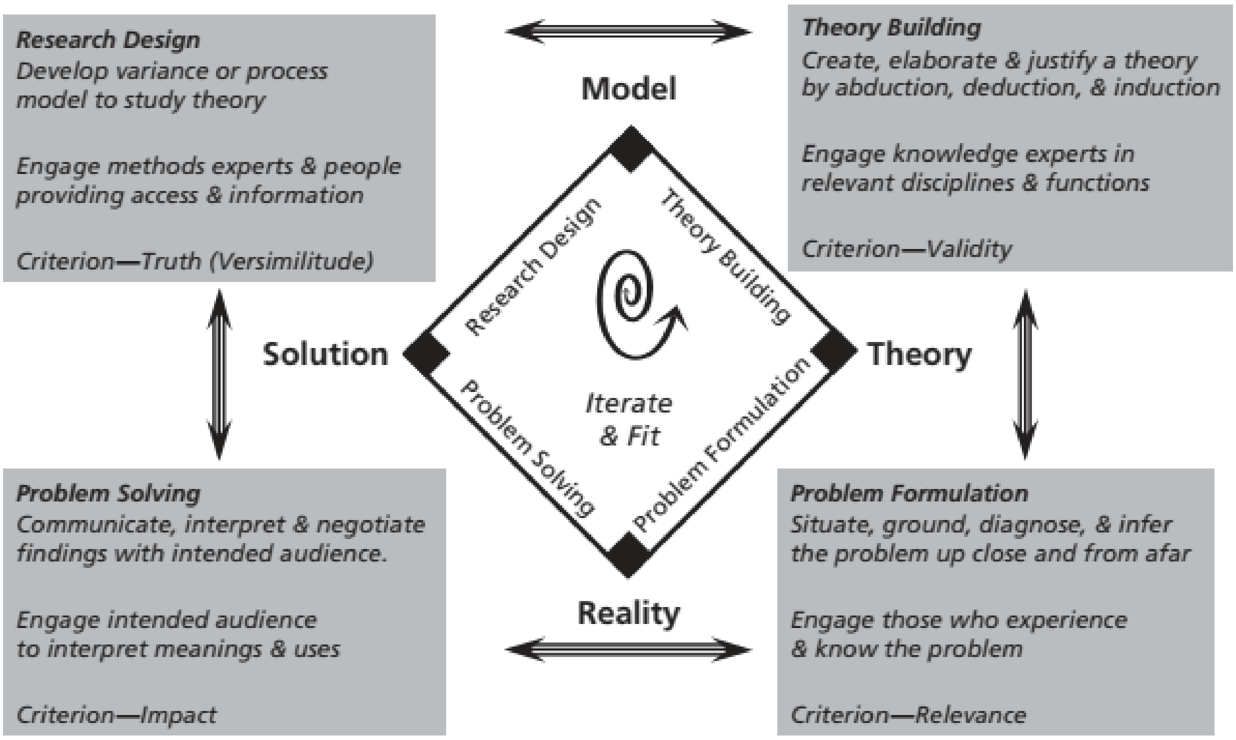

Figure 1: Engaged scholarship model. *Source: Van der van 2009*

4.2 Problem formulation

At the beginning of 2019 the Authors, along with 6 representatives of two Tuscan water companies and 3 representatives of the Italian National Institute of Health, Department of Environment and Health - Section of Water, the research body of the Ministry of Public Health, were involved in a committee that looked at the links between water protection, health protection and climate change. In November 2019 this committee faced with the need to implement WSPs in Italy and discussed how to develop an approach to implement WSPs that can ensure integrated risk assessment, the participation of different types of stakeholders and their collaboration, the protection of ecosystems involved in drinking water supply and the quality and safety of the drinking water itself. Unfortunately, the working activities had been slowed down by the COVID-19 pandemic, and only in June 2020 a dedicated Operational and Research Team (Fig. 2 and Table 1) was created to work on this issue, who decided to follow the Engaged Scholarship Theory with the aim to contribute in a practical way to real problems and generate a knowledge able to enrich the scientific debate on integrated and collaborative risk management. As explained in the following sections after having formulated the problem the study phase started, focusing on risk management, climate change and stakeholder engagement.

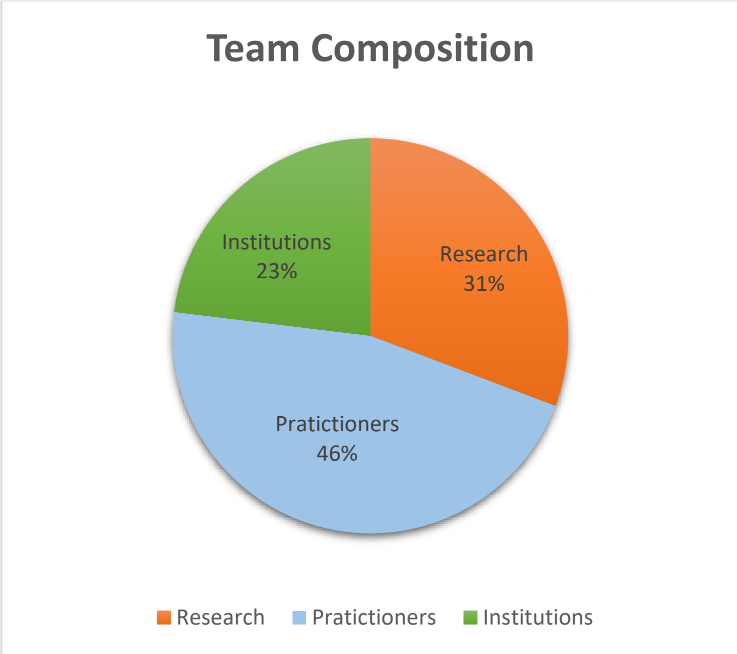

Figure 2: Team Composition

Organization	Function	Expertise
ASA S.p.A.	Area Manager	Process and Infrastructure
	Geologist	Environmental Science
	Quality Manger	Chemical and Biological risks
Acque S.p.A.	Operational Manager	Process and Infrastructure
	HSE Manager	Health, Security and Environmental Procedures
	Quality Manager	Chemical and Biological risks
Sant'Anna School of Advanced Studies	Research Project Coordinator	Natural Capital Governance and Sustainable Development
	Senior researcher	Environmental Science and Sustainable Development
	Senior researcher	Economy and Sustainable Management
	Junior researcher	GIS expert and Sustainable Management
Italian National Institute of Health	Department coordinator	Water Governance and Public Health
	Senior researcher	Chemistry and Biological Risks
	Senior researcher	Chemistry and Biological Risks

