Risk reduction of climate change related risks in water systems

Guidance to risk treatment step

COLOPHON

Title

Risk reduction of climate change related risks in water systems. Guidance to risk treatment step.

Report number

PREPARED 2013.028

Deliverable number

D2.4.3

Author(s)

Maria do Céu Almeida (LNEC)

Clemens Strehl (IWW)

Paula Vieira (LNEC)

Hans-Joachim Mälzer (IWW)

Maria Adriana Cardoso (LNEC)

Quality assurance

Rita Ugarelli (SINTEF)

This report is:

Public

Summary

Climate dynamics induces significant risks for water systems operators. Potential effects can involve the aggravation of existing conditions as well as the occurrence of new hazards or risk factors. To deal with this issue, within the PREPARED project a water cycle safety planning (WCSP) framework was proposed and tested. The WCSP is a preventive and systematic risk approach to support decisions on adaptive measures and strategies for the whole urban water cycle.

For both WCSP integrated and system's levels, there is a risk treatment step, whose purpose is to modify the previously identified risks that need treatment and invloves the selection and evaluation of risk reduction measures.

This report gives guidance for developing the step of risk treatment within the WCSP framework, including guidance on the selection of measures to mitigate risks associated with events for which risk level was estimated as non-acceptable; and, evaluation of selected measures using multiple criteria, not only from an economic perspective but also in terms of performance (e.g. technologic, functional, environmental and social) and effectiveness in reducing risk. Both qualitative and quantitative approaches are mentioned.

The methodology adopted in this report has been divided into three main parts: identification of risk reduction measures; comparison and selection of alternative risk reduction measures; assessment of residual risk; and, recommendations for developing a risk reduction program. Finally, examples of application in demonstration cases and of quantification of measures are presented.

Contents

List of figures

List of tables

Acronyms

CAPEX	Capital expenditure
CBA	Cost benefit analysis
CF	Carbon footprint
CSO	Combined sewer overflow
EAD	Expected annual damage
IPCC	Intergovernmental Panel on Climate Change
NPV	Net present value
OPEX	Operational expenditure
RIDB	Risk identification database
RRDB	Risk reduction measures database
RRM	Risk reduction measure
SCC	Social cost of carbon
SSO	Stormwater sewer overflow
SSP	System safety plan
UWC	Urban water cycle
WCSP	Water cycle safety plan

1 Introduction

1.1 Background

Climate dynamics induces significant risks for water systems operators. Water services in urban areas are essential to quality of life and socioeconomic activities and capacity to deal with climate extremes represents an important factor to cities resilience.

Climate related risks can be relevant to water supply, to wastewater collection and treatment systems and to stormwater management; other city functions can also be affected directly by meteorological phenomena as well as by low performance or failure of the urban water systems. Therefore, the tasks of risk assessment and management can bring an important contribution if analysed in an integrated way within the water cycle.

Potential effects of climate changes on the urban water cycle (UWC) involve the aggravation of existing conditions as well as occurrence of new hazards or risk factors. Climate change can aggravate the risk of service failure, since for instance raising variation in precipitation patterns is expected globally. Extreme precipitation events are expected to happen more frequently as well as droughts.

Given the interactions of urban water and natural systems and the effects of climate changes 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 problematic is of interest.

The water cycle safety planning (WCSP) framework proposed and tested within the PREPARED project (Figure 1) is a preventive and systematic risk approach to support decisions on adaptive measures and strategies for the whole UWC based on the best available knowledge. The implementation of the WCSP in two levels of action (integrated level and system level), through a continuous collaborative process involving various stakeholders acting in the water cycle, allows integration of different objectives, points of view and perceptions of risk. Besides providing a technical basis for decisions, the WCSP approach also results in a platform of stakeholders with a comprehensive view of the adaptations needed to reduce the risks that affect the various components of the urban water cycle. Consequently, decision making processes can be better supported and resources used more efficiently (Almeida *et al*., 2013d). This perspective is especially important for the risk treatment steps, at integrated or system's levels since often implementation of risk reduction measures will only be effective if different parties are involved.

