ISSN 1831-9424

European Commission

JRC TECHNICAL REPORT

Technical Guidance Water Reuse Risk Management for Agricultural Irrigation Schemes in Europe

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2022

Joint Research Centre

EUR 31316 EN

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JRC129596

EUR 31316 EN

PDF ISBN 978-92-76-59112-2 ISSN 1831-9424 doi:10.2760/590804 KJ-NA-31-316-EN-N

Luxembourg: Publications Office of the European Union, 2022

How to cite this report: Maffettone R., Gawlik B.M., *Technical Guidance - Water Reuse Risk Management for Agricultural Irrigation Schemes in Europe*, Publications Office of the European Union, Luxembourg, 2022, doi:10.2760/590804, JRC129596.

Contents

Abstract

In the context of the new Circular Economy Action Plan that was adopted in 2020, the Regulation 741/2020 on minimum requirements for water reuse for agricultural irrigation aims to boost water reuse practices in Europe. The Regulation sets out minimum water quality and monitoring requirements, permitting and transparency provisions related to water reuse, as well as risk management requirements to ensure safe reuse of treated urban wastewater in agricultural irrigation. Annex II of the Regulation reports key elements to develop a Risk Management Plan. On this basis, considering world-wide established approaches (ISO 20426:2018, Australian Guidelines (2006), WHO Guidelines (2006, 2016)), and taking into account the European legal framework set out within the Water Framework Directive, the Joint Research Centre (JRC) of the European Commission developed the proposed technical guidelines for the application of the key risk management principles for the assessment and management of health and environmental risks linked to a water reuse system.

Experts of the water reuse sector, representatives and authorities of European Union Member States, and stakeholders contributed to the development of the guidelines. Dedicated workshops (Title: Risk Management for Agriculture Irrigation in Europe – Ruggedness Testing of Guidelines), and consultations with members of working groups on water reuse were organized by JRC. Case studies from several European Member States, which were presented during those events, are also reported in these guidelines.

Foreword

The overall objective of this report is to support the implementation of the European Water Reuse Regulation 2020/741 by providing practical guidance on risk management, thus tapping into the full potential of water reuse practices for contributing to the European Green Deal, the SDGs, the 8th Environment Action Programme and the Zero Pollution Monitoring Framework as well as the Circular Economy Action Plan. Ultimately, this facilitates the application of the technologies and encourage the take up of the practices.

While there is a growing number of international guidance and also standards on the subject, Europe is still finding its way towards a systematic use of direct water reuse as part of an integrated water management. While few countries, mainly in the Mediterranean region, have created a sound and evidence-based knowledge base, the acceleration of climate change triggers the need to employ water reuse schemes more systematically in European regions, which traditionally did not feel the need to do so. This report is an important step to further deepen the European water reuse know-how and propose approaches which are rooted in experience and sound scientific work.

The work conducted and presented here by the JRC would not have been possible without the important support of the respective community of practice and the interested reader will find, in addition to a significant amount of technical advice and guidance, practical illustrations from European water reuse schemes. Sharing this knowledge will also further contribute to build public confidence in reuse practices.

Acknowledgements

We would like to thank the colleagues indicated hereafter for their professional and technical contribution to the JRC Technical Report Water Reuse Risk Management for Agricultural Irrigation Schemes in Europe:

- Serena Radini, Università Politecnica delle Marche, for providing technical insights on water reuse systems and risk management.
- Kyriakos Manoli, Nireas-International Water Research Center of the University of Cyprus, for providing scientific and technical insights and sharing expertise in wastewater treatment and reuse.
- Doha Zamel, Union for the Mediterranean, for her editing and technical layout contributions.
- Richard Elelman, Water Europe and EURECAT, for his support in improving the readability of this document and for his help in all aspects of social engagement.
- Valentina Bastino, European Commission Directorate-General for Environment, for her legal advice and policy input regarding the Water Reuse Regulation.
- Caterina Cacciatori, European Commission Joint Research Centre, for general technical support and feedback on specific elements.

The authors are also particular grateful to all participants to the technical workshops for their observations on the applicability of these guidelines, to those providing comments on the draft documents, and to the contributors of the case studies. Their help has been fundamental in providing insightful comments, feedbacks and practical illustration of the applicability of the report, while also promoting a dialogue between different stakeholders: Alfieri Pollice (IRSA CNR, Italy), Ana Allende (CEBAS-CSIC, Spain), Anabela Rebelo (APA Ambiente, Portugal), Andrea D'Anna (MM S.p.A., Italy), Andrea Turolla (Politecnico di Milano, Italy), Angeliki Larcou Yiannakou (Ministry of Agriculture, Rural Development and the Environment, Cyprus), Attilio Toscano (Università di Bologna, Italy), Caterina Jane Saracino (MM S.p.A., Italy), Claudio Carini (CIIP, Italy), Domenico Santoro (AquaSoil SrL, Italy), Eliana Tofa Christidou (Ministry of Agriculture, Rural Development and the Environment, Cyprus), Fabian Kraus (KWB, Germany), Francesco Fatone (Università Politecnica delle Marche, Italy), Franziska Gromadecki (Abwasserverband Braunschweig, Germany), Gertjan Medema (KWR, The Netherlands), Isabel León (CEDEX, Spain), Jacopo Foschi (Politecnico di Milano, Italy), Jade Mitchell (Michigan State University, USA), Jordi Martín Alonso (Aigües de Barcelona, Spain), Jos Frijns (KWR, The Neatherlandas), Manuel Sapiano (The Energy and Water Agency, Malta), Manuela Antonelli (Politecnico di Milano, Italy), Manuela Helmecke (UBA, Germany), Marco Bernardi (CAP Holding SpA, Italy), Marco Blazina (MM S.p.A., Italy), Maria Leal (CEDEX, Spain), Maryna Peter (FHNW, Switzerland), Massimo Spizzirri (ACEA, Italy), Pedro Simon Andreu (ESAMUR, Spain), Rita Hochstrat (FHNW, Switzerland), Ruud P. Bartholomeus (KWR, the Netherlands), Thomas Wintgens (FHNW, Switzerland), Ulf Miehe (KWB, Germany), Veronika Zhiteneva (KWB, Germany), Wolfgang Seis (KWB, Germany).

1 Introduction

Today, one third of the European Union (EU) territory suffers from water stress all year round, and water scarcity is a concern for many EU Member States (MS). According to climate change projections, the problem will increase across the EU in the next decades (Bisselink et al., 2020). Reduced availability of freshwater negatively affects EU citizens and economic sectors (e.g., agriculture, tourism, industry, energy and transport). This may affect competitiveness and the movement of goods, services, capital and persons within the EU Internal Market ([1]) (European Commission, 2018). In this setting, reuse of appropriately treated water from urban wastewater treatment plants (UWWTPs) has been identified as a reliable alternative of water supply for various purposes such as agricultural irrigation or aquifer recharge.

In December 2014, the European Commission (EC) Joint Research Centre (JRC) published the report "Water reuse in Europe. Relevant guidelines, needs for and barriers to innovation", which provides a synoptic overview of relevant regulations and guidelines on water reuse, analysing the associated technical, environmental, health and socioeconomic challenges (Gawlik and Alcalde-Sanz, 2014). Further work from JRC resulted in a technical proposal of minimum quality requirements for two specific water reuse categories: agricultural irrigation (crops irrigation) and aquifer recharge (direct recharge) (Gawlik and Alcalde-Sanz, 2017). The proposed requirements aimed at ensuring appropriate health and environmental protection and, thus, fostering public confidence in reuse practices. In addition, health protection of workers, public likely exposed, consumers and animals (e.g., cattle), as well as environmental protection goals, were addressed. The suggested minimum quality requirements, based on a series of international and national water reuse standards such as theAustralian Guidelines for Water Recycling and Australian Drinking Water Guidelines (NRMMC-EPHC-AHMC, 2006; NHMRC-NRMMC, 2011), US Guidelines for water reuse (EPA, 2012) or WHO Guidelines for the safe use of wastewater (WHO, 2006a), were then incorporated into the Commission's proposal for a Regulation on minimum requirements for water reuse – the Water Reuse Regulation 2020/741 (indicated as "Water Reuse Regulation" throughout the text) was adopted and entered into force in 2020, with application of rules starting in June 2023.

Article 5 and Annex II of the Water Reuse Regulation introduced the obligation for a Risk Management Plan (RMP) to be developed as a condition to set up a water reuse system. The RMP should comprise the identification and management of risks associated with the use of reclaimed water of a specific quality required for particular uses. It must be based on the elements of risk management listed in Annex II of the Water Reuse Regulation, following a systematic approach that includes a structured analysis of the water reuse system, the identification of potential hazards and hazardous events along with the populations and environments at risk and the related exposure routes, and the management of the assessed risks with the use of existing and/or possible preventive measures and barriers, when appropriate, to mitigate them. It also includes communication and cooperation among the parties involved to ensure that corrective actions are taken and communicated opportunely. While the Water Reuse Regulation establishes 12 Key Risk Management (KRMs) principles in Annex II divided in Part A, B and C, further guidance based on technical consensus is needed to facilitate a consistent implementation in all the EU MS.

The objective of this document is thus to explore the technical elements for the establishment of a RMP as required by Article 5 and to provide technical information to the MS in ensuring correct management of the health and environmental risks linked to water reuse for the production, supply and use of reclaimed water. It excludes any assessment done for the application of the Article 2 of the Water Reuse Regulation to identify if it is not appropriate to reuse water for agricultural irrigation considering the geographic and climatic condition of the area, the existing pressures of other water sources and the environmental and resources costs associated with the use of reclaimed water.

Although these guidelines are not formally legally binding, they provide a shared EU objective and approach, allowing, at the same time, flexibility to consider the different circumstances at national, regional and local levels. All the MS are thus encouraged to adopt the framework suggested in this document considering the necessary variation across the territories and depending on the operations of the specific water reuse system. MS and local jurisdiction may use their own legislative and regulatory tools to refine the information provided here into their own guidelines.

([1]) The European single market: internal market or common market is a EU space that ensures the free movement of goods, capital, services, and people within the EU.

This guidance originates from a work that included the revision of existing guidelines, the outcomes of EU-funded projects on water reuse (e.g., DEMOWARE), consultations with representatives of MS and relevant stakeholders, comments from experts in the water reuse field, and numerous inputs received during the Ad-Hoc technical workshops and meetings.

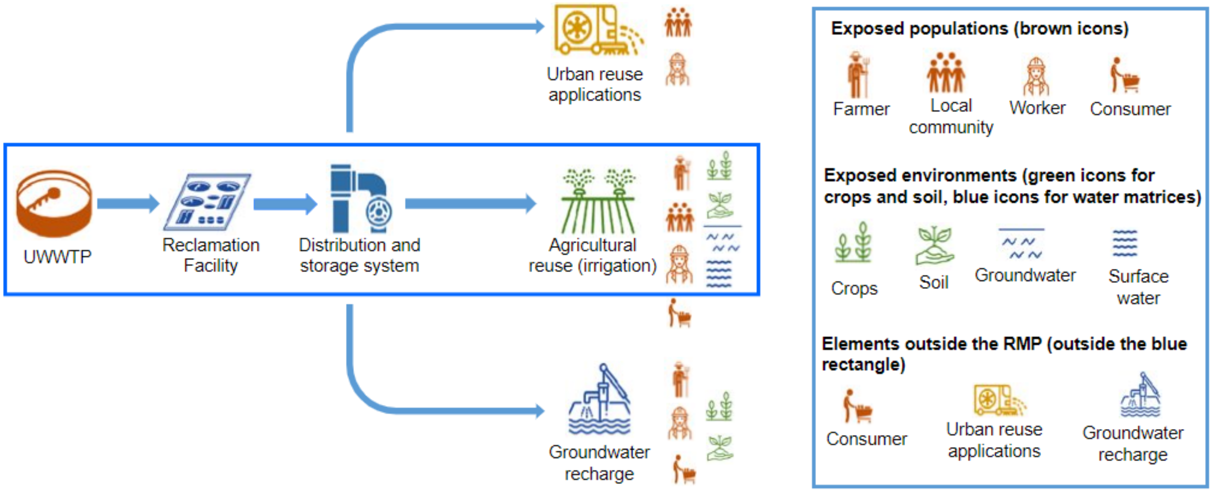
Chapter 1 is an overview of the main approaches and guidelines for risk management in water reuse systems. The suggested approach for the development of a RMP for a water reuse system is presented in Chapter 2. Chapter 3 includes a series of case studies of water reuse systems from several EU MS that were presented during a series of Technical Workshops on Risk Management for Agricultural Irrigation in Europe, organized by JRC between May and November 2021.

2 Risk management approaches for water reuse

Risk management is an essential component of a water reuse system to secure that the reclaimed water is used in a way that ensures the protection of the human and animal health and of the environment. Rather than only checking quality parameters in reclaimed water and irrigated crops, a risk management approach is based on the identification of all the risks of a water reuse system and on their minimisation by using preventive measures and appropriate control procedures to timely implement necessary intervention to avoid, for example, the contamination of the irrigated product or the propagation of other hazards or hazardous events.

Structured methodologies of risk management are based on the acknowledgement of the fact that the use of reclaimed water resources is accompanied by a risk, which must be minimised with a systematic, transparent, and scientific approach. Generally, risk management activities aim at managing and controlling any risk identified within a system. Risks associated to the reclaimed water can be identified based on the hazards and hazardous events related to its use, considering the potential groups and environmental compartments subjected to the exposure of these hazards, depending on the use of reclaimed water. Figure 1 presents an overview of potential receptors and pathways associated to a water reuse system with different final uses of reclaimed water. The blue rectangles of Figure 1 present the elements associated to the use of reclaimed water for agricultural irrigation according to the Water Reuse Regulation.

Figure 1. Example of exposed populations and environments associated to different final uses of reclaimed water



Methods for the assessments and management of health and environmental risks for the reuse of reclaimed water in different applications (e.g., agricultural reuse, aquifer recharge, and urban reuse) are proposed in several existing international guidelines and standards. The reuse of reclaimed water for agricultural irrigation, which is the scope of this guidance, is also addressed in specific guidelines which were consulted for the preparation of this document, such as: International Organization for Standardization (ISO) 20426:2018 guidelines for non-potable water reuse (ISO, 2018), ISO 16075:2020 for the use of treated wastewater for irrigation projects (ISO, 2020), World Health Organisation (WHO) guidelines for the safe use of wastewater (WHO, 2006a) and for quantitative microbial risk assessment (WHO, 2016), WHO Sanitation Safety Planning Manual (WHO, 2015), Australian Guidelines for Water Recycling (NRMMC-EPHC-AHMC, 2006), and US EPA Guidelines for Water Reuse (EPA, 2012). Other methodologies were proposed in several European research projects and initiatives, such as: the Water-Cycle Safety Plan from the PREPARED project (Almeida et al., 2013), and the Water Reuse Safety Plans from the demonstration project DEMOWARE ([2]). These standards, guidelines and projects are briefly presented in the following sections.

2.1 International Organization for Standardization guidelines

The ISO (International Organization for Standardization) provides several guidance documents for the standardization of water reuse from any source and for any final use (e.g., ISO 2076:2018 – *Water reuse in urban areas*; ISO 16075:2020 – *Guidelines for treated wastewater use for irrigation projects, Part 1 to 4*; ISO

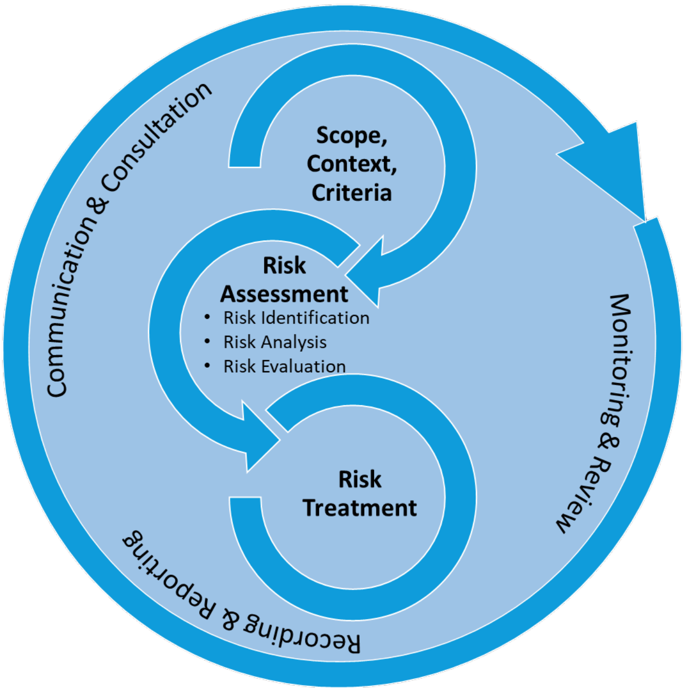
([2]) http://demoware.ctm.com.es/en

22449:2020 – *Use of reclaimed water in industrial cooling systems*). The ISO also provides guidelines on managing risk faced by any organisation. The ISO 31000:2018 – *Risk management — Guidelines* includes a group of standards for risk management. It suggests an approach to manage any type of risk, not industry or sector specific, which can be used by any organisation as a tool to design, implement and improve risk management as a part of an overall strategy or governance. Its goal is to control, prevent and/or reduce any type of risk whatever its nature. It is a part of the risk management process and effectively implements the risk management principles at all relevant levels and functions of the organization. The ISO outlines the principles, framework and process on which risk management should be based. While the scope of the risk management framework is to assist any organization to use risk management in the organization activities, a risk management process involves the application of policies, procedures and practises to risk management activities.

According to the ISO 31000 (Figure 2), the main steps of the risk management process are:

- Characterization of the context.
- Risk assessment, which includes steps of risk identification, risk analysis and risk evaluation.
- Risk treatment including steps of choice and implementation practices of the risk treatment measures.
- Monitoring and review of the process and risk treatment measures.
- Communication and consultation.

Figure 2. Risk management process



Source: ISO 31000 (ISO, 2018)

Box 1. Definitions of risk management plan and process

Risk management plan

A Risk Management Plan (RMP) is a document prepared to anticipate risks, estimate or possibly quantify their impacts and likelihood, and defines responses to mitigate these risks. As such, it defines the management components (governance) such as procedures, practices, responsibilities and activities, as well as resources to be applied to manage (and mitigate) each risk.

Risk management process

The Risk Management Process as defined by ISO 31000 (ISO, 2018), is a multi-step and iterative process designed to identify, analyse and treat risks in an organizational context.

2.2 Hazard analysis and critical control points

The Hazard Analysis and Critical Control Points (HACCP) is a science-based and systematic system that identifies specific hazards and measures for their control to ensure the safety of food. In countries, in which water is considered "food"-like, e.g., Switzerland, the HACCP system is already applied to drinking water systems. It can also influence the risk management approach for water reuse schemes in the context of agricultural irrigation practices. HACCP is a tool to assess hazards and establish control systems that focus on prevention rather than relying mainly on end-product testing. Any HACCP system is capable of accommodating change, such as advances in equipment design, processing procedures and/or technological developments. However, while the HACCP approach is undeniably useful, there are challenges in implementing the HACCP system in small/medium-sized water reuse systems, simply because of the entailed workload to develop such a system from scratch in some cases. Considering, for instance, experiences from the food sector, an adopted and simplified version of what could be defined a complete RMP is to be considered. While a risk management framework is generic and can be applied to virtually all technological processes and practices, in this specific case it must be tailored and adapted to the needs of water services and eventually the reuse of treated wastewater.

2.3 World Health Organization guidelines

WHO developed the Sanitation Safety Planning (SSP) (WHO, 2015) to operationalise the WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (WHO, 2006a). SSP is a step-by-step risk-based approach to assist in the implementation of local level risk assessment and management for the sanitation service chain - from catchment, conveyance, treatment and end use of disposal. SSP supports the implementation of the WHO Guidelines for Safe Use of Wastewater (WHO, 2006a). The SSP process (Figure 3) coordinates stakeholders along the sanitation chain and prioritizes improvements and system monitoring based on health risk. The underlying purpose of sanitation interventions is to protect public health. The development of this enabling environment has many similarities to the development phase of Water Safety Plans (WSPs) framework suggested for drinking water (WHO, 2006b). However, given the inter-sectoral nature of sanitation and resource recovery with reuse operations, the process may require prolonged policy discussion to achieve sector-wide endorsement and inter-sectoral cooperation.

Figure 3. The Sanitation Safety Planning (SSP) process

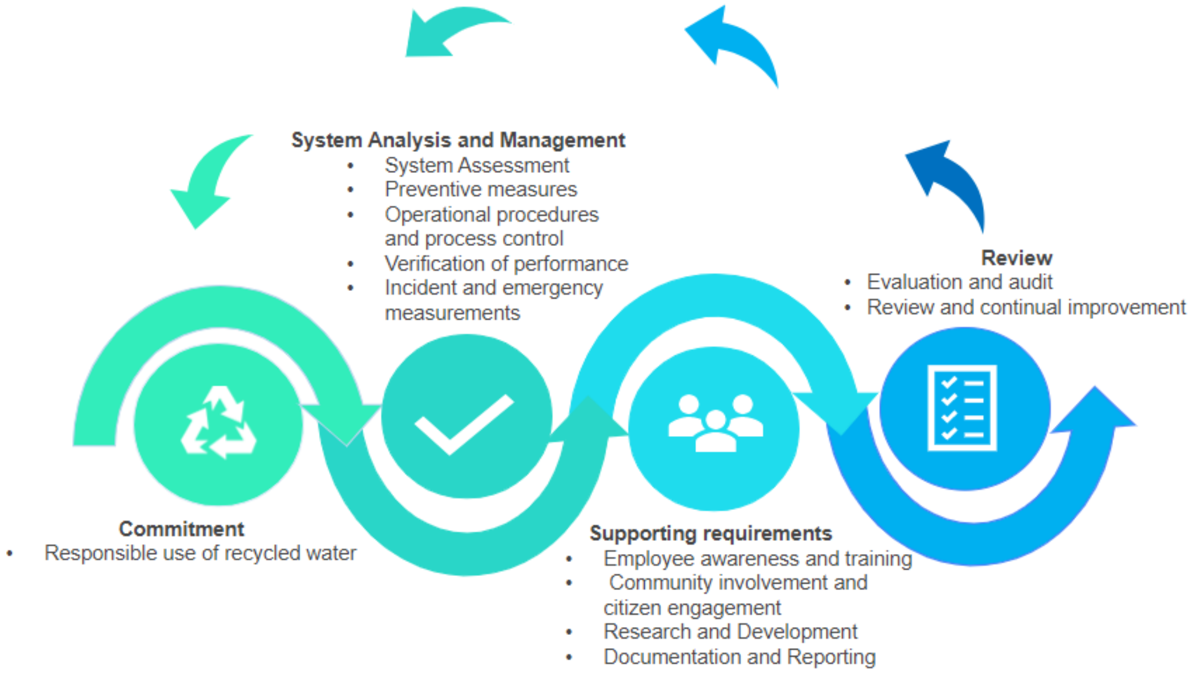
Source: WHO Sanitation Safety Planning Manual (WHO, 2015)

2.4 Australian guidelines

The risk management framework used in the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (phase I) (NRMMC-EPHC-AHMC, 2006) provides a generic approach for the safe use of recycled water in several applications, such as agriculture, municipal and industry. The risk management framework of the Australian Guidelines is structured into twelve distinct elements falling into four main categories (Figure 4):

- The commitment to the responsible use and management of recycled water.
- System analysis and its management.
- The definition of supporting requirements such as training, citizen engagement, R&D, validation, documentation and reporting.
- Review requirements such as auditing and evaluation.

Figure 4. Australian approach for risk management framework for the use of recycled water



Source: Australian Guidelines (NRMMC-EPHC-AHMC, 2006) (adapted)

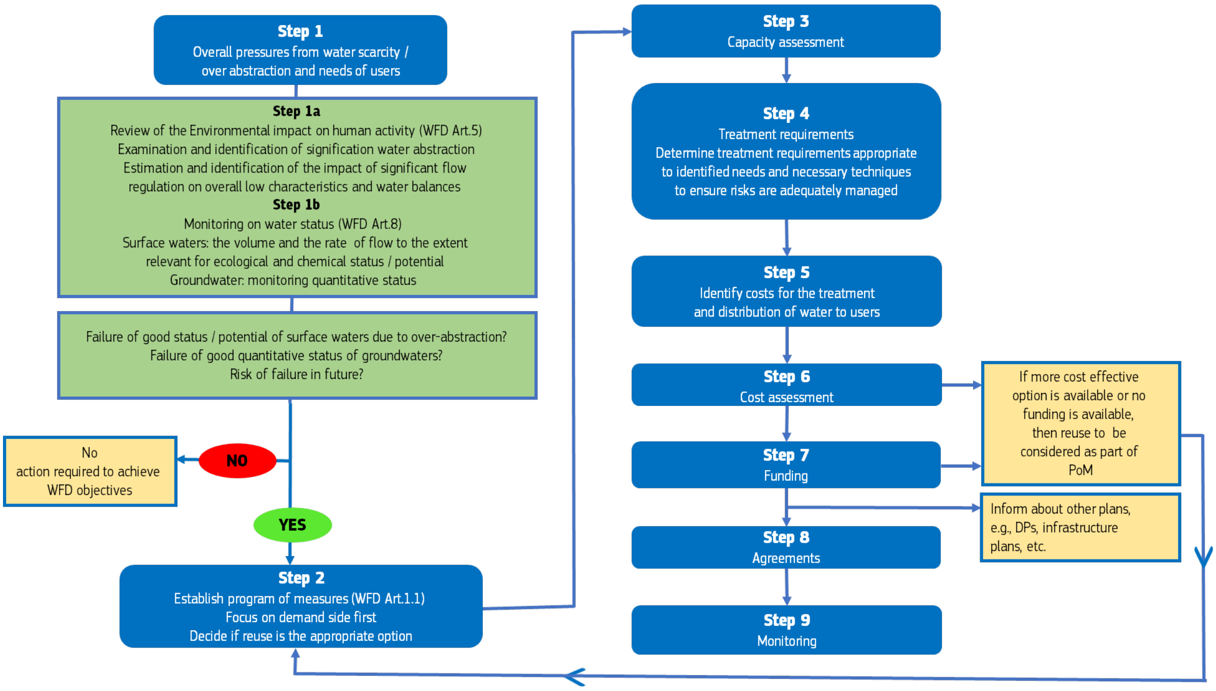
These guidelines aims to provide a reference for the beneficial and sustainable reuse of treated waters from sewage, grey water and stormwater. These guidelines established a complete set of guidance for the management of health and environmental risks associated with recycled water for agricultural irrigation. In particular, the approach used in the Australian Guidelines for the management of environmental risks for soils and crops was considered for the development of the RMP proposed in this document.

2.5 Common Implementation Strategy guidelines

To assist MS authorities, a first set of guidelines on water reuse was published in 2016 (European Commission, 2016). These guidelines illustrate the policy and planning context for the reuse of treated wastewater under the Common Implementation Strategy (CIS) for the Water Framework Directive (WFD). As no harmonised EU standards were in place at the time, this document did not recommend specific standards/technologies for treatment or hands-on guidance on the implementation of a risk management approach, but referred to other sources for such information.

In total, nine main steps were identified (Figure 5), linking the design process of a water reuse scheme to the so-called CIS of the WFD – an agreed and structured formal dialogue between the MS and the EC on how to operate the Directive and implement the necessary measures. Indeed, water reuse was highlighted as an important possible measure for further EU action in the Water Blueprint ([3]).

Figure 5. Planning steps for reuse of treated wastewater according to CIS Guidelines



Source: CIS Guidelines (European Commission, 2016)

The 2015 Communication "*Closing the loop - An EU action plan for the Circular Economy*" (European Commission, 2015) ([4]) went further, stating that the Commission would have taken a series of actions to promote the reuse of treated wastewater. One of these actions led to the CIS Guidelines on Integrating Water Reuse into Water Planning and Management in the Context of the WFD.

2.6 PREPARED project

Under the umbrella of the EC's Seventh Framework Programme for Research (FP VII), an initial proposal for a framework for risk management was developed by the PREPARED project ([5]). The so-called Water Cycle Safety Plan (WCSP) provides an approach aiming specifically at facilitating water reuse in an urban setting, by building on the experience gained from the implementation of WSPs. The proposed approach amended the concept of WSPs by incorporating the developments of generic risk management frameworks, thus widening the scope of the plans to the entire urban water cycle. This approach required addressing additional primary safety aims (public safety and protection of the environment, in addition to the protection of public health) allowing water utilities to work using similar approaches for different risks (Almeida et al., 2013).

Although the PREPARED project focused on the urban water cycle and its adaptation to climate change, the development of the WCSP approach anticipated an application in a broader context, i.e., beyond urban reuse practices. It therefore constitutes the first important input to the present document.

2.7 DEMOWARE project

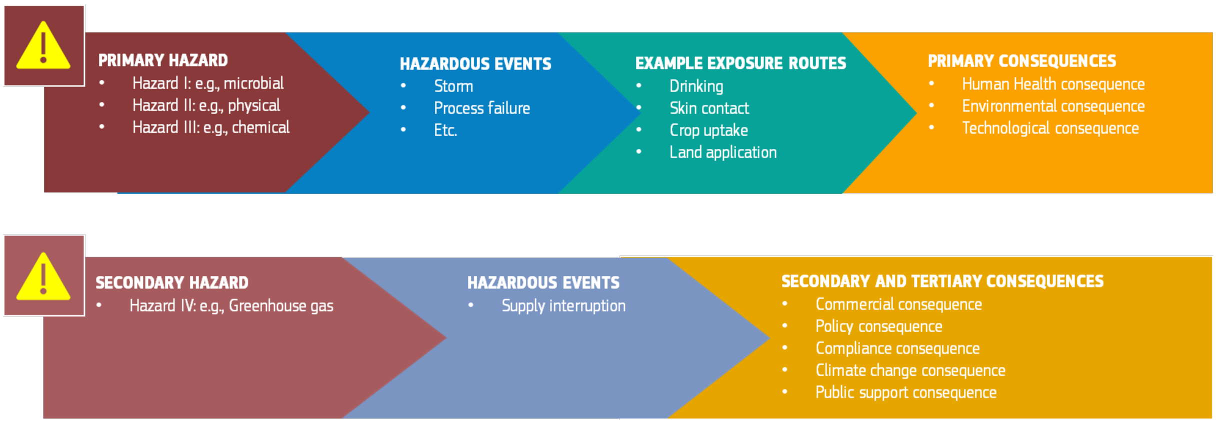
DEMOWARE project provided an overview of what is called "the safety plan framework" and its application in water supply, sanitation and water cycle risk management. This project developed on the approach proposed by Goodwin *et al.* (2015) that promotes a concept of applying the WHO WSPs to water reuse and introduces

([3]) Water Blueprint - Environment - European Commission (europa.eu)
([4]) Circular economy action plan (europa.eu)
([5]) https://cordis.europa.eu/project/id/244232

the terminology of a specific Water Reuse Safety Plan (WRSP). Through reviewing the existing evidence base, the authors investigated the potential for adapting the WSPs into an approach for water reuse.

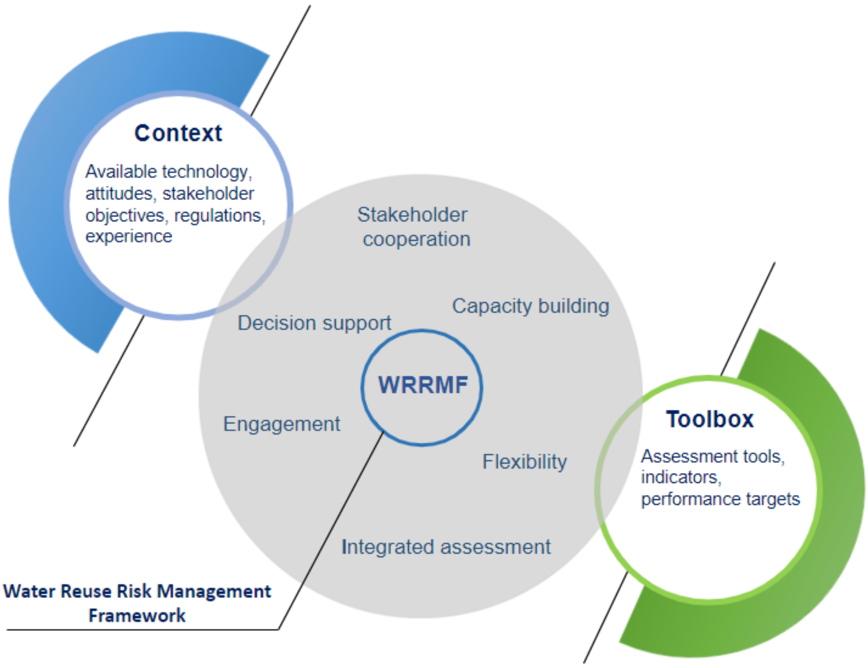
By analysing the possible consequences and risk interactions and by grouping them into first, second and third order consequences (Figure 6), the authors mapped specific considerations to the various elements of a water safety plan, resulting into a conceptual framework for Water Reuse Risk Management (Figure 7).

Figure 6. Illustrative example of possible risk interactions for water reuse with primary, secondary and tertiary consequences



Source: Goodwin et al., 2015 (adapted)

Figure 7. Conceptual framework for Water Reuse Risk Management



Source: Goodwin et al., 2015 (adapted)

Moreover, Goodwin *et al.* (2019) analysed and described the various challenges related to the management and governance of water reuse schemes. According to the literature reviewed by the authors, risks involved in water reuse schemes encompass not only direct and indirect health and environmental threats – addressed by the Water Reuse Regulation – but also socio-economic aspects, e.g., financial viability and political acceptance. Apart from risk, from a financial perspective, wastewater reuse is a potentially valuable component of integrated water resources management, along with demand-side and supply augmentation management (World Bank, 2003). Other recognised risk factors for water reuse schemes include meeting customer expectations (West *et al.*, 2016) and political aspects of water resource management (Furlong *et al.*, 2016). Cultural and religious reasons appear to be less relevant in an EU setting, and the reader is redirected to the respective chapter of WHO Guidelines (WHO, 2006a).

Based on the conclusions from Goodwin *et al*. (2019), that a more integrated systems approach to risk management for water reuse, encapsulated within a risk management framework and operationalised through the WRSP would help managers to better anticipate potential risks and opportunities, the FP VII large-scale Demonstration project DEMOWARE attempted to provide such guidance. DEMOWARE translated these considerations into a guidance for drafting a WRSP and illustrated its viability in a series of case studies.

The applicability of safety plans to water reuse as well as their similarities and differences to water, sanitation and water cycle safety plan approaches are subject of discussion. The project proposed in parallel a combined approach to preventive and systematic risk management for water reuse schemes addressing (1) a structured analysis of the system (hazards and related risks), (2) the use of multi-barrier approaches to control risks, and (3) the importance of communication, cooperation and review. The proposed modules, analysed and described for a planning and operational phase, addressed the necessary steps and topics for the design and operation of what was called by the authors "Water Reuse Safety Plans", in analogy to the respective WSP operated for Drinking Water Supply Systems. The idea was the same methodology to be applied for the identification, quantification and management of risks.

The modules addressed four main phases:

— Preparation.

— System assessment (health risk, environmental impact).

— Operational monitoring.

— Management and communication.

2.8 Suggested approach for risk management plan

Along with elements from WHO and Australian Guidelines, the deliverables and findings of the EU Demonstration Projects DEMOWARE and PREPARED influenced the structure of the RMP proposed in this document. Some technical components, including identification of health hazards, health risk management framework, environmental risk assessment on freshwater resources and the effects of reclaimed water on soil and crops were developed based on relevant parts of the ISO 16075 (2020), the ISO 20426 (2018) and the Australian Guidelines. The existing risk management approaches for water supply processes require some adaptation, to account for the special aspects related to water reuse systems in agriculture. In the European context, the challenge is to ensure compliance with legislation, guidelines and other legal requirements at local, regional, national and European level, while meeting the societal and political challenges of going from citizen information to true citizen engagement, ideally in a co-participatory process. A procedure on how to identify the legislative context of the EU Acquis applied to a specific water reuse system is also proposed in the document.

The Impact Assessment (SWD (2018) 249 final/2 accompanying the document *Proposal for a Regulation of the European Parliament and of the Council on minimum requirements for water reuse* (European Commission, 2018)) analyses and contextualises a range of potential risks associated with the use of reclaimed water which is likely to contain pollutants (organic, inorganic, biological, chemical, etc.). These risks differ by type of reuse practice and entail contamination of the environment (water resources, soil) as well as human health (direct exposure, ingestion of food products irrigated with reclaimed water, etc.).

In case of agricultural irrigation, risks to be addressed can be grouped into 2 categories:

— Health risks to humans exposed to reclaimed water (workers, bystanders, and residents in nearby communities).

— Risks to the local environment (surface waters and groundwater, soil and relevant ecosystems).

While these key elements are certainly a good indication of what needs to be done from a regulatory perspective, authorities and practitioners are not provided with indications on how these key elements can be addressed in practice.

According to the DEMOWARE approach, the individual sections and topics to be addressed reflect the original ideas laid down in the WHO Guidelines. They are also in line with the twelve different elements of the Australian Guidelines and are compliant with the Water Reuse Regulation and its eleven key risk management elements. The DEMOWARE's proposal is based on the practical differences between the design and planning of a water reuse scheme on one side, and the deployment and operation of the scheme on the other. It allows for addressing the key factors in assuring the health and environmental safety of water reuse projects in irrigation, but similar to the Goodwin-design, it can be equally used to manage risks of other water reuse applications, such as urban landscape irrigation or aquifer recharge. Some risk management elements are relevant for all reuse schemes, while others are not.

To design a comprehensive guide, it is necessary to understand which aspects are of essential character and how to address them. Besides, the aforementioned difference between *planning* a new scheme and *operating* an existing one must be considered. According to ISO 16075 (2020), a proper guidance for agricultural irrigation has to specifically address the following aspects:

— The meticulous monitoring of treated wastewater quality to ensure the system functions as planned and designed.

— The design and maintenance instructions of the irrigation systems to ensure their proper long-term operation.

— The compatibility between the treated wastewater quality, the distribution method, and the receiving soil and crops to ensure a viable use of the soil and undamaged crop growth.

— Compatibility between the treated wastewater quality and its use to prevent or minimize possible contamination of groundwater or surface water sources.

Considering all the aforementioned elements, experiences and designs, a modified and more targeted approach, that includes elements of the other discussed approaches, is proposed and widely discussed in the following section.

3 A European manual of water reuse risk management plan for agricultural irrigation

The aim of Section 3 is to provide the necessary elements to guide water practitioners and competent authorities in the implementation of the **RMP** as required by the Article 5 of the Water Reuse Regulation 2020/741. Considering that a water reuse system complies with the minimum requirements for water quality of the Annex I of the regulation, the overall objective of a RMP is to guarantee that a water reuse system operates while ensuring the protection of the health of workers, farmers and consumers, and safeguarding the environment. A RMP shall 1) set out any necessary requirements for the reclamation facility operator, in addition to those specified in Annex I, to further mitigate any risks before the point of compliance; 2) identify hazards, risks and appropriate preventive and/or possible corrective measures; 3) identify additional barriers in the water reuse system and set out any additional requirements after the point of compliance to ensure that the water reuse system is safe, including conditions related to distribution, storage and use where relevant, and 4) identify the parties responsible for meeting those requirements. When planning for a RMP, it is important to identify specific objectives that will help to address the aforementioned points. This will include the identification of all the applicable additional requirements by the local authorities in charge, to ensure compliance of the water reuse system with the regulatory framework. The RMP is a tool of paramount importance to ensure the integration of site-specific particularities and requirements into a larger regional, national and even European framework, usually defined by ordinances, laws and the EU Water Acquis.

3.1 Key elements of risk management

According to the Water Reuse Regulation, the RMP must be based on the elements of risk management listed in Annex II of the regulation. These 11 key elements of the risk management plan (KRMs) represent the basis to ensure that the reclaimed water is used and managed safely to protect the human and animal health and the environment, and constitute the basis of the suggested framework approach:

1. **System description (KRM1):** description of the entire water reuse system from the entry point to the urban wastewater treatment plant to the point of use.
2. **Parties, roles and responsibilities (KRM2):** identification of all the parties involved in the water reuse system along with their roles and responsibilities.
3. **Hazards identification (KRM3):** identification of potential hazards (pathogens and pollutants) and hazardous events (e.g., treatment failures) associated to the water reuse system.
4. **Populations and environments at risk and exposure routes (KRM4):** identification of populations and environments potentially exposed to each identified hazard.
5. **Environmental and health risk assessment (KRM5):** identification of potential risks associated to each previously identified hazard to each receptor (people, animals, crops or plants, other terrestrial biota, aquatic biota, soils or the environment in general) for each exposure route. Risk assessment may be conducted with qualitative and semi-quantitative methods; quantitative risk assessment would require sufficient supporting data. The health and environmental risk assessment should also take into account any obligations and requirements set out by the EU regulatory framework indicated in the Regulation, as well as any relevant national or local legislation.
6. **Additional requirements (KRM6):** the outcomes of the risk assessment might identify additional or stricter water quality and monitoring requirements than those from Section 2 of Annex I of the Regulation. The inclusion of additional parameters or limits should be based on the outcomes of the risk assessment and supported by scientific evidence that they originate from the water reuse system and not from other sources. These additional parameters may also include the following pollutants: heavy metals, pesticides, disinfection by-products, pharmaceuticals, contaminants f emerging concern (including micro pollutants and micro plastics), anti-microbial resistance determinants.
7. **Preventive measures (KRM7):** identification of preventive measures or barriers, additional or already in place, to be applied to parts of the water reuse system, for example access control methods, additional water treatments or specific irrigation technologies or barriers to limit or mitigate any identified risk.
8. **Quality control systems (KRM8):** determination of quality control measures, including protocols for monitoring the reclaimed water for the relevant parameters and maintenance programs for the

equipment, to ensure the effectiveness of the treatment chain and of the preventive measures adopted.

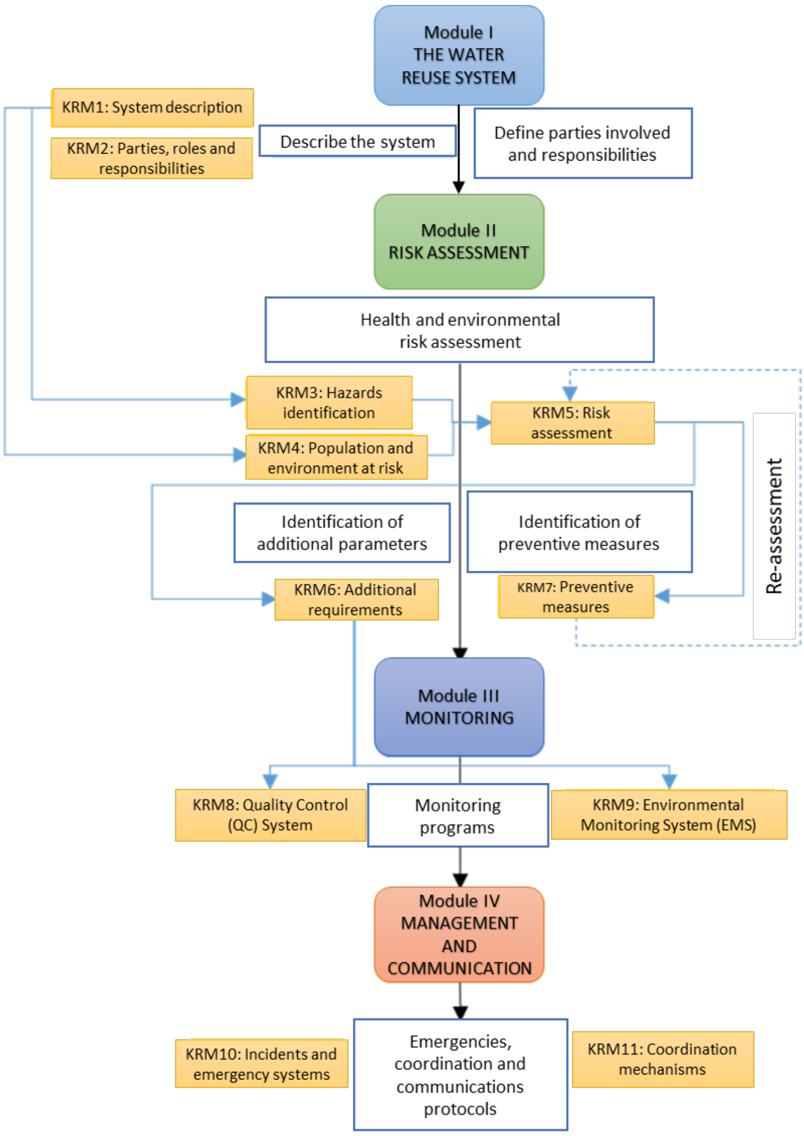
9. **Environmental monitoring system (KRM9):** set up of an environmental monitoring system to assess the release of the identified pollutants in the exposed environmental receptors (e.g., freshwater, groundwater, soil). The monitoring system could include documented procedures already in place to ensure ongoing environmental protection, where appropriate, or further developed or tailored depending on the results of the environmental risk assessment.

10. **Incidents and emergency systems (KRM10):** set up of protocols to manage incidents and emergencies.

11. **Coordination mechanisms (KRM11):** definition of coordination and communication mechanisms amongst the different actors involved in the water reuse system.

Based on the suggested approach, the KRMs can be mapped within four modules, i.e., Module I: the Water Reuse System (KRMs 1 and 2). Module II: Risk Assessment (KRMs 3, 4, 5, 6 and 7). Module III: Monitoring (KRMs 8 and 9). Module IV: Management and Communication (KRMs 10 and 11), following the approach proposed in the DEMOWARE project. The schematic of this framework, with the 11 KRMs integrated in each of the Modules, is proposed in Figure 8.

Figure 8. Conceptual representation of key risk management elements (KRMs) organised in four modules for the setup of a risk management plan.



3.2 Module I – the water reuse system

Module I consists of a series of preparatory activities necessary to set up the RMP. These activities include a detailed description of the entire water reuse system, with its extensions and limitations, and the identification of the roles and responsibilities of the involved actors.

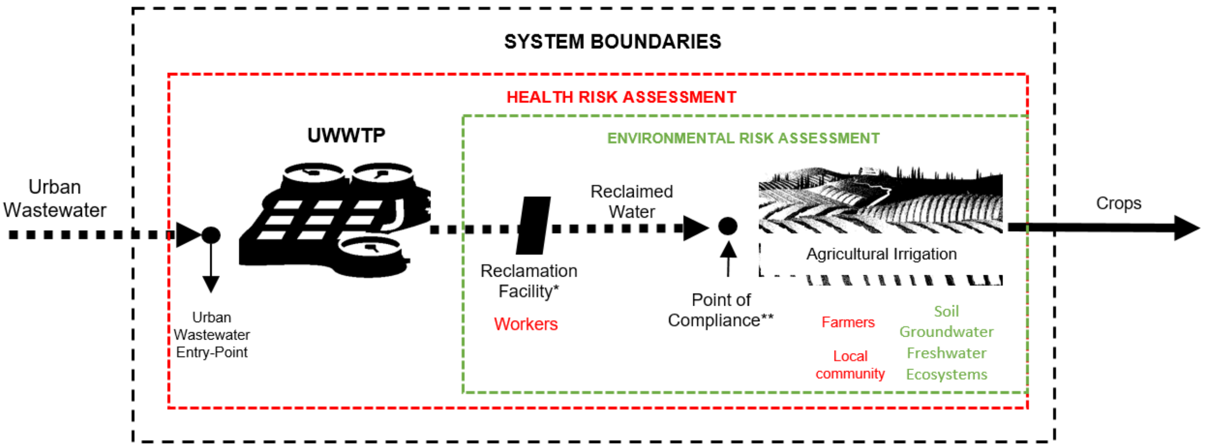
The activities required in the Module I should include at least:

- Identification of the boundaries of the water reuse system to where the RMP extends.
- Any limitations, including external and internal factors influencing it, including any regulatory requirements.
- Flow diagram including interlinkages between the different subsystems.
- Identification of the criteria to identify the actors involved in the water reuse system with their roles and responsibilities.