Table 1: Multidisciplinary competencies of the Team

4.3 Theory building

4.3.1 Risk Assessment and Management

The objective of risk assessment and management in the water supply sector is to ensure safe water (Roeger etal., 2018). The literature consulted in the context of the water utilities sector (inter alia Jaratneet al., 2006) identified *Hazard Analysis and Critical Control Points* (HACCP) and ISO 9001

as the most frequent risk-based methodologies or systems applied to achieve the objective of ensuring water quality. The HACCP system is an international established methodology, whose principles and implementation guidelines have become the scientific basis for identifying specific hazards and the relative control measures in order to ensure water safety. Indeed, most published WSPs are based on models adapted from HACCP procedures (Roeger et al., 2018, citing Hamilton et al. (2006)). A few case studies (Malzer et al., 2010, Six et al., 2015; Ye et al. 2015) report also the use of check-lists that guide in the identification of hazardous events related to the presence of different anthropic activities or land uses in the territorial context of wells and other DWSS infrastructures. Contrarily, the literature concerning case studies for risk assessment in WSPs shows the frequent use of semi-quantitative matrices (Ye etal., 2015, Six et al., 2015, Mahmud et al., 2007). In most of the case studies consulted, the focus of the analysis seems to be more or exclusively on hazardous events and dangers affecting supplied water (and thus more on the infrastructural component), rather than on the natural water resource. In any case, the use of a methodological approach that guides the identification of hazardous events through a broader analysis of the infrastructural system, which also grasps its relations with the environmental and socio-economic system, appears to be absent or is not reported. Within the more general framework of water resource governance, one of the most widely used models for the study of the relationships between environmental and human systems is the *Drivers-Pressures-State-Impacts-Responses* (DPSIR) model (EEA,1999). This model consists of a framework of causal relationships between different categories. In particular, it is based on the assumption that social and economic developments (Drivers) cause Pressures on the environment, thus determining a change in its State (understood as the quality and features of the environment). Significant changes in the State of the environment can in turn cause Impacts, which manifest themselves as alterations in ecosystems, in their ability to sustain life, human health, social and economic performance. This requires the identification of Responses that can act on Drivers, State or directly on Impacts to reestablish a situation of equilibrium.By recognizing the relationships between causes (Drivers, leading to pressures) and effects (States, leading to Impacts) for a given environmental risk, the DPSIR model supports the risk management process as these relationships provide the information needed to identify the causes and therefore efficient policies or strategies to solve the problems (Cheng Chen et al., 2014).
The DPSIR model is incorporated in the principles of the Water Framework Directive (WFD) 2000/60/EC and the *Integrated Water Resource Management* (IWRM)[3] framework and is used for the analysis of pressures and impacts on water bodies at the basin scale. The DPSIR model and some of its variants have been used in several projects to describe the relationships between environmental pressures, water resources and health. Boelee et. al (2019), for example, analyses some water-related health problems (due to chemical pollution, microbiological contamination and the enabling habitat variables for disease vectors), applying the DPSIR model adapted from Yee et al (2015) to the description of the relationships between environmental health (in which ecosystem services fall) and human health.. Shields et al. (2014) uses the *Driving Force-Pressure-State-Exposure-Effect-Action* (DPSEEA) model, developed by the WHO in 1995, to explore the link between water-related diseases (diarrhea, arsenic and fluoride poisoning) and their significant drivers, identifying these as population growth, agriculture, deforestation, extreme weather events and climate change.

4.3.2 Risk Assessment and Management of Climate Change

Concerning risks from climate change, one of the guiding documents related to WSP implementation is Climate-resilient water safety plans: Managing health risks associated with variability and change (WHO, 2017). This publication states that climate change, together with population growth, increasing urbanization and rising demand for water, will place an additional burden on water supply in the future, which creates the urgency to initiate a transition towards an approach that will focus on resilience and adaptation for water bodies. This document introduces two relevant complementary approaches that should be considered through the WSP process to ensure a sufficient level of climate change risk management. The first is *Disaster Risk Reduction* (DRR; UNGA, 2016), which focuses on mitigation of exceptional events, mainly through improving resilience. DRR aims at preventing and reducing new or existing disaster risks and managing the eventual residual risks, in order to strengthen the resilience of the system. The second is the *Integrated Water Resource Management* (IWRM), which provides a framework for adaptation to long-term changes associated with climate change. These approaches support the identification of climate change-related hazards, the assessment of the likelihood and severity of climate change impacts, the identification of additional control measures and management procedures to be adopted. DRR can contribute on WSP implementation through better preparedness and planning to facilitate, under emergency conditions, both security of water supply and faster recovery of normal functions after the exceptional event. Tools related to the IWRM framework offer a range of adaptation options that can directly or indirectly help in reducing risk levels for water supply systems. Recent literature (Rickert et al.,2019) on the integration of WSPs and climate change aspects has shown that such integration focuses more on the phase of team building, system description, hazard analysis and risk assessment, improved planning and development of management procedures.

4.3.3 Integrated and collaborative risk assessment and management model development

The results of these study phases were discussed by the Team, with different implications for risk assessment ana management, and stakeholder engagement, as described below.
Considering the risk analysis model, the discussion was heated. For while it was clear to the researchers that one had to look at the water system-that is, the water resources, infrastructure, and facilities-not just in itself, but as embedded in a given environment and dynamic, this was difficult for the business representatives to understand. In fact, fear of complexity made them lean toward a more standardized risk analysis. Even for researchers at the National Institute of Health, it was not immediately clear how such an assessment system could work, with what data, and with what IT support. However, they were fascinated and interested in deepening this approach. Faced with these reactions, the researchers worked on a simplification of the risk analysis model. As explained in the detail in the following paragraphs (see paragraph 5.1 The DP_SI_R model), the University researchers proposed a simplified version of the *Drivers-Pressures-State-Impacts-Responses* (DPSIR) framework, that took into account principles and concepts of all the different theories on risk analysis and assessment previously identified and studied. The model proposed is composed by three Macrocategories of variables: *Drivers and Pressures, State and Impacts, and Responses*.The first two Macrocategories aim at identifying all the factors affecting the quality, quantity and acceptability of the drinking water provided by the utilities, investigating the natural conditions of the resource, the status of the infrastructures, the procedures of the utilities and the environmental and anthropic pressures exerted on the territory under analysis, comprehensive of climate change implications. The latter Category consisted in the control and management strategies applied to face all the potential risks related to the factor previously assessed. The DP_SI_R was subsequently presented, discussed and accepted by Team members.

