DEMOWARE

Deliverable D3.4
Water Reuse Safety Plans - a manual for practitioners

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Abstract	The report promotes the adoption of a risk management framework in water reuse. A short comparative analysis reveals that preventive and systematic risk management approaches have some common features and elements. They are based on a structured analysis of the system (hazards and related risks), often refer to multi-barrier approaches to control risks and highlight the importance of communication, cooperation and review. A dedicated Water Reuse Safety Plan (WRSP) is introduced to operationalise such a framework. The WRSP elements and implementation steps draw on the Water Safety Plan and Sanitation Safety Plan approaches of the World Health Organisation. Yet they are complemented. The proposed modules include • Preparation • System assessment (health risk, environmental impact) • Operational monitoring • Management and communication

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Executive Summary

The report promotes the adoption of a risk management framework in water reuse. A short comparative analysis revealed that preventive and systematic risk management approaches have some common features and elements. They rely on a structured analysis of the system (hazards and related risks), often refer to multi-barrier approaches to control risks and highlight the importance of communication, cooperation and review. A dedicated Water Reuse Safety Plan (WRSP) is introduced to operationalise such a framework. The WRSP elements and implementation steps draw on the Water Safety Plan and Sanitation Safety Plan approaches of the World Health Organisation.

The proposed modules include

- Preparation
- System assessment (health risk, environmental impact)
- Operational monitoring
- Management and communication

Based on the DEMOWARE project work we explicitly distinguish water reuse scheme planning from water reuse scheme operation. The decision for choosing water reuse over other water supply options should be based on a broader set of considerations (not only health impacts) and be taken into account in scheme design. Combinations of life cycle assessment, risk assessment and water resource impact indicators could be applied. Yet any established scheme should than fall under the common procedures of a WRSP.

The overall goal of this report is to provide readers advice in designing appropriate water reuse schemes as well as an adequate management system to guarantee the required quality of water. This report shall enable operators and authorities to develop viable management and safety concepts for existing water reuse systems.

The document draws on activities (Risk assessment, LCA) performed in the demonstration sites of the DEMOWARE project. Results or concepts of this work are referred to as examples. The full reports are available at the DEMOWARE website www.demoware.eu

1 Background

1.1 Regulating water reuse in Europe

Though the water sector is largely regulated by European directives, there is no such dedicated legal instrument for water reuse on European level. National regulations, guidelines and standards govern the operation of reuse schemes and application of reclaimed water in Europe.

These rules target the various protection goods such as human health, groundwater and related surface waters, soil and agricultural products. In most cases this is expressed in a **water quality limit** for a parameter of concern, physico-chemical as well as microbiological.

Regulations with legally binding standards for water reuse are thus often issued jointly by the respective ministries and authorities responsible for the **environment and health**, e.g. in Italy, France, Spain and Greece.

The microbial parameters aim at ensuring human health in either direct contact with the water (e.g. inhalation, swallowing and skin contact during application) or through other indirect exposure routes (uptake through food).

The physico-chemical parameters are aimed at protecting both the environmental compartments (soil, groundwater, surface water) against e.g. chemical contamination, salinisation, clogging or eutrophication and human health (heavy metals, pesticides and other chemicals of emerging concern). Compliance with set standards is a prerequisite for the authorisation and operation of schemes.

A suite of recommendations and suggestions, such as Best-Practice Manual (like in Spain) or norms of the International Standardisation Organisation have been issued. They provide advice on how to plan, implement and operate water reuse schemes.

A summary of the regulations in force or norms in use can be found in Alcade-Sanz & Gawlik (2014). It reveals that few EU member states have adopted quite different limit values for almost the same application in different countries and also the set of parameters to be monitored vary between countries and within applications.

This diversity gives rise to discussion about the validity/scientific justification of these values, how they have been derived and whether they provide different levels of health and environmental protection.

1.2 Actions on EU level

In the last five years, the European Commission has committed itself to a number of actions to promote the further uptake of water reuse in member states (see Figure 1). Besides generating better access to EU funding for water reuse and ensuring a better integration of water reuse within other EU policies, the commission is working on a legislative proposal that sets out minimum quality requirements for reused water for irrigation and groundwater recharge in the EU. This proposal is accompanied by a Common Implementation Strategy (CIS), to inform relevant Member State authorities about the process of planning and implementing a water reuse scheme for treated wastewater. Just recently, the Joint Research Centre has drafted a suggestion for minimum quality requirements for agricultural irrigation and aquifer recharge. The release of the document was accompanied by a stakeholder consultation about the most appropriate (legal) instrument to establish such requirements. This consultation again highlighted that between 80 % and 90 % of respondents perceived "policy barriers, including insufficient clarity in the regulatory framework to manage risks associated with water reuse or insufficient consideration for water reuse in integrated water management" as high (Deloitte, 2017).

The latest documents issued and drafted particularly refer to the usefulness of risk assessment approaches to derive quality standards and wider risk management frameworks to assure safe operation of schemes and reuse of reclaimed water.

- 2007 – Report on Mediterranean wastewater reuse, MED-EUWI Wastewater Reuse Working Group – *key recommendation: guidance framework*
- 2012 – Impact assessment for the Blueprint Communication – *identifying knowledge gaps, opportunities (RBMP) and barriers*
- 2013 – Wastewater reuse in the European Union, TYPSA (Update)
- 2014 – Report "Water Reuse in Europe" JRC
- 2014 – Public Consultation on Policy Options to optimise Water Reuse in the EU
- 2015 – Report "Optimising water reuse in the EU", BIO - «problem tree, policy options»
- 2015 – Action plan Water Reuse as part of Circular Economy
- 2016 – CIS Guidance document elaborated by Ad-hoc Task Group Water Reuse – adopted by Water Directors
- 2016 – JRC Minimum water quality requirements (Draft proposal - Report for information only)
- 2017 – Public consultation on policy options to set minimum quality requirements for reused water in the EU

Figure 1 Overview of actions on water reuse on EU level

1.2.1 CIS guidelines on integrating water reuse into water planning and management

The Guidelines righteously claim that the development of water reuse practice must not compromise objectives of (water) legislation in force. Yet, the legal background on EU level does not provide a framework for risk management.

The CIS Guidelines (EC, 2016) present a series of steps in the planning for the reuse of treated wastewater, particularly in supporting the implementation of the Water Framework Directive and achieving its objectives. It is considering water reuse in the context of River Basin Management Plans and programme of measures thus addresses a wide range of issues (Figure 2). The process is driven by the identification of the need and opportunity for water reuse, also looking into the water balance of a catchment. Where appropriate reuse schemes shall be established. This includes determininge treatment requirements, techniques for risk management and their economic assessment, as well as the monitoring systems to ensure safe reuse.

Step 9 in the planning for reuse addresses the systems of monitoring and control. ‘It is important that public authorities identify the appropriate systems of inspection and control of the treatment, supply and use of the treated wastewater, based on robust, scientific determination of risks’. Risk assessment is a prerequisite for the management of water reuse to ensure environmental and public health protection. A risk management approach should guide the development of specific standards for the quality of reused water, as well as guide the use of that water. The document makes reference to the Sanitation Safety Plan.

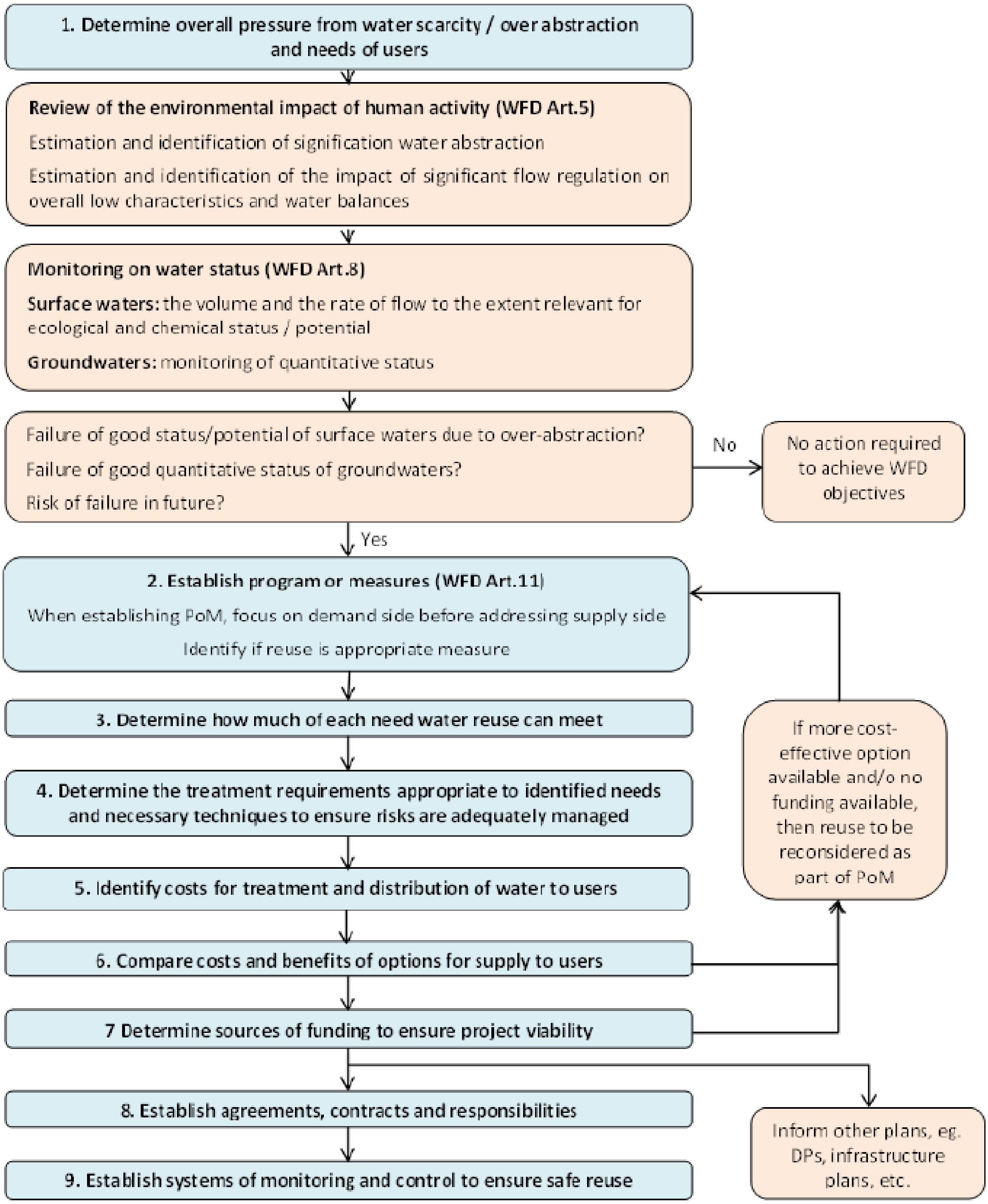

Figure 2 Summary of the steps in planning for reuse of treated wastewater set out in the CIS Guidelines

1.3 Frameworks for safe water services

1.3.1 Risk Management Framework

Acknowledging the fact that there is no risk-free undertaking structured approaches for managing risks have been developed. The Risk Management Framework (RMF) (ISO 31000:2009) is broad and applicable to any field and any type of risk and is not specific to any industry or sector. RMF can be used by any organization as a tool to design implement and improve risk management strategies as a part of overall strategy or governance and has a goal to control, prevent or reduce any type of risk whatever its nature, whether having positive or negative consequences (ISO 31000:2009). A risk management plan is a scheme within the framework specifying the approach, the management components, such as procedures, practices, assigning of responsibilities and activities, as well as resources to be applied to manage the risk. It is part of the risk management process and implements the risk management principles effectively at all relevant levels and functions of the organization. The main steps of the risk management process according to the ISO 31 000:2009 are summarized below.

