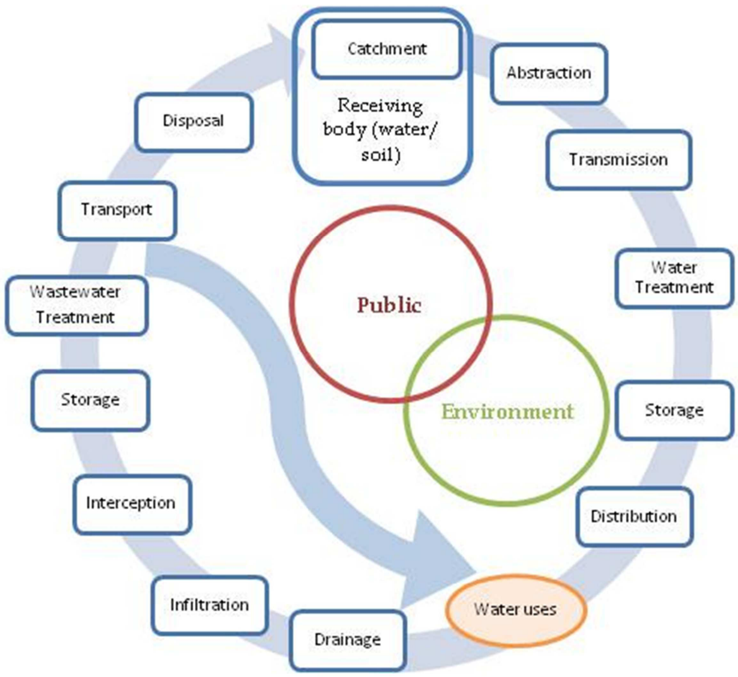
Water cycle safety plan framework

Proposal



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Summary

Potential effects of climate dynamics on the urban water cycle can involve the aggravation of existing conditions as well as occurrence of new hazards or risk factors. The risks associated with expected climate changes have to be dealt with by the society in general and by the water utilities and other stakeholders in particular.

The challenges created by climate changes require an integrated approach for dealing with existing and expected levels of risk. Given the interactions of urban water and natural systems, adaptation measures should address all water cycle components and their interactions.

A generic framework is proposed in this document in order to identify relevant risks and opportunities while incorporating uncertainties, in a systematic way. The main purpose of this report is to setup an overall framework for development and implementation of Water Cycle Safety Plans (WCSP). The subsequent PREPARED tasks allow this initial proposal of framework to be tested and adjusted using the selected case studies of the project.

Throughout this document, examples and tools are provided to clarify and assist implementing a WCSP framework. The final version of the proposed framework (deliverable D2.1.4) will further include, for each WCSP step, practical examples of its application to the PREPARED project case studies.

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Acronyms

ADWG	Australian drinking water guidelines
AOB	Annual operating budget
CCP	Critical control point
CSO	Combined sewer overflow
ERP	Emergency response plan
GHG	Greenhouse gases
HACCP	Hazard analysis and critical control points
PRP	Prerequisite programmes
RMF	Risk management framework
RMP	Risk management process
RRM	Risk reduction measure
SOP	Standard operating procedures
SSP	System safety plan
RIDB	Risk identification database
RRDB	Risk reduction database
WCSP	Water cycle safety plan
WHO	World health organization
WSP	Water safety plan

1 Introduction

1.1 Background

Climate dynamics trends impose important challenges to the water sector. Alteration of the range of operation conditions, potentially resulting from increase in atmosphere and sea temperatures, variation in precipitation quantity and patterns or increase of average sea level, needs to be dealt with proactively by the different stakeholders involved in the urban water cycle.

Potential effects on the urban water cycle involve the aggravation of existing conditions as well as occurrence of new hazards or risk factors.

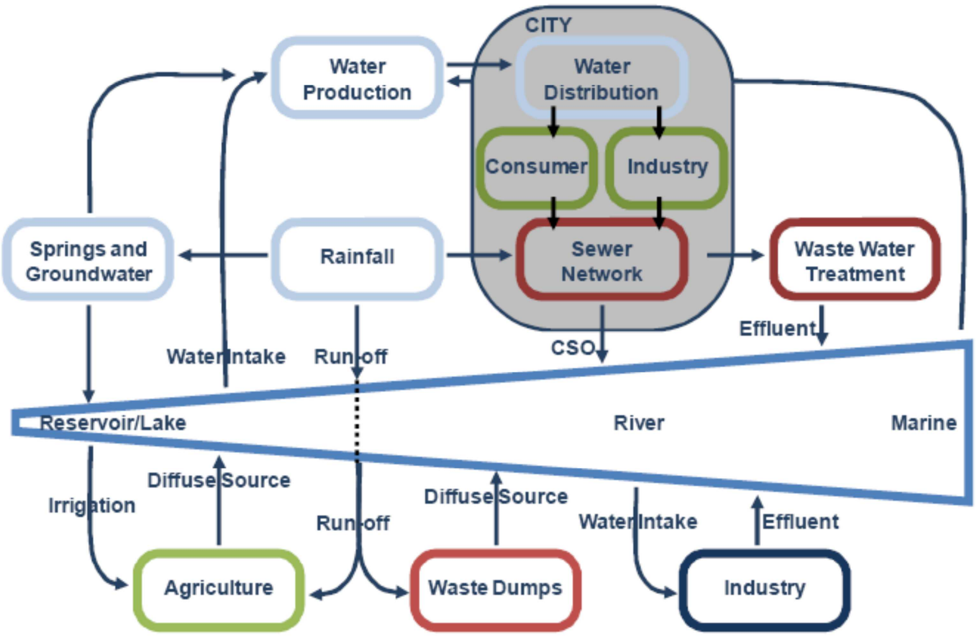


Figure 1 - Water cycle interactions and the city (Extract from PREPARED DoW)

The risks associated with expected climate changes have to be dealt with by the society in general and by the utilities and other stakeholders specifically. Challenges require an integrated approach for dealing with existing and expected levels of risk.

Given the interactions of urban water and natural systems and the effects of climate dynamics affecting the entire water cycle, adaptation measures should address all water cycle components and their interactions. Therefore, a generic framework to tackle the climate change issues is required. This framework should include identification of risks and opportunities related to alternative actions, be systematic and incorporate uncertainties.

Over the last decade, several risk driven frameworks and strategies have been developed and applied to water supply systems in order to ensure the safety of drinking water, including the **Water Safety Plan** (**WSP**) approach developed by WHO/EC for drinking water. Most of these are grounded in risk assessment and management approaches.

Given the evolution of the generic risk management procedure and efforts to standardize the approach and the terminology (ISO 31 000:2009 and ISO Guide 73:2009) a proposal of a water cycle safety plan framework should incorporate these latest developments.

The **Risk Management Framework (RMF)** is a general systematic approach applicable by organizations to develop and implement risk treatment strategies as a part of their overall governance, strategy and planning. According to IEC (1995) and ISO 31 000 (2009a) the objective of the overall process is to control, prevent or reduce loss of life, illness, injury, damage to property and consequential loss, and environmental impact. The RMF incorporates a **Risk Management Process** (**RMP**) for the effective implementation of risk management principles at all relevant levels and functions of the organisation. The RMP has been used not only in water supply but in a wide range of other activities.

Figure 2 shows the main steps of RMP. These steps are: description of the context of risk management, risk assessment (including risk identification, risk analysis and risk evaluation), risk treatment (including selection and implementation of risk treatment measures) and monitoring and review of the whole process. Successful risk management also requires communication of risks between the involved stakeholders.

Looking back at the origins of the Water Safety Plans, they are grounded on a hazard analysis and critical control points approach.

The **Hazard Analysis and Critical Control Points (HACCP)** strategy was originally conceived for the food industry to assure food safety and that all food products reaching the consumer are safe for consumption. Its principles are presented in Codex (2003) and the main steps are presented in Figure 2.

As preliminary steps a project team is assembled, the product and its intended use are identified and the industrial process that originates the product is described in a flow diagram. The second phase deals with hazards. At this point, hazards are identified and, for each one, control measures are defined and critical control points (CCPs) are determined.

Critical control point is as a new concept introduced in HACCP and is defined as a step at which control can be applied and is essential to prevent or eliminate a hazard or reduce it to an acceptable level. For each CCP, critical limits and the corresponding monitoring should also be established to detect loss of control in time to make adjustments through corrective actions that should be specified. In the case of water supply systems, although the application of the HACCP approach for treatment plants is relatively straightforward, some difficulties arise when applying it for the catchment and for the distribution systems. Requirements for identification and control of CCPs are not always easy for the system manager due to lack of direct control; achievement of results depends on other external parties within the water cycle.

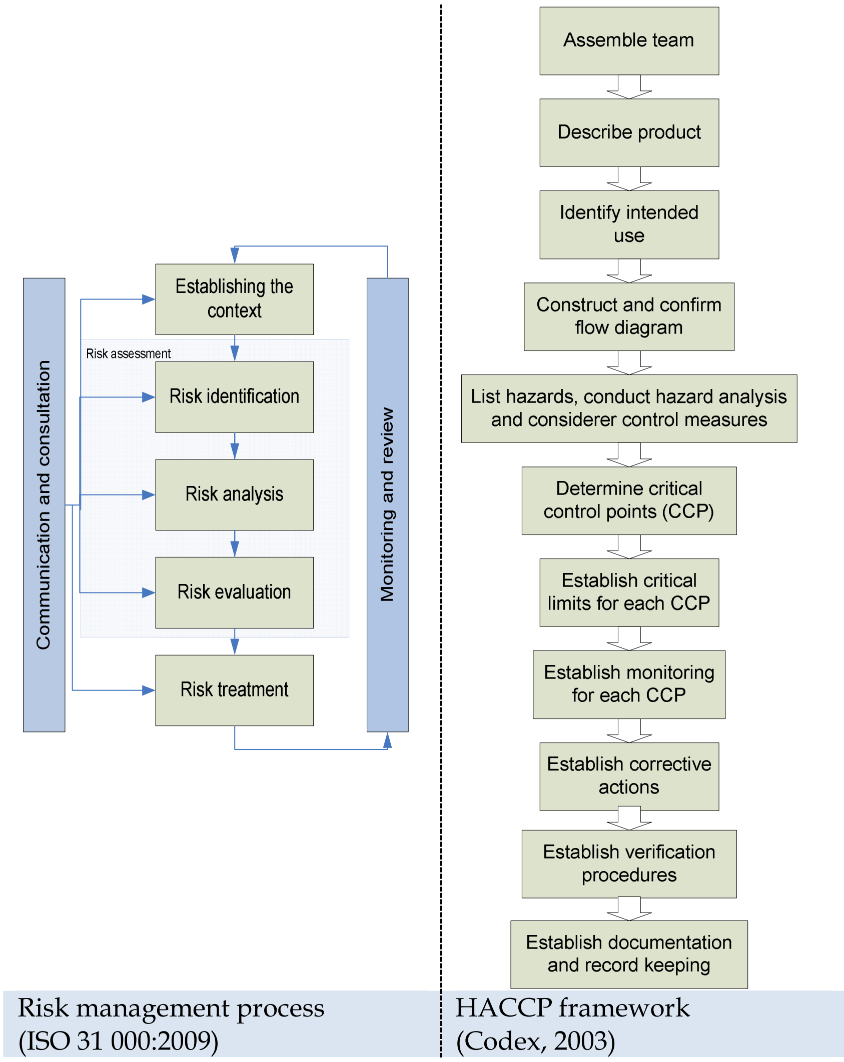


Figure 2 - Risk management process and HACCP framework

Verification procedures, establishment of adequate documentation and record keeping are also components of the HACCP system.

Although there are similarities between the two frameworks, some aspects of the RMP are not included in HACCP, e.g. establishment of context, risk acceptance/tolerability assessment and evaluation principles. Also, the use of the method for selection of risk reduction measures is not fully considered. An additional limitation to the HACCP approach is that it is hardly auditable.

The **ISO 22000 (2005)** integrates the principles of HACCP and specifies the requirements for a food safety management system, thus having the advantage of being auditable and suitable for certification purposes. The approach described in this standard goes beyond HACCP as it incorporates additional recommendations and clarifies some existing ones. Figure 3 highlights the main differences between the two frameworks. New application steps included in the ISO 22000 are related to the requirement for the implementation of prerequisite programmes PRP (basic conditions and activities to maintain a hygienic environment throughout the food chain suitable for the production of safe products; an example is the monitoring system) and to the validation of combinations of control measures. Another new component in the ISO 22000 is communication, both inside and outside the organization.

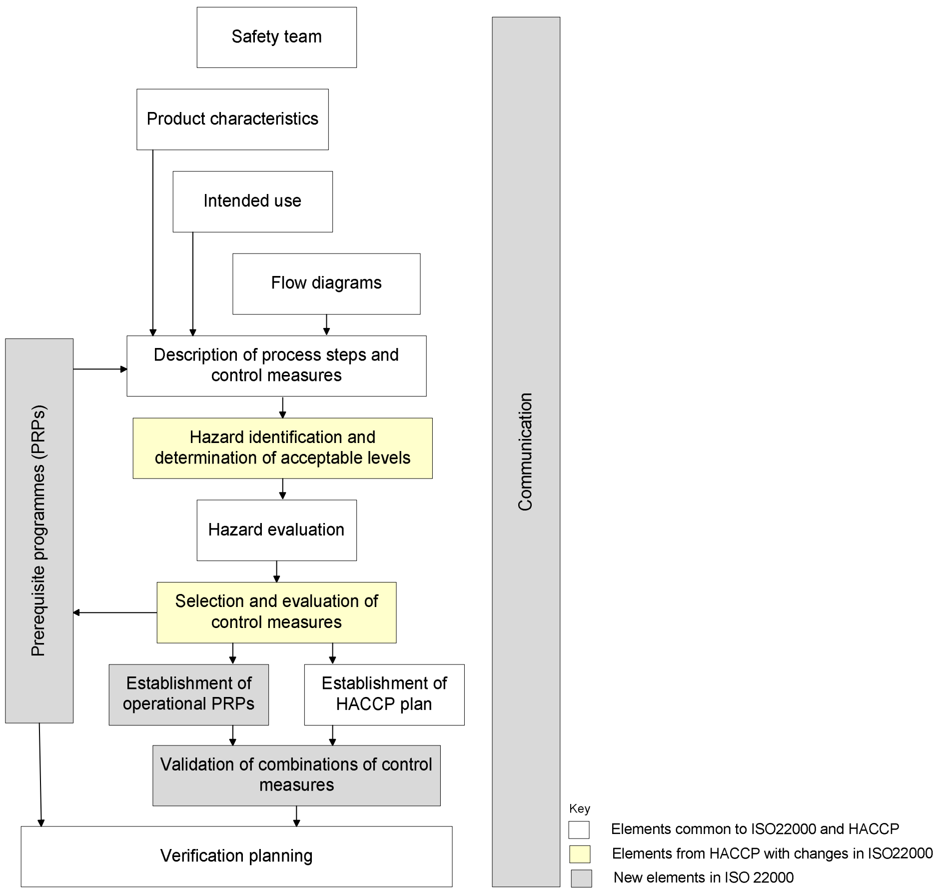
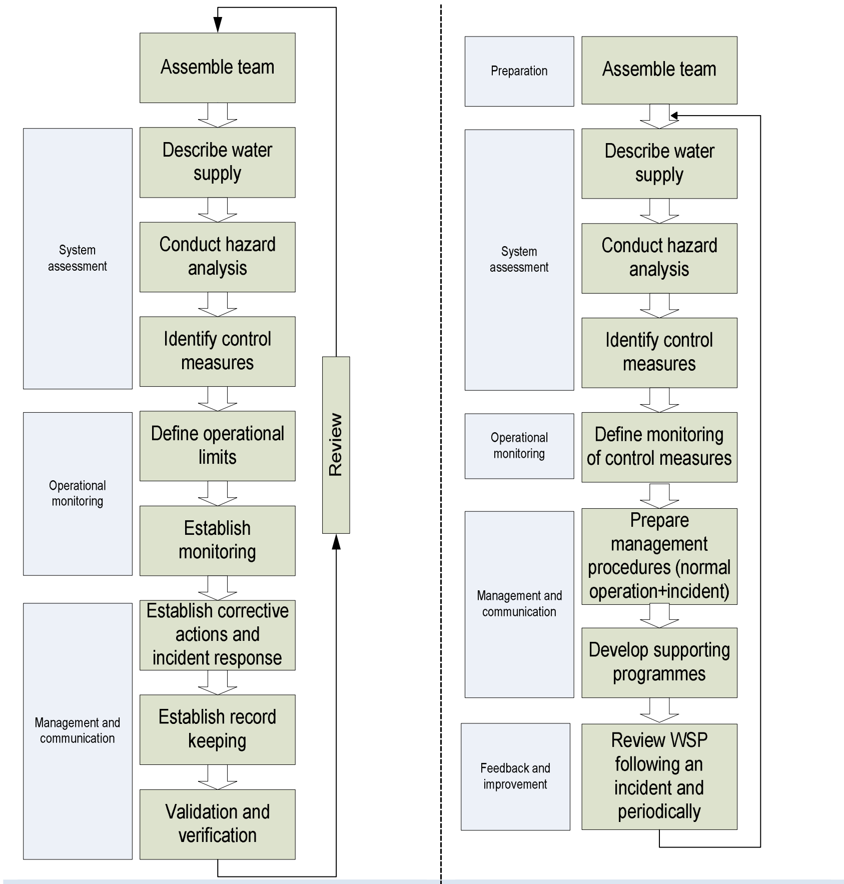