3.2.1 Water reuse system description (KRM1)

A complete characterization of a water reuse system is of a paramount importance to identify not only hazards and preventive measures, but also the multiple actors involved. A water reuse system is composed by multiple elements. Each of these elements has normally a complex set up, often constituted by a series of sub-systems operated in sequence or in parallel that contribute to different aspects of risk management, from the treatment of the wastewater to its delivery and application for agriculture irrigation. The system description consists in the identification and description of each element of the system: influent, UWWTP and/or the reclamation facility, any infrastructure related to pumping, storage and distribution, irrigation systems, and final uses within the identified system boundaries. The boundaries of the system should reflect the specific objectives and enclose the whole water reuse system and its area of influence, including the sources of water and their final reuse applications and end-users, the scope of operations, any administrative boundaries and the extent of the sanitation catchment area, and specific exposure groups, so that any health and environmental risks can be determined (Figure 9).

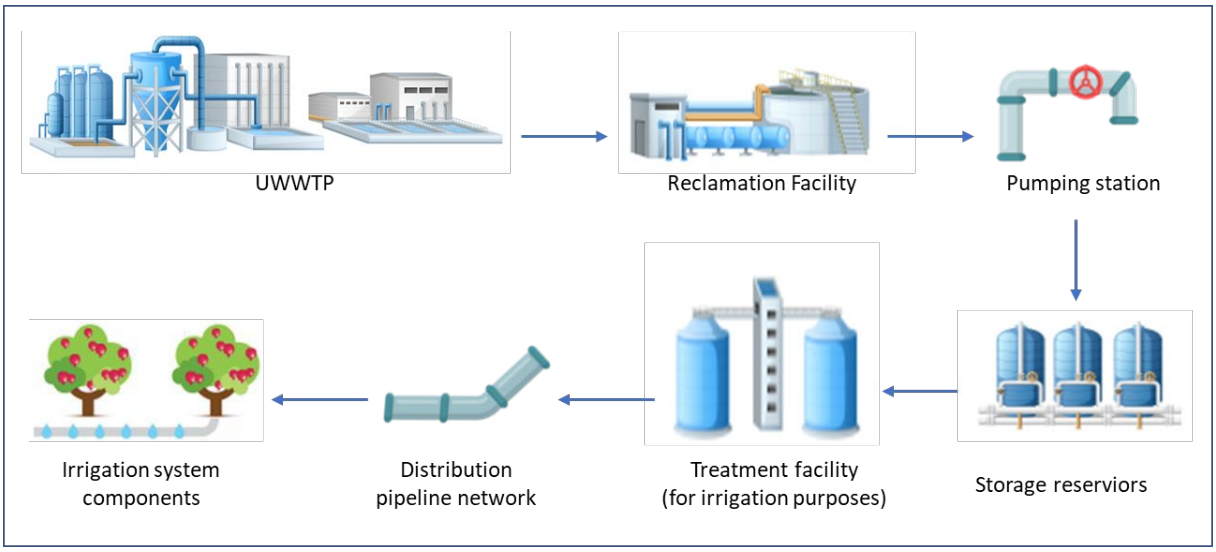
Figure 9. Extension of boundary conditions of a water reuse system within health and environmental risks



**Reclamation Facility*: it can be the UWWTP or other facility that further treats urban wastewater that is fit for a use specified in Section 1 of Annex I of the Water Reuse Regulation.
***Point of Compliance:* the point where a reclamation facility operator delivers reclaimed water to the next actor in the chain. In this image the reclaimed water is delivered directly to the end-users, but in other situations it may be delivered to a distribution operator or a storage operator.

System description includes an outline of all subsystems taken into account when defining the boundary conditions as described above, i.e., the wastewater treatment plant (treatment units and processes), the reclamation plant with a focus on further water quality enhancements (e.g., additional disinfection), the distribution and storage system, and the irrigation system to the point of use including adjacent systems, e.g., run-off canals and buffer strips (Figure 10).

Figure 10. Main elements of a water reuse system



The water reuse system and its subsystems should be accurately described through a flow diagram illustrating the interrelations between stages, and their inputs and outputs. This flow diagram should outline all the steps and processes, describe each part summarizing its basic components, and identify any permitted uses and limitations on the irrigated fields and receiving environments. System description could integrate desk studies with field visits and photographic documentation of the principal elements of the system. It should also include the water quality characterisation of the sources of wastewater entering the UWWTP, water flow data along with any variability and weather events, and any detailed characterisation of the surrounding environmental matrices (soil, groundwater and surface water, ecosystems) to collect the necessary data for the risk assessment. Clearly, the level of detail and documentation is different from case to case, weather an existing system is described or newly planned system is designed. Independent of the status of a reuse system, the following basic aspects shall be defined:

- Water flow.
- Reuse application/s (current/future).
- User/s of the reclaimed water (current/future).
- Requirements in terms of quality and quantity of the supplied water (including seasonal fluctuations, storage, etc.).
- Potential restrictions for irrigation such as nutrients, salt, seasonal demand.
- Interactions with existing water resources (e.g., indirect reuse, blending, groundwater recharge).
- Characteristics that are unique to the system.

The system description should also include important information regarding national quality standards, specifications, guidelines or acknowledgment of lack of them, thus facilitating the permitting process. Additional information related to system performance or management, demographics and land use as well as seasonal and climatic conditions should be documented. The requirements in terms of quality and quantity of the reclaimed water will have to be specified too. Additional to the protection of public health and of the environment, other external factors that require consideration are water quality parameters that affect crop needs and soil, hydrogeological conditions, and climate.

Nonetheless, as risk management is an iterative approach towards ensuring the required safety standard, starting with a rough description of the proposed system and updating information as details become available is part of any risk-based management procedure.

3.2.1.1 Technical components of a water reuse system

A water reuse irrigation project features a series of technical components to be addressed from a risk management perspective. These elements include:

— Wastewater treatment plant.

— Reclamation facility.

— Pumping station.

— Storage reservoirs.

— Treatment facilities (for irrigation purposes).

— Distribution pipeline network.

— Irrigation system components.

Specifications for the main units that can be found in a water reuse system are summarised below.

Examples of elements of a water reuse system are reported for each case study presented in Section 4.

3.2.1.1.1 Wastewater treatment plant and reclamation facility

The description of UWWTP and the reclamation plant (if any) should outline the treatment configuration, including information about size, materials, peak flows, backup systems and bypass. Treatment capacity must be expressed, together with influent flow, any problem related to industrial discharges or hotspots, and water quality produced, including variabilities and seasonal variation of flow and demand.

All the units and processes applied should be described, including primary, secondary and tertiary treatments, nutrient reduction, disinfection, etc. Efficiencies should be specified for each unit, together with the related basic characteristics and level of variability, defining reliability of processes. Monitoring equipment and automation level should also be described. Particular focus should be given to tertiary treatments, specifying disinfectant residual, contact time and chemical consumption (e.g., coagulants, filtration aids, and disinfectants).

3.2.1.1.2 Storage system

Storage facilities ensure an important regulation function in a water reuse system as they allow for compensation for daily and seasonal variations in water supply and demand, thus minimising the risk of a disruptive operation of the water reuse system. They may also be used to introduce an additional treatment step and act consequently as barrier. However, they may also introduce new risks, mainly related to the possibility of bacterial regrowth or re-contamination during storage.

Storage may be short- or long-term, underground or open. Short-term storage facilities usually use concrete or plastic tanks as well as small ponds, whereas long-term storage requires larger installations such as dams, large ponds, lakes, or aquifer storage (indirect water reuse). Based on storage type and duration, different problems and strategies are to be considered. The storage conditions and duration influence the physical, chemical, and biological quality of the treated wastewaters.

The main parameters of interest include storage design, including depth, materials, size, storage capacity and detention time, protections (e.g., covers, enclosures, access), treatment efficiencies, algae, macrophytes or zooplankton–plant dynamics, aquatic community characteristics and presence of any protection status, seasonal variations of stratification and algal blooms, presence of recreational or human activity or use of the site by birds.

For the following step of risk assessment (Module II), typical biological processes to be considered for storage facilities are:

— Bacterial regrowth.

— Nitrification and/or denitrification.

— Algae growth in reservoirs and biofilm growth in pipes.

— Production of H_2S, leading to odour emission and corrosion.

— Recontamination by external sources (e.g., wild animals).

In the same way, physicochemical processes of relevance are:

— Increase in suspended solids and sediments.

— Change of pH.
— Loss of dissolved oxygen.
— Introduction of residual disinfectants.
— Water retention time and operation conditions of the reservoir.
— Temperature of the treated wastewater, climate conditions (e.g., rainfall).

Box 2. Sources of information for storage systems

ISO 29419 (2018) can be consulted for information on the management of storage system. It provides guidelines on several aspects: data assessment of biological processes for design and maintenance, microbial regrowth, algae development, NOM, external pollution, climate, run-off, evaporation, chemical stratifications and pH changes.

3.2.1.1.3 Irrigation system components

The description of the irrigation devices includes the definition of the application method (e.g., spray, drip, subsurface irrigation), permitted uses, quantities required, time of application and variability, application rates and schedules (e.g., night-time only), plumbing standards and requirements (e.g., location of piping, colour coding, labelling), cross-connection, controls and audit systems, access controls (e.g., fencing) or physical barriers (e.g., buffer zones, trees and shrubs), local vegetation, characteristics and proximity of sensitive or protected ecosystems, site hydrology (groundwater, soil permeability, drainage), characteristics and proximity of groundwater, including nature of existing aquifers, current uses, depth and quality, characteristics of receiving surface water (marine or freshwater, flows, volume, tidal movement, current uses and environmental values), soil characteristics (i.e., receiving environments), type of crops or plants to be irrigated (i.e., endpoints), climatic conditions and evapotranspiration rates.

Box 3. Sources of information for irrigation systems

ISO 29419 (2018) can be consulted for information on components of irrigation systems that use reclaimed water.

3.2.1.1.4 Treatment for irrigation systems

The additional treatment prior to application could include filtration (e.g., to prevent clogging in sprinkler and micro-irrigation systems) as well as an additional disinfection (e.g., chlorination). Depending on the type of irrigation system, different filter systems are used and installed upstream or downstream of the pumping station.

Disinfection measures aim specifically at avoiding bacterial regrowth and algae/biofilm development, and the technologies used may include oxidants/disinfectants to protect the irrigation infrastructure (e.g., biofilm formation in the pipes transferring reclaimed water from the UWWTP to the field). Chlorine-based disinfectants are commonly used in practice and have high disinfection efficiencies but may generate disinfection by-products (DBPs) that may create additional toxicity.

Physical methods include ultraviolet (UV) light, ultrasound, carbon atom related antibacterial materials, electrochemical treatment and membrane filtration. They have the advantages of not generating DBPs and can have high disinfection efficiencies, but their high cost might limit their general application for irrigation water.

Box 4. Sources of information for treatments systems and irrigation methods

Part II of ISO 16075 covers the components needed for water reuse for irrigation. It outlines specific instructions and requirements which relate to various pressure and open irrigation systems, specifically drip irrigation as this method represents an efficient method of water delivery and water saving (ISO 16075-3).

ISO 29419 (2018) can also be consulted for information on how to assess irrigation methods when reclaimed water is used.

3.2.1.1.5 Pumping stations and distribution pipeline network

Pumping stations, usually powered with electricity, are needed for pressurised irrigation systems and need to be chosen based on the respective system. The subsequent distribution network consists of one or more main and sub-main pipes and a variety of pipe materials can be used. The most commonly used materials in a treated wastewater distribution network are the ductile iron (DI), steel, polyvinyl chloride (PVC), high-density polyethylene (HDPE), aluminium, and for large (main) irrigation networks, a commonly used material is glass-fibre reinforced polyester (GRP) for diameters >900 mm. The materials vary in function of the irrigation technology used, which may require specific material properties regarding pressure resistance, tube elasticity or weight. Accessories such as valves, blowoffs, flowmeters and hydrants are essential to support the correct operation and maintenance of the system and need to be considered duly in the assessments.

Possible relevant hazards may include water quality deterioration (regrowth), leakage or intrusion. Presence of drinking water protection area, areas of high ecological value, or other possibly affected recreational areas should be underlined.

3.2.1.1.6 Water quality characterisation

Once the water reuse system has been described, it is important to characterize the inlet water sources and the reclaimed water quality. This will help to identify, later in Module II, any hazard to the public health and the environment, as well as any effect that reclaimed water may have on crops, soil and groundwater (see KRM3).

A complete characterization of the influent entering the water reuse system and the treated reclaimed water can include:

- Identification of influent water sources.
- Identification of influent characteristics.
- Identification of reclaimed water characteristics.
- Identification of potential illegal, inappropriate or accidental discharges.
- Reviewing historical data and report of the UWWTP and reclamation facility.

Characterisation of influent water should include data on flows, physical, chemical and microbial constituents, including bacteria, viruses, protozoa and helminths, detergents, industrial chemicals, major ions, salinity, hardness, pH, metals and radionuclides, nutrients (nitrogen and phosphorus), organic chemicals, disinfection by-products, biologically active compounds including endocrine disruptors and pharmaceuticals, together with seasonal and event changes (including infrequent events such as droughts or floods), source reliability and spatial variations.

Reclaimed water may still contain nutrients (nitrogen, phosphorus), inorganic compounds (chloride, sodium, boron, potassium, sulphur) and other chemical elements, including heavy metals (e.g., zinc, manganese, copper, mercury, silver, chromium, nickel, lead, cadmium), and fluorine. It may also contain organic constituents, including hormones, pharmaceuticals, personal care products, proteins, carbohydrates, oils, fuels and lubricants, surfactants, as well as pesticides, or other chemicals of domestic or agricultural origin - all potentially to be considered in the risk management. Physical, chemical and biological properties of treated wastewater might also change due to alterations of normal functionality of the infrastructure, e.g., drought or flooding events. Some substances resulting from the upfront treatments, like DBPs or disinfectant residual may also be present.

It is important to identify all the potential substances present in the reclaimed water to help to determine specific hazards and additional treatment requirements. Potential additional restrictions, identified with the legal requirements and obligations, can also be identified at this stage. Relevant parameters of reclaimed water include suspended solids or turbidity, biochemical oxygen demand, microbial quality, including faecal pathogens and indicators, chemical quality, salinity, total dissolved solids (TDS) or electrical conductivity (EC), sodium adsorption ratio (SAR), nutrients, heavy metals and metalloids, pesticides and other organics, algal counts, organic matter, colour, pH, disinfectant residual and DBPs.

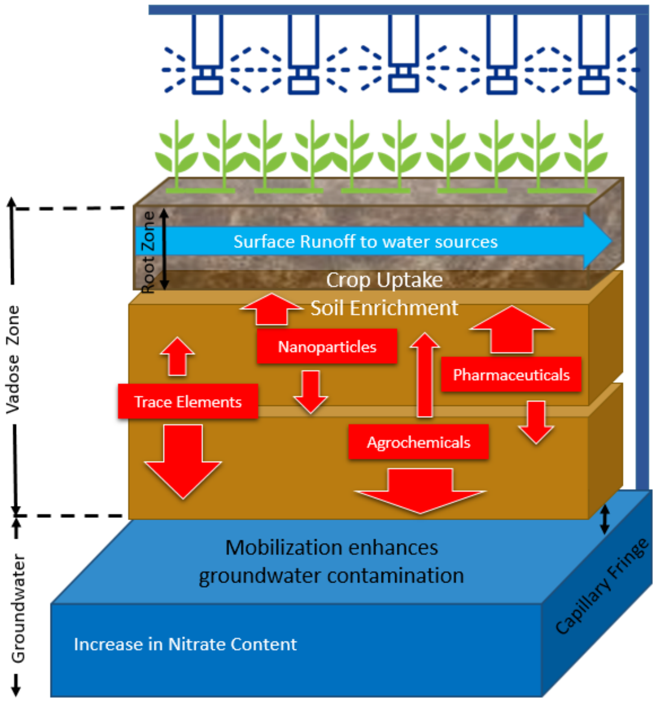
When reclaimed water is used for agriculture irrigation, considerations should be conducted for potential effects of water quality on crop needs, soil conditions, and groundwater (Figure 11). The presence of nutrients (nitrogen, phosphorus, and potassium) in the water can be an advantage due to possible savings in fertilizers, but they may pose an issue to soil fertility and groundwater protection, e.g., due to salination, or eutrophication and an increase nitrates transport into the saturated zone.

Box 5. Sources of information for water quality parameters

ISO 16075 (2018) can be consulted to identify water quality parameters relevant to irrigation with reclaimed water.

- Nutrients (quantity, availability to plants, both chemically and timely) specifically for nitrogen, phosphorous, potassium
- Salinity
- Other elements such as fluoride, silicon, vanadium, chromium, manganese, iron, cobalt, nickel, copper, zinc, selenium, molybdenum, strontium, iodine, boron, cadmium, mercury, and lead.

Figure 11. A conceptual model of the impact of inadequate quality of irrigation water sources on soil and crop



Source: Malakar et al. (2019)

3.2.1.1.7 Irrigated crops

Annex I of the Water Reuse Regulation sets out the minimum requirements for the class of reclaimed water depending on the type of crops and the application of barriers after the point of compliance. Additional requirements on crops and water quality may also be considered. Water quality and distribution patterns used for irrigation are essential for the yield and quality of crops, and water management is paramount in this respect, i.e., combining the right crop with the proper water quality and irrigation technique. As an example, some crops do not require additional barriers, depending on their characteristics or their use, such as industrial crops (cotton), sun-dried fruit harvested at least 60 days after the last irrigation (e.g., sunflower, popcorn, corn, chickpea, and wheat), edible seeds or seeds harvested at least 30 days after the last irrigation, grove or vegetation plot without public access, turf or grassland with no public access during its cultivation, and energy and fibre crops. In case of high salinity levels, crops should be selected based on their salt tolerance during seedling development and all growth phases.

3.2.1.1.8 Soil

The risks stemming from the use of reclaimed water in agricultural irrigation mainly depend on the local soil properties and the water quality and availability. It is therefore of utmost importance to address these risks in a site-specific manner. The inherent soil quality is governed by the soil-forming process and each soil is affected by water quality.

Thus, an area irrigated with reclaimed water needs to be evaluated based on the assessment of pertinent soil and geologic properties, topography, hydrology, climate, zoning, and cropping intentions. A water reuse system can be operated only if a site provides the necessary hydrogeological, climatic, and physical characteristics to maintain the inherent features of the local soil and the underlying groundwater. It is worth noting that similar considerations apply to any irrigation scheme.

The amount of water, and nutrients available for plant growth is influenced by the soil physical and hydrological properties and by management practices. The physical and hydrological soil parameters are required to make predictions, estimates and assessments of the phenomena that affect the movement of water in the soil/groundwater/surface stream system. They also serve for environmental assessments in relation to the filtering function performed by soils for contaminants to groundwater. The main soil physical and hydrological properties are texture, structure, saturated hydraulic conductivity, consistence, bulk density, and available water capacity.

Site acceptability should be based on pertinent soil and geologic properties, topography, hydrology, climate, zoning, and cropping intentions. A site is classed as suitable for wastewater reuse application if it possesses appropriate hydrogeological, soil, climatic, and physical characteristics so that the use of reclaimed water would not cause any damage to the soil or the groundwater. Site conditions should avoid any detrimental offsite movement of reclaimed water through leaching, groundwater migration, surface run-off, or drift from irrigation spray. The main soil characteristics determining soil sensitivity to water quality are texture, pH, organic matter content, bulk density, hydraulic conductivity, and water retention capacity. Many soil indicators interact with each other and thus, the value of one is affected by one or more of the selected parameters.

Box 6. Sources of information about soil quality

At European level, information about soil can be found in the European Soil Data Centre (ESDAC) (https://esdac.jrc.ec.europa.eu/). Data include soil properties and threats (erosion, soil organic carbon, landslides, compaction, salinization, soil biodiversity, contaminated sites, soil sealing, etc.), as well as soil point data (LUCAS, SPADE, etc) and projects results.

Moreover, the European Commission, in collaboration with Member States, developed 28 Agri-Environmental Indicators (AEIs) to track the integration of environmental concerns into the Common Agricultural Policy (CAP) at EU, national and regional levels (https://ec.europa.eu/eurostat/web/agriculture/agri-environmental-indicators). Among them, the soil quality indicator provides an account of the ability of soil to provide agri-environmental services through its capacities to perform its functions and respond to external influences (https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Archive:Agri-environmental_indicator_-_soil_quality). The agri-environmental soil quality index consists of four sub-indicators which have relevance either to the agricultural and/or to environmental performance of soil, such as productivity index, fertiliser response rate, production stability, and soil environmental services index, and measures the carbon storage, filtering, transforming, and soil biodiversity.

Box 7. Hydrogeological, climatic, and physical characteristics of soil

Texture: The particles that compose the soil can be divided by size categories. There is a great variability in the particle size: coarser particles (>2 mm in diameter) form the skeleton, whereas the finer ones form the fine earth.

Structure: Structure is the arrangement of the grain-size particles into aggregates which have easily distinguishable shapes. The aggregates can have laminar, granular, angular or prismatic form or soil may be structureless (single sand grains or shapeless resistant masses).

Saturated hydraulic conductivity: Saturated hydraulic conductivity (K_{sat}) refers to the ability of a soil to transmit water when a soil is fully saturated. It is expressed as cm of water/hour and depends on the properties of both porosity (pore geometry) and the fluid (stickiness and density).

Consistence: Consistence describes the resistance of a soil, at different moisture content, to mechanical stress or handling. It expresses cohesive and adhesive forces holding soil particles together: plasticity and stickiness. Consistence is an indicator of the tendency of a soil to develop compacted zones, crusts, cemented layers that create issues of water stagnation, seedling emergence and root growth.

Bulk density: Density is the soil mass per unit volume and is expressed as g/cm^3. Soil bulk or dry density is the ratio of the mass of the solid phase of the soil to its total volume (solid and pore volume), whereas soil particle density is the ratio of the mass of the solid phase to the volume of only the solid phase. Bulk density is always lower that particle density and vary considerably depending on texture, water content and structure.

Available water capacity (AWC): Available water capacity is the volume of water that should be available to plants if the soil was at field capacity. It is expressed in cm of water for each soil horizon or layer and it is the difference between field capacity and permanent wilting point water contents. AWC is an important factor in the choice and management of irrigation to predict water resources for a better choice of agricultural crops and also to predict yields.

Source: https://ambiente.regione.emilia-romagna.it/en/geologia/soil/physical-hydrological-properties

Box 8. LUCAS database for topsoil properties

The "*Land Use/Cover Area frame statistical Survey Soil*" (LUCAS Soil) is an extensive and regular topsoil survey that is carried out across the European Union to derive policy relevant statistics on the impact of land management on soil characteristics. LUCAS Soil represents the largest harmonised open-access dataset of topsoil properties available for the European Union at global scale. LUCAS Soil was developed as an expandable resource, with new parameters and sampling locations being added over the successive campaigns. Data are available to the scientific community and decision makers and may serve as reference database for soil sensitivity data in the planning, deployment and operation of water reuse systems (Orgiazzi *et al.*, 2018).

Source: LUCAS - ESDAC - European Commission (europa.eu)

3.2.1.2 Regulatory requirements

Full compliance of the reclaimed water with any legislation applicable in the water reuse system area and the requirements for the hygiene of feed and foodstuff legislations for agricultural irrigation, would ensure the protection of the environment as well as of human and animal health. The risk management plan should ensure, therefore, that the use of reclaimed water does not lead to a harmful concentration of contaminants in a specific environmental matrix (e.g., groundwater) and that appropriate preventive measures are taken to prevent this (e.g., by appropriate treatments to reduce pollutants within relevant concentration limits, by minimising any accidental release to the surroundings). Therefore, regulatory requirements for a water reuse system need to be identified and documented too. These include, any EU, national and local legislation applied to the specific context, but also other requirements that may oversee the design, installation, maintenance, use and management of reclaimed water, such as permits, operating licences, industry standards and code of practise. There may also be legal and other requirements concerning the individual responsibilities of the actors involved in the system (see KRM2).

Some regulatory requirements for the use of reclaimed water for agricultural irrigation are listed at Point 5 in Annex II of the Water Reuse Regulation, including legislations concerning the protection of food and feed, soil, crops, and animals. The relevance of the requirements of these legislative instruments to a specific water reuse system will depend on the types of cultivation (e.g., production of foodstuff or feedstuff) and practises (e.g., use of pesticides, use of sewage sludge) on the agricultural field irrigated with reclaimed water and on the specific characteristics of the area (Table 1). Additional requirements (national and local) may be identified on the specific case.

Table 1. Directives and regulations of Point 5 of Annex II and evaluation of their application on a water reuse system

Directive/Regulation	**Requirements**	**Applicability**
NITRATES DIRECTIVE 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources.	To reduce and prevent water pollution from nitrates.	If the risk assessment identifies any surface water and groundwater regulated under this directive (e.g., identified as vulnerable zone to nitrates) that would potentially be exposed to reclaimed water used for agricultural irrigation (e.g., via run-off or infiltration, respectively).
DRINKING WATER DIRECTIVE 202/2184 on the quality of water intended for human consumption.	To meet the requirements for protected areas for water intended for human consumption, namely protected areas for drinking water production (DWPAs).	If the risk assessment identified surface water and groundwater which are classified as DWPAs and would potentially be exposed to reclaimed water used for agricultural irrigation (e.g., via run-off or infiltration, respectively).
WATER FRAMEWORK DIRECTIVE 2000/60/EC	To meet the environmental objectives on surface water and	If the risk assessment identifies potential risks to surface water and groundwater

Directive/Regulation	Requirements	Applicability
establishing a framework for community action in the field of water policy.	groundwater and the environmental quality standards for pollutants of national concern (River Basin Specific Pollutants) for surface water.	(e.g., via run-off or infiltration) for which a chemical status was identified (good surface water chemical status and good groundwater chemical status).
GROUNDWATER DIRECTIVE 2006/118/EC on the protection of groundwater against pollution and deterioration	To prevent groundwater pollution.	If the risk assessment identified groundwater resources regulated under this directive that would potentially be exposed to reclaimed water used for agricultural irrigation (e.g., through infiltration).
ENVIRONMENTAL QUALITY STANDARDS DIRECTIVE 2008/105/EC on environmental quality standards in the field of water policy	To meet the environmental quality standards for priority substances and certain other pollutants.	If the risk assessment identifies surface waters (or sediment and biota) potentially exposed to reclaimed water used for agricultural irrigation (e.g., via run-off) for which priority substances and Environmental Quality Standards (EQS) are established within a River Basin Management Plan (RBMP).
BATHING WATER DIRECTIVE 2006/7/EC concerning the management of bathing water quality	To meet the bathing water quality standards.	If the risk assessment identifies water bodies used for bathing activities and that are potentially exposed to reclaimed water used for agricultural irrigation (e.g., via run-off).
SEWAGE SLUDGE DIRECTIVE 86/278/EEC on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture	To protect the environment and the soil.	If sewage sludge is used in the agricultural field of the water reuse system.
Regulation (EC) No 852/2004 on the hygiene of foodstuffs	To address microbiological risks in fresh fruits and vegetables at primary production through good hygiene.	If the agricultural field irrigated with reclaimed water is used for the production of fresh fruits and vegetables.
Regulation (EC) No 183/2005 laying down requirements for feed hygiene	To meet the requirements of feed hygiene.	If the agricultural field irrigated with reclaimed water is used for the production of feed (e.g., non-food crops including crops used to feed milk- or meat-producing animals).
Regulation (EC) No 2073/2005 on microbiological criteria for foodstuffs	To meet the relevant microbiological criteria.	If the agricultural field irrigated with reclaimed water is used for the production of foodstuff.
Regulation (EC) No 1881/2006 setting maximum levels for certain contaminants in foodstuffs	To meet the requirements regarding maximum levels for certain contaminants in foodstuffs.	If the agricultural field irrigated with reclaimed water is used for the production of foodstuff.
Regulation (EC) No 396/2005 on maximum residue levels of pesticides in or on food and feed of plant and animal origin	To meet the requirements regarding maximum residue levels of pesticides in or on food and feed.	If the agricultural field irrigated with reclaimed water is used for the production of foodstuff and feedstuff to which pesticides are applied.
Regulations (EC) No 1069/2009 and (EU) No 142/2011 laying down animal health requirements	To meet the requirements regarding animal health.	In case the use of reclaimed water could affect the health of animals (feed or exposure in the field).

3.2.2 Parties involved, roles and responsibilities (KRM2)

The parties involved in the water reuse system along with their roles and responsibilities should be identified for each element of the system: actors responsible of the plants operation (UWWTP and reclamation facility operators), of transport and storage, where relevant, and of the irrigated fields (farmers), any relevant authorities or bodies (e.g., water authorities, public health authorities, environmental authorities), or other parties such as, for example, associations of farmers and consortia of irrigators. The responsible parties involved can be identified by using the flowchart built for the water reuse system. If the system is large or complex, it may be necessary to identify the different responsible organizations for the subsystems. A lead organization could also be designated to coordinate activities for each subsystem. At this stage, relevant stakeholder can be identified as well. Although the stakeholders do not take part for the development of the RMP, their identification can help to develop proper communication. A tool to identify relevant actors involved in a water reuse system, along with their roles and responsibilities is reported in Table 2.

Table 2. Tool to identify parties, roles and responsibilities of a water reuse system

Element of the water reuse system	**Actor**	**Role**	**Responsibilities for the RMP**
Catchment area	Operator (public or private)	Operate sewer network management	Control discharges in the sewer network
UWWTP	Operator (public or private)	Operate the UWWTP	Identify and manage risks of the UWWTP
Reclamation facility	Operator (public or private) – it can be different than the UWWTP	Operate the water reclamation facility	Identify and manage risks of the water reclamation facility
Water reuse system (all)	Research institutes	Test innovative solutions, provide additional monitoring	Support the risk management
Point of compliance	Public Authorities (Health, Environmental)	Control compliance with regulation and requirements	Control for validation and verification monitoring, provide permits
Distribution network and storage system	Irrigation consortium (public or private)	Operate the distribution network and storage systems	Identify and manage risks of the distribution/storage infrastructure
Protected areas	Protection Agencies	Protect sensible areas	Define additional requirements or barriers.
Groundwater or surface water	Public Authorities (Health, Environmental)	Protect groundwater and surface water quality	Control cross-contamination
End-use	Farmer	Irrigate with reclaimed water	Identify and manage risks at the point of use

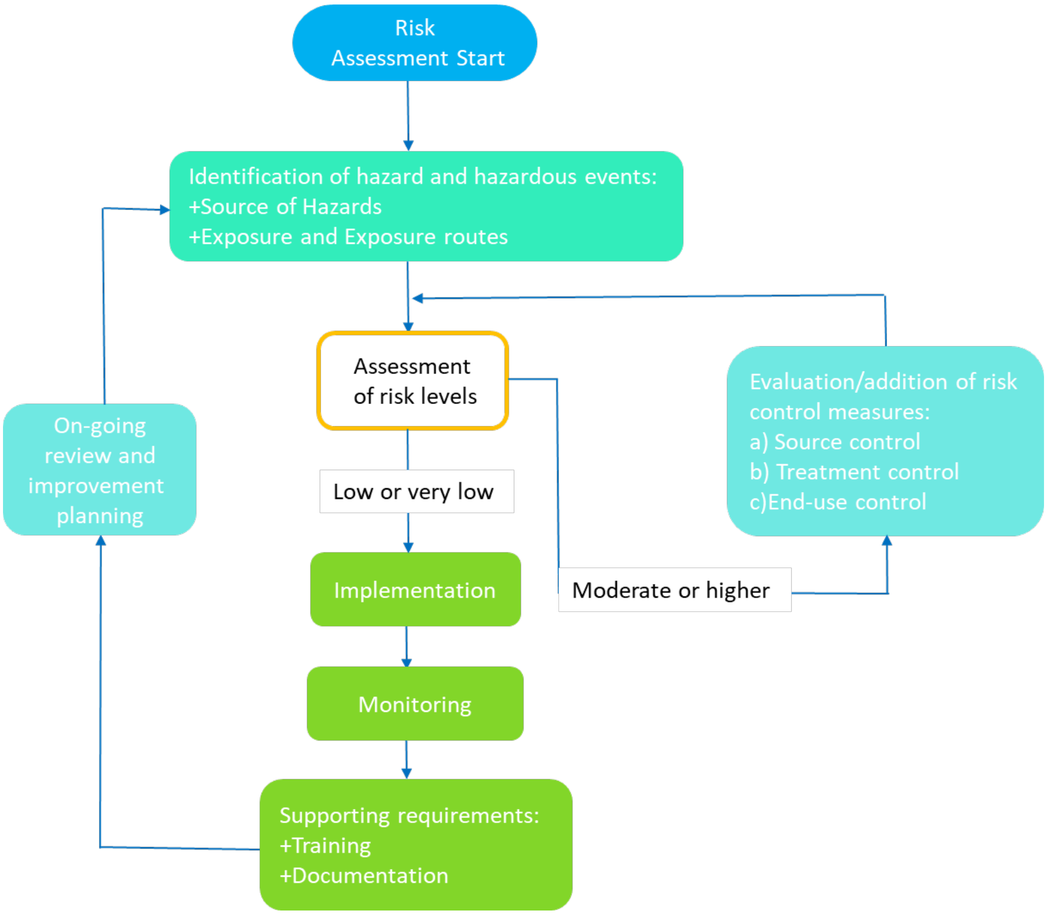
At this stage, a RMP team can also be identified. The team will be responsible for the development, implementation and maintenance of the plan, including effective communication with the participating organisations. Experts with different skills need to be considered as team members to ensure good balance of technical expertise, health and environmental skills to enable identification of hazards and hazardous events as well as understanding of control measures and uncertainty calculations. The roles and responsibilities should be summarized in a table outlining activities and responsible team members. A successful implementation hence requires commitment of all stakeholders at all levels (including the top management) within each organisation. Typically, various stakeholders are involved in water reuse systems, each with their own objectives and tasks. Thus, as one of the first steps, it is necessary to identify all stakeholders that should be involved, and to identify their corresponding roles and responsibilities.

Examples of responsible parties involved in a water reuse system are reported for each case study illustrated in Section 4.

3.3 Module II – risk assessment

Annex II of the Water Reuse Regulation requires health and environmental risk assessments and this section provides guidance and examples on how such risk assessments can be carried out. The ISO 20426 (2018) is used as a reference here to evaluate and manage risks (Figure 12).

Figure 12. Health risk assessment and management framework



Source: ISO 20426:2018

A first step is the characterization of elements **KRM3** and **KRM4**, that include: 1) the identification of any potential hazards (pollutants and pathogens) or hazardous events (failure of treatments, accidental leakages, contamination) that originate from the water reuse system and might pose a risk to public health and/or to the environment; 2) the characterisation of potential exposure routes of each hazards to the identified human, animal, or environmental receptors (populations and environments exposed). These elements are needed for the subsequent assessment of the health and environmental risks **(KRM5)**.

3.3.1 Hazards and hazardous events (KRM3)

According to ISO 20426 (2018) the identification of hazard includes (i) the identification of hazardous constituents in water and (ii) the identification of most probable hazardous events. Hazards and other types of consequences of hazardous events need to be identified at each step of the water reuse system characterized, as described in the previous section.

3.3.1.1 Hazardous events

Hazardous events are events linked to a water reuse system that might result in people or environment being exposed to a hazard. Hazardous events might happen during normal system operations (e.g., faulty infrastructure, system overloading, lack of maintenance, unsafe behaviours), due to a system failure or accident, or may be related to weather conditions. Hazardous events can cause direct exposure to a hazard, or indirect exposure to a hazard when its effect goes beyond the boundaries of the system, for example, it affects populations or environments not directly involved in the system, or through cumulative processes (e.g., salinization of soil). Hazardous events should be identified by analysing each process of the flow chart of the water reuse system individually. In case of systems at the planning stage, this process is obviously more a desk work in which each planned sub-system must be analysed with regard to possible hazardous events. Some examples of hazardous events with potentially exposed receptors and routes of exposure are reported in Table

3. Further examples can be found in the cited standards and guidelines and in the case studies of Section 4 of this document.

Table 3. Examples of hazardous events, potentially exposed receptors and route of exposures in a water reuse system

Hazardous event	Exposed receptor	Route of exposure
- Treatment failures - Accidental or illegal discharges	- Workers (reclamation facility operators) - End users (farmers) - By-standers - Environment (freshwaters, marine water, soil and related biota) - Crops	- Direct contact with reclaimed water - Accidental ingestion - Absorption to crops
- Non-compliance of reclaimed water due to failure of treatment - Contamination of storage and distribution system	- Workers (reclamation facility operators) - End users (farmers) - Environment (freshwaters, marine water, soil and related biota)	- Direct contact with reclaimed water - Accidental ingestion - Infiltration to groundwater - Run-off to surface water
Accidental exposure to reclaimed water due to design and operational accidents: pipe burst or leaks, inadequate irrigation timing	- Workers (reclamation facility operators) - End users (farmers) - By-standers - Environment (freshwaters, marine water, soil and related biota)	- Direct contact with reclaimed water - Accidental ingestion
Leaks from reclaimed water pipelines or distribution systems	Environment (freshwaters, marine water, soil and related biota)	- Infiltration to groundwater - Run-off to surface water
Accidental exposure to reclaimed water caused by end-use system failures	- End-users (farmers) - By-standers - Crops	- Direct contact with reclaimed water - Accidental ingestion - Inhalation (aerosols)
Human errors due to inadequate training and information about permitted use	- End-users (farmers) - By-standers - Crops	- Accidental ingestion - Direct contact with reclaimed water - Contamination of crops

Source: Australian Guidelines (NRMMC-EPHC-AHMC, 2006), ISO 20426, (ISO, 2018).

3.3.1.2 Hazards

The hazards (KRM3) should include any pathogens and chemical pollutants in the reclaimed water that might pose a risk to the human and/or animal health and/or to the environment.

A screening level phase could help identify hazards by matching the contaminants found in the specific reclaimed water, with these contaminants' thresholds values set out in applicable directives, regulations and guidelines. Along with the characterisation of the reclaimed water, an initial screening list of relevant hazards (pathogens and chemical pollutants) might be identified by also taking into account all the relevant EU, national and local legislation, as well as the requirements from the legislation, listed in Annex II point 5 of the Water Reuse Regulation, on the protection of surface and groundwater resources.

3.3.1.2.1 Pathogens

Microbial pathogens in reclaimed water (e.g., *E. coli* and other bacteria, viruses, parasites) used for agricultural irrigation could be responsible for water-borne disease outbreaks (e.g., gastroenteritis) and other acute effects ([6]). A list of microbial pathogens and their reference pathogens for health risk assessment from relevant standards and guidelines are proposed in Table 4. Other microbial parameters could be identified if the risk assessment identifies a potential risk of contamination of a water body protected under a particular legislation. For example, Table 5 gives an overview of microbial limits from the bathing water directive. Microbial hazards might be organised in groups and the risk assessment based on the reference pathogen. Other microbial

([6]) Acute effects: health effects that usually occur rapidly, as a result of short-term exposure. Chronic effect: adverse health effect resulting from long-term exposure to a substance.

requirements can be identified considering applicable regulations on feed and food hygiene (Regulation (EC) No 852/2004, Regulation (EC) No 183/2005, Regulation (EC) No 2073/200, and Regulation (EC) No 1881/2006.

Table 4. List of microbial hazards usually detected in raw wastewater and their effect on health and reference pathogens

Pathogen	**Examples**	**Disease**	**Reference pathogen** (1)
Bacteria	*Shigella*	Shigellosis (bacillary dysentery)	*E. coli O157:H7* *Campylobacter*
	Salmonella	Salmonellosis, gastroenteritis (diarrhoea, vomiting, fever), reactive arthritis, typhoid fever	
	Vibrio cholerae	Cholera	
	Pathogenic E. coli	Gastroenteritis and septicemia, haemolytic uremic syndrome	
	Campylobacter	Gastroenteritis, reactive arthritis, Guillain-Baré syndrome	
Protozoa	*Entamoeba*	Amebiasis (amebic dysentery)	*Cryptosporidium*
	Giardia	Giardiasis (gastroenteritis)	
	Cryptosporidium	Cryptosporidiosis, diarrhoea, fever	
Helminths	*Ascaris*	Ascariasis (roundworm infection)	*Intestinal Nematodes (Helminth Eggs)*
	Ancylostoma	Ancylostomiasis (hookworm infection)	
	Necator	Necatoriasis (roundworm infection)	
	Trichuris	Trichuriasis (whipworm infection)	
Viruses	*Enteroviruses*	Gastroenteritis, heart anomalies, meningitis, respiratory illness, nervous disorders, others	*Rotavirus*
	Adenovirus	Respiratory disease, eye infection, gastroenteritis	
	Rotavirus	Gastroenteritis	

(1) Selected from Gawlik and Alcalde-Sanz (2017)

Source: ISO 20426 (2018)

Table 5. Quality standards for *Intestinal* enterococci and *E. coli* set in the Bathing Waters Directive

	***Intestinal* enterococci (CFU/100 ml)**		***E. coli* (CFU/100 ml)**	
Quality Class	Freshwaters	Coastal and transitional waters	Freshwaters	Coastal and transitional waters
Excellent	200 (1)	100 (1)	500 (1)	250 (1)
Good	400 (1)	200 (1)	1000 (1)	500 (1)
Sufficient	330 (2)	185 (2)	900 (2)	500 (2)

(1) 95th percentile of measured concentrations.
(2) 90th percentile of measured concentrations.

Source: Directive 2006/7/EC

3.3.1.2.2 Chemical pollutants

Chemical pollutants possibly present in reclaimed water might also pose a risk to human health. Chemical contaminants are usually present at low concentrations in UWWTP effluents from domestic wastewater and generally require a longer exposure to cause illnesses or acute reactions, thus, generally resulting in an overall lower risk than from pathogens. Pathogens can immediate cause a health risk, even during a short period of system failure (malfunctioning). In case of chemical exposure, acute toxicity caused by a short-term failure is rather unlikely. To assess risks related to chemical pollutants, it is important to identify any industries located in the area served by the UWWTP whose discharges in the urban collection system might contribute to high concentration of specific chemical pollutants in the urban wastewater (e.g., pharmaceutical industries, galvanisation industries). Uncontrolled concentrations of chemical hazards in UWWTP effluents might occur as a result of hazardous events, like accidental or inappropriate discharges, the likelihood of which can be minimised by appropriate preventive measures (WHO, 2016). In agricultural production, chemical uptake through handling needs to be assessed as well, in this case the values set out by the European Food Safety Authority (EFSA) (7) might be considered if detected in the reclaimed water. The handling of hazardous chemicals in operation and maintenance of the reuse system can be a risk for people and environment, too, e.g., chlorine-based cleaning agents and disinfectants. Consequently, safe handling of such chemicals should be considered in *Occupational Health Safety and Environment* policies and rules.

(7) https://www.efsa.europa.eu/en

For the screening of chemical hazards, the legislation for drinking water could be considered, in particular if the reclaimed water may affect water sources used for drinking water. Table 6 reports, as example, a list of contaminants selected from the Drinking Water Directive that could be present in UWWTP effluent. Similarly, potential hazards present in the reclaimed water that could affect other environmental compartments can be selected consulting the Environmental Quality Standard Directive (EQSD) list of pollutant (Table 7).

Table 6. Examples of some chemical pollutants listed in the Drinking Water Directive potentially present in urban wastewater.

Pollutant	**Value**
Nitrate (NO_3)	50 mg/L
Copper	2.0 mg/L
Uranium	30 μg/L
Chromium	25 μg/L
Nickel	20 μg/L
Arsenic, Tri- and Tetrachloroethene	10 μg/L
Selenium	20 μg/L
Cadmium, Lead	5 μg/L
Antimony	10 μg/L
1,2 - dichloroethane	3 μg/L
Mercury, Benzene	1.0 μg/L
Vinyl chloride	0.50 μg/L
PFAS Total	0.50 μg/L
Sum of PFAS	0.10 μg/L
Acrylamide, PAHs, Epichlorohydrin	0.10 μg/L
Benzo(a)Pyrene	10 ng/L
Bisphenol A,	2.5 μg/L
Trihalomethanes Total	100 μg/L
Haloacetic acids (HAAs)	60 μg/L
Directive 2020/2184 introduces a watch list mechanism to address emerging compounds, such as endocrine-disrupting compounds, pharmaceuticals and microplastics. The Commission Implementing Decision of 19.1.2022 establishes, for the watch list of substances and compounds of concern for water intended for human consumption, the following endocrine-disrupting compounds: 17-beta-estradiol ≤ 1 ng/L nonylphenol ≤ 300 ng/L	

Source: Annex I, Part B of Directive 2020/2184 (Minimum requirements for parametric values used to assess the quality of water intended for human consumption). Pollutants were selected by Pistocchi et al. (2019) and adapted considering revisions of the new Drinking Water Directive and substances that could be found after disinfection.

Table 7. Example of priority pollutants listed in the Environmental Quality Standard Directive potentially present in urban wastewater ([1])

Pollutant	**Annual Average Concentration (μg/L)**		**Maximum Allowable Concentration (μg/L)**		**μg/kg wet weight**
	Inland surface waters ([2])	Other surface waters	Inland surface waters ([2])	Other surface waters	Biota
Anthracene	0.1	0.1	0.1	0.1	-
Benzene	10	8	50	50	-
Brominated diphenyl-ethers (Sum of the concentrations of congener numbers 28, 47, 99, 100, 153 and 154)	-	-	0.14	0.14	0.0085
Cadmium and its compounds (depending on water hardness classes)	0.08 to 0.25	0.2	0.45 to 1.5	0.45 to 1.5	-
C10-13 Chloro-alkanes (No indicative parameter is provided for this group of substances. The indicative parameter(s) must be defined through the analytical method).	0.4	0.4	1.4	1.4	-
1,2-Dichloroethane	10	10	not applicable	not applicable	-

Pollutant	Annual Average Concentration (µg/L)		Maximum Allowable Concentration (µg/L)		µg/kg wet weight
	Inland surface waters (2)	Other surface waters	Inland surface waters (2)	Other surface waters	Biota
Dichloromethane	20	20	not applicable	not applicable	-
Di(2-ethylhexyl)-phthalate (DEHP)	1.3	1.3	not applicable	not applicable	-
Fluoranthene	0.0063	0.0063	0.12	0.12	30
Hexachloro-benzene	-	-	0.05	0.05	10
Hexachloro-butadiene	-	-	0.6	0.6	55
Lead and its compounds	1.2 (bioavailable concentrations of the substances)	1.3	14	14	-
Mercury and its compounds	-	-	0.07	0.07	20
Naphtalene	2	2	130	130	-
Nickel and its compounds	4 (bioavailable concentrations of the substances)	8.6	34	34	-
Nonylphenols (4-Nonylphenol)	0.3	0.3	2.0	2.0	-
Octylphenols ((4-(1,1′,3,3′-tetramethylbutyl)-phenol))	0.1	0.01	not applicable	not applicable	-
Pentachloro-benzene	0.007	0.0007	not applicable	not applicable	-
PAH Benzo(a)pyrene (3)	1.7×10^{-4}	1.7×10^{-4}	0.27	0.027	-
Tributyltin compounds (Tributyltin-cation)	0.0002	0.0002	0.0015	0.0015	-
Trichloro-benzenes	0.4	0.4	not applicable	not applicable	-
Trichloro-methane	2.5	2.5	not applicable	not applicable	-
Perfluorooctane sulfonic acid and its derivatives (PFOS)	6.5×10^{-4}	1.3×10^{-4}	36	7.2	9.1
Hexabromo-cyclododecanes (HBCDD)	0.0016	0.0008	0.5	0.05	167

(1) Selected among the 45 priority substances set by the EQSD that includes pesticides, household and industrial chemicals.
(2) Inland surface waters encompass rivers and lakes and related artificial or heavily modified water bodies
(3) For the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), the biota EQS and corresponding AA-EQS in water refer to the concentration of benzo(a)pyrene, on the toxicity of which they are based. Benzo(a)pyrene can be considered as a marker for the other PAHs, hence only benzo(a)pyrene needs to be monitored for comparison with the biota EQS or the corresponding AAEQS in water.

Source: EQS Directive 2013/39/EU; pollutants were selected by Pistocchi et al. (2019).

The assessment of agro-chemicals such as pesticides or veterinary medicinal applications (VMA) can also be considered through the respective environmental legal framework in place.

3.3.1.2.3 Non-regulated pollutants

Some other pollutants are not regulated and are not included in the listed directives and regulations. These include:

- Contaminants of emerging concern (CECs) related to excretion or use by people (e.g., ingredients of personal care products, residues of household chemicals, pharmaceuticals).
- Engineered materials at the micro- and nano-size, including microplastics and nanoplastics
- Antibiotic-resistant bacteria and antibiotic resistance genes (ARB/ARGs).