Key steps of the risk management process (RMP):

- 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

Sources: Almeida et al. (2013) and ISO 31000:2009

Some aspects of RMF are also reflected in the concept of Hazard Assessment and Critical Control Points (HACCP) which was originally developed for the food industry. Whilst the risk management as such is generic, it can be tailored and adapted to the needs of water services. In the following we provide an overview of the safety plan framework and its application in water supply, sanitation and water cycle risk management. The applicability of Safety plans to water reuse as well as its similarities and differences to water, sanitation and water cycle safety plan approaches are discussed.

It shall provide the reader with essential background information. It is does not replace the need to refer to the original documents for further readings.

1.3.2 Safety Plans – a concept developed by the WHO

The World Health Organisation promotes the concept of safety planning for both drinking water supply and sanitation. The objectives are focused on human health outcomes and health protection. This shall be achieved by moving from mere end-product quality control to a comprehensive, systematic process control. This favours and demands the understanding of the (relative) importance of system components for the delivery of a safe product.

1.3.2.1 Water safety plans

The water safety plan (WSP) concept is specific to drinking water supply systems. Its major focus is on the risks related to the health of the one user group - consumer of the drinking water. Water safety plans have been developed for practitioners to operationalize the WHO framework for safe drinking water. The framework comprises five major components, summarized in Figure 3 and shortly explained in the following section.

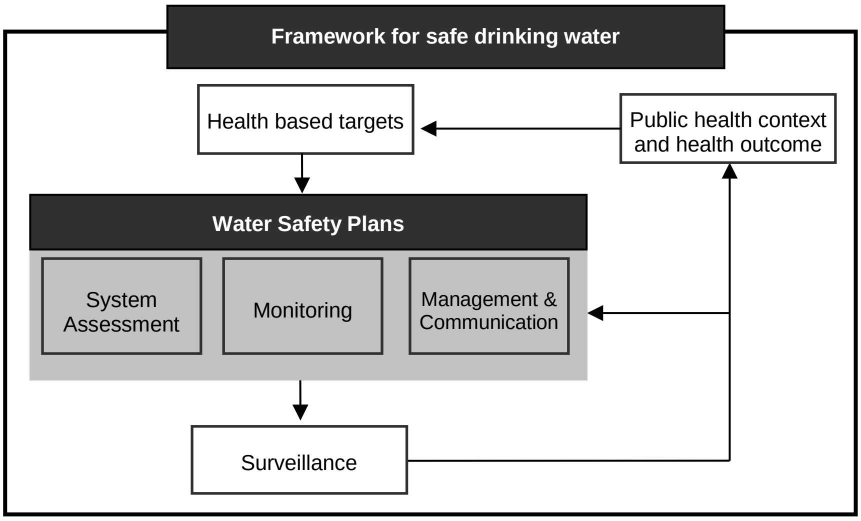

Figure 3 Components of the framework for safe drinking water (adopted from WHO, 2011)

Health based targets

Health based targets provide a "benchmark" for water supplies (WHO, 2011) and represent the overall policy objective for water safety. They represent the acceptable level of risks against which the adequacy of the existing installations, goals of the WSP and verification of their successful implementation can be evaluated. In principle, four types of health based targets can be defined:

- Health outcome targets are health based targets which focus on the quantifiable reduction in the overall level of disease and are often estimated based on the exposure and dose-response relationship
- Water quality targets - representing health risk from long-term exposure to individual drinking-water constituents, usually expressed as guideline values
- Performance targets are expressed as required reductions of substances of concern. They are applied for substances where short term exposure can cause a severe public health risk or where large fluctuations of concentration within a short time period are expected.
- Specified technology targets usually applied for smaller community or household water supplies and focus on the identification of the specific processes, devises or generic system types (WHO, 2011)

The Water Safety Plan includes three essential components: system assessment and design, operational monitoring and management plans (Figure 3):

- System assessment is meant to identify whether the water supply chain is able to deliver water of quality needed to meet set health based targets. It includes identification of the potential hazards at each step of the water supply chain, extensiveness of risk of each identified hazard, prioritization of the hazard and the probability of its occurrence and the appropriate measures to control the identified risks and hazards.
- Operational monitoring is meant to define type, frequency and points of the monitoring measures for each control measure identified and implemented during the system assessment phase to ensure that any deviation from the set standard is detected rapidly.
- The management plan has the goal to define the actions which need to be taken when there is risk of non-compliance with the health targets or regulations, potential risk to human health or failure to meet an operational control.

The primary objective of the WSP is to protect human health and ensure good practices in operating water supply schemes from source to consumer at any scale, size or complexity. The WSP approach has the goal to organize the monitoring and management practices, systematize them and is based originally on the multiple barrier approach as well as Hazard Analysis and Critical Control Points (HACCP). The key steps of the development and implementation of the WSP approach for any water supply system are as follows:

Key implementation steps of the WSP:

- Set up a team and decide a methodology by which a WSP will be developed;
- Identify all the hazards and hazardous events that can affect the safety of a water supply from the catchment, through treatment and distribution to the consumers' point of use;
- Assess the risk presented by each hazard and hazardous event;
- Consider if controls or barriers are in place for each significant risk and if these are effective;
- Validate the effectiveness of controls and barriers;
- Implement an improvement plan where necessary;
- Demonstrate that the system is consistently safe

Source: WHO, WSP Manual, 2009

Surveillance is the fifth component of the drinking water safety framework going beyond the WSP and is the "continuous and vigilant public health assessment and overview of the safety and acceptability of drinking water supplies" (WHO WSP 2005). Surveillance requires a systematic surveying including auditing of particular water safety plans, sanitary inspections, water quality monitoring and institutional aspects and covers the whole system from source to consumer.

1.3.2.2 Sanitation safety plans (SSP)

In a similar approach the WHO developed the Sanitation Safety Plans (SSP) to operationalise the WHO Guidelines for the Safe Use of Wastewater, Excreta and Greywater (WHO, 2006). The main focus is on the safe use of human waste. It shall help to systematically identify and manage health risks along the sanitation chain and to provide assurance on the safety of the sanitation related products and services. (WHO, 2016). It explicitly refers to water reuse, by addressing the safe use of wastewater and excreta in agriculture and aquaculture.

Again a step-wise analytical procedure is proposed (Figure 4)

- To assess the system and exposure. This includes a description of the system, the mapping and identification of the potential risks and hazards along the sanitation chain. The exposure of all user groups and all exposure routes need to be assessed and different exposure levels established and ranked according to severity and likelihood.
- To derive an incremental improvement plan, i.e. considering treatment, non-treatment or behavioural options to control identified risks and define actions needed to implement those.
- To establish operational monitoring at e.g. at critical control points in the chain. This can serve also as a basis to identify the need of upgrade, restoration or expansion of the system.
- To set up a supporting programme to implement the measures and review the plan

Figure 4 Illustration of the SSP approach (WHO, 2016)

Both safety plan approaches form a good foundation for applying this concept to non-potable water reuse applications and potentially for potable reuse. For the latter, the WHO is planning the publication of a Potable Reuse Guidance for Producing Safe Drinking-Water manual in 2017.

1.3.3 Other concepts for risk-based frameworks

1.3.3.1 Water cycle safety plans

Another approach, which emerged from the EU project PREPARED, is a Water-Cycle Safety Plan (WCSP) which addresses multiple primary aims. While in WSP and SSP, protection of public health is the overarching goal, although in case of WSP only consumers are in the focus, while SSP addresses different exposure groups, WCSP considers also protection of the environment and safety.

Thus, WCPS approach focuses on water safety for protection of public health, public safety and environment. The compatibility with the WSP and SSP approaches is the one of the major objectives of the WCSP framework in order to allow progressive transition from WSP which might have already been put in place by an utility to adoption of risks related to public safety and environmental protection and not necessarily repeating the whole process.

In general, WCSP can cover all aspects of the urban water cycle including some water reuse schemes. Consideration of environmental protection and public safety into the Safety Plan framework is a concept highly relevant for all water reuse schemes. In spite of the growing interest, only a limited number of schemas have applied a Safety Plan based approach to water reuse schemes (Almeida et al. 2013 and 2014).

1.3.3.2 Water reuse safety plan

A recent approach by Goodwin et al. (2015) promotes the concept of applying the water safety plan to water reuse. Based on a review of safety planning they propose modifications to the existing WSP approach and its overarching risk management framework (Figure 5). This particularly refers to supporting communication and engagement with the public, stakeholders and governing bodies. Improved decision support mechanisms would be desirable to deals with uncertainty, risk interactions and risk prioritisation.

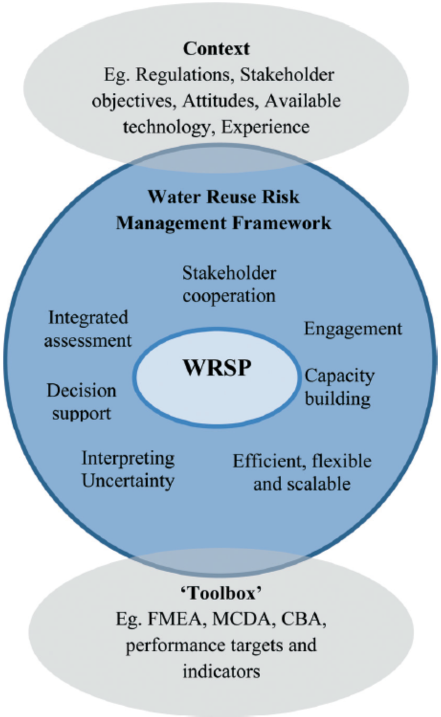

Figure 5 A conceptual Water Reuse Risk Management Framework operationalised through a WRSP (Goodwin et al., 2015)

1.3.3.3 Australian Guidelines for Water Recycling

The Australian Guidelines for Water Recycling: Managing Health and Environmental Risks are an example for a risk management framework dedicated to water reuse. "The framework describes a generic process for developing and implementing preventive risk management systems for recycled water use. (…) The aim is to provide a measurable and ongoing assurance that performance requirements are met and that, as far as possible, faults are detected before recycled water is supplied, discharged or applied, so that corrective actions can be implemented". The elements to be addressed are divided in four group (Figure 6) of which the first requires the commitment. Then system analysis and management establish the basis and procedures for risk assessment and management. Supporting requirements assure training, transparency and knowledge increase, whilst review procedures assist in perpetual improvement.