Figure 3 - Comparison between ISO 22000 (2005) and HACCP frameworks

Water being a product in the food chain, HACCP has also been applied in the water industry. The publication of the 3rd edition of the *WHO Guidelines for drinking water quality* (WHO, 2006) establishes the need for water utilities to follow risk assessment and risk management approaches by implementing **Water Safety Plans (WSP)** the aim of which is to consistently ensure the safety and acceptability of drinking water considering health-based targets. This approach incorporates not only end-product testing but also process control from source to tap.

WSPs were first described in detail in WHO (2005) and, more recently, in WHO (2009), a manual for WSP development and implementation. In terms of main steps, this second version of WSP contains no major changes (Figure 4). Minor changes are related to different grouping of the steps (e.g., the step “supporting programmes” in WHO, 2009, includes the step “establishment of record keeping” from WHO, 2005).

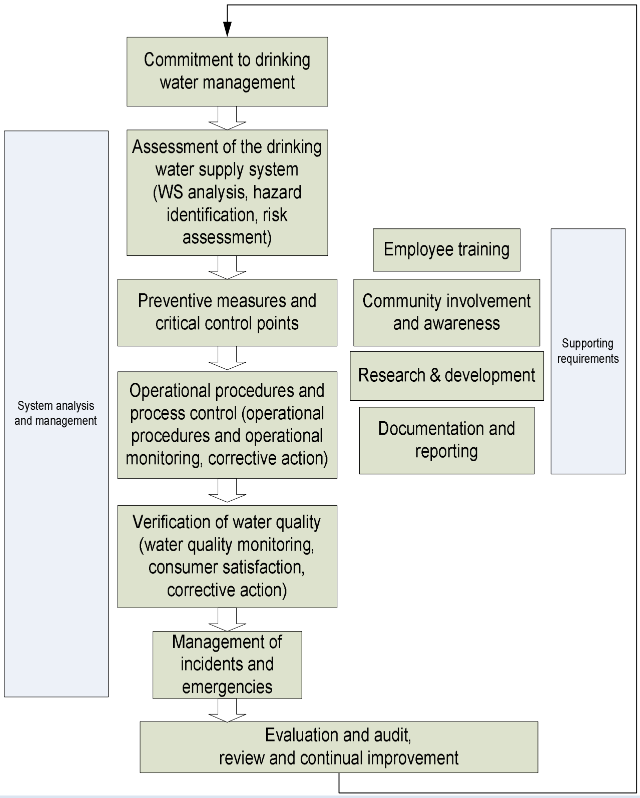


Water Safety Plan framework (WHO, 2005) | Water Safety Plan framework (WHO, 2009)

Figure 4 - Water Safety Plan framework evolution

WSP incorporates HACCP principles and both are based on a multiple barrier approach. WSPs can be seen as an adaptation of the HACCP approach to the specific field of water supply. Figure 2 and Figure 4 show that the key steps of WSP and HACCP are similar, though some expressions differ when used to describe similar tasks. Even the definition of *hazard* used by WSP (*a biological, chemical, physical or radiological agent that has the potential to cause harm*) is very similar to the one given in the description of HACCP. A difference between the two approaches is that WSP does not explicitly use the concept of “critical control point” in determining where control measures should be implemented. For drinking water supply no single control point in the multiple barriers is considered to be ´critical´ since all barriers are needed to provide safety.

WSP is specific to water supply systems, and focuses on risks related to human health. Conversely, the RMP approach is broader, applicable to any field and can be used to manage any type of risk. Application and adaptation of the RMP to manage drinking water quality has been followed in the scope of the Australian Drinking Water Guidelines (ADWG) (NHMRC, 2004) (Figure 5).



Framework for management of drinking water quality including risk management (NHMRC, 2004)

Figure 5 - Framework for management of drinking water quality including risk management

As can be seen in Figure 2, Figure 4 and Table 1, WSPs have several similarities with RMP in terms of the key steps:

- the preparatory work carried out before the risk management steps is similar in both frameworks, in establishing the context in RMP, and in assembling a team and describing the water supply system in WSP. However, the former is broader in scope;
- the step of hazard analysis in WSP can be considered in order to include steps two and three of RMP (risk identification and risk analysis). The latter has the advantage of improving clarity in concepts and steps, facilitating the understanding and implementation of the approach;
- the risk treatment step in RMP can be considered in order to include the identification of control measures, definition of operational limits and establishment of corrective actions (steps four, five and seven in WSP);
- record keeping, monitoring and review are components of both frameworks.

Two main differences between RMP and WSP that should be mentioned are as follows:

- the risk evaluation step in RMP (decision on which risks need treatment, which is based on the comparison of results from risk analysis with previously set criteria) is not included in WSP. According to Rosén *et al.* (2009) this is probably due to the fact that WSP work is guided by health based targets and decisions about tolerable risk are made when the targets are compiled. However, to deal with risks that cannot be controlled using predetermined targets, the risk tolerability decision should be included as part of the work;
- supporting programmes that assist other steps in WSP are not explicitly included in RMP.

Table 1– Comparison between RMP and WSP frameworks

Component of Risk Management Process and Framework (RMP/RMF)	Component of Water Safety Plan framework (WSP)
Establish the context	Assemble team Describe water supply
Risk identification Risk analysis	Hazard analysis
Risk evaluation	
Risk treatment	Identify control measures Define operational limits Establish corrective actions
Monitoring and review	Establish record keeping Establish monitoring Review Validation and verification
-	Supporting programmes

General aspects common to all above described frameworks used to deal with water supply safety are:
- adoption of a preventive and systematic risk approach for managing risk;
- use of a multi-barrier approach to control risks;
- end-product testing is complemented by a process control approach that considers risks from source to tap;
- frameworks are mainly directed at quality aspects and not quantity;
- importance of periodic reviews;
- importance of co-operation between stakeholders;
- importance of communication inside and outside the organizations.

The European project TECHNEAU already considered the integration of risk management approaches in WSP (Rosén *et al.*, 2009). However, despite the modifications introduced it is not yet harmonised with the RMP.

1.2 Scope of the WCSP

While WSP are focused solely on the protection of public health, the intended scope of WCSP is broader. Extent and specific focus depends on the level and strategic objectives considered by the stakeholders.

Safety aspects to be incorporated in a water cycle safety plan should consider the context both in formal documents (e.g. legislation and standards) and in accepted good practices. Principles in current standards and practices need to be taken into account for establishing the safety primary aims in the water cycle.

Overall, directions for water utilities and other stakeholders included in the ISO and EN standards (ISO 24511:2007, ISO 24512:2007 and EN 752:2008) cover aspects such as:

- protection of public health;
- safeguard public safety;
- protection of surface and groundwater;
- sustainable use of resources (water, energy, …);
- continuity of service;
- fulfil needs and expectations of consumers and other users;
- sustainability of the service.

Furthermore, relevant EU Directives have to be taken into account, namely:

- **Water Framework Directive** (2000/60/EC) which aims at protecting European water resources (rivers, lakes, groundwater, estuaries and coastal waters). It requires Member States to achieve "good ecological and chemical status" in all water bodies by 2015, by preventing water pollution and deterioration of water quality, and to ensure that the achieved status does not deteriorate. In terms of quantity, the Directive restricts abstraction of water from water sources to a quantity that corresponds to the portion of the overall recharge not needed by the ecology.
- **Drinking Water Directive** (98/83/EC revision in progress) the objective of which is the protection of the consumers' health by guaranteeing the quality of drinking water. It sets quality standards for drinking water at the tap (microbiological, chemical and organoleptic parameters) and the general obligation that drinking water should be wholesome and clean. The inclusion of a WSP-type approach in this directive is being considered in the on-going revision process (WHO, 2007).
- **Urban Waste Water Treatment Directive** (91/271/EC) the objective of which is to protect the environment from the adverse effects of urban waste water discharges and discharges from some industrial sectors. It sets requirements in terms of level of wastewater treatment and limits for pollutants in the treated wastewater.
- **Bathing Water Directive** (2006/7/EC) which aims to ensure good bathing water quality. It sets quality standards for bathing waters by

establishing limits for physical, chemical and microbiological parameters.

- **Groundwater Directive** (2006/118/EC) the aim of which is the protection of groundwater from pollution and deterioration. It sets groundwater quality standards (at present, the maximum limits for pollutant concentrations have been set for nitrate and pesticides) and introduces measures to prevent inputs of pollutants into groundwater.
- **Floods Directive** (2007/60/EC) that promotes the assessment and management of flood risks considering climate change aspects. It requires Member States to identify water courses and coast lines at risk from flooding, to map the flood extent and assets and humans at risk in these areas and to implement control measures to reduce the flood risk.

Other documents to take into account include:

- **EU Communication on Water Scarcity and Drought** (COM 2007/414) that addresses the challenge of water scarcity and droughts in the European Union. It promotes, among other measures, the development of drought risk management plans.
- **EU Thematic Strategy for Soil Protection** (COM 2006/231) that addresses the protection and sustainable use of soil, based on guiding principles including preventing further soil degradation and preserving its functions and restoring degraded soils to a level of functionality consistent at least with current and intended use.
- **EU Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC** (COM 2006/232).

Other important aspects to take into consideration include efficiency in the use of resources and minimisation of greenhouse gases (GHG).

Widening scope of safety plans implies multiple primary aims when looking at the water cycle. Therefore, the envisaged scope of the water cycle safety plans comprises the **protection of public health** but also the **public safety** and the **protection of the environment**.

Aspects of water quality as well as water quantity need to be addressed. Numerous examples of interaction between quality and quantity can be given such as the potential effect of water shortages in deterioration of water quality. Insufficient water supply as well as excessive water may cause safety issues (e.g. lack of water for fire fighting, flooding).

1.3 Definitions adopted

Given the existing differences in terminology and approaches, an effort has been made to harmonise and integrate recent developments in risk management standards. Thus, the definitions presented in Table 2 are adopted within the present document. The main source document used is the ISO Guide 73:2009.

Table 2 – Risk management definitions adopted

Expression	Definition
consequence	outcome of an **event** affecting objectives. An event can lead to a range of consequences. A consequence can be certain or uncertain and can have positive or negative effects on objectives and be expressed qualitatively or quantitatively. Initial consequences can escalate through knock-on effects.
control	measure that is intended to modify **risk**. Controls include any process, policy, device, practice, or other actions which modify risk and may not always exert the intended or assumed modifying effect.
event	occurrence or change of a particular set of circumstances. An event can be one or more occurrences, can have several causes, can consist of something not happening. An event can be referred to as an "accident" or "incident". The latter is an event without **consequences**.
exposure	extent to which an organization or individual is subject to an **event**.
hazard	source of potential harm. A hazard can be a **risk source**.
likelihood	chance of something happening, whether defined, measured or determined objectively or subjectively, qualitatively or quantitatively, and described using general terms or mathematically such as a **probability** or a **frequency** over a given time period. Probability is the measure of the chance of occurrence expressed as a number between 0 and 1, where 0 is impossibility and 1 is absolute certainty. In some languages **probability** is used with the same broad meaning.
residual risk	**risk** remaining after **risk treatment**. Residual risk can contain unidentified risk and can also be known as "retained risk".
resilience	adaptive capacity of an organization in a complex and changing environment.
risk	effect of uncertainty on objectives. An effect is a deviation from the expected and can be positive or negative. The objectives can have different aspects (such as financial, health and safety, and environmental goals) and can apply at different levels (such as strategic, organization-wide, project, product and process). Risk is often characterized by reference to potential **events** and **consequences**, or a combination of these, and is often expressed in terms of a combination of the consequences of an event (including changes in circumstances) and the associated **likelihood** of occurrence. Uncertainty is the state, even partial, of deficiency of information related to, understanding or knowledge of, an event, its consequence, or likelihood.
risk analysis	process to comprehend the nature of **risk** and to determine the **level of risk.** Risk analysis provides the basis for **risk evaluation** and decisions about **risk treatment** and includes risk estimation.
risk assessment	overall process of risk identification, risk analysis and risk evaluation
risk evaluation	process of comparing the results of risk analysis with risk criteria to determine whether the risk or its magnitude is acceptable or tolerable. Risk evaluation assists in the decision about risk treatment.

Table 2 – Risk management definitions adopted (cont.)