4.3.4 Stakeholder engagement and collaboration

According to the classical definition (Freeman, 1984), stakeholders are those who influence or are influenced by a decision or action. Within the broader process of stakeholder engagement, *stakeholder analysis* is the process that: i) defines the aspects of a social and natural phenomenon that are affected by a decision or action; ii) identifies individuals, groups and organizations that are influenced or can influence this phenomenon and iii) prioritizes these individuals and groups for involvement in the decision-making process (Varvasovszky, Z., & Brugha, R. 2000; Reed et. al, 2009). Almeida et. al (2014), proposing a new framework, the Water Cycle Safety Plan (WCSP), which extends the concept of the Water Safety Plan to the urban water cycle, envisages the participation of a broad group of actors comprising, in addition to the technical operators, local governments (municipalities), environmental and health authorities, river basin authorities, regional level authorities, regulators, civil protection and emergency response services, non-governmental

bodies and other users of the resource. Also, Bartram et al. (2009), reporting on the experience of British companies, states that it is necessary to enlarge the participation in WSP also to representatives from industry, infrastructure and forestry. Despite the relevance of stakeholder engagement for the successful implementation of WSPs, the analysis of the case studies available in the literature frequently reveals limited information on how this process has been carried out.
For this reason, it was necessary for the Team members to develop a process that would guarantee the inclusion of actors belonging to different field of expertise that will embrace the complexity of the social, environmental, economic and infrastructural factors affecting the DWSS and water security. All the Team members embraced the need and perspective for stakeholder mapping, appropriate engagement strategy, and functional collaboration in the risk assessment phases. Both the representatives of the companies and those of the Italian National Institute of Health applauded this collaborative vision, which is capable of generating a lasting governance system in the target territories. This collaborative governance of risks makes it possible to look at human health and water protection as truly connected, by constantly analyzing the interconnections between a territory, its natural resources and vulnerabilities, the local communities, local economy and businesses, climate change as well as other changing dynamics, buildings, infrastructures, water infrastructures and their operations. This integrated vision requires a common understanding among different stakeholders and a constant flow of information exchange.
For this reason, the Team worked on a replicable framework to ensure stakeholder involvement and engagement on the long term in the implementation of WSP. The first step is carried out through the *stakeholder analysis* methodology (Varvasovszky & Brugha. 2000; Reed et. al, 2009). It consists firstly in a consultation of the literature (scientific and grey) concerning stakeholder engagement in the context of WSPs and water resource governance, aimed at identifying an initial list of potential categories ofstakeholders to be involved. Subsequently, through the so-called *snowball* method (Butler, 2015 and Maskrey, 2016), this preliminary list is shared with some experts in the field through interviews, in order to receive an indication from them about possible other categories to be involved. The list produced at the end of the previous activity is enriched by consulting documents such as the water utility company's Sustainability Report and other material deemed relevant for the specific purpose (e.g., documents produced as part of projects developed by the company and concerning water resource management). The identified stakeholders are then categorized and classified in a dataset containing the most relevant information (such as their category, specific interests, influence) in order to prioritize the stakeholder following specific criteria relevant to WSP implementation, such as their relative influence and their expertise on water governance themes. This activity is essential for the identification of the members of the Multidisciplinary Team (see paragraph 5.2 Multidisciplinary Group and Stakeholder engagement) and for the development of specific engagement strategies for the different stakeholder identified. All stakeholders are involved, either in plenary or in subgroups, depending on the specific topic of interest, in activities such as interviews or focus groups, with the aim of deepening the perceptions and views of individual actors on the issues that will emerge as most criticalin the implementation of the plan. The continuous and up-to-date information information flow was managed through an online CLOUD platform. Any member of the Mutidisciplinary Group had access to the platform through a personal ID user and password and was able to consult and upload all the documents and data related to the WSP implementation.

4.5 Testing of the Model

The DP_SI_R model and the collaborative approach was applied to 2 territories/water utilities through an in dept data collection and analysis with the support of several operational roles in the DWSS organizations, and the documentation provided by all the stakeholders involved through dedicated in-person and online meeting, and the CLOUD platform.

4.5.1 Study 1: Application of the WSP model in the Empoli water system

The first application of the integrated and collaborative risk assessment model for WSP was in the territory of Acque SpA, which manages the drinking water supply system (DWSS) in the region of Basso Valdarno, in Tuscany, that includes the city of Empoli.

The DWSS, shown the following map (Fig. 3), is made up of a complex and fragmented set of infrastructures within a simulated perimeter that covers the territories of six municipalities. The identification of this perimeter started from the study of the characteristics of the pipe system, of its interconnections and, above all, of the supply zones with homogeneous quality obtained through mathematical modelling (Epanet software). The infrastructure thus delimited consists of 79 wells (distributed in 9 well fields), 1 spring, 10 drinking water treatment plants, 30 storage tanks, 26 pumping stations and 388 km of aqueduct network.

This infrastructure system is located in a predominantly flat area of Basso Valdarno, crossed by the Arno River and the Pesa Torrent, and subject to a strong process of industrial and commercial development in the 1960s and 1970s. The area under consideration was also affected by a strong urbanization, with Empoli as the main node of the lowland settlement system. The infrastructures considered are all located in the Empoli plain, but in different local territorial contexts (Fig. 4): in some cases, they fall within or in close proximity to urban or industrial areas, in other cases in more agricultural contexts.