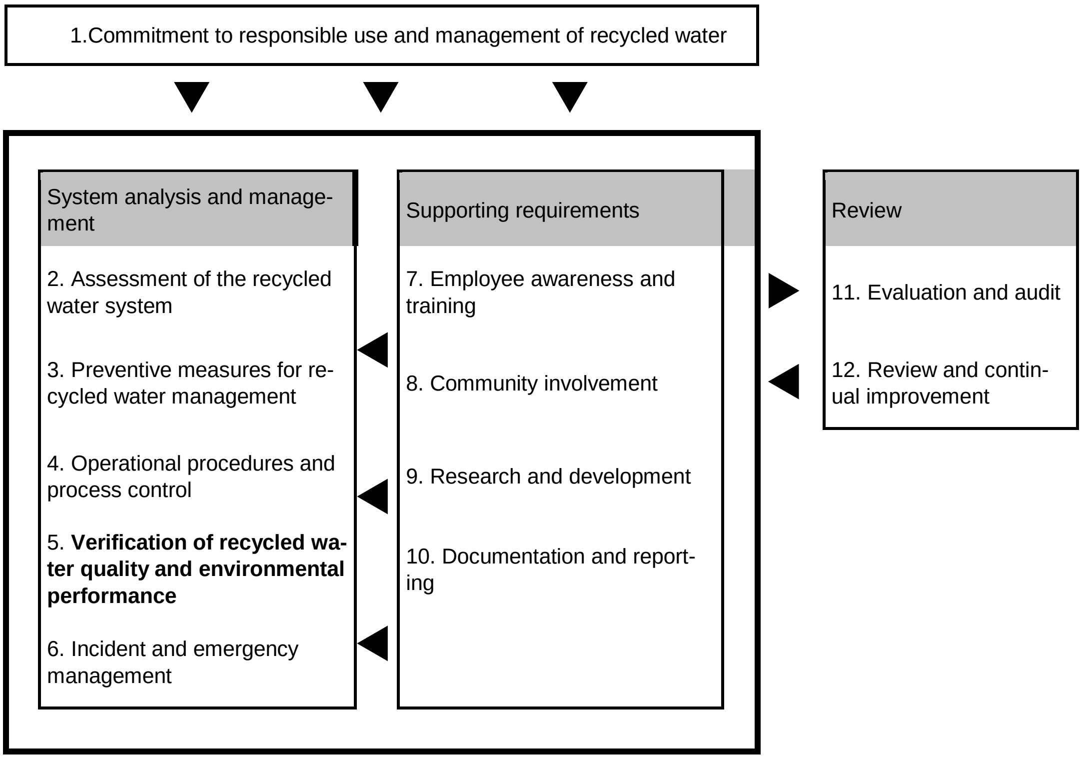

Figure 6 Elements of the framework for managing water quality and use in the Australian Guidelines for Water Recycling: Managing Health and Environmental Risks (AGWR 2006)

Risk assessment is an integral part within the Australian Guidelines for Water Recycling. Acknowledging that not all hazards and risks can be identified and assessed in advance, the guidelines offer a step-by step implementation procedure. At each implementation stage the required level of detail of the assessment increases thus demanding more information being collected at each stage. With more information available also the complexity of the applied methodologies increases, starting with simple checklist at the earlier implementation stages to hydrogeological modelling and quantitative microbial risk assessment at the more advanced stages. E.g. for managed aquifer recharge such implementation stages include:

- Entry level assessment (check for the demand for a reuse project, its degree of difficulty and conformity with other water management objectives)
- Maximum risk assessment (assessment of the risk level of a project without the presence of preventive measures)
- Residual risk assessment (pre-commissioning) (assessment of the capability of proposed preventive measures to keep risk below acceptable levels)
- Residual risk assessment (operational) (assessment of the capability of an ongoing project to keep risk below acceptable levels)

Table 1 compares the various approaches to safety planning in the water cycle.

Table 1 Planning approaches and Water Reuse Safety Planning concept, based on WHO (2009, 2016), Almeida et al. (2013) and Goodwin et al., 2015)

	Established and applied WHO testified concepts		Proposed modified or complementary concepts		National concept
	Water safety plan WSP	Sanitation safety plan SSP	Water cycle safety planning - WCSP	Water reuse safety planning WRSP	Australian guidelines for water recycling
Objective	to protect human health and ensure good practices in operating water supply schemas from source to consumer at any scaled, size or complexity	to systematically identify and manage health risks along the sanitation chain, provide assurance on the safety of the sanitation related products and services	protection of public health, safety and protection of the environment of the urban water systems	avoid negative health and environmental impacts of reusing greywater or wastewater while maximizing the benefits of their use; produce fit-for-purpose water	Provide a generic process for developing and implementing preventive risk management systems for recycled water use.
Focus	Production of drinking water for human consumption and domestic use	wastewater treatment for disposal or reuse in agriculture and aquaculture	whole urban water cycle with all water services (catchment, supply, collection treatment, flood management)	Safe application of treated wastewater for all kinds of beneficial purposes	Safe application of treated wastewater for all kinds of beneficial purposes
Core components	1) system assessment, 2) monitoring 3) management		1) system assessment, 2) monitoring 3) management	1) system assessment, 2) operational monitoring 3) management & communication	Commitment, System assessment & management, Supporting requirements, Review
Implementation steps	• Set up a team and methodology; • Identify all the hazards and hazardous events and assess risk they present • Assess control measures barriers and;Implement an improvement plan where necessary		• Commitment, assemble team; • Urban water cycle characterisation; • Risk identification in the water cycle; • Risk analysis and evaluation; • Integrated risk treatment; • Programme for action; • Management and communication programmes and protocols; • Development of supporting programmes; • Monitoring and review.	Not specified Yet water reuse risk management framework elements • characterise risks and provide decision support tools to interpret uncertainty; • integrate and prioritise risks, risk controls and operational monitoring; • progress the understanding of technological performance and improve the capabilities of water professionals; • support engagement and communication with regulators, stakeholders and the	• Commitment to responsible use and management of recycled water • Assessment of the recycled water system • Preventive measures for recycled water management • Operational procedures and process control • Verification of recycled water quality and environmental performance • Incident and emergency management • Employee awareness and training • Community involvement • Research and development • Documentation and reporting • Evaluation and audit • Review and continual improvement
Implementing agency Stakeholders	Utility level Drinking water inspectorate Health authorities	Utility level Health authorities	Shared roles and responsibilities between utilities, agencies and authorities	Shared roles and responsibilities between utilities, agencies and authorities , multiple and different stakeholders in scheme planning and operation	Roles and responsibilities are shared between utilities and authorities, Multiple stakeholders
Risk Management approach	risk management, HACCP, Stockholm Framework	risk management, HACCP, Stockholm Framework	risk management, HACCP, Stockholm Framework, ISO 31000:2009	risk management, HACCP, Stockholm Framework, ISO 31000:2009	Uses risk management, HACCP,
Legal / regulatory boundary conditions	Drinking water EU wide (quite) homogeneous legislation on drinking water quality requirements exists	UWWTD	Various water related legislation (DWD,UWWTD, WFD, BWD)	Few national dedicated water reuse regulations, norms, guidelines Must not compromise other water related regulations' objectives	

2 Towards Water Reuse Safety Planning

As outlined in chapter 1.3 preventive and systematic risk management approaches have some common features and elements. They are based on a structured analysis of the system, often refer to multi-barrier approach to control risks and highlight the importance of communication, cooperation and review.

Other authors have already discussed the match of Water Safety Plan elements with water reuse schemes and have identified gaps in practical knowledge on its application (Goodwin et al. 2015). The suggested broader framework will require adequate institutional / governance settings. They summarize the following concerns regarding risk assessment typically used for SSP and WSP:

- need to account for variability and uncertainty during risk assessment and compromise which might be taken due to availability of resources and expertise to implement more complex quantitative methods;
- any reuse risk management guidance needs to consider potential risk interactions and the related risk controls, particularly for schemes with multiple and mixed end user requirements. No guidance is available on how to accommodate more complex and system wide risk interactions with cumulative effects arising from interactions of multiple hazards and exposure pathways.
- consideration of non-technical barriers e.g. behaviour change or restriction of access or exposure.

The water safety plan approach has been introduced in the context of the overarching risk management framework and the major changes needed to apply it to water reuse mentioned.

In water reuse, a Water Reuse Safety Plan (WRSP) approach is not meant to replace other possible risk management approaches which are already used, including HACCP approach (Dewettinck et al., 2001) or the risk management framework introduced by Australian Guidelines. It should rather be implemented as a complementary approach and its strength should be considered in compatibility with existing WSP and SSP for any part of the reuse system. We thus draw on the approaches of the WHO and their concept of Safety Plans, of which the Sanitation Safety Plan already addresses water reuse in agriculture. This is why the proposed structure largely mirrors these concepts, while expanding its application to any type of water reuse. We acknowledge the recent developments on EU level in guiding the implementation of water reuse. In view of these undertakings and having regard to published and applied concepts in safety planning for different water services we suggest an adaptation of these framework to water reuse. Whilst the CIS documents only refers to types of approaches to pursue (e.g. risk or environmental impact assessment), our report seeks to detail specific steps and exemplify them with work performed in the DEMOWARE project (Chapter 4)

Based on the DEMOWARE project work we explicitly distinguish water reuse scheme planning from water reuse scheme operation. The decision for choosing water reuse over other water supply options should be based on a broader set of considerations (not only health impacts) and be taken into account in scheme design. Yet any established scheme should than fall under the common procedures of a WRSP.

Figure 7 summarizes the major steps of a proposed Water Reuse Safety Plan approach. In the preparation phase it has to be considered that that the system is more complex than just a water supply system and thus requires a thoughtful selection of multiple stakeholders to be involved in the team. For the system assessment this affords more complex risk assessment due to variety of exposure pathways, risk interactions and multiple dimensions of consequences. Control measures and related operational monitoring need to reflect this and have to be designed to assure reliability and residual risk. Choices for online and real-time monitoring or processes *vs* only product control (water quality limit) seem appropriate. Communication is deemed to be more challenging, as water reuse is generally viewed quite critical by the public, and includes involving multiple stakeholders and user groups with often not well-defined responsibilities.