CECs, microplastics and ARB/ARGs are receiving attention from the scientific community. For example, the presence of CECs in treated wastewater used for agricultural irrigation triggered a significant number of investigations and research (Petrie *et al.,* 2015; Krzeminski, 2019; Golovko et al., 2021), mainly aiming to address plant-uptake and hazards related to food consumption or to address their fate and effects in soil, groundwater and receiving water bodies (Christou et al., 2017). On the other hand, cause-effect studies on possible consequences of these compounds and their mixtures on human and animal health are generally lacking. Relevant environmental processes, which are influencing the behaviour of CECs, include plant uptake, short- and long-term adsorption processes, biological metabolization, chemical and biological transformation processes as well as diffusion to the unsaturated and saturated zones and run-off. While the concentration of many of CECs in wastewater decrease during treatment in wastewater treatment plants, they remain detectable from an analytical point of view in wastewater treatment plant effluents and some of them tend to degrade over time and form by-products. While partially this can be explained by an increased performance of the analytical instrumentation at hand, their presence and possible resulting effects from the combination of many chemicals, nourish a general concern, even mistrust among the public, but also environmental authorities. In addition, the use of agro-industrially relevant chemicals (pesticides, veterinary medicinal agents, food additives for animal husbandry) in conjunction with a wide-spread use of manure as fertilizer, makes it difficult to properly estimate the environmental risk related to the presence of the CECs in treated wastewater used for irrigation. Furthermore, no European standard on CECs in irrigational water exist.

Deviller *et al.* (2020) proposed to derive quality standards for chemical pollutants in reclaimed water intended for agricultural irrigation but failed to put this realistically into relationship to other water sources used for irrigation, e.g., surface water. Likewise, the proposed idea of prioritisation process for the specific purpose is unrealistic and would discriminate the water reuse practices compared to other irrigations practices often using water of an inferior quality.

By using treated wastewater for irrigation, organic micro-contaminants may be introduced into soils and potentially transferred to the groundwater. Consequently, Helmecke *et al.* (2020) postulated a systemic risk assessment to evaluate this potential contamination by chemicals of emerging concern, including all relevant exposure pathways, however left the question open which chemicals should be tested or how a meaningful limit value of concentration can be established.

The presence of these contaminants and their possible role in a risk management framework shall be evaluated on a case-by-case basis. The risk to human and animal health or the environment associated to their presence shall be supported by scientific evidence. It should also be proven that these contaminants originate from the water reuse system and not from other sources.

3.3.1.2.4 Agronomic hazards

Other specific aspects linked to the effect of reclaimed water quality parameters on agronomic characteristics, including hazards on soil and crop/plants, should also be considered. According to ISO 16075-1:2020, agronomic hazards from reclaimed water that could damage soil and irrigated crops are chemical substances, such as salts (salinity), sodium, chloride, boron (specific ion toxicity), other chemical elements, and nutrients that could affect the soil and crops characteristics. The most important soil-related agricultural risks associated with these hazards might include:

- Mobilization of inorganic adsorbable pollutants.
- Slaking or clogging of the upper soil layer.
- Salinization and sodification of soils.
- Mobilization of boron.
- Groundwater pollution through leaching of chemicals.
- Accumulation and mobility of nitrogen and phosphorus.

Pathogens that could cause disease to plants or crops are not usually found in reclaimed water from UWWTP effluents. However, their presence in reclaimed water could be assessed on site-specific conditions (e.g., run-off of irrigation water infected with plant pathogens). Table 8 presents a list of agronomic hazards potentially present in reclaimed water that could affect soil, freshwater resources and crops during irrigation.

Table 8. Key environmental hazards, environmental receptors and potential negative effect of reclaimed water used for agricultural irrigation

Hazard	Environmental Receptor	Potential effect
Nitrogen	Soil Groundwater (leaching) Surface water (run-off) Crop	Nutrient imbalance in crops; eutrophication; toxic effect on terrestrial biota Contamination Eutrophication
Phosphorus	Soil Surface water	Eutrophication/toxic effect on biota Eutrophication
Chlorine disinfection residuals	Surface water Crop	Toxicity to aquatic biota Crop toxicity
Salinity (TDS, ECw)	Soil (salinization)	Soil damage; crop stress; crop uptake of cadmium

Hazard	Environmental Receptor	Potential effect
	Surface water Groundwater	Increase salinity
Boron	Soil (accumulation)	Crop toxicity
Chloride	Crop Soil Surface water Groundwater (leaching)	Crop toxicity (sprayed on leaves) Crop toxicity via roots uptake Toxicity to aquatic biota
Sodium	Crop Soil	Crop toxicity (sprayed on leaves) Soil damage (crop toxicity)
Inorganic adsorbable pollutants (e.g., heavy metals)	Soil accumulation	Crop toxicity

Source: Australian Guidelines (NRMMC-EPHC-AHMC, 2006), ISO 16075-1 (ISO, 2020).

3.3.2 Populations and environments at risk (KRM4)

3.3.2.1 Exposed populations

At this stage, any population exposed to reclaimed water and related routes of exposure should be identified (Table 9). This includes workers along the water reuse system that could be directly exposed to the reclaimed water. Public health risks for workers and their families depend mainly on the quality of the reclaimed water, the irrigation methods and equipment used. For example, sprinkler irrigation systems that generates aerosols can pose potential risks for neighbours of irrigated plots. Aerosol-related risks depend on the irrigational water quality and wind velocity (responsible for the dissemination of aerosols in the surroundings of the irrigated area).

Table 9. Health relevant exposure groups and routes in case of agricultural irrigation

Exposure group	Related exposure route
Farmers, workers (including water treatment operators)	Direct skin contact in field or during handling, inhalation, ingestion
By-standers	Inhalation, ingestion, direct skin contact
User of connected recreational areas	Direct skin contact after dilution
Crop merchants, handlers, and technical/operational staff	Direct skin contact, ingestion
Residents or by-passers of areas irrigated	Inhalation, ingestion, direct skin contact

3.3.2.2 Exposed environments

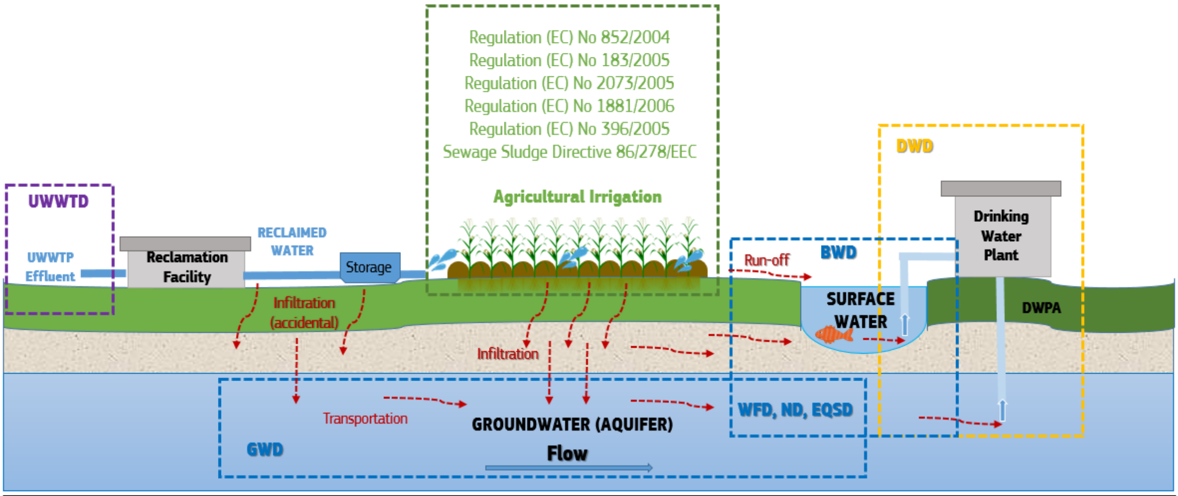
The use of reclaimed water for agricultural irrigation may affect the surrounding environment through different pathways (e.g., irrigational water run-off, infiltration to groundwater, etc.), it is therefore important to identify any of the environmental compartments that could be affected by hazards present in the irrigational water and any pathways of exposure (Table 10).

Table 10. Summary of environment-relevant exposure targets and pathways in case of agricultural irrigation

Exposed environment	Related exposure pathways and processes
Soil	Acidification, salinization, contamination impacting soil functions and biodiversity
Animals	Exposure of wildlife and animal husbandry
Vegetation	Alteration of biodiversity, contamination
Groundwater	Infiltration involving adsorption/desorption processes, leaching, biodegradation
Surface Water	Run-off, partitioning, dilution, vector-borne transmission of diseases across species

The identification of any environmental compartment potentially exposed to the use of reclaimed water for irrigation can be first done in parallel with the identification of any applicable legislation in the area as explained in Section 3.2.1.2. A graphical example on how to identify potential pathways of the reclaimed water to the environmental matrices (freshwater resources) due to accidental leakages or via run-off from the irrigated field, is suggested in Figure 13. Figure 13 also illustrates the regulations and directive listed at point 5 of Annex II of the Water Reuse Regulation that might apply to the identified environmental targets.

Figure 13. Example of identification of potential pathways of reclaimed water to the surrounding environments (surface water and groundwater) and of regulations and directives that could apply



UWWTPD: Urban Wastewater Treatment Directive; DWD: Drinking Water Directive (if surface or groundwater are classified drinking water protected area (DWPAs); BWD: Bathing Water Directive (if surface water is used for bathing activities); GWD: Groundwater Directive; WFD: Water Framework Directive; EQSD: Environmental Quality Standard Directive; ND: Nitrate Directive (if water reuse scheme falls into Nitrate Vulnerable Zone (NVZ))

When all the pathways of reclaimed water and exposed environments are identified, threshold values of applicable legislation might be compared with the values of the hazards present in the reclaimed water. For example, the assessment might take into account the environmental objectives of Article 4 of the WFD (i.e., good surface water ecological and chemical status and good groundwater chemical status), the requirement of the Nitrate Directive if the water reuse system and the irrigated areas are located near a Nitrate Vulnerable Zone (NVZ), the requirement of the Drinking Water Directive (DWD) if the reclaimed water could migrate to water bodies classified as Drinking Water Protected Areas (DWPAs), the Environmental Quality Standard Directive (EQSD) including their Watch List, and the River Basin Specific Pollutants (RBSPs) identified at national level. These laws set standards and/or monitoring obligations for pathogens or for chemicals (e.g., heavy-metals, DBPs, pharmaceuticals and other substances classified as priority pollutants).

Box 9. Sources of information for chemical status of freshwaters, environmental quality standards and emissions of pollutants

Chemical status of freshwaters identified by MS within the RBMP can be consulted via the WISE system. Information on EQS for priority substances can be consulted via the ECHA database. Relevant information on emissions of specific pollutants can be found in the European Pollutant Release and Transfer Register (E-PRTR) (applicable to UWWTP with capacity of 100 000 P.E.).

WISE Freshwater resource catalogue

Environmental Quality Standards – ECHA

The European Pollutant Release and Transfer Register (E-PRTR) - Environment - European Commission (europa.eu)

3.3.3 Risk assessment (KRM5)

Environmental and health risk assessment **(KRM5)** should be conducted by taking into account previously identified hazards and hazardous events, potential routes of exposure and the receptors identified within the water reuse system. Risk assessment may be conducted by qualitative or semi-quantitative methods. Qualitative risk assessment is suggested as the most appropriate and economically feasible methodology. Quantitative risk assessment could be used for projects with high risk and when enough supporting data are available for their implementation. Qualitative, semi-quantitative and quantitative risk assessment methodologies can be applied for health or environmental risk assessments. The health risk assessment evaluates any risk to human and animal health, whereas the environmental risk assessment aims to determine if the identified contaminants in the reclaimed water affect the quality status of environmental matrices.

Qualitative and semi-quantitative risk assessments can be developed through several approaches, such as event trees, matrices or indicators. A usual methodology is the one based on a combined evaluation of likelihood and magnitude/severity of the impact of a hazard on the exposed receptor. Likelihood analysis can be performed through historical data review or assessment of human error, fault trees and event trees. The analysis of the impacts is usually done through a classification into categories, with increasing levels of severity of the impact.

Quantitative risk assessments can provide a numerical estimation of the risk, for example the impact of specific microbial infection in one year under a specific scenario. This characterisation of the risks to human and animal health is usually based on dose-response relationships to identify if a hazard or hazardous event might have an effect on the health. A health risk assessment by microbial hazard can be done using a Quantitative Microbial Risk Assessment (QMRA), based on the evaluation of dose-response relationships between the concentration of a hazard and the effect it may cause on the receptors. The outputs of this method represent the values of the probability of adverse health effects and are expressed by probability of infection or by the Disability-Adjusted Life Years (DALY) indicator. Methodologies and criteria for QMRA and DALY can be consulted from the WHO Guidelines (WHO, 2006a) and the WHO Guidelines on QMRA (WHO, 2016). A quantitative approach for assessment of the environmental risk or Quantitative Chemical Risk Assessment (QCRA) is usually based on the ratio of the Predicted Environmental Concentration (PEC), calculated with complex models on fate and transports of a specific pollutant to environmental compartments, and the Predicted No-Effect Concentrations (PNEC) or its maximum allowable concentration set out by applicable legislations (e.g., EQS applicable to water bodies according to their quality status). This approach requires a significant volume of monitoring data from the water reuse projects and a detailed characterisation of the surrounding environment which limits its applicability only to projects were sufficient data are available and assumptions are supported by scientific evidence.

Health and environmental risks can be assessed using different approaches with a varying degree of complexity and data requirements, depending on the specific water reuse system. By way of illustration, the following sections report some qualitative and semi-quantitative risk assessment methods and tools selected among those proposed in published practises and standards: ISO 20426 (ISO, 2018), WHO Sanitation Safety Plan (SSP) Manual (WHO, 2016), ISO 16075-1 to 2 (ISO, 2020), and Australian Guidelines (NRMMC-EPHC-AHMC, 2006).

3.3.3.1 Health Risk Assessment

Although reclaimed water, if treated properly, usually shows a better microbiological quality than many sources of surface water used in irrigation, it is commonly accepted that one cannot exclude that the direct or indirect contact with reclaimed water may still have health risks for individuals. It is important to highlight though that tertiary treated municipal wastewater usually has no health implications. Contact can be by intended users or simply by-standers, the latter not being aware of being exposed. Collection and treatment of wastewater, and the sub-sequent storage and distribution of treated wastewater, the use of reclaimed water, or the “after-use” situation are all processes providing contact opportunity and need to be addressed. Health risks may also be present during the operations and/or maintenance work of the facilities and processes. All possible health implications vary in terms of impact and likelihood of occurrence: they can be moderate in some cases and serious in others, and continue for a short, moderate, or long period of time.

3.3.3.1.1 Qualitative Health Risk Assessment

In a qualitative or semi-quantitative risk assessment, the level of risk for each identified hazards results from a combined evaluation of the likelihood level of an event to happen and the level of its consequences or severity, as in the following expression:

$$Level\ of\ Risk = Likelihood\ \times Consequence\ (or\ Severity)$$

Likelihood indicates, in a certain timeframe, the probability of occurrence of a hazardous event with potential harmful effects. The probability of occurrence can be evaluated by reviewing available historical data or assessing human error, by using fault or event trees. In a water reuse system, such likelihood might derive from a combination of the probability of human exposure to the reclaimed water (e.g., via ingestion) containing a hazardous element (e.g., *E. coli*) and the probability of the presence of the hazard in reclaimed water (e.g., resulting from a hazardous event like accidental release).

Consequence or Severity indicates a potential adverse health effect resulting from the exposure to a hazard. Consequence levels can be determined by a qualitative evaluation based on a descriptive representation of the outcomes or by using other tools (e.g., decision trees) considering hazards and hazardous event.

In a qualitative and semi-quantitative risk assessment, hazard/hazardous events and the assignments of their likelihood and consequences levels are based on the risk assessment team's judgment and experiences. The level of risk can be expressed as *very low, low, moderate, high, and very high* by combining the levels of likelihood and consequences (Table 11).

Table 11. Matrix for qualitative risk assessment

LIKELIHOOD	**CONSEQUENCES**				
	1 – Insignificant	**2 – Minor**	**3 – Moderate**	**4 – Major**	**5 – Catastrophic**
A – Rare	Very low	Very low	Low	Low	Moderate
B – Unlikely	Very low	Low	Low	Moderate	High
C – Possible	Low	Low	Moderate	High	High
D – Likely	Low	Moderate	High	High	Very high
E – Almost certain	Moderate	High	High	Very high	Very high

Source: ISO 20426 (ISO, 2018)

An alternative risk matrix is based on a semi-quantitative method for which a more rigorous approach is required (e.g., by using formulas) to assign a specific numerical value to likelihood and severity to each identified hazard and hazardous events to determine a risk level or score (Table 12).

Table 12. Semi-quantitative risk assessment matrix

LIKELIHOOD	**SEVERITY**				
	Insignificant – 1	**Minor – 2**	**Moderate – 4**	**Major – 8**	**Catastrophic – 16**
Rare (very unlikely) – 1	1	2	4	8	16
Unlikely – 2	2	4	8	16	32
Possible – 3	3	6	12	24	48
Likely – 4	4	8	16	32	64
Almost certain – 5	5	10	20	40	80
Risk Score R = L x S	<6	7-12		13-32	>32
Risk level	Low Risk	Medium Risk		High Risk	Very High Risk

Source: WHO SSP Manual (WHO, 2016)

In a semi-quantitative approach, it is necessary to define likelihood/probability levels, based on hazards or hazardous event, and of consequence/severity levels, considering, for example, the exceedance of hazardous substances in reclaimed water at overprotective threshold and the magnitude of its associated health outcomes. These definitions should be developed based on a specific water reuse system and local context and always consider the principle of public health protection and any applicable regulatory impacts. Some definitions are reported in Table 13 and Table 14.

Table 13. Suggested measures of consequence or severity of the impact

Level – Descriptor	**Example description**
1– INSIGNIFICANT	Hazard or hazardous event resulting in no or negligible health effects ([1]) compared to background levels.
2 – MINOR	Hazard or hazardous event potentially resulting in minor health effects ([2]).
3 – MODERATE	Hazard or hazardous event potentially resulting in a self-limiting health effects or minor illness ([3]).
4 – MAJOR	Hazard or hazardous event potentially resulting in illness or injury ([4]); and/or may lead to legal complaint or concern.
5 – CATASTROPHIC	Hazard or hazardous event potentially resulting in serious illness or injury ([5]), or even loss of life; and/or will lead to major investigation by regulator with prosecution likely.

([1]) *no or negligible health effect*: not observed health effect.
([2]) *minor health effect*: e.g., temporary symptoms like irritation, nausea, headache.
([3]) *self-limiting health effects or minor illness*: e.g., acute diarrhoea, vomiting, upper respiratory tract infection, minor trauma.
([4]) *illness or injury*: e.g., malaria, schistosomiasis, food-borne trematodiases, chronic diarrhoea, chronic respiratory problems, neurological disorders, bone fracture.
([5]) *serious illness or injury*: e.g., severe poisoning, loss of extremities, severe burns, drowning.

Source: ISO 20426 (ISO, 2018); WHO SSP Manual (WHO, 2016)

Table 14. Suggested measures of likelihood that exposure events can happen

Level – Descriptor	**Example description**
A – RARE	Has not happened in the past and it is highly improbable it will happen in the reasonable period ([1]).

Level – Descriptor	Example description
B – UNLIKELY	Has not happened in the past but may occur in exceptional circumstances in the reasonable period.
C – POSSIBLE	May have happened in the past and/or may occur under regular circumstances in the reasonable period.
D – LIKELY	Has been observed in the past and/or is likely to occur under regular circumstances in the reasonable period.
E – ALMOST CERTAIN	Has often been observed in the past and/or will almost certainly occur in most circumstances in the reasonable period.

([1]) The reasonable period depends on the level of risk and local jurisdiction.

Source: ISO 20426 (ISO, 2018); WHO SSP Manual (WHO, 2016)

The identified risk levels associated to hazard/hazardous events per route of exposure and receptor will determine priorities for risk management and any preventive measures that will reduce the risk(s). For example, if the level of risk is *medium* or higher, a preventive measure should lower the risk level. This evaluation could include the assessment of any preventive measures already in place and the identification of additional measures/actions for those hazards with no existing or no effective measures in place. If a preventive measure can adequately control the risk, then actions may require the setup of monitoring and other operational control methods to ensure its functionality. The multi-barrier approach with multiple preventive measures and barriers in place provide more reliable risk management than a single measure/barrier. The selected preventive measures and barriers should then be re-assessed to verify whether risk levels have decreased.

3.3.3.1.2 Quantitative Health Risk Assessment

In general, quantitative risk assessment is recommended for water reuse systems with potentially high and immediate health risk, e.g., domestic or potable reuse system. This is not the case of water reuse in agricultural irrigation. However, this approach is particularly recommended for research projects exploring the introduction of a reuse system or in the case of new demonstration projects. In many cases, even if the quantitative assessment is recommended, there are often not enough data to perform a quantitative risk assessment. The main drawback for quantitative risk assessment is that, for the majority of the cases, no data is available to determine the impact of the different factors affecting microbial risk.

Although the quantitative risk assessment provides a significantly more detailed and indeed quantitative risk appreciation, a detailed quantitative risk assessment is possible only for a limited range of contaminants, and this with high uncertainties due to numerous knowledge gaps. Therefore, it is recommended for research and demonstration purposes.

Exposure assessment

Typical health risks of water reuse in irrigation are linked to unintended ingestion, inhalation or skin contact during and after use. Frequency and duration depend on the irrigation regime, which also define the possible dose of (unintended) ingestion, inhalation or skin contact. The respective values are also influenced by local and regional conditions or legislation in place. The realistic and appropriate setting for volume, frequency, and duration of unintended ingestion, inhalation or skin contact, require reliable data or estimates thereof. This introduces uncertainty and requires an analytical and dialectic approach, often subject of exploratory research or even estimates and first approximations. This is one of the reasons why a quantitative risk assessment for water reuse in agricultural finds its application mainly for research activities rather than for the operation of reuse systems.

Dose-response assessment

As mentioned above, the primary risks in water reuse in irrigation schemes are of microbial nature and the quantitative risk assessment is primarily a microbiological one. Dose-response assessment aims to establish the relationship between the dose of a pathogen that individuals or population groups are exposed to and the probability of adverse health effect (e.g., infection, illness, death). From this estimated quantitative relationship (dose-response model), one obtains the probability of potential adverse health effects of a given severity stemming from a given exposure to a specific pathogen.

The dose–response modelling describes the magnitude of the adverse health effect (infection, illness) caused in an individual, as a function of exposure (or doses) to a stimulus or stressor (usually a specific pathogen) after a certain exposure time. These dose–response relationships can be described by so-called dose-response curves, while the output of a dose-response assessment is a value or a set of values for the dose-response parameters.

The challenge is that these parameters can only be set appropriately where adequate and reliable data sets exist.

Health risk characterization

Following the WHO approach for health risk assessment, to characterise the health risk, the Disability-Adjusted Life Years (DALY) is used, since the Water Reuse Regulation 2020/741 builds on the same. The outputs of health risk characterizations are the values of the probability of adverse health effects (e.g., infection, illness, death) and are expressed by probability of infection or DALY.

DALY is an indicator expressing the severity of a health effect through its magnitude, and it is expressed by the following formula:

$$DALY = YLL + YLD$$

Years of Life Lost (YLL) are years lost due to premature mortality. YLL is calculated by subtracting the age at death from the longest possible life expectancy for a person at that age. For example, if the longest life expectancy for men in a given country is 75, but a man dies of cancer at 65, this is 10 years of life lost due to cancer. Years Lived with Disability (YLD) can also be described as years lived in less-than-ideal health. This includes conditions such as influenza, which may last for only a few days, or epilepsy, which can last a lifetime. For the respective condition (e.g., a disease), it is measured by taking the prevalence of the condition (how often does the disease occur) multiplied by the disability weight which can be obtained from infection data. Disability weights reflect the severity of different conditions and are developed through surveys of the general public.

3.3.3.2 Environmental risk assessment

The Environmental Risk Assessment (ERA) aims to identify the impact of chemical and physio-chemical contaminants rather than microbial hazards. This is because treated effluents can still contain a wide range of inorganic and organic chemical agents, and chemical hazards generally may pose a greater risk to the environment than microbial hazards. In addition, one must bear in mind that heavy chemical contaminations may indeed co-exist with weaker microbial contaminations. Moreover, for pathogenic microorganisms, the preventive measures taken to protect human health will generally be more than sufficient to protect the environment. However, it must be emphasized that this does not imply that chemical hazards are less relevant to human health, and environmental contamination unavoidably causes indirect risks to humans, therefore the minimization of risks to the environment will positively affect the human health.

The risk assessment of water reuse system has to be conducted taking into account the existing regulatory framework that will apply on the specific case as illustrated in Section 3.2.1.2. The Water Reuse Regulation sets the requirements and obligations within which the risk assessment takes places. This environmental framework is related to impacts on specific endpoints or receptors within the environment, and any exceedance of such values should trigger action. This framework is defined by the European, national or regional legislation in force and needs to be considered site-specifically. Embedded thresholds and limit values also provide a trigger value between '*no appreciable risk*' and a risk level that needs further investigation, for specific reuse systems. The values inform the risk assessment process set out hereafter, supplementing (rather than substituting for) a risk-based approach to recycled water management.

As for the health risk assessment, also for the environmental risk assessment a qualitative approach is suggested. However, in some specific situations, a quantitative risk assessment may be possible if there is sufficient data on the most sensitive endpoints identified for the specific reuse system to be assessed. Environmental risk assessment by quantitative method can be based on the predicted no-effect level or concentration (PNEC), which represents the concentration of a chemical which marks the limit at which below no adverse effects of exposure in an ecosystem are measured. PNEC are typically generated from the lowest acute or chronic toxicity value generated from a bioassay. Ecological risk assessment is generally done by comparing Measured Environmental Concentrations (MECs) of a contaminant to its Predicted No Effect Concentrations (PNECs) from ecotoxicological data which ideally represent the most sensitive species over several trophic levels. If the risk quotient calculated from the MEC/PNEC ratio is greater than one, then the contaminant is a concern and action should be undertaken to confirm the environmental risk, identify the sources of contamination, and reduce the release of contamination.

3.3.3.2.1 Risk assessment on freshwater resources

The procedure for risk assessment on freshwater resources proposed herein was developed according to Section 6 of ISO 16075-1 (ISO, 2020), and Section 4.2 of the Australian Guidelines (NRMMC-EPHC-AHMC, 2006). It aims at providing a guide to assess the risks associated to hazards present in reclaimed water on freshwater resources (surface water and groundwater). This procedure can also be followed for the assessment of CECs.

STEP 1 – Hazards screening

Comparing hazards in reclaimed water with known values from regulation, directives, standards and guidelines depending on the potentially affected environmental compartment (see Figure 9). This could include maximum allowable concentrations or Environmental Quality Standards (EQS) for regulated contaminants in the potentially exposed environmental compartments whose compliance will in most cases ensure the protection of exposed environments. A worst-case scenario can be used, in which the 95th percentile or maximum-recorded concentration is compared with its lowest guidelines value (e.g., EQS). Hazardous events linked to the release of these hazards should also be identified (e.g., leaks from reclaimed water pipelines or distribution systems).

STEP 2 – Probability of substances to reach the environmental receptor

Likelihood could be estimated by assessing if the hazards could reach the environmental receptor considering any preventive measure and barrier in place. For groundwater and surface waters, the likelihood will depend on the hydrogeological conditions of the site (e.g., presence of an aquifer), the probability of the substance to move in the non-saturated zone for infiltration (e.g., soil type and hazard characteristics), and to the type of irrigation conditions (e.g., agricultural practises, crop needs, soil type, probability of reclaimed water to overflow from drainage systems).

STEP 3 – Consequence/severity of the damage

Consequence or severity of the damage levels will depend on the initial quality status of surface water or groundwater. The severity levels could define to what extent the hazard concentration will cause a detrimental effect to the environmental compartment. For example, the level of severity of damage will depend on the extent to which a hazard would contribute to the deterioration of the status of the water body considered. Consequence levels could include other factors, for example if the water sources are used for the production of drinking water.

STEP 4 – Assessment of risk levels

Once all the hazards and their likelihood and severity levels have been identified (either by assigning a qualitative level or a numerical value), then a qualitative or semi-quantitative matrix can be used to assess risk levels as those proposed for the health risk assessment.

The probability of a certain substance reaching a water body can be estimated by using the following tools from the ISO 16075-1 (2020), which assess the vulnerability of groundwater and surface water to infiltration or run-off of reclaimed water, respectively. With this tool, surface water and groundwater are classified in four *sensitivity groups*, which are based on hydrogeological conditions for groundwater, and on the presence of drainage system to control run-off to surface water (Table 15).

Table 15. Sensitivity groups definition for surface water and groundwater

Sensitivity group	Surface water	Groundwater
High (I)	Presence of surface run-off during irrigation or presence of surface accumulation, which is likely to wash out during rain events.	Presence of an unconfined acquirer beneath the irrigated area with clay content [2] < 5 % within the top 2 m of soil. Presence of an aquifer at a depth less than 5 m.
Medium (II)	Design and operation of irrigation system prevents surface run-off. Presence of a shallow underground drainage system (at a depth of 80 cm or less).	Presence of an aquifer at a depth of over 5 m from the surface with clay content of 15 to 40 % within the top 2 m soil.
Low (III)	Design and operation of irrigation system prevents surface run-off. Presence of a deep drainage system (over 80 cm).	Presence of an aquifer at a depth of over 5 m with clay content > 40 % within the top 2 m soil.
Zero (IV)	Design and operation of irrigation system prevents surface run-off.	No aquifer under the irrigated area and no hydrogeological continuity which will likely transfer the water to a nearby aquifer [3].

Sensitivity group	Surface water	Groundwater
	Irrigation system does not include drainage (1).	

(1) The passage in the underground section provides filtration of contaminants. The existence of effective land drainage reduces the water content from the soil but might lead to increased loads on surface water systems.
(2) Clay content can be determined by sieve analysis.
(3) Group to be selected only when a thorough hydrogeological analysis has been conducted. In the absence of clear knowledge of the underground geo-hydrogeology, the site should be regarded as if there was an aquifer beneath the irrigated area.

Source: ISO 16075-1 (2020)

The combination of the sensitivity groups for groundwater and surface water with the level of infiltration to groundwater or surface run-off, respectively, can indicate a level of vulnerability of the water body (Table 16).

Table 16. Example of vulnerability (1) level of groundwater and surface water

INFILTRATION RATE			**No infiltration to groundwater**	**Low infiltration to groundwater**	**Medium infiltration to groundwater**	**High infiltration to groundwater**
			I	II	III	IV
Sensitivity to Groundwater	Shallow aquifer or no clay protection	I	1	2	3	3
	Deep aquifer with clay protection	II	1	2	2	3
	Deep aquifer with significant clay protection	III	1	1	2	2
	No aquifer with hydrological continuity to the area	IV	1	1	2	2
SURFACE RUN-OFF			**High surface run-off**	**Medium surface run-off**	**Low surface run-off**	**No surface run-off**
			IV	**III**	**II**	**I**
Sensitivity to surface water			3	3	2	1

(1) The term *vulnerability* was substitute to the original term *risk* used in table C1 of ISO 16075-1 (2020) to avoid misinterpretation with the *risk levels* used in this document to indicate the combination of likelihood with severity of damage according to Table 13 and Table 14.

Source: ISO 16075-1 (2020)

An example of application of a semi-quantitative methodology for the risk assessment on freshwater resources is illustrated in the Case Study 4: *Water Reuse for Agriculture Irrigation in Alentejo Region, Beja, Portugal* in section 4.5.

3.3.3.2.2 Risk assessment of agronomic hazards

For the assessment of agronomic hazards in soils and crops, a first comparison with reference values could be performed. Reference values of parameters of agronomic concern depend on the local context (e.g., soil type, soil acidity, climate conditions, type of irrigated crops and their tolerance). Applicable legislation and reference standards could help define any maximum allowable concentration on the specific identified hazards. Reference standards can be found in the ISO 16075-1 and some resources are reported in the box.

Box 10. Available information on agronomic hazards

Annex B and C of ISO 16075-1 (2020):

— Overview of soil-related risks (Table B.2) – e.g., mobilisation of inorganic adsorbable pollutants, salinization of soil, slaking of upper soil layer, mobilisation of boron, accumulation, and mobility of phosphorus.

— Examples of maximum levels of nutrients in treated wastewater used for irrigation (Table C.1); example of maximum electrical conductivity of irrigation water, according to plant tolerance, when irrigated by overhead sprinkling (Table C.2); example of relative tolerance of selected crops to foliar injury from saline water applied by overhead sprinklers (Table C.3); combined effect of electrical conductivity of irrigation water and Sodium Adsorption Ratio (SAR) on the likelihood of water infiltration (permeability) problems (Table C.4); example of maximum levels of salinity factors in treated wastewater used for irrigation according to crop sensitivity (Table C.5).

— Example of average value and maximum value of other chemical elements in treated wastewater (Table C.6.): suggested values in reclaimed water that would likely cause toxicity to the plants, excess adsorption by the crops followed by accumulation of toxic levels of other chemical elements in plant tissues, and movement of other chemical elements into the ground water.

Another approach to assess the agronomic hazards is the one proposed in the Australian Guidelines (NRMMC-EPHC-AHMC, 2006) and adapted for these guidelines. In this approach, the environmental risks related to the aforementioned agronomic hazards are assessed using a qualitative approach (Risk = Impact x Likelihood). What follows is a summary of their evaluation to be taken into consideration.

Boron

The observable concentrations of boron in recycled water are unlikely to be high enough to cause direct toxicity to plants through foliar application. However, boron from recycled water irrigation can accumulate in the root zone, if it is not leached out through soil, thus leading to plant toxicity problems.

Chlorine disinfection residuals and by-products

Chlorine is commonly used either for disinfection to reduce pathogen concentrations or to control biofilm growth in distribution systems. However, if chlorine residuals and persistent disinfection by-products (such as chloro-amines and chloro-organics) are not managed appropriately, they may harm terrestrial and aquatic organisms.

Hydraulic logging

Excess application of water to surface soils (hydraulic logging) can result in various on-site and off-site environmental consequences that need to be carefully managed.

Waterlogging makes oxygen less available to plant roots and to other organisms (hypoxia) and causes run-off. Waterlogged plants usually grow very slowly, and roots become very susceptible to infections from disease-causing organisms. Run-off can be a threat to the quality of surface waters if it contains high nutrient loads (see also the respective sections on phosphorus and nitrogen). Excess hydraulic loading can also transfer pollutants to groundwater and surface water run-off.

Nutrients

In addition to being a useful plant nutrient, nitrogen and phosphorus from run-off can enter water bodies and cause excessive growth of algae (eutrophication) in storage dams, lakes, rivers or estuaries. Nitrate nitrogen is mobile in the soil and can leach to groundwater bodies, contaminating them. Such 'off-site' effects of nitrogen are hard to rectify and need careful management. Prevention is the main management goal.

Risks linked to nitrogen that need to be considered when using reclaimed water are:

— Plant nutrient imbalance during irrigation.

— Increased plant pest and disease incidence.

— Eutrophication of surface waters.

— Contamination of groundwater.

Salinity

Salinity is the concentration of soluble salts in water, measured as total dissolved solids (TDS) or electrical conductivity (EC). The environmental risk from salinity is high, due to its effect on plants via increased soil salinity. As water evaporates from soils or is used by plants, salts are left behind. This increases the concentration of salts in the soil with time and influences the amount of water a plant can take up from the soil due to the osmotic effect it creates on root tissues. Moreover, salt leaching through soil can change the quality of groundwater.

Chloride and sodium

Chloride and sodium are the principal elements contributing to salinity. In addition to their role in salinity, which has been addressed above, chloride and sodium may be toxic to plants at high concentrations.

Soil sodicity

Soil sodicity is the accumulation of sodium salt relative to other types of salt cations, especially calcium. An increase in soil pH and decreases in calcium and magnesium usually accompany this process. Sodicity is a complex interaction between physical and chemical properties of soil that can be difficult to manage.

Table 17. Environmental risks associated to the indicated hazards

Environmental hazard	Environmental risk category	Description
Boron	Low	Direct toxicity to plants (foliar application)
		Exposure pathways through cross-connections (because of likely dilution and the likely short duration of cross-connections)
	Moderate to high	Toxicity to plants irrigated with recycled water
Chlorine disinfection residuals	Low	Cross-connections, where recycled water is used for irrigation
	Moderate to high	Irrigation of sensitive crops or plants
Hydraulic logging	Low	Cross-connection (because the recycled water would otherwise be used in other uses, and should be considered in the risk assessment)
	Moderate to high	Waterlogging of soils during irrigation
		Secondary salinity from groundwater rise
		Hydraulic load from leaky storage reservoirs
		Movements of nutrients and salts to groundwater from irrigation
Nitrogen species	Low	Risks from cross-connections
		Direct toxicity to plants
		Unintentional discharges (pipe burst) resulting in nutrient imbalances and groundwater contamination with nitrate
	Moderate to high	Nutrient imbalance in plants
		Increased pest and disease incidence in plants
		Contamination of groundwater
		Eutrophication of storage reservoirs
		Eutrophication of surface waters from run-off of irrigation waters
Phosphorous species	Low	Hazards from cross-connections in pipework (because of dilution and short duration)
		Direct toxicity to plants (at observed concentrations in recycled water), when applied directly to plant foliage
	Moderate to high	Eutrophication of surface waters from irrigation
		Terrestrial eutrophication of bushland from irrigation
		Eutrophication of storage reservoirs
		Toxicity to sensitive native plants from irrigation
Salinity	Low	Unintentional discharges (pipe burst) on to land due to the 'one-off' nature
	Moderate to high	Soil salinity from irrigation
		Salinisation of freshwater aquatic systems
		Cadmium released from soils due to increased chloride salts
		Salt damp or rusting of infrastructure
		Salinisation of groundwater that could affect ecosystems dependent upon this groundwater
Chloride and sodium	Moderate to high	Sodium and chloride toxicity to plant from irrigation and cross-connections
		Chloride toxicity to aquatic biota from irrigation
Soil sodicity	Low	Unintentional discharges (pipe burst), because sodicity is more a chronic than an acute problem, and these are generally short term in nature
	Moderate to high	Irrigation with recycled water
		Cross-connections associated with recycled water

Appendix I reports a table regarding a general environmental risk assessment for agricultural reuse schemes considering those key hazards. Following the approach of the Australian Guidelines, the table distinguishes between a maximum risk, in the absence of preventive measures, and the residual risk once preventive measures have been installed. The maximum risk assessment also helps decide on sampling frequencies and monitoring points in the environment.

3.3.3.2.3 Risk assessment of CECs

Since the reuse of treated wastewater is meant to be an alternative to the use of other irrigational water, coherence with established European and national legislation is needed. The guidance to be provided must define logical further requirements and measures to address potential hazards and to assess the risk levels for groundwater and surface water in particular. Besides, it goes without saying that it is practically impossible to establish threshold values of all potential contaminants found in wastewater. At the same time, it cannot be left to the user to determine representative elements for contaminant groups or concentration levels.

The following approach for the environmental risk assessment for CECs originates in the European Water Acquis. Although the European Water Framework Directive 2000/60/EC establishes a list of Priority Substances, the respective EQS would be too stringent for treated wastewater, considering that the WFD allows for direct discharge of higher concentrations if EQS settings are met after a certain mixing area, the so-called Mixing Zones. They are established near points of discharge in alignment with Directive 2008/105/EC and allow for local exceedance of the EQSs. The same directive refers in this context to the river basin management plans established in accordance with the Water Framework Directive.

For each river basin district, EU countries must set up an inventory of emissions, discharges and losses of all substances listed in Part A of Annex I of the directive. Based on this inventory, a minimum list of chemicals substances to be considered is obtainable for each water reuse system location.

While no European framework for soil protection exist, the European Groundwater Directive 2006/118/EC establishes limit values for "*active substances on pesticides including relevant metabolites, degradation and reaction products*". Single substance shall not exceed 0.1 μg/L and the total sum of compounds shall not exceed 0.50 μg/L. It is suggested to use the same limits for those chemicals identified in the river basin specific inventories and use them as surrogates for the CECs in the environmental risk assessment.

For CECs, it is suggested to follow the qualitative risk assessment on freshwater resources reported in Section 3.4.2.3.1.

3.3.4 Risk assessment outcomes

3.3.4.1 Additional requirements (KRM6)

The outcome of the health and environmental risk assessment will help establish if any **specific additional requirements (KRM6)** for parameters (additional to or stricter than those specified in Section 2 of Annex I) should be added for water quality and monitoring. This could include additional pathogens or pollutants identified by the health and environmental risk assessment taking into account the site-specific conditions, as well as the applicable directives and regulations as described before. For example, the risk assessment could identify that a specific pollutant in reclaimed water (e.g., nitrates) could negatively affect a nearby water body (e.g., by eutrophication) if present in the reclaimed water at higher concentration than the predicted maximum allowable. Therefore, a limit based on the maximum allowable concentration, resulting from the risk assessment, could be established for the reclaimed water quality and the parameter could be included among those to be monitored. The maximum allowable concentrations could also be equal to the required limits, for example, for the specific quality class (e.g., EQS) of the exposed water body. A list of additional parameters, along with the identified limits, could be added for water quality and monitoring, if they originate from the water reuse system and the set-up of their reference values is supported by the risk assessment and by a sufficient degree of scientific knowledge.

3.3.4.2 Preventive measures (KRM7)

KRM7 should include the identification of **preventive measures and barriers** applicable to the water reuse system to remove or reduce to an acceptable level the identified hazards that might lead to a risk. Preventive measures are any treatments, actions or procedures, already implemented or identified during the risk assessment, that can be applied at different parts of the water reuse system: for example at the UWWTP (e.g., by evaluating the process in place and/or by identifying additional treatments), at the reclamation facility (e.g., considering adding advanced treatments), at the irrigated fields (e.g., by considering alternative irrigation methods that minimise risks to exposure, providing buffer zones, etc.), for the workers and farmers (e.g., identifying specific PPE or hygiene protocols, additional to possible measures already taken to comply with health and safety at work rules). The identification of barriers or modifications to the existing irrigation system could be based on the evaluation of existing methods, type of crops and class of water, and should be decided in consultation with the farmers and other actors in the water reuse system.

Table 18 presents a list of preventive measures that could be considered at different parts of a water reuse system in accordance with Articles 5 and 6 and Annex I Section 2 of the Regulation. The examples aim to illustrate the type of analysis required to identify the type and number of preventive measures and barriers, depending on the type of crops and the water quality class, based on international standards and practices. It should be noted that the analysis needs to be performed on a case-by-case basis, considering the specific context, and the examples presented below should therefore not be understood as being automatically applicable to all cases and in every possible circumstance. Additional examples of preventive measures can be found in the case studies.

Table 18. Examples of preventive measures for a water reuse system.

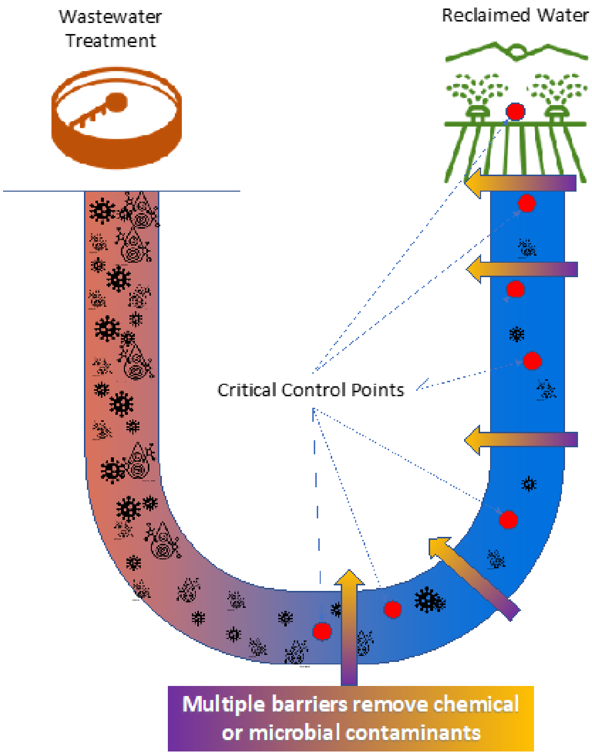
Type of preventive measure	Examples
Protection of urban wastewater sources	- preventing or managing industrial discharges in urban wastewater by ensuring any applicable EU and local legislation are met - protecting stormwater from animal and human waste - controlling type of water discharged into in sewage system (e.g., setting limits)
Additional treatment of the UWWTP effluent	- treatment processes to reduce microbiological and chemical pollutants in the effluent (e.g., additional disinfection or pollutants removal measures)
Protection and maintenance of storage system for reclaimed water	- use of buffer zones - avoid algal growth by minimizing light (e.g., by covering the storage system) - maintaining drainage and sites (e.g., ground cover, nutrient balancing) - backflow prevention and cross-connection control on connected plumbing - chemical treatment to avoid clogging or bacterial regrowth
Control and maintenance of distribution systems and plumbing	- adoption of reclaimed water plumbing codes of practise (e.g., colour coding) - avoid connection of drinking water plumbing to reclaimed water plumbing (e.g., installing air gap or backflow prevention devices)
Specific requirements on irrigation systems (e.g., drip or subsurface, spray, micro-spray) and agricultural field	- establishment of minimum safety distances to reduce human and environmental exposure (e.g., from surface water, including sources for livestock, or activities such as aquaculture, fish farming, shellfish aquaculture, swimming and other aquatic activities) - control of slope inclination, field water saturation and karstic areas - control of clogging of emitters in drip irrigation systems - control of rate of application to minimize impact on receiving environments, including soils, groundwater and surface water (e.g., moisture sensors in soil, determination of water and nutrient balances, mechanisms to reduce impacts from salinity and sodicity) - decrease of the irrigation frequency - control of time of application (e.g., limiting irrigation only at night) - control of environmental conditions during application (e.g., irrigation during low temperature and low windy periods) - control of hydraulic loading and interception drains - specific requirements for sprinkler irrigation (e.g., maximum wind speed, distances between sprinkler and sensitive areas; install systems to minimize production of aerosols in spray and drip irrigation systems) - increase of the rotation speed of the sprinklers - increase of the size of the water drop (decreasing the sprayer degree) - increase of the application volumes (but keeping it lower than the soil infiltration rate) - select the irrigation system where water does not contact foliage (e.g., micro-irrigation systems)
Specific requirements on irrigation of crops	- use of additional barriers - selection of high drought- or quality-tolerant crops (plant breeding)
Control of access and use of signage	- use of fences (e.g., simple railings, security mesh depending on the quality of reclaimed water) - use of signage indicating that water is not suitable for drinking (e.g., reclaimed water — do not drink) or other types of signage (e.g., reclaimed water being used – do not enter when irrigation is in progress) - access control: application methods, rates and times
Protection of workers and farmers	- use of Personal Protective Equipment (PPE) - education and training on hygiene (e.g., frequent handwashing) - education and training on equipment control (e.g., on backflow prevention and cross-connection control, on correct installation of plumbing and appliances, best-practise management)

Sources: Point 7 of Annex II of the Water Reuse Regulation, Box 2.6 and Appendix 3 of Australian Guidelines (NRMMC-EPHC-AHMC, 2006), WHO Guidelines (WHO, 2006a), ISO 16075-2 (ISO, 2020).

3.3.4.3 Barriers

To expand the group of crops that can be irrigated with the different qualities of treated wastewater, the concept of creating (multiple) barriers has been developed (Figure 14). In this approach, a well-trained operations team put in place a series of multiple technical or non-technical barriers used to reduce the total risk from chemical or microbial threats stemming from the reclaimed water. The efficiency and effectiveness of each barrier is then assessed, monitored and controlled at the Critical Control Points (CCP). In agricultural irrigation, more focus is put on microbial risk since chemical hazards are largely controlled at the entry point of the reclamation plant by limit concentration for targeted chemical parameters.

Figure 14. Illustration of the multi barrier approach



These barriers, often situated between the transition of sub-systems or elements, thereof prevent contact between the water used for irrigation and humans who ingest the irrigated food crops or who use the irrigated land or who can inhale aerosols produced during irrigation.

As stated in Section 4.3 of ISO 16075-2, additional barriers that can be set out to minimise microbial contamination of the food produce chain from the reclaimed wastewater could include:

— Further disinfection of the treated water.

— Physical separation or installation of physical barriers (e.g., sun-resistant cover sheet, mulching) between the reclaimed water and the produce.

— Subsurface drip irrigation to avoid capillary action of the reclaimed water ascending to the ground surface.

— Interruption of irrigation practices ahead of harvesting to allow microbial pathogen die-off.

— Crop disinfection after harvesting.