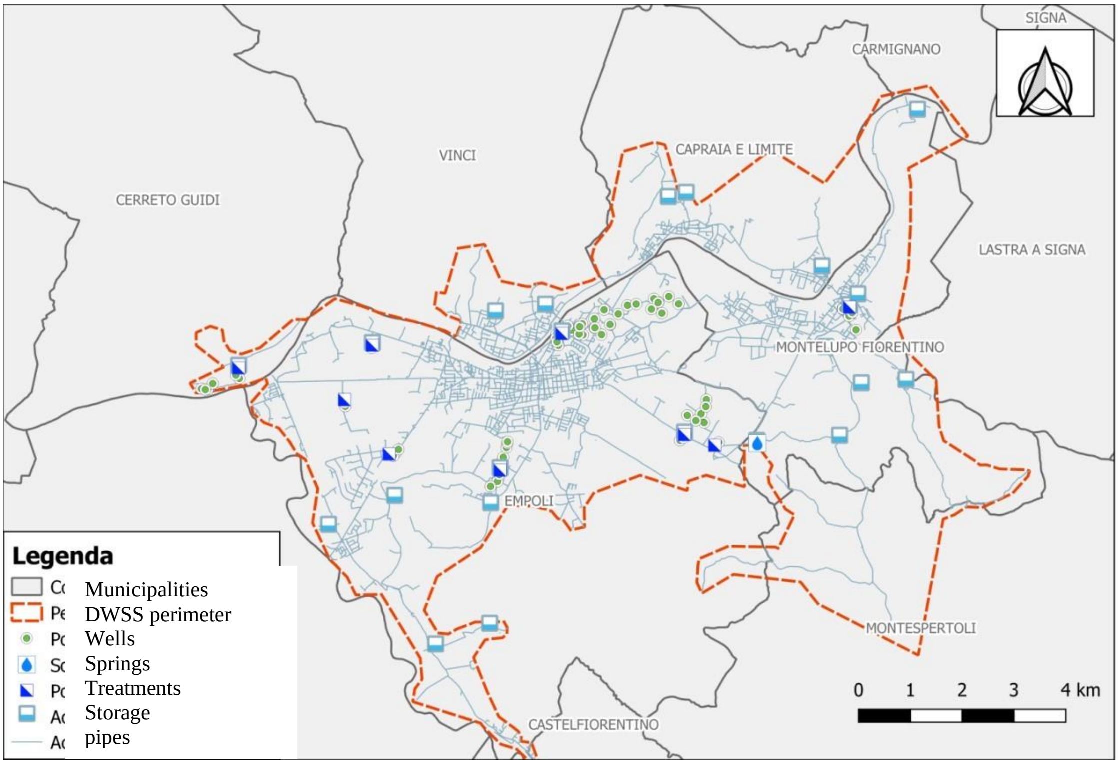

Figure 3: Empoli DWSS: infrastructure

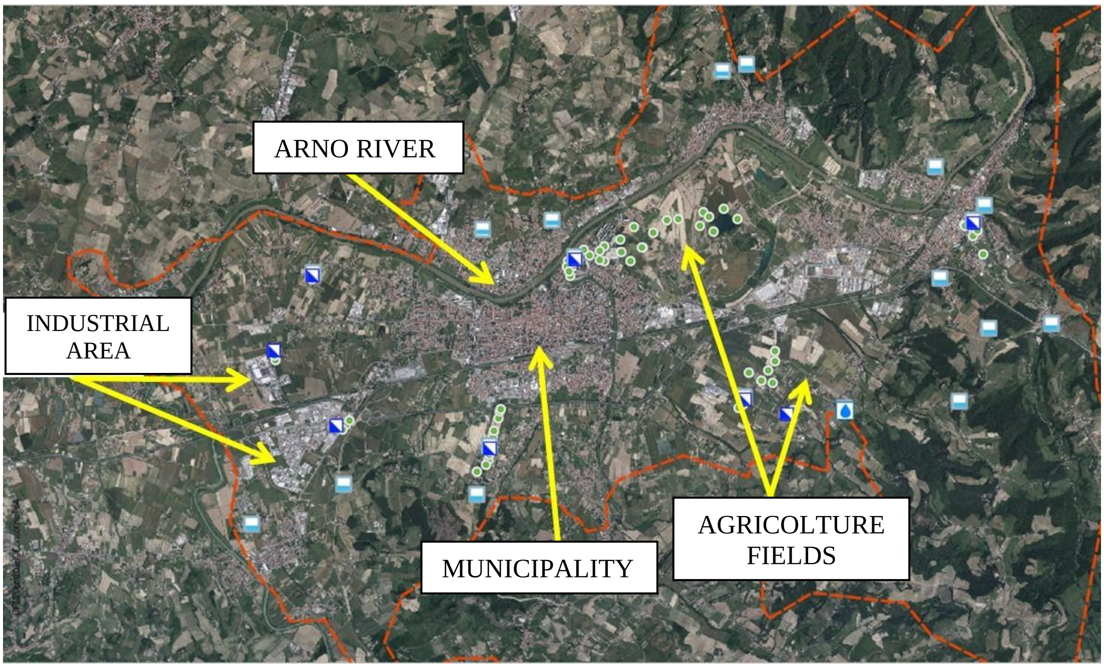

Figure 4: Empoli water system: territorial context

4.5.2 Study 2: Application of the WSP model in the area of Bibbona and Val di Cornia

The second study describes the implementation of the WSP model in two pilot sites in the territory under the responsibility of Azienda Servizi Ambientali (ASA) SpA, the water supplier of the Territorial Conference N.5 "Toscana Costa", which occupy the area of Bibbona and the area of Val di Cornia (VDC).

VDC is characterized by different complexity factors, both infrastructural (due to the high number of infrastructures and the presence of complex drinking water plants) and anthropic. The territory, which administratively encompasses four municipal territories, has been the subject of numerous environmental and hydrogeological studies that highlighted some aspects of vulnerability such as the subsidence phenomenon, the presence of industrial and agricultural activities, the high-water demand and the presence of several private wells. The overall context of Bibbona is less complex in terms of infrastructure, with a high seasonal water demand due to the intense touristic activity. The meteo-climatic impacts represent an intermediate level of criticality in both settings.

The following table provides some necessary information on the characteristics of the two pilot water systems.