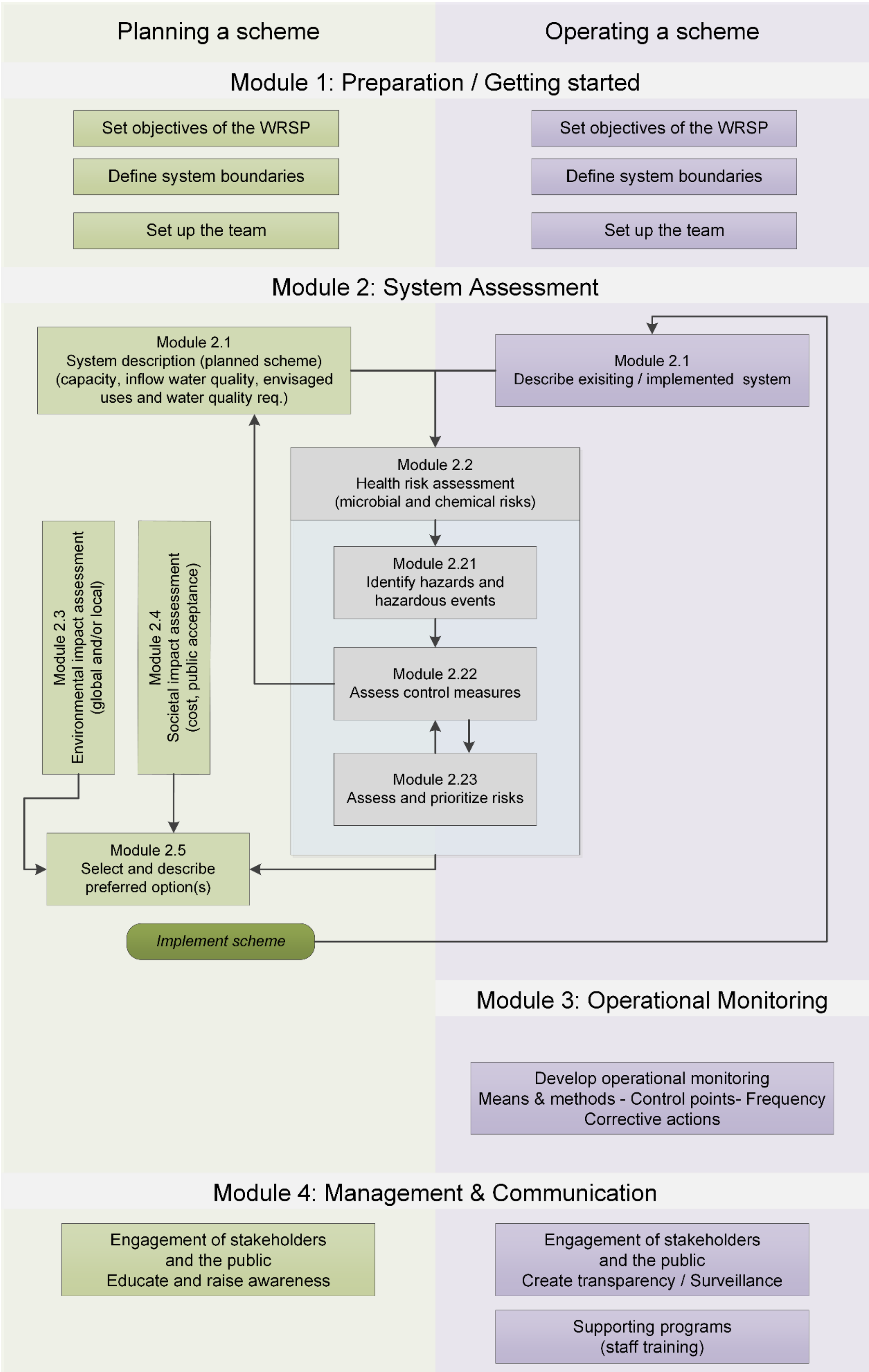

Figure 7 Steps and elements of a proposed Water Reuse Safety Plan / Processes in Water Reuse Safety Planning

3 Water Reuse Safety Planning

In this section, the modules and different steps of water reuse safety plan concept are described and discussed.

3.1 WRSP Module 1: Preparation

The goal of the preparation activities is to clearly define the objectives, limitations and boundary conditions of the safety plan.

As presented in chapter 1.3.2 the definition of health-based targets is not part of WSP processes. It is a key element of the boundary conditions. Likewise, in Water Reuse Safety Planning, the definition of health-based targets to be achieved by the safety plan procedures cannot be subject to the safety plan itself. Health-based targets are thus to be set in a separate process. This was recently reconfirmed by the JRC in relation to water reuse, when they stated: *"The responsibility for the implementation of WRSPs lies with the water utility managers, while the accountability for setting health-based targets falls to the corresponding authorities"* (Alcalde-Sanz and Gawlik, 2014). For water reuse schemes and their current implementation framework the limit values of regulations and eventually permits are proxys for health-based targets.

Particularly in scheme planning, the expected outcome should be defined and clarified. Shall it form the decision basis for implementing or not? How to identify preferred options?

In regard to the systems in planning, the preparation phase also helps to define options to consider for further specification on the later stages (e.g. shall modules 2.3 and 2.4 be applied). In contrary to the water/sanitation safety plan, a Water Reuse Safety Plan has to include an additional preparation step focusing on setting clear and defined objectives beyond improving health outcomes of different user groups.

Thus, the way the risk is measured varies with the context. While DALYs can be used to measure disease burden, other targets need to be defined for environmental risks such as eutrophication, groundwater contamination and salinization etc. Also the consequences of redirecting water from discharge to the environment into direct uses will require attention. This encompasses aspects such as minimum ecological flow.

Compatibility with the existing risk management approaches needs to be considered at this stage. In case there are already WSP or/and SSP for any part of the system, they can be used a basis for development of the WRSP and further extended to address re-use specific objectives and components of the system. Hence, in the preparation phase the scope of the WRSP and its relation to existing safety planning approaches can be defined.

The preparation module includes different submodules shortly summarized in the following sections:

3.1.1 Set objectives

A Water Reuse Safety Plan focuses on assuring safe operation of water reuse schemes i.e. preventing detrimental health outcomes for the public, workers or end-users. In relation to that also the objective of operating a reuse scheme should be revisited and made clear. In the context of water reuse, other objectives might also be targeted such as protection of the environment e.g. having regard to aspects of broader regional (e.g. water scarcity countermeasures), national or even global significance like climate impacts of due to energy consumption.

3.1.2 Defining system boundaries

A reuse scheme constitutes a combination of different sub-systems which are closely connected and constitute and contribute different risks aspects. It must be made clear at this stage, to which subsystem the WRSP shall extend, as this determines which relevant stakeholders are informed and involved in the process.

The boundaries involve the scope of the water reuse, source of water, type of reuse application, administration boundaries, areas of use of products, specific exposure groups or area to be considered. Subsystems with different responsible organizations can be defined for larger or more complex systems. A lead organization must be nominated and should finally coordinate activities for different subsystems to assure that individual subsystems are integrated.

Water reuse schemes are demanding in that respect as they are meant to close the water cycle, and thus inevitably include treatment and supply aspects. At this stage, the boundaries of the system should be considered and decision taken on what processes should be included in the safety plan, what is already covered by SSP and WSP or other risk management frameworks and what areas have to be addressed (see Table 2).

Table 2 Division of reuse scheme into subsystems, indication of boundaries and WRSP relevant aspects for analysis

Aspects to be considered in WRSP			Aspects to be considered in WRSP if within boundaries
Catchment of wwtp	Wastewater treatment		Problematic industry discharges or hotspots Inflow variabilities (e.g. stormwater, run-off)
WWTP			Treatment capacity seasonal variation of flow and demand
Reclamation plant or process units (if different from WWTP)		Water supply and use	Feed and product water quality, system reliability
Distribution & storage			Water quality deterioration (regrowth), leakage or intrusion
Water application Irrigation scheme Industrial process Urban applications			Drinking water protection area, areas of high ecological value, possibly affected recreational areas
Consumer of irrigated crops End-user (public, visitors, sportsmen			Local community Vulnerable population Consumer in export countries

Also the dimensions to be considered for the system assessment (Module 2) should be clarified. Health and safety aspects are priority; however, financial and economic consideration, acceptance issues, environmental impacts and reputation are worth being considered (see also Table 9).

3.1.3 Setting up the team

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.

Multiple stakeholders are needed, to assure that also all steps outside of the responsibilities of the lead institution are represented. Experts with different skills need to be considered as team members to assure good balance of technical expertise, health and environmental skills to enable identification of hazards and hazardous events as well as understanding of control measures. The roles and responsibilities should be recorded in a table outlining activities and responsible team members.

The team will be responsible for the development, implementation and maintenance of the WRSP, including effective communication with the participating organisations. A successful WRSP requires commitment of all stakeholders at all levels (including the top management) within each organisation.

3.2 Module 2: System Assessment

Once the boundary conditions are defined, the system assessment will provide a step-wise description, characterisation and evaluation of the reuse system and associated risks. In the planning phase of reuse schemes this module is to shape the decision on actually supplied users and technology selection.

This is brought about in different major steps:

- System description
- Risk Assessment
  - Identify hazards and hazardous events,
  - Assess existing (or planned) control measures (and resulting exposure risk)
  - Assess and prioritise risks

These steps are not strictly consecutive but an iterative process.

In practice of water reuse, risk assessment (RA) tries to assess the probability and the consequences of the occurrence of hazardous events, which lead to the presence of a hazard (chemical or biological) in the reclaimed water. This prompts the team to find answers to the following questions:

- What can happen?
- How likely is it to happen?
- What are the consequences? Who will be affected?
- How do we prevent it from happening and control consequences?

The steps include identification of hazards, hazardous events and other types of consequences and assessing control measures for defined options or system in operation. A risk prioritization should aid decision of which measures to take. Different methods, addressing different dimensions of risks leading to the final choice of the system in case of planning or prioritization of risks to be addressed for established systems.

3.2.1 Module 2.1: System description

As initial step the system under investigation is to be described. This includes all subsystems taken into when defining the boundary conditions (section 3.1.2).

Also depending on whether we consider an existing scheme or a planned one, the description will take different levels of detail. Whilst for schemes in operation it can be a precise description of what is installed, how it operates and how water is re-used, for planned schemes the description may still contain a number of placeholders to be actually determined by this WRSP procedures.

Yet also for schemes in planning basic design parameters such as envisaged flow and reuse application shall be defined. For the latter specify who will be the user of reclaimed water and what are their requirements in terms of quality and quantity. Potential restrictions or boundary conditions should be identified, such as nutrients, salt, seasonal demand)

A flow diagram depicting the water reuse system (and subsystems) is a good starting point. Is shall illustrate the interrelations between stages, their inputs and outputs. Water of different qualities crossing boundaries of sub-systems should be identified as this is often related to a transfer of responsibilities, too. It is important to ensure that system characterisation is not simply a desk study and field visits are done. Available quantitative information such as flowrates and capacity needs to be recorded.

At this stage also, different product uses and exposure modes are identified. The users of the outputs of each system or subsystem should be indicated, as well as vulnerable users.

For each step in the flow diagram, relevant information regarding national quality standards, specifications, guidelines or acknowledgment of lack of them should be compiled. In addition, information related to system performance or management, demographics and land use and seasonal conditions should be collected as well.

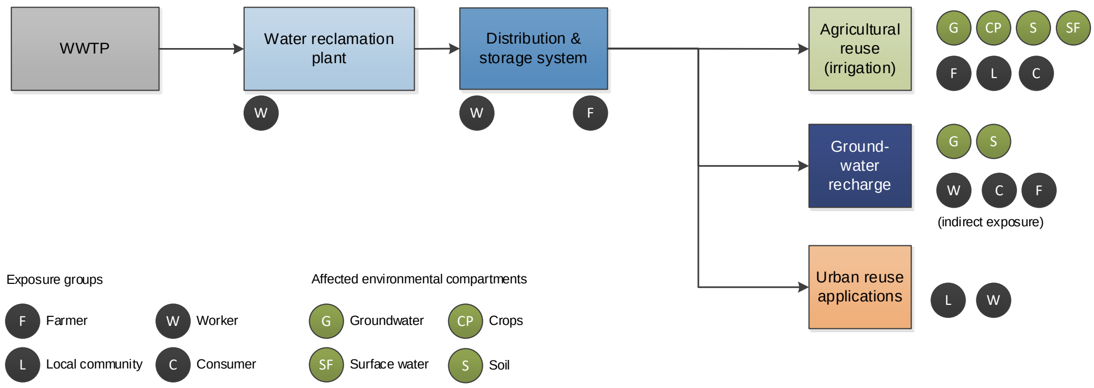

Figure 8 Example for scheme mapping – exposure groups

3.2.2 Module 2.2: Health risk assessment

3.2.2.1 Module 2.21 Identify hazards and hazardous events

The goal of this part is to identify who is at risk and how the hazardous events causing risk can occur. Hazards and other types of consequences of hazardous events need to be identified at each step along the water reuse system characterized in Module 2.1.