Among the groups of potentially exposed people, particular attention must be given to consumers of products, who ingest the produce deliberately. While the quality of the irrigational water used is an important factor, it is not the only variable that can ensure the health of the consumers of the product irrigated. Certain characteristics of food crops can prevent the ingestion of the microbial pathogens by the consumer, e.g., if a food crop is consumed cooked or after peeling. By considering such characteristics, lower quality water can be used for the irrigation of certain food crops.

The characteristics of crops that can prevent the microbial pathogens from being ingested by the consumer include the following:

— Fruit with an inedible skin (such as citrus fruits, banana, and nuts).

— Crops that are always cooked before consumption (such as potatoes).

— Fruit and cereals undergoing a very high-heat treatment prior to ingestion (such as wheat).

3.3.4.3.1 Types of barriers

FAO/WHO (2019) published a report identifying of risk mitigation options assessing, their qualitative effectiveness for produce irrigated with reclaimed water. The suggested measures represent a simple way to apply the multi-barrier concept also for smaller and medium reuse schemes, even in low-income contexts:

— With a high effectiveness:
  - Change from raw eaten vegetables to boiled ones.
  - Change from overhead irrigation to drip irrigation.

— With a moderate effectiveness:
  - No irrigation before harvesting for at least three days.
  - Peeling fresh produce.
  - Washing salad with running potable water and added sanitizer.

— With an additional, but limited effectiveness:
  - On farm-treatment ponds with 18+ hours sedimentation period.
  - Furrow irrigation.
  - Filtering water before irrigation (e.g., fine sand or biochar).
  - Washing salad with potable water.

These measures are an example of the multi-barrier principle, i.e., the possibility to combine measures even of limited effectiveness if used stand-alone but becoming very powerful if combined.

Following this approach, the following types of barriers are suggested (Table 19).

Table 19. Suggested types of barriers for the irrigation of food crops

Barrier type	**Description**	**Pathogen reduction in Log Units**	**Number of barriers**
Drip irrigation	Drip irrigation of low-growing crops such as 25 cm or more above from the ground	2	1
	Drip irrigation of high-growing crops such as 50 cm or more above from the ground	4	2
	Subsurface drip irrigation where water does not ascend by capillary action to the ground surface	6	3
Spray and sprinkler irrigation	Sprinkler and micro-sprinkler irrigation of low-growing crops such as 25 cm or more from the water jet	2	1
	Sprinkler and micro-sprinkler irrigation of fruit trees such as 50 cm or more from the water jet	4	2
Additional disinfection in field	Low level disinfection	2	1
	High level disinfection	4	2
Sun-resistant cover sheet	In drip irrigation, where the sheet separates the irrigation from the vegetables	2 to 4	1
Pathogen die-off	Die-off support through irrigation cessation or interruption before harvest	0.5 to 2 per day considering crops and weather conditions	1 to 2 considering crops and

			weather conditions
Produce washing before selling to the customers	Washing salad crops, vegetables, and fruits with drinking water	1	1
Produce disinfection before selling to the customers	Washing salad crops, vegetables, and fruits with a weak disinfectant solution and rinsing with drinking water	2	1
Produce peeling	Peeling of fruits and root crops	2	1
Produce cooking	Immersion in boiling water or under high temperature until the product is cooked	6 to 7	3

Source: ISO 16075-2 (adapted)

Table 20. Suggested type of barriers for the irrigation of fodder and seeded crops

Barrier type	**Description**	**Pathogen reduction in Log Units**	**Number of barriers**
Access control	Restricting entry into the irrigated field for 24 h and more after irrigation, for example, animal entering in pastures or entering of field workers	0.5 to 2	1
	Restricting entry into the irrigated field five days and more after irrigation	2 to 4	2
Sun drying of fodder crops	Fodder crops and other crops that are sun-dried and harvested before consumption	2 to 4	2

Source: ISO 16075-2 (ISO, 2020) (adapted)

The barriers outlined above are valid, considering that good agricultural practices are implemented. For example, fruits and vegetables with edible skin should not be recovered from the ground. While there are numerous competing definitions of which method constitute good agricultural practice, there are several broadly accepted schemes that producers can adhere to. These practices specify procedures to be implemented to produce food for consumers or further processing that is safe and wholesome, using sustainable methods. The list of barriers cannot be mapped to specific good practices but need to be evaluated case by case by the water reuse system manager.

A particularity in these considerations are those crops which do not come in contact with the public or are protected from the survival of microorganisms on them as a result of their method of cultivation. These categories can be acceptable for irrigation by all the quality categories of reclaimed water without the use of barriers. The following is a partial list of such crops:

- Industrial crops (such as cotton).
- Sun-dried fruit, if harvested at least 60 d after the last irrigation (e.g., sunflower, corn, chickpea, and wheat).
- Irrigated crops of edible seeds or seeds for sowing which have not been irrigated for 30 days prior to harvesting.
- A grove or vegetation plot without public access.
- Turf or grassland that is not intended for subsequent use for domestic lawns and for which there has been no public access during its cultivation.
- Energy and fibre crops.

Subsurface and drip irrigation systems (considered as barriers) should be designed and implemented in a way that water does not rise to the surface (the detection of water puddles on the surface should disqualify the subsurface drip irrigation system from being considered as a barrier).

According to Table 1, Annex I, Section 2 of the Regulation, a specific crop category shall be irrigated with the corresponding minimum water quality classes. A lower water quality class can be used if appropriate additional barriers are used, which result in achieving the quality requirements of the class for the given crop category.

ISO 16075-2 defines minimal distances between irrigated areas and residential areas according to wastewater quality (Table 21).

Table 21. Distance between irrigated borders and protected areas

Quality of reclaimed water	Radius of throw (m)	Maximum operating pressure (bar)	Distance wetted area and area to be protected (with screen) (m)	Distance wetted area and area to be protected (without screen) (m)
Very high (Class A)	No restrictions			
High quality (Class B)	< 10	≤ 3.5	5	20
	10 – 20	≤ 4.0	10	30
	> 20	≤ 5.5	10	40
Good quality (Class C)	< 10	≤ 3.5	10	40
	10 – 20	≤ 4.0	15	50
	> 20	≤ 5.5	20	60
Medium quality (Class D)	< 10	≤ 3.5	20	50
	10 – 20	≤ 4.0	30	60
	> 20	≤ 5.5	40	70

Source: ISO 16075-2 (adapted)

Appendix B gives examples on how to combine reclaimed water quality classes and accredited barriers for the irrigation of a specific class category according to the recommendations of ISO 16075-2 (2020).

3.4 Module III – monitoring (KRM8 and KRM9)

KRM8 and **KRM9** elements include all the monitoring activities planned for the water reuse system: identification of procedures and protocols for the Quality Control (QC) of the system and for the Environmental Monitoring System (EMS). Operational and environmental monitoring programmes provide assurances to workers, the public and authorities, of adequate system performance. They should include protocols, programmes (e.g., location, parameters, frequency) and procedures for at least the requirements on routine monitoring and any additional parameters and limits as identified as additional requirements by the risk assessment (KRM6). A quality management system, developed according to ISO 9001 standards or equivalent, may also be prepared by the plant operators whenever appropriate. The EMS protocols should be based on the results of the environmental risk assessment to ensure continued protection of the environment when using reclaimed water. Protocols should be in line with other legislation already in place, e.g., water resources monitoring should comply with Directive 90/2009/EC ([8]) to ensure comparison with WFD monitoring results.

3.4.1 Operational and routine monitoring

Sampling and analytical error, as well as the maintenance and calibration of online analysers, need to be taken into consideration in the development of a Quality Assurance (QA) and Quality Control (QC) program. While analytical laboratories typically implement a rigorous internal QA/QC program, it does not replace a monitoring- and operations-based QA/QC program, which can be of benefit in assessing the precision and accuracy of the laboratory protocol. It is important to acknowledge that treated wastewater typically contains contaminant levels that are extremely low, often near the analytical detection limits. Under such conditions, the potential for sampling and analytical errors is high, and a rigorous QA/QC is critically important.

Consideration should be given to using two or more laboratories periodically during the monitoring program to carry out duplicate analyses as a means of assessing laboratory bias with respect to accuracy. Careful consideration should be given to ensuring the sample location is representative and that methods used to sub-sample do not introduce errors. For example, inadequate agitation of the collected sample during sub-sampling can result in particle-associated contaminants being under-represented in the sub-sample.

The QA/QC program should include field/travel blanks, replicate, split, surrogate and spiked samples. The sample bottles should be labelled in such a way as to keep the laboratory "blind" as to the sample source or the identity of duplicate samples. The sampling program should be evaluated in detail by an expert third-party at frequency of not less than every five years.

([8]) Directive 2009/90/EC laying down, pursuant to Directive 2000/60/EC, technical specifications for chemical analysis and monitoring of water status, OJ L 201, 01.08.2009, p.36

Field instruments should be checked frequently following the manufacturer's instructions and operational feedback, and the instrument should be recalibrated, if required. A calibration check should be carried out to determine calibration drift. If the calibration drift exceeds the manufacturer or QA/QC criteria, the amount of drift should be recorded, the readings taken since the last calibration check should be qualified, and the instrument recalibrated. Similarly, calibration checks should be carried out of online instruments using calibrated field instruments and/or calibration-sample analyses. If the calibration drift exceeds the manufacturer or program QA/QC criteria, the online instrument readings should either be adjusted or the instrument recalibrated, as appropriate.

The monitoring program should have a formal QA/QC program including an annual review to ensure each and every step of the sampling and post-sampling process follows documented protocols and that proactive method improvement practices are performed. Field instruments and equipment used should be regularly maintained and calibrated, and maintenance logs should be kept.

Major sampling programs should also have a formal QA/QC Manual that documents all resources, policies and procedures pertinent to that sampling program. The QA/QC Manual should include detailed descriptions of the topics outlined in this section and should clearly define the QA/QC responsibilities of management, supervisory staff, and field samplers.

An example of a Quality Control System applicable to a water reuse system is given for the Case Study 5: *Digital Water City Irrigation Scheme of Peschiera WWTP, Italy – Early Warning System for safe water reuse* at section 4.6.

3.4.1.1 Operational monitoring

Effluents of treated municipal wastewater contain a wide range of naturally occurring and synthetic trace organic and inorganic chemicals, residual nutrients, dissolved solids, and residual heavy metals, as well as pathogens (Drewes and Khan, 2015). The effluent quality is also subject to seasonal and temporal variations and depends on the sewer system itself. Likewise, the water reuse scheme is a complex system, and its components are equally subject to the same variations.

Operational monitoring comprises the establishment of procedures to demonstrate that the control measures are working as intended. This is to verify the intactness and performance of treatment and technical barriers as well as adherence to behavioural rules. It is one of the key characteristics of risk management approaches not only to confirm the water quality as a result of a water treatment but also to monitor the process itself. In water reuse systems, it is particularly important to start at the wastewater system due to high variabilities and high level of microbial and chemical hazards. Parameters and methods detecting unauthorized (industrial) discharge and high variability during meteorological extreme events in wastewater collection system might be advisable.

Operational monitoring should also specify corrective actions for events of non-compliance with specified values (WHO, 2015). The type of operational monitoring depends on the control measures in place and may extend to all types of barriers. Although measuring parameters at control points is a standard way of monitoring, observational monitoring might be useful particularly where suitable analytical capabilities are missing. Audits and visual inspections using checklists and interviews can be beneficial as well and help operators to better understand the functionality of the system as well as background of the risk management process.

Monitoring procedures need to establish parameters and their limits, methods, frequency and responsibilities. The frequency of monitoring needs to be defined in a way to enable rapid response if notable deviations occur and affect quality of water or other products. Ideally, on-line monitoring systems and real time data reporting are used. Grab samples and more complex analysis can be carried out to validate on-line monitoring tools.

Regarding public health protection, microbial water quality analysis is essential. Microbial performance indicators such as *E. coli* and thermotolerant coliforms are typical parameters to monitor water quality. The major concern is that a minimum of 24 hours are required to obtain the results. Total cell count using online flow cytometry for drinking water applications is a new technique which can be used to monitor fluctuations of bacterial numbers in water in real time. In case chlorination is used at any stage, chlorine residual is a parameter which can be easily monitored.

For chemical water quality, the choice of parameters will depend on the site-specific application of regulations, water source and inputs (regulated and not) which can affect it, type of chemicals and technologies used in the treatment processes as well as availability of analytical equipment and expertise.

However, regular and frequent monitoring for every potential chemical substance is not feasible or necessary. Chemical indicators are substances which are likely to be found in water and are representative for a class of chemicals and can be used for assessment of performance of processes. Surrogate parameters such as TOC, VOC, Electrical Conductivity may be suitable for online monitoring of process performance. Methods used for monitoring of performance of treatment steps, such as integrity tests in membrane filtration or DBPs control for chlorination need to be considered for each step.

Non-targeted chemical analysis and effect-based monitoring tools can be advisable to obtain a more comprehensive picture of the site-specific source water characteristics and treatment steps performance and can be applied in longer intervals.

The development and implementation of an appropriate monitoring strategy is a crucial step for the health and environmental safety of water reuse projects. This compliance monitoring is performed usually at the outlet of the wastewater reclamation facility.

The following monitoring objectives are to be addressed:

- Human health protection: monitoring programs include selected microbial indicators at concentrations which depend on health risk (risk of direct contact, risk related to the type of crops, etc.), as well as few other parameters which indicate the reliability of operation of the wastewater treatment (e.g., turbidity, suspended solids, BOD, etc.).
- Prevention of adverse effect on crops: monitored parameters (also named agronomic parameters, include nutrients, soluble salts, sodium, trace elements, etc.).
- Prevention of adverse effects on environment (natural water sources and soil).
- Prevention of clogging of irrigation system (e.g., drip and sprinkler irrigation).

3.4.2 Water sampling and analysis methods

The selection of sampling points to control water quality and treatment performance, named "performance control points" or "critical control points", depends on the type of application and the level of health and environmental risks.

The key water quality control point is located at the outlet of the wastewater reclamation plant. Sampling at the plant outlet follows ISO 5667-4 (ISO, 2016). Treated wastewater is monitored either through grab sampling or composite sampling, depending on the monitored parameters and local regulations. As a rule, suitable monitoring strategies have to verify the performance and integrity of the respective treatment, possibly using parameters which are easy to measure like Oxidation Reduction Potential (ORP), turbidity, conductivity and alike.

Composite samples (for 24 h using refrigerated equipment) are very important for relevant monitoring of physic-chemical parameters as they represent an average quality of reclaimed water. Microbiological parameters, dissolved oxygen, pH and temperature are monitored in grab samples in situ, if possible, during diurnal peak flow. Ideally, dissolved oxygen, pH and temperature are measured online in situ.

Similarly, the sampling frequency of other parameters related to prevention of adverse effects on crops, soils and environment should be adapted to assess the risk associated with sensitive crops and/or sensitive environment (e.g., shallow aquifers used for potable water supply), and/or specific irrigation equipment. The decision about the sampling (composite or grab) for these parameters should also consider the daily variations in raw wastewater. Specific monitoring strategies to target changes in water quality due to rainy conditions are to be considered, too. Such condition might influence not only secondary/biological wastewater treatment but also subsequent treatment steps, like disinfection or particle removal.

As an indication, the sampling of treated wastewater used for irrigation should consider:

- The type of samples depending on the measurement's objective (grab or composite samples, online).
- All samples should be well labelled, indicating the type of water, site location, date, time and other pertinent data.
- Sampling frequency should be defined by water reuse granted permit.
- For the better planning and management of the irrigation scheme, seasonal samples should be taken depending on seasons in the concerned region, in order to obtain representative data on the variation in

water quality, in particular nitrogen and salinity as well as changes during varying weather conditions (dry vs. wet weather periods).

- The baseline monitoring for human health protection should be undertaken by sampling at the outlet of the treatment facility (see ISO 16075-2: 2015). To check the reliability of operation of treatment processes, additional sampling points could be added when necessary, in particular in the case of non-compliance.
- For verification of potential contamination or regrowth in storage reservoirs and/or distribution network, additional control points for sampling can be established as a function of the final use, site location and irrigation method.
- Sampling and handling should be done safely with suitable precaution to avoid disease transmission by means of plastic gloves or using other protection.
- Quality control samples should be collected as part of any routine sampling programme. Sampling and handling of raw wastewater and treated wastewater should follow Table 22.

Table 22. Recommendations for sample preparation and handling

Parameter	Container	Additives	Conservation	Comment
Anions and cations (chloride, sulphate), as well as general physic-chemical parameters (pH, suspended solids, conductivity, turbidity)	1 L HDPE or PP bottles with double caps or self-sealing caps, with or without air	No additive	Dark, 4 °C	Temperature, pH and dissolved oxygen should be measured on site.
Phosphorus and N Kjeldahl	1 L HDPE or PP bottles with double caps or self-sealing caps, with or without air	H_2SO_4 to pH = 2	Dark, 4 °C	
Boron	100 ml HDPE or PP bottles with double caps or self-sealing caps	HNO_3 to pH = 2	Dark, 4 °C	
COD	100 ml HDPE or PP bottles with double caps or self-sealing caps, no air	H2SO4 to pH = 2	Dark, 4 °C	No additive is needed if the samples are analysed within 48 h
BOD	500 ml HDPE or PP bottles with double caps or self-sealing caps, no air	No additive	Dark, 4 °C	Na_2SO_3 should be used for dealing with samples with residual chlorine. Preserve sample and add seed for chlorinated and dechlorinated wastewater samples.
Trace elements and heavy metals	250 ml HDPE or PP bottles with double caps or self-sealing caps, with or without air	HNO_3 to pH = 2	Dark, 4 °C	A special bottle [such as polytetrafluoroethylene (PTFE)] and additive are needed for the analysis of mercury (Hg).
Organic micropollutants	1 L dark glass bottle or PTFE bottle, no air rinsed with organic solvents	Ascorbic acid (1 000 mg L^{-1}) if residual chlorine is present	Dark, 4 °C	
Microbiological parameters (total	1 L to 5 L sterile HDPE or PP bottles	No additive	Dark, 4 °C	Additive of sodium thiosulfate at a well-defined concentration is

Parameter	Container	Additives	Conservation	Comment
and faecal coliforms, helminths, viruses, or other additional microbiological parameters)	with double caps or self-sealing caps bottle, with air			mandatory in presence of residual chlorine and recommended in all cases.

3.4.2.1 Sampling from irrigation system

Water quality should be checked by the end user according to the following procedure. Note that water samples should not be taken when fertigation (fertilization through irrigation) is taking place.

- Turn on the irrigation system until the system operates to full designed pressure and let the system irrigate until the pipe have flushed of all stagnant water from the previous irrigation event.
- Collect a sample from a control filter or from an irrigation emitter (a sprinkler, micro-jet or a dripper).
- The water sample should be collected in bottles as provided or recommended by the analytical laboratory. For bacterial sampling, a sterile bottle should be used. Write all necessary details on a sticker attached to the bottle (name, address, date, location, etc.) and seal the lid.
- Preserve samples according to standard laboratory practice and transport them to an analytical laboratory within the time period recommended for the analysis (see Table 22).

For more information about sampling from an irrigation system, see ISO 5667-10.

3.4.2.2 Sampling from storage reservoir

To evaluate a potential change in the quality of treated wastewater during storage, a sample from the storage reservoir should be taken according to the following procedure.

- It is recommended to take the sample as close as possible to the pumping point.
- Avoid sampling downwind to prevent the collection of floating materials (plant or algae residues) transported by water waves to the downwind side of the storage reservoir.
- Tie an empty bottle to a weight and attach both to a pole.
- Lower the bottle so that the neck is submerged in the storage reservoir to a depth of about 100 mm or 10 cm and fill the bottle.
- Remove the bottle from the storage reservoir, seal it and label the bottle.
- Preserve the sample if required or refer to Table 22 to determine if and what preservative is required. Store the samples and take them to the laboratory within the time period recommended by the analytical laboratory or procedure.

For more information about sampling from a storage reservoir, see ISO 5667-4.

3.4.2.3 Reclaimed water sampling

In order to characterize treated wastewater at the outlet of the plant in order to take into account the fluctuations of WW quality, a composite sample should be taken. Composite sampling should be done within a 24-h duration. A refrigerated automatic sampler should be used.

3.4.3 Monitoring of soil and crops

3.4.3.1 Crop monitoring

Crops irrigated with treated wastewater should be monitored by:

a) visual detection of deficiency or excess of elements, or

b) analysing and examining of any part of a crop.

Laboratory analysis on a leaf or petiole sample is capable of determining toxic ion concentration (chloride, boron, sodium), as well as crop nutrients concentration (nitrogen, phosphorus, potassium and micronutrients).

3.4.3.1.1 Field crops and vegetables

Annual crops should be tested as soon as possible so that results remain relevant to the current crop season.

Frequency of field crops and vegetables monitoring vary with the crop. Samples may be obtained at various times during the growing season. The frequency varies with the crop and the ability to use the data to correct irrigation and fertilization management immediately during the current growing season.

3.4.3.1.2 Perennial crops

For perennial crops, the results obtained in the current season are applicable in determining the fertilization programme for the following season. The concentration of elements in the leaves should be determined by sampling leaves at the time of the year for which there are reference data regarding the optimal concentration expected for the crop. Each crop has its recommended sampling and analysis period. Typically, this period should be close to the fruit harvesting.

Occasionally, a comparative analysis between damaged and healthy leaves can be conducted at any time of the season when there is a visual sign for leaf damage and it is difficult to verify the cause of the damage. In this manner, it is easy to detect the source of the damage. This method should be used due to lack of criteria for normal concentration of elements in crops leaves in a period out of the time recommended for sampling.

Appropriate methods for each crop are described in the respective literature and out-of-scope of this document.

3.4.3.2 Soil monitoring

3.4.3.2.1 Frequency of soil monitoring

The most recommended sampling interval for soil monitoring is 10 years. Higher frequency can be adopted in the case if significant risks of accumulation of one or several trace elements have been identified. In this context, the "Land Use/Cover Area frame statistical Survey Soil" (LUCAS Soil) mentioned before (Box 8) is a reference for data collection.

First sampling during irrigation season should be at the beginning of each irrigation season. Afterwards, the soil should be sampled in the root zone at a frequency according to water quality, soil characteristics, irrigation regime and crop tolerance to salinity. In general, sampling should be more frequent when there is higher salt concentration in the treated wastewater, the soil has higher clay content, large volumes of irrigation water are applied or the crop has lower salt tolerance.

Sampling in soil for trace elements (heavy metals, CECs) should reflect the risk identified during project design (e.g., initial soil and treated wastewater characterization). As mentioned previously, monitoring is a costly process and it is important to design a monitoring program that gives sound information at an affordable cost.

Among the best methods for analysing trace elements from soil extracts is Inductively Coupled Plasma Mass Spectrometry (ICP-MS). However, the extract method and the analytical methods to determine the trace elements would need to adapt to the methods used to set the limit values used locally and according to local regulations.

Trace element accumulation in soils in relation to uptake by plants depends on the chemical forms of elements and their interactions with soil components (e.g., exchangeable, sorbed, organic-bound, carbonate and sulphate forms). Their absorption and accumulation by plants depends on the soil supplying these elements to plant roots, on the rhizosphere environment, and on the characteristics of the plant root system.

Soil pH has been shown to have a significant influence on plant uptake of trace elements because it affects the solubility of trace elements in soils. The pH effect is substantially more consistent than other soil variables such as organic matter content, cation exchange capacity and soil texture. Trace element toxicities to plants are more common in acid soils. Other soil components can also react to prevent trace element movement such as clay, organic matter, hydrous iron and hydrous manganese oxides, organic acids, amino acids, humic and fulvic acids.

The respective sampling procedure must consider the irrigation technology and composite samples of ca. 1 kg should be taken. Samples are stored in appropriate containers avoiding any cross-contamination. Samples should be delivered to the processing laboratory as soon as possible.

3.4.4 Environmental monitoring system

For a monitoring program to be effective and relevant, it needs to address a specific question or hypothesis, which are formulated considering the system assessment and the respective risk assessment (Modules I and II). Typically, the monitoring of the receiving environment focuses on a.) surface water, b.) groundwater and c.) to a lesser extent and only of relevant coastal or transitional water (if relevant). In addition, according to the local regulations in force, specific monitoring of water bodies is required for both drinking water protected areas and sensitive zones.

Applications for irrigation purposes are primarily intended to meet the evapotranspiration requirements, but numerous examples exist that water reuse schemes are also applying reclaimed water in excess, thus contributing to groundwater and/or surface water flows. In principle, this places water reuse in irrigation in the same regulatory context of groundwater recharge and effluent discharge to water bodies.

Because treated wastewater can contain residual levels of contaminants, which can be of concern with respect to the down-gradient extraction of water, a receiving environmental water quality monitoring program is needed. This program will be designed in agreement with the risk identified depending on treated wastewater quality, hydrological and geological context. Based on the treated wastewater characteristics (i.e., for projects with a higher risk level), monitoring plans should be more stringent and adapted to the local conditions of each region.

3.4.4.1 Groundwater sampling

The monitoring of groundwater (network of piezometers, sampling frequency and trigger values) should apply to a scheme with an identified risk on groundwater resources. The number and location of monitoring wells is site-specific and considers the monitoring program objectives and the soil hydraulic conductivity variability. Groundwater sampling stations should be located in monitoring wells within the area irrigated by treated wastewater, as well as immediately up-gradient and down-gradient of the area. The purpose of the up-gradient monitoring wells is to assess the background groundwater quality. A sufficient number of up-gradient wells should be installed to assess the degree of area variability.

The purpose of the monitoring wells located within the irrigation area is to assess “worst-case” water quality conditions, as these stations are more likely to detect contaminant contributions from treated wastewater before those effects may be masked by dilution from other groundwater sources down-gradient. The monitoring wells within the irrigation area also serve as an early warning indicator of potential downstream groundwater impacts. The down-gradient monitoring wells provide verification of the overall water quality impacts of the treated wastewater irrigation that may affect down-gradient groundwater extraction uses. Monitoring plans may be reviewed and the sampling frequency may be decreased when the monitoring results show the absence of impact after a 3-year sampling procedure.

3.4.4.2 Surface water sampling

Surface water sampling stations should be established downstream of the upper hydrological system. The number, location of sampling points and the monitoring program are site-specific. If negative impacts on the surface water due to the irrigation with treated wastewater are detected, a thorough hydrological examination should be conducted to identify the source of contamination. Corrective measures should be applied to prevent further pollution and irrigation should be interrupted when justified. Upon interruption of water reuse, the alternative discharge of reclaimed effluents to water bodies or soil should also be justified.

Monitoring plans may be reviewed and the sampling frequency decreased when monitoring results show the absence of impact after a three-year sampling procedure. For information about surface water sampling, see ISO 5667-6 and ISO 5667-11.

3.5 Module IV – management and coordination (KRM10 and KRM11)

KRM10 and **KRM11** include management, emergencies and communication protocols linked to the elements KRM10 – Emergency Management, and KRM11 – Coordination. These programmes constitute the base of effective communication between the party(ies) responsible for a risk management plan and the actors involved. KRM11 should include protocols on how the information will be communicated between actors, formats and procedures for reporting accidents and emergencies, notification procedures, sources of information and consultation processes.

Management and communication programmes and protocols should be developed for effective communication of procedures as well as results among stakeholders within the team and with the public, during the maintenance of the RMP. These programmes and protocols help in managing the complexity of a RMP and the relation between the different parties involved. Aspects to be defined and described in the communication programmes include information flows, adequate reporting formats, notification procedures, stakeholders' contacts, and availability of information and consultation processes (Almeida *et al.*, 2014).

Communication with all relevant stakeholders and the public is a key element of any supporting program. In water reuse, this step is more essential than in case of, for instance, water safety plans for drinking water, due to the involvement of multiple stakeholders and user groups in the system.

3.5.1 Emergency management

Emergency protocols should be developed based on the risk assessment for a specific water reuse system. Internal and external communication protocols should also be established with the involvement of relevant agencies (e.g., health, environment and other regulatory agencies), given that effective communication plays an important role when managing incidents and emergencies. Table 23 presents a list of events that can lead to emergencies, along with actions needed to deal with them.

Table 23. Examples of events that can lead to emergencies and actions that could be addressed in emergencies and communication protocols

Events	**Actions to be addressed in protocols**	**Note**
- Non-conformity with limits, guideline values and other requirements - Failure of treatment systems (e.g., system failure, incorrect dosage of chemicals, equipment breakdown, mechanical failure, etc.) - Accidental or illegal discharges (e.g., spills in catchments, illegal discharges into collection systems, etc.) - Prolonged power outages - Extreme weather events - Natural disasters (e.g., fire, earthquakes, lightning damage to electrical equipment) - Human actions (e.g., serious error, sabotage, strikes) - Outbreaks of illness leading to increased pathogen on treatment systems - Bio film or algae or microbial re-growth in storages or waterways - Killings of fish or other aquatic life - Crops damaged or destroyed by irrigation with reclaimed water (suspected)	- Define potential incidents and emergencies and document procedures and response plans with the involvement of relevant agencies - Define response actions, including increased monitoring - Define responsibilities and authorities among internal and external actors - Identify alternative water supply in case of emergencies - Train employees and regularly test emergency response plans - Define a protocol to investigate any incidents or emergencies and revise them as necessary - Define communication protocols and strategies (including internal and external communication) - Include a contact list of key responsible parties and authorities with defined responsibilities, including emergency night and week-end shifts.	- Employees should be trained in emergency response and incident protocols - Farmers and other stakeholders should be trained on good practices within water reuse context, especially in emergency response and incident protocols - Regularly reviewing and practising emergency response plans including outside normal working hours (night and weekends). Such activities improve preparedness and provide opportunities to improve the effectiveness of plans before an emergency occurs - Following any incident or emergency, an investigation should be undertaken and all involved staff should be debriefed, to discuss performance and address any issues or concerns to prevent new crises or reduce their effect

Source: Australian Guidelines (NRMMC-EPHC-AHMC, 2006)

Box 11. Available information to develop an emergency response plan

- Wastewater Emergency Response Plan Template Instructions (epa.gov)

- Emergency Response for Drinking Water and Wastewater Utilities | US EPA

3.5.1.1 Surveillance

Surveillance conducted by independent agency is one of the three core components of the WHO`s Safe Drinking Water Framework which goes beyond the Safety Plan Framework. It is essential to include surveillance activities as well as their proper communication as the next step after development of the safety plan in water reuse applications due to generally higher risks of the reuse systems to health and environmental impacts but also sensitivity of water reuse to acceptance, image and reputation. The surveillance activities are basically external periodic reviews of drinking water production at different stages covering the entire system. When it comes to water reuse, the reviews should cover the system at all stages including source water quality and its variability as well as available barriers preventing entering of chemical and microbial hazards into the system. Water quality testing undertaken should be complementary to the water quality testing done within the operational monitoring by the utility, and not replace it. The number of parameters, frequency and locations of testing need to be based on regulations.

The results of surveillance related activities need to be communicated to different stakeholders as well as made publicly accessible. The range of stakeholders includes:

- Utilities or a group of utilities operating the system or part of it.
- Regulatory agencies in case the surveillance activities are done by a non-governmental agency.
- Consumers and all types of other users.
- Non-governmental organizations (e.g., associations of domestic consumers, associations representing the general public).
- Local authorities in case auditing has been done by a centralized Governmental Agency.

3.5.1.2 Training

Activities under this step are to assure that the WRSP operation is framed by clear management procedures. It shall support the development of people's skills and knowledge, and organization's ability and capacity to meet WRSP commitments (WHO, 2016).

Staff training might be required to ensure proper operation and maintenance of installed control measures or operational monitoring. Active involvement in research can be a means of further improving the reuse system.

3.5.1.3 Governance

Challenges related to the management of water reuse systems are presented in Table 24.

Table 24. Challenges and solutions for governance and management of reuse systems

Challenge	Theme
Develop mutual understandings of diverse needs and expectations	Understand water quality requirements
	Understand risk perceptions
	Maintain trust
Define clear roles and responsibilities	Gain clear commitment
	Link procedures
	Streamline rules and regulations
Improve awareness, knowledge and capabilities	Raise awareness
	Increase technical knowledge and understanding
	Improve industry skills and experience
	Enhance decision-making
Use inclusive, collaborative and learning processes to build knowledge and mutual understandings	Informally generate knowledge through risk taking, experimentation and learning by doing
	Formally use different types and levels of engagement to encourage learning

Source: Goodwin et al., (2019)

3.5.1.4 Communication

The reuse of treated wastewater may raise public concerns. Proper planning and decision making on the use of treatment to the required standards will help address these concerns. It is important to engage with the public and other stakeholders in the planning and introduction of systems for water reuse, preferably at an early stage as possible. This helps to create transparency and allows for useful information to be gathered from stakeholders.

The DEMOWARE activities have shown that public acceptance of, or opposition to, water reuse is largely based on (the lack of) public trust in regulation and monitoring, the technical process, the water reuse organisation, and ultimately, the quality and safety of the reused water itself. Different approaches, including stakeholder collaboration, public engagement and information provision, are needed to build trust in water reuse.

Successful implementation of water reuse systems requires broad support. Stakeholder involvement is a key component in creating trust and acceptance. Multi-stakeholder platforms are needed to facilitate early dialogue and engagement when developing water reuse plans. Good practice encompasses multiple levels of public and stakeholder participation, ranging from targeted awareness raising campaigns through to consultation and higher levels of stakeholder involvement in planning and decision- making.

Public education and communication are needed to make people aware of the water cycle, of the need to reuse water, and of the associated benefits of reuse. Informing, raising awareness, and education are key instruments to build public acceptance and trust for water reuse.

The CIS Guidelines on water reuse planning suggest gathering the following information before communication begins:

- The justification of the need for water reuse, e.g., the context of water scarcity, including under future climate conditions.
- The costs of installing treatment and distribution systems.
- The environmental benefits and drawbacks/risks.
- The social and economic benefits and drawbacks/risks.
- Transparency on exposure risks to the public, how these will be addressed and the treatment levels to appropriate standards.

All of these should be analysed within the planning process in order to provide a clear justification for the introduction of the water reuse scheme. An important element of an adequate water reuse communication strategy is to provide objective and comprehensive information through multiple communication channels so as to reach a wide audience. Information should be objective in that it outlines the challenges, possible solutions, and costs and benefits of water reuse in relation to other possible solutions. Next, information on the suitability and value of water reuse itself, working examples of successful water reuse schemes, as well as site visits to existing reuse facilities could increase public exposure and address the stigma around recycled water. Leaflets, brochures and fact sheets are useful means to provide technical information about water recycling. Interactive methods such as focus groups, public exhibitions, demonstration events, trade shows and social media stories allow for an exchange of information, providing operators, regulators and public actors with the opportunity to listen to concerns, learn from each other, and to answer questions and address problems and opportunities in real-time.

The exact framing of water reuse plays a significant role in the formation of public preferences. In this regard, avoiding jargon, acronyms, and unnecessary negative terms is important. The use of a positive, clear and direct language can contribute to the public acceptance of water reuse. Framing reused water as '*being the logical acceleration of a natural process in a world where much of the drinking water is already derived from unplanned reuse*' is an appealing example in this regard.

Educational material and messages about water reuse should wherever possible tap into personal experiences and address water concerns and challenges of the locality, while at the same time recognising global and long-term challenges associated with water scarcity. Therefore, an understanding of the perceptions and concerns of the target audience is a precondition for an effective communication strategy.

3.6 Additional aspects not addressed by the risk management plan

3.6.1 Socio-economic impact assessments (cost, public acceptance, cultural)

Citizen engagement becomes challenging if the many stakeholders involved have an inadequate understanding of their different roles and responsibilities (Goodwill *et al.*, 2019). Societal perception leads to political reality, independently of having or not a scientific basis for its assumptions. The sound management of water reuse schemes must therefore also address communication and citizen engagement while striving for consensus. One main challenge here is to identify ALL stakeholders involved and make them aware about their role and responsibilities in the process. This encompasses those distributing the water as well as the final users, i.e., farmers. Informed knowledge leads to consensus, which in return is necessary for local political acceptance, which ensures a long-term political continuity.

Perception of hazards and risks strongly influence the acceptability of the water reuse schemes. Indeed, Goodwin *et al.* (2019) concluded that integrating stakeholders and affected communities in the risk assessment, control and management may prove to be advantageous. This will help to improve confidence in water reuse practices and the overall risk management.

While it goes beyond the scope of this document, to provide a detailed guidance on the socio-economic impact assessment, it is of pivotal importance to understand the needs and expectations of multiple stakeholders and to satisfy the concerns of reclaimed water users, including the public.

The same is applicable for costs. The level of operating and monitoring costs is related to treatment technology chosen and efforts for verification and operational monitoring requirements and schedules. In the planning and selection of schemes, it must thus be considered how a scheme be economically sustainable, i.e., how cost recovery will be achieved and what is the willingness of potential customers to pay. The socio-economic dimensions to be considered for a water reuse system have been described by Almeida *et al.* (2013) and are shown in Table 25.

Table 25. Socio-economic dimensions to be considered for water reuse systems

Dimension	**Impacts to be considered**
Health	Impact on health of different user groups: consumers of water, employees, consumers of other products of the system – can be characterized as a number of people affected through mortality or disability (through e.g., the DALY concept), or number of people affected by disease
Occupational safety	Impact on safety of employees – characterized through number of injuries
Environmental impact	Impact on water resources, land quality, air quality, flora and fauna, climate change, extent (affected area, duration), vulnerability (protected areas), global warming potential.
Acceptance	Continuity of service (no supply cuts or restrictions) expressed in duration of interruptions or other performance measures, as well as utility functions. Customer satisfaction: An aspiration (taste, odour, colour) concern expressed in number of complaints. Willingness to pay.
Financial and economic	Economic losses expressed as value of lost business opportunities, monetary value of direct costs to utility.
Reputation and image	Impact on image expressed through number of complaints, frequency of negative and positive reports or liability issues.

Source: Almeida et al., (2013)

4 Case studies

4.1 Technical workshops on risk management for agricultural irrigation in Europe

This section presents an overview of the case studies collected during the technical workshops on risk management for agricultural irrigation in Europe, *Case Studies for Water Reuse: Ruggedness Testing of Guidelines,* organized by JRC between May and November 2021. The workshop series aimed at facilitating the discussion on the applicability of the RMP and of the 11 KMR elements listed in the Annex II of the Regulation 741/2020. The case studies presented in a tentative to develop a RMP constitute the basis to collect comments and feedbacks from experts, representatives of MS and stakeholders on technical guidance for the element of the RMP.

The case studies are presented here following the risk management approach proposed in Section 3. The aim is to give examples to the reader on the development of each KRM in different water reuse settings (e.g., hazards identification, risk assessment methodologies, monitoring systems). **It is worth noting that the information presented here are not to be intended as completed or suggested RMPs of each water reuse systems, which are still under elaboration, but developed to propose examples of how each KRM element could be addressed in a specific setting.** For the same reason, not all the KRM elements were addressed for each case study depending on the information available at the time of the workshops. Therefore, each case study will provide examples on specific KRMs.

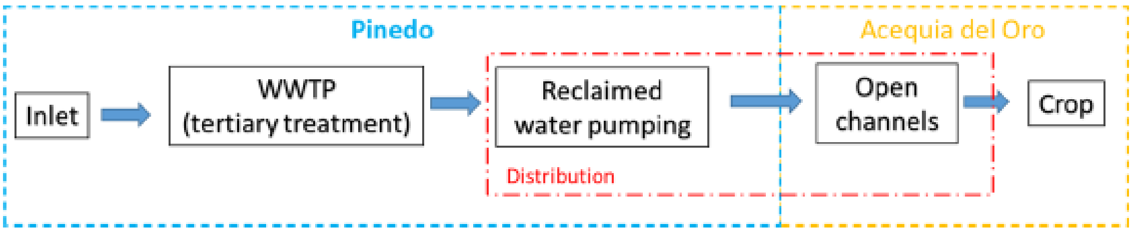
4.2 Case Study 1: Pinedo-Acequia del Or water reuse system, Spain ([9])

MODULE I

System description (KRM1)

The Pinedo-Acequia del Oro water reuse system (Figure CS1.1) is located in Valencia, Spain ([10]). The system is composed by a 1.5 M P.E. biological WWTP (pre-treatment, physicochemical, primary, biological, and secondary treatment) followed by tertiary treatment (physicochemical, sand filtration, UV, chlorination) for the production of reclaimed water that is used to irrigate rice fields (1,200 ha) and vegetables fields (75 ha). The flow of reclaimed water used for irrigation is 15,000 m^3/d during the season September-May, and 180,000 m^3/d between May-September, and it is distributed via a network of 80 km of open channels.

Figure CS1.1. Schematic of the *Pinedo-Acequia del Oro* water reuse system



Parties involved, roles and responsibilities (KRM2)

Information on the roles and responsibilities of the parties involved in this case study is given in Table CS1.1.

Table CS1.1. Roles and responsibilities of parties involved at the *Pinedo-Acequia del Oro* water reuse system

Parties involved	Roles	Responsibilities
Entitat de Sanejament d'Aigües (EPSAR)	Entity for Sanitation of Valencia	Public Sanitation
Temporal Union of Companies (GOMA-SAV-DAM)	WWTP and reclamation facilities operators	Operations of WWTP and reclamation facility Production and supply of reclaimed water Prepare, review and update the RMP for the production, supply and part of the distribution of reclaimed water Comply with the requirements set out in the RMP

([9]) Contributors: María Leal, CEDEX, Spain. maria.leal@cedex.es; Isabel León, CEDEX, Spain. isabel.leon@cedex.es

([10]) Pinedo WWTP and reclamation facility: https://goo.gl/maps/xkEhzTC9dWfjwMUN8; Irrigation community Canal de Riego del Río Turia - Acequia del Oro: https://goo.gl/maps/PGgawhkZ6CAhHg2w5

Parties involved	Roles	Responsibilities
		Coordinate with end-users to ensure correct implementation of the RMP
Irrigation Community Canal de Riego del Río Turia	End-users (farmers)	Preparation of the RMP for the distribution of reclaimed water through open channels and the irrigation of crops along with any updates and revisions Ensure safe irrigation with reclaimed water according to the implementations of identifies measures, barriers and requirements Coordinate with WWTP and reclamation facility operators to ensure correct implementation of the RMP
Jucar River Hydrographic Confederation	Water Authority	Responsible for granting the users permits Control the volume of produced reclaimed water Coordinate activities and measures (users and operators)
Health authorities	Health Authority	Draft a binding report in the user permit procedure
Natural Park of L'Albufera Authorities	Natural Park Protection Authority	Establish additional conditions Ensure implementation of some preventive measures in the user's area

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4)

Hazards and hazardous events were identified for both health and environmental risk assessment. The environments exposed with the use of reclaimed water for agricultural irrigation were identified as shown in Figure CS1.2. Health and environmental hazards and hazardous events, along with the populations and environments exposed and related pathways are presented in Table CS1.2.

Figure CS1.2. Identification of exposed environments at the Pinedo-Acequia del Oro water reuse system

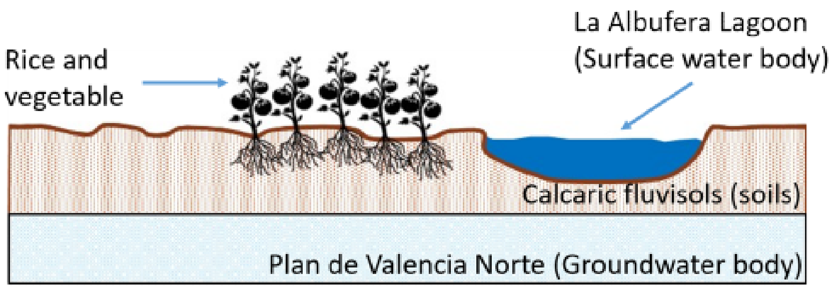


Table CS1.2. Identification of hazards, route of exposure and populations and environment at risk at the Pinedo-Acequia del Oro water reuse system

Hazards		Populations and environments at risk	Routes of exposure
Health Hazards	*E. coli* (Identified from Regulation (UE) 2020/741 and ISO 16075-2:2020. Health authorities involved in the process have not identified any other health hazards.	Local community and by-standers	Ingestion and/or direct skin contact with reclaimed water
		WWTP and reclamation facility workers	Inhalation, ingestion and/or direct skin contact with reclaimed water
		Farmers	Ingestion and/or direct skin contact with reclaimed water
Environmental Hazards (Figure CS1.2)	Boron, chloride, sodium, cadmium, chlorine, salinity, phosphorus and nitrogen (identified considering ISO 16075-1:2020).	Crops (rice and vegetables)	Crops uptakes or direct contact with reclaimed water
		Soil (soil type: calcaric fluvisol, FAO and WRB classifications)	Infiltration in the soil
	Nitrates	Groundwater Plana de Valencia Norte (Code 080.141) – Good status not reached	Infiltration of reclaimed water
	Nutrients (total nitrogen and total phosphorus)	Vulnerable and protected areas: Regional natural park, Flora Micro reserve, Wetlands Catalogue of the Valencian Community,	Run off or infiltration of reclaimed water

Hazards		Populations and environments at risk	Routes of exposure
		Vulnerable zone (regional level), Sensitive area (national level), Site of Community Importance, Special protection area, Wetlands of International Importance (Waterfowl Habitat)	
Hazardous events			
WWTP and reclamation facility: Chemical dosing failures, Inadequate mixing of coagulants/chemicals, overflows, significant flow changes, alarm and/or monitoring system failures, accidental leakages Distribution system: leakage, local community and by-standers access, biofilms and regrowth, build-up of sediments and slimes User zone: Failure of access controls, inadequate education and information about permitted uses, unauthorised use			

Risk assessment (KRM5)

The health risk assessment was conducted by a qualitative method following mainly the ISO 20426:2018 (ISO, 2018) for which the risk is identified by a combination of likelihood and consequences. Table 2 and 3 of ISO 20426:2018 were used as a reference to define, respectively, the likelihood of occurrence of a hazardous event or the exposure to a hazard, and its consequences. For the environmental risk assessment, the matrices from ISO 16075 (ISO, 2020) were used to evaluate the risk of water bodies to be affected by the reclaimed water.

Additional requirements (KRM6)

Additional requirements were set for the environmental hazards that could pose a risk to crops, soil, surface or groundwater, or any of the protected areas (e.g., nitrates, boron, chloride, sodium).

Preventive measures (KRM7)

Information on the preventive measures identified in this case study is given in Table CS1.3.

Table CS1.3. Identification of preventive measures at the Pinedo-Acequia del Oro water reuse system (1)

WWTP and reclamation facility	At end-users (irrigated areas)
Planned cleaning cycles Spare equipment Periodic visual inspections of the facility Equipment maintenance programs Sampling in some critical points Daily control of the used chemicals and reagents On-line monitoring (see Table CS1.4)	Protection system along bike line Periodic check Ensuring the reclaimed water to flow through crops before reaching the Albufera water body to minimize nutrients contribution Farmers training and set up of logbooks to record water source, flow and quality Increasing soil organic contain and improving water infiltration During winter (out of rice seasons) the crop fields are flooded with different water sources from reclaimed water to leach salts and prevent salt accumulation, sodification and infiltration problems Implementation of good practise Implementation of action programs for vulnerable areas

(1) National Park and other authorities control the implementation of effective preventive measures

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

Information on the monitoring system applied in this case study is given in Table CS1.4.

Table CS1.4. Monitoring system set-out at the Pinedo-Acequia del Oro water reuse system (1)

Quality Control System (KRM8)	Environmental Monitoring System (KRM9)
Operational monitoring: pH, EC, redox, SS, DO (online), flows, turbidity, polyelectrolyte dosing, turbidity, colour. Samples and analyses for routine monitoring are carried out by the WWTP and reclamation facilities operator Monitoring of reclaimed water for additional parameters identified for the protection of the environmental receptors (e.g., nitrate, total phosphorus, total nitrogen). EPSAR carries out periodically sampling and analysis in different points of the WWTP and the Reclamation Facility and at the outlet to check and supervise the water quality	Monitoring of soil: soils samples collected every 5 years for analysis of salts and other elements accumulation Surface water and groundwater monitored for: temperature, pH, electrical conductivity, dissolved oxygen, chlorophyll.