Expression	Definition
risk factor	something that can have an effect on the risk level, by changing the probability or the consequences of an event. Risk factors are often causes or causal factors that can be acted upon using risk reduction measures. Typically three main categories are considered namely human factors, environmental factors and equipment/infrastructure factors.
risk financing	form of risk treatment involving contingent arrangements for the provision of funds to meet or modify the financial consequences should they occur.
risk identification	process of finding, recognizing and describing risks. Risk identification involves the identification of risk sources, events, their causes and their potential consequences. It can involve using historical data, theoretical analysis, informed and expert opinions, and stakeholder's needs.
risk management	coordinated activities to direct and control an organization with regard to risk
risk perception	view of stakeholder's on a risk, reflecting the needs, issues, knowledge, belief and values
risk profile	description of any set of risks. The set of risks can contain those that relate to the whole organization, part of the organization, or as otherwise defined.
risk source	element which alone or in combination has the intrinsic potential to give rise to risk. A risk source can be tangible or intangible. Risk source is where the hazardous event potentially begins.
risk treatment	process to modify risk. Risk treatment can involve: — avoiding the risk by deciding not to start or continue with the activity that gives rise to the risk; — taking or increasing risk in order to pursue an opportunity; — removing the risk source; — changing the likelihood; — changing the consequences; — sharing the risk with another party or parties [including contracts and risk financing]; and — retaining the risk by informed decision. Risk treatments that deal with negative consequences are sometimes referred to as "risk mitigation", "risk elimination", "risk prevention" and "risk reduction". Risk treatment can create new risks or modify existing risks.
stakeholder	person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity.
vulnerability	intrinsic properties of something resulting in susceptibility to a risk source that can lead to an event with a consequence.

Within the scope of WSP, where **protection of public health** was the sole aim, the **hazard** is the source of potential harm to the **consumer** and the hazardous event, or **event**, is the occurrence or change of a particular set of circumstances that has the potential to cause consequences to the consumer. When consequences exist there is an **accident**; if the event is without consequences then can be referred to as **incident**. Furthermore, **exposure** of the consumer to a hazard is determinant for the event to occur.

There are numerous factors that determine the level of risk. These **risk factors** can have an effect on the risk level by changing the **likelihood** or the **consequences** of an event. These risk factors are often causes or causal factors that can be acted upon using risk reduction measures.

In Figure 6 an illustration of the risk management concepts is presented.

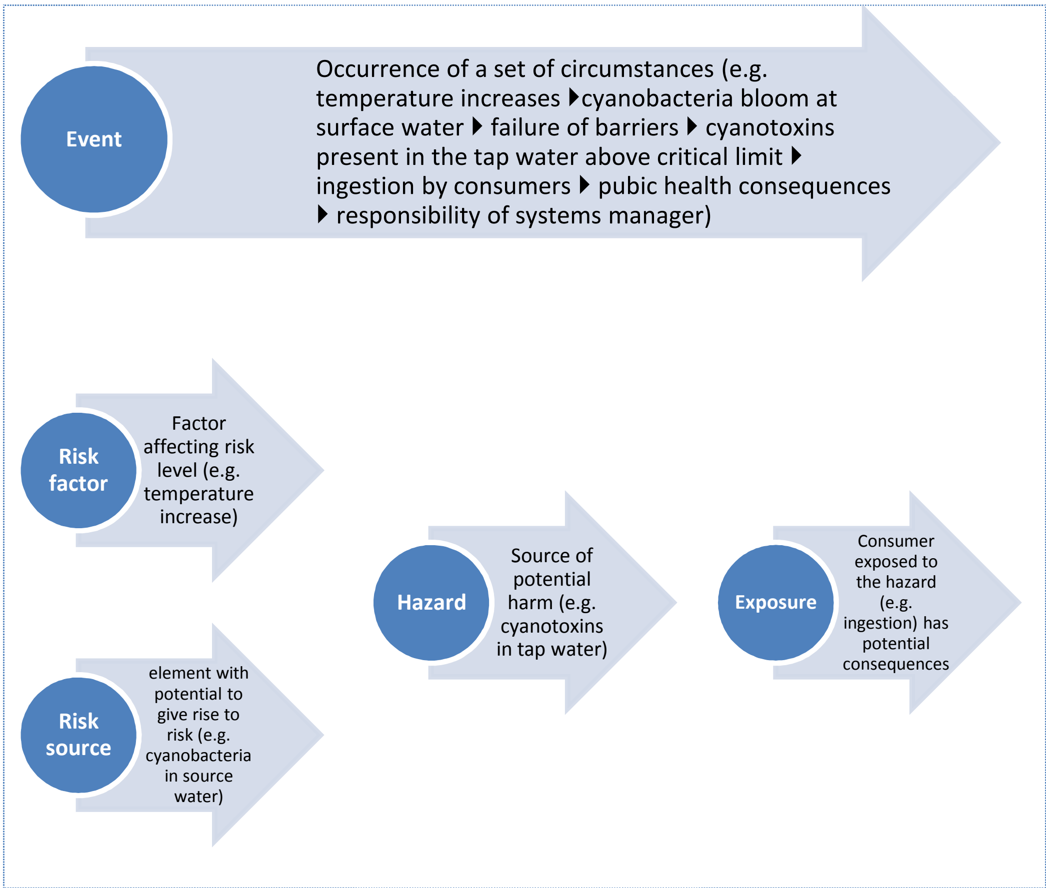


Figure 6 - Example of application of risk management concepts

1.4 Structure of the document

The main purpose of this report is to set out an overall framework for development and implementation of Water Cycle Safety Plans (WCSP). In an introductory chapter, the background for WCSP is presented through a brief review of existing risk driven frameworks and strategies that have been applied to water supply systems. The scope of WCSP and the definitions adopted in the document are also presented in this first chapter.

An overview of the proposed WCSP framework is presented in Chapter 2, including the primary aims to be addressed and the steps to be followed when developing and implementing a WCSP. These steps are further detailed in Chapter 3 for the water cycle level and in Chapter 4 for the system level. For each step, a description of the key actions to be taken is presented; common difficulties encountered are also identified and expected results are listed.

Throughout the text of this document, examples and tools are provided to clarify and help implementing the WCSP framework. The final version of the report will further include, for each WCSP step, practical examples of its application to PREPARED case studies.

2 Water cycle safety plan framework overview

2.1 WCSP primary aims

Considering the scope of WCSP, the primary aims of the water cycle safety plans are the **protection of public health and safety** and **protection of the environment**. For each primary aim the elements at risk need to be identified for the specific situation.

As a result of broadening the approach, when compared with the WSP approach, different hazards are to be considered. Nonetheless, the approach is about "water safety" to people and to the environment and centralised on the urban water systems. Accordingly, as a general rule, mainly aspects related to the water cycle from systems managers' point of view are of interest.

For each primary aim, exposure to hazards should be considered taking into account the items presented in Table 3.

Table 3 – Definition of the aims of the WCSP

Primary aim	Exposure to hazards	Generic / typical hazards
Protection of public health	Consumer / user	Non-safe water at consumption or use (chemical, microbial characteristics)
	Recreational user	Polluted water when bathing (microbial, chemical contamination)
	Public	Flooding with water contaminated with sewage
Protection of public safety	Consumer / user Public Utility worker*	Infrastructure collapses / bursts Flooding Chemical spillage Release of toxic gases
Protection of environment	Receiving water bodies (water quality, ecosystems) (Soil)	Overuse of resources Pollution affecting ecological / chemical status of water bodies

* In general these issues are dealt with by health and safety legislation, thus not necessarily included in WCSP unless specific conditions occur

A water company that has already implemented a WSP might consider complementing the approach to upgrade to a WCSP framework by including public safety and environment protection in the analysis.

For organisations where risk management is adopted comprehensively other primary aims will naturally be considered by stakeholders, since the risk management approach does not strictly deal with safety.

2.2 Steps of the WCSP framework

Achieving the overall aim of improving safety in the water cycle, in an effective and efficient way, primarily depends on the involvement of key stakeholders sharing common principles and objectives that underpin the establishment of collaborative processes.

An inherent aspect that should be ensured in these collaborative processes is the recognition of the broad duties of each stakeholder and the overall importance of adopting integrated approaches to address societal aims, such as public health and safety and environmental protection.

Management objectives and risk perceptions of stakeholders will differ according to their specific duties and aims. Assembling a multi-stakeholder team allows different points of view to be taken into account and to improve individual perceptions for the different risks. Consequently, decision making processes may be better supported and information and technologic resources more efficiently used.

Therefore, the proposed framework incorporates two levels of action: the water cycle integrated level and the system level.

At the **water cycle integrated level** issues are dealt with at a macro scale and interactions considered. Detailed analysis is carried out at the **system level**. At both levels safety plans should be produced, one for the water cycle and as many system plans as the existing number of organizations managing water systems (Figure 7). Other planning instruments should be taken into account as appropriate, for instance the river basin management plans, as stipulated in the EU Water Framework Directive.

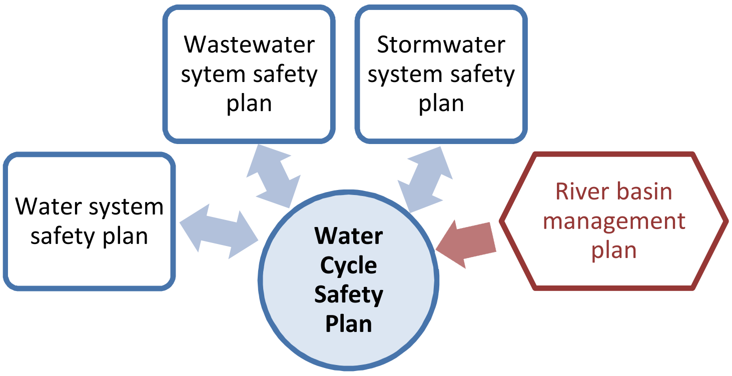


Figure 7 – Typical WCSP levels

Following the structure of a WSP, nine steps were considered for the preparation of a WCSP, as follows (see Figure 8):

1. Commitment and establishment of water cycle safety policy and scope;
2. Urban water cycle characterisation;
3. Preliminary risk identification in the water cycle;

4. Preliminary risk analysis and evaluation in the water cycle;
5. Development of system safety plans (SSP) (system level);
6. Integrated risk analysis and evaluation;
7. Integrated risk treatment;
8. Management and communication programmes and protocols;
9. Monitoring and review.

These steps follow a logical sequence but can be arranged in a different order or some may be carried out concomitantly, according to each situation.

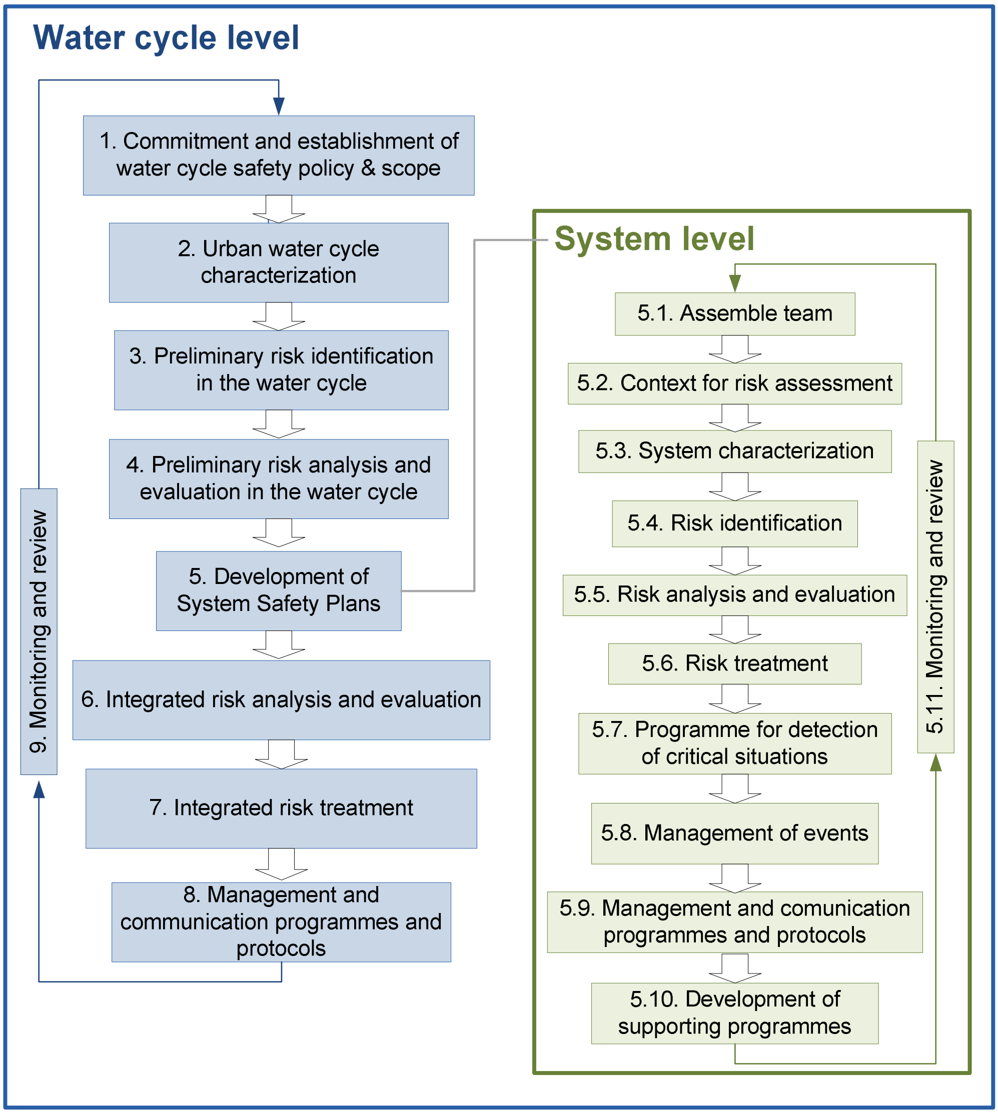
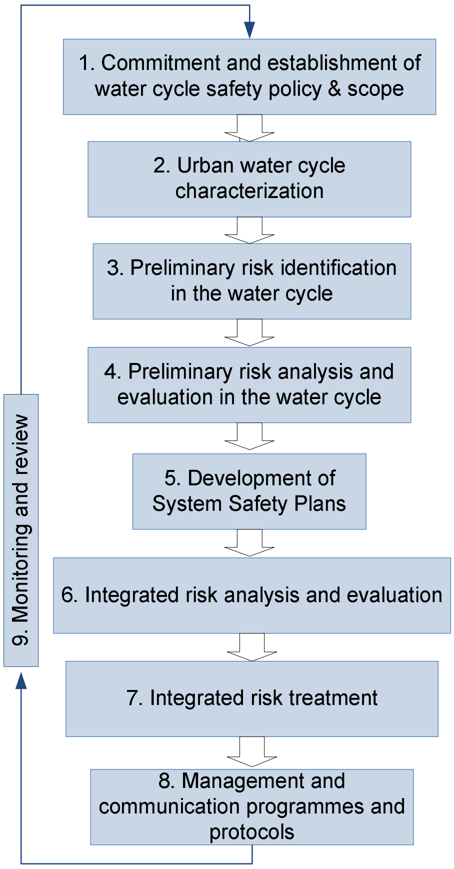


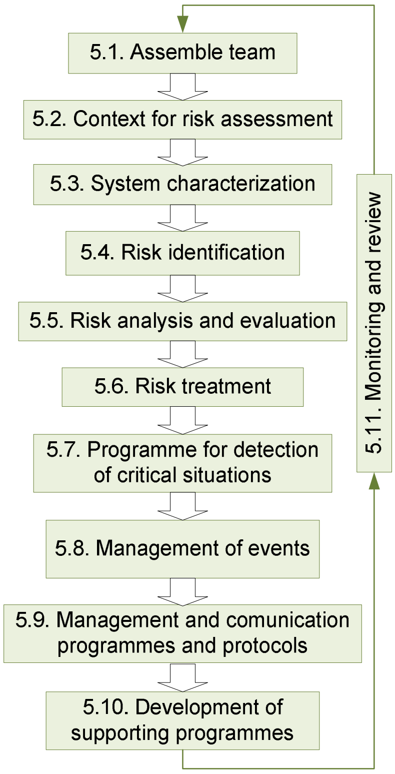
Figure 8 - WCSP framework

In Figure 9 and Figure 10 the key actions to consider in each step of a water cycle safety plan and system safety plans are presented, respectively. Detailed presentation of each step is included in Chapters 3 and 4.