Evaluation elements	VAL DI CORNIA	BIBBONA
Inhabitants served	57.000	3.000/20.000
N. Municipalities	4 (Piombino 34,320, Suvereto 3,130, Campiglia Marittima 13,263, San Vincenzo 7,000)	1
Aqueducts	9	3
Presence of Potabilisation Plants	Boron (2), As (3), Hg(2), Dioxide	NO
No. of Wells/Sources	89	7
N. Tanks	39/2	7
N. Booster plants	27	6
Presence/Absence of large interconnections	SI	SI
Ease of inspection (easy to more complex +, ++, +++)	+++	++
Availability of past data andstudies	SI	NO
Other aspects/considerations	LIFE, SIN (PARK), Subsidence	Wells type
Influence tourism		SI
Territorial impacts	Agriculture; Industry; Irrigation; Elba thrust	Tourism, agriculture
Presence of private wells (+; ++, +++)	+++	+
Climatic weather impacts	++	++

Table 2: Characteristics of the two pilot sites: Val di Cornia and Bibbona

4.5.3 Data Collection

The implementation of the DP_SI_R model entailed the collection of a large number of different types of information and data. The data were systematized through the creation of check lists containing all the information required in order to provide an updatedand detailed snapshot of the DWSS and its relations with the environmental and socio-economic system of reference. The collection of the identified data took place partly in desk mode, partly in the field as part of infrastructure inspections and partly with the contribution of the multidisciplinary team's stakeholders. With regard to the infrastructure component, desk-based data collection was supplemented by conducting on-site inspections of the infrastructure, also aimed at verifying the actual state of knowledge of the water system under study, the actual state of the sites and the adequacy of the available documentation. This activity was carried out following the approach adopted in the framework of management systems, with the aim of pursuing maximum integration between the procedures for carrying out inspections and any procedures already provided by the management systems adopted at company level. It was supported by the self-assessment forms contained in the National Health Institute guidelines for the implementation of WSPs (ISTISAN 14/21), document analysis, interviews to relevant roles of the water utility and the identification of useful criteria for the selection of the infrastructures to be subjected to on-site inspection as a representative sample of the entire system. To facilitate and organize data collection and analysis a GIS software project was implemented. Georeferenced data on the infrastructure system and open access data on the environmental and anthropic context were structured and entered in the software. This step was essential for the visualization, through cartography, of the relations between the various systems described by the DP_SI_R model. This tool proved to be an indispensable means for the elaboration of certain indicators (especially those of "Drivers and Pressures"), providing powerful support for the subsequent vulnerability analysis.

4.5.4 Vulnerability analysis and risk assessment matrix

Once the data had been collected, the indicators describing the macro-categories 'Drivers and Pressures' and 'State and Impacts' were processed, analyzed and systematized in the vulnerability report. This document entails a qualitative vulnerability rating assigned to each indicator, based on its scientific and objective quantification, in order to establish the extent to which the water resource is threatened by that specific factor. Specifically, we used a scale with three different levels of vulnerability (low, medium and high).

The assignment of the level of vulnerability was configured as a preparatory step to the actualrisk assessment- The operational tool that allowed the risk assessment is the water system risk matrix that contains, for each node and internode of the WDSS, all the elements useful for describing the hazardous events identified through the DP_SI_R model and assessing the level of risk associated. To carry out the risk assessment, we adopted a semi-quantitative approach set out in the ISTISAN guidelines, determining, through the assignment of Probability and Severity scores, first the value of the theoretical risk (which does not take into account the existence of the control measures already adopted in the system) and then the value of the actual risk. The latter is the value of the risk in the light of the judgement of effectiveness on each existing control measure - both in terms of adequacy of the measures adopted and evidence of the actions achieved (validation). The Macrocategories of “Drivers and Pressures” and “State and Impacts” were essential for the risk assessment phase, while the Macrocategory “Response”, including procedures, projects, physical control measures, initiatives and long-term plans, was relevant for the risk management implementation.

4.6 Problem solutions: results of field studies

The performance of the vulnerability analysis and, subsequently,of the risk assessment depicted efficiently the relationships between the different Macro categories and was preliminary to the identification of the response needed to ensure the entire DWSS and guarantee the safety and acceptability of the drinking water provided. The analysis revealed, in both the case studies, a high vulnerability of the supplied resource linked to several categories of 'Drivers-Pressures' (including climate change) and territorial hazard (State of the Environment). Considering the totality of hazardous events, the theoretical risk was highest in the treatment phase, followed by the uptake and distribution phase; the re-evaluation of the risk, taking into account the effectiveness of the control measures already in place, revealed a low actual risk in all phases of the drinking water supply chain, demonstrating that the existing control measures implemented by the water supplier were, mostly, effective. For hazardous events with a medium or high residual risk, specific response measures were also identified. Most of them were related to the status of the water, to the treatments provided and to infrastructure conservation. Focusing on responses to the most critical environmental or anthropic, the team identified a series of measures that have been or will be

implemented (depending on the priority) through collaboration between different stakeholders. The discussion among the different stakeholders was fundamental to guarantee the reliability of the process and thus reduce possible *biases* linked to subjective judgement.
The mapping activity of stakeholders made it possible to identify, at a territorial level, numerous specific competencies in the area of protection, management and control of water resources, whichwere added to the strictly technical of the supplier. The team included technicians, experts and operational figures capable of ensuring in-depth knowledgeof each segment of the chain in the water system of reference and of the dangers, of various nature and origin, that can be associated with it. Approximately 15 meetings of the two operational groups for the first case study and 20 meeting for the second one, were held over the course of the WSP implementation, either in plenary or in subgroups of the two operational groups separated. With regard to the EOG, the different components met in plenary for the sharing of the main and most delicate phases relating to the implementation of the WSP, such as the data collection phase, the validation of the theoretical model and the developing of the risk matrix.

5) Results and Discussion

5.1 The DP_SI_R model

The research team simplified the classical structure of the D.P.S.I.R. model by merging Drivers and Pressures on the one hand, and State and Impacts on the other, thus obtaining a model called DP_SI_R consisting of three Macro categories (Fig. 5). Each of these is broken down into a series of sub-categories that are in turn described by one or more indicators. The model enabled the multidisciplinary team to take into account all the possible hazards in the specific reference context. The Macro category "Drivers and Pressures" framed the demographic, socio-economic and environmental system in which the water system under consideration is inserted and consequently identified and classified all the potential vulnerability factors of natural or anthropic origin that are exerted on the water resource, including climate change implications. These factors described by means of a set of qualitative or quantitative indicators developed at appropriate territorial scales. The Macro category "State and Impacts" instead contains a set of variables, and related indicators, that describe, for each phase of the drinking water supply chain, the state of the environment, the state of the aqueduct infrastructures, the state of the water resource and the temporal frequency of events capable of provoking a qualitative-quantitative alteration of the drinking water resource with consequences on human health (interpreted as Impacts). This Category included also some indicators related to the consumer perception of the water and the overall services provided.