Selection of risk reduction measures is not a straightforward task; not only information is limited but situations are often complex and decision needs to take into account multiple criteria. Therefore, guidance and tools for carrying out this task are recognised as valuable by both practitioners and decision makers.

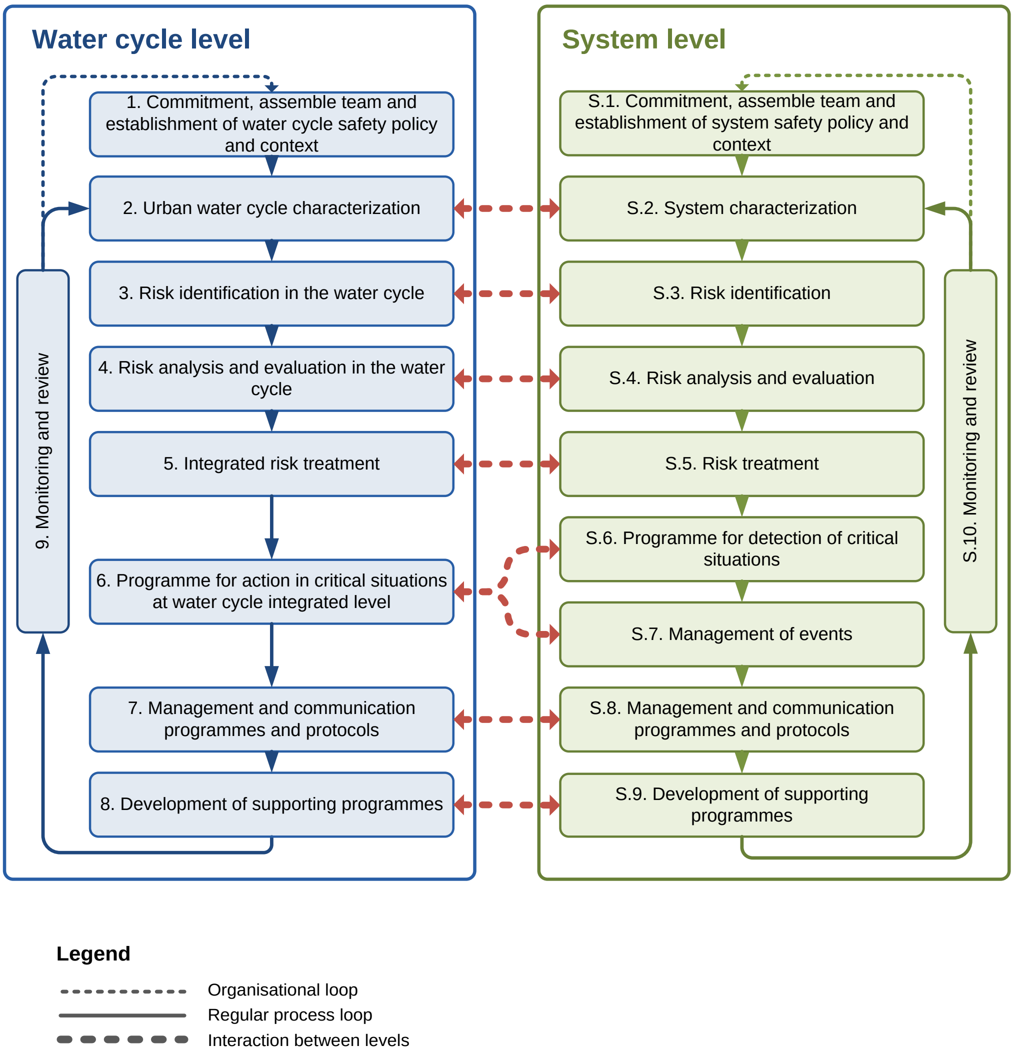


Figure 1 - WCSP framework (Almeida et al., 2013d)

Important steps of the framework include identification of risks and of opportunities in terms of alternatives to reduce risks. While climate changes affect probability and consequences of events, and ultimately originate different events not traditionally experienced in a region, alternatives to address the problems originated by these events are not climate dependent. Hence, classification of interventions or risk reduction measures (RRM) intrinsically associated with the events resulting in undesired effects is of interest.