Step	Key actions
1.	▸ Identify stakeholders and assemble team ▸ Define the time frame to develop the WCSP ▸ Compile formal requirements ▸ Define the water cycle safety policy ▸ Set criteria for subsequent risk analysis
2.	▸ Water cycle components and interactions ▸ Identify criteria and targets for products and services
3.	▸ Identify relevant hazards, risk sources and risk factors ▸ Assess the potential effect of climate change trends ▸ Explore scenarios and potential events
4.	▸ Assess the likelihood and consequences for each event ▸ Estimate the level of risk for each event ▸ Evaluate risk for each event
5.	(See Figure 10)
6.	▸ Aggregate information from system safety plans at the water cycle level ▸ Compare and reassess estimated risks
7.	▸ Identify risk reduction measures ▸ Compare, prioritize and select risk reduction measures ▸ Develop a risk treatment programme ▸ Assess residual risk
8.	▸ Develop and implement communication programmes and protocols ▸ Develop and implement management programmes and protocols ▸ Review management programmes and protocols
9.	▸ Define tasks and responsibilities ▸ Keep the WCSP up to date ▸ Record and report results

Figure 9 - WCSP framework- detail for water cycle level



Step	Key actions
5.1.	‣ Identify necessary qualifications and expertise of team members ‣ Secure management commitment and financial support ‣ Define roles and responsibilities of team members ‣ Appoint a team coordinator ‣ Define the time frame to develop the SSP
5.2.	‣ Define the scope for risk management ‣ Set risk acceptability criteria
5.3.	‣ Construct a flow diagram ‣ Describe the system and its subsystems
5.4.	‣ Identify relevant hazards, risk sources and risk factors ‣ Assess potential effect of climate change trends ‣ Explore scenarios and potential events
5.5.	‣ Assess the likelihood and consequences for each event ‣ Estimate the level of risk for each event ‣ Evaluate the risk for each event
5.6.	‣ Identify risk reduction measures ‣ Compare alternatives, prioritize and select risk reduction measures ‣ Develop a risk treatment programme ‣ Assess residual risk
5.7.	‣ Establish operational monitoring procedures ‣ Set critical limits
5.8.	‣ Establish corrective actions ‣ Develop an Emergency Response Plan
5.9.	‣ Develop and implement communication programmes and protocols ‣ Develop and implement management programmes and protocols ‣ Review management programmes and protocols
5.10.	‣ Identify and develop supporting programmes needed for the implementation of the SSP ‣ Review supporting programmes
5.11.	‣ Define tasks and responsibilities ‣ Keep the WCSP up to date ‣ Record and report results

Figure 10 - WCSP framework- detail for system level

An important aspect that was taken into account in the definition of the framework was ensuring compatibility with existing approaches. Therefore, existing documentation on approaches described in Chapter 1 were important sources for the following chapters.

3 WCSP Framework ▸ Step by step

3.1 Overview

The proposed WCSP framework is divided in nine steps. These nine steps are generally applicable to all urban water cycles but some aspects, such as data collection, data analysis and risk evaluation techniques, will vary according to size, technological complexity, functions and components of each case.

This chapter presents in detail the steps required to develop and implement a WCSP. The following sections of this chapter describe each step of the WCSP and are divided into four items: description, key actions, common difficulties and expected results for the step. In the description, a brief overview of the step is given, emphasizing the objectives and contribution to the overall framework. The key actions are the activities that should be carried out in the step. Common difficulties are those challenges that often happen during implementation phase of a WCSP. The planned tests within the scope of the PREPARED project using real case-studies will be extremely useful to complement this point. The expected results include the standard outcomes from the step. Illustrations using examples are included whenever adequate.

3.2 WCSP ▸ 1. Commitment and establishment of water cycle safety policy and scope

3.2.1 *Description*

Effectiveness of a WCSP requires carrying out some preliminary actions in order to obtain support and commitment from all stakeholders, to establish the context and to formulate the water cycle safety policy.

3.2.2 *Key actions*

Identify stakeholders and assemble team

Typically, the management of urban water systems involves multiple stakeholders. Most system managers are only responsible for a part of the water cycle and only in few situations one organization is responsible for water supply, wastewater and storm water services. The most common situation is to have utilities only for the water supply and distribution systems while others manage wastewater and stormwater systems (Figure 11).

Thus, as a first step, it is necessary to: (i) identify all relevant stakeholders that should be involved in the development and implementation of a WCSP, and (ii) identify the corresponding roles and responsibilities. Relevant stakeholders are those who can affect, or can be affected by, the activities carried out within the water cycle.

As mentioned in Chapter 2, consideration of the whole water cycle and incorporation of the different perspectives and objectives requires taking into account two levels of action, namely:

- a multi-stakeholder team to comprise the whole water cycle (water cycle level);
- a team at each utility for each system or sub-system (systems level).

At the water cycle level, team members should be in agreement with country, region and local organisational structures. Stakeholders that should have a representative in the team include:

- water utilities (water supply, wastewater and stormwater systems managers);
- regulators;
- local government authorities (e.g., municipalities);
- regional water boards;
- authorities for basin management;
- environment authorities;
- health authorities;
- civil protection and emergency response services;
- other water users (e.g., recreational uses, agriculture uses, industrial uses);
- non-governmental organizations (e.g. associations of domestic consumers, associations representing the general public).

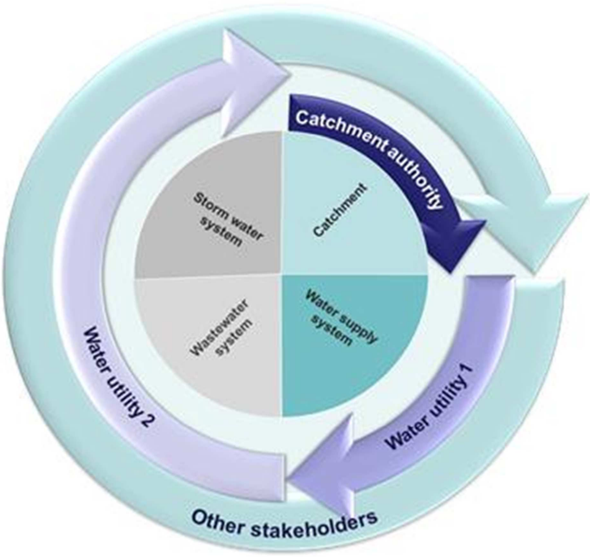


Figure 11 – Example of stakeholders in urban water cycle and corresponding areas of intervention

This team will be responsible for the development, implementation and maintenance of the WCSP at the water cycle level, according to the steps described in this chapter.

Collectively, team members should have adequate qualifications, technical expertise and good knowledge of the systems to facilitate:

- realistic identification of hazards that may affect safety throughout the water cycle;
- management of associated risks;

- definition and implementation of measures to control these.

For a successful implementation of a WCSP, team members should also have the commitment of organisation top management to put into practice the necessary changes in the respective organizations. The *modus operandi* of the team should be defined; roles and responsibilities of each team member should be clearly defined and a team coordinator should be appointed to drive the project.

Define the time frame to develop the WCSP

The WCSP should be a continued process, an on-going collaboration process of stakeholders and should become part of current processes at utilities.

A realistic planning for the development of the different steps of the WCSP is essential to keep progress and involvement of team members. Programming the development and implementation of WCSP should take into account the considerable time required to develop system safety plans (SSP). Moreover, developments at the two levels should be concomitant.

Compile formal requirements

Activities within the water cycle are subject to a set of formal requirements either regulatory, legal or others. All relevant requirements should be identified and documented for each specific case. Examples of types of requirements to be compiled are the following:

- state, federal, regional or municipal legislation or regulation;
- operating licenses;
- contracts and agreed levels of service;
- industry standards and codes of practice.

These documents will serve as a basis for defining the responsibilities and jurisdictions of each stakeholder within the water cycle, for setting criteria for risk analysis and, in general, to characterise the external context of the analysis.

An information system to archive and manage the information should be set up and periodically updated to reflect changes in requirements.

Define the water cycle safety policy

A water cycle safety policy should be formulated and endorsed by all WCSP team members. A set of ideas, strategic plans and decisions are laid down upon agreement between all parties involved and will be used as a basis for decision making during the subsequent phases of the WCSP.

Successful implementation and maintenance of the WCSP requires commitment of all stakeholders and at all levels within organizations. The water cycle safety policy will also ensure that long-term commitment is achieved.

The water cycle safety policy should address the following aspects:

- clear definition of risk management objectives, in line with the objectives of the organizations;

- definition of roles and responsibilities for managing risk;
- ensure compliance with legal, regulatory or other formal requirements;
- definition of the scope of the WCSP and system/sub-system safety plans (SSP), describing which parts of the water cycle are covered and the general classes of hazards to be addressed;
- definition of the risk acceptability criteria (e.g. all risk levels defined as low are acceptable);
- ensure that necessary resources (financial, staff, information, etc.) are allocated to the WCSP project;
- definition of mechanisms for communication and reporting among stakeholders (information flows, adequate reporting formats, availability of information, consultation processes, etc.) both within the team, within the organizations and with the public;
- definition of ways to deal with conflicting interests;
- establishment of procedures for reviewing the water cycle safety policy periodically or in response to an event or change in circumstances.

The formulated policy should be effectively communicated and disseminated throughout the organizations.

Set criteria for subsequent risk analysis

The criteria to be used should be defined by the WCSP team at the beginning of the risk management process. These criteria should reflect the objectives of risk management and be consistent with the risk management policy previously defined. Legal, regulatory or other type of formal requirements can impose some of the criteria.

The following aspects should be considered when setting the criteria:

- nature and types of causes and consequences that can occur and how they should be measured;
- how likelihood is defined;
- the timeframe of the likelihood or consequence(s);
- how is the level of risk estimated;
- stakeholders points of view;
- levels at which risk becomes acceptable or tolerable;
- whether combinations of multiple risks should be taken into account; if combinations are included, how and which combinations should be considered.

Criteria should be periodically updated to reflect relevant changes (e.g., in legal requirements).

3.2.3 *Common difficulties*

- Identifying and engaging stakeholders.
- Ensure involvement of stakeholders, requiring fitting additional workload within existing roles.
- Management of a large team.

- Ensuring that stakeholder's representatives have both broad technical expertise and authority to promote implementation of necessary changes in the respective organisation.
- Keeping team together and communicating effectively.
- Ensure communication mechanisms with participating organisations.

(To be completed throughout the project)

3.2.4 *Expected results*

- Establishment of an experienced, multidisciplinary and collaborative team that understands the overall aims and sector specificities.
- Action-programme for development and implementation of a WCSP.

3.3 WCSP ▸ 2. Urban water cycle characterisation

3.3.1 *Description*

The comprehensive characterisation of the urban water cycle has to be made by the WCSP team to ensure that, in subsequent steps of the WCSP, risks are adequately identified, assessed and treated.

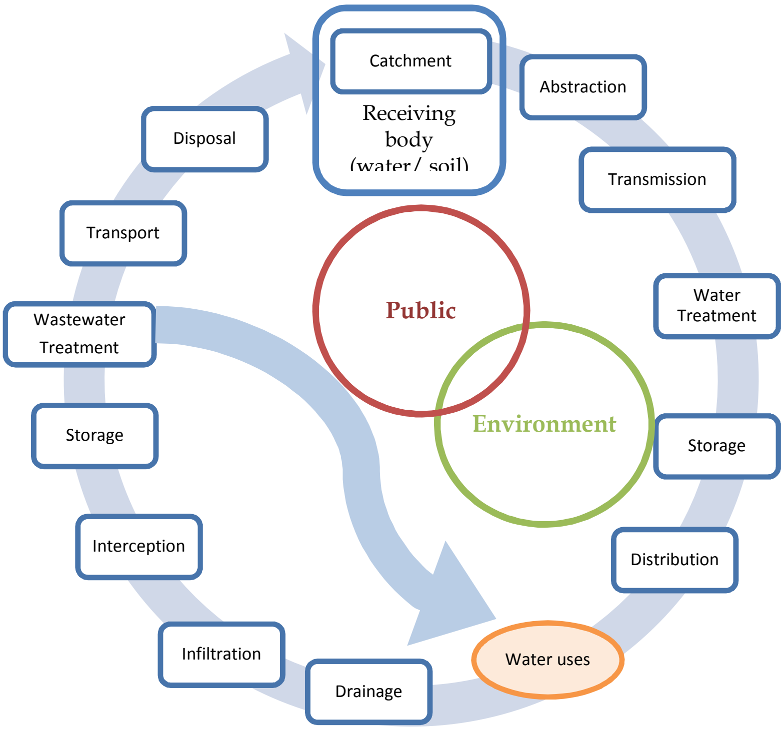


Figure 12 - Water cycle typical functional components

The characterisation of the urban water cycle should be in agreement with the characterisation carried out at the system level of analysis and updated accordingly. For the approach at the water cycle level, major functions and interactions have to be identified. At the system level (see Section 4.4), a more detailed characterisation is required to support the subsequent risk assessment process.

Additionally, stakeholders' roles and responsibilities should be refined at all systems boundaries.

3.3.2 *Key actions*

Water cycle components and interactions

Construct a water cycle flow diagram

One essential component of the water cycle description is a flow diagram. A process flow diagram is a graphical representation of a process showing the interrelationship between stages, the direction of the process flow and inputs (resources needed to carry out the process) and outputs of the process (products or services created by the process). In the scope of WCSP, a standard set of symbols is proposed to be used in flow diagrams as presented in Table 4. This proposal is based on widely used symbols for flow charting of industrial manufacturing processes but with some modifications.

The flow diagram may be cross-referenced with other type of documents such as maps. This diagram should be periodically updated according to the changes that occur in the water cycle.

The different systems and subsystems that integrate the water cycle have to be identified, and boundaries between them should be clearly defined and represented in the flow diagram. Main systems and subsystems may include the following (not exhaustive):

- **Catchment basin** - surface water catchment; groundwater catchment.
- **Drinking water system** - surface water reservoir; groundwater reserves; abstraction system; groundwater recharge; water treatment; transmission; pumping stations; storage; distribution; plumbing systems.
- **Non-drinking water system** - catchment system; water treatment; advanced wastewater treatment; transmisson, pumping stations; storage; distribution; plumbing systems.
- **Wastewater system** - wastewater collection network; interceptor system; wastewater treatment; combined sewer overflows; pumping stations; storage structures; infiltration systems; outfalls.
- **Stormwater system** – urban catchments; stormwater collection network; infiltration systems; source controls, stormwater treatment, stormwater overflows; pumping stations; storage structures.
- **Receiving waters**– river; estuary; lake; coastal water.