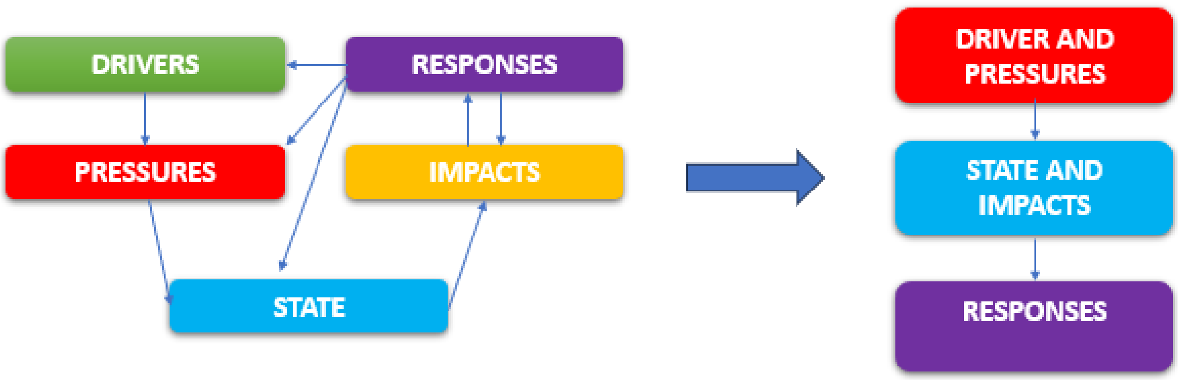

Figure 5 DPSIR and DP_SI_R model comparison

The 'Responses' macro-category brings together a set of measures to respond to the risks identified in the specific risk assessment phase. These measures have been divided into three categories. The first category includes regulatory and normative instruments that act on a broad scale to protect the water resource, either directly or indirectly. The second category refers to hazardous event control measures already implemented in the water system (e.g. remote control, maintenance, physical protection of infrastructure), which must be evaluated in terms of their effectiveness and validated within the risk matrix. The third category consists of all actions aimed at controlling each hazard and associated residual risks (on a priority scale) that the control measures already in place don't tackle efficiently. The model was integrated with a series of information and indicators, relating to the epidemiological and climatic aspects. For the latter, the integration of indicators was carried out through a reinterpretation of the water, environmental and socio-economic system according to the IWRM and DRR approaches.
The variables included in the DP_SI_R model are represented in the graph below.

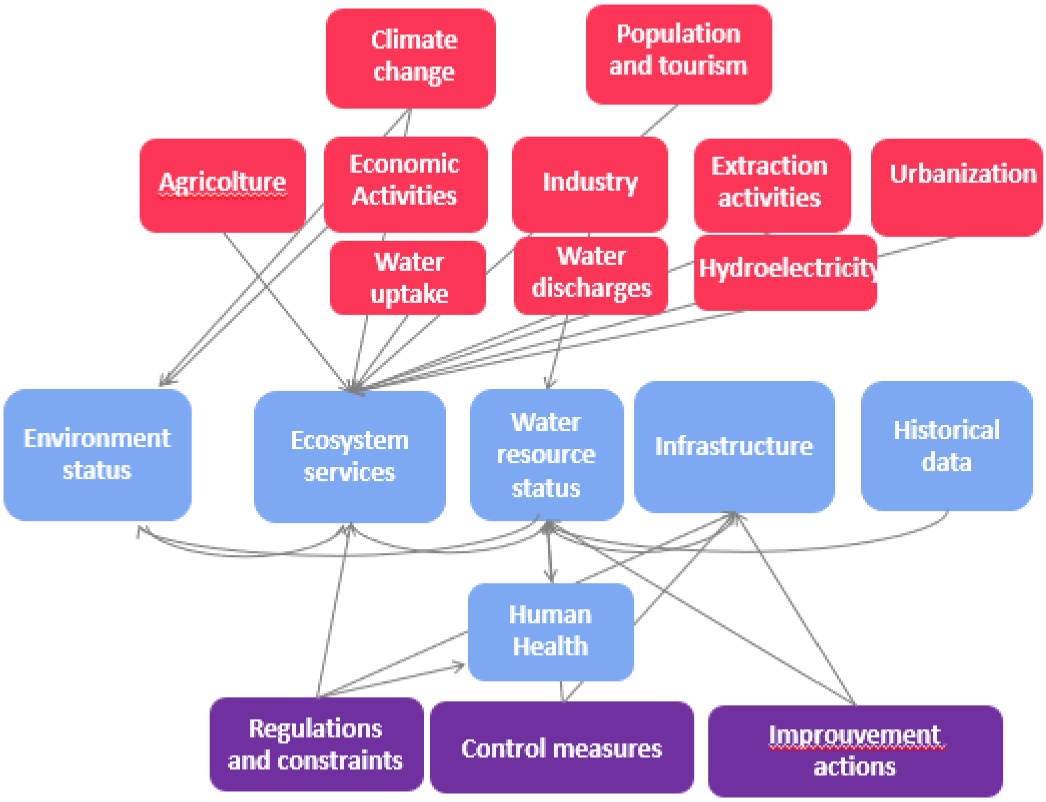

Figure 6: Final diagram of the DP_SI_R model

5.2 Multidisciplinary Group and Stakeholder engagement

In academic literature on WSP the stakeholder engagement strategies are, in most of the cases, still unclear (Hubbard et al. 2013), and represent one of the biggest challenges still open (Ferreo et al. 2018; Keirle & Hayes 2007, Parker et al, 2013). According to that, Schmoll et al, 2011 underlined that in Germany both public utilities and local public health authorities perceived an already high levels of service quality and compliance of the DWSS and, therefore, couldn't see the added value of the WSP approach; while Ncube et. al. (2013) reported that the main challenges related to assembling the team involved convincing stakeholders of their potential contribution on the issue of water security. Even once the team was established, the commitment from its members was lacking and, according to String et al., (2016) there is also little evidence of the long-term activities of the team. In addition to the importance of external engagement, several studies on WSP implementation have found that one of the key requirements for WSP success is the commitment of leadership and the involvement of internal stakeholders (Summeril et al., 2010). However, this aspect is often lacking (e.g. Ncube et. al, 2013 and Kanyesigye et al.,2019). The topic of organization culture, defined by Shein et al., (2004) as the set ofattitudes, norms, experiences, beliefs and values shared by an organization, is recurrent in thditerature on WSPs (Summerill et al., 2010 and 2011, Amjad et al. 2016, Ferrero et al. 2018).