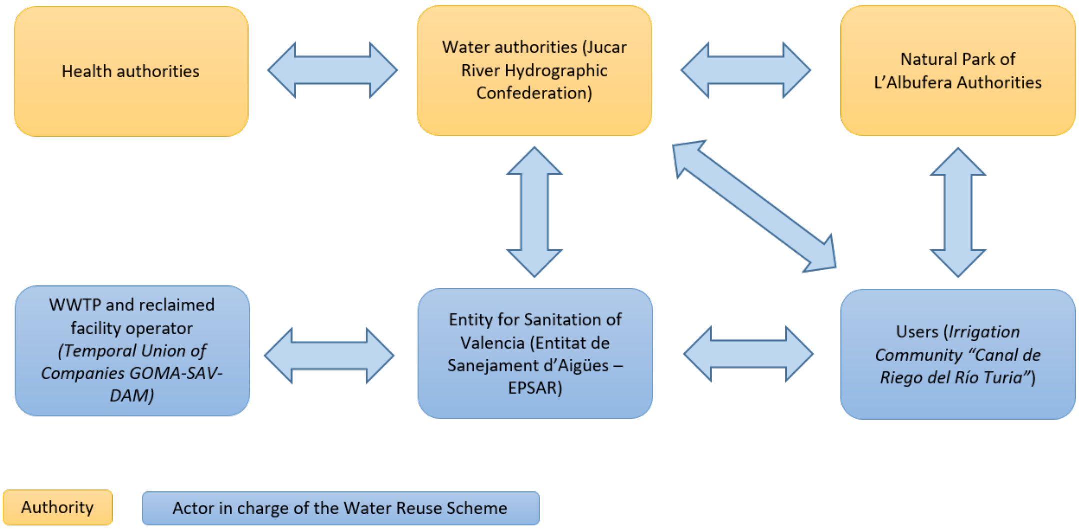
(1) Monitoring systems were used to control the effectiveness of preventive measures in place.

MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

The scheme below (Figure CS1.3) shows the relations among actors in charge of the water reuse system and also Authorities involved in the process of permits.

Figure CS1.3. Examples of coordination among the parties involved



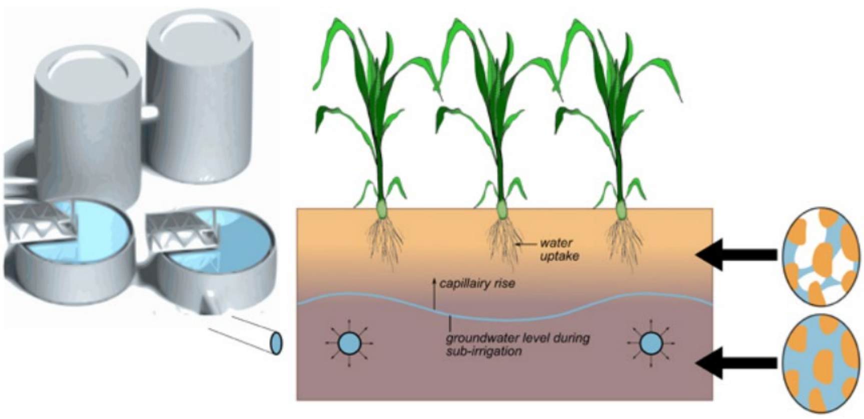
4.3 Case Study 2: Haaksbergen water reuse pilot system, The Netherlands ([11])

MODULE I

System description (KRM1)

The Haaksbergen water reuse pilot system, in operation since 2015, is located at Haaksbergen, the Netherlands ([12]). The area is characterised by Pleistocene sands, with summer groundwater level of approximate 2 m under the soil surface, and increased drought conditions, thus making treated wastewater an alternative available source for irrigation. Under normal operation, the effluent from the Haaksbergen WWTP is discharged into a surface water body (the *Bolscherbeek stream*) that can then be used by farmers for the supply of water for agriculture irrigation (indirect or *de facto* water reuse).

Figure CS2.1. Schematic of the pilot Haaksbergen water reuse system, the Netherlands. Subirrigation by drainage/infiltration pipes and continuous water supply during the growing season raises the water table and the soil moisture conditions.



Source: Bartholomeus et al. (2016)

([11]) Contributor: Ruud P. Bartholomeus, KWR, the Netherlands ruud.bartholomeus@kwrwater.nl

([12]) Haaksbergen WWTP: https://goo.gl/maps/QMSPwdmZEVWjioer5

A pilot system for direct water reuse is set-up at the WWTP for research purposes (Bartholomeus et al., 2016). The system receives the effluent from the secondary treatment of the Haaksbergen sewage plant and directly reuse it via a subsurface irrigation (sub-irrigation) system using a climate adaptive drainage system for the irrigation of crops for animal feed (corn and grass) (Figure CS2.1). With this system, the soil moisture availability to the crops can be increased significantly. The risk assessments focused on the potential effects of the contaminants of emerging concerns, in particular pharmaceuticals, on the root zone of the crops and on the shallow and deeper groundwater.

Parties involved, roles and responsibilities (KRM2)

The parties involved in the management of the pilot project are listed in Table CS2.1.

Table CS2.1. Roles and responsibilities of parties involved at the Haaksbergen water reuse system (1)

Parties involved	Roles	Responsibilities
Water board Vechtstromen	Haaksbergen plant operator	Operations of the Haaksbergen treatment plant Production and supply of reclaimed water
Farmer	End-user	Crop irrigation with reclaimed water
KWR and KnowH2O	Research institutions	Research activities
Not identified authority (no uniform regulation, under development)	Competent authority	Granting the permits

(1) The table refers to the parties involved in the management and not in RMP, which were not identified at the preparation of this guidance document.

MODULE II

Hazards and hazardous events (KRM3), environments and populations at risk (KRM4), risk assessment (KRM5) and additional requirements (KRM6)

The health risk assessment was mainly based on the evaluation of the likelihood of exposure of micropollutants to the crops and the spreading of pollutants in the groundwater system when water is applied through subsurface irrigation. As the soil acts as buffer, direct exposure to any pathogens was not investigated. Chloride-bromide ratio (Cl:Br) was used as tracer to identify the spreading of effluent. Some micropollutants (pharmaceuticals) were selected in the reclaimed water for potential risks on crops, soil and groundwater (Table CS2. 2).

Table CS2.2. Identification of hazards, routes of exposure, and populations and environments at risk at the *Haaksbergen* pilot water reuse system

	Hazards	**Populations and environments at risk (1)**	**Routes of exposure**
Health	Specific health hazards not identified due to limited knowledge on benefits and risks of subsurface irrigation with effluent.	Local community and by-standers	No direct contact since the subirrigation system limits any contact with reclaimed water. Ingestion was excluded, since crops are for animal feed (1)
		WWTP and reclamation facility workers	No direct contact since the subirrigation system limits any contact with reclaimed water.
		Farmers	No direct contact since the subirrigation system limits any contact with reclaimed water.
Environmental	Micropollutants: - Chloride/Bromide (Cl:Br) - Pharmaceuticals (Other specific environmental hazards not identified due to limited knowledge on benefits and risks of subsurface irrigation with effluent.	Crops	Irrigation - limited contact of crops with reclaimed water because the subirrigation system delivers water only at the roots.
		Soil	Infiltration of reclaimed water supplied by sub-irrigation
		Groundwater	Infiltration: no pathway to deeper groundwater was identified due to predominant lateral flow towards Bolscherbeek stream, shallow loam layers (3m-ss) and an impermeable clay layer at 12m-ss.

(1) Even if in this case-study it was specified, consumers wouldn't be considered anyway in RMP, since they are not within the water reuse system boundaries. Accidental ingestion may be considered for farmers and by-standers.

As reported in Table CS2.2, no health risks were identified for the local communities, workers and farmers since the type of sub irrigation system limits any contact of reclaimed water with the group of receptors. Also, no risks were identified for the crops since the sub-irrigation system delivers the water to the root of the crops and the part of the plant growing over the soil is isolated. Additionally, only the root zone directly above irrigation pipes is influenced by effluent; in-between pipes the impact is negligible (while water availability is improved). Regarding the environmental risks, the deeper groundwater is isolated by a clay layer, and infiltrated water is drained laterally by the streams. Given the precipitation surplus and drainage in winter, part of the infiltrated water is removed from the system. However, attention must be paid to persistent and immobile solutes. Although no high risk was identified, additional requirements were set up for the monitoring of the pilot system for Cl:Br and pharmaceuticals necessary also for research purposes (Narain et al., 2020). Scientific publications are being prepared, providing process-based knowledge on the spreading of micropollutants in the groundwater system.

Preventive measures (KRM7)

Other than the treatment units and controls already set up at Haaksbergen plant, the following preventive measures were identified at end-users (irrigated areas) for the management of any risks:

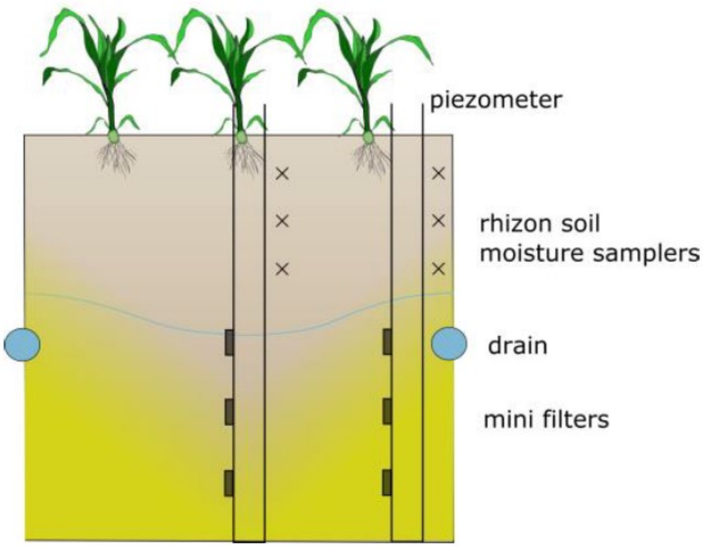
- Ensure correct functionality of the closed sub-irrigation system which avoid direct contact of workers and farmers with reclaimed water.
- Ensure that no plant operators have access to the point of use.
- Ensure that the irrigated crops end use is for animal feed (not for human consumption).
- Ensure that the reclaimed water is supplied from below the root zone to avoid direct contact with crops.
- Use precipitation surplus in winter to discharge (part of) the infiltrated water and 'reset' the system

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

So far, monitoring was implemented for research purposes at the *Haaksbergen* pilot water reuse system, to provide knowledge on required routine controls and quality control (KRM8). Environmental monitoring (KRM9) was performed for Cl:Br as tracer of the effluent, micropollutants / pharmaceuticals 4 times/year, through depth transects in both the unsaturated and saturated zone (Figure CS2.2), next to and in between drainage/infiltration pipes.

Figure CS2.2. Environmental Monitoring System at the Haaksbergen pilot water reuse system



MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

Regular emergency management is set up by water board in case of failure WWTP. Water utility coordinates farmer for water supply/demand and the research institutions (KWR and KnowH2O) for monitoring (KRM 11).

4.4 Case Study 3: Limassol-Amathus water reuse system, Cyprus ([13])

MODULE I

System description (KRM1)

The water reuse system *of Limassol-Amathus* ([14]), located in Limassol, Cyprus ([15]) (Figure CS3.1) and in operation since 1995, is composed by a conventional WWTP (40,000 m^3/d, 272,000 P.E.) with primary, and secondary treatments including the removal of N and P and tertiary treatments (sand filtration and chlorination). The tertiary effluent is reused for multiple uses:

- Irrigation of crops for animal feed, olive trees and citrus trees, as well as green areas. (Irrigation of leafy vegetables and bulbs eaten raw by reclaimed water is not allowed by the local legislation (Cyprus Code of Good Agricultural Practice).
- Recharge of the *Akrotiri Aquifer*, used for irrigation only.
- Stored in the *Polemidia Dam*, used for irrigation only.

Reusing reclaimed water for agricultural purposes is the most beneficial alternative for Cyprus. Over the winter months, the effluent is discharged to the sea with a limitation on nutrients (N, P).

Figure CS3.1. View of the Limassol – Amathus water reuse system (Cyprus)

Parties involved, roles and responsibilities (KRM2)

Information on the roles and responsibilities of the parties involved in this case study is given in Table CS3.1.

Table CS3.1. Roles and responsibilities of parties involved at the Limassol-Amathus water reuse system

Parties involved	Roles	Responsibilities
Water Development Department – Ministry of Agriculture, Rural Development and the Environment – Limassol District Office	Regulatory Authorities	Responsible for the supply of reclaimed water for agricultural irrigation purposes, recharge to Akrotiri Aquifer and storage in Polemidia Dam.
Department of Environment Ministry of Agriculture, Rural Development and the Environment		Granting and control of the discharge permits
Sewerage Board of Limassol – Amathus (SBLA)	WWTP and reclamation facilities operators (public utility organization)	Construction, operation and maintenance of the WWTP facility
Private operator (operator of Sewerage Board of Limassol WWTP)		

([13]) Contributors: Angeliki Larcou Yiannakou, Sanitary Engineer and Eliana Tofa Christidou, Limassol District Engineer, Water Development Department, Ministry of Agriculture Rural Development and the Environment, Cyprus. ayiannakou@wdd.moa.gov.cy, wddlim@wdd.moa.gov.cy

([14]) Water reuse system for Moni WWTP of Limassol-Amathus: https://goo.gl/maps/5DiALAWpVHAbHtxC7

([15]) Link to website: https://www.sbla.com.cy/en/Station

Parties involved	Roles	Responsibilities
Farmers	End-users	Managing irrigation with reclaimed water following the Cyprus Code of Good Agricultural Practice.

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4), risk assessment (KRM5), additional requirements (KRM6)

Quality standards in reclaimed water are set out to ensure the protection of public health and the environment and the effects on soil and crops. Hazards are identified by considering any requirements set out in water and environmental EU directives and regulations and in national and local legislation. The risk assessment does not follow a specific methodology, but any health and environmental risks are minimized by ensuring that the reclaimed water complies with regulatory limits and local quality standards (e.g., the relevant Discharge Permit, General Requirements for the Discharge of Wastewater from WWTPs and the Cyprus Code of Good Agricultural Practice). The General Requirements for the Discharge of Wastewater from WWTPs (Regulatory Administrative Act 379/2015) defines limits for biological and microbiological parameters (BOD_5, COD, SS, FOG, *E. coli*) and their maximum permissible concentrations according to five different categories of irrigated crops. In addition, the Cyprus Code of Good Agricultural Practice provides specific guidelines to be followed in relation to the use of reclaimed water for irrigation purposes such as safety measures for handling the water, the type of plants irrigated and irrigation methods to be used. In addition to the regulatory requirements, health hazards were further screened with the involvement of the Department for Agriculture by testing irrigated crops for specific parameters. Environmental hazards were identified considering the environments surrounding the areas connected to the use of reclaimed water (e.g., groundwater present under the irrigated fields, surface waters in the proximity of the irrigated fields). The management of risks is thus achieved by controlling the correct operations of the preventive measures and irrigation methods in place for the water reuse system and by ensuring an appropriate monitoring of regulated parameters in the reclaimed water and in the environmental compartments (groundwater, soil samples of the irrigated fields). Control of groundwater is based on the requirements set out by the legislation, whereas any hazards and limits in soil samples are determined on a case by case. Additional preventive measures and monitoring requirements are also set out for the control of the acquirer recharge as well as the discharge in Polemidia dam (used only for agricultural irrigation). Identified hazards (pathogens, pollutants) and other parameters monitored are reported in Module III of this case study. Apart from the regular monitoring of the quality of reclaimed water and of the various environmental compartments additional sampling takes place, in cases of possible exceedance of the limits set out for certain parameters, at the point where reclaimed water is given to the end-user or in tanks of the Water Development Department used for storage of the water.

Preventive measures (KRM7)

Preventive measures used to reduce hazards in the reclaimed water are set in the Discharge Permit. The control of the correct functionality of any preventive measures and any corrective actions are also based on the assessment of data collected during the monitoring. The correct implementation and operations of preventive measures in place are controlled by the Water Development Department and the Department of Environment - responsible for controlling compliance with the Discharge Permit.

MODULE III

Quality control (KRM8)

Operational and routine monitoring procedures are in place to ensure that any hazard in the reclaimed water complies with the regulatory limits and any other parameters are controlled to ensure that the preventive measures in the whole water reuse system are functioning properly. Number and type of parameters and frequency of monitoring is based on the specific end use of the reclaimed water (discharged, reused for irrigation, reused for aquifer recharge or storage in Polemidia dam) (Table CS3.2). Operations are controlled via a computer-based SCADA (supervisory control and data acquisition system) which provides a centralized overview of all the treatment plant's functions allowing the changing of process variables locally, centrally or remotely.

Table CS3.2. Operational and routine monitoring in the reclaimed water based on the final use.

Final use of reclaimed water	Parameters (1)	Frequency
For agricultural irrigation of crops,	pH, conductivity, BOD_5, COD, SS, TN, TP, *E. coli*, free Chlorine, FOG, Cl, B	Every 3 months
	Pb, Cd, Hg, Zn, Cu, Cr, Ni	Every 6 months

Final use of reclaimed water	Parameters (1)	Frequency
orchard and bulbs not eaten raw (2)	Toxicity (Acute toxicity: MicroTox, Daphnia, Algae)	Every 12 months
	Chloropyrifos, Dieldrin, Aldrin, Naphtalene, Diuron	Two times per year (January and February)
For Akrotiri Aquifer recharge	pH, conductivity, BOD_5, COD, SS, *E. coli*, free Chlorine, FOG, TP	Before the recharge and every 15 days during the recharge operations
	Active substances in pesticides (including their relevant metabolites, degradation and reaction products), Trichloroethylene, Tetrachloroethylene	Before the recharge and one time during the recharge period
	Cl, NO_3, NO_2, SO_4, NH_4, As, Pb, Cd, Hg, Zn, Cu, Cr, Ni, B Toxicity (Acute toxicity: MicroTox, Daphnia, Algae)	Before the recharge and two times during the recharge period
	Chloropyrifos, Dieldrin, Aldrin, Naphtalene, Diuron	Two times per year (January and February)
For storage in the Polemida Dam (3)	pH, conductivity, BOD_5, COD, SS, TN, TP, *E. coli*, free Chlorine, FOG	Before the discharge in the dam and every 15 days during the discharge period
	Pb, Cd, Hg, Zn, Cu, Cr, Ni, B	Before the discharge in the dam and one time during the discharge period
	Toxicity (Acute toxicity: MicroTox, Daphnia, Algae)	Before the discharge in the dam and four times during the discharge period
	As, Al, Be, Co, Fe, Li, Mn, Mo, Se, V,	Before the discharge in the dam and one time during the discharge period
	Chloropyrifos, Dieldrin, Aldrin, Naphthalene, Diuron	Two times per year (January and February)

(1) Selected considering Environmental Directives (e.g., GWD, 91/414/EEC and Directive 98/8/EC) and national legislation. Monitoring systems includes any hazards in the reclaimed water identified to control health and environmental risks.

(2) Irrigation of crops to be eaten raw, such as leafy vegetables and root crops, is not allowed as defined in the Code of Good Agricultural Practice.

(3) Parameters and threshold values used for the monitoring of reclaimed water discharged for storage in Polemidia Dam aim not to further deteriorate the quality of the water body.

Environmental monitoring system (KRM9)

In addition to the monitoring of specific parameters and contaminants in the reclaimed water, additional samples are collected from the environmental compartments potentially connected to the reuse for the control of the surrounding environments (Table CS3.3). Samples are collected from the *Akrotiri Aquifer* and the *Polemidia Dam* and analysed for specific monitoring parameters and from other groundwater bodies present in the irrigated areas and from the soil of the irrigated fields. In relation to the monitoring of groundwater bodies in the irrigated area, maximum concentration levels for certain contaminants were included in the Discharge Permit that were set up for the exact particular area based on the use of water and soil background.

Table CS3.3. Monitoring protocols in the environmental compartments

Environmental compartment	Parameters	Note
Groundwater bodies in the irrigated area (1)	Conductivity, TN, TP, Active substances in pesticides (including their relevant metabolites and degradation and reaction products), Trichloroethylene, Tetrachloroethylene, Cl, NO_3, NO_2, SO_4, NH_4, As, Pb, Cd, Hg, Zn, Cu, Cr, Ni, B	Analysis one time per year (September to October)
Soil of irrigated fields (2)	pH, Exchangeable Sodium Percentage, water content, Pb, Cd, Hg, Zn, Cu, Cr, Ni, Sb, Ti, As, Ba, Co, V, TN, TP, PAHs, Benzo(a)pyrene, Anthracene, Benzo(ghi)perylene, Naphthalene, Benzo(k)fluoranthene, Indeno(123-cd)Pyrene, Benzo(a)Anthracene, Chrysene, Fluoranthene,	Analysis of 3 representative soil samples formed by a composite sample of at least 10 points. Frequency: every 1 year.

Environmental compartment	Parameters	Note
	Phenanthrene, Trichloromethane, Chloride compounds as a total Cl, Phenols.	
Akrotiri Aquifer (3)	Conductivity, BOD_5, COD, TN, TP, Active substances in pesticides (including their relevant metabolites, degradation and reaction products), Trichloroethylene, Tetrachloroethylene, Cl, NO_3, NO_2, SO_4, NH_4, As, Pb, Cd, Hg, Zn, Cu, Cr, Ni, B.	Frequency: 1 time before, 2 times during and 1 time after the recharging operations. Sample points: 1 borehole upgradient and 4 boreholes downgradient of the recharge points.
Polemidia Dam water (4)	Conductivity, BOD_5, COD, DO, *E. coli*, TN, TP, NO_3, NO_2, PO_4, Ni, Chloropyrifos, Dieldrin, Aldrin, Naphtalene, Diuron	Before, during and after the discharge period.

(1) Parameters selected considering the Groundwater Directive 2006/118/EC
(2) Selection of parameters were not based on standard threshold values, but evaluated on a case by case
(3) Parameters selected considering the Groundwater Directive 2006/118/EC
(4) Parameters as defined in the Discharge Permit evaluated for this particular case, considering also the parameters used for monitoring of surface water status according to the Water Framework Directive and the Priority Substances Directive

MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

Emergency management and coordination plan between the involved parties are defined. In particular, an Action Plan for the management of reclaimed water of Limassol-Amathus for the system run by the Water Development Department, from the delivery point of WWTP at Moni up to the discharge points, is applied aiming at:

1. The taking of decisions in relation to the proper management of the available reclaimed water including the cases of malfunction and/or exceedance of the limits set out for certain parameters in the Discharge Permit.
2. The monitoring of the various environmental compartments (groundwater bodies and Akrotiri Aquifer, soil of irrigated fields, surface water of Polemidia Dam) and of the impact the use of reclaimed water has on them.
3. Daily and timely update of the involved personnel of Water Development Department on the reclaimed water quality and prediction of possible exceedance of the limits for the various parameters.

This plan includes primary, visual checks like colour, odour, surface foaming etc., as well as the sampling procedures and analyses of the water to all the points of interest of the system.

For the implementation of the Action Plan for the management of reclaimed water of Limassol-Amathus, personnel of the Water Development Department (Limassol District Office and the Wastewater and Reuse Division) including scientific and technical officers and inspector is involved. The Sewerage Board of Limassol-Amathus is in close cooperation with the Water Development Department.

4.5 Case Study 4: water reuse for agricultural irrigation in Alentejo Region, Beja, Portugal (16)

MODULE I

System description (KRM1)

The water reuse system ApR "Production of Water for Reuse" is a pilot irrigation scheme located in the Alentejo Region, Portugal, treating the effluent from the Beja WWTP (4,830 m^3/d; 32,750 PE). A flow of 5 m^3/d is diverted from the Beja plant and further treated in the pilot system by filtration and UV/solar disinfection and reused to drip irrigate pomegranates trees for use in the cosmetic industry (Figure CS4.1). Based on the type of crops and irrigation method, a reclaimed water quality class D was selected from the (EU) Water Reuse Regulation 741/2020. The pilot study was used to develop and test a methodology for risk management plan according to the Annex II of the WR Regulation and to the Portuguese Regulation on water reuse for irrigation (Decree-Law 119/2019, 21/08) (17), following a fit-for-purpose approach. Along with the health risk assessment and the

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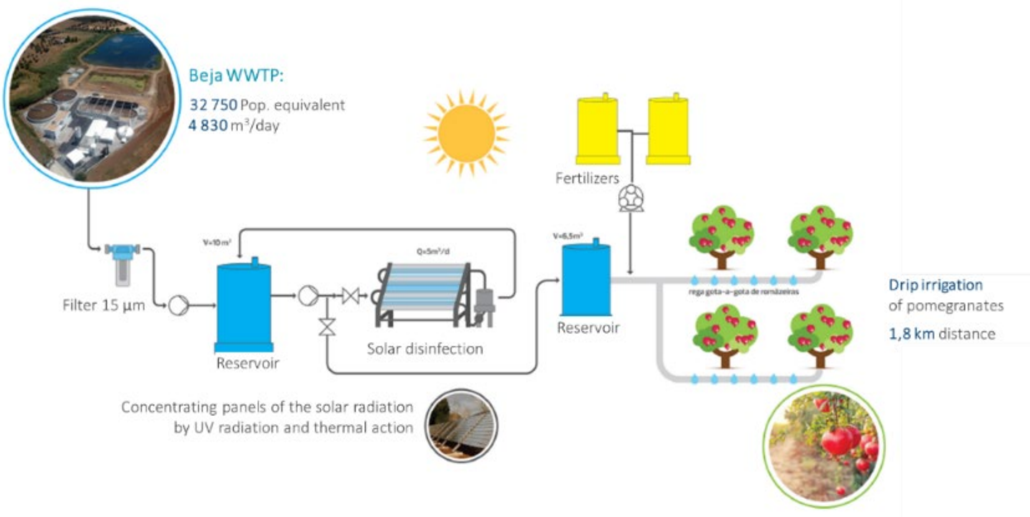
(17) Available at: https://files.dre.pt/1s/2019/08/15900/0002100044.pdf

environmental risks on water bodies, the pilot system was used for additional research activities which included: analysis on the growth of irrigated crops, evaluations on savings of fertilizers dosage by reusing reclaimed water rich in nutrients, any effects on soils and crops.

Figure CS4.1. Schematic of the Water Reuse pilot system in Alentejo Region, Beja, Portugal.



Parties involved, roles and responsibilities (KRM2)

The actors involved in the Risk Management Plan, along with their roles and responsibilities are presented in Table CS4.1. According to the Portuguese legislation on water reuse (Decree-Law 119/2019, 21/08), the environment authority (Portuguese Environmental Agency) grants two permits: one for the production of reclaimed water (which is equal to the permit defined in the Regulation (EU) 2020/741), and a permit for the use of reclaimed water (which is optional in the Regulation (EU) 2020/741), and for both is mandatory a formal opinion from health and agriculture authorities. The Portuguese Decree-Law requires that a risk assessment is done for the production of the reclaimed water until the point of delivery. The point of delivery coincides with the Point of Compliance as intended in the Regulation (EU) 741/2020 (Art. 3(11)) ([18]). From the point of delivery to the point of application (end-use), a second risk assessment is required for the granting of the permits to the end users. According to the Portuguese Decree Law, the risk assessment for the production of reclaimed water is responsibility of the reclamation plant manager, while the end-user assumes the responsibility for the process from the point of compliance until the application point. However, under agreement between these parties, the two risk assessments can be merged in one, namely for new water reuse systems.
Information on the roles and responsibilities of the parties involved in this case study is given in Table CS4.1.

Table CS4.1. Roles and responsibilities of parties involved of the *ApR* water reuse pilot system in Beja, Portugal

Parties involved	**Roles**	**Responsibilities**
AdP Valor	Project Leader	Development of risk assessment until the point of compliance [1] and to the point of application
Aguas Publicas do Alentejo (AdP Group enterprise)	Water Reclamation facility operator (producer of the reclaimed water).	Responsible for the operation of the reclamation facility. Responsible for the risk assessment up to the point of compliance (point of delivery).
Farmers	End-user. Producer of pomegranates	Irrigation of pomegranates. Responsible for the risk assessment and management after the point of compliance to the point of application of reclaimed water.

([18]) NB: According to Article 3 (11) of the Regulation (EU) 2020/74, the Point of Compliance is the point where a reclamation facility operator delivers the reclaimed water to the next actor in the chain.

Parties involved	Roles	Responsibilities
Portuguese Environment Agency (APA)	Permitting Authority	Validation of risk assessment and risk management and definition of risk management measures (preventive measures and multi-barriers). Granting of the permits.
ARS, Regional Health Administration	Health Authority	Provide mandatory formal opinion on risk assessment and management.
Regional Agriculture Directorate	Agriculture Authority	Provide mandatory formal opinion on risk assessment and management.
ERSAR	Water and waste services regulation authority	Responsible for the protection of the users' and consumers' interest by promoting the quality of service provided by operators
IGAMAOT	Environmental and Agricultural inspections	Conducting inspection activities on the environmental matrices and agriculture.

([1]) In the Portuguese legislation the Point of Delivery is equal to the Point of Compliance of the Regulation (EU) 2020/741. In this pilot study the project leader developed a single risk assessment for the whole project (until the end-use site) under agreement of both parts.

Other actors were involved in the project to support the activities related to the pilot study REUSE, such as: the *School of Agriculture (ISA) of Lisbon University*, which conducted studies on agronomic aspects; the *Operative Centre for Irrigation Technologies (COTR)*, which benchmarked the environmental and economic performance of the water reuse with the use of freshwater; EDIA, the *Responsible Company for the Alqueva Multipurpose Project*, which dealt with project promotion and communication.

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4), risk assessment (KRM5)

The risk management applied to this case study followed the methodology presented in Figure CS4.2 according to the methodology presented in the APA Guidelines for the reuse of reclaimed water in agricultural irrigation (APA, 2019). Hazards, populations and environments at risks, and route of exposures were identified as shown in Table CS4.2. Risks were assessed by using a semi-quantitative methodology (Rebelo et al., 2020). Likelihood of hazards/hazardous events and consequences/damage were assessed using Table 2 and 3 of ISO 20426:2018. For the environmental risk assessment, the matrices from ISO 16075:2020 were used to evaluate the vulnerability of water bodies affected by the use of reclaimed water. In both health and environmental risk assessments, the levels of likelihood and levels of consequences were identified by applying numerical formulas and assigning a numerical value, named "importance factor", varying from 1 to 9. The methodology also considered the probability of failures of any barriers in place to determine the damage (consequences). Number of equivalent barriers were identified according to the ISO 16075-2:2020. The probability of barrier failure at the receptors and their severity of damage from failure were evaluated according to the ISO 20426:2018 in a time frame within the validity of the permit with an empirical assessment based on the field experience. For instance, the total damage from the several barriers failure was determined by the formula:

$$Damage = \frac{\sum(d_i \, x \, n)}{f_{normalization}}$$

$$f_{normalization} = f_{i,max} \, x \, n$$

Where n is the number of barriers (evaluated according by ISO 16075-2:2015 or assumed equal to 1 for the barriers not listed), and d is damage from failure applicable to each barrier in place (obtained by a matrix adapted from the one described on the ISO 20426:2018).

Figure CS4.2. Risk management methodology applied at the Water Reuse pilot system in Alentejo Region, Beja, Portugal.

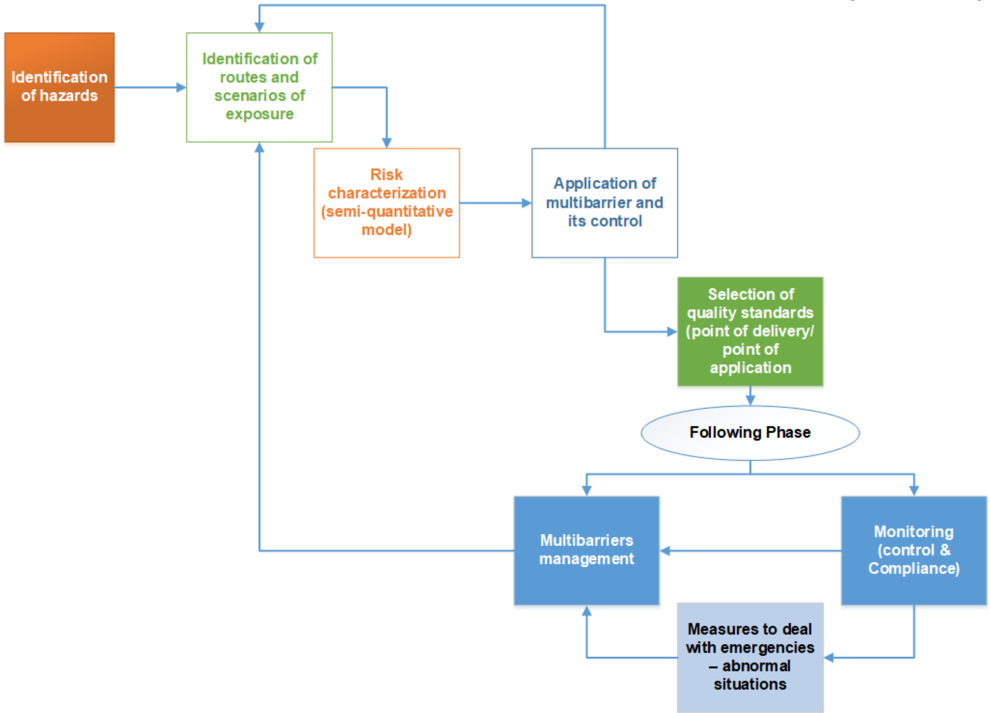


Table CS4.2. Identification of hazards, routes of exposure and populations and environments at risk at the Water Reuse pilot System in Beja, Portugal.

Hazards		**Populations or environments at risk**	**Routes of exposure** [1]
Health Hazards	*E. coli* (Identified by considering microbiological content in the wastewater)	At the reclamation facility: - Workers - Dog (as a way of transfer)	Ingestion (intentional and non-intentional) of reclaimed water Dermal absorption by direct contact with reclaimed water through direct and indirect pathways
		Along the distribution system: - workers - neighbours	
		At the storage system: - end-use site workers - neighbours	
		At the irrigation system: - end-use site workers - neighbours	
Environmental Hazards	Nutrients (N, P) Priority pollutants (Selected using the Combined Approach from the WFD)	Surface water (status: good)	Run-off
		Groundwater (within an area vulnerable to nitrates. Status: poor, due to nitrates)	Infiltration/Percolation

([1]) The exposure was evaluated under different scenarios: intentional or unintentional (e.g., due to accidents, treatment failure or damages), direct or indirect (e.g., through contact with vegetation, soil, clothes or equipment).

Health Risk Assessment

Health risks were assessed for each population exposed (single receptor) by applying the following formula:

$$R_{Receptor} = Hazard\ x\ Vulnerability_{Receptor}\ x\ Damage$$

Global risk for the water reuse system was then calculated by applying:

$$R_{Global} = \frac{\sum R_{Receptor}}{N_{Receptor}}$$

Based on the results, risk was classified as:

— Despicable Risk if R < 3

— Acceptable Risk if 3 ≥ R < 7

— Unacceptable Risk if Risk ≥ 7

This importance factor (assigned to account and identify the levels of hazards, vulnerability of receptors and damages) was assigned by considering several aspects: initial concentration of contaminants, disinfection treatment level, presence of safety measures and PPE, existence of training and communication plan, knowledge, previous experience, etc. For example, the importance factor for the hazard *E. coli* was assigned considering its initial concentration in wastewater and treatment level. Regarding the route of exposure, an importance factor of 9 (highest) was assigned to ingestion due to severe effect on health, whereas skin contact was linked to a lower impact factor (3) considering that the effect on the health and infections data were moderate. By applying this methodology, a health global risk = 1.31 was calculated for the ApR ([19]) water reuse system (despicable risk).

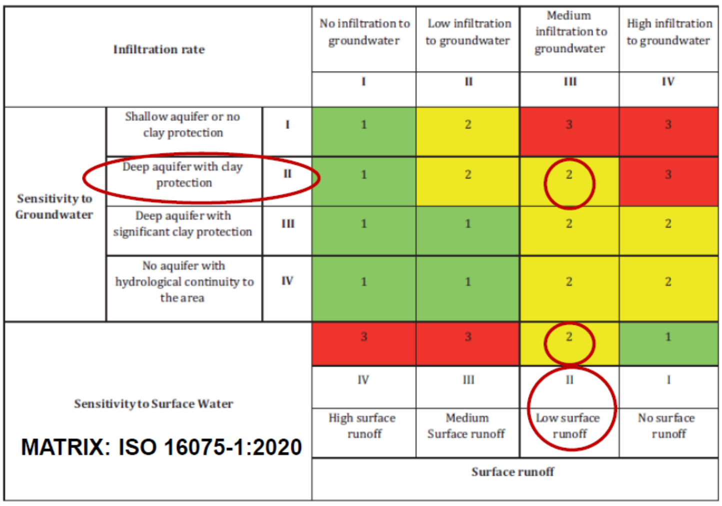
Environmental Risk Assessment:
For the environmental risk assessment, the vulnerability of groundwater and surface water was assigned considering the Hydrogeological characteristics of the area and considering the matrix from ISO 16075-1: 2020 (Figure CS4.3). The total vulnerability for both surface water and groundwater (identified as environments at risk) were calculated by considering the following formula:

$$V_{WR} = vp_{SW} x fp_{SW} + vp_{GW} x fp_{GW}$$

Where:
V_{WR} is the vulnerability of the water resources.
vp_{GW} is the partial vulnerability of groundwater.
fp_{SW} is a partial ponderation factor (fp_{SW}=vp_{SW} / (vp_{SW} + vp_{GW}).
vp_{SW} is the partial vulnerability of surface water.
fp_{GW} is a partial ponderation factor (fp_{GW}=vp_{GW} / (vp_{SW} W + vp_{GW}).

An importance factor of 9 was assigned to the hazards N, P due to the absence of treatments at the reclamation facility for their removal. The risk assessment result would indicate if treatment was needed. Likelihood of occurrence and severity of damage for the freshwater resources were evaluated considering the matrix from ISO 20426:2018 (Figure CS4.3) and taking into account the failure of any barriers.

Figure CS4.3. Matrix for sensitivity to surface water and groundwater.



Source: ISO 20426:2018

([19]) ApR (Portuguese Acronym of Water for Reuse)

Global vulnerability and global damage were calculated, respectively, by:

$$V_{global} = V_{WR} \frac{\sum fi_{barrier}}{f_{max} \; x \; n_{scen}}$$

$$D_{global} = \frac{\sum(di \; x \; n_{scen})}{f_{max} \; x \; n_{scen}}$$

The levels for the severity of damage were assigned considering the initial status of surface water (good status) and groundwater (status less than good) and the likelihood of contamination pathways (demonstrated, likely, possible).
Risks for N and P resulted equal to 2.16, corresponding to a despicable risk. Thus, no additional removal of N/P was identified.
Chemicals were excluded from the environmental risk assessment because not relevant presence was determined in the treated water. The wastewater plant is a typical urban system without industrial wastewater connections to the network.

Preventive measures (KRM7)

Based on the results of the risk assessment, preventive measures, barriers and appropriate monitoring programs were developed to reduce and manage any identified risks. The risks were then re-assessed considering the measures in place to verify their effectiveness and the assessment was repeated until the required residual risk levels were reached. The preventive measures were determined for each identified scenario (e.g., unintended, accidental) and, in addition to water treatment and barriers, also included: use of PPE, training, control of leakages, control of animal access, operational procedures, monitoring protocols, equipment maintenance procedure, and the development of an emergency plan.

MODULE III

Monitoring programs were developed for the operational and routine monitoring, quality control system, and the environmental monitoring.

Quality control (KRM8)

Table CS4.3 gives an example of the quality control system based on the identification of critical control points along the water reuse system, the parameters or item checked, the frequency of analysis and any specific corrective action.

Table CS4.3. Example of a Quality Control System protocol at the Beja Pilot water reuse system, Portugal

Critical Control Point position	Parameter/Item checked	Critical limit	Frequency	Method of measurement/assessment	Corrective action
Entry to UV disinfection	UV Intensity (Wh/m^2)	-	Daily	By WWTP meter	Adjust according to UV radiation intensity
Recirculation tank	Faecal coliforms (MPN/100 mL)	10,000	Weekly	Lab analysis	Increase recirculation/contact time/reduce volume
	E. coli (CFU/100mL)	10,000	Weekly	Lab analysis	Increase recirculation/contact time/reduce volume
	Contact time (h)	6-8	Daily	Calculation from volume	Adjust according to UV radiation intensity and log reduction target
	Temperature (°C)	38-40	Daily	By WWTP meter	Adjust recirculation/contact time
Outlet from disinfection	Faecal coliforms (MPN/100 mL)	10000	Weekly	Lab analysis	Stop supply of reclaimed water
	E. coli (CFU/100mL)	10000	Weekly	Lab analysis	Stop supply of reclaimed water
	Temperature (°C)	38-40	Daily	By WWTP meter	Adjust recirculation/contact time

Storage tank	Faecal coliforms (MPN/100 mL)	10,000	Weekly	Lab analysis	Stop supply of reclaimed water, discharge the water and clean the storage tank
	E. coli (CFU/100mL)	10,000	Weekly	Lab analysis	Stop supply of reclaimed water, discharge the water and clean the storage tank
	TSS (mg/L)	35	Weekly	Lab analysis	Stop supply of reclaimed water, discharge the water and clean the storage tank
Irrigation system	Pipe integrity	-	Every 3 months	Visually	Stop supplying the reclaimed water and repair the damaged pipe
Irrigation system	Pipe integrity	-	daily	By comparing the level in the storage tank with the reclaimed water volume pumped	Detection of leakage point, stop supplying the reclaimed water and repair the damaged pipe

Operational monitoring of reclaimed water was planned considering monitoring requirements from the EU regulation for Reclaimed Water Quality Class D, any additional requirements identified from the risk assessment for key environmental hazards for soil and crops, any additional site-specific parameters considering the ISO 16075 part I-II and set-out by the Portuguese legislation (Table CS4.4). Other samples were collected for research purposes: influent, effluent from disinfection, at the point of delivery, at the point of compliance and soil samples. Crops were not subjected to monitoring at the first stage of the pilot project.

Table CS4.4. Example of operational and routine monitoring protocol at the Beja Pilot water reuse system, Portugal

Sampling point	Parameter	Frequency
WWTP effluent	*E. coli*	Twice/week
	TSS, BOD, N, P, pH, turbidity, Faecal coliforms, worm eggs	Once/week
	Cl, NO_3, NH_4, salinity, SO_4	Once/week
	SAR, Na, O&G, HCO_3, CO_3, Mg, B, Fe, Zn, Ni, Cu, Cr, Cd, Pb	Once/month
	Hg	Once/year
Entry point to the recirculation tank (exit from filter)	Turbidity, TSS	Once/week
Exit from the solar disinfection system	*E. coli*	Twice/week
	TSS, turbidity, COD, faecal coliforms, worm eggs	Once/week
Exit from the UV/solar system	*E. coli*	Twice/week
	TSS, turbidity, COD, faecal coliforms, worm eggs	Once/week
	BOD, N, P, SAR, salinity, Cl, NO_3, NH_4, SO_4	Once/month
Exit from storage tank (point of compliance)	*E. coli*	Once/week
	TSS, faecal coliform, worm eggs	Once/week
	BOD, COD, N, P, SAR, pH, turbidity, Cl, NO_3, NH_4, salinity, SO_4, Na, HCO_3, CO_3, Mg, B, Fe	Once/month
	Zn, Ni, Cu, Cr, Cd, Pb	Bi-monthly

Environmental monitoring system (KRM9)

An environmental monitoring system was set out based on the results of the risk assessment for the surface water and groundwater (Table CS4.5). Soil and crops monitoring was not considered for the RMP. Soil parameters were monitored for research activities.

Table CS4.5. Environmental Monitoring System at the Beja Pilot water reuse system, Portugal

Environmental compartment	Parameter	Frequency
Surface and groundwater	SAR, Ca, pH, salinity, NaCl, NO_3, alkalinity, Mg, faecal coliforms, *E. coli*, worm eggs, Fe, B	Twice/year

MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

Any major emergencies or incidents at the WWTP or at the reclamation facility that may compromise water quality, including any taken or proposed actions or corrective measures, have to be reported within 24 hours to the Portuguese Environmental Agency (mandatory by the Portuguese Law). Minor incidents have to be reported within 5 days.

Coordination

The APA (district basin departments) coordinates abnormal situation with regional health and agriculture authorities according to the needs.

The risk management plan is included on both permits for the production and application of reclaimed waters (according to respective responsibilities) in form of specific conditions (preventive and control risk measures), self-monitoring programs and reporting requirements that must be complied.

4.6 Case Study 5: Digital Water City irrigation scheme of Peschiera WWTP, Italy – Early Warning System for safe water reuse ([20])

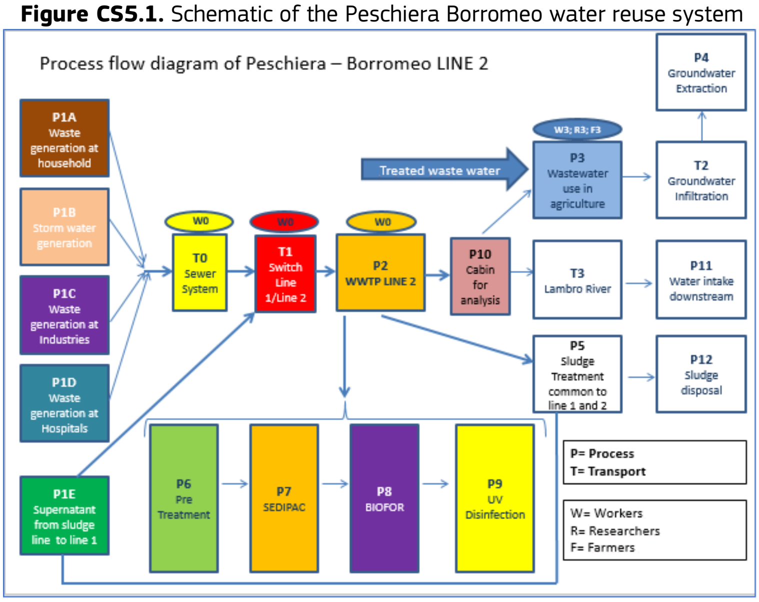
MODULE I

System description (KRM1)

The *Peschiera Borromeo* Integrated Urban Wastewater and Reuse System (Figure CS5.1) is located in the peri-urban area (South Agricultural Park) of Milan, Italy ([21]) and is developed under the EU H2020 project Digital-Water City ([22]). The project boosts the support of digital tools as control measures to minimise risks and facilitate water reuse, also with a focus on water-energy-carbon-food nexus. Peschiera Borromeo WWTP has a treatment capacity of 500,000 P.E. and is divided in two treatment lines, of which the one selected to deliver reclaimed water is composed by pre-treatments, lamellar settler, biologic treatment combined with filtration and tertiary UV disinfection unit. The effluent water quality met class C minimum requirements for irrigation of fodder crops and crops for biomass production (mainly maize and mustard) through drip irrigation techniques. However, as precautionary measure to further reduce health and environmental risks, it was decided to set the compliance with quality standard limits for class B.

The developed approach followed 7 steps on i) the description of the operational framework and the integrated system; ii) choice of the water quality class to meet; iii) analysis of WWTP efficiencies; iv) risk assessment following semi-quantitative and quantitative approaches; v) implementation of Early Warning System (EWS) for safe water reuse; vi) validation and vii) operational and verification monitoring.

Figure CS5.1. Schematic of the Peschiera Borromeo water reuse system



([20]) Contributor: Marco Bernardi, CAP Holding SpA, Italy, Marco.Bernardi@gruppocap.it

([21]) Peschiera Borromeo WWTP: https://goo.gl/maps/wousinJiXmh5JEyAA

([22]) Project website: https://www.digital-water.city/

Parties involved, roles and responsibilities (KRM2)

Information on the roles and responsibilities of the parties involved in this case study is given in Table CS5.1.

Table CS5.1. Roles and responsibilities of parties involved at the Peschiera Borromeo water reuse system

Parties involved	Roles	Responsibilities
CAP Holding SpA	WWTP and reclamation facilities operators	Operations of WWTP and reclamation facility Production and supply of reclaimed water
Istituto Superiore della Sanità (ISS)	Health authority	Co-design the risk management plan, with expertise on health protection
Università Politecnica delle Marche	Research institute	Co-design the risk management plan, with expertise on wastewater processes
Università di Milano	Research institute	Co-design the risk management plan, with expertise on agriculture
Irrigation Consortium	Distribution network	Responsible for the pipelines and the storage systems used to collect and transport the reclaimed water
Farmers	End-users	Select the proper irrigation technique according to the reclaimed water quality and the crop destination

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4)

Health and environmental hazards and hazardous events, along with the populations and environments exposed and related pathways are presented in Table CS5.2.