Next to a description of the hazardous event and its likelihood also the impact in terms of number of affected persons (directly and indirectly) and the severity of health implications or environmental damage caused shall be analysed.

In case of systems in planning, each reuse scheme option characterized in module 2.1 has to be analysed with regard to possible hazards or hazardous events. Hazards similar for all options can be grouped and clearly distinguished from those different for each option.

In operational schemes the focus should be on the hazardous events which might occur:

- during normal operation of the system
- due to a system failure
- accident on-site or in WWTP catchment area
- due to hazardous events weather conditions

as well as indirect hazardous events due to variations in operation of parts of the system beyond its boundaries, affecting population or environment not directly involved in the system as well as affecting people or environment through cumulative processes (e.g. salinization of soil).

Such analysis will require to refine the flow sheets and break it down into processes. Suggestions for a structured compilation of hazards, hazardous events and affected groups are provided in the SSP Manual (WHO, 2016).

Key hazards and exposure groups in water reuse

Water reuse related hazards to human health and the environment are mostly related to wastewater constituents, especially microbial water borne pathogens. In regards to environmental impact, chemicals hazards are prevailing. Typical hazards are listed in Table 3.

Table 3 Wastewater constituent posing a potential hazard in water reuse
Other chemical hazards relevant for environment include (adapted from D.3.1. and AGWR, 2006)

Microbial	Chemical		
	Toxic compounds	Compounds of agronomic relevance	Compounds of emerging concern of uncertain effects
Microbial pathogens Bacteria &, protozoa and viruses from faecal sources, e.g. Vibrio cholera, Cryptosporidium, Hepatitis E) **Helminths** (e.g. hookworm) **Vector-borne pathogens** (e.g. Schistosoma ssp., Malaria, Dengue virus) **Antibiotic resistance**	**Heavy metals** from industrial sources, pipes, surface runoff, **Volatile organic compounds** from industrial solvents **Algae toxins** formed due to growth processes in storage reservoirs or surface waters **Herbicides and pesticides** from stormwater (facade treatment, private gardening and agricultural runoff), illegal disposal or applications on crops synthetic industrial chemicals from local industries **Disinfection by-products** formed during disinfection.	**Boron, chloride, sodium, cadmium** and **chlorine** in large quantities are toxic to plants and aquatic organisms. **Salinity** causes water stress in plants, degrades soils and groundwater. It makes cadmium already in the soil more available to plants. **Sodium** can degrade soil structure, making it difficult for water and plant roots to penetrate the soil. **Phosphorus** and **nitrogen** can affect nutrient balances in plants, and lead to eutrophication of water sources.	**Micropollutants** including pharmaceuticals, steroid hormons, antibiotics, industrial chemicals through excretion by people and use of cosmetics, medical and household products **Nanoparticles** **Microplastic**
Dose-response relationship often known Content of pathogens rarely monitored	Toxic levels often known, mostly not exceeded in wastewater	Control through treatment	Many not regulated Fate and effect not always known

Human exposure occurs through direct consumption and via environment. In most cases, microbial hazards pose greater risk to human health and therefore are primarily in the focus of the WSP. In water reuse, microbial hazards for water reuse systems are similar to those summarized in SSP (WHO, 2016). An extended list of different organisms can be found in DEMOWARE report D.3.1 and WHO Drinking water guidelines. Control measures to protect human health from microbial hazards will likely be sufficient to protect environment as well.

Knowledge about the presence and relevance of these organisms and compounds in the site under investigation must be collected. Helminths are not a major issue in Europe, and are rarely found in treated wastewater in Southern Europe (Levantesi et al., 2010). Whether vector-borne pathogens and diseases might become more prominent with climate change favouring the breeding of vectors should be observed.

Additionally the application as such can also be a hazard. Water excesses causing waterlogging, raise of water table and potentially affecting soil salinity.

Next to wastewater constituents, handling of hazardous chemicals in operation and maintenance of the reuse scheme can be a risk for men and environment (e.g. chlorine based cleaning agents and disinfectants) Safe handling of such chemicals should anyhow be considered in Occupational Health Safety and Environment policies and rules.

Exposure groups and routes

Exposure groups for each environmental compartment relevant for water reuse as well as corresponding environmental processes and impact are summarised in the Table 4. The major difference between microbial and chemical exposure assessment is that pathogens as single particles can already cause a health risk which can occur also during a short period of system failure of malfunctioning. In case of chemical exposure, acute toxicity caused by short term failure is rather unlikely and concentrations are modelled. In case of water reuse systems involving agricultural production, it should be considered that chemical uptake through handling and food consumption need to be assessed as well.

Table 4 Overview of environmental compartments, relevant exposure groups and impacts (adapted from D.3.1)

Environmental compartment / product	Exposure group	Processes to be considered	Impact
Drinking water	Consumers of drinking water	Potable reuse: ingestion, exposure to volatile compounds, dermal adsorption	Health (pathogens, human toxicity)
Agriculture (Soil)	Farmers, Flora/fauna, soil	Biodegradation, volatilisation, leaching , atmospheric deposition	Environmental impact (e.g. acidification, salinization), health (e.g. human toxicity)
Agriculture (Agricultural products)	Consumers of agricultural products, farmers, workers in the supply chain for products	Consumption of agricultural products, handling products during production or supply chain	Health (pathogens, human toxicity)
Groundwater	Groundwater, groundwater consumers, farmers	Biodegradation, volatilisation, leaching	Health (human toxicity, salinization), environmental impact (salinization, contamination)
Recreational surface waters	Users of recreational waters, flora/fauna, water bodies	Dermal contact, ingestion Adsorption, dilution	Health impact (pathogens, toxicity, vector borne transmission of diseases), environmental impact (e.g. eutrophication, ecotoxicity)

Surface water	Water utilities and their customers, flora/fauna, fisheries, water bodies	Partitioning, Dilution	Environmental impact (e.g. eutrophication, freshwater ecotoxicity), health impact (pathogens, toxicity, vector borne transmission of diseases)
Climate Change	Global impact	Energy demand, gas emissions	Environmental impact (global warming potential)

3.2.2.2 Module 2.22: Describe and assess control measures (possible alternative treatment options, multi-barrier approaches)

The previous modules helped to characterise the scheme and the hazards related to its operation. The purpose of this module is to assist in elaborating and assessing control measures and decide where to place them in the system. In the case of scheme planning this might largely influence the reclamation technology to be implemented.

Having regard to the identified hazards and exposure routes, the identification and design of control measures is key in managing the risks. This is to understand how control measures (barriers) reduce hazards and cut exposure pathways. It will also have to estimate the consequences of barrier failure.

Generally speaking, three types of control measures can be applied that either target water quality or work on the exposure routes:

- (water)treatment
- Non-treatment but technical and
- non-technical (behavioural) measures

Examples for treatment and other health protection measures are given in Table 5 and the various WHO documents (WHO, 2006, WHO 2016).

The options can be collected in an improvement plan and can include capital works, operational measures, behaviour change campaign and protective measures. They should consider available controls and potential for its improvement, technical effectiveness, reliability and local acceptability, responsibility issues and required training for implementation, distance to the source of the risk and costs.

It is worth pointing out that the measures differ also in the level of monitoring that can be applied to confirm that they are properly functioning or comply with the targets set.

Table 5 Examples for treatment and other health protection measures

	Treatment	Non-treatment	Non-technical, behavioural
Agricultural irrigation	Wastewater treatment Disinfection	Irrigation technique Access restriction (fencing, signage) Die-off in the field	Protective clothes and equipment Hygienic practices Crop restriction Irrigation schedule Wind protection / shield Harvesting practice Waiting periods Washing of produce

Grouping options and finding synergies can be an important exercise to identify options which can address several risks with a single control. The question of reliability needs to be addressed at this level as well. Reliability in consistently providing water or other products of required quality can be achieved through combination of

- measures that go beyond the minimal requirements, such as additional spare infrastructure (spare pump) or additional treatment steps to assure redundancy
- overall robustness of the system, showing resistance even to complete failure or catastrophic hazardous events, which often can be achieved through multiple barrier approach
- detection measures (e.g. online monitoring) which allow shut-down of water supply in case of major treatment failure

The extent of residual risk remaining after an implementation of a control measure should then be evaluated against the targets.

Control measures

For established systems, the control measures already in place to mitigate the risk of the hazardous event can be identified. How effective these control measures are in practice as well as how effective they could be should be evaluated based on the technical and performance information available as well as results of current monitoring or detailed technical assessment. In case actual and potential performance vary, the reasons should be identified were possible.

For systems in planning, possible control measures can be noted or considered. The effectiveness of **treatment technology** as (risk) control measures or barriers can be estimated or assessed in various ways:

- evidence data from operative schemes and pilots on removal effectiveness
- expert opinion based on experience and studies
- predictive models derived and based on such knowledge

A validation monitoring will be required to confirm the supposed performance (see Module 3, section 3.3).

The WHO Guideline (2006) includes removal credentials for different barriers for pathogenic organisms.

A range of options to control the most relevant hazardous events should be elaborated and assessed. The matrix below exemplifies the concept. More detailed examples can be found in the SSP Manual (WHO, 2016)

Table 6 Example for a general matrix to classify effectiveness of control measures for different hazards

Hazard / hazardous event	Control measure 1	Control measure 2	Control measure 3
Hazard 1	Mitigation efficiency for hazard or exposure reduction Removal effectiveness LRV, %age,		
Hazard 2			
Hazard 3			

3.2.2.3 Module 2.2.3 Assess and prioritize the risks

Risk assessment

The purpose of the risk assessment is to identify and evaluate the health risks associated with water supply/a sanitation chain, to determine if health hazards are adequately controlled and identify necessary improvements and upgrades.

The hazard identification step will result in a long list of hazards, hazardous events and their consequences, part of which can cause a serious risk, another part only moderate or insignificant risk. Thus, risks associated with each event need to be established.

Different approaches of risk assessment are used in the Safety Plan Approach including:

- risk scoring and prioritization in sanitary inspections,
- use of risk matrices
- quantitative microbial risk assessment (QMRA) and
- quantitative chemical risk assessment (QCRA).

The outcomes of the risk assessment process is an understanding of hazards, hazardous events, validity of control measures and their relative significance and provides an evidence based justification for an improvement plan. (WHO, 2016a). Table 7 lists various approaches to assess the risks.

Table 7 Different approaches to assess risks

Approach	What is assessed?	(Model) Input	(Model) Output
team based descriptive risk assessment	Type and quality of different risks	none	Classification of risks associated with hazardous events as high, medium, low or uncertain/ unknown risk
Risk Matrix	Likelihood and severity of an hazardous event	none	Ranking according to scores
Quantitative microbial risk assessment (QMRA)	Probability of a specific system to deliver water of a predefined quality and the consequences of its failure to do so.	Exposure assessment + dose response model	Risk of infection/illness Health indicators (e.g. DALYs)
Quantitative chemical risk assessment (QCRA)	The probability of chemical agents exceeding predefined environmental or health based limit or precautionary values	Emissions, production volumes, environmental concentrations at different endpoints, daily intake (for humans) + limit values, acceptable daily intake	Ratio between predicted environmental concentration and predicted no effect concentration (PEC/PNEC)

Thus, risk assessment is a decision support tool that provides the risk managers with a rational picture of known or assumed quantified risks. All these risk assessments are valid and their use is context and resource specific. While sanitary inspections and risk matrixes are often applied as simple and common approaches to evaluate the range of different water quality associated risks in the WSP, QMRA is a more formal, quantitative approach. It combines scientific knowledge on microorganisms (presence, fate and transport) the routes of exposure, effects of natural and engineered barriers and hygiene measures. In contrary to the sanitary inspection and risk matrix which are judgment based, QMRA allows evidence-based transparent and coherent management of risks. The role of QMRA in the water and sanitation safety planning is to provide valuable quantitative inputs into all steps of WSP. It can provide a clear and transparent approach for comparing system risks with a health outcome target, and makes it possible to evaluate whether a system or pathway is safe. This can be conducted in the format of a deterministic, screening-level risk assessment (WHO, 2016a).