To overcome this problem, the proposed approach includes a strategy based on stakeholder identification and active engagement that resulted in a successful collaboration throughout the entire process of WSP implementation. The following prioritization allowed to identify the member of the Multidisciplinary Team, that, as shown in Figure 7 and Table 3, has been divided into two groups:

- Restricted Operating Group (ROG), which was in charge of the implementation of the WSP in all its stages;
- Enlarged Operational Group (EOG), which ensured the provision of valuable contributions, in terms of data and information supply, for carrying out an exhaustiveand reliable risk assessment and control measure implementation.

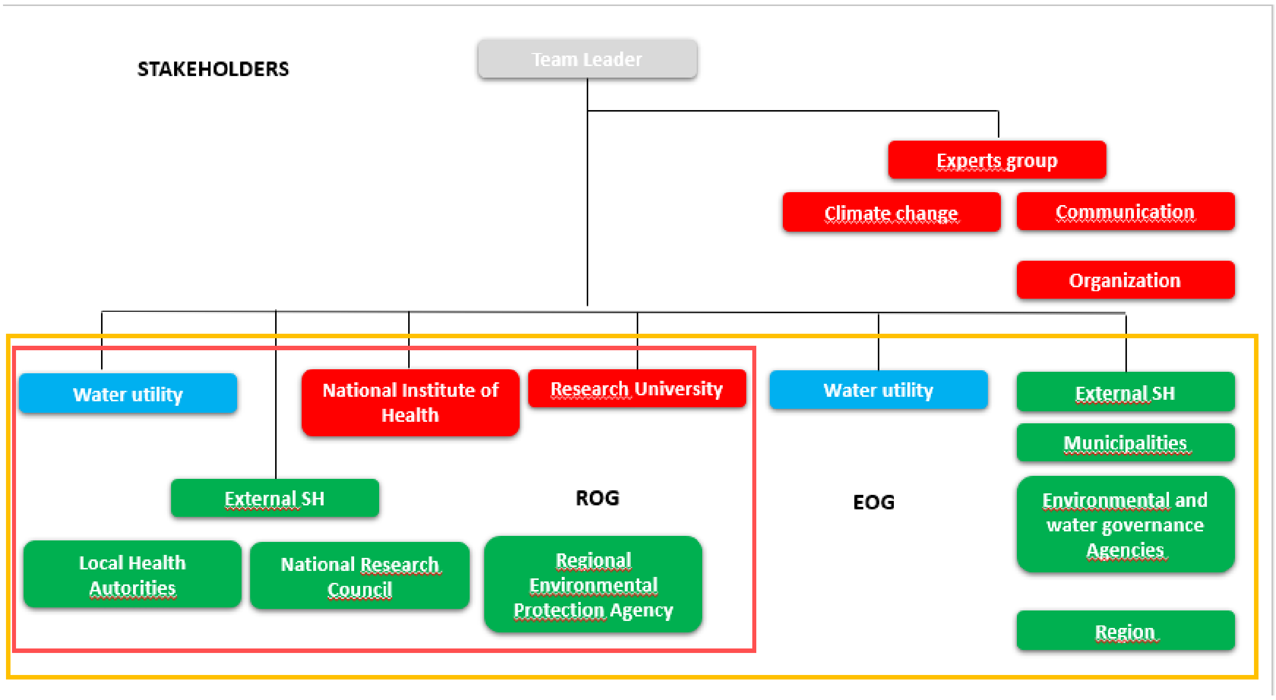

Figure 7: Organigram of the multidisciplinary team

Stakeholder	ASA S.p.A.	Acque S.p.A.	Team
Water Utility	Area Manager	Operational Manager	GOR
	Geologist	HSE Manager	GOR
	Quality Manger	Quality Manager	GOR
	Leadership		GOA
	Employee involved in the territory of the WSP		GOA
Research University	Research Project Coordinator - Natural Capital Governance and Sustainable Development		GOR
	Senior researcher - Environmental Science and Sustainable Development		GOR
	Senior researcher - Economy and Sustainable Development		GOR
	Junior researcher - GIS expert and Sustainable Development		GOR
National Institute of Health	Department coordinator - Water Governance and Public Health		GOR
	Senior researcher - Chemical and Biological risks		GOR
	Senior researcher - Chemical and Biological risks		GOR
Local Health Autorities	ASL - Area Manager		GOR
National Research Institute	CNR - Water Governance		GOR
Regional Environmental Protection Agencies	ISPRA - Regional Manager		GOR
Region	Tuscany Region Rapresentative for environmental protection		GOA
Environmental and water governace Agencies	Autorità Idrica Toscana		GOA
	Autorità di Bacino Distrettuale dell'Appennino Settentrionale		GOA
	Consorzio di Bonifica		GOA
Municipalities	Piombino, Campiglia Marittima, Suvereto, San Vincenzo, Bibbona	Empoli, Vinci, Montelupo Fiorentino, Cerreto Guidi, Capraia, Limite	GOA
Other Stakeholder	Geoexplorer S.r.l. (Climate and environmental experts)	Ingegnerie Toscane (Engineers)	GOA

Table 3: Composition of the Multidisciplinary Group

The two groups are engaged at different levels: the members of the ROG are asked to participate in periodic meetings, necessary for the implementation of the WSP, in order to contribute, according to their specific knowledge and skills, to all implementation phases; the members of the EOG and the group of experts are involved to solve some specific issues or tackle explicit needs highlighted by the WSP and during the most important implementation phases. The heterogeneous and wide-ranging composition of the multidisciplinary team, thanks to the application of *stakeholder analysis*, ensure that the necessary information, points of view and skills were brought in throughout the implementation process. Consequently, continuous cooperation of the multidisciplinary team is desirable to ensure effective risk prevention and management. The interest shown, during the in-filed studies, by some team members, also following the risk assessment, in identifying a specific communication protocol with thewater service provider for reporting information relevant to the operational phase of the planis a good basis for long-term cooperation, which may have positive repercussions on the environment, as already argued by other authors (Roeger et a., 2018, Almeida et. al 2014, Hubbard et al. 2013), and particularly on resource protection and water sector governance (Roeger et al., 2018). While stakeholder engagement is one of the biggest challenges still open in theimplementation of WSPs Ferrero et al. (2018), the collaborative approach developed and tested during this research, proved that a structured approach to stakeholder engagement foster active participation and collaboration.