For risk assessment purposes, some steps included in the water cycle flow diagram may need to be further detailed at systems level.

Describe urban water systems

A comprehensive description of the urban water systems belonging to the water cycle should complement the flow diagram, including identification of: subsystems and boundaries between system/subsystems, products that cross boundaries and services provided.

At the water cycle level, major functions also have to be identified. Responsibilities and stakeholders associated with each major function have also to be clearly recognised. This is particularly relevant to proceed with risk analysis and for the selection of risk reduction measures at each component of the water cycle.

In addition to the location of systems/subsystems and detection of existing interactions between them, water uses and other exposure modes at different parts of the cycle need to be identified. The users of the outputs of each system/subsystem (e.g., drinking water system, reclaimed water system) and the uses of the water (e.g., household use, irrigation) should be documented. Vulnerable users should be given special attention (e.g., hospitals are vulnerable users of the product "drinking water").

Pollution sources and potential points of entry into supply sources or recreational waters (herein only those related with urban water systems) should also be identified and characterised.

Historical information and on-site checking are essential to ensure that the final result does include all relevant components and issues to be addressed.

The description should include only the relevant information for subsequent risk assessment at water cycle level.

The following items should also be included in the description of the water cycle; this is not an exhaustive list, nor is every point relevant for all cases:

- alternative water sources, in case of failure or insufficiency of usual sources;
- details of land use within the catchment;
- other potential risk sources.

Identify criteria and targets for products and services

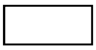
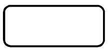
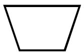
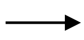
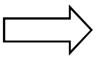
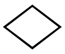
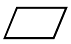
The application of the concept of 'safety plan' to the whole water cycle implies widening the approach from only considering the 'water' as a product, to incorporate several different products and services.

Within the scope of WCSP, the product water can be intended for public water supply, having quality compatible with potable uses as in WSP, for non-potable urban uses, to be disposed at receiving water bodies or soil or reclaimed water, each having specific quality standards.

Services are relevant especially when considering the aims of safeguarding public safety but also the water quality in receiving bodies. Examples of the former include ensuring non-occurrence of flooding or pipe collapses; for the latter, the maintenance of conditions for recreational uses is an example.

Each intended use or service requires the setting of performance criteria, metrics and corresponding targets. These have to be dealt with, in a generic approach, at the water cycle level, where major interactions have to be identified, and in a detailed approach for each responsible utility. For all products and services relevant regulatory standards should be taken into account.

Table 4 – Symbols for process flowcharting

Symbol	Name	Description	Examples
Operation symbols			
	Operational step	Represents an operational step of a process	Abstraction from Catchment 1 Newday dam Tavir wastewater treatment plant
	Alternate process	Represents an alternate process; it is used when the process step is an alternate to the normal process step; flow lines associated with an alternate process step are dashed	Treatment of water from Xplace
	Delay	Represents a waiting period that is part of the process	-
	Manual operation	Represents a process step that is not automated	-
Branching and control of flow symbols			
	Flow line connector	Represents the direction of the process flow	-
	Transport	Shows a water transfer/transport step	Raw water transfer to System XY5 Distribution system to Hillcity
	Storage	Represents the storage of water, wastewater, etc	Rosetree reservoir
	Decision	Indicates a decision to be made in the process flow, i.e., a choice between two options; this shape has one input arrow and two output arrows usually labelled *yes/no* or *true/false*	-
	Inspection	Represents an inspection point in the process flow	pH
	Diversion	Shows when a process diverges, usually, for more than 2 branches; lines outgoing from this symbol are labelled to indicate the criteria to follow in each branch	-
	Junction	Shows when multiple branches converge into a single step	-
	Off-page connector	Represents: ▪ a jump from one point in the process flow to another; useful to avoid flow lines crossing shapes ▪ a continuation of a flow chart from one to another page It is labelled with numbers to show matching points.	3
Input and output symbols			
	Output	Represents the output from a process, i.e., the intended water use	Drinking water for household use Reused water for irrigation
Other symbols			
---------	Boundary	Represents systems' boundaries inside the water cycle	-

3.3.3 *Common difficulties*

- Inaccurate urban water systems layouts and databases.
- Insufficient operational data.
- Insufficient knowledge of land uses, including industrial uses and discharges.
- Unwillingness in sharing information (confidentiality issues).
- Time required for carrying out this step, including field work.
- Out-of-date procedures and documentation.

(To be completed throughout the project)

3.3.4 *Expected results*

- Water cycle detailed and up-to date description, including flow diagram.
- Set of criteria and targets for products and services in the water cycle.

3.4 WCSP ▸ 3. Preliminary risk identification in the water cycle

3.4.1 *Description*

In this step, a first screening of existing risks within the water cycle should be carried out. The main objective is to identify risk sources (including hazards) and risk factors at integrated level, and how sensitive these might be to the expected regional climate trends (climate change impact). Potential events (sequence of individual occurrences of consequences) can also be explored to help assessing potential risks.

Assessment of the exposure modes is also important when identifying risk.

Historical data should be used to assure that information from past events is considered; useful data can derive from the case under analysis as well as events from other situations.

The PREPARED risk identification database (RIDB) incorporates information intended to facilitate the application of this step.

3.4.2 *Key actions*

Identify relevant hazards, risk sources and risk factors

The identification of the relevant hazards, risk sources and risk factors should be carried out thoroughly, looking at the whole cycle, based on:

- information compiled in Section 3.3, expert knowledge of the team;
- site visits;
- historical information (internal and external), including relevant studies.

Assess the potential effect of climate change trends

The potential effect of climate change trends for the region on the previously documented and new hazards, risk sources and risk factors should be assessed; this assessment should use appropriate measures to allow classification of the magnitude of the effect. For instance, a simple categorical scale can be used.

Explore scenarios and potential events

From the previously identified information, potential events should be explored considering different combinations of risk sources and factors. Effectiveness of existing barriers, and need for additional barriers, should also be considered. Taking into account existing barriers or controls is essential to ensure that existing risks are adequately estimated.

3.4.3 *Common difficulties*

- In practice, steps 3.4 and 3.5 are better carried out concurrently.
- These tasks can turn out to be extensive when a significant number of risk sources and risk factors exist and when systems are large and complex.
- Lack of data or poor knowledge of activities and components of the water cycle adds difficulty and uncertainty to this step.

(To be completed throughout the project)

3.4.4 *Expected results*

- Lists of hazards, risk sources and risk factors for the water cycle and component systems, with indication of susceptibility to climate change trends.
- Description of potential events for selected scenarios.

3.5 WCSP ▸ 4. Preliminary risk analysis and evaluation in the water cycle

3.5.1 *Description*

An integrated water cycle analysis approach is facilitated if interactions and boundaries are considered both at the water cycle level and at the systems level. Furthermore, stakeholders have perceptions of risk that are depending on focus of activity and level of knowledge about detailed processes.

This step allows a first adjustment of perceptions about important risks and respective magnitudes. The use of compatible categories of risk, likelihood and consequences is essential. Specific methods for risk estimation can then be used for each system or sub-systems. Typically, qualitative or semi-quantitative methods are used to estimate risk for this type of applications.

Incorporation of this information in the next steps helps improving compatibility between systems and in coordinating actions. Within the set of events considered, special attention should be given to those risks particularly dependent or increased by expected climate change trends.

3.5.2 *Key actions*

Assess the likelihood and consequences for each event

For each plausible event, the likelihood and the consequences should be estimated using the method and scales selected at step 1, Section 3.2. Different consequence dimensions should be used in order to express adequately the criteria relevant to the stakeholders. In Table 5 and Table 6 examples of possible scales for qualitative risk assessment approaches are presented.

Scales used should be selected or constructed to reduce subjectivity in the application by different people as much as possible. Refer to Annex for additional information on selection of scales and risk matrix.

Table 5 – Example of likelihood scale

Classes	Likelihood	Probability values range (%)
1	Rare	[0; 1.5%[
2	Unlikely	[1.5%; 5%[
3	Moderate	[5%; 15%[
4	Likely	[15%; 40%[
5	Almost certain	[40%; 100%[

Table 6 – Example of consequence scale using two dimensions

Classes	Consequence level	Dimensions	
		Health and safety (public and occupational)	**Financial**
1	**Insignificant**	Minor injuries or health disturbances not requiring medical assistance. No fatalities or life threatening injuries; total recovery.	< 0.1 % AOB*
2	**Low**	Injuries requiring hospital treatment; no-admissions. No fatalities or life threatening injuries; total recovery.	0.1% ≤ AOB < 1 %
3	**Moderate**	Injuries requiring hospital admissions ≤ 15 days. No fatalities or life threatening injuries; disability ≤ 20%.	1% ≤ AOB < 5 %
4	**High**	Severe injuries requiring hospitalization > 15 days. Up to 2 fatalities or persons with disability > 20%.	5 ≤ AOB < 30 %
5	**Very high**	> 2 fatalities or persons with disability > 20%.	≥ 30 % AOB

* Annual Operating Budget

Estimate the level of risk for each event

Following the assessment of likelihood and consequence levels for each event, risk can then be estimated using the selected method and scale at step 1, Section 3.2. In Table 7 and Figure 13 examples of typical risk scale and risk matrix are presented, respectively. Consistent scales and matrix should be used (e.g. Cox, 2009). Risk levels should be associated with acceptance criteria.

Table 7 – Example of risk scale, including relation with risk acceptance levels

Classes	Risk level	Acceptance and tolerability level	Action for risk reduction*
1	Low	Broadly acceptable region	Not likely to be required.
2	Medium	Tolerable region	Costs and benefits are to be taken into account and opportunities to be balanced against potential adverse consequences.
3	High	Intolerable region	Risk cannot be justified

* AS/NZS (2005)

		Consequence				
		1	2	3	4	5
Likelihood	5	Low	Medium	High	High	High
	4	Low	Medium	Medium	High	High
	3	Low	Low	Medium	Medium	High
	2	Low	Low	Low	Medium	Medium
	1	Low	Low	Low	Low	Low

Figure 13 – Example of risk matrix for qualitative risk estimation

Evaluate risk for each event

Risk evaluation involves comparing the levels of risk estimated during the risk analysis with the risk criteria established in step 1.

The results are used to make decisions about future actions on:

- risks that need treatment;
- priorities for treatment actions.

3.5.3 *Common difficulties*

- Decision on the method to be used for risk estimation is not always straightforward.
- Usually difficulties exist in identifying potential events and in associating the potential likelihood and consequences levels, having in mind the different values to protect (public health and safety, environment).
- Difficulties in defining risk acceptability and tolerability levels.
- Compatibility of different perceptions and points of view.

(To be completed throughout the project)

3.5.4 *Expected results*

- Preliminary report on potential events with corresponding results in terms of risk.

- Preliminary report on risks that need treatment and priorities for treatment actions.

3.6 WCSP ▸ 5. Development of system safety plans

As for WSP, the recommendation is to develop a System Safety Plan (SSP) for each individual water system or subsystem (supply or wastewater or stormwater) of the water cycle. The results of the several SSPs will then be analysed and integrated at the water cycle level as described in 3.7 and 3.8.

The steps to develop a SSP are outlined in Figure 10 and include the following:

5.1. Assemble team;

5.2. Context for risk assessment;

5.3. System characterisation;

5.4. Risk identification;

5.5. Risk analysis and evaluation;

5.6. Risk treatment;

5.7. Programme for detection of critical situations;

5.8. Management of events;

5.9. Management and communication programmes and protocols;

5.10. Development of supporting programmes;

5.11. Monitoring and review.

A detailed description of each step can be found in Chapter 4.

3.7 WCSP ▸ 6. Integrated risk analysis and evaluation

3.7.1 *Description*

Once stakeholders responsible for water systems management collect information relevant to be considered in upgrading the results of the preliminary risk identification and risk analysis in the water cycle (Steps 3 and 4), these steps should be revised.

The relevant aspects from SSP are to be considered but for the purpose of an integrated analysis at water cycle level. It is not intended to repeat actions from the SSP nor carry out analysis at same detailed level within systems. However, relevant aspects not considered within the SSP should be tackled at water cycle level. Specific issues include those not covered by individual utilities but that may be relevant for the objectives and the consideration of how each system impacts the others and the water cycle.

3.7.2 *Key actions*

Aggregate information from system safety plans

Each stakeholder responsible for managing a water system should aggregate and report to the team the results from their internal risk assessment, provided that these are relevant for the water cycle level. Special attention should be given to SSP boundary issues.

Compare and reassess estimated risks

Results from each SSP risk assessment process should be compared with results from steps 3 and 4. Reassessment of risks and evaluation should be upgraded according to procedures used in steps 3 and 4.

The final results are used to make decisions about future actions on:

- risks that need treatment;
- priorities for risk treatment.

3.7.3 *Common difficulties*

- Usually difficulties exist in identifying potential events and in associating the potential likelihood and consequences levels.
- Compatibility of different perceptions and points of view.

(To be completed throughout the project)

3.7.4 *Expected results*

- Report on potential events with corresponding results of risk.
- Report on risks that need treatment and priorities for treatment.

3.8 WCSP ▸ 7. Integrated risk treatment

3.8.1 *Description*

The purpose of risk treatment is to modify the previously identified risks that need treatment. This involves the selection and evaluation of Risk Reduction Measures (RRM). These are actions that can be applied to the systems in order to prevent or minimize the occurrence of hazardous events. These measures can act on risks in different ways:

- reducing the level of risk either by modifying the likelihood and/or by changing the consequences;
- avoiding the risk by discontinuing the activity that originates the risk;
- removing the risk source;
- modifying the level of risk sources or risk factors;
- sharing the risk with another party.

The PREPARED risk reduction database (RRDB) incorporates information intended to facilitate the application of this step.

At the water cycle level not only risk treatment measures acting on technical systems are available. Stakeholders other than water systems managers can implement measures to reduce risk, such as measures to control land use or enforcing specific regulations.

Efficient detection and alarm systems can also be an important way to reduce risk. Thus, a programme for detection of critical situations at the water cycle level should be developed to complement those existing at system level.

3.8.2 *Key actions*

Identify risk reduction measures

The WCSP team should identify and document all the potential alternatives to reduce each identified risk that needs treatment (RRM), at both levels if applicable.

For some risks, multiple RRM can be identified and be used individually or in combination (e.g. "multiple barriers") to accomplish a more effective risk reduction.

Compare, prioritize and select risk reduction measures

Comparison of alternative RRMs should be carried out using appropriate criteria and measures to balance costs of implementation against expected benefits.

Aspects to consider in the assessment of each RRM are: level of risk to be controlled; effectiveness (achievement of the desired reduction in risk); efficiency (achievement of the desired effect with least resource consumption); sustainability; cost of implementation; side effects (e.g., some RRM may create secondary risks); legal and regulatory viability; acceptability by stakeholders and by the public; and protection of the environment.

After comparison, RRM alternatives should be prioritised using the selected criteria and a decision made on which RRM to implement. When RRMs can negatively impact on risks for the utilities, the team should re-analyse those measures.