Rather simple team based descriptive risk assessment as well as semi-quantitative matrix of likehood and severity that is recommended as two of the tools in Water Safety Plan approach can be less applicable to water reuse due to a challenge of comparing and prioritizing risks for different exposure groups and uses. Nevertheless both approaches can be applied when variables used to express relative values are well thought due to relative simplicity of the approaches compared to quantitative methods. The team-based descriptive risk assessment method applies the team's judgement to assess the risk of each hazardous event by classifying them according to high, medium, low or uncertain/unknown risk. It is important to record why a certain decision was taken at that point of time. The team can decide to conduct semi-quantitative or quantitative risk assessment at a later stage and integrate it into the next version of the WRSP when more experience and resources are available. When implementing semi-quantitative matrix risk assessment, the team assign a likelihood and severity to each identified hazardous event to arrive at a risk category or score. The team needs to develop its own definitions for likelihood and severity considering different dimensions of consequences of the hazardous events. The goal is to summarize the highest risks which will be addressed through the improvement actions. The challenge of application of team based and matrix risk assessment and prioritization methods in water reuse is comparing and prioritizing risks for different exposure groups, dimensions of consequences and uses.

Thus, a more sophisticated QMRA/QCRA (quantitative chemical risk assessment) can be a better choice when resources are available. Another method to prioritize safety measures - multi-criteria decision analysis - can be recommended.

QMRA, QCRA - Simplified and straight-forward implementation steps of QMRA and QCRA which can be applied under the WRSP umbrella are not available yet. This was addressed in the DEMOWARE project report D3.1. "Appropriate and user friendly methodologies for Risk assessment, Life Cycle Assessment, and Water Footprinting" (Seis and Remy, 2016). In the report a summary of guidelines and default values for different exposure scenarios was collected from different guidelines documents (WHO, Australia, US-EPA) in order to develop a first simplified and thus user friendly risk estimate. Clearly, the QMRA as well as QCRA are region and site specific and local data collection is mandatory, however the list is useful for the first simplified quantitative risk assessment and more advanced than descriptive team based methods. The most important steps of the methods were summarized and explained in detail in order to simplify implementation of the approach in the Water Reuse Safety Plan or other risk assessment and management framework. Application examples can be found in Kraus et al (2017, DEMOWARE deliverable D3.2).

3.2.3 Module 2.3 Environmental impact assessment of alternative options

When based on risk assessment different options are found equally effective or safe, further criteria will guide the decision for implementing one or the other. Next to merely economic considerations, environmental impact should be accounted for.

This module takes into account environmental impact on local and/or global scale. The result from such assessment can help decision makers:

- to compare the environmental impact of different options to supply additional water (water reuse vs water transfer or desalination)
- to compare different technology choices and treatment trains to achieve the envisaged water quality and/or health-based targets

There are different methodologies available to assess environmental impacts: Environmental Impact Assessment (EIA) is often equated with Life Cycle Assessment (LCA) which is not correct, since LCA is only one very popular of many methodologies of EIA.

However LCA should be considered in the planning phase of water reuses systems to compare alternatives regarding global environmental footprints (e.g. energy demand, global warming potential), nonetheless it should be noted that LCA is based on global models and is in some circumstances weak when it comes to assess local environmental effects (e.g. eutrophication, toxicity, water scarcity).

Therefore, other methods of EIA, e.g. Environmental Exposure assessment according to EU Standards, can be applied. They are more suited and precise to assess environmental impacts on a local level (IHCP, 2003).

Table 8 Overview of methods to assess environmental impacts

	What is assessed?	Scale	Model Input	Model Output
Life Cycle Assessment (LCA)	Potential environmental impact of products or systems, often comparing scenarios with the same function	Impact assessment based on regional to global scale, general assessment	Resources and emissions during all stages of a product or system life cycle	Indicators representing potential environmental impacts (various indicators and methodologies available)
Water footprinting (WFP)	Consumptive and non-consumptive water use, including changes in water quality related to a certain product or system	Impact assessment on local, regional or global scale	Amount and quality of water withdrawals and discharge along the life cycle	WFP indicators, e.g. Water Impact Index, water footprint network indicator, virtual water
Environmental impact assessment (EIA)	Impacts of the site construction and operation on the environment (habitats, water body status)	Local, regional	(no numerical model) Mass flows of e.g. nutrients or pollutants, landscape alteration	

Life Cycle Assessment as defined in ISO 14040/44 follows a methodological framework to enable a systematic and comprehensive characterization and quantification of selected environmental impacts which are associated with a product or a service, like providing reused water.

In general, a water footprint (WFP) is a set of methods that assesses quantitative and qualitative impacts of water withdrawal and discharge, as well as emissions into water or air that affect water quality. In line with the life cycle perspective of LCA, WFP accounts for qualitative and quantitative impacts throughout the system under study and related upstream and downstream processes. WFP has recently been standardized in a new ISO standard ((ISO 14046, 2014)) aligned on the ISO 14040/14044, where basic requirements have been formulated towards a methodological framework for WFP.

3.2.4 Module 2.4 Assess societal impact and response (cost and public acceptance)

How hazards or risks are perceived will impact on the acceptability of the water reuse system. Goodwin et al (2015) conclude that integrating stakeholders and affected communities in the risk assessment, control and management may prove to be advantageous. Better understanding and integration of stakeholder and public attitudes will help to improve confidence in water reuse practices and the overall risk management. This includes understanding the needs and expectations of multiple stakeholders and satisfying the concerns of reclaimed water users, including the public.

Thus, the WRSP requires a supporting programme for stakeholder engagement and communication with regulators and the public; see Module 4.

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 can be run economically sustainably. i.e. how cost recovery will be achieved and what is the willingness to pay of potential customers. Methods for cost-benefit analysis have been applied in two DEMOWARE demonstration sites (see section 4.6).

3.2.4.1 Dimensions of consequences

In contrary to the WSP and SSP which focus on health related hazards, the dimensions of consequences relevant for the water reuse systems should be taken broader. Table 9 summarizes main consequences and their characteristics. It should be noted that the dimensions are interrelated, e.g. the interruption of service has an impact on health due to lack of water or use of alternative water sources, as well as impact the system acceptance and utility functions as well as reputation.

Table 9 Dimensions of consequences relevant for water reuse (adapted from Almeida et al., 2013)

Dimension	Examples of variables useful to express relative value in each case
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. 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 expressed in the dimensions of severity through recovery time, 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. Customers 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 in media or liability issues.

3.2.5 Module 2.5. Choosing the system from pre-defined and characterized options in the planning process

By this module a synopsis of the various assessments shall lead to the selection of a scheme or improvements to be implemented. This would require a ranking to prioritise options and could take the form of a modified cost utility analysis where the above mentioned criteria / dimensions are taken into account.

A generic assessment of treatment trains concerning their environmental impact and risk reduction potential was carried out in the DEMOWARE project. An example for such a characterisation of various options is shown in Figure 9. It illustrates the range of effectiveness of different process combinations for the removal of viruses and bacteria. Whilst double membrane processes are highly effective they come with the highest global warming potential. Yet for a medium virus and bacteria elimination the environmental impact of effective process combinations can vary up to the factor 3.

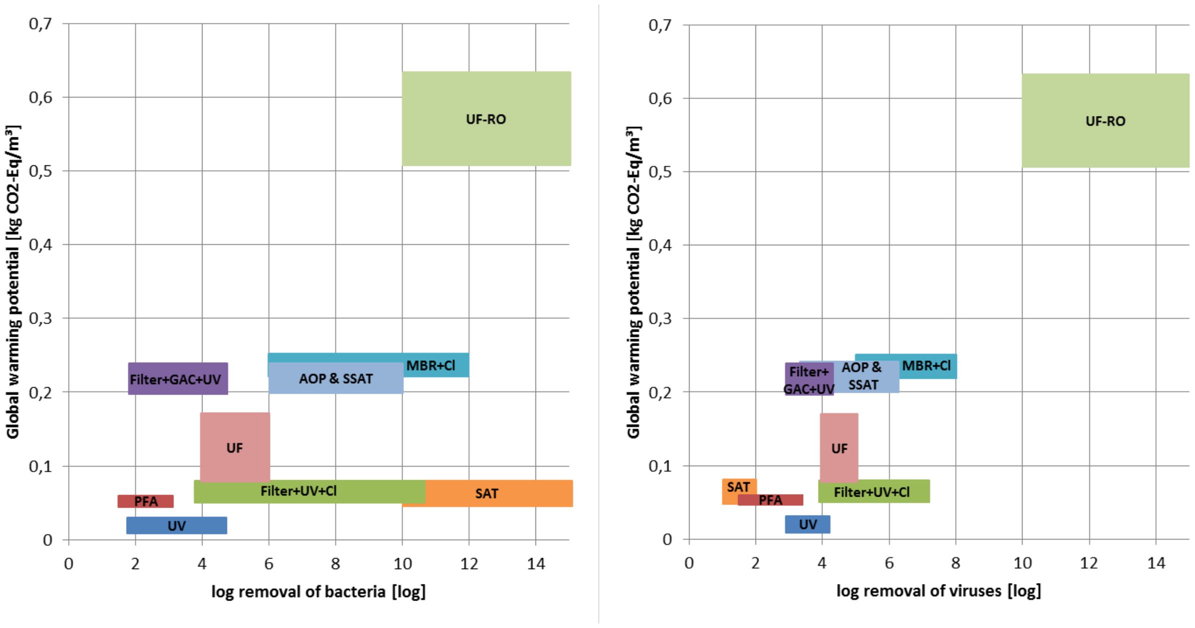

Figure 9 Range in global warming and risk reduction potential (log removal of bacteria and viruses) for selected treatment trains (for SAT 100-200 d travel time assumed, for SSAT 30-35 d travel time assumed) (Kraus et al., 2016)

3.3 Module 3: Operational monitoring

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 result of a water treatment but also to monitor the process itself.

Operational monitoring should also specify corrective actions for events of non-compliance with specified values (WHO, 2009 Water Safety Plan Manual). The type of operational monitoring depends on the control measures in place (see Module 2.22) 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 check-lists 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.

While establishing monitoring, parameters and their limits, methods, frequency and responsibility are crucial. 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.

In water reuse systems, 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 unauthorised industrial discharge and high variability during meteorological extreme events in wastewater collection system might be advisable.

Fast response times between the sample, measurement and the alarm are important especially in potable reuse schemas in order to detect a failure or trend leading to a failure before water is supplied to the customer. In such cases, on-line monitoring systems and real time data reporting are advisable. Grab samples and more complex analysis can be sued to validate on-line monitoring tools.