5.3 Risk assessment and management

The main goal of the risk assessment is to enable managers to be fully aware of the water resource systems in which they operate, in order to assess prevent risks and explore opportunities as a whole. Indeed, the proposed approach develop aims to broaden the understanding of the DWSS by describing its relationship with the environmental and socio-economic system. The model identified, which can also be easily replicated in other contexts, allows a robust identification of the vulnerability factors and therefore of the hazardous events, that threaten water safety, going beyond the mere application of generic checklists of hazardous events, as occurs in some cases reported in the literature. This approach complements the traditional WSP framework ensuring that both quantitative and qualitative aspects are taken into account, facilitating also the integration of the possible consequences of climate change and considerations regarding the governance of the resource. Such a broad reading of the water system emphasizes the need for robust stakeholder engagement methodologies that support shared and integrated risk management. The methodological approach exposed in the previous paragraphs may be a valuable tool to guarantee a comprehensive risk assessment, which requires the collaboration of various stakeholders and experts and the provision of specific information and know-how. In the risk assessment and management phase, coordination and collaboration between the various team members were indispensable. As reported in the previous paragraphs, this collaboration is fundamental in the phases of data collection, validation of the model and territorial scale of investigation, risk assessment and identification of some response measures. The team meetings represented important occasions not only for the discussion and sharing of purely operational aspects, connected to the main phases of WSP implementation, but also for the consolidation of relations between the various members of the group and for becoming aware, through the examination of the nature of the hazardous events included in the matrix, of the roles and contributions of the various stakeholders in the protection of the water resource. This approach also laid the foundations for further collaboration. These results confirmed the evidence already reported in the literature (Roeger et al, 2018) regarding the focal role that collaboration between different stakeholders plays in the implementation of an effective WSP. Despite some initial difficulties in the involvement of some territorial stakeholders, a frequent element in the literature (e.g. in Ncube et al. 2011), this study demonstrates that if the stakeholders involvement is effective, continuous and coordinated, it makes an important contribution in all phases of water safety plan development: provision of data, identification of hazardous events and response measures. The in-filed part of this research demonstrates that through their collaborative attitude, the possibility to participate in the risk assessment and in the identification and development of improvement measures and actions, the different stakeholders definitively show that they understand the weight of their role and take responsibility for these improvements, as asserted by McKie et al, 2016.

6) Conclusions

Since their introduction in 2004 as part of the third edition of the Drinking Water Quality Guidelines, WSPs have been implemented at different scales in different regions of the world, consistently demonstrating significant benefits in risk management, and are now considered a key tool for achieving the universal *SDG 6 Clean Water and Sanitation* goal.

Hazardous events that may cause a risk related to drinking water consumption have different origins and nature, from country to country and from site to site, as they are closely linked to the territorial, economic and social context in which the resource is supplied. However, it is clear that the effects of climate change and the presence of new contaminants represent global threats that the WSP can effectively address, not only for the protection of human health but also for environmental and

resource protection. This issue requires the adoption of a model for risk assessment that is replicable and comparable across different water systems and the collaboration between the relevant stakeholder during all the stages of the WSP implementation process. A broad, structured, conscious and sustained engagement of all stakeholders is essential in order to translate the WSP into a systematic and recognized tool within integrated water resource management policies.
The experience of the two case studies demonstrates precisely that team members, if involved in an effective, continuous and coordinated manner, make an important contribution at all stages of plan development (provision of data, identification of hazardous events and response measures) and that the commitment of the leadership and technical operators in water utilities is a key element for the success of the WSP. Through their collaborative attitude and the improvement measures and actions that were identified for the protection of the resource, the different stakeholders, internal and external, demonstrated to take the responsibility of their role in the implementation of the WSP and to understand the importance of collaboration. From the manager's point of view, the experience also demonstrates the importance of adopting a model for risk assessment that is replicable, comparable and integrated with the company's already adopted procedures. Stakeholder engagement, both internal and external, are essential elements, as is the commitment of the personnel involved, at all levels.
Our proposals to complement the traditional WSP approach to broaden the analysis to the effects of climate change and to the qualitative-quantitative state of the resource and epidemiological aspects has been shown to be a valuable contribution to the overall water quality and quantity management. This collaborative approach and the systemic analysis of all the element related to the socio-economic and environmental context of the DWSS resulted in a dramatic reduction of potential risks for water safety in both the case studies. A fundamental stage of this process was the involvement and collaboration among scholars and practitioners. It allows to ground the needs of WSP on strong theoretical framework and to structure procedures, solutions and methods that were feasible for the water utilities. It was clear, indeed, from the first meeting among Team members, that the utilities had the necessity to find a way to integrated the principles of WSP implementation in their consolidated standards and procedures in order to implement the overall quality management of drinking water. The continuous dialogue between researchers, technicians and utilities' managers enable the Team to collect valuable data, develop a strategy and implement policies and solutions to face the risks affecting water safety in their territories. Thanks to the continuous development of the methodologies obtained through the application of the WSP model in increasingly different DWSS and territorial systems, this tool can improve over time its effectiveness not only in protecting human health but also that of the environment and the resource. Not surprisingly, indeed, most of the procedures described and pursued in these case studies recall the general approach described in the most recent ISS guidelines. Nonetheless the efficiency of the model proposed by the authors needs to be further tested and validated in different contexts, in order to evaluate its replicability and flexibility.
The results of this study are particularly relevant for scholar and practitioners involved in water governance, since it proposes an effective and efficient management protocol based on systemic risk assessment and collaborative approach.

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