For both WCSP integrated and system's levels, there is a risk treatment step. The purpose of this step is to modify the previously identified risks that need treatment and the selection and evaluation of risk reduction measures (RRM). For that purpose, adequate tools need to be ready to speed up the identification, selection and implementation of measures. Guidance and tools were developed in PREPARED especially for the steps of risk identification and risk treatment steps (Almeida *et al.*, 2011a, 2011b, 2013a, 2013b, 2013c; Strehl *et al.*, 2013).

Although the focus of PREPARED being on adaptation to climate change, the proposed WCSP framework is generally applicable as a risk based approach to water utilities. Therefore, the guidance given in this report has also a more general application.

1.2 Scope of this report

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. These measures include actions, activities or processes that can be applied at integrated or system level in order to reduce the occurrence and minimize consequences of events.

At both WCSP levels of analysis, risk treatment key actions include identification, comparison, prioritisation and selection of risk reduction measures. Subsequently, residual risk should be assessed and a risk treatment program developed.

A number of tools are available from PREPARED to guide application of the WCSP as presented in Figure 2 (Almeida *et al*., 2013d). One of those tools is the PREPARED RRDB that incorporates information intended to facilitate the application of these steps, especially for identification of risk reduction measures. In addition to these tools, guidance manuals were also developed.

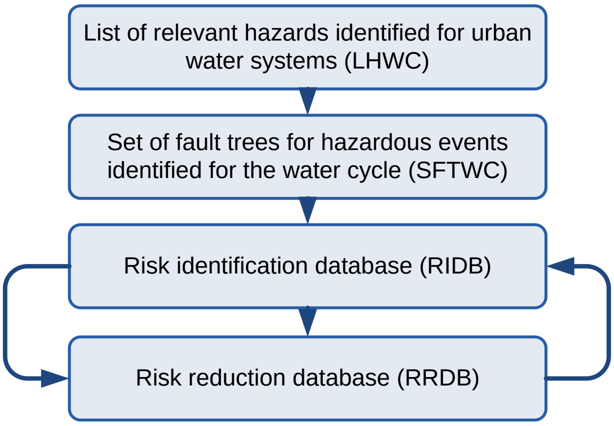


Figure 2 – Tools developed to support application of the WCSP framework

This report gives guidance for developing the step of risk treatment within the WCSP framework, including guidance on the selection of measures to mitigate risks associated with events for which risk level was estimated as non-acceptable; and, evaluation of selected measures using multiple criteria, not only from an economic perspective but also in terms of performance (e.g. technologic, functional, environmental and social) and effectiveness in reducing risk. Both qualitative and quantitative approaches are mentioned.

The methodology adopted in this report has been divided into three main parts: identification of risk reduction measures (section2.3); comparison and selection of alternative risk reduction measures (section 2.4); assessment of residual risk (section 2.5); and, recommendations for developing a risk reduction program (section 2.6). Finally, examples of application in demonstration cases and of quantification of measures are presented (chapter 3).

1.3 Climate change related risks in the water cycle

From the main aims of the WCSP, hazards found relevant to water cycle water systems managers were identified and are presented in Almeida *et al.* (2013d) and Table 1.

Table 1 – Hazards list per aim and exposure mode

Primary aim of WCSP	Exposure mode	Hazards
1. Protection of public health	Tap water: consumption (ingestion)	▪ Presence of microbial pathogens in tap water ▪ Presence of cyanotoxins in tap water ▪ Presence of chemical contaminants in tap water ▪ Presence of radiological contaminants in tap water ▪ Extended periods without supply
	Tap water: personal hygiene and other uses (skin contact, inhalation , ingestion,)	▪ Presence of microbial pathogens in tap water ▪ Presence of cyanotoxins in tap water ▪ Presence of chemical contaminants in tap water ▪ Presence of radiological contaminants in tap water
	Recreational or non-recreational: immersion (accidental ingestion, inhalation, skin contact)	▪ Presence of microbial pathogens in water bodies used for recreational activities ▪ Presence of cyanobacteria and cyanotoxins in water bodies used for recreational activities ▪ Presence of microbial pathogens in flooding water ▪ Presence of toxic chemicals in water bodies used for recreational activities
	Recreational or non-recreational: non-immersion	▪ Presence of microbial pathogens in water bodies used for recreational activities ▪ Presence of microbial pathogens in flooding water ▪ Presence of microbial pathogens in water used for irrigation
2. Public safety	Socio-economic activities: public areas or private properties (injuries)	▪ Water infrastructure collapses or bursts potentially causing injuries to public ▪ High velocity runoff in public streets ▪ High depth flooding in public areas or private properties ▪ Collapse of structures, urban equipment or trees due to effect of water ▪ Presence of toxic gases in the atmosphere of locations to which the public or workers might have access ▪ Presence of toxic chemicals in locations to which the public or workers might have access
3. Environment	Not detailed	▪ Discharge of organics in the water cycle or soil ▪ Discharge of nutrients (P/N) in the water cycle ▪ Discharge of heavy metals and other chemicals in the water cycle or soil ▪ Water scarcity affecting ecosystems