In regard to public health protection, microbial water quality analysis is essential and microbial water quality parameters and should not overcome limits at all times. 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 regulations, water source and inputs (regulated and not) which can affect it, type of chemicals and processes used in the treatment processes as well as availability of analytical equipment and expertise. In section 3.2.2.1 relevant chemical hazards brought in relation to water reuse are summarized. Emerging contaminants, which are not yet regulated, need to be assessed as well. However, regular and frequent monitoring for every potential chemical substance is not feasible. 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, EC are suitable can be used for online monitoring of process performance as well. Methods used for monitoring of performance of treatment steps, such as integrity tests in membrane filtration or DBP control for chlorination need to be considered for each step.

Non-targeted chemical analysis can be advisable to obtain a more comprehensive picture of the site specific source water characteristics and treatment steps performance.

Actions which need to be undertaken when critical limits exceed the norm need to be clearly defined. Verification of the system performance is intended to be done periodically to ensure that trends in overall system performance are detected. The methods may be more advanced, and verification monitoring can be also done by the responsible surveillance agency only in few points, such as effluent water quality, soil status, groundwater status etc.

3.4 Module 4: Management and communication

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 WRSP. These programmes and protocols help in managing the complexity of a WRSP 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 WSP due to involvement of multiple stakeholders and user groups in the system as well as sometimes critical or missing public support.

3.4.1 Engagement of stakeholders and the public

The reuse of treated water can 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 schemes requires broad support. Stakeholder (including public) 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 is 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 re use, 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.

3.4.2 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 schemas 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. In regard 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 schema. 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 type 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.

3.4.3 Supporting programmes – staff training

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

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

4 Annex – Examples from the DEMOWARE project

4.1 Water reuse systems addressed in the project

Risk assessment and environmental benefit analysis was conducted in a number of DEMOWARE demonstration sites, as listed in Table 10. The cases cover a range of treatment process combinations to produce water for agricultural or park irrigation, urban uses such as toilet flushing or street cleaning but also indirect potable reuse. In these sites some of the aspects

The detailed assessments can be found in Kraus et al. (2016, 2017) and Seis & Remy (2016, 2017).

Table 10 List of demonstration cases in DEMOWARE and aspects investigated which are relevant for WRSP development

No	Train	Target contaminants	Reuse site	Type of reuse	Size	Aspects investigated
1	UV or performic acid (PFA)	Pathogens	Braunschweig (DE)	Agricultural irrigation	Pilot	LCA, RA
2	Filtration + UV + Chlorination	Particles, Pathogens	El Port de la Selva (ES)	Private/public irrigation	Full	LCA, RA
3	Filtration + GAC + UV	Particles, Bulk organics, Trace organics, Pathogens	El Port de la Selva (ES)	Artificial groundwater recharge (indirect potable reuse)	Full	LCA, RA
4	Membrane bioreactor + GAC + Chlorination	Particles, (Bulk organics), (Nutrients), Pathogens	Old Ford Water Recycling Plant (UK)	Urban reuse (toilet flushing, park irrigation)	Full	LCA, RA
	Membrane bioreactor + Chlorination + UV	Particles, Bulk organics, Trace organics, Pathogens	Sabadell (ES)	Urban reuse (park irrigation, street cleaning)	Full	LCA, RA
5	Soil-Aquifer Treatment (SAT)	Particles, (Bulk organics), Nutrients, Pathogens	Shafdan (IL)	Agricultural irrigation	Full	LCA
6	Filtration + Ozonation + SAT	Particles, Bulk organics, Nutrients, Trace organics, Pathogens	Shafdan (IL)	Agricultural irrigation	Pilot	LCA
7	Ultrafiltration	Particles, Pathogens	Shafdan (IL)	Side-stream treatment (agricultural irrigation)	Pilot	LCA
8	Ultrafiltration + Reverse Osmosis	Particles, Bulk organics, Nutrients, Trace organics, Pathogens, Salinity	Torreele (BE) Shafdan (IL)	Indirect potable reuse/ agricultural irrigation	Full Pilot	LCA

4.2 (Health-)Risk assessment for water reuse systems - Module 2.2.

Quantitative microbial risk assessment (QMRA) is a powerful tool to describe expected health impacts of a reuse scheme, provided sufficient and reliable data are available on occurrence, exposure and dose-response relationships. DEMOWARE applied QMRA in a number of sites. In relation to this work two reports were produced:

Seis & Remy (2016, D3.1): This report provides the reader with an overview of assessment methodologies used within DEMOWARE and the specific features when using QMRA, QCRA, LCA, and WFP approach for the assessment of water reuse systems. For the actual application of LCA and water footprint databases and assessment software is needed. Therefore, three complementing goals were to be achieved:

- To provide practitioners with the principles, methods and limitations of QMRA, QCRA, LCA and WFP
- To provide LCA, WFP, RA practitioners with additional information when using the respective method for the assessment of water reuse systems.

For QMRA a summary of guidelines and default values is collected from different guidelines documents (WHO, Australia, US EPA), which allow a first simplified and thus user-friendly risk estimate.

The results of Life Cycle Assessment, Water footprinting, and quantitative microbial and chemical risk assessment for selected demo-sites of water reuse in Europe, measuring the potential impacts of different types of water reuse on environment and human health is summarised in Kraus et al. (2017, D3.2).

Table 11 gives a first overview of consideration in microbial risk assessment in water reuse application compared to drinking water.

Table 11 Similarities and differences between microbial risk assessment for drinking water and water reuse systems

Characteristic	Drinking Water	Water reuse
Population	Drinking water consumers	Various sub-groups, depending on reuse category (e.g. workers at the reuse site, consumers of products irrigated with reclaimed water)
Exposure route	Drinking water consumption Inhalation (e.g. *legionella spp.)*	Depending on use category, generally several different routes of exposure during various steps of water reuse (pre-treatment, storage, post-treatment, distribution)
Raw water quality	Depends on water source: Protected groundwater source (usually of high microbiological quality), surface water: high variability, prediction of source water quality at a given time challenging	Low microbial and chemical quality of secondary effluent but: Quality of source water (effluent wastewater treatment) can be controlled and predicted to a certain extend
Sources of contamination	Surface water: often multiple sources of contamination, hard to identify unknown sources, microbial source tracking as a major field of research	Main sources of pollution: human and animal faeces and industrial discharges (toilet flushing, surface runoff), prior information of presence of pathogens and chemical substances exist through epidemiological and local data
Risk management approaches	Water Safety Plans, country specific approaches depending on the organisation of the water sector	Sanitation Safety Plans, Water Reuse Safety Plans (in progress)

Ingested volume	High volume (0.5-2L) intentionally ingested Unintentional inhalation	Usually small volumes unintentionally ingested (except from potable reuse applications) Exposure via other routes of exposure products (e.g. raw vegetables) possible
Type of barriers	Multiple barrier principle (source protection, treatment, network, installations in buildings), Focus on water quality control	Control measures may include treatment and non-treatment options aiming at water quality and exposure reduction, respectively.

4.3 Life Cycle Assessment (Module 2.3)

Life Cycle Assessment as defined in ISO 14040/44 follows a methodological framework to enable a systematic and comprehensive characterization and quantification of selected environmental impacts which are associated with a product or a service, like providing reused water.

Using the life-cycle perspective, all relevant processes upstream and downstream of the system under study are described with input-output models, listing all required inputs from the environment (e.g. fossil fuels, metal ores, land use) and outputs into the environment (e.g. emissions into air, water, and soil). From this detailed list of input and output flows (forming the "Life Cycle Inventory"), selected indicators are calculated to describe the potential environmental impact of these flows regarding specific areas of environmental concern (e.g. cumulative energy demand of fossil fuels, global warming potential, eutrophication of surface waters, or human/eco-toxicity) (see Figure 10).

Using a well-defined system boundary and functional unit and assuring functional equivalency between compared options, different scenarios or processes can be compared in their indicator profiles to reveal potential environmental benefits or drawbacks and promote an informed decision making process between alternatives (different types of tertiary treatment for water reuse or alternative water supply).

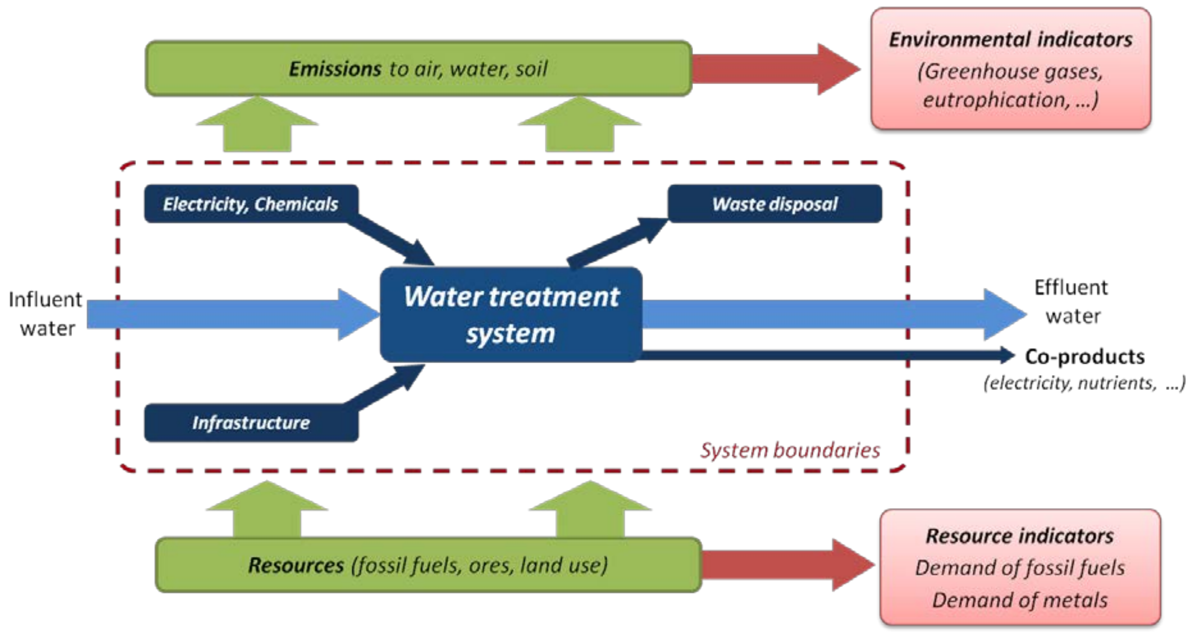

Figure 10 Typical system boundaries of an LCA for water reuse

An example for the outcome of a comparative LCA in terms of the impact category cumulative energy demand is shown in Figure 11 for the Case Study of El Port de la Selva. Via this assessment, it becomes apparent that water reuse is competitive with alternative options of water supply (e.g. with water import). Furthermore it becomes apparent that water reuse or water import is favored in terms of cumulative energy consumption compared to the alternative supply via seawater desalination.