Table CS5.2. Identification of hazards, routes of exposure and populations and environments at risk at the Peschiera Borromeo water reuse system

Hazards		**Populations and environments at risk**	**Routes of exposure**
Health	Microbial contamination indicators (*E. coli*) and pathogens.	Local community and by-standers	Ingestion and/or direct skin contact with reclaimed water
		WWTP irrigation facilities workers	Inhalation, ingestion and/or direct skin contact with reclaimed water
		Farmers	Ingestion and/or direct skin contact with reclaimed water
Environment	Parameters established by the Italian Decree D.Lgs. n 152/2006 (e.g., ammonium, nitrate, phosphate and suspended solids) measured at the effluent of the WWTP.	Crops for animal feed	Irrigation (crops uptakes or direct contact with reclaimed water)
		Soil	Infiltration in the soil (salinization and soil structure decline)
		Surface water and groundwater	Run-off or infiltration of reclaimed water
Hazardous events			
Catchment – sewer network: Overflows, significant flow and load changes, unexpected discharges. *WWTP:* System failures for each treatment unit, inefficiencies due to variabilities/inadequacy of operative parameters, maintenance issues *Distribution-field:* microbial regrowth due to discontinuous use/reuse service interruption or use of different reclaimed water quality classes, system failures.			

Risk assessment (KRM5) and additional requirements (KRM6)

The health risk assessment was conducted, according to WHO guidelines (WHO, 2006a), using first a semi-quantitative approach, then implemented with a quantitative method, in collaboration with the national health authority Istituto Superiore della Sanità (ISS) and the other parties involved reported in Table CS5.1.

As concern the semi-quantitative approach (WHO, 2015), a risk matrix was developed according to the following steps:

- Description and characterization of the integrated system, from wastewater catchment to treatment and reuse in agriculture-
- Identification of possible hazards and hazardous events at each step of the system, with the support of preliminary checklists and several interviews to technical operators and stakeholders of the team.

- Quantification of risks by the attribution of scores to probability and severity of the detected hazardous events, based on team expertise and knowledge of the water reuse system, as shown in Table CS5.3. Risk values were then calculated using the matrix proposed by the WHO SSP Manual (WHO, 2015) and reported in Table 12 of Section 3.3.3.1.1.

Table CS5.3. Risk definitions for semi-quantitative risk assessment of Peschiera Borromeo water reuse system

Descriptor		**Description**
Likelihood (L)		
1	Very Unlikely	Has not happened in the past and it is highly improbable it will happen in the next months (or another reasonable period).
2	Unlikely	Has not happened in the past but may occur in exceptional circumstances in the next 12 months (or another reasonable period).
3	Possible	May have happened in the past and/or may occur under regular circumstances in the next 12 months (or another reasonable period).
4	Likely	Has been observed in the past and/or is likely to occur in the next 12 months (or another reasonable period).
5	Almost Certain	Has often been observed in the past and/or will almost certainly occur in most circumstances in the next 12 months (or another reasonable period).
1	Insignificant	Hazard or hazardous event resulting in no or negligible health effects compared to background levels.
Severity (S)		
2	Minor	Hazard or hazardous event potentially resulting in minor health effects and/or may lead to legal complaints and concern; and/or minimal regulatory non-compliance (downgrading of the quality of the refined water of 1 class, distributed for about 1% of the time).
4	Moderate	Hazard or hazardous event potentially resulting in a self-limiting health effects or minor illness and/or may lead to legal complaints and concern; and/or minor regulatory non-compliance (downgrading of the quality of the refined water of 1 class, distributed for about 10% of the time).
8	Major	Hazard or hazardous event potentially resulting in illness or injury and/or may lead to legal complaints and concern; and/or major regulatory non-compliance (downgrading of the quality of the refined water of 2 classes).
16	Catastrophic	Hazard or hazardous event potentially resulting in serious illness or injury, or even loss of life and/or will lead to major investigation by regulator with prosecution likely.

According to the results of the semi-quantitative analysis, risks were prioritised to select the most appropriate integrative control measures to introduce, such as the Early Warning System for safe water reuse (see the following section *Preventive measures (KRM7)*).

A more detailed analysis was conducted for health risk assessment, following the WHO guidelines for Quantitative Microbial Risk Assessment (QMRA) (WHO, 2016) and using the web-tool QMRA.org ([23]). This approach includes the definition of reference pathogens (e.g., *Campylobacter*, *Rotavirus* and *Cryptosporidium*) concentrations and the related removal efficiency along the treatment line. As a microbial contamination indicator, measured *E. coli* concentrations, as well as literature assumptions on indicator/pathogens ratio, were used to evaluate reference pathogens concentrations and removals. Non-technical measures, such as irrigation techniques and harvesting procedures were also considered as further barriers. Probability of infection and illness were calculated considering different exposure scenarios for all the populations at risk. Risk was then expressed as Disability-adjusted life years (DALYs) and compared with the health target of 10^{-6} DALYs proposed by WHO guidelines for QMRA (WHO, 2016).
Moreover, in order to identify the physical and chemical hazards to evaluate the feasibility of the implementation of a Quantitative Chemical Risk Assessment (QCRA), FMEA (Failure Modes-Effects Analysis) and PCA (Principal Components Analysis) models were applied to the following parameters monitored with lab

([23]) Wolfgang Seis, 2022. QMRA (Version 0.1.3) [Computer software] Link: QMRA | Zenodo analyses: Conductivity, BOD_5, COD, Total Suspended Solids, Total Nitrogen, Ammonium, Nitrate, Total Phosphorous, Phosphates, Chlorides, Sulphates, Sulphites, Sulphides, Cyanides, heavy metals (e.g., Cadmium, Chromium, Iron, Mercury, Nickel, Lead, Copper, Zinc) and organic surfactants. As confirmed by PCA analysis, results of the FMEA model, using limits set by ISO 16075-1:2020 for the most significant parameters and by national regulation for water reuse DM 185/2003, proved that the accomplishment of a QCRA was not justified and health and environment protection were confirmed ([24]).

Preventive measures (KRM7)

Other than the treatment units and controls already set up in the WWTP, additional preventive measures were implemented in Peschiera Borromeo water reuse system, as reported in Table CS5.4.

Table CS5.4. Identification of preventive measures at the Peschiera Borromeo water reuse system

WWTP and reclamation facility	At end-users (irrigated areas)
Short-term implementation: Early Warning System Online monitoring (see Module III) Sensor maintenance and calibration Sensor data cleaning Long term implementation: Upgrading of the disinfection system Periodic investigation on toxic, persistent and /or emerging compounds Building of water reservoirs to avoid reuse service interruption	Drip irrigation Field monitoring (see Module III)

Early warning systems EWS ([25]) are tools that use real-time signals and other WWTP data to detect system malfunctions or anomalous events occurrence, allowing rapid interventions in case possible hazardous outcomes are identified. Those tools can overcome technical barriers related to the delay in data acquisition from grab samples due to the lag time between sampling, measuring and lab analysis. The EWS developed for the Peschiera Borromeo water reuse system aims to manage microbial and chemical risks by using machine learning tools to perform analyses on the signals acquired from the multi-parameter network of sensors installed at the WWTP, as well as data from lab analysis and open-source models and tools, to provide rapid alert in case of failures detection. The EWS is designed to predict effluent TSS concentrations, since it was observed that solid content could be related to *E. coli* contamination, as well as COD and BOD_5 in the effluent.
The EWS uses Artificial Neural Network (ANN) techniques to provide predictions on effluent values of TSS, COD or BOD values, using as input the parameters detected along the plant (flowrate, pH, ammonia, phosphates, temperature and dissolved oxygen in biological tank and effluent nitrates).

MODULE III

Monitoring programs include operational and routine monitoring, quality control system, and environmental monitoring systems.

Quality control system (KRM8)

The integrated Reuse System of *Peschiera Borromeo* is equipped with a series of sensors for continuous monitoring of raw wastewater, effluent and reclaimed water reused in agriculture (Table CS5.5).
Correct and continuous maintenance is essential for the affordability of sensors signals. Moreover, a data-cleaning procedure based on the integration of statistical methods (moving standard absolute deviation M-SAD and T-squared) was applied to remove sensors faults and outliers ([26]).
The WWTP is provided with a Supervisory Control And Data Acquisition (SCADA) system for remote control and continuous acquisition of online sensors. Equipment status and related alarms on electro-mechanical units are also continuously monitored. Energy meters are installed to monitor the most consuming treatment units, such as biological treatments and UV disinfection.
A specific software (*WaterLims*) is used to upload and update laboratory analyses results. Other offline data about cumulative energy consumptions, chemicals supply, sludge and waste production are stored in internal management systems as well.

([24]) Link to Deliverable D1.3: https://www.digital-water.city/resources/
([25]) Link to website: https://www.digital-water.city/solution/early-warning-system-for-safe-reuse-of-treated-wastewater-for-agricultural-irrigation/
([26]) Link to Deliverable D1.1: https://zenodo.org/record/6496855#.YvYdH3ZBxPa

Operational monitoring includes laboratory analyses, which are periodically performed for influent and effluent characterization to verify compliances with D. Lgs 152/2006 (according to WFD).
The Early warning system (see Module II – Preventive measures) is going to be implemented as a support tool to forecast the TSS values in the effluent to indirectly determine microbial contamination by using the other sensors data installed in the WWTP (e.g., flowrate, pH, ammonia, phosphates, temperature and dissolved oxygen in biological tank and effluent nitrates). Moreover, COD and BOD_5 effluent values could be also predicted, according to the specific operative monitoring needs.

Table CS5.5. Monitoring system set out at the Peschiera Borromeo water reuse system

Control point	Parameters	Source of data	Communication
Influent	Ammonium, pH, Conductivity, ORP, Phosphates, TSS	Online sensors (5-15 min response time)	Connected to SCADA
	Parameters foreseen in D. Lgs 152/2006 (according to WFD).	Weekly lab analyses	Connected to WaterLims
Effluent	Ammonium, pH, Conductivity, Phosphates, TSS, Nitrates, UV - 254 nm, ORP, TOC.	Online sensors (5-15 min response time)	Connected to SCADA
	Parameters foreseen in D. Lgs 152/2006 (according to WFD).	Weekly lab analyses	Connected to WaterLims
Biologic treatment	DO, T, Nitrates, REDOX	Online sensors (5-15 min response time)	Connected to SCADA
UV treatment	UV intensity/transmittance	Online sensor	Connected to SCADA
Energy consuming units (e.g., UV lamps, aeration system)	Energy meters	Online sensors (15 min response time)	Connected to SCADA
Electromechanical equipment	Status (on/off) and alarms	Online sensors	Connected to SCADA
All WWTP	TSS predictions	Early Warning System	Implementing

Additional sampling campaigns were performed for pathogens and CECs, such as pharmaceuticals (Table CS5.6). Moreover, an innovative sensor, the ALERT System described in Angelescu et al. (2020), was tested for online *E. coli* detection, reducing the response time to 10-12 hours in respect to standard lab analyses.

Table CS5.6. Additional monitoring carried out at the Peschiera Borromeo water reuse system

Parameter	Data Acquisition
E. coli	Tests on Alert System sensor
Pathogens (*Coliforms, Coliphages, Salmonella, Campylobacter, Norovirus, Cryptosporidium*)	Site-specific sampling campaign
Pharmaceuticals	Site-specific sampling campaign

Environmental monitoring system (KRM9)

Analytical measures are performed for contaminants accumulation in soil, plants and irrigated environment. Moreover, ground sensors, satellite data and active unmanned aerial vehicle (drone) are used to monitor water stress and other relevant parameters in the soil-plant-atmosphere system. Those data are then acquired by the Match making tool (see Module IV).

MODULE IV

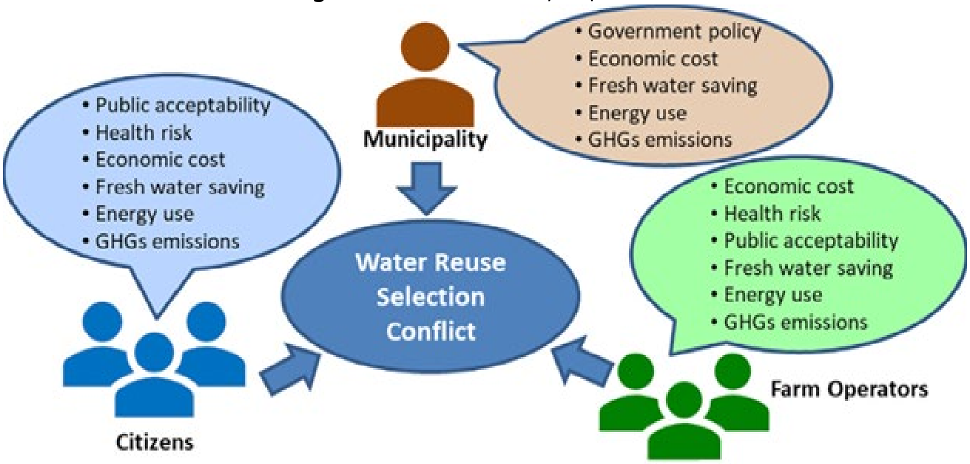
Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

Specific programmes are planned for emergency management. Moreover, the quality control system (EWS) supports decision making.
The Match making tool (MMT) is going to be used to manage communication and information between water utility and final users. It consists in a web-app which provides information on reclaimed water quality and available quantity, as well as data on field and crops. The MMT allows to share information with farmers and promote smart irrigation techniques. The water utility will ensure tracking of water quality and available quantities, while farmers will share site-specific information about crops, sowing date, soil and irrigation method.
Even if communication, public involvement and dissemination activities are not part of RMP, additional tools were applied to increase public involvement and awareness on *Peschiera Borromeo* water reuse project.

A Serious Game ([27]) was developed to show the nexus between water-energy-carbon and food, using real data from the *Peschiera Borromeo* water reuse system, to increase social awareness about the benefits of water reuse. The player can select a territory and a WWTP configuration, as well as cultivated crop and irrigation technique, and receive information about the sustainability of its system.

Moreover, dissemination of project results, as well as stakeholder engagement and feedback collection are planned in Community of Practices (Figure CS5.2), which consist in periodic meetings every 3 months with actors and interested stakeholders (policymakers, end-users, actors, possible interested stakeholders).

Figure CS5.2. Community of practices



4.7 Case Study 6: water reuse systems of Gavà-Viladecans and Baix Llobregat – application of Sanitation Safety Plan, Spain ([28])

MODULE I

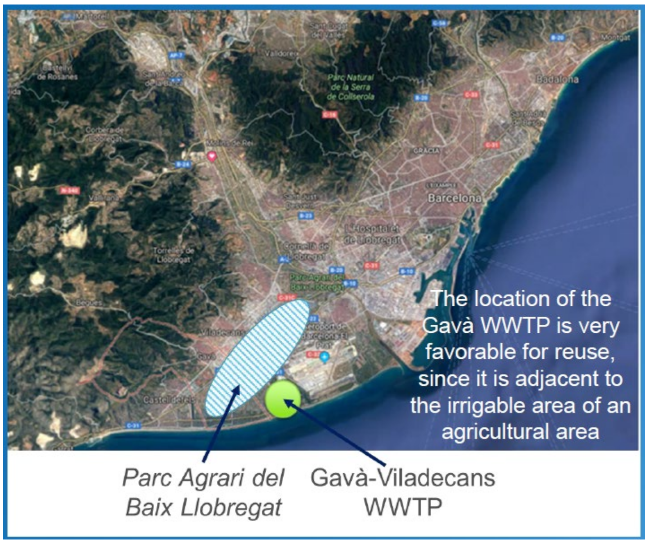
System description (KRM1)

Two water reuse systems were analysed for risk assessment, according to the Sanitation Safety Planning (SSP) and the Water Safety Plan (WSP) approaches (WHO, 2016). The *Gavà-Viladecans* water reuse system (Figure CS6.1) is located near Barcelona, Spain ([29]), close to an agricultural area (*Parc Agrari del Baix Llobregat*). It has a capacity of 384,000 P.E. and usually treats wastewater with a capacity of 194,649 P.E. ([30]). The WWTP layout is made up by primary treatments, biological treatment integrated with MBR and a disinfection unit with chlorine. Up to 2.9 Hm^3/y (2020) is provided for agricultural reuse. Due to the closeness of Mediterranean Sea, the water is saline.

The *Baix Llobregat* WWTP, located in the Barcelona metropolitan area, is characterised by a more complex configuration. Because the WWTP may pump treated wastewater upstream to a drinking water treatment plant (DWTP), the SSP was developed considering also drinking water production requisites as well as impacts in the environment. Additionally, because the effluent is discharged into a river, some priority substances were also considered in the risk assessment.

([27]) Link to the serious game: https://www.seriousgame4dwc.eu/dev/introduction
([28]) Contributor: Jordi Martín Alonso, Aigües de Barcelona, Spain. jma@aiguesdebarcelona.cat
([29]) Gavà Viladecans WWTP: https://goo.gl/maps/yw5AZ8dhXGf5VgUU8
([30]) https://uwwtd.eu/Spain/treatment-plant/es9083010001010e/2014

Figure CS6.1. Identification of the *Gavà-Viladecans* water reuse system



Parties involved, roles and responsibilities (KRM2)

A working group involving all the actors was established by the competent authorities (Prat) and it was led by the Authority of Metropolitan area of Barcelona (AMB) (PRIMA-MAGO project for Gavà-Viladecans). These actors, along with their roles and responsibilities are identified in Table CS6.1.

Table CS6.1. Roles and responsibilities of parties involved at the Gavà-Viladecans and Baix Llobregat water reuse systems

Parties involved	Roles	Responsibilities
Aigües de Barcelona (AB)	WWTP and reclamation facilities operators	Responsible for sanitation systems. Prepared RMP.
Health authority (DS)	Health protection authority	Provide additional suggestion to include viruses in risk assessment, controls
Catalan Water Agency (ACA)	Environment Protection authority	Environmental controls
Authority of Metropolitan area of Barcelona (AMB)	Catchment (wastewater supplier)	Discharge sewage to WWTP
Farmers	Final users	Irrigation with reclaimed water

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4)

A similar risk assessment approach was applied for the two water reuse systems, considering their site-specific conditions and requirements, as summarised in Table CS6.2.

For the Gavà-Viladecans system, only health and environmental hazards related to reuse in agricultural irrigation were considered, while for the Baix Llobregat a more detailed analysis was carried out to also include the assessment due to possible contamination of drinking water and surface water resources in the area.

Table CS6.2. Identification of hazards, routes of exposure and populations and environments at risk at the Gavà-Viladecans and Baix Llobregat water reuse systems

Hazards		**Populations and environments at risk** (1)	**Routes of exposure**
Health Hazards (Gavà-Viladecans)	Water quality parameters for reuse in agriculture. Influent: TSS, BOD_5, COD, Turbidity, Conductivity, Nitrogen, Phosphorus, Al, B,	Local community and by-standers	Ingestion and/or direct skin contact with reclaimed water
		WWTP workers	Inhalation, ingestion and/or direct skin contact with reclaimed water
		Farmers	Ingestion and/or direct skin contact with reclaimed water

Hazards		Populations and environments at risk (1)	Routes of exposure
Environmental Hazards (Gavà-Viladecans)	Cd, Cu, Cr, Fe, Mn, Mo, Ni, Pb, Se, Zn, Na, Ca, Mg, K, F. Effluent: TSS, BOD_5, COD, Turbidity. Parameters and values selected according to RD 1620/2007, discharge authorization and FAO guidelines (1). Viruses (as required by the health authority).	Crop	Irrigation (crops uptakes or direct contact with reclaimed water)
		Soil and environment	Infiltration in the soil (salinization and soil structure decline)
Health and environmental hazards (*Baix Llobregat*)	Water quality parameters: UV absorption, Perfluorooctanosulfonic acid and its derivatives (PFOs), Aclonifen, Alachlor, Aldrin, Ammonia, Antimony, Anthrax, Arsenic, Atrazine, Barium, Benzene, Benzo (a) pyrene, Benzo (b) fluoride, Benzo (k) fluorescent, Benzo (g.h.i) perilene, Indene (1,2,3-cd) pyre, Bifenox, Cadmium and its compounds, $CaCO_3$, Cyanides, Cibutrina, Cypermethrin, Clorfenvinfós, Chloroalkanes C10-C13, Chloroform, Chlorpyrifos (chlorpyrifos-ethyl), Conductivity, Copper, Chrome, Total DDT, 4,4'-DDT, p-p'-DDT, 1,2-dichloroethane, Dichloromethane. According to: permits (Doc614970 – ACA), Management Plan of Catalonia District River, RD 817/2015 (surface water and environmental quality), catchment and treatment quality limits.	Drinking water	Direct water reuse for drinking purpose
		Environmental impact	Infiltration due to reclaimed water released in environment
		Surface water	Infiltration, mixing of reclaimed water with surface water
Hazardous events			
Hazardous events are identified for each critical control point (CCP) and listed in a risk matrix. Focus on issues related to water salinity and seawater intrusion were considered, due to higher frequency of non-compliance. Other hazardous events include: influent solids peak, sludge overflows, sedimentation issues, insufficient dosage for P removal, insufficient nitrification due to aeration malfunctions or environmental conditions, biologic and internal recycles functioning.			

(1) Selected according to the FAO guidelines on water quality for agriculture (Ayers and Westcot, 1985).

Risk assessment (KRM5), additional requirements (KRM6) and preventive measures (KRM7)

Aigües de Barcelona has developed its own *SSP Management Manual and Procedures* following the WHO Guidelines for WSP and SSP. This procedure consists of:

1. Preliminary steps: constitution of the work team, product description, final uses identification, process diagrams elaboration.
2. Risk assessment: hazard identification and risk quantification based on existing analytical data and analysis of the cause and origin of the hazard. Definition of Prerequisites (PR, considered as the conditions, activities and practices that must be performed in order to ensure that water is safe, Critical Points (CCP, considered as a step at which control can be applied and is essential to prevent or eliminate a food safety hazard or reduce it to an acceptable level),and Operational Prerequisites (OPR, considered as a Prerequisite identified as being critical to water safety for controlling an specific hazard, thus requiring an operational monitoring for ensuring its efficacity).
3. Hazard analysis and critical control point (HACCP) and Prerequisite Program plan to analyse causes, actors and actions to be performed (what, who and how)
4. Management, verification and review procedures

Risks for each identified hazard were assessed using a semi quantitative matrix (Table CS6.3). An HACCP Plan was developed for the identified CCP and hazards. Main non-compliance was observed for conductivity due to water salinity. Causes are analysed, responsible actors are defined, as well as corrective measures to prevent non-compliances. Preventive measures are set in the HACCP Plan for each critical CCP and must be operating before reclaimed water is provided for reuse, to ensure that compliance is guaranteed not only when analyses are performed. Verification on preventive measures efficacy and analytical measures of hazardous parameters are also periodically planned.

Table CS6.3. Criteria for qualifying risks according to probability and impact

		Probability				
		1 Decennial or more	2 Quinquennial	3 Yearly	4 Trimonthly	5 Monthly
Impact	1	1	2	3	4	5
	5	5	10	15	20	25
	10	10	20	30	40	50

R ≤ 10	: Low risk
15 ≤ R ≤ 20	: Average risk
R ≥ 25	: High risk

A methodology based on a decision tree was defined for determining how to manage the identified risks considering the preventive measures, the CCP and the PPR (Figure CS6.2). Any actions are identified to prevent non-compliances, rather than to correct them. If the safety of the reclaimed water cannot be ensured, the problem should be identified before the water leaves the WWTP.

Figure CS6.2. Decision tree at the *Gavà-Viladecans and Baix Llobregat* water reuse systems

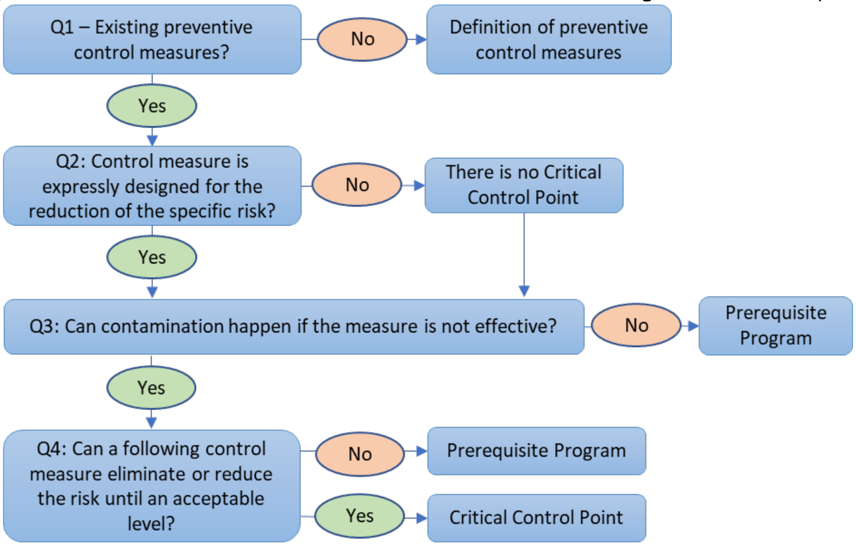


Table CS6.4 reports an example of the HACCP method with the identification of CCP, associated preventive measures with definition of limits for the management of hazards (total phosphorus, total nitrogen, salinity and microbial parameters).

Table CS6.4. Summary of the critical control points and associated preventive measures identified at the Gavà-Viladecans water reuse systems for other parameters.

Point	**Process**	**Hazard**	**Cause**	**Origin**	**Preventive measure**	**Control parameter**	**Unit**	**Alert limit**	**Critical limit**
CCP	Effluent from MBR	Total Phosphorus MBR	Insufficient coagulant dosage	Incorrect phosphorus removal	Modify the $FeCl_3$ dosage	Average change in the aeration. Effluent Phosphorus sensor	ppm	1.5	2

Point	Process	Hazard	Cause	Origin	Preventive measure	Control parameter	Unit	Alert limit	Critical limit
CCP	Effluent from MBR	Total Nitrogen MBR	Malfunctioning of aeration (nitrification)	Incorrect air supply/temporisation of nitrification-denitrification	Modify parameters of nitrification-denitrification	Total Nitrogen measured at control laboratory	ppm	13	20
CCP	Effluent from MBR	Salinity MBR	Seawater intrusion in the WWTP	Triangle of Murtra (small local lake)	Act on the pumping system of Murtra	Measured Conductivity of influent wastewater (total)	µS/cm^2	5000	6000
CCP	Tertiary treatment	Microbial parameters	Breaking of the fibres of MBR	Deterioration / aging of membranes	Check which train fails by stopping them one by one until the problematic is located, leaving the one stopped	Turbidity at the effluent from MBR	NTU	2.5	5

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

Operational monitoring (Table CS6.5) is performed according to the HACCP Plan. Frequency of monitoring depends on the parameter. When a parameter is higher than the critical limit, an alarm is sent to the SCADA system. The WWTP operator is provided with a monitoring screen to check if any risk is detected. According to the health authority suggestion, viruses were included in the list of monitored parameters.

Table CS6.5. Monitoring system set out at the Gavà-Viladecans and Baix Llobregat water reuse systems

Control point	Gavà-Viladecans	Baix Llobregat
Influent and Effluent	Physic-chemical parameters concentrations, statistics (e.g., mean, minimum, maximum), comparison with limits of regulation 2020/741.	Physic-chemical parameters concentrations, comparison with different Regulations requirements (permits (Doc 614970 –), Management Plan of Catalonia District River, RD 817/2015 (surface water and environmental quality), catchment and treatment quality limits)

Tables CS6.6 and CS6.7 show the tool used for the identification of corrective actions and management of the hazards using the monitoring system in place (example for salinity).

Table CS6.6. Table tool used to analyse hazards, identify corrective actions via monitoring (example for salinity).

Monitoring			Corrective actions			
Monitoring frequency of control parameters	Responsible	Register	Action in case of overcoming the critical limit	Emergency management	Responsible	Register
Daily	Operator	Supervisory Control and Data Acquisition (SCADA) system	Activate the pumping system of Murtra	-	WWTP manager	-

Table CS6.7. Table tool used to verify hazards (example for salinity).

Verification of control parameter						Analytic verification of the hazard				
Activity	Criteria	Frequency	Responsible	Data source	Register	Activity	Parameter	Frequency	Responsible	Register
Indicator IND-200 of % of samples with Conductivity ≤ 5000 (WWTP lab)	95%	Monthly	WWTP manager	SIGEDA (Own dataset and control system)	File Transfer Protocol	Conductivity reclaimed water (limit 4500)	Conductivity	HACCP Plan	Lab technician	Laboratory Information System (LIMS) / SIGEDA

MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

Food safety management certification complying to ISO 22000:2005 (ISO, 2005) was obtained in 2009 and a reduction of non-compliances, incidents and health outcomes was observed (Setty et al., 2017). Management of risks is planned according to the HACCP plan as indicated in the Tables CS6.4 to CS6.7.

4.8 Case Study 7: the Braunschweig model, Lower Saxony, Germany ([31])

MODULE I

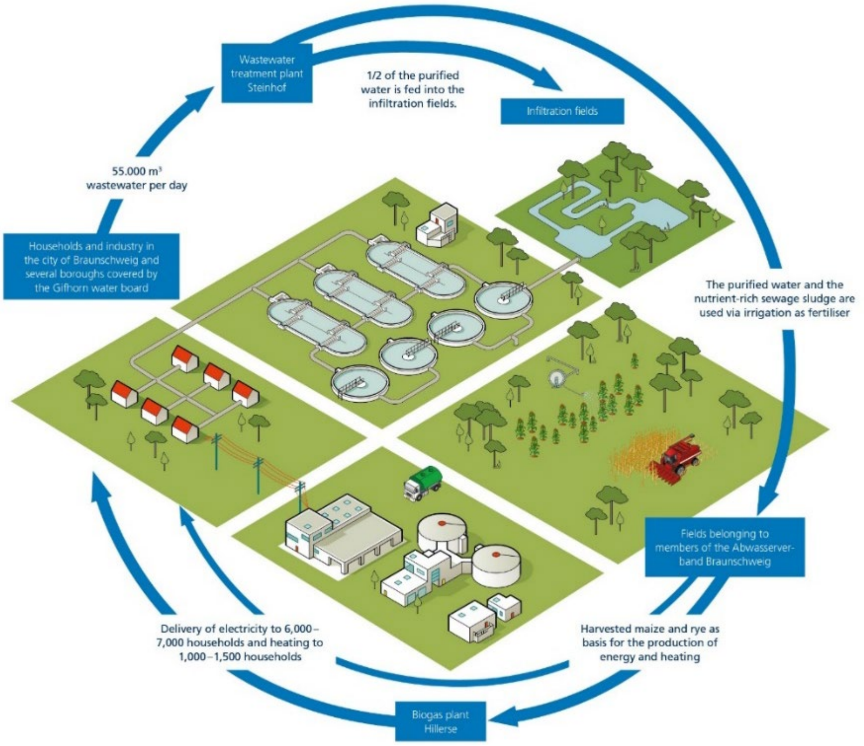
System description (KRM1)

The *Braunschweig* water reuse system (Figure CS7.1) is located in Lower Saxony, Germany ([32]). The system is composed by the wastewater catchment area, infiltration fields, WWTP, sprinkler irrigation fields and four pumping stations to deliver reclaimed water. The area is characterised by sandy soil, with a low water holding capacity, with higher evaporation rate than precipitation, and dry summer season occurred especially since 2018. The *Steinhof* WWTP serves 350,000 PE, with a daily flow of 55,000 m^3/d, and is composed by mechanical pre-treatments, biological unit with activated sludge treatment and nutrient removal through anaerobic sludge treatment. The sludge is treated for nutrient recovery and bio-fertiliser production. A total amount of 3,300 tons TS/y (2021) is produced, of which 1,320 tons TS/y (40%) are spread by sprinkler irrigation in the "Sewage board area", while 660 tons TS/y (20%) are reused in agriculture by other application techniques (spreader) (to cover a part of nutrient requirement) the remaining 40% were incinerated. Round about half of the treated wastewater roughly 10 Mm^3/y is fed into 275 hectares of drainage/infiltration area the other half is used for sprinkler irrigation of agricultural fields. Because the additional water requirement of agricultural crops is only 4 Mm^3/y, there is a groundwater recharge under the irrigation area of roughly 6 Mm^3/y. The management of the water reuse system follows a circular economy approach with a closed water and energy cycle. The reclaimed water reaches the irrigation area by gravity flow pipes to be then distributed by pressure pipes to 3,000 ha of fields, mainly cultivated with potatoes, sugar-beets, grain and maize, for processed food production or biogas plant feed.

([31]) Contributor: Franziska Gromadecki, Managing Director Abwasserverband Braunschweig, Germany. mailto:franziska.gromadecki@abwasserverband bs.de

([32]) Steinhof WWTP: https://goo.gl/maps/uNiNMzUG38UjvCP17

Figure CS7.1. Schematic of the *Braunschweig* water reuse system



Parties involved, roles and responsibilities (KRM2)

Information on the roles and responsibilities of the parties involved in this case study is given in Table CS7.1 and in Figure CS7.2.

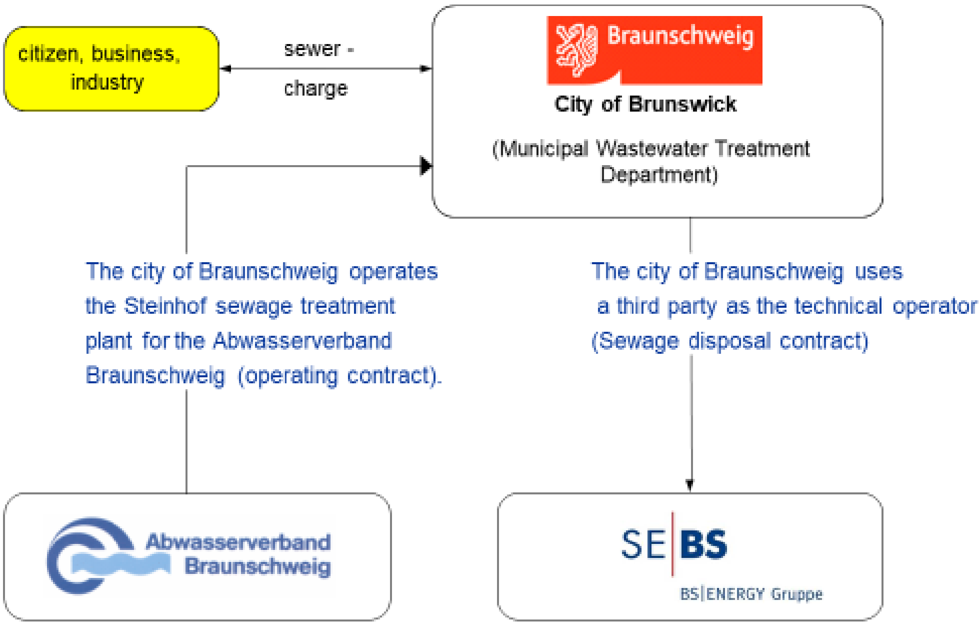
Table CS7.1. Roles and responsibilities of parties involved at the Braunschweig water reuse system ([1])

Parties involved	Roles	Responsibilities
Water and ground association Abwasserverband Braunschweig[33]	Association of parties involved	Owner of WWTP Cost assumption for all costs of the sewage treatment plant. Holder of discharge permits and provide water reuse to irrigate fields of association's members.
City of Braunschweig, Gifhorn water board with communities of Papenteich, Meinersen and Wendeburg	Wastewater suppliers	Finance wastewater treatment incl. water reuse by wastewater fees
City of Braunschweig – municipal wastewater department.	sovereign tasks	Coordination between parties. Responsible for Sewage disposal contract and for operating contract. .
SE – BS Energy Gruppe	WWTP operator	Third party responsible for technical operations of sewer system and WWTP
Agricultural landowners (434 members, of which 100 owners of reclaimed water irrigated fields)	End-users	Irrigate fields with reclaimed water
Water authority	Control authority	Analysis on water and groundwater
Environmental Protection Agency	Control authority	Yearly controls on farmers

([1]) The table refers to the parties involved in the management and not in RMP, which were not identified at the preparation of this guidance document.

([33]) Website: Abwasserverband Braunschweig (abwasserverband-bs.de)

Figure CS7.2. Identification of involved parties at the *Braunschweig* water reuse system



MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4)

Information on hazards and hazardous events, populations and environments at risk and related routes of exposures are reported in Table CS7.2.

Table CS7.2. Identification of hazards, route of exposure and populations and environments at risk at the *Braunschweig* water reuse system

	Hazards	**Populations and environments at risk**	**Routes of exposure**
Health Hazards	Water and sludge quality parameters for reuse in agriculture	Local community and bystanders	Ingestion and/or direct skin contact with reclaimed water
		WWTP workers	Inhalation, ingestion and/or direct skin contact with reclaimed water
		Farmers	Ingestion and/or direct skin contact with reclaimed water
Environmental Hazards	Water and sludge quality parameters for reuse in agriculture (heavy metals, trace substances), according to treated wastewater standards and irrigated water standards (limit of 75 mg/l COD).	Crops (grain, potatoes, sugar-beets, maize and others) for food production after processing	Irrigation (crops uptakes or direct contact)
		Soil	Irrigation in the soil with reclaimed water and sludge spread
		Groundwater	Infiltration of reclaimed water

Risk assessment (KRM5)

Risk assessment should include both water reuse and sludge recovery as fertiliser in the agricultural fields. Environmental risk should consider groundwater recharge. No health effects on human or animals were detected during 30 years of water reuse. Although a detailed risk assessment has not been performed yet, at the moment of the publication of these Guidelines, risks are managed through the monitoring plan.

Additional requirements (KRM6)

Analysis on multi resistance bacteria and measure of log reduction of bacteria along the treatment processes, as well as detection of trace substances are included.

Preventive measures (KRM7)

Other than the treatment units and controls already set up in the WWTP, additional preventive measures were implemented in the *Braunschweig* water reuse system, as reported in Table CS7.3.

Table CS7.3. Identification of preventive measures at the Braunschweig water reuse system

Sewer and WWTP	At end-users (irrigated areas)
Indirect discharges monitoring in the Braunschweig catchment for 40 years through regular sampling of 401 dischargers (e.g., Garages and petrol stations, Hospitals, metal, food and chemical industries, glass processing, dry-cleaners, institutes and laboratories).	Prevention of aerosol spray by hedges alongside roads. Consultancy of farmers to support soil nutrient demand and supply, crop fertilisation, farmers information, balance of sprinkler-water and nutrient load.

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

In addition to the routine controls and monitoring of WWTP operations and wastewater quality (KRM8), already performed by water utility and control authorities, additional monitoring is implemented (Table CS7.4). Environmental monitoring is performed for reclaimed water, sludge, groundwater and soil. Monitored parameters include pH, electrical conductivity, dissolved oxygen, total P, nitrite N, nitrate N, ammonium N, organic bound nitrogen, TOC, COD, BOD_5 for water samples; heavy metals and trace substances (e.g., Cadmium) for sludge; nutrient content for soil; fertilisation tests on crops.

Table CS7.4. Monitoring system set-out at the *Braunschweig* water reuse system

Routine and operational monitoring (KRM8)	Environmental Monitoring System (KRM9)
Monitoring of sludge and water. Monitoring of sewage sludge with certified quality, focus on heavy metals (e.g., Cadmium) and trace substances.	Water monitoring in 6 discharge points from 500 ha drained area and groundwater testing of 33 observation wells (3 wells monitored by water authority with 4 samples/year). Monitoring of soil nutrient demand/supply. Fertilisation tests on crops.

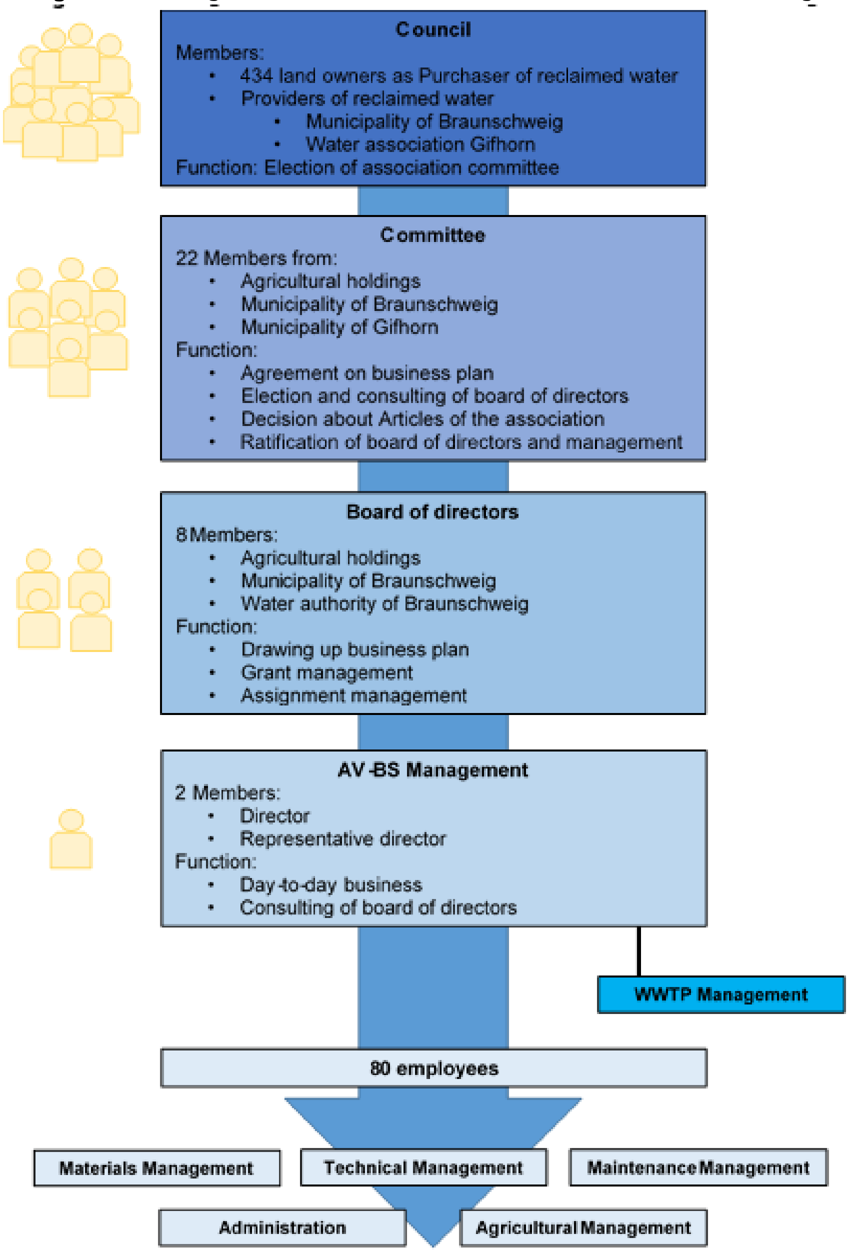
MODULE IV - GOVERNANCE, MANAGEMENT AND COMMUNICATION

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

Cooperation counts on long-term experience, transparency and communication, as well as contractual obligations between water/sludge suppliers and users.

The cooperation structure of Abwasserverband Braunschweig consists of a council assemble of 400 landowners, city of Braunschweig and water association Gifhorn, who elect the 22 members of association committee, which agree on business plan, grant and assign management (Figure CS7.3).

Figure CS7.3. Organizational structure of the Abwasserverband Braunschweig



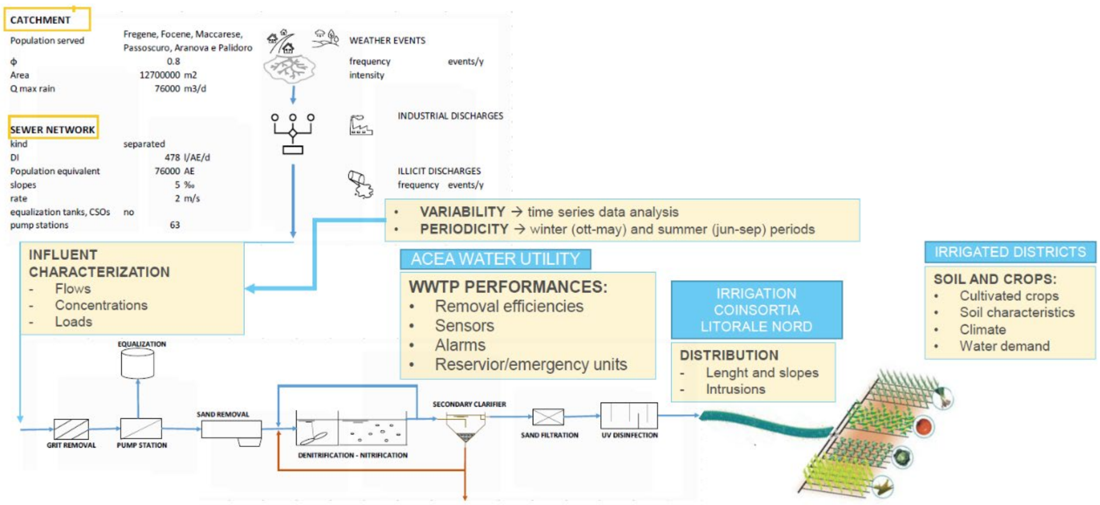
4.9 Case Study 8: Fregene ACEA water reuse system, Italy (34)

MODULE I

System description (KRM1)

The *ACEA Fregene* water reuse system (Figure CS8.1) is located in Fregene (Rome), Italy (35). It serves a 13 km^2 catchment area with limited industrial presence that collects urban wastewater in separated sewer network that conveys it to the Fregene WWTP. The area is characterised by high touristic fluxes over the summer season, which causes a significant variability in the influent. The Fregene WWTP is located within a Natural Reserve and near a WWF Protected Area (36). The WWTP has a capacity of 76,000 P.E. and it is composed by pre-treatments, biological and secondary treatments, sand filtration and UV disinfection. The reclaimed water is conveyed to an open channel from where it is withdrawn and reused for irrigation in agriculture, mainly for horticultural crops.

Figure CS8.1. Schematic of the *ACEA Fregene* water reuse system, Italy



Parties involved, roles and responsibilities (KRM2)

Information on the roles and responsibilities of the parties involved in this case study is given in Table CS8.1.

Table CS8.1. Roles and responsibilities of parties involved at the ACEA Fregene water reuse system (1)

Parties involved	Roles	Responsibilities
ACEA SpA	WWTP operator	Operations of the Fregene WWTP Production and supply of reclaimed water
Università Politecnica delle Marche	University - Research institute	Collaborate in the development of risk assessment and management plan (expertise on wastewater treatment and processes)
Università di Bologna	University - Research institute	Collaborate in the development of risk assessment and management plan (expertise on agriculture and irrigation infrastructure)
Consorzio di Bonifica Litorale Nord	Irrigation infrastructure manager	Responsible of the operation and maintenance of the irrigation infrastructure
Farmers	End-users	Irrigation with reclaimed water
Health and environmental agencies	Public health and environmental authorities	Validate the plan and oversee/control the system
Local/regional governments	Local/regional government	Grant the permits

(34) Contributors: Francesco Fatone, Università Politecnica delle Marche, Italy. f.fatone@univpm.it; Attilio Toscano, Università di Bologna, Italy; Massimo Spizzirri, ACEA, Italy.

(35) Fregene WWTP: https://goo.gl/maps/GRyHFDJawQipp2ii6

(36) https://www.wwf.it/dove-interveniamo/il-nostro-lavoro-in-italia/oasi/oasi-di-macchiagrande-foce-dellarrone-e-vasche-di-maccarese/; https://www.parchilazio.it/litoraleromano

([1]) The table refers to the parties involved in the management and not in RMP, which were not identified at the preparation of this guidance document.

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4)

Both health and environmental hazards were identified considering the effluent characteristics and the applicable EU and national legislations. Populations and environments at risk, along with the routes of exposure were identified as illustrated in Figure CS8.2 and Table CS8.2.