From this set of hazards, and taking into account exposure modes and risk factors and sources, a set of generic fault trees was proposed (Almeida *et al.*, 2013a). These fault trees are useful for identifying the relevant events that materialise the risks under analysis. In Figure 3, an example of a fault tree is presented.

Not all events are influenced by climate dynamics. Therefore, in the PREPARED databases (RIDB and RRDB) an attribute was included to give, for each event, an indication of the impact in the event of relevant climate change indicators or effects, as described in Ugarelli *et al.* (2010) and in Table 2. The climate indicators are those alterations on climate variables that have direct effect on urban water systems processes, whereas the climate change direct effects are modifications in the water cycle environment that also influence system's behaviour.

From the RIDB and looking at the fault trees, events that are sensitive to the different climate indicators and effects can be easily found, and selected for further analysis (for further details see Almeida *et al.*, 2013a).

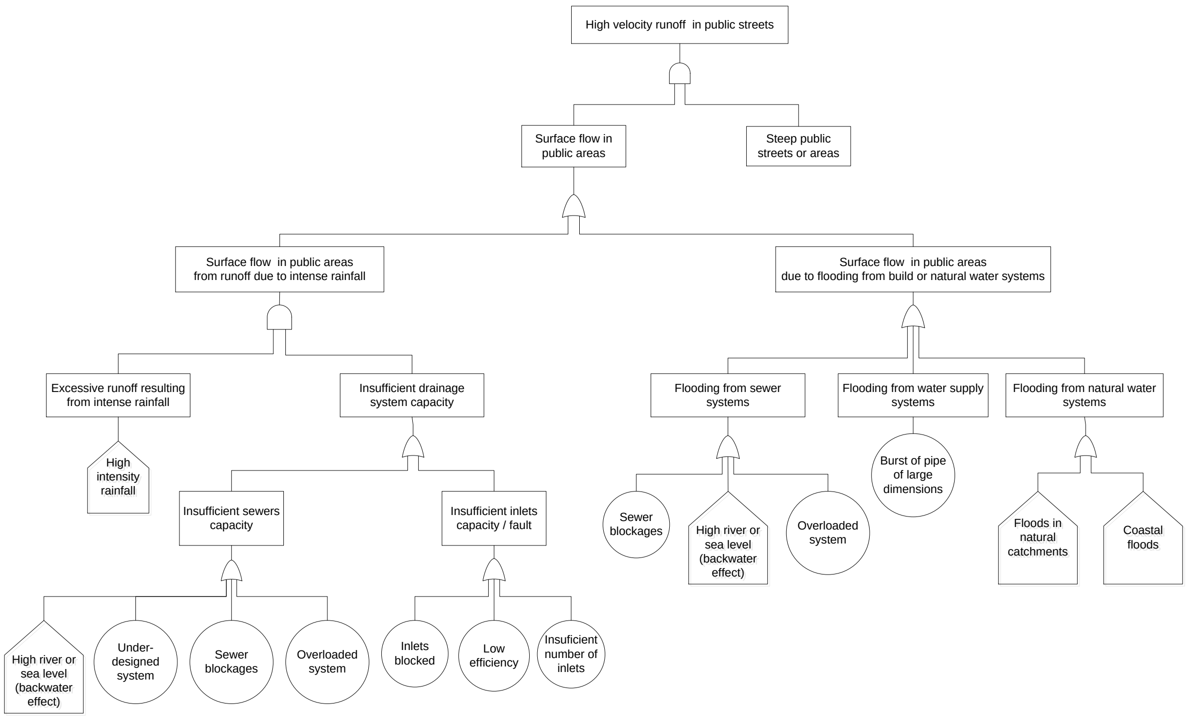


Figure 3 – Example of a fault tree for the hazard 'High velocity runoff in public streets'