Develop a risk treatment programme

After RRMs are selected for implementation it is necessary to develop a risk treatment programme that documents the way RRM will be implemented. This plan should include:

- summary of the RRM selection process;
- coordinator responsible for implementation of the programme;
- proposed actions, implementation schedule and responsible for the implementation;
- necessary resources to implement the programme;
- financing and supporting of programme implementation;
- requirements for reporting and monitoring.

Assess residual risk

The nature and extent of residual risk remaining after risk treatment should be assessed. When appropriate, the residual risk can be estimated per action, per implementation phase or for the whole programme. This residual risk should be subjected to monitoring, review and, if necessary, further treatment.

3.8.3 *Common difficulties*

- Extensive work because a large number of RRM might be identified.
- Uncertainty in prioritizing risks due to lack of sufficient data or poor knowledge of the area in terms of the activities that influence risk levels.
- Eventually conflict of interests may exist.
- Difficulties may arise for financing the risk treatment programme.
- Delays in RRM implementation in cases where several stakeholders are involved and where responsibility issues may exist.
- Difficulties in assessing residual risk due to uncertainty on the effect of the action once implemented.

(To be completed throughout the project)

3.8.4 *Expected results*

- Report on RRM for each identified risk that needs treatment, with evidence on how each measure performs and the corresponding assigned priority.
- Report on the risk treatment programme at water cycle integrated level including estimation of residual risk.

3.9 WCSP ▶ 8. Management and communication programmes and protocols

3.9.1 *Description*

For effective communication of procedures as well as results during the maintenance of the WCSP, it is necessary to develop management and communication programmes and protocols. These programmes should facilitate communication among stakeholders within the WCSP team and with the public.

All these documents should be easily accessible to whom they may concern and should be, periodically, reviewed and updated by the WCSP team.

3.9.2 *Key actions*

Develop and implement communication programmes and protocols

Aspects to be defined and described in the communication programmes include: information flows, adequate reporting formats, notification procedures, stakeholder's contacts, and availability of information and consultation processes.

Develop and implement management programmes and protocols

In practice, the management programmes and protocols correspond to a set of management procedures documenting actions to be taken:

- when water cycle systems are operating under normal conditions - usually known as Standard Operating Procedures (SOP);

- when water cycle systems are operating in incident or accident situations - these procedures describe corrective actions identifying the specific operational response required following deviations from the set limits that were detected through monitoring of control measures.

The programmes developed at the water cycle level should have cross-references to management procedures at system level for the different stakeholders.

A generic emergency plan should be prepared, to feed not only system emergency plans but also existing regional or national plans. In case of occurrence of an incident or accident for which there are no corrective actions documented, this plan should be followed.

Management procedures for normal operation and for incidents or accidents should address:

- operational monitoring relevant to the water cycle level;
- corrective actions and corresponding responsibilities of stakeholders;
- responsibilities for coordinating actions to be taken in emergency situations.

Review management programmes and protocols

Management programmes and protocols should be subjected to reviews, especially after an emergency situation or after emergency simulation.

In the reviewing process, current procedures should be assessed for adequacy (based on emergency reporting) as well as need for modifications. Identification of the need for new procedures can also be made during the review.

3.9.3 *Common difficulties*

- Keeping the procedures updated.
- Managing the complexity of the plan and the relation with the different parties involved.
- Keeping awareness.

(To be completed throughout the project)

3.9.4 *Expected results*

- Programmes and protocols documenting communication and management procedures.

3.10 WCSP ▸ 9. Monitoring and review

3.10.1 *Description*

Monitoring and review are critical components of the WCSP. They consist of a regular checking and surveillance of the whole process with the following purposes:

- ensure that RRM are implemented and are effective; this can be done for example through internal and external auditing;

- obtain further information to improve risk assessment;
- analysing past event, changes, trends, successes and failures in order to learn from experiences and avoid the future occurrence of similar situations;
- identify and assess emerging risks.

Review should take into account the experience obtained during the implementation process of the WCSP and the results of monitoring.

3.10.2 *Key actions*

Define tasks and responsibilities

Tasks and responsibilities for the monitoring and review process should be clearly defined among team members.

Keep the WCSP up to date

In order to keep the WCSP up to date, the WCSP team should monitor and review the plan:

- at regular intervals;
- following changes in the SSP relevant to the water cycle level;
- following stakeholders changes.

Record and report results

Procedures for reporting and registering events (incidents and accidents) relevant within the scope of the WCSP should be set up, including a specific database. Reporting should be prepared for predefined intervals.

The results of the monitoring and review process should be recorded and communicated to all stakeholders.

3.10.3 *Common difficulties*

- Ensuring continued support for the WCSP process.
- Setting up the events reporting and recording procedures.
- Ensure that all events are incorporated in the database.
- Keeping records of all changes made to the WCSP.

(To be completed throughout the project)

3.10.4 *Expected results*

- Review and monitoring programme.
- Report and database of events (accidents and incidents).
- Revised WCSP incorporating improvements arising from past experience and according to the objectives of stakeholders.

4 WCSP ▸ Development of system safety plans

4.1 Overview

The detailed application of the water safety concepts should be carried out for each individual system part of the region object of the water cycle safety plan. As for WSP, the recommendation is to develop a safety plan for each individual water system or subsystem (supply or wastewater or stormwater).

As presented in Section 3.3, the WCSP framework proposed herein covers not only safety of the product “drinking water” to consumers and users but also safety to public and environment of the water “outputs” from the different water systems, within the water cycle. Furthermore, effective provision of a number of services to protect the public in general from hazards, such as those associated with loss of system components structural integrity or flooding, among others, is considered.

While the generic systematic principles of the approach in WSP are maintained, modifications proposed include widening in the primary aims and incorporation of the risk management terminology and process as presented in the ISO guide 73:2009 and the ISO 31 000:2009.

In the following sections the steps for developing SSP are presented.

4.2 SSP ▸ 5.1. Assemble team

4.2.1 *Description*

At each water utility, a multidisciplinary team should be assembled to develop, implement and maintain a System Safety Plan for each system/subsystem. The designated team should also be responsible for effective communication, i.e., for getting the SSP approach disseminated and accepted both inside the utility and by stakeholders outside the utility. Relevant team elements to consider should contribute not only for the development of the SSP but should also facilitate its implementation. At least one of the members of the team at SSP level should also be member of the team at WSCP level.

4.2.2 *Key actions*

Identify necessary qualifications and expertise of team members

Team composition should take into account the organization structure and the processes involved. Relevant members to be included are:

- systems operation supervisors (e.g., treatment plants supervisors, distribution supervisors, wastewater collection supervisors);
- maintenance supervisor;
- water quality control (laboratory) supervisor;
- technical staff involved in the daily operation of the system;

- asset financial managers;
- utility managers;
- if necessary, external experts in specific areas of knowledge.

External stakeholders should also be involved e.g. energy supply, fire-fighters, as adequate.

Collectively, team members should have adequate qualifications, experience, technical expertise and good knowledge of the systems in order to realistically identify hazards that may affect safety throughout the water systems and subsystems, to manage associated risks and to define and implement measures of control. For a successful implementation of a SSP, teams should also have authority to put into practice the necessary changes in the water system / subsystem.

Secure management commitment and financial support

Even if not represented as a SSP team member, it is crucial that the utility's top management is engaged in the development of the SSP. This facilitates the implementation of the necessary changes in the processes and ensures the corresponding financial support.

Define roles and responsibilities of team members

Roles and responsibilities of each team member should be clearly defined and recorded.

Appoint a team coordinator

A team coordinator should be appointed to drive the project and ensure team motivation and cohesion. The team coordinator should have authority inside the organization to effectively play this role.

Define the time frame to develop the SSP

The SSP should be a continued process, an on-going collaboration process of the team and stakeholders and should become part of current processes at utilities.

A realistic planning for the development of the different steps of the SSP is essential to keep progress and interest of the team.

4.2.3 *Common difficulties*

- Fitting the additional working load of the selected appointed team members in the existing duties and tasks already assigned to each member in the organisation.
- Select team members with specific skills.
- Maintain the team together in regular activity.

(To be completed throughout the project)

4.2.4 *Expected results*

- SSP comprehensive team.

4.3 SSP ▸ 5.2. Context for risk assessment

4.3.1 *Description*

The risk management process should be aligned with the utility objectives and strategies and should target the specific risks affecting the achievement of those objectives. Thus, it is necessary to establish the context for risk management, which consists of the identification (by the utility) of all external and internal parameters to be considered when managing risk. In this SSP step, the scope and risk acceptability criteria are set for the remaining SSP process.

As part of a water cycle, selection of the approach at system level should take into consideration existing interactions and boundaries. Alignment of methods and criteria between water cycle and system level facilitates integration within the integrated level.

4.3.2 *Key actions*

Define the scope for risk management

The scope of the risk management process should include the specification of:

- the objectives of the utility;
- parts of the organization (activities, processes, functions, projects, products, services or assets) where the risk management process will be applied;
- resources (financial, personnel, etc.) required;
- responsibilities and authorities;
- records to be maintained;
- communication mechanisms inside the organization and with external stakeholders;
- risk assessment methods.

Set risk acceptability criteria

The criteria to be used in the evaluation of the significance of risk should be defined in the light of the utility's objectives and resources and should be in line with WCSP agreements. Legal, regulatory or other type of formal requirements can impose some of the criteria. The following aspects should also be considered in criteria setting:

- nature and types of causes and consequences that can occur and how they will be measured;
- how likelihood is defined;
- timeframe of the likelihood and/or consequence(s);
- how the level of risk is defined;
- views of the stakeholders;
- level at which risk becomes acceptable or tolerable;
- whether combinations of multiple risks should be taken into account; if so, how and which combinations should be considered.

Criteria should be periodically updated to reflect relevant changes, such as modifications in legal, contractual or licencing requirements.

4.3.3 *Common difficulties*

- Lack of technical expertise on risk management.
- Decision on the method to be used is not always straightforward.
- Difficulties in defining risk acceptability and tolerability levels.

(To be completed throughout the project)

4.3.4 *Expected results*

- Set of guidelines, including methods and criteria to support risk assessment.

4.4 SSP ▶ 5.3. System characterisation

4.4.1 *Description*

For the subsequent risk identification, assessment and treatment, a detailed description of the system should be produced at the beginning of the SSP.

4.4.2 *Key actions*

Construct a flow diagram

A flow diagram is an essential part of the system description where some steps included in the water cycle flow diagram are further detailed. This is done in sub-ordinate flow diagrams at systems level. Furthermore, flow diagrams should be constructed for all subsystems of the system under analysis. The water treatment is an example and the corresponding flowcharts including all unit process operations should be developed.

The standard set of symbols included in Section 3.3 may also be used at system level. Flow diagrams may be complemented using other type of documents such as maps (e.g., maps of sewer networks, maps of distribution networks).

Validation of flow diagram completeness and accuracy should be made by the SSP team members that are most familiar with the processes. On-site visits might be needed for this purpose. A copy of the validated flow diagram(s) should be kept as a part of the SSP.

Flow diagram(s) should be periodically updated to reflect changes in the system and subsystems.

Describe the system and its subsystems

A full, detailed and updated description of the system and, if existing, subsystems should be part of the SSP. If applicable, definition of operation/control zones should be considered in the subsystems description and in the flow diagram.

Relevant and sufficient information for subsequent risk assessment should be included. Table 8 contains some hints that might be of interest. The table is not intended to be exhaustive.

Table 8 – Information that may be included in the system´s descriptions

System	Subsystem / component	Information
Catchment basin	Surface water Groundwater	Geology and hydrology Meteorology and weather patterns General catchment and river health Drinking water source protection area Wildlife Competing water uses Nature and intensity of development and land-use Other activities in the catchment which potentially release contaminants into source water Planned future activities Alternative sources in case of incident; interconnectivity of sources Known or suspected changes in source quality due to weather or other conditions
Drinking water system	Surface water	Description of water body type (e.g. river, reservoir, dam) Physical characteristics such as size, depth, thermal stratification, altitude Flow and reliability of source water Retention times Relevant water quality parameters Protection (e.g. enclosures, access) Recreational and other human activity Bulk water transport
	Groundwater	Confined or unconfined aquifer Drinking water source protection area Aquifer hydrogeology Flow rate and direction Dilution characteristics Vulnerability to pollution Recharge area Well-head protection Depth of casing Bulk water transport
	Water treatment	Treatment processes (including optional processes) Equipment Monitoring equipment and automation Treatment chemicals added to the water Treatment efficiencies Disinfection contact time and disinfectant residual
	Transmission, pumping, storage and distribution	Characteristics of storage and pumping installations Retention times Seasonal variations Protection (e.g. covers, enclosures, access) Distribution system characteristics and condition Hydraulic conditions (e.g. water age, pressures, flows) Chemicals and materials in contact with water Backflow protection Disinfectant residuals Uses and users of water

Table 8 – Information that may be included in the system´s descriptions (cont.)

System	Subsystem / component	Information
Non-drinking water system	Catchment system	Catchment characteristics of rainwater systems Meteorology and weather patterns Contaminant sources
	Water and wastewater treatment	Treatment processes (including optional processes) Equipment Monitoring equipment and automation Treatment chemicals added Treatment efficiencies
	Transmission, pumping, storage, distribution and plumbing	Characteristics of storage and pumping installations Seasonal variations Protection (e.g. covers, enclosures, access) Distribution system and plumbing characteristics and conditions Hydraulic conditions (e.g. pressures, flows) Disinfectant residuals Uses and users of water
Waste water system	Wastewater network	Network characteristics and condition Monitoring system Maintenance and operation activities Type of flows (domestic, industrial, health facilities, etc.) Type of system (separate, combined, on-site) History of failure events (collapses, blockages, floods)
	CSO, pumps, storage structures	Characteristics of CSO, storage and pumping installations Monitoring equipment and automation Characteristics of discharges History of events
	Wastewater treatment	Treatment processes (including optional processes) Equipment Monitoring equipment and automation Treatment chemicals Treatment efficiencies
	Advanced wastewater treatment (for reuse)	Treatment processes Treatment efficiencies Requirements for reuse Uses and users of water
Storm water system	Catchments	Geology and hydrology Land use characteristics Area
	Stormwater network	Network characteristics and condition Monitoring system Maintenance and operation activities History of failure events (collapses, blockages, floods) Infiltration facilities Stormwater treatment
Receiving waters		Relevant water quality parameters Water uses Self-purifying ability Monitoring

4.4.3 *Common difficulties*

- Inaccurate urban water systems layouts and databases.

- Insufficient operational data.
- Insufficient knowledge of land uses, including industrial uses and discharges.
- Time required to carry out this step, including field work.
- Out-of-date procedures and documentation.

(To be completed throughout the project)

4.4.4 *Expected results*

- System detailed and up-to date description, including flow diagram.
- Set of criteria and targets for products and services in the system and interaction with other systems within the water cycle.

4.5 SSP ▸ 5.4. Risk identification at system level

4.5.1 *Description*

This step is similar to the corresponding step in the water cycle level but to be applied in detail at system level. The main objectives are to identify the risk sources (including hazards) and risk factors at system level, and to determine how these can be affected by the expected regional climate trends (climate change impact). Potential events (sequence of individual occurrences of circumstances) can also be explored to help assessing potential risks.