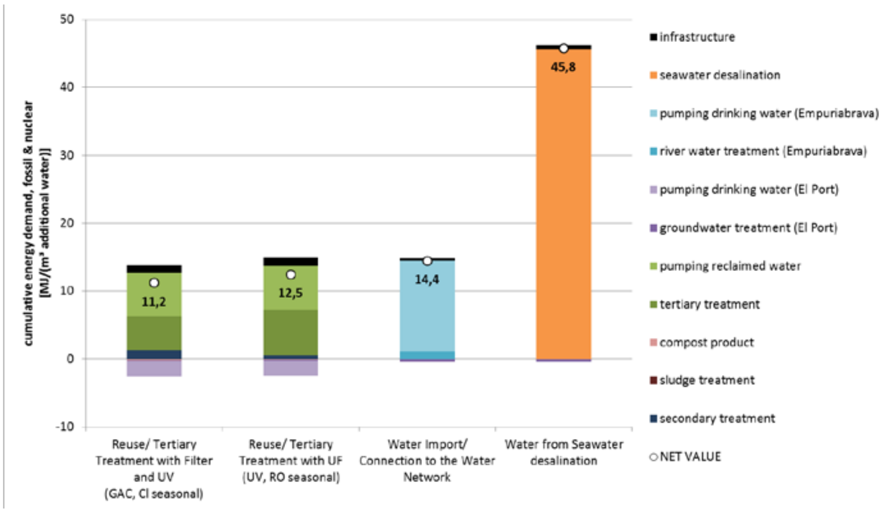

Figure 11 Changes in fossil and nuclear cumulative energy demand of the different scenarios compared to status-quo per m³ additional water in El Port de la Selva (see D3.2)

In general, a water footprint (WFP) is a set of methods that assesses quantitative and qualitative impacts of water withdrawal and discharge, as well as emissions into water or air that affect water quality. In line with the life cycle perspective of LCA, WFP accounts for qualitative and quantitative impacts throughout the system under study and related upstream and downstream processes. WFP has recently been standardized in a new ISO standard ((ISO 14046, 2014)) aligned on the ISO 14040/14044, where basic requirements have been formulated towards a methodological framework for WFP.

A comparable example for a WFP (the WIIX) is shown in Figure 12. The interpretation drawn from Figure 12 is that seawater desalination is the best option to reduce local water scarcity, reuse systems also reduce water scarcity in significant amounts and water import via water network has no effect on the water footprint of El Port de la Selva. Rethinking this conclusion and the concept of water footprint (partly localized assumptions in a global model) is thereby of importance.

In fact, WFP as it described in ISO 14046 is a proper tool to assess the water footprint of a service or a product (e.g. manufacturing a car). When it comes to local water reuse, drinking water supply or wastewater treatment, the more global (partly localized) WFP assessments reveal specific weaknesses. Summarizing this, WFP assessments can be considered in the planning phase of a reuse system, but the results of WFP should be interpreted with care and discussed critically.

- A detailed methodology description for LCA and WFP (WIIX) is conducted in DEMOWARE "D3.1 Appropriate and user friendly methodologies for Risk assessment, Life Cycle Assessment, and Water Footprinting".
- Site specific assessments are performed and discussed in DEMOWARE "D3.2 Show case of the environmental benefits and risk assessment of reuse schemes" for six Case Studies.

- A generic assessment regarding different technologies for tertiary treatment can be extracted from DEMOWARE "D 3.3: Generic assessment of treatment trains concerning their environmental impact and risk reduction potential" to provide first indications

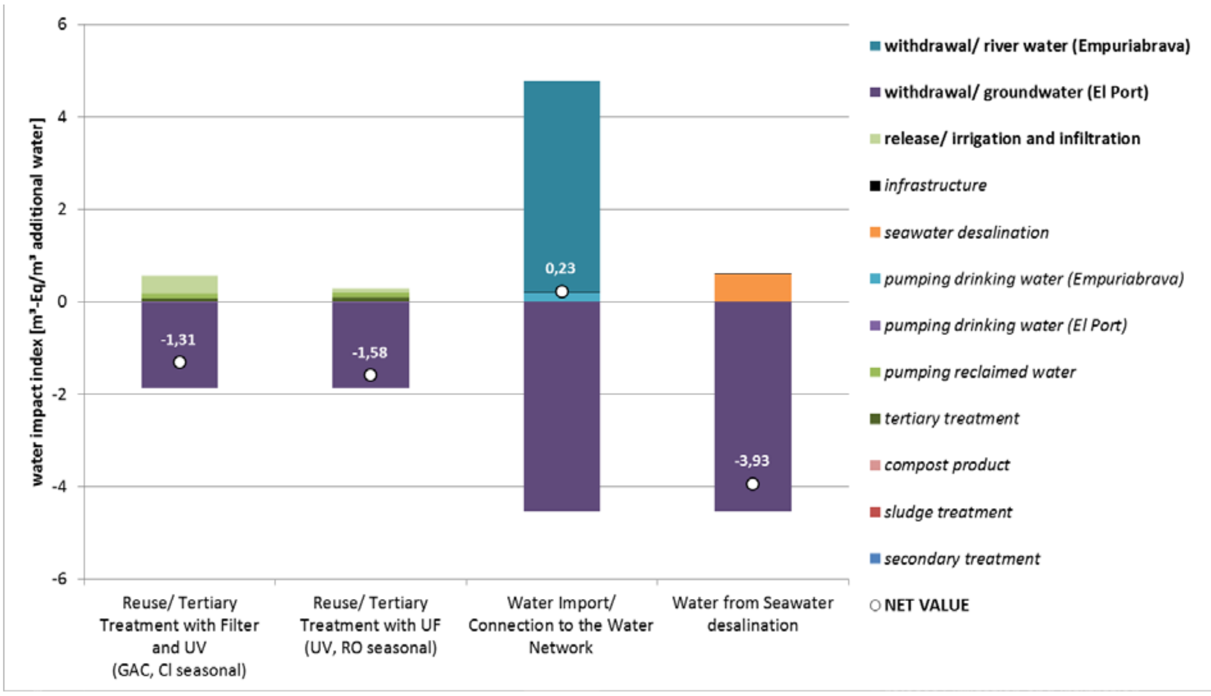

Figure 12: Changes in water impact index of the different scenarios compared to status-quo per m³ additional water in El Port de la Selva

4.4 Integrated treatment train assessment (Module 2.5)

As contribution to Module 2.5 the integrated treatment train assessment elaborated (Kraus et al., 2016; Deliverable D3.3) can be referred to.

This report describes different options for tertiary treatment of secondary effluent from municipal wastewater treatment plants for the purpose of water reuse. For each of the treatment trains, associated environmental impact (represented by energy demand and related global warming potential) and risk reduction potential (i.e. removal of chemical and microbial contaminants) are described based on the results of the DEMOWARE case studies. This should inform water professionals about impacts and benefits of different options for producing reclaimed water, enabling an informed decision on an adequate treatment train depending on the water quality targets for the respective reuse purpose.

After an introductory overview of all trains and the related type of water reuse, the report summarizes details on process description, flow scheme, consumptives (electricity and chemicals required for operation) and their associated primary energy demand and global warming potential, removal rates for contaminants, and additional remarks for operation and maintenance. The final chapter gives an overview of existing uncertainties of this generic assessment and a comprehensive comparison of all options for tertiary treatment in their environmental efforts (= associated global warming potential) and benefits for water quality (= removal of contaminants). A short checklist elaborates on key questions for operators and regulators of water reuse systems from an environmental point of view (Kraus et al., 2016)

4.5 Risk assessment and life cycle assessment for the Vendee region

A comprehensive assessment for a planned indirect potable water reuse scheme in France is presented by Seis and Remy (2017) in Deliverable D6.5. Drinking water reservoir augmentation is envisaged to address recurring water shortages in the region. This first assessment of the planned IPR scheme was based on a set of monitoring data for water quality and the planned design of the tertiary treatment developed during the DEMOWARE project.

The study rules out unacceptable risks for human health using quantitative microbial risk assessment. The risk from chemicals were found to be insignificant as substances were found only in concentrations below the guideline values for drinking water quality, even when taking the higher range of detected concentrations in the reclaimed water ("realistic worst-case approach"). However, selected substances should be monitored more closely to confirm the results of this study with more data.

Life Cycle Assessment shows that water reuse is competitive in energy demand and associated greenhouse gas emissions when compared to water import from another reservoir. Seawater desalination was shown to impose higher environmental impact (energy and greenhouse gas emissions) than the planned water reuse scheme technology.

Overall, both risk assessment and Life Cycle Assessment confirm that an IPR scheme in the proposed site could be operated without unacceptable risks for human health and ecosystems, and with overall environmental benefits compared to water import or seawater desalination. The authors however recommend to reaffirm findings with larger datasets also taking into account effect based monitoring given the lack of knowledge regarding general toxicity as well as low dose mixture and chronic effects of many chemicals.

4.6 Relevant project deliverables

These are the publically available deliverables:

Title	Abstract
D3.1 Appropriate and user friendly methodologies for Risk assess-ment, Life Cycle Assessment, and Water Foot-printing	This report provides the reader with an overview of assessment methodologies used within DEMOWARE and the specific features when using QMRA, QCRA, LCA, and WFP approach for the assessment of water reuse systems. For the actual application of LCA and water footprint databases and assessment software is needed. Therefore, three complementing goals shall be achieved: To provide practitioners with the principles, methods and limitations of QMRA, QCRA, LCA and WFP To provide LCA, WFP, RA practitioners with additional information when using the respective method for the assessment of water reuse systems. For QMRA a summary of guidelines and default values is collected from different guidelines documents (WHO, Australia, US-EPA), which allow a first simplified and thus user friendly risk estimate.
D3.2 Show case of the environmental benefits and risk assessment of reuse schemes	This report summarizes the results of Life Cycle Assessment, Water footprinting, and quantitative microbial and chemical risk assessment for selected demo-sites of water reuse in Europe, measuring the potential impacts of different types of water reuse on environment and human health. The case studies show that water reuse is often preferable from an environmental point of view in areas with water scarcity problems if compared to other alternatives such as water import or seawater desalination. Potential risks of water reuse for ecosystems or human health can be adequately managed if suitable processes for reclaimed water treatment are used and operated correctly. However, the study also shows the trade-offs

	between a higher level of reclaimed water treatment and increased environmental impacts from associated efforts in energy, chemicals and infrastructure. This inherent trade-off requires a site-specific assessment of reuse schemes to choose an adequate treatment scheme for risk management with reasonable global environmental impacts.
D3.3 Generic assessment of treat-ment trains concerning their envi-ronmental impact and risk reduction potential	This report describes different options for tertiary treatment of secondary effluent from municipal wastewater treatment plants for the purpose of water reuse. For each of the treatment trains, associated environmental impacts (represented by energy demand and related global warming potential) and risk reduction potential (i.e. removal of chemical and microbial contaminants) are described based on the results of the DEMOWARE case studies. This should inform water professionals about impacts and benefits of different options for producing reclaimed water, enabling an informed decision on an adequate treatment train depending on the water quality targets for the respective reuse purpose.
D4.3 Cost-benefit analysis approach suited for water reuse schemes.	
D4.4 Social and environmental benefits of water reuse schemes – Economic considerations for two case studies	
D6.5 Health and environmental risk management for the operation of the greenfield demo site (not publically available can be made available upon request)	This report presents the assessment of the planned water reuse scheme at Le Jaunay reservoir (Vendée) in its potential risks for human health and ecosystems, and also in its overall environmental impacts. Methods of risk assessment (quantitative microbial and chemical risk assessment) and Life Cycle Assessment are used to characterize the potential hazards associated with the use of reclaimed water, but also the environmental benefits compared to other options for additional drinking water supply. The assessments show that water reuse can be operated without unacceptable risks for humans and the environment, and that it is competitive to other options of water supply in its energy demand and greenhouse gas emissions. Data quality should be improved in a demonstrator phase to validate the outcomes of this first assessment.

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