Table 2 – Climate indicators and effects as identified in Ugarelli et al. (2010)

Climate indicator	Climate change direct effects
Increase of air temperature	Increase of water temperature
Increase of air temperature variability	Increase of sea temperature
Increase of precipitation annual amount	Sea-level rise
Decrease of precipitation annual amount	Increase of river flow
Increase of frequency of intense precipitation events	Decrease of river flow
Increase of winter precipitation	Changes in river flow pattern
Decrease of summer precipitation	Decrease of Arctic sea ice coverage
Changes in precipitation patterns	Decrease of snow, lake and river ice cover
Increase of winter storms	

1.4 Definitions adopted in this document

In risk management different terms are often used for the same purpose, or the same term is used with different meanings. Thus, a number of definitions are included in this section (Table 3) to help communication between different partners. These definitions are adopted in the present document and are intended to clarify the meaning as used by the authors. Definitions are aligned with those presented in all other PREPARED reports related to the WCSP.

Table 3 – Definitions adopted in the document

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.
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.
hazardous event	An event which can cause harm, e.g. a situation that leads to the presence or release of a hazard. The hazardous event is part of the event pathway.
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.
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 (e.g. financial, health and safety, and environmental goals) and can apply at different levels (e.g. 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.
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

Table 3 – Definitions adopted in the document (cont.)

Expression	Definition
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.
risk reduction measure	Set of actions allowing modification of risk. RRM includes any process, policy, device, practice, or other actions which modify risk and may not always exert the intended or assumed modifying effect.
risk reduction action	Specific action needed to properly implement the selected RRM. Actions can be of very different nature.
stakeholder	Person or organization that can affect, be affected by, or perceive themselves to be affected by a decision or activity.

1.5 Structure of the document

This report is structured in four chapters. In chapter 2, methodological guidance to proceed with risk treatment is given by providing a schematic decision framework and the description of the key actions for risk treatment.

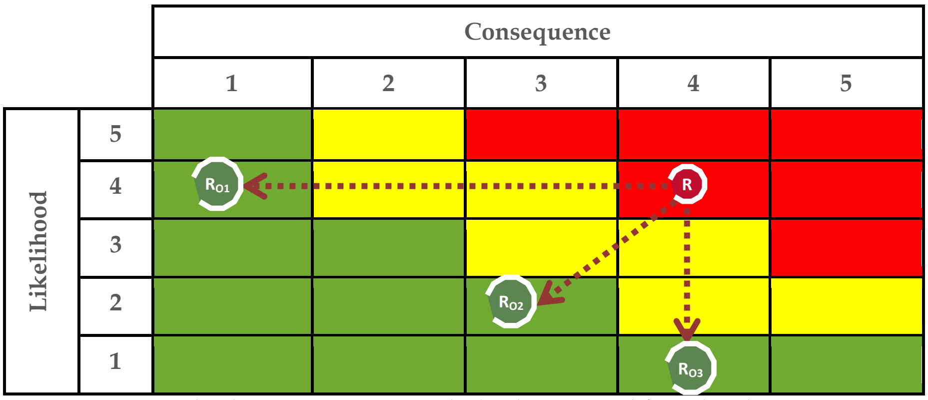
Chapter 3 details on how the methodology can be applied by illustrating its application in the Eindhoven case.

Some final remarks are made in chapter 4 on data to support risk treatment.

2 Methodology for risk treatment

2.1 Key actions for risk treatment

The main objective of risk treatment is to reduce risk as illustrated in Figure 4.



Key: R – Estimated risk; R_{01}, R_{02}, R_{03} are residual risks estimated for risk reduction measures 01, 02 and 03, respectively.