Assessment of the exposure modes is also important when identifying risk.

Historical information should be used to assure that past events are considered, from the case under analysis as well as events from other cases.

The PREPARED risk identification database (RIDB) incorporates information intended to facilitate the application of this step.

4.5.2 *Key actions*

Identify relevant hazards, risk sources and risk factors

The identification of the relevant hazards, risk sources and risk factors should be carried out thoroughly, preferably for each sub-system, based on:

- information compiled in Section 4.4;
- expert knowledge of the team;
- site visits;
- historical information (internal and external), including relevant studies.

Assess potential effect of climate change trends

The potential effect of the climate change trends for the region on the previously documented hazards, risk sources and risk factors should be assessed using a measure allowing for classification of the magnitude of the effect. For instance, a simple categorical scale can be used.

Table 9 – Hazards identification - examples

Primary aim of WCSP	Risk source, risk factor	Hazard
Protection of public health	**Risk source** Presence of cyanobacteria in source water **Risk factor** Temperature increase	Presence of cyanotoxins in tap water Presence of cyanobacteria in bathing water
	Risk source Presence of pathogens in water reused for irrigation **Risk factor** Irrigation during hours of public use of a public park or similar	Presence of pathogens in water used for irrigation
Protection of public safety	**Risk source** Stormwater runoff **Risk factor** Deterioration of infrastructure High intensity rainfall events	Infrastructure collapses/bursts causing injuries to public
	Risk source Stormwater runoff **Risk factor** Increased rainfall	High velocity runoff in public streets
	Risk source Release of gaseous chlorine at treatment plant **Risk factor** Malfunctioning of safety systems to detect and contain gaseous leaks	Presence of gaseous chlorine in the atmosphere of locations where workers or public might have access to
	Risk source Release of toxic gases from sewers **Risk factor** Temperature increase	Presence of toxic gases in the atmosphere of locations where workers or public might have access to
Protection of environment	**Risk source** Overuse of resources due to competing uses (agriculture and public supply) **Risk factor** Decreased rainfall	Water scarcity at source (affecting ecosystems)
	Risk source Discharges of untreated wastewater to receiving water bodies **Risk factor** Increased rainfall	Increased levels of pollutants (affecting the ecological /chemical status of receiving water bodies)

Explore scenarios and potential events

From the previously identified information, potential events should be explored considering different combinations of risk sources and factors. Effectiveness of existing barriers, and need for additional barriers, should also be considered. Taking into account existing barriers or controls is essential to ensure that existing risks are adequately estimated.

4.5.3 *Common difficulties*

- In practice, steps 5.4 and 5.5 are better carried out concurrently.
- These tasks can turn out to be extensive when a significant number of risk sources and risk factors exist and when systems are large and complex.
- Lack of data or poor knowledge of activities and components of the water cycle chain adds difficulty and uncertainty to this step.

(To be completed throughout the project)

4.5.4 *Expected results*

- Lists of hazards, risk sources and risk factors for the system, sub-systems and components, with indication of susceptibility to climate change trends.
- Description of potential events for selected scenarios.

4.6 SSP ▶ 5.5. Risk analysis and evaluation at system level

4.6.1 *Description*

Adopting an approach similar to that used at the water cycle level, in this step important risks, and respective magnitudes, are estimated. Use of categories of risk, likelihood and consequences that are compatible with those used at the water cycle level is essential. Although methods for risk estimation can be used for each system or sub-systems other than those used for water cycle level analysis, it is important to guarantee the compatibility of approaches at the two levels. Typically, qualitative or semi-quantitative methods are used but, at subsystem level or for specific components, use of quantitative methods could be of interest.

Within the set of events considered, special attention should be given to those particularly dependent or enhanced by climate change expected trends.

4.6.2 *Key actions*

Assess the likelihood and consequences for each event

For each plausible event, likelihood and consequences should be estimated using the method and scales selected at step 5.2, Section 4.3. Consequence dimensions should be used allowing the correct expression of the criteria relevant to the stakeholders. In Table 5 and Table 6 examples of typical scales used in qualitative risk assessment approaches are presented.

Estimate the level of risk for each event

Following the assessment of likelihood and consequence levels for each event, risk can be estimated using the selected method and scale at step 5.2, Section 4.3. Risk levels should be associated with acceptance criteria. When estimating risk, existing safety measures that contribute to reduce real risk level should be included.

Evaluate the risk for each event

Risk evaluation involves comparing the levels of risk estimated during the risk analysis with the risk criteria established in the context for risk assessment. When the risk is accepted the assumption is that the decision maker is retaining the risk by informed decision.

The results are used to make decisions about future actions on:

- risks that need treatment;
- priorities for treatment actions.

4.6.3 *Common difficulties*

- Identifying potential events and associating the potential likelihood and consequences levels.
- Omissions during the risk analysis imply that other risks that are missed are retained by the organisation.

(To be completed throughout the project)

4.6.4 *Expected results*

- Report on potential events with corresponding results of risk estimation.
- Report on risks that need treatment and priorities for treatment actions.

4.7 SSP ▸ 5.6. Risk treatment

4.7.1 *Description*

The purpose of risk treatment is to modify the previously identified risks that need treatment and involves the selection and evaluation of Risk Reduction Measures (RRM). These are actions that can be applied to the systems in order to prevent or minimize the occurrence of hazardous events. These measures can act on risks in different ways:

- reduce the level of risk either by modifying the likelihood and/or by changing the consequences;
- avoiding the risk by discontinue the activity that originates the risk;
- removing the risk source;
- sharing the risk with another party.

The PREPARED risk reduction database (RRDB) incorporates information intended to facilitate the application of this step.

For technical systems, some generic types of measures to reduce risk include (Rausand and Høyland, 2004):

- **Barriers** - Any physical impediment that tends to confine and/or restrict a potentially damaging condition, thus reducing the probability of events.
- **Redundancy** - Additional, identical and redundant components in a system introduced to decrease the likelihood of failure of subsystems.
- **Personnel training** – courses or other instruction programmes to improve knowledge of personnel, mainly with procedures, and competencies to execute them correctly during all conditions of operation, thus reducing the probability or the consequences of an undesirable event.
- **Monitoring, testing and inspection** – monitoring in conjunction with alarm systems, as well as condition inspections, to potentially reduce the probability of undesired events.

The measure consisting in risk sharing with another party typically includes insurance and careful contract management, for instance, outsourcing.

4.7.2 *Key actions*

Identify risk reduction measures

The SSP team should identify and document all the potential alternatives to reduce each identified risk that needs treatment (RRM).

For some risks, multiple RRM can be identified and be used individually or in combination ("multiple barriers") to accomplish a more effective risk reduction. Situations that could lead to simultaneous failure of multiple barriers should be taken into account.

In some systems, some RRM may already be implemented but might need improvements. In these cases, these RRM should be assessed (e.g., by site inspection or using monitoring data) to determine its effectiveness in controlling risk. When identifying measures, their potential to continue to be effective considering uncertain future scenarios should also be balanced in terms of measures adaptability.

Compare, prioritize and select risk reduction measures

In order to select the RRM that will be implemented, all previously identified RRM should be compared by balancing the costs (monetary as well as non-monetary) of implementation against the benefits obtained. Aspects to be considered in the assessment of each RRM are: level of risk to be controlled, effectiveness (achievement of the desired reduction in risk), efficiency (achievement of the desired effect with least resource consumption), sustainability, cost of implementation, side effects (e.g., some RRM may create secondary risks), legal and regulatory viability, acceptability by stakeholders and by the public and protection of the environment.

After comparison, alternative RRM should be prioritised relatively to several criteria considered relevant by the utility and a decision is made on which RRM to implement. For example, muticriteria analysis can assist decision makers in this decision process. When RRM can impact on risks outside the utility, other relevant stakeholders should be involved in the decision process.

Develop a risk treatment programme

After RRM are selected for implementation, it is necessary to develop a risk treatment programme that documents the way RRM will be implemented. This plan should include the following aspects:

- summary of the RRM selection process;
- person responsible for the approval of the plan and person responsible for its implementation;
- proposed actions and priority for implementation;
- necessary resources for the plan implementation;
- reporting and monitoring requirements;
- schedule for implementation.

The utility managing the system may not have the necessary authority to implement some RRM (e.g., source water protection if the source management is not under the responsibility of the supply system utility) and require the involvement of other stakeholders. These situations are dealt with at the water cycle level.

Assess residual risk

The nature and extent of residual risk remaining after risk treatment should be assessed. This residual risk should be subjected to monitoring, review and, if necessary, further treatment.

4.7.3 *Common difficulties*

- For large systems, extensive work is likely due to the large number of RRM that can be identified.
- Uncertainty in prioritizing risks due to lack of sufficient data or poor knowledge of the systems in terms of the activities that influence risk levels.
- Delays in RRM implementation in cases where several stakeholders are involved and where responsibility issues may exist.

(To be completed throughout the project)

4.7.4 *Expected results*

- A catalogue of RRM for each identified risk that needs treatment, with evidence on how each measure performs and the corresponding assigned priority.
- A risk treatment programme for implementing the selected RRM.

(To be completed throughout the project)

4.8 SSP ▸ 5.7. Programme for detection of critical situations

4.8.1 *Description*

A programme should be developed for the detection of critical situations, i.e., situations where critical limits are exceeded because implemented RRM are not functioning as desired or because levels of risk sources or risk factors exceed what is to be expected in regular circumstances.

The level of risk factors and risk sources should be assessed through this programme.

4.8.2 *Key actions*

Establish operational monitoring procedures

Detailed procedures for operational monitoring should be developed, including:

- definition of parameters to be monitored (water quality, water quantity, systems condition, rainfall, etc.);
- definition of monitoring frequency of each parameter;
- selection of monitoring locations, including identification of CCP;
- selection of sampling equipment and other resources needed;
- selection of methods for quality assurance of both sampling and analytical procedures;
- definition of responsibilities and necessary qualifications of monitoring staff (sampling staff and laboratory staff);
- definition of requirements for recording and reporting results.

The definition of monitoring procedures, especially the choice of parameters to monitor, should allow enough time for the sequence of detection of deviation and completion of corrective action to be finished in a timeframe adequate to maintain safety. For this reason, in most cases, monitoring will be based in simple surrogate parameters instead of complex measurements.

Set critical limits

For each monitored parameter, it may be necessary to define critical limits (upper and/or lower), i.e., the criteria that indicates whether the process is under control and the RRM is effective. If critical limits are exceeded, corrective actions should be initiated.

4.8.3 *Common difficulties*

- Ensure that resources are available to implement adequate monitoring procedures.
- Ensure the quality of analytical results (which can be done through quality assurance certification of analytical laboratories).
- Lack of single surrogate parameters to monitor.

(To be completed throughout the project)

4.8.4 *Expected results*

- Monitoring network, including CCP.
- A monitoring programme for detection of critical situations including monitoring procedures and critical limits.

4.9 SSP ▸ 5.8. Management of events

4.9.1 *Description*

Although preventive strategies are intended to prevent events (incidents or accidents) and associated emergency situations from occurring, some events can happen. Immediately following the detection of a deviation from critical limits, appropriate corrective actions should be taken in order to:

- identify and eliminate the cause of detected nonconformities;
- bring the process back into control maintaining safety;
- prevent recurrence of the situations of non-conformity.

Wherever possible, emergency scenarios should be identified and emergency response plans should be developed.

4.9.2 *Key actions*

Establish corrective actions

For each critical limit previously set in Section 4.8, the SSP team should identify and describe in detail the corrective actions to be initiated when the critical limit is exceeded.

The description of a corrective action includes:

- detail of the procedure to carry out; this detail can be given in Standard Operating Procedures (in this case the location of the SOP should be specified in the corrective action);
- responsibilities for the implementation of the corrective action;
- means for recording corrective actions taken and corresponding results;
- location of backup equipment (only for some corrective actions);
- notification procedures (only for some corrective actions);
- other relevant logistic and technical information.

To ensure that adequate means are available at the moment when a deviation occurs, resources for carrying out corrective actions should be identified in the SSP and allocated in advance.

Develop an Emergency Response Plan

In case of occurrence of events for which there are no corrective actions documented, an Emergency Response Plan (ERP) should be prepared.

The ERP should be developed in consultation with all relevant stakeholders and be consistent with other existing emergency plans at higher levels.

Aspects to address in an ERP are as follows:

- response actions to be taken in emergency situations;
- responsibilities for coordinating response actions, including a list of contacts;
- communication protocols, including notification procedures;
- mechanisms for increased surveillance.

4.9.3 *Common difficulties*

- Ensuring that resources are available to timely respond to an incident, accident or emergency.
- Keeping resources in operational condition (e.g. equipment).
- (To be completed throughout the project)

4.9.4 *Expected results*

- Corrective action protocols.
- An Emergency Response Plan.

4.10 SSP ▸ 5.9. Management and communication programmes and protocols

4.10.1 *Description*

For an effective communication during the maintenance of the SSP and for an effective documentation of all aspects of the plan, it is necessary to develop management and communication procedures.

Communication programmes facilitate communication among the SSP team members, within the utility and outside the utility with the public and other stakeholders.

Management procedures document in detail all the activities related to the operation of the system and its subsystems.

All these documents should be easily accessible to whom they may concern and should be, periodically, reviewed and updated.

4.10.2 *Key actions*

Develop and implement communication programmes and protocols

Aspects to be defined and described in the communication programmes include: information flows, adequate reporting formats, notification procedures, contacts from utility personnel that are relevant for water safety issues, availability of information and consultation processes.

Develop and implement management programmes and protocols

In practice, the management programmes and protocols correspond to a set of management procedures documenting actions to be taken, such as:

- when water cycle systems are operating under normal conditions - these procedures are usually know as Standard Operating Procedures (SOP);
- when water cycle systems are operating in incident or accident situations - these procedures describe corrective actions identifying the specific operational response required following deviations from the set limits that were detected through monitoring of control measures.

A generic emergency plan should also exist. In case of an incident or accident, for which there are no corrective actions documented, this plan should be followed.

Management procedures for normal operation and for incident, accident or emergency usually address the following points:

- corrective actions and responsibilities for its implementation;
- operational monitoring;
- responsibilities for coordinating actions to be taken in emergency situations;
- quality control procedures (e.g., within analytical laboratories);
- procedures for distributing emergency supplies of water.

Review management programmes and protocols

Management programmes and protocols should be subjected to reviews, especially after an emergency situation or after emergency simulation.

In the reviewing process, current procedures are assessed for adequacy (based on emergency reporting) and need for modifications. Identification of the need for new procedures is also made during review.

4.10.3 *Common difficulties*

- Keeping the procedures updated.
- Effective communication on changes in management procedures.

(To be completed throughout the project)

4.10.4 *Expected results*

- A set of programmes and protocols documenting communication and management procedures.

4.11 SSP ▸ 5.10. Development of supporting programmes

4.11.1 *Description*

Supporting programmes include activities addressing workers, equipment and records that ensure the successful implementation of the SSP in the organization but do not directly affect water safety. These programmes usually relate to staff training, research & development, equipment calibration, equipment maintenance and record keeping.