Figure CS8.2. Identification of exposed populations and routes of exposure at the *ACEA Fregene* water reuse system

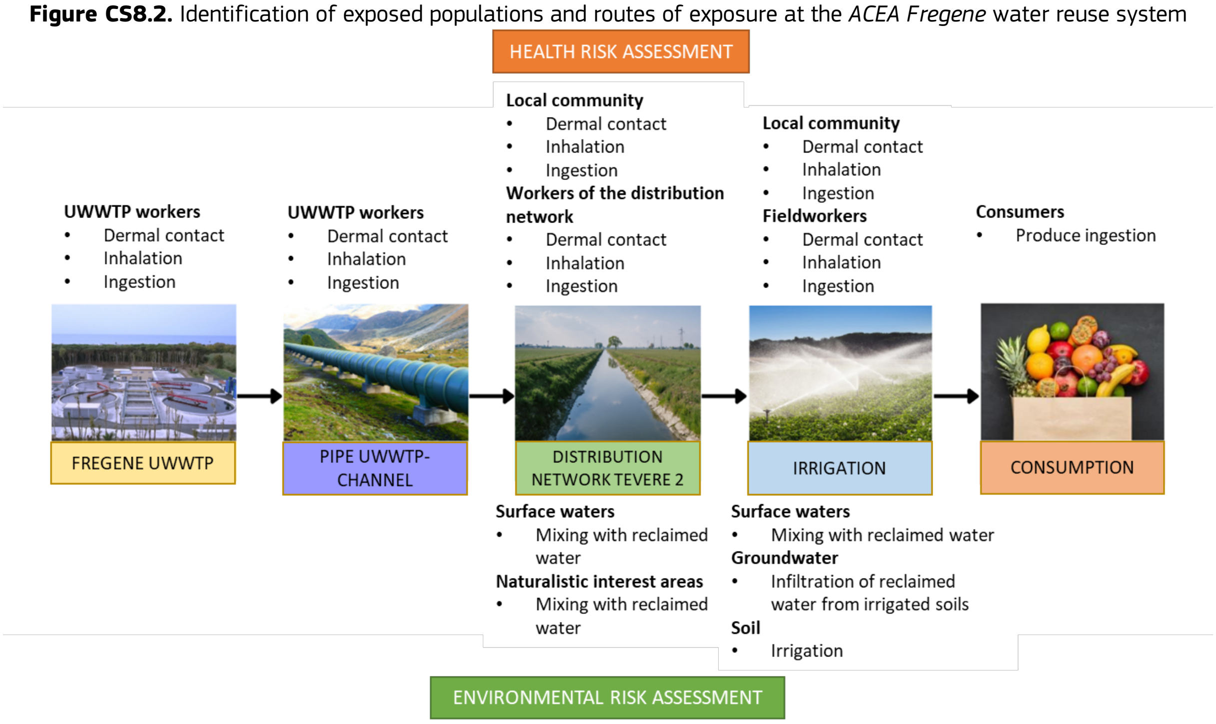


Table CS8.2. Identification of hazards, route of exposure and populations and environments at risk at the ACEA Fregene water reuse system

	Hazards	**Populations and environments at risk ([1])**	**Routes of exposure**
Health Hazards	Microbial parameters (*E. coli*), according to EU 741/2020 and National Regulation on water reuse DM 185/2003	Local community and bystanders	Ingestion, aerosol and/or direct skin contact with reclaimed water
		WWTP and reclamation facility workers	Ingestion, aerosol and/or direct skin contact with reclaimed water
		Farmers	Ingestion, aerosol and/or direct skin contact with reclaimed water
Environmental Hazards	Physical-Chemical parameters, according to EU 741/2020, National Regulation on water reuse DM 185/2003, as well as Italian Decree D.Lgs. n 152/2006	Crops	Crops uptakes or direct contact with reclaimed water during irrigation
		Soil	Infiltration of reclaimed water in the soil
		Surface water	Run-off of reclaimed water
		Groundwater	Infiltration of reclaimed water
		Vulnerable and protected areas	Run off or infiltration of reclaimed water
Hazardous events			
At the catchment area: unexpected overflows or loads in the sewer network, saline water intrusion, unexpected industrial discharges. *At the WWTP*: failures at different treatment stages, nitrification-denitrification, UV malfunctioning, chemical dosage failures, solids escape, sedimentation issues, sensors faults.			

([1]) Even if in this case-study they were considered, consumers wouldn't be taken into account in RMP, since they are outside water reuse system boundaries.

Risk assessment (KRM5)

Risk assessment methodologies for the water reuse system of Fregene were under development at the preparation of this guidance document. The suggested approaches for health and environmental risk assessments are described here.

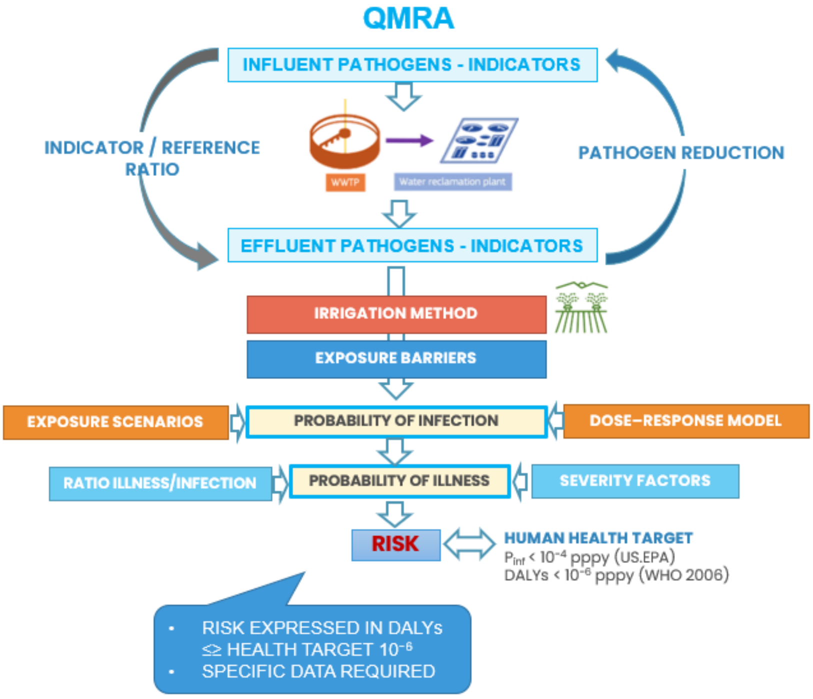
Health Risk Assessment

The health risk assessment approach follows a semi-quantitative method developed according to the WHO Guidelines for Sanitation Safety Planning (WHO, 2015).

This approach includes: i) the characterization of the integrated system, from wastewater catchment to treatment, delivery and reuse in agriculture, also with the support of checklists; ii) the identification and the analysis of possible hazards and hazardous events and iii) the quantification of risks by the attribution of scores to probability and severity of the detected hazardous events (the scores were attributed based on the knowledge of the water reuse system and expertise), as reported in Table 12 of Section 3.3.3.1.1.

In case a deeper analysis would be required, a quantitative approach, following the WHO guidelines for Quantitative Microbial Risk Assessment (WHO, 2016) could be followed. This approach includes the characterisation of reference pathogens (e.g., *Campylobacter*, *Rotavirus* and *Cryptosporidium*) and the related removal efficiency along the treatment line. Non-technical measures, such as irrigation techniques and harvesting procedures can be also considered as further barriers. Probability of infection and illness are calculated considering different exposure scenarios for all the populations at risk. Risk can be expressed as Disability-adjusted life years (DALYs) and compared with the health target of 10^{-6} proposed by WHO (
Figure **CS8.**).

Figure CS8.3. Proposed methodology for QMRA



Environmental Risk Assessment

For the environmental risk assessment, possible hazards were identified, such as Boron, Salinity, Chlorides, Sodium, heavy metals, Carbonates, Nutrients and suspended solids. Effluent concentrations were compared with regulatory requirements to verify the acceptability of the environmental risks. However, in case further analyses were required, a quantitative chemical risk assessment (QCRA) is proposed. This method is based on the verification of the following equation:

$$RQ = \frac{PEC}{PNEC} < 1$$

Where:

— RQ: Risk quotient

— PEC: Concentration at the endpoint exposed, defined through measured or/vs estimated data

— $PNEC$: Predicted no effect concentration

Preventive measures (KRM7)

Preventive measures are made up by the sequence of treatment units and by the quality control system (see Module III) applied in the plant, with the support of real-time sensors.
Moreover, at the final effluent, a by-pass system can diverge treated wastewater to discharge instead of reuse, in case of non-compliances.

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

Monitoring programs (Table CS8.4) are performed through quality control system, including operational and routine monitoring.
The WWTP is provided with a network of sensors connected to remote-control system for continuous monitoring and management of the processes.
Operational monitoring includes laboratory analyses, which are periodically performed for influent and effluent characterization to verify compliances with D. Lgs 152/2006 (according to the WFD).

Table CS8.3. Monitoring system set out at the ACEA Fregene water reuse system

Control point	Parameters	Frequency
Influent and Effluent	Internal controls of macro-contaminants: pH, Conductivity, TSS, BOD5, TN, TP, Ammonia, Nitrites and Nitrates	Instantaneous and/or averaged samples, 2/week
	External (ARPA) controls of parameters foreseen in D. Lgs 152/2006 (according to WFD).	Instantaneous and/or averaged samples, 1/week
Biologic treatment	DO, T, Nitrates, REDOX	Online sensors (continuous monitoring)
Electromechanical equipment	Status (on/off) and alarms	Online sensors (continuous monitoring)
Effluent	Flowrates, Ammonia, Phosphates, Chlorides, Conductivity, Nitrates, Turbidity and pH	Online sensors (continuous monitoring)
WWTP	TSS predictions by EWS	Continuous monitoring

MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

The emergency management is automated. Alarms are connected to remote control, as well as maintenance programs. The work orders are managed through the SAP system and are sent via tablet to local staff, selected on the basis of proximity, professionalism or equipment required. The system manages operators' agendas and organise the most appropriate team to carry out work orders.

4.10 Case Study 9: San Benedetto del Tronto water reuse system, Italy ([37])

MODULE I

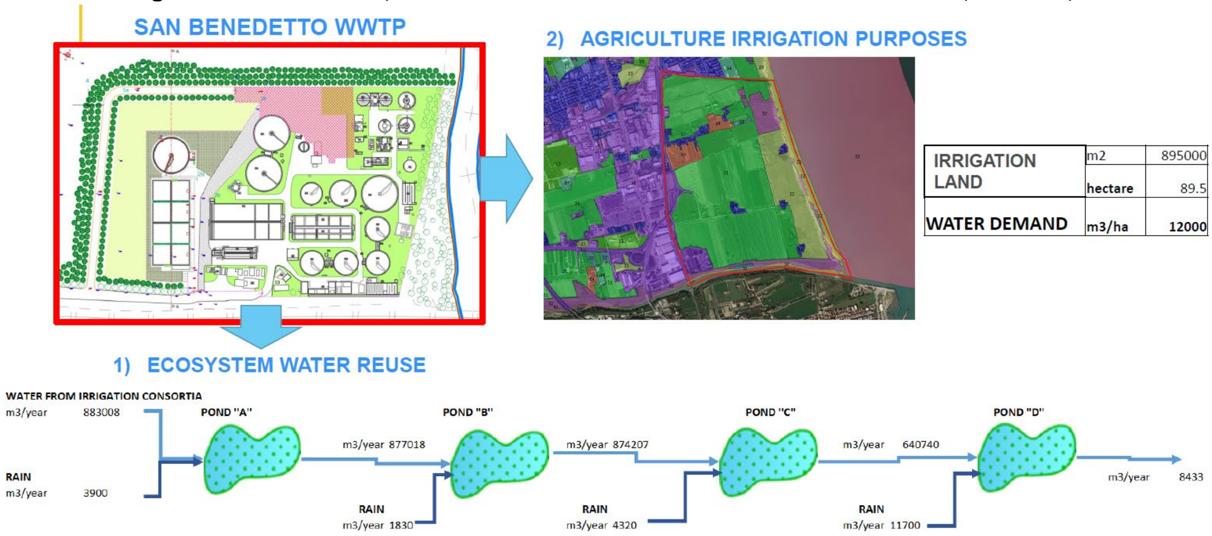
System description (KRM1)

The *San Benedetto del Tronto* water reuse system (Figure CS9.1) is planned to be located in the Marche Region, Italy ([38]). The urban catchment (25.4 km^2) is characterised by a relevant touristic area, with a population of 47,000 inhabitants which can reach up to 800,000 non-residents tourist presences over the summer period. Moreover, due to the earthquakes occurred in recent years, the Region started to suffer water scarcity, making the issue of water availability. The aquifer presents conditions of over-exploitation and, therefore, seawater intrusion phenomenon occurs during drought periods (mainly between May and September). The seaside is certified with the Blue Flag, by Foundation for Environmental Education. In the territory, the Natural Reserve Sentina ([39]) is a Natura 2000 site that covers about 177 ha and 1.7 km of coastline, including some agricultural activities and high hydro-demanding habitats. The WWTP, with a design capacity of 180,000 PE and an influent

([37]) Contributors: Francesco Fatone, Università Politecnica delle Marche, Italy. f.fatone@univpm.it; Claudio Carini, CIIP, Italy
([38]) San Benedetto del Tronto WWTP: https://goo.gl/maps/ZmzEhEtLo7weptMP8
([39]) Natural Reserve Sentina: https://www.riservasentina.it/it/sentina-natural-regional-reserve.html

average flow rate of 25,000 m³/d, is currently composed by a lifting unit, pre-treatment, primary sedimentation, activated sludge treatments with intermittent aeration, secondary sedimentation and final chemical disinfection. Tertiary treatments are being implemented with filtration and UV disinfection. Reclaimed water can be used for irrigation or for ecosystem reuse.

Figure CS9.1. Preliminary schematic of the *San Benedetto del Tronto* water reuse system, Italy



Parties involved, roles and responsibilities (KRM2)

Information on the roles and responsibilities of the parties involved in this case study is given in Table CS9.1.

Table CS9.1. Roles and responsibilities of main parties potentially involved at the San Benedetto del Tronto water reuse system ([1])

Parties involved	**Roles**	**Responsibilities**
CIIP SpA	WWTP operator	Operations of WWTP Production and supply of reclaimed water
Università Politecnica delle Marche	University - Research institute	Collaborate in the development of risk assessment and management plan, with expertise on wastewater treatment and processes
Natural Park Sentina authority	Environmental protection authority	Collaboration for ecosystem water reuse
Farmers	End-users	Irrigation with reclaimed water
Consorzio di Bonifica delle Marche	Irrigation infrastructure manager	Responsible of the operation and maintenance of the irrigation infrastructure
Health and environmental agencies	Public health and environmental authorities	Validate the plan and oversee/control the system
Local/regional governments	Local/regional government	Grant the permits

([1]) The table refers to the parties involved in the management and not in RMP, which were not identified at the preparation of this guidance document.

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4)

Information on the hazards and the hazardous events identified, together with the related populations and environments at risk and their routes of exposures are reported in Table CS9.2.

Table CS9.2. Identification of hazards, route of exposure and populations and environment at risk at the San Benedetto del Tronto water reuse system

	Hazards	**Populations and environments at risk**	**Routes of exposure**
Health Hazards	Microbial parameters (*E. coli*), according to EU	Local community and by-standers	Ingestion, aerosol and/or direct skin contact with reclaimed water

	Hazards	Populations and environments at risk	Routes of exposure
	741/2020 and National Regulation on water reuse DM 185/2003	WWTP and reclamation facility workers	Ingestion, aerosol and/or direct skin contact with reclaimed water
		Farmers	Ingestion, aerosol and/or direct skin contact with reclaimed water
Environmental Hazards	Physical-Chemical parameters, according to EU 741/2020, National Regulation on water reuse DM 185/2003, as well as Italian Decree D.Lgs. n 152/2006. Focus on salinity, Chlorides and metals (Fe, Cu, Zn, Mn, etc.)	Crops	Irrigation (crops uptakes or direct contact with reclaimed water)
		Soil	Infiltration in the soil (salinization and soil structure decline)
		Surface water	Run-off of reclaimed water
		Groundwater	Infiltration of reclaimed water
		Vulnerable and protected areas	Run off or infiltration of reclaimed water

Risk assessment (KRM5)

The health risk assessment is being conducted following a semi-quantitative method according to WHO Guidelines for SSP (WHO, 2015) and it will include: i) the characterization of the integrated system, from wastewater catchment to treatment, delivery and reuse in agriculture, also with the support of checklists; ii) the identification and the analysis of possible hazards and hazardous events, and iii) the quantification of risks by the attribution of scores to probability and severity of the detected hazardous events.

Additional requirements (KRM6)

Additional requirements were not identified from risk assessment evidence, even if additional monitoring could be set for the environmental hazards that could pose a risk to crops, soil, surface or groundwater, or any of the protected areas (e.g., salinity, chloride, metals).

Preventive measures (KRM7)

Preventive measures include treatment units and controls already set up in the WWTP. Multiparametric sensors are installed for continuous online monitoring and control system.

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

Monitoring programs are performed through quality control system, including operational and routine monitoring.

The WWTP is provided with a network of sensors for continuous monitoring and management of the processes. Operational monitoring is already applied at WWTP level (KRM8), including periodic standard lab measures (according to D. Lgs 152/2006 and WFD), coupled with real-time monitoring with sensors.

For RMP, different monitoring plans are proposed, considering different levels of detail, frequencies and digital support (Table CS9.3).

Table CS9.3. Monitoring plans proposed for the San Benedetto del Tronto water reuse system

Level	Control point	Parameters	Frequency
Base	Effluent reclaimed water	pH, Conductivity, UV absorption for organic load, TSS/Turbidity	Continuous (sensors)
		TSS, Nitrates, Ammonia, Phosphates, BOD5, COD, *E. coli*, Salmonella, Legionella, Intestinal Nematodes, other parameters from DM 185/2003	From weekly to monthly (lab analyses)
Moderate	Effluent reclaimed water	pH, Conductivity, UV absorbance, TSS/Turbidity, Nitrates, Ammonia, Phosphates	Continuous (sensors)
		TSS, Nitrates, Ammonia, Phosphates, BOD5, COD, *E. coli* (weekly), Salmonella, Legionella, Intestinal Nematodes, other parameters from DM 185/2003	From weekly to monthly (lab analyses)
Advanced	Effluent reclaimed water	pH, Conductivity, UV absorbance, TSS/Turbidity, Nitrates, Ammonia, Phosphates	Continuous (sensors)
		E. coli	Daily
		TSS, Nitrates, Ammonia, Phosphates, BOD5, COD, Salmonella, Legionella, Intestinal	From weekly to monthly (lab analyses)

Level	Control point	Parameters	Frequency
		Nematodes, other parameters from DM 185/2003	
		CECs e.g., pharmaceuticals, microplastics, pesticides, disinfection by-products, antibiotic resistance	Semestral-annual (lab analyses)
	Distribution	*E. coli*, Salmonella, Legionella, Intestinal Nematodes (optional Coliforms and Faecal streptococci)	From weekly to monthly (lab analyses)
	Soil	pH, organic matter, C, N, assimilable P-Na-K, Chlorides, Coliforms, Streptococci, heavy metals	Beginning and end of irrigation season
Additional Digital support	WWTP	Alert System sensor for *E. coli* and Enterococchi measurements (see Peschiera Borromeo case-study)	Continuous (sensors)
		Early Warning System (see Peschiera Borromeo case-study)	
		TOC sensor	
		Sensors network implementation at the influent	

MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

Coordination and communication are established among the involved parties: Water Utility, Irrigation infrastructure, Natural Park.

4.11 Case Study 10: risk assessment framework for Malta's New Water Project, Malta ([40])

MODULE I

System description (KRM1)

New Water is a new programme for developing *water reuse system*s in Malta to produce high quality standards reclaimed water suitable for safe crop irrigation ([41]). The project involved the development of three polishing plants (reclamation facilities) within the WWTPs equipped with Ultra-Filtration (UF), Reverse Osmosis (RO) and Advanced Oxidation (AO) processes for the further treatment of effluents from three WWTPs to remove bacteria, chemicals, CECs and salinity exceeding second class standards (Figure CS10.2). The three systems are located at Ras il –Hobz (Ghajnsielem) in Gozo, Tac-Cumnija (Mellieha) in the North of Malta, and Ta' Barkat (Xghajra) in the south of Malta. Each water reuse system also includes storage units and dedicated distribution networks, which delivers the reclaimed water to automated distribution points (hydrants which are accessed by electronic cards) accessible to farmers (Figure CS10.1). The total l design production capacity of the three plants is 18,000 m^3/d peak corresponding to 35% of the current Maltese irrigation demand. The current production level peaks at 8,700 m^3/d due to the need to expand the distribution networks, which is under development, and to variability in irrigation demand. By treating water to high quality standard, *New Water* also aims at achieving good groundwater quantitative status in all groundwater bodies of the Maltese islands.

([40]) Contributor: Manuel Sapiano, The Energy and Water Agency, Malta. manuel.Sapiano@gov.mt

([41]) https://www.wsc.com.mt/information/new-water/

Figure CS10.1. Schematic of the *new water reuse systems* in Malta

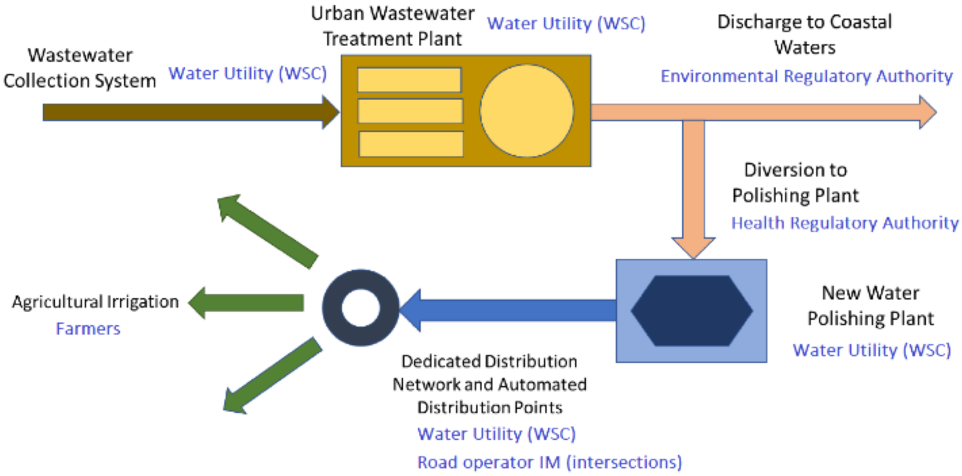
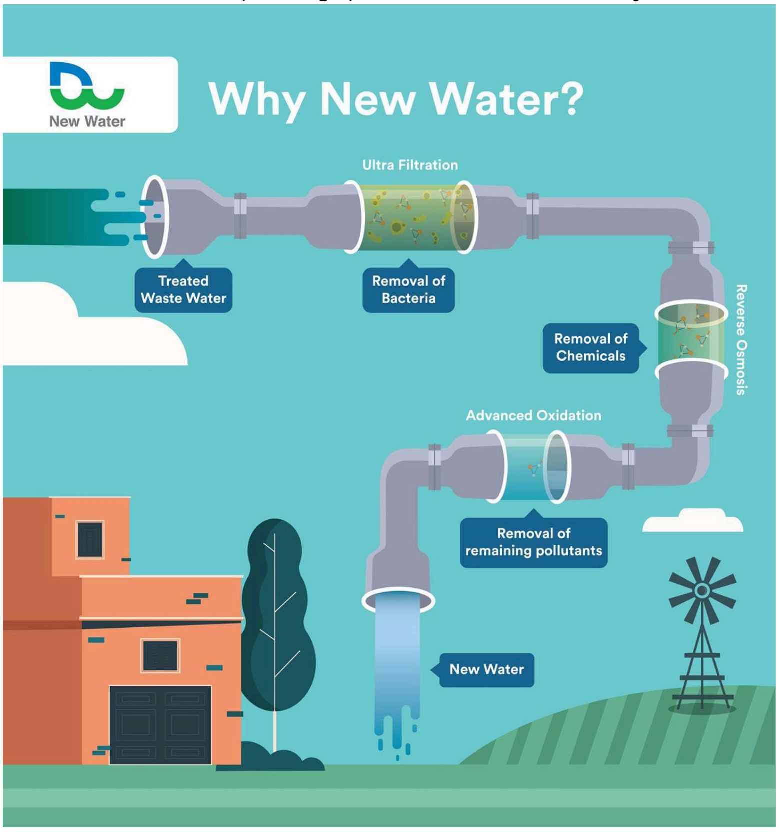


Figure CS10.2. Treatment line of the polishing systems of the *New Water Project* for water reuse in Malta



Parties involved, roles and responsibilities (KRM2)

Multiple institutions are involved in the promotion, regulation and provision of reclaimed water under the *New Water* programme.

Information on the roles and responsibilities of the parties involved in this case study is given in Table CS10.1.

Table CS10.1. Roles and responsibilities of parties involved at the new water reuse system ([1])

Parties involved	Roles	Responsibilities
Health Regulatory Authority (Food Safety Commission)	Approval of New Water System	Control reclaimed water quality at the point of compliance (points of exit from the distribution hydrants) in case of water reuse ([2])

Parties involved	Roles	Responsibilities
Environment and Resource Authority (ERA)	Environmental Regulatory Authority	Regulates the quality of the effluent discharged in coastal waters (2)
Regulatory for Energy and Water Services (REWS)	Economic Regulatory Authority	Regulates and monitor the efficient production and use of water
Water utility (WSC)	Provider of Water Services in the Maltese islands, and operator of the water reclamation plants.	Operations of sewer networks, WWTPs, reclamation facilities, storage systems and distribution networks
Infrastructure Malta (IM)	Agency for the development, maintenance and upgrading of the road network and other public infrastructure	Involved due to intersections between the distribution network and the roadways
Farmers	End-users	Responsible for private irrigation systems after the distribution points

(1) Ministries and regulators of water, environment, agriculture, health and economy (MESD, MECP, MAFA) are involved in the promotion, regulation and provision of reclaimed water. Parties responsible for the RMP were not yet identified at this stage.

(2) According to the Regulation (EU) 741/2020 (Art 3 (11), point of compliance means the point where a reclamation facility operator delivers reclaimed water to the next actor in the chain. In this case, the next actor in the chain are the farmers.

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4), risk assessment (KRM5), and additional requirements (KRM6)

Health and environmental hazards were identified by considering the quality of the treated effluents and any directive, regulation and legislation applicable based on the identified exposed environments via potential routes. Health and environmental risks were assessed qualitatively. No specific health hazards (pathogens or pollutants) were considered in the reclaimed water for risk assessment due to its elevated quality standard[42]. However, hazardous events that would negatively impact the water quality and could pose a risk to the health of workers and farmers were identified and specific preventive measures and actions were planned to ensure that any accidental contact with reclaimed water is minimized.

The environmental risks were evaluated by assessing the presence and status of any surface water and groundwater connected to the irrigated fields. Environmental risks were thus managed by ensuring compliance of the reclaimed water with the parameters listed in the Nitrates, DWD, WFD and GWD directives. Risks to soil and crops were minimized by following the requirements of the FAO Guidelines (Ayers and Westcot, 1985) for irrigational water quality standards (Table CS10.2).

Table CS10.2. Identification of hazards and hazardous events, routes of exposure, populations and environments at risk, and resulting risks for the new water reuse system

	Hazards	Populations and environments at risk	Routes of exposure	Risks
Health	Bacteria (*E. coli*).	WWTP and reclamation facility workers	Inhalation, ingestion and/or direct skin contact with reclaimed water	Minimal due to the high quality of the effluent which reaches DWD standards (1). (Health hazards were further assessed considering hazardous events).
		End users (farmers)	Ingestion and/or direct skin contact with reclaimed water	
Environment	Parameters which could inhibit crop growth and cause degradation of soil structure, identified from	Crops	Irrigation (crops uptakes or direct contact with reclaimed water)	Risks minimized by ensuring compliance of reclaimed water quality with FAO

(42) The effluent from the WWTP complies with the quality standards indicated in the DWD.

	Hazards	Populations and environments at risk	Routes of exposure	Risks
	FAO's Water Quality for Agriculture (2): Salinity: Electrical Conductivity, Total Dissolved Solids, Cations and Anions (Calcium, Magnesium, Sodium, Carbonate, Bicarbonate, Chloride, Sulphate) Nutrients: Nitrate-Nitrogen, Ammonia-Nitrogen, Phosphate-Phosphorus, Potassium Miscellaneous: Boron, pH, SAR	Soil	Infiltration in the soil (that would cause salinization and soil structure degradation)	Water Quality for Agriculture.
	Drinking water quality parameters, according to the DWD	Catchment area for drinking water below the irrigation fields (groundwater)	Infiltration in the overlaps between irrigational field and drinking water catchment areas located in low vulnerability zones	Risk minimized by quality of reclaimed water reaching DWD standards
	Nitrates, according to the Nitrates Directive ([3])	Groundwater and soil	Run-off and infiltration of reclaimed water	Low risk since Nitrate content of reclaimed water <5mg/l
	Water quality parameters, according to the WFD ([4])	Surface water and groundwater	Run-off and infiltration of reclaimed water	Risk minimized by quality of reclaimed water reaching DWD standards.
	Additional contaminants identified from the GWD ([5]), including: Pharmaceuticals Contaminants of Emerging Concern Disinfection by-products Salinity	Groundwater	Infiltration of reclaimed water	Risks of potential input of Emerging Contaminants in groundwater is mitigated by the high-end treatment system (including membrane filtration) and any risk is further balanced by the beneficial contribution of low salinity content in reclaimed water contributing to good status of the groundwater.
Hazardous events				
Sewer network: Uncontrolled discharges WWTP and reclamation facility: malfunctions Distribution system: improper storage of reclaimed water User zone: Improper storage and mixing of reclaimed water with other sources				Monitoring programs and regulatory frameworks are in place to identify hazardous events and actions are planned to minimize risks.

([1]) Drinking Water Directive – DWD 98/83/EC, recast 2020/2184/EU
([2]) (Ayers and Westcot, 1985). Water quality for agriculture. FAO Irrigation and Drainage Paper, 0254-5284.
([3]) Nitrates Directive 91/676/EC
([4]) Water Framework Directive – WDF 2000/60/EC
([5]) Groundwater Directive – GWD 2006/118/EC

Any parameters identified from the health and environmental risk assessment, additional to the minimum requirements, (KRM6) were then included in the monitoring programmes. This list includes all the parameters and contaminants, along with their thresholds, identified from any directive and regulations considered during the risk assessment (i.e., WFD, DWD, GWD, FAO guidelines).

Preventive Measures (KRM7)

Other than the treatment processes and controls already set up in the WWTPs, additional preventive measures were implemented in the new water reuse system, as reported in Table CS10.3.

Table CS10.3. Identification of some preventive measures at the new water reuse system in Malta

At the WWTP and reclamation facility	At end-users (irrigated areas)
Ultra-Filtration for Bacteria removal Reverse Osmosis for chemicals removal and salinity Advanced Oxidation for the removal for other pollutants (CECs) removal Access limited to only WSC personnel Set-up of an on-line monitoring system (see Table CS10.4)	Users access controlled and limited by automated access system Pressurized distribution system (to avoid leakage and salinity intrusion), use of underground pipes Clear delineation of distribution network (purple) to avoid cross-contamination Isolated distribution reservoirs Remote control of distribution points (see Table CS10.4)

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

In addition to the operational and routine monitoring already in place at the WWTPs to assess correct operations of treatments performed by water utility and control authorities, monitoring activities were set out based on the additional requirements identified from the risk assessment. Control points, additional to the point of compliance, were also identified along the water reuse system to check the effectiveness of the preventive measures in place (Table CS10.4).

Table CS10.4. Monitoring system set out at the new water reuse system, Malta

Quality Control System (KRM8)	Control points
Operational monitoring of chemical and biological parameters: agronomic parameters (SAR, boron, salinity), pharmaceuticals, CECs, DBPs. Automated monitoring system (see Module IV) Additional monitoring at reservoirs (storage system within the New Water network) to validate monitoring at the exit of the treatment plant.	Exit points from treatment plants. Exit from network distribution points (point of compliance). Controls by Health Regulatory Authority (verification monitoring).

MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

The Emergency Response System consists of an automated monitoring system for immediate alert to site operators and remote control of the distribution system. The access to the reclaimed water distribution points can be withheld from a central control room. The contact details of permitted users are centrally held by the public utility and used for prompt communication and warning notices.

4.12 Case Study 11: quantitative microbial risk assessment for agricultural irrigation – practical case in Murcia Region, Spain ([43])

MODULE I

System description (KRM1)

The water reuse systems of this case study are located in Cartagena (system 1) and Lorca (systems 2 and 3) (Murcia, Spain) ([44]). Each water reuse system consists of a combination of a WWTP, one or two reservoirs (at the WWTP and/or farmer levels), a distribution network, and irrigation systems (Figures CS11.1, CS11.2 and

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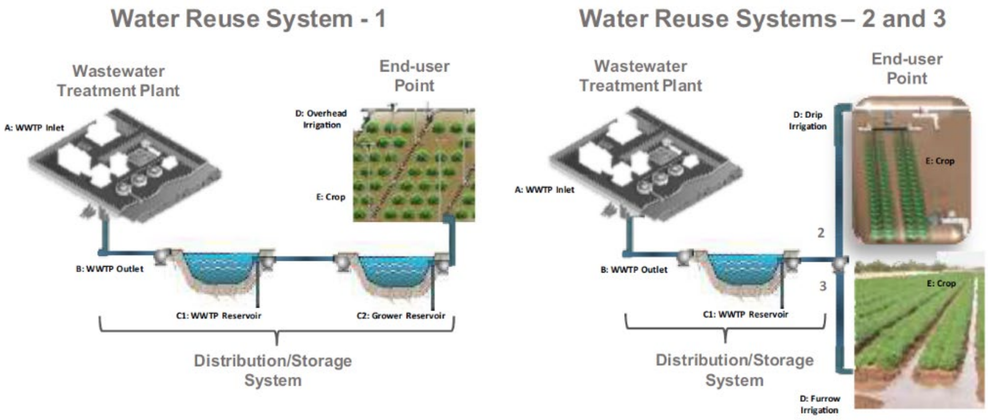
([44]) Cartagena WWTP: https://goo.gl/maps/b8aNvibEpn5KQahC7;

CS11.3). The two WWTPs of the water reuse systems differ for the disinfection treatment, i.e., WWTP of system 1 employs ultraviolet-C light (UV-C) and the WWTP of systems 2 and 3 employ sodium hypochlorite (NaClO).
Cartagena water reuse system is supplied from reclaimed water of Torre Pacheco WWTP. This WWTP is an extended aeration system and consists of a conventional pre-treatment, followed by a biological reactor and secondary clarifier. The reclamation process consists of a physio-chemical process with a lamellar clarifier, sand filtration and disinfection by UV-C. Capacity of Torre Pacheco WWTP is 7,500 m^3/day.
Lorca water reuse system is supplied from reclaimed water of Lorca WWTP. This WWTP consists of a conventional pre-treatment followed by two stages of biological treatment and clarifier. Reclamation plant consists of sand filtration and sodium hypochlorite. Capacity of Torre Pacheco WWTP is 20,000 m^3/day, with an average influent flow of 11,300 m^3/day.
For system 1 (Cartagena), the reclaimed water is first stored in a water reservoir located at the WWTP, and then reclaimed water is stored by the farmers in a second reservoir, and it is supplied by overhead (sprinkler) irrigation method for the cultivation of spinach. For systems 2 and 3 (Lorca), reclaimed water is stored in a water reservoir located at the WWTP, but there is no storage of reclaimed water by the farmers. In these cases, drip irrigation (system 2) or furrow irrigation (system 3) methods are applied for cultivation of lettuce. The three water reuse systems were monitored to ensure compliance with the minimum requirements set out in the Regulation (EU) 741/2020. The study was conducted between 2018-2020 and included a comparison of the efficiency of the WWTPs and of the irrigation systems (drip, furrow and overhead) used in the three systems.

Figure CS11.1. Schematic of the three water reuse systems located in the Murcia Region, Spain



Source: Truchado et al. (2021)

Figure CS11.2. Water reuse systems 2 and 3

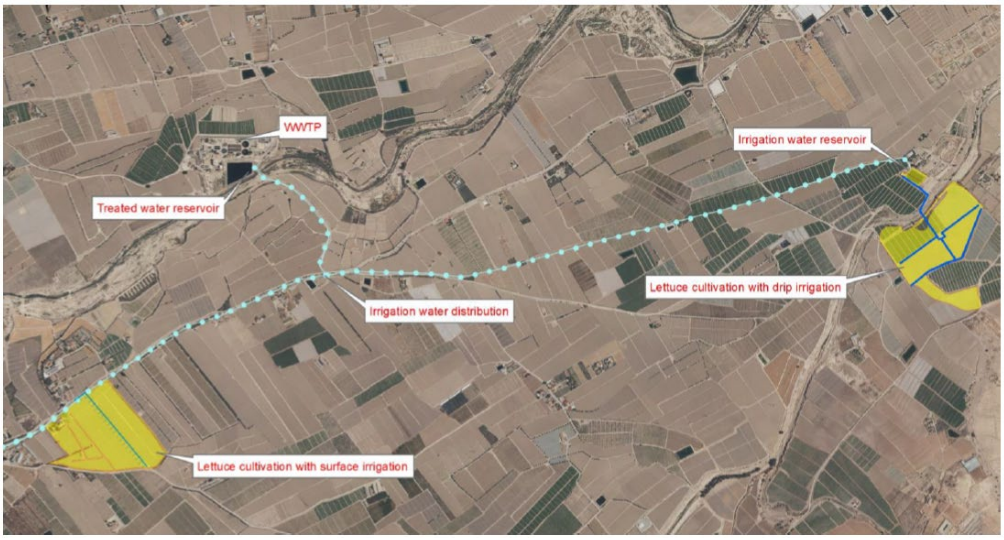


Figure CS11.3. Water reuse system 1

Parties involved, roles and responsibilities (KRM2)

The parties involved in the study conducted on the water reuse systems, along with their roles and responsibilities, are indicated in Tables CS11.1 and CS11.2.

Table CS11.1. Roles and responsibilities of parties involved in the water reuse system 1

Parties involved (1)	Roles	Responsibilities
CADAGUA	WWTP and reclamation facility operator	Operation of WWTP and reclamation facility. Production and supply of reclaimed water
ESAMUR	Wastewater management responsible	Promotor of QMRA
CEBAS-CSIC	Research center	Development of QMRA
Irrigator Association (Comunidad de regantes del Campo de Cartagena)	Management of reservoirs and distribution	Responsible of main reservoirs and water distribution
Farmers	End users	Responsible for private reservoirs and irrigation

(1) The table refers to the parties involved in the management and not in RMP, which were not identified at the preparation of this guidance document.

Table CS11.2. Roles and responsibilities of parties involved in the water reuse systems 2 and 3

Parties involved (1)	Roles	Responsibilities
AGUAS DE LORCA	WWTP and reclamation facility operator	Operation of WWTP and reclamation facility. Production and supply of reclaimed water
ESAMUR	Wastewater management responsible	Promotor of QMRA
CEBAS-CSIC	Research center	Development of QMRA
Irrigator Association (Comunidad de regantes del Campo de Lorca)	Management of reservoirs and distribution	Responsible of main reservoirs and water distribution
Farmers	End users	Responsible for private reservoirs and irrigation

(1) The table refers to the parties involved in the management and not in RMP, which were not identified at the preparation of this guidance document.

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4)

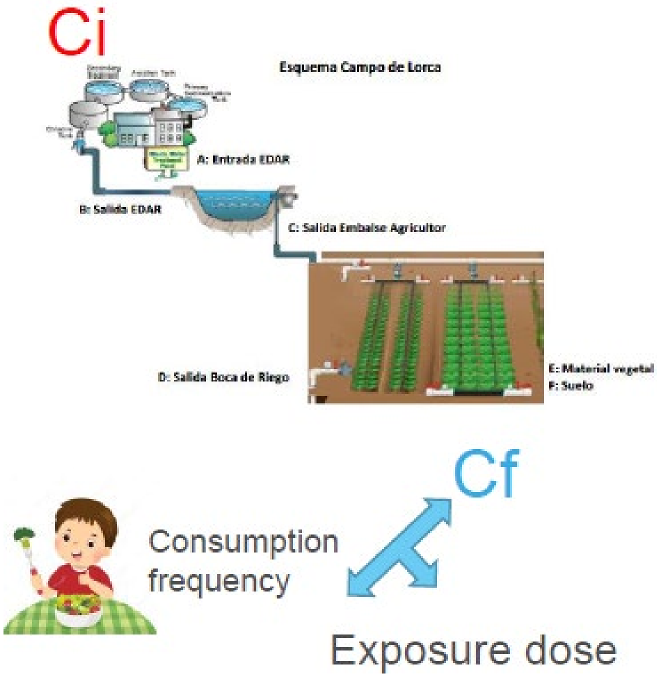
The aim is to identify the hazards related to the water reuse systems, populations at risk, and how the hazardous events causing risk can occur. The hazards included in this exposure assessment together with the populations at risk are presented in Tables CS11.3 and Figure CS11.4.

Table CS11.3. Identification of hazards, route of exposure and populations and environment at risk at the Murcia Region water reuse systems

	Hazards and hazardous events	**Populations and environments at risk ([1])**	**Routes of exposure**
Health and environmental hazards	Biological: Salmonella spp. STEC (pathogenic *E. coli*) Norovirus Hepatitis A	Local community and by-standers	Ingestion and/or direct skin contact with reclaimed water
		WWTP and reclamation facility workers	Inhalation, ingestion and/or direct skin contact with reclaimed water
		Farmers	Ingestion and/or direct skin contact with reclaimed water
		Consumers of agricultural products	Ingestion of crops
		Flora/ fauna	Environmental impact
	Chemical: Disinfection-by-products (DBPs) including THMs and chlorates	Consumers of agricultural products	Ingestion of crops
		Groundwater	Environmental impact
		Soil	Environmental impact
		Flora/ fauna	Environmental impact
Hazardous events	WWTP: Punctual failure of disinfection treatment (UV-C and/or chlorine failure)	Local community and by-standers WWTP and reclamation facility workers; Farmers; Consumers of agricultural products; environment	
	Cross-contamination during the distribution of the water (Cow barn run-off)		

(1) Even if in this case-study they were considered, consumers wouldn't be taken into account in RMP, since they are outside water reuse system boundaries.

Figure CS11.4. Identification of exposed environments at the Murcia Region water reuse system



Risk assessment (KRM5)

In this case study, an exposure assessment model was developed to describe the risk associated with the consumption of leafy greens irrigated with reclaimed water from the two WWTPs, using *E. coli* as indicator microorganism ([45]). Although other microorganisms were also evaluated (spores of *Clostridium perfringens* and *coliphages*), the case study focused on an exposure assessment of the indicator microorganism *E. coli*.

The model was implemented as a Bayesian Network, where the conditional probabilities have been estimated using experimental data gathered in several fields located in Murcia, Spain. The model was supported by previous scientific evidence which establish the probability of finding a pathogenic microorganism based on *E. coli* levels present in the reclaimed water (Truchado et al., 2018).

Four different scenarios were analysed depending on the range of WWTPs effluent data (Scenario 0: *E. coli* not detected; Scenario I: *E. coli* < 1 log CFU/100 mL; Scenario II: *E. coli* < 2 log CFU/100 mL; Scenario III: *E. coli* > 2 log CFU/100 mL. Concentrations and consumption frequencies were combined to obtain the exposure dose and, through dose-response curves, to get the probability of illness.

The microbial concentration in the irrigation water on the outlet of the WWTP (within the ranges and conditions included in this study) had little impact on the probability of microbial concentration on the crop being higher than 2 log CFU/g (a value commonly used as threshold). This probability is also barely affected by the irrigation system (overhead, drip or furrow). Instead, it is dominated by soil-to-plant contamination due to rain splashing (i.e., when raindrops splash pathogens from the soil onto crops).

Regarding chemical hazards, the results of this study showed that when reclaimed water after chlorine treatment was used for irrigation, there was a chlorate accumulation in lettuce, even though the level of chlorate in reclaimed water did not exceed the level allowed for potable water. It is worth noting that the chlorate content in the lettuce samples was always higher than in the soil samples ($p < 0.001$), showing a mean value of 5.3 folds higher in lettuce than soil.

Additional requirements (KRM6)

Additional requirements were set for microbial hazards to measure their concentrations at different stages of the system and to investigate the correlations between indicators (*E. coli*) and pathogens. For chemical hazards, DBPs were chosen. Additional parameters included:

- Indicators: *E. coli*, *Clostridium* perfringens spores and Coliphages.
- Pathogens: *E. coli* O-157, Shiga toxin-producing, *E. coli* (STEC), *Salmonella spp.*, Norovirus, hepatitis A.

([45]) It should be noted that a risk assessment related to the consumers is not required by these guidelines since they are outside water reuse system boundaries

— DBPs, Trihalomethanes and Chlorates.

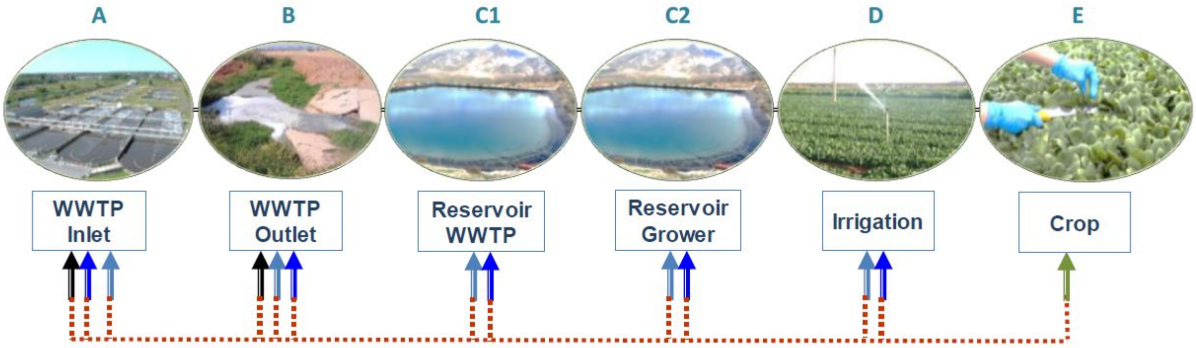
Preventive measures (KRM7)
Other than the treatment units and controls already set up in the WWTP, additional preventive measures were implemented in the *Murcia Region* water reuse system at end-users (irrigated areas), including storage reservoir and the use of different irrigation techniques (drip, sprinkler, surface).

MODULE III

Quality control (KRM8), environmental monitoring systems (KRM9)

Other than the monitoring already performed by water utility and control authorities, additional monitoring was implemented with two-year monitoring campaign on WWTPs influent and effluent, reservoir, farmers reservoirs, distribution, irrigation systems and crops, with 570 collected samples, as shown in Figure CS11.5. Monitored parameters included microbial indicators and pathogens, as well as DBPs.

Figure CS11.5. Monitoring points at the Murcia Region water reuse system



MODULE IV

Incidents and emergency systems (KRM10), coordination mechanisms (KRM11)

The water reuse system includes not only the efficacy of water-reclamation treatment processes but also all the steps from the generation of the water to the point of use at the field. To avoid potential contamination of reclaimed water, all the actors play a role in the preservation of the quality of the water.
Communication between all the actors of the water reuse systems was continuous during the studies and the results have been communicated to Water Authority and Health Authorities and disseminated in numerous technical forums and scientific publications.

4.13 Case Study 12: towards zero pollution and integral wastewater reuse - the case study of Fasano, Italy ([46])

MODULE I
System description (KRM1)
The water reuse system of *Fasano-Forcatella*, in operation since 2007, is located in Fasano (Puglia, Italy) ([47]). The system is composed by a biological WWTP whose effluent is further treated by clarifloculation, advanced oxidation with ozone, lamellar clarifiers and PAC filter (Figure CS12.1). The reclaimed water, treated to irrigation standards levels of Italian law on water reuse DM 185/2003, is then collected in a storage, stabilization and naturalization basin of 40,000 m^3 (*Lago Forcatella*, Figure CS12.2) ([48]) to compensate for the changes in demand from farmers while allowing to the reinstatement of biodiversity in the area. During lower water demand for irrigation, the overflow from the storage basin is dispersed on the ground to allow for indirect aquifer recharge and mitigate seawater intrusion, a minimum flowrate is used to control the seawater intrusion and groundwater overexploitation. The reclaimed water is distributed to more than 50 local farmers on-demand via a pay-as-you-go service (fees are based on distance and volume, treatment fee is not charged). Further

([46]) Contributors: Domenico Santoro, AquaSoil SrL. Teresa Masi: info@aquasoil.it
([47]) https://goo.gl/maps/e38hCQ36tb4JGTU6A
([48]) Aquasoil - Impianto di affinamento acque reflue urbane "Lago Forcatella"

activities include pilot scale experiments for the investigation of water reuse used for irrigation of vineyards and ornamental plants.