4.11.2 *Key actions*

Identify and develop supporting programmes needed for the implementation of the SSP

If not already implemented in the water utility, the following programmes should be developed, according to the needs of each specific case:

- training (e.g., short courses) of personnel involved in systems operation and maintenance, both in technical aspects and in all the aspects specifically related to the SSP approach; this training aims not only at increasing personnel technical knowledge and skills but also at keeping personnel awareness;
- equipment calibration to ensure the accuracy of monitoring equipment;
- equipment maintenance to ensure proper functioning of equipment and that not failures occur;

- research & development to support decisions to improve the quality of products or services;
- protocols for the use of chemicals and materials;
- occupational health and hygiene (safety at work);
- certified quality assurance systems for laboratories to ensure the quality of analytical results;
- record keeping;
- groundwater mapping, assessment of vulnerability and definition of protection zones.

Some of these programmes may already exist and need only to be updated or revised.

Review supporting programmes

Existing supporting programmes should be revised as necessary.

4.11.3 *Common difficulties*

(To be completed throughout the project)

4.11.4 *Expected results*

- Set of supporting programmes reports.

4.12 SSP ▸ 5.11. Monitoring and review

4.12.1 *Description*

Monitoring and review are critical components of a SSP and consist of a regular check and surveillance of the whole process with the following purposes:

- ensure that RRM are implemented and are effective; this can be done for example through internal and external auditing;
- obtain further information to improve risk assessment;
- analyzing past event, changes, trends, successes and failures in order to learn from experiences and avoid the future occurrence of similar situations;
- identify and assess emerging risks.

Review will take into account the experience obtained during the implementation of the SSP and the monitoring results.

4.12.2 *Key actions*

Define tasks and responsibilities

Tasks to be carried out and responsibilities for the monitoring and review process should be clearly defined among SSP team members.

Keep the SSP up to date

In order to keep the SSP up to date, the SSP team should meet regularly in order to monitor and review the plan. The meetings should occur:

- at regular intervals;

- following major changes in the system and subsystems (e.g., changes in a catchment area, inclusion of a new source water, changes in a treatment plant);
- following relevant changes in the staff;
- immediately after incidents and accidents.

When monitoring and reviewing after incidents, accidents or emergency situations it is important to identify the causes leading to those situations as well as the adequacy of the response and the existence of sufficient resources (equipment, human resources, communications, etc) for this response.

Record and report results

The results of the monitoring and review process should be recorded and communicated inside the utility and be reported to the WCSP team.

4.12.3 *Common difficulties*

- Ensuring continued support for the SSP process.
- Keeping records of changes made to the SSP.
- Keeping a "non-guilt" culture allowing truthful identification of the causes of incidents, accidents and emergency situations.

(To be completed throughout the project)

4.12.4 *Expected results*

- Periodic reports of monitoring.
- Revised SSP that incorporates improvement arising from past experience and that serves the objectives of the utility in terms of water safety.

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Annex ▸ Guidelines for selection of a risk estimation method

Introduction

The adoption of a risk management approach and the selection of the method and criteria for risk estimation and evaluation should be defined before application to specific problems. Within the WCSP framework this definition is included in step 1 (Section 3.2), at water cycle level, and in step 5.2 (Section 4.3) at system level.

The consequence-probability matrix, or risk matrix, is a common method in situations where there is insufficient data for detailed analysis or when time available and effort are not compatible with a quantitative risk estimation approach. This method is also widely used for ranking or screening risks when more than one risk is identified, providing a way to select those that require further analysis or to identify those that are broadly accepted or not accepted (ISO, 2009b). This is also the method proposed for dealing with risk estimation within the WSP approach (WHO 2005, 2009). Using this method, a qualitative or semi-quantitative approach is assumed. This annex gives some hints to obtain a consistent method are presented. This annex is largely based in Almeida and Leitão (2010).

Application of this method requires the definition of scales for expressing the likelihood and consequence levels of potential events and of a matrix to combine the two levels and derive a corresponding risk level. Scales used should be selected or constructed to reduce subjectivity in the application by different people.

For a qualitative risk assessment method, a ranking scale has to be selected to establish the ranges of probability or consequence values. The scale has to be at least an ordinal scale. The use of an ordinal scale has some limitations in terms of admissible operations. The properties that apply to this type of scale are 'equivalence' and 'greater than'. Statistics admissible are median and percentiles and non-parametric statistical tests (ranking statistics or order statistics) (Siegel and Castellan, 1988).

Other alternative methods available are not detailed in this document (see, for instance, ISO, 2009b); whenever appropriate quantitative methods should be applied provided that sufficient information exists.

Definition of likelihood scale

Likelihood classes can be defined by different probability intervals. In Table 10 and Figure 14, alternative likelihood classes derived from linear, exponential and logarithmic functions are presented.

In several problems, use of linear or exponential functions is not adequate since the upper limit for the lower class is already too high to be considered a rare event. Thus, classes showing a logarithmic type of function are often used.

The selection of a specific scale for defining likelihood classes should take into account the selected criteria, which depend on the type of problem and on the range of possibilities accepted by the decision making team, strongly related to the decision maker perception of risk.

Table 10 - Alternative probability class definition: linear, exponential and logarithmic functions

Classes	Likelihood	Probability values range (%)		
		Linear function	**Exponential function**	**Log function**
1	Rare	[0; 20[	[0; 68[	[0; 1.5[
2	Unlikely	[20; 40[	[68; 82[	[1.5; 5[
3	Moderate	[40; 60[	[82; 90[	[5; 15[
4	Likely	[60; 80[	[90; 95[	[15; 40[
5	Almost certain	[80; 100[	[95; 100[	[40; 100[

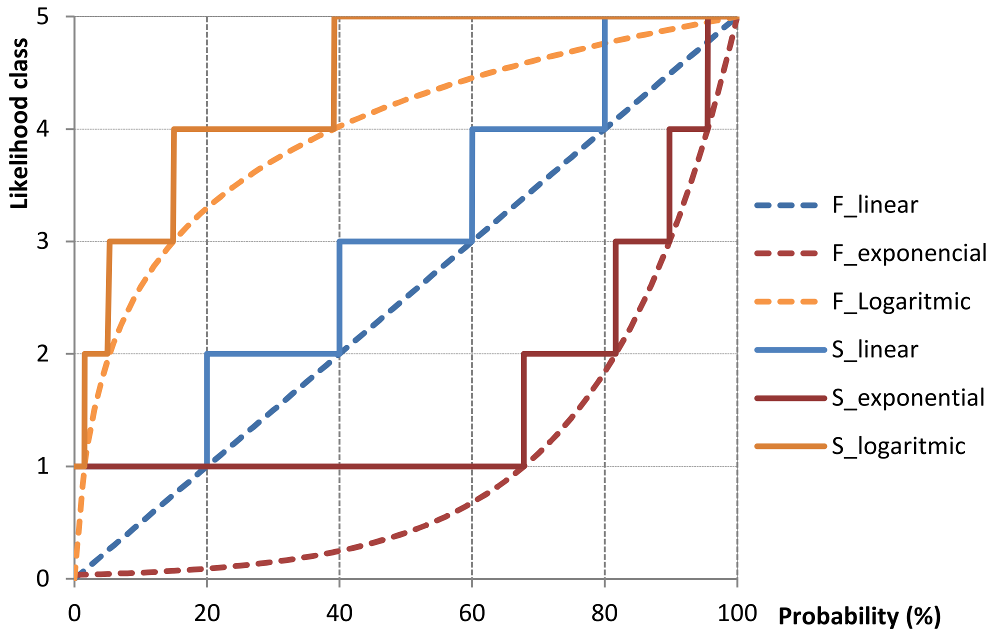

Figure 14 - Alternative ranking scales for likelihood

Definition of a scale and dimensions of consequence

Any event affecting the objectives or performance of water systems, independent of its type, can result in potential consequences of different sorts: public health and safety, environmental impacts, water infrastructures and services, structures and other infra-structures. Moreover, consequences can also incorporate socio-economic impacts on public and private property, including those derived from disruptions to society. Herein, the different ways an event can impact the current situation are called dimensions; when assessing the risk associated with a specific event, different consequence dimensions can be used in order to adequately express the criteria relevant to the stakeholders. Dimensions that can be of interest include those presented in Table 11; some examples of criteria or variables that can be used to allow a more objective application by different users are also presented in this table.

Table 11 – Examples of dimensions of consequence

Dimension	Examples of criteria or variables useful to express relative value in each class
Health and safety	▪ number and severity of injuries ▪ number and severity of people affected by disease ▪ number of people affected permanently (mortality and disability)
Financial	▪ monetary value; should be a function of the size of utility e.g. annual operating budget (AOB)
Service continuity	▪ duration of service interruption (availability and compliance with minimum standards); differentiation of type of client affected can be used (residential, hospital, firefighting) ▪ various performance measures (e.g. client.hours.lost without supply, number of interruptions); thresholds can be associated with legal requirements
Business continuity	▪ damage to materials, service capacity, available human resources to maintain system function and recovery time (e.g. % capacity affected.hours)
Environmental impacts	Impact on water, land, air, flora, fauna. ▪ severity (e.g. expressed as expected recovery time) ▪ extent (e.g. dimension of afected area, water quality index, volume or duration of event) ▪ vulnerability (e.g. protected areas, areas of influence for water supply abstraction)
Functional impact on the system	▪ various reliability measures (e.g. number of specific failures or failure modes per time unit); thresholds can be associated with legal requirements
Reputation and image	▪ number of complaints; frequency of negative references to the utility in the media; frequency of lawsuits
Project development	▪ effect on deviation of objectives (e.g. scope, schedule, budget)

The different dimensions of consequence have to be evaluated using comparable scales (see example in Table 12). A consequence in any class should have the same impact in the decision maker point of view, for all the dimensions considered in the application (e.g. health and financial).

For this type of method that does not allow aggregation of risks, it is common practice that when an event has associated consequences in more than one dimension the risk is estimated using the maximum class in all dimensions considered; therefore consequence scales used to calculate risk using different dimensions need to be comparable.

In cases where consequences can be mostly expressed in financial terms, a number of cost components can be distinguished, allowing subsequent calculation of the total consequence value of each event.

In Table 12, examples of possible scales for qualitative risk assessment approaches are presented. Environmental impacts can also be expressed by recovery cost. The severity of damage can be expressed as deviation from defined quality standards.

Table 12 – Example of consequence scale using three dimensions

Classes	Consequence level	Dimensions		
		Health and safety (public and occupational)	**Financial**	**Environmental impact**
1	**Insignificant**	Minor injuries or health disturbances not requiring medical assistance. No fatalities or life threatening injuries; total recovery.	< 0.1 % AOB*	Expected recovery time < 1 week ∧ Severity of the damage**: low ∧ Vulnerable areas*** not affected.
2	**Low**	Injuries requiring hospital treatment; no-admissions. No fatalities or life threatening injuries; total recovery.	0.1% ≤ AOB < 1 %	Expected recovery time < 1 month ∧ Severity of the damage**: low ∧ Vulnerable areas*** not affected.
3	**Moderate**	Injuries requiring hospital admissions ≤ 15 days. No fatalities or life threatening injuries; disability ≤ 20%.	1 ≤ AOB < 5 %	Expected recovery time < 1 year ∧ Severity of the damage**: medium ∨ Vulnerable areas*** affected
4	**High**	Severe injuries requiring hospitalization > 15 days. Up to 2 fatalities or persons with disability > 20%.	5 ≤ AOB < 30 %	Expected recovery time < 5 years ∧ Severity of the damage**: medium ∧ Vulnerable areas*** affected
5	**Very high**	> 2 fatalities or persons with disability > 20%.	≥ 30 % AOB	Expected recovery time > 5 years ∧ Severity of the damage**: medium or high ∨ Vulnerable areas*** severely affected

* Annual Operating Budget
** Appropriate measure e.g. dimension of affected area, water quality index, volume or duration of event
*** Protected areas, areas of influence for water supply abstraction, sensitive water bodies

Definition of a risk scale, risk matrix and acceptance criteria

For estimating risk using the consequence-probability matrix approach, both a risk scale and a risk matrix need be selected. A risk matrix provides a discrete approximation to an underlying quantitative relation between Consequence (C) and Probability (P).

According to Cox (2009), when using the risk matrix, a qualitative method, three levels or classes of risk should be used. The same author emphasises some basic rules to select the risk matrices to assure consistent results.

In order to generate a valid risk matrix (Figure 15), the correlation between C and P has to be positive. In other words, the risk matrix should account for the unknown joint distribution of C and P. Usually, the scales for likelihood and consequence scales are ordinal (e.g. 1, 2, 3, 4, 5); as mentioned previously, levels of the C scale should have the same or equivalent "value" for the different dimensions.

		Consequence				
		1	2	3	4	5
Likelihood	5	Low	Medium	Medium	High	High
	4	Low	Medium	Medium	Medium	High
	3	Low	Low	Medium	Medium	Medium
	2	Low	Low	Low	Medium	Medium
	1	Low	Low	Low	Low	Low

(a) Utility profile: bold

		Consequence				
		1	2	3	4	5
Likelihood	5	Low	Medium	High	High	High
	4	Low	Medium	Medium	High	High
	3	Low	Low	Medium	Medium	High
	2	Low	Low	Low	Medium	Medium
	1	Low	Low	Low	Low	Low

(a) Utility profile: moderate

		Consequence				
		1	2	3	4	5
Likelihood	5	Medium	Medium	High	High	High
	4	Low	Medium	Medium	High	High
	3	Low	Medium	Medium	Medium	High
	2	Low	Low	Medium	Medium	Medium
	1	Low	Low	Low	Low	Medium

(a) Utility profile: cautious

Figure 15 – Examples of valid risk matrices for different utility profiles

Cox (2009) provides some guidelines to improve the selection of an appropriate risk matrix to minimise the weaknesses of the method. There are a few basic rules that should be followed when designing a risk matrix:

- Red cells (high risk) cannot contact green cells (low risk);
- The left column and the bottom row have to be mostly green (low risk);

A risk matrix should have at least three risk levels (low, medium and high risks) which are to be associated with the acceptance levels to be used later on at the risk evaluation block:

- Low (acceptable)
- Medium (tolerable)
- High (not acceptable)

In Figure 15, examples of valid risk matrices are presented. For different utility profiles different matrices can be considered as an attempt to illustrate how the attitude of the utility decision makers towards risk can be reflected in the method. Herein three utility profiles are considered: bold, moderate and cautious. The calculation of risk using the product of class numbers is not a valid operation since ordinal scales are used.

When using more than one consequence dimension, usually the assigned value of risk to the event is the one resulting to the maximum risk level, thus the higher value of all dimensions since the probability is fixed for the event.

A typical risk scale is presented in Table 13 including acceptance criteria for each risk level.

Table 13 – Example of risk scale, including relation with risk acceptance criteria

Classes	Risk level	Acceptance and tolerability level	Action for risk reduction*
1	Low	Broadly acceptable region	Not likely to be required.
2	Medium	Tolerable region	Costs and benefits are to be taken into account and opportunities to be balanced against potential adverse consequences.
3	High	Intolerable region	Risk cannot be justified

* AS/NZS (2005)