Figure CS12.1. Schematic of the reclamation facility treatments of the water reuse system Fasano-Forcatella, Italy

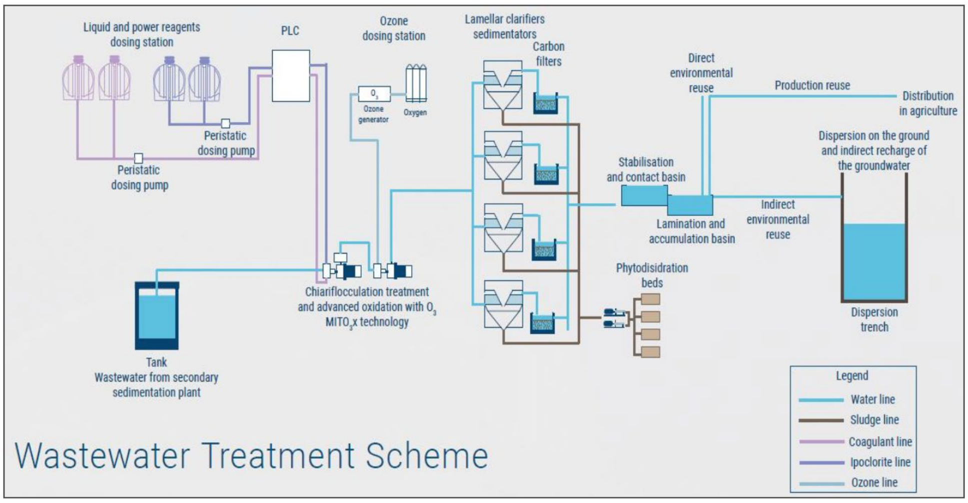


Figure CS12.2. View of the water reuse system Fasano-Forcatella (left) and of the *Lago Forcatella* accumulation basin (right)

Parties involved, roles and responsibilities (KRM2)

The responsible parties involved in the management of the Forcatella water reuse system are reported in Table CS12.1.

Table CS12.1. Roles and responsibilities of parties involved for the management of the water reuse system Fasano-Forcatella (Italy) ([1])

Parties involved	**Roles**	**Responsibilities**
AquaSoil s.r.l ([2])	Environmental Consultant Company	Management of the reclamation facility
Regione Puglia	Regional Authority	Management and protection of water resources at regional scale
Autorità Idrica Pugliese	Apulian Water Authority	Representative of the Apulian municipalities for public water management
Comune di Fasano	Fasano Municipal Authority	Plant owner
Provincia di Brindisi	Provincial Authority	Local regulators
ARPA Puglia	Regional Environmental Protection Agency	Compliance control

([1]) Roles and responsibilities for the Risk Management Plan were not identified at this stage.

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4), risk assessment (KRM5) and additional requirements (KRM6)

Risk assessment aimed at identifying risks linked to the acquirer recharge using reclaimed water (MAR) (Masciopinto et al., 2020). A risk management procedure was developed to assess any risks linked to the infiltration of the reclaimed water accumulated in The *Lago Forcatella* basin and its transportation to the coastal area in order to protect the aquifer and the human health during recharging procedure (Table CS12.2). The infiltration of reclaimed water to groundwater is facilitated using a ditch connected to the accumulation basin (Figure CS12.3).

Table CS12.2. Identification of hazards, routes of exposure and populations and environments at risk due to irrigation and MAR operations at the Fasano-Forcatella water reuse system

Hazards	**Populations and environments at risk**	**Routes of exposure**
E. coli	Individuals that could eat raw crops irrigated with reclaimed water (1)	Ingestion
	Individuals bathing in downstream beaches that receive reclaimed water from the aquifer	Ingestion Dermal contact
	Bathing water (environmental risk)	Transportation of reclaimed water from aquifer recharge to the coast

(1) Farmers or by-standers. Consumers are excluded from the RMP (see boundary in Figure 9 of Section 3.2.1).

The risk assessment was conducted for the pathogenic bacteria O157:H7 and O26:H11 by quantitative approach (QMRA) using a dose-response model and a Monte Carlo Markov Chain (MCMC) Bayesian method. The MCMC allowed for the calculation of the most probable pathogen counts at the target while minimizing the number of water samplings. Sampling stations were positioned along the coast based on the results of a groundwater flow and pathogen transport models (Figure CS12.4 and Figure CS12.5).

QMRA indicated tolerable (<10^{-6} DALY) health risks for both the reuse practises analysed at the Forcatella water reuse system: (direct irrigation of horticultural species to be eaten raw and indirect aquifer recharge with subsequent bathing near the springs. The results show low health risk and insignificant impacts on the coastal water quality even when the *E. coli* concentration exceeded by 5.3 times (53 CFU/100 ml) the EU regulation limit of 10 CFU/100 mL for Class A of reclaimed water.

Additional research activities conducted at the Forcatella water reuse system include the investigations of innovative treatment processes and technologies and emerging water quality issues like pathogens in biofilm, micro-pollutants, antibiotic-resistant bacteria, disinfection/oxidations by-products, and process control strategies.

Figure CS12.3. Details on acquirer recharge procedure and water sampling points (S1, S2, S3).

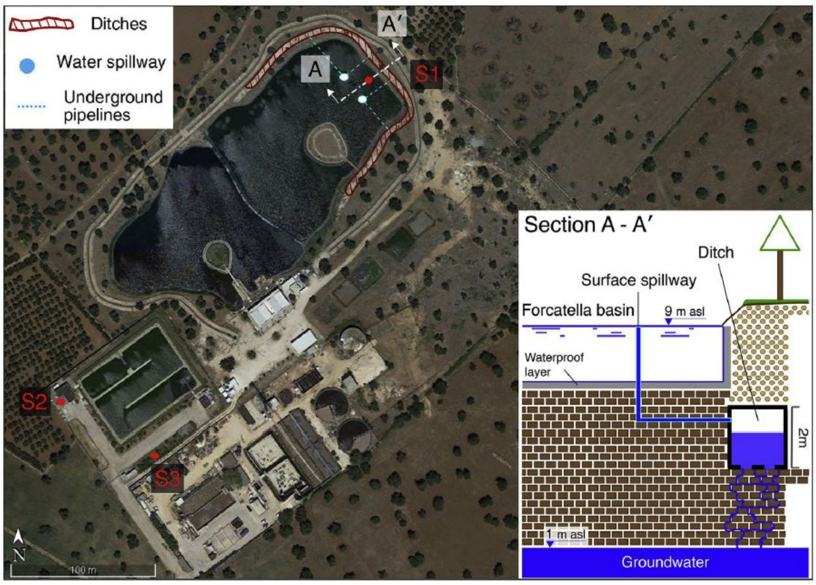


Figure CS12.4. Overview of the sampling stations: a) map of the study area; b) positions of the sampling stations of IRSA (Istituto di Ricerca Sulle Acque) (from S1 to S10) and ARPA (from AP1 to AP3), and irrigation pipelines (blue lines).

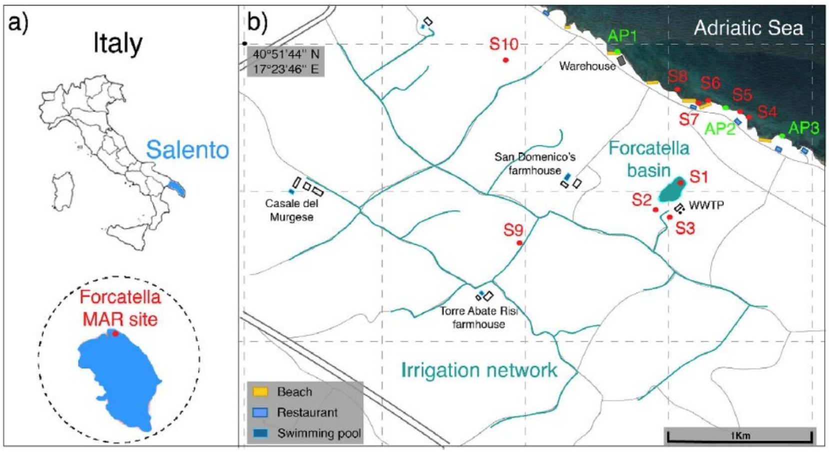
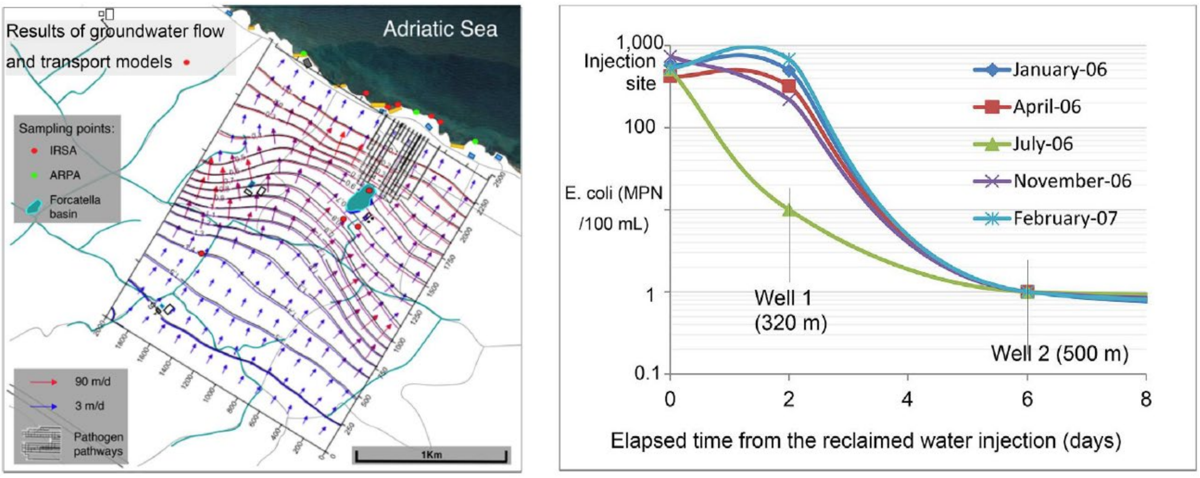


Figure CS12.5. Simulation results showing the flow velocity vectors and *E. coli* pathways (solid black lines) or plumes, during recharge operations at the *Forcatella* plant.



Note: The results show piezometric surface heads under both natural (red contour lines) and recharge groundwater flow conditions (blue contour lines) (left), and efficacy of soil aquifer treatment (SAT) on the *E. coli* removal from wastewater during filtration in fractured limestone aquifers**.**

4.14 Case Study 13: Water Reuse System of the San Rocco WWTP (Milan, Italy) – Application of a QMRA ([49])

MODULE I

System description (KRM1)

The water reuse system of Milano San Rocco (Italy) is located in Milan (Italy) ([50]) and it is operated by *Metropolitana Milanese (MM) SpA*. The biological WWTP of San Rocco is equipped with tertiary treatment (coagulation and sand filtration followed by UV disinfection) for the production of reclaimed water used for agricultural and industrial reuse. The UV disinfection aims at treating up to 4 m^3/s reclaimed water to *E. coli* < 10 CFU/100 mL during the irrigation season from May to September (Figure CS13.1). Reclaimed water from the San Rocco WWTP is then discharged in channels used for agricultural irrigation within a basin area of 101 km^2. The channels, namely *Roggia Pizzabrasa* and *Roggia Carlesca*, receive up to 3 and 1 m^3/s of reclaimed water, respectively (Figure CS13.2). The reclamation facility at the time of the preparation of this guidance, was operated under the requirements of the Italian Decree Law 185/2003 for water reuse with monitoring of BOD, COD, TSS, TN, TP, NH_4, and *E. coli* below the regulated limits for water reuse.

([49]) Contributors: Manuela Antonelli, Andrea Turolla, Jacopo Foschi (jacopo.foschi@polimi.it), Politecnico di Milano, Italy; Jade Mitchell, Michigan State University, USA; Marco Blazina, Andrea D'Anna, Caterina Jane Saracino (c.saracino@mmspa.eu), MM S.p.A., Italy.

([50]) https://goo.gl/maps/rV126Q4ujwRtN2H89

Figure CS13.1. Schematic of WWTP/reclamation facility of San Rocco (Italy)

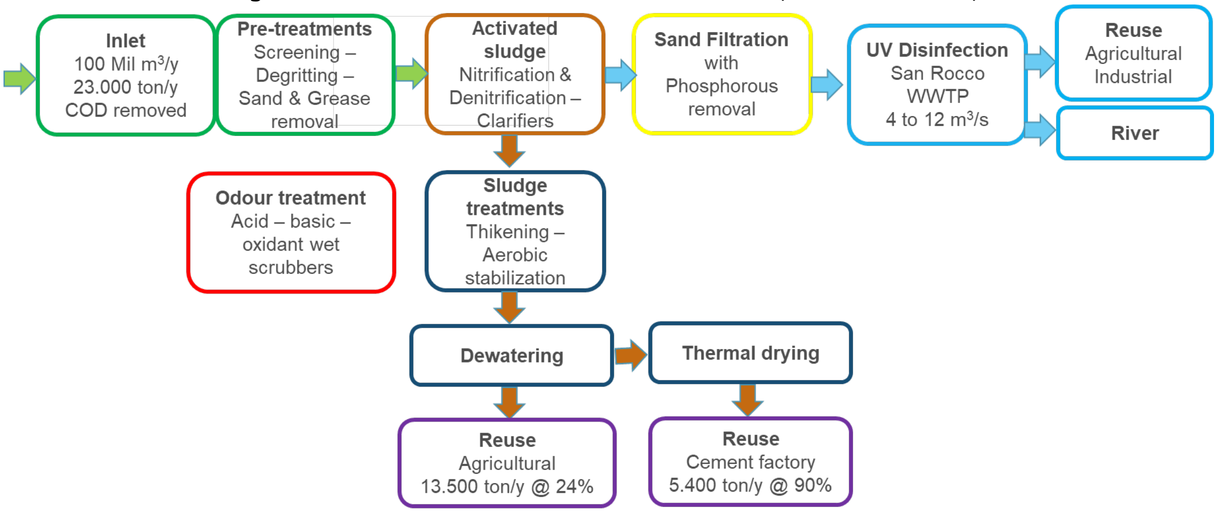
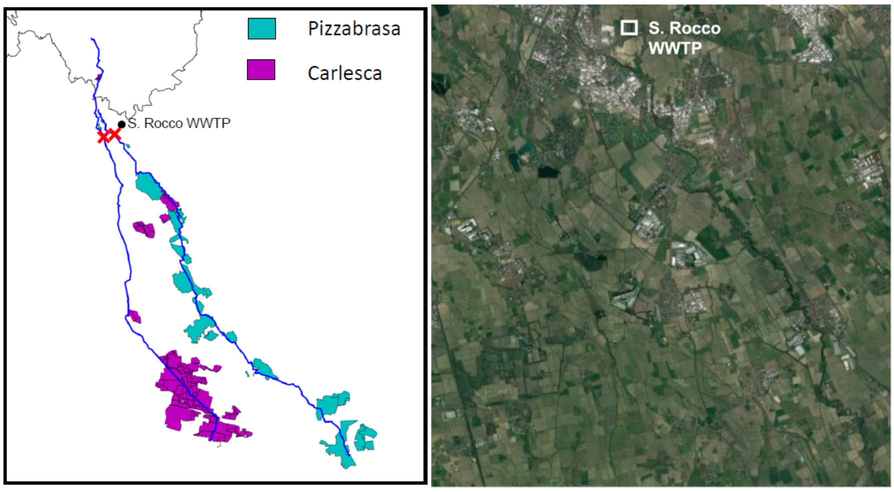


Figure CS13.2. Aerial view of irrigational channels and area served by the San Rocco water reuse system



For this case study, a quantitative microbial risk assessment (QMRA) was performed to assess any health risks linked to the indirect reuse of the reclaimed water discharged in the channels for use in agricultural irrigation. The methodology, developed by the DICA group of Politecnico di Milano and the RAMADA group of Michigan State University ([51]), is reported in the following section.

MODULE II

Hazards and hazardous events (KRM3), populations and environments at risk (KRM4), risk assessment (KRM5) and additional requirements (KRM6)

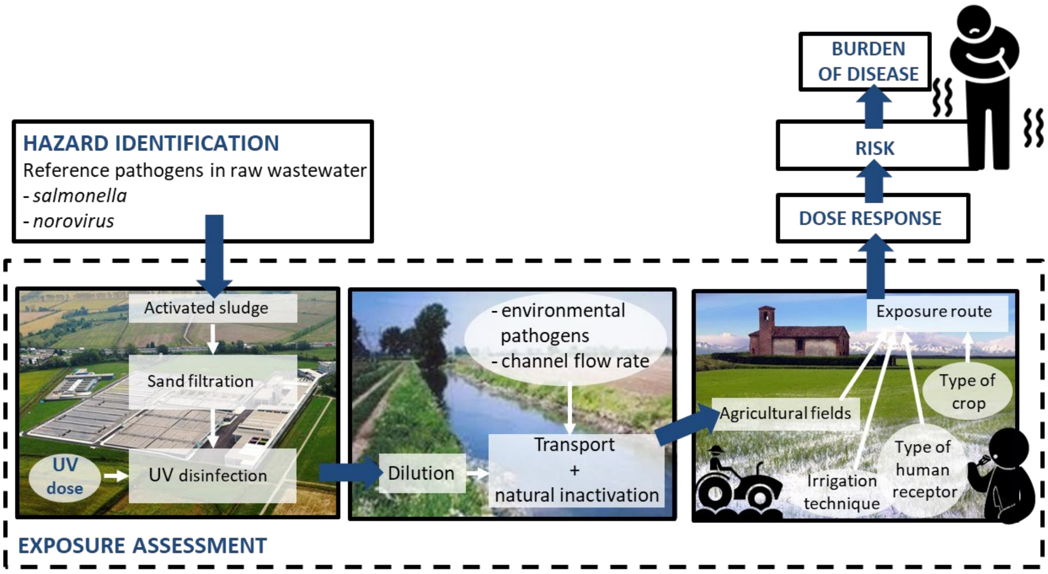
Health Risk Assessment was performed through a QMRA. The QMRA methodology follows a protocol that includes hazard identification, assessment of exposure of populations to health risk, identification of dose-response mathematical models, and characterization of risks by calculation of a burden of disease indicator.

Hazard identification: *salmonella* and *norovirus* were identified as reference pathogens for hazards on human health, being two of the main causes of waterborne gastroenteritis outbreaks. **Exposure assessment**: accidental ingestion of irrigation water particles by workers was considered as exposure scenario. Concentration of pathogens in irrigation water was estimated by modelling both removal throughout the WWTP treatment train and fate and transport after discharge, including dilution in canals and natural inactivation before reaching the point of exposure. Particularly, scenarios at increasing UV disinfection dose were explored, to assess beneficial impact of disinfection on irrigation water quality. Probability of ingestion of given amount of water containing pathogens by agricultural workers was simulated according to a model available in literature. **Dose-**

([51]) Department of Civil and Environmental Engineering (DICA), Politecnico di Milano, Milan, Italy. Biosystems and Agricultural Engineering Department (BAE), Michigan State University, Michigan, USA.

response: models available in literature were used to estimate risk of disease given the estimated concentration of pathogens in irrigation water and the resulting ingested dose. **Risk characterization**: Disability Adjusted Life Years (DALY) was computed as indicator of the burden of disease. DALY is one of the most widespread indicators, since it is a comprehensive measure of the overall disease burden, summing all the years lost due to illness, disability and/or early death.
Risk assessment was carried out with a probabilistic approach, where model input and parameters were assumed as probability distributions and risk and burden of diseases were estimated as probability distributions through the Monte Carlo method. The overall QMRA framework and exposure assessment conceptual model are reported in Figure CS13.3.

Figure CS13.3. Quantitative Microbial Risk Assessment methodology to assess health risks from pathogens at the San Rocco Reclamation facility.



An example of probabilistic QMRA output is presented in Figures CS13.4 and CS13.5. Figure CS13.4 shows the mapping of the 95th percentile of DALY resulting from accidental ingestion of salmonella and norovirus over agricultural fields, considering three scenarios with increasing average of UV disinfection dose. Same results are reported in Figure CS13.5 too, where areas with 95th percentile of DALY higher than 10^{-6} (person^{-1} y^{-1}), being the tolerable threshold set by WHO, are highlighted as “unsafe”. As can be seen, both disinfection and distance from the discharge point contribute to lower health risk by several order of magnitudes. In case of the lowest considered disinfection dose (45 mJ cm^{-2}) microbial quality at the point of discharge is not acceptable, but risk can be considered as tolerable if exposure occurs at sufficient distances. Differently, at higher disinfection doses, all areas can be considered as safe for the considered exposure scenario.
Figure CS13.4 shows how risk from *norovirus* decreases less rapidly than for the case of *salmonella*. This is due to a slower natural inactivation rate reported in scientific literature so far. This is an example of how specific characteristics of considered pathogens can impact QMRA output.
Overall, the QMRA revealed a very low risk for the system under study, thanks to a generally well-designed reuse system, suggesting that UV disinfection could be run at low doses, saving energy while still guaranteeing a tolerable health risk.

Figure CS13.4. Quantitative Microbial Risk Assessment results. Mapping of DALY gradient over agricultural fields.

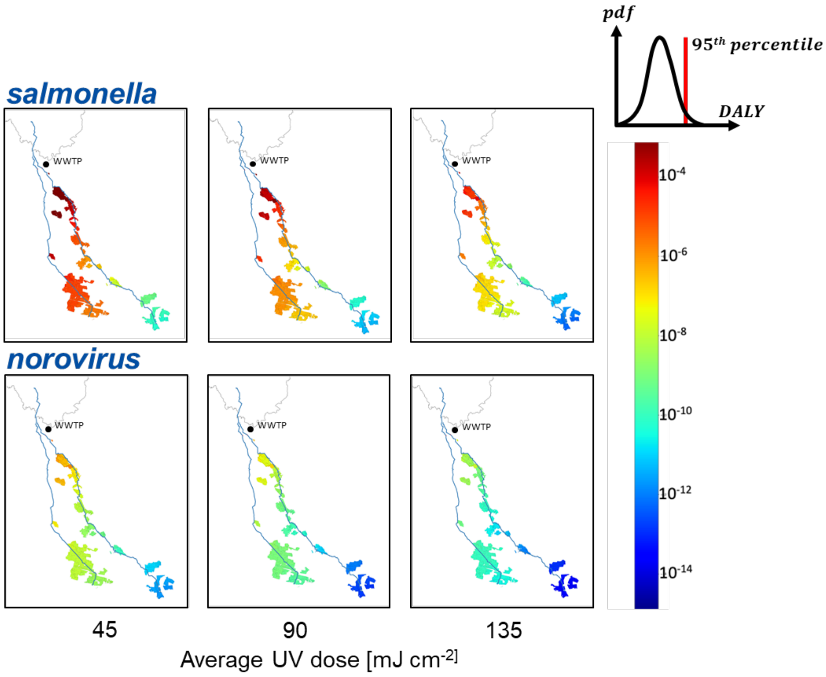
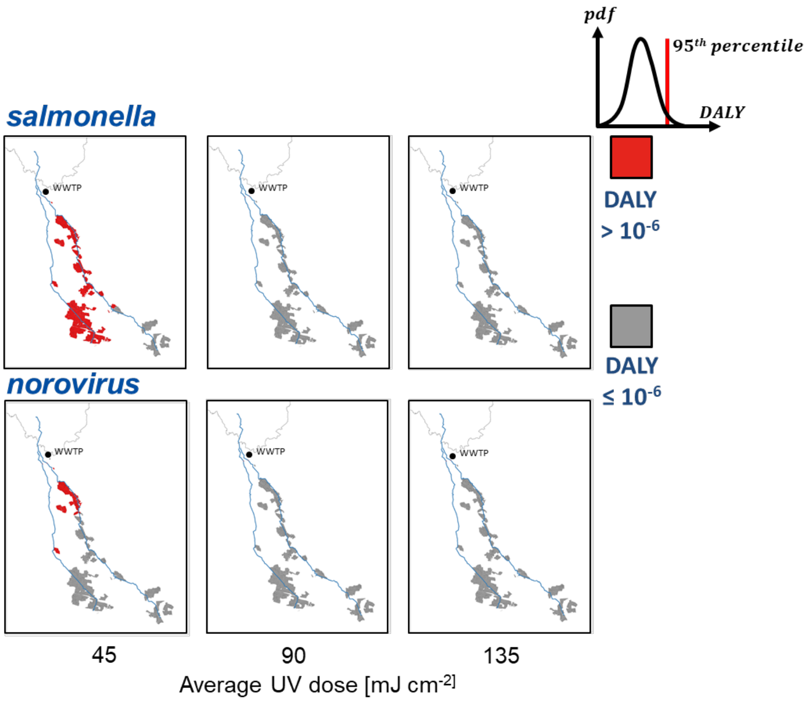


Figure CS13.5. Quantitative Microbial Risk Assessment results. Identification of safe and unsafe areas according to WHO threshold of 10^{-6} (person^{-1}y^{-1})



This work aims at impacting the traditional management of wastewater UV disinfection in wastewater reuse systems, by providing a risk-based quantitative approach to assess the trade-off between health risk and energy consumption coming from the increase in UV dose. In details, results highlighted importance of disinfection in controlling health risk, but suggested that all additional barriers met by pathogens in their path from discharge to exposure (e.g., natural inactivation) should be considered to optimize UV disinfectant dose, avoiding excessive energy consumption. QMRA can then support optimal management of disinfection as part of an integrated water reuse system.

Moreover, characterizing risk by QMRA allows to compare current case studies to risk-based guidelines and regulations, which are promoting a shift to risk-based management of water reuse systems.

Despite many benefits, performing QMRA requires to face several experimental and modelling challenges. Literature data on pathogen concentrations and inactivation (or regrowth) kinetics are often scarce or not representative of the system under study. Monitoring of pathogens is then needed to carry on QMRA which is as much site-specific as possible. Moreover, QMRA requires to model many and diverse infrastructure, environmental compartment and phenomena, which could require collection of specific additional data and expertise availability.

5 Conclusions

The EU's water resources are increasingly coming under pressure. This is leading to water stress, when water resources are insufficient to meet the needs, and to a deterioration in water quality. In addition, climate change, unpredictable weather patterns and drought are contributing significantly to the strain on the availability of freshwater. The use of reclaimed water in agricultural irrigation is widely recognised as a practice that helps manage water resources more efficiently and helps adapt our systems to climate change, in line with the EU's strategy set out in the European Green Deal.

Water reuse is commonly and successfully practiced in several EU Member States, as well as in, for example, Australia, California, Israel, and Singapore. However, water reuse is so far deployed below its potential in the EU. The limited awareness of potential benefits among stakeholders and the general public, and the lack of a supportive and coherent framework for water reuse were identified as two major barriers that prevent a wider spreading of this practice in the EU.

The Water Reuse Regulation, applicable from 26 June 2023, sets uniform minimum water quality requirements for the safe reuse of treated urban wastewater in agricultural irrigation. Harmonised minimum requirements will ensure the safety of agricultural produce across the European single market and boost consumer confidence.

In addition to the uniform minimum requirements for water quality, the Regulation also sets out uniform minimum monitoring requirements, risk management rules to assess and address potential additional health risks and environmental risks, permitting obligations, and rules on transparency, under which key information on all water reuse projects must be made publicly available.

This report provides an input to answer to article 11(5) of the Water Reuse Regulation, which requires the Commission, in consultation with Member States, to draw up guidelines for applying the Regulation, in particular with regard to the creation and implementation of a risk management plan. The risk management plan consists of additional requirements for plant operators, to be met before the water is delivered to the next actor in the chain. It also requires appropriate preventive/corrective measures and barriers, monitoring and/or other procedures to be applied in the water reuse system, to ensure its safety after the point of compliance. The risk management plan describes the tasks and requirements, and clearly identifies the responsibilities of the relevant actors in the scheme.

The report also provides a detailed guidance on how to address the so-called key elements of risk management (KRMs) established by the Water Reuse Regulation. The related risk assessment may be conducted with qualitative and semi-quantitative methods; quantitative risk assessment would require sufficient supporting data. This risk assessment should also consider any obligations and requirements set out by the EU legislation indicated in the Regulation, as well as any relevant national or local legislation.

Organised in 4 Modules (i.e., Module I – The Water Reuse System (KRMs 1 and 2); Module II - Risk Assessment (KRMs 3, 4, 5, 6 and 7); Module III – Monitoring (KRMs 8 and 9); Module IV- Management and Communication (KRMs 10 and 11)), this report presents a possible structure to implement water reuse risk management plans. It represents the current state of the art in the EU.

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List of abbreviations and definitions

AMHC	Australian Health Ministers' Conference
AMR	antimicrobial resistance
ARB	antibiotic-resistant bacteria
ARGs	antibiotic resistance genes
BOD	biochemical oxygen demand
CDPH	California Department of Public Health
CECs	contaminants of emerging concern
CIS	Common Implementation Strategy
DALY	Disability Adjusted Life Years
DBPs	Disinfection by-products
EC	European Commission
EPA	Environment Protection Agency
EPHC	Environment Protection and Heritage Council
ERA	Environmental Risk Assessment
EU	European Union
FP VII	Seventh Framework Programme for Research and Innovation
HACCP	Hazard Assessment and Critical Control Points
ICP	Inductively Coupled Plasma
ISO	International Standardization Organization
JRC	Joint Research Centre
KRM	key element of risk management
LUCAS	Land Use and Coverage Area frame Survey
MS	mass spectrometry
NRMMC	Natural Resource Management Ministerial Council
QA	Quality Assurance
QC	Quality Control
RBMP	River-basin Management Plan
RMF	Risk-Management Framework
RMP	Risk Management Plan
SSP	Sanitation Safety Planning
TDS	total dissolved solids
TOC	total organic carbon
VMA	veterinary medicinal application
VOC	volatile organic compound
WFD	Water Framework Directive
WHO	World Health Organization
WCSP	Water-Cycle Safety Plan
WRSP	Water Reuse Safety Plan

WSP	Water Safety Plan
US	United States
UV	ultraviolet
UWWTP	Urban Wastewater Treatment Plant
WWTP	Wastewater Treatment Plant
YLD	Years Lived with Disability
YLL	Years of Life Lost

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Annexes

Annex 1. Examples on risk assessment of agronomic hazards by the application of preventive measures

Table A1. Agronomic hazards - Environmental risk assessment for agricultural irrigation (Modified from Table A4.17 of Australian Guidelines, NRMMC-EPHC-AHMC, 2006)

Hazards, routes of exposure, exposed environment and effect			**Maximum risk – no preventive measure**			**Control point and preventive measures**		**Residual risk – with preventive measure**		
Use or route of exposure entry point	**Receiving environment or receptor**	**Potential effect**	**Likelihood**	**Severity**	**Risk**	**Control point**	**Preventive measure/s**	**Likelihood**	**Severity**	**Risk**
Boron										
Irrigation	Crops	Toxicity	Possible	Moderate	High	Crops	Grow crops that are tolerant to boron	Unlikely	Minor	Low
			Possible	Moderate	High	Soils	Select soil that does not contain boron (soil with clays of marine origin)	Unlikely	Minor	Low
			Possible	Moderate	High	Treatment process	Decrease boron concentration	Rare	Minor	Low
			Possible	Moderate	High	Distribution system	Dilute reclaimed water with fresh water to decrease boron concentration	Unlikely	Minor	Low
Chlorine residuals										
Irrigation	Crops	Toxicity	Possible	Moderate	High	Treatment Process	Install a de-chlorination system or lower chlorination doses	Unlikely	Minor	Low
Water storage system (e.g., reservoir)	Water bodies (aquatic biota)	Toxicity	Possible	Minor	Moderate	Water storage system	Develop a management plan for fish and aquatic biota	Unlikely	Minor	Low
Discharge from storage and distribution system (unintentional, e.g., leaking)	Water bodies (aquatic biota)	Toxicity	Possible	Moderate	High	Distribution system	Substitute pipeline infrastructure	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Incident management system	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Maintenance schedule	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Install interception/drainage system	Unlikely	Minor	Low
Hydraulic loading										
Irrigation	Crops	Waterlog ging	Possible	Minor	Moderate	Irrigation method	Use irrigation methods or tools that do not saturate the top soil	Rare	Minor	Low
			Possible	Minor	Moderate	Irrigation	Use irrigation method that deliver appropriate volume of water	Unlikely	Minor	Low
			Possible	Minor	Moderate	Soils	Select site with soil with sufficient drainage capacity	Rare	Minor	Low

	Soils	Waterlogging	Possible	Minor	Moderate	Soils	Improve drainage using subsoil drainage system	Rare	Minor	Low
			Possible	Minor	Moderate	Groundwater	Monitoring water-table to be below 2 m	Unlikely	Minor	Low
	Groundwater	Waterlogging	Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
			Possible	Moderate	High	Irrigation	Monitoring water-table to be below 2 m	Unlikely	Minor	Low
			Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
			Possible	Moderate	High	Soils	Drainage	Unlikely	Minor	Low
		Salinity	Possible	Minor	Moderate	Irrigation	Irrigation tools	Unlikely	Minor	Low
			Possible	Minor	Moderate	Groundwater	Monitoring water-table level to be below 2 m	Unlikely	Minor	Low
			Possible	Minor	Moderate	Crops	Monitoring for changes	Unlikely	Minor	Low
			Possible	Minor	Moderate	Crops	Select crops not affected by salinity	Unlikely	Minor	Low
Storage system discharge (unintentional)	Water bodies	Waterlogging	Possible	Moderate	High	Storage system	Design storage system to prevent infiltration	Unlikely	Minor	Low
			Possible	Moderate	High	Groundwater	Monitoring for water-table level to be below 2 m	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution	Monitoring for water losses	Unlikely	Minor	Low
		Salinity	Possible	Moderate	High	Storage and distribution system	Design storage system to prevent infiltration	Unlikely	Minor	Low
			Possible	Moderate	High	Groundwater	Monitoring for salinity	Unlikely	Minor	Low
Nitrogen										
Irrigation	Crops	Nutrient imbalance	Possible	Minor	Moderate	Irrigation and fertilisation	Nutrient balancing on crop demand	Unlikely	Minor	Low
		Pest and disease	Possible	Minor	Moderate	Irrigation	Use irrigation method that do not promote humid microclimates	Unlikely	Minor	Low
	Surface water	Eutrophication	Possible	Minor	Moderate	Soils	Use buffer distances and strips	Unlikely	Minor	Low
			Possible	Minor	Moderate	Soils	Consider in the management plan	Unlikely	Minor	Low
	Groundwater	Contamination	Possible	Moderate	High	Irrigation and fertilisation	Nutrient balancing on crop demand	Rare	Moderate	Low
			Possible	Moderate	High	Irrigation	Identify and implement irrigation methods or scheduling that will minimise leaching of nitrate to groundwater	Rare	Moderate	Low
			Possible	Moderate	High	Soils	Site selection - avoid sandy soil where nitrate can leach	Rare	Moderate	Low
			Possible	Moderate	High	Groundwater	Monitoring for contamination	Possible	Moderate	High
			Possible	Moderate	High	Crops	Crops grown	Unlikely	Minor	Low
			Possible	Moderate	High	Fertilisation	Soil improver	Unlikely	Monir	Low
	Surface water	Eutrophication	Unlikely	Moderate	Moderate	Irrigation and fertilisation	Nutrient balancing on crop demand	Rare	Moderate	Low
			Unlikely	Moderate	Moderate	Soils	Management plan	Unlikely	Moderate	Low
			Unlikely	Moderate	Moderate	Soils	Buffer distances and strips	Unlikely	Moderate	Low
			Unlikely	Moderate	Moderate	Surface water	Monitoring for nitrogen	Rare	Moderate	Moderate
Storage system			Possible	Moderate	High	Storage system	Crops grown	Unlikely	Minor	Low

	Water bodies (aquatic biota)	Eutrophication	Possible	Moderate	High	Storage system	Rinsing with fresh water	Unlikely	Minor	Low
			Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
			Possible	Moderate	High	Storage system	Irrigation tools			
			Possible	Moderate	High	Storage system	Light reduction	Unlikely	Minor	Low
	Soil (crops)	Eutrophication	Possible	Minor	Moderate	Storage and distribution system	Use buffer distances and strips	Unlikely	Minor	Low
			Possible	Minor	Moderate	Storage and distribution system	Training and education	Unlikely	Minor	Low
			Possible	Minor	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
			Possible	Minor	Moderate	Storage and distribution system	Site selection - avoid sandy soil where nitrate can leach	Unlikely	Minor	Low
			Possible	Minor	Moderate	Storage and distribution system	Interception / drainage	Unlikely	Minor	Low
	Surface water	Eutrophication	Unlikely	Moderate	Moderate	Storage and distribution system	Management plan	Unlikely	Minor	Low
			Unlikely	Moderate	Moderate	Storage and distribution system	Use buffer distances and strips	Unlikely	Minor	Low
			Unlikely	Moderate	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
Phosphorous										
Irrigation	Soil (crops)	Eutrophication	Possible	Moderate	High	Irrigation	Use buffer distances and strips	Unlikely	Minor	Low
			Possible	Moderate	High	Irrigation	Management plan	Unlikely	Minor	Low
		Nutrient imbalance	Possible	Minor	Moderate	Irrigation and fertilisation	Soil improver	Unlikely	Minor	Low
		Toxicity	Possible	Moderate	High	Crops	Crops grown	Unlikely	Minor	Low
			Possible	Moderate	High	Irrigation and fertilisation	Nutrient balancing on crop demand	Unlikely	Minor	Low
	Surface water	Eutrophication	Possible	Moderate	High	Irrigation	Management plan	Unlikely	Moderate	Moderate
			Possible	Moderate	High	Soils	Buffer distances and strips	Unlikely	Moderate	Moderate
			Possible	Moderate	High	Surface water	Monitoring	Unlikely	Moderate	Moderate
Storage system	Water bodies (aquatic biota)	Eutrophication	Possible	Moderate	High	Storage system	Crops grown	Unlikely	Minor	Low
			Possible	Moderate	High	Storage system	Mix reclaimed water with water with low phosphorus	Unlikely	Minor	Low
			Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low
			Possible	Moderate	High	Storage system	Irrigation tools	Unlikely	Minor	Low

			Possible	Moderate	High	Storage system	Light reduction to minimize algal growth	Unlikely	Minor	Low
Discharge	Soils (crops)	Toxicity	Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Rare	Moderate	Low
			Possible	Moderate	High	Storage and distribution system	Incident management	Rare	Moderate	Low
			Possible	Moderate	High	Storage and distribution system	Site selection	Rare	Moderate	Low
	Surface water	Eutrophic ation	Possible	Moderate	High	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Management Plan	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Incident Management	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Site Selection	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Maintenance	Unlikely	Minor	Low
Salinity (measured as electrical conductivity or total dissolved salts)										
Irrigation	Infrastructure	Salinity	Possible	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
	Soils (crops)	Salinity	Likely	Minor	Moderate	Plants	Crops grown	Possible	Moderate	High
			Likely	Minor	Moderate	Irrigation	Irrigation tools	Possible	Moderate	High
			Likely	Minor	Moderate	Soils	Site selection	Unlikely	Minor	Low
			Likely	Minor	Moderate	Influent to sewage treatment plant	Hazard source control	Unlikely	Minor	Low
		Contamin ation	Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
			Possible	Moderate	High	Treatment process	Decrease concentration	Unlikely	Minor	Low
			Possible	Moderate	High	Soils	Soil improver	Unlikely	Minor	Low
		Sodicity	Possible	Moderate	High	Soils	Irrigation tools	Unlikely	Minor	Low
			Possible	Moderate	High	Distribution system	Decrease concentration	Unlikely	Minor	Low
			Possible	Moderate	High	Treatment process	Soil improver	Unlikely	Minor	Low

	Groundwater	Salinity	Possible	Moderate	High	Irrigation	Irrigation tools	Possible	Moderate	High
			Possible	Moderate	High	Soils	Site selection	Possible	Moderate	High
Storage system	Groundwater	Salinity	Unlikely	Moderate	Moderate	Storage system	Buffer distances and strips	Unlikely	Minor	Low
			Unlikely	Moderate	Moderate	Treatment process	Decrease concentration	Unlikely	Minor	Low
			Unlikely	Moderate	Moderate	Soils	Site selection	Unlikely	Minor	Low
Discharge	Groundwater	Salinity	Possible	Moderate	High	Storage and distribution system	Storage design	Unlikely	Minor	Low
			Possible	Moderate	High	Groundwater	Monitoring for salinity	Unlikely	Minor	Low
			Possible	Moderate	High	Storage and distribution system	Monitoring for leakage	Unlikely	Minor	Low
Washing	Infrastructure	Salinity	Possible	Minor	Moderate	Infrastructure	Monitoring	Rare	Minor	Low
Chloride										
Irrigation	Crops	Toxicity	Possible	Minor	Moderate	Irrigation	Incident management	Rare	Minor	Low
			Likely	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
			Likely	Moderate	High	Plants	Crops grown	Unlikely	Minor	Low
	Soil (crops)	Toxicity	Possible	Moderate	High	Soils	Crops grown	Possible	Minor	Moderate
			Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low
			Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
	Surface water	Toxicity	Possible	Moderate	High	Irrigation	Irrigation	Unlikely	Minor	Low
			Possible	Moderate	High	Soil	Buffer distances and strips	Unlikely	Minor	Low
Discharge	Water bodies (aquatic biota)	Toxicity	Possible	Minor	Moderate	Storage and distribution system	Buffer distances and strips	Unlikely	Minor	Low
			Possible	Minor	Moderate	Storage and distribution system	Incident management	Unlikely	Minor	Low
			Possible	Minor	Moderate	Storage and distribution system	Interception/drainage	Unlikely	Minor	Low
			Possible	Minor	Moderate	Storage and distribution system	Maintenance	Unlikely	Minor	Low
Sodium										
Cross-connection	Crops	Toxicity	Possible	Minor	Moderate	Distribution system	Training and education	Unlikely	Insignifica nt	Low
	Soils	Sodicity	Possible	Minor	Moderate	Distribution system	Training and education	Unlikely	Minor	Low
Irrigation	Crops	Toxicity	Possible	Minor	Moderate	Plants	Crops grown	Rare	Moderate	Low
			Possible	Minor	Moderate	Irrigation	Irrigation tools	Rare	Moderate	Low
	Soil (crops)		Possible	Minor	Moderate	Plants	Crops grown	Unlikely	Minor	Low
			Possible	Moderate	High	Irrigation	Irrigation tools	Unlikely	Minor	Low

		Toxicity	Possible	Moderate	High	Soils	Site selection	Unlikely	Minor	Low
	Soils	Sodicity	Possible	Moderate	High	Soils	Soil improver	Unlikely	Minor	Low
			Possible	Moderate	High	Soils	Site selections	Unlikely	Minor	Low
			Possible	Moderate	High	Treatment process	Decrease concentration	Rare	Moderate	Low

Source: Australian Guidelines (NRMMC-EPHC-AHMC, 2006)

Annex 2. Examples on identification of barriers depending on water quality class and crop type

Table A2. Examples on how to calculate number and types of barriers based on type of crop and required reclaimed water quality classes as for the Water Reuse Regulation

Crop category (Annex 1 Table 1 of the Water Reuse Regulation) (1)	Example crops (Table A.1 ISO 16075-2:2020) (2)	Reclaimed water quality class (Annex 1 Table 1 of the Water Reuse Regulation) (1)	Number of required barriers (Table 3 ISO 16075-2:2020) (3)	Possible accredited barriers (Table A.1 ISO 16075-2:2020 (2) and Table 2 ISO 16075-2:2020) (4)	Number of barriers (Table 2 ISO 16075-2:2020) (4)	Note
All food crops consumed raw where the edible part is in direct contact with reclaimed water and root crops consumed raw	Leafy crops grown on the soil surface eaten raw (e.g., lettuce, spinach, Asian cabbage, cabbage, celery). Food crops ingested raw, which grow above ground and edible portion is <25 cm above soil surface (e.g., pepper, tomato, cucumber, courgettes, young beans).	A	0	-	0	-
		B	1	Sun resistant cover sheet OR Additional disinfection in field (low level)	1	-
		C	3	High level disinfection + Sun resistant cover sheet	2+1	-
				Subsurface drip irrigation where water does not ascend by capillary action to the ground surface + Sun resistant cover sheet*	3 (+1)	*Sun resistant cover sheet is an extra barrier to prevent contact by capillary action of drip irrigation. -
		D	forbidden*	-	-	*according to Table 3 ISO 16075:2020, and NOTE 3 of Table A.1: Effluents of medium quality (D) should not be used for the irrigation of vegetables.
	Food crops than can be ingested raw, which grow in the soil (e.g., carrot, radish, onion)	A	0	-	-	-
		B	1	Low level disinfection	1	-
		C	3	No combination of accredited barriers seems to be possible	-	-
		D	forbidden*	-	-	*according to Table 3 ISO 16075:2020, and NOTE 3 of Table A.1: Effluents of medium quality (D) should not be used for the irrigation of vegetables.
	Food crops ingested raw, which grow above ground and edible portion is >25 cm	A	0	-	-	-
		B	1	Sun resistant cover sheet	1	-

	above soil surface* *with edible skin			OR Additional disinfection in field (low-level)		
		C	3	Low level disinfection + Drip irrigation of low-growing crops such as 25 cm or more above from the ground + Sun resistant cover sheet	1+1+1	-
		C	3	High level disinfection + Drip irrigation of low-growing crops such as 25 cm or more above from the ground	2+1	-
Food crops consumed raw where the edible part is produced above ground and is not in direct contact with reclaimed water, processed food crops and non-food crops including crops used to feed milk- or meat-producing animals	Food crops grown on the soil that can be eaten raw after peeling (e.g., watermelon, melon, pea)	A	0	-	-	-
		B	0	-	-	Inedible skin (or peeling) counts as 1 barrier
		C	2	Drip irrigation of low-growing crops such as 25 cm or more above from the ground OR Sprinkler and micro-sprinkler irrigation of low-growing crops such as 25 cm or more from the water jet + Sun cover sheet (in drip irrigation, where the sheet separates the irrigation from the vegetables)	1+1	-
				Low level disinfection + Drip irrigation of low-growing crops such as 25 cm or more above from the ground	1+1	-
	Food crops grown above ground where edible portion is <25 cm above soil surface, eaten cooked or processed (e.g., eggplant, pumpkin, green beans, artichoke)	A	0	-	-	-
		B	0	-	-	-
		C	2	Low disinfection + Sun resistant cover sheet	1+1	-
				Subsurface drip irrigation where water does not ascend by capillary action to the ground surface + Sun resistant cover sheet for extra protection)	3+1	-
	Food crops eaten cooked which grown in the soil (e.g., potato);	B	0	--	-	-
		C	2	High level disinfection	2	-
	Food crops grown above ground that can be eaten after drying and cooking (dry beans, lentils).	B	0	--	-	-
		C	2	High level disinfection OR Prolonged air drying*	2	*according to crops and weather conditions
	Food crops which grow above such as > 50 cm or more above from	B	0	-	-	The natural distance from fruits (high growing crops such as 50 cm or more above the ground) to
		C	0	-	-	

	the ground with edible skin (orchard for fruits with edible skin: apple, plum, pear, peach, apricot, persimmon, cherry, citrus fruits, dates; or orchard for fruits eaten after peeling: mango, avocado, papaya, pomegranate). Orchard for fruits eaten after processing (e.g., olives)					irrigation system avoids direct contact with the edible part of the crop.
		D	3	Drip irrigation of high-growing crops such as 50 cm or more above from the ground + Die-off support through irrigation cessation or interruption before harvest*	1 + 2	*stop irrigation for more than 24h before the harvest.
	Orchard for nuts (e.g., almonds, pistachio)	C	1	Sun-dried crops*	2	*According to crops and weather conditions.
		D	3	Die-off support through irrigation cessation or interruption before harvest + Sun-dried crops*	1(2)*+2	*According to crops and weather conditions.
	Fodder crops for feed milk- or meat-producing animals (e.g., alfalfa)	C	1	Die-off support through irrigation cessation or interruption* before the entrance of animals in the field	1	*Stop irrigation at least 24h before the entrance of animals. Animals must not be exposed to fodder irrigated with reclaimed water unless there are sufficient data to indicate that the risks for a specific case can be managed. Fodder has to be dried or ensiled before packaging.
		D	3	Die-off support through irrigation cessation or interruption before the entrance of animals in the field + Low level disinfection	2+1	Exclude grazing animals from pasture for five days after last irrigation. Animals must not be exposed to fodder irrigated with reclaimed water unless there are sufficient data to indicate that the risks for a specific case can be managed.

						Fodder has to be dried or ensiled before packaging.

(1) Table 1. Classes of reclaimed water quality and permitted agricultural use and irrigation method (Annex I of Regulation 741/2020).
(2) Table A.1. Example of how to calculate the number and type of barriers (ISO 16075-2:2020).
(3) Table 3. Suggested number of barriers that are needed for irrigation with TWW (treated waste water) according to their quality (ISO 16075-2:2020).
(4) Table 2. Suggested types and accredited number of barriers (ISO 16075-2:2020).

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