Figure 4 – Purpose of risk treatment

According to the WCSP framework (Almeida *et al.*, 2013d), the steps to deal with risk treatment at water cycle and system levels are developed in steps 5 and S.5, respectively (Figure 1). In both steps, the main key actions are:

- Identification of risk reduction measures;
- Assessment, prioritization and selection of risk reduction measures;
- Assessment of residual risk;
- Development of a risk treatment programme.

To decide on the best risk reduction program all possible risk reduction measures for the events aligned with the risks needing treatment need to be identified at first. For this purpose, the PREPARED risk reduction database (RRDB) should be consulted first (Almeida, 2011b). As far as possible, there will be a set of possible risk reduction measures defined for each relevant risk with a non-acceptable level of risk.

For the selected measures, appropriate methods should be used to assess and prioritize them. The final decision will result in a selected set of measures to implementation, and a final estimation of risk, using the same methods as in previous risk assessment, allows a verification of acceptable or at least tolerable residual risk.

In the following sections, guidance on how to proceed with these key actions, and some alternative methods are described.

2.2 Decision framework

The risk treatment decision framework is based on the steps of the WCSP framework and on the key actions for the risk treatment steps.

In Figure 5, the decision framework is presented.

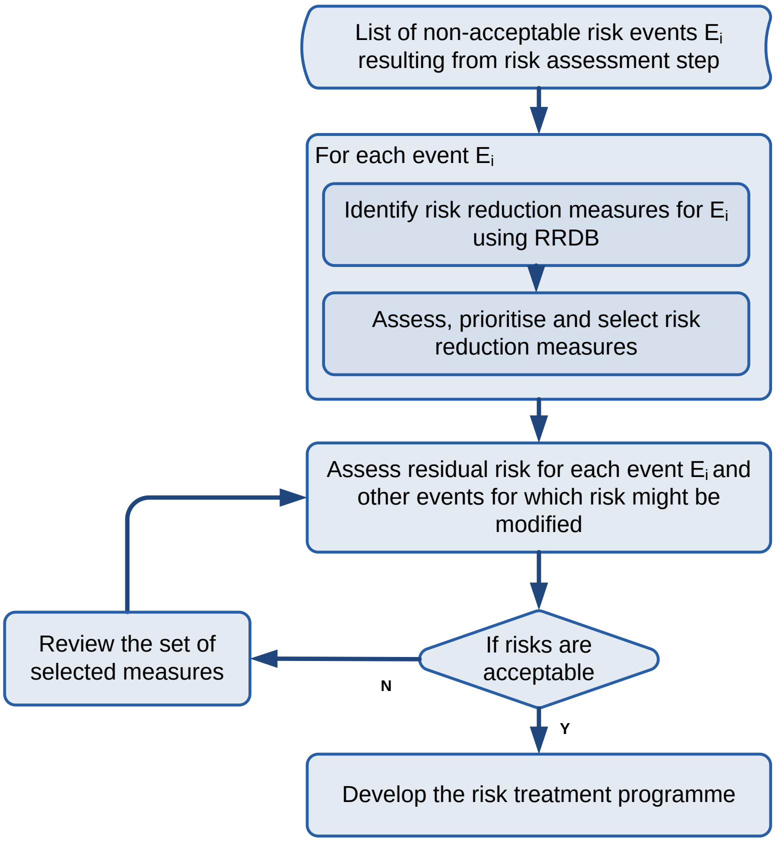


Figure 5 – Risk treatment decision framework

2.3 Identification of risk reduction measures

The water cycle safety planning (WCSP) and system safety planning (SSP) teams, respectively at the integrated or system levels, need to identify and document all the potential alternatives that can reasonably be analysed to reduce each identified risk that needs treatment.

For some risks, multiple measures 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.

For each measure, appropriate actions needed for its implementation should also be described since they are relevant in terms not only of implementation effort but also for effectiveness and efficiency of implementation.

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.

Different types of risk reduction measures can be considered. Almeida *et al.*, (2011a) resume measures reported in the literature in the following types:

- **Barriers** – any physical impediment or containment method that tends to confine or restrict a potentially damaging condition, reducing the probability of events, or containment of event after its occurrence, thus reducing consequences.
- **Redundancy** – additional, identical and redundant components in a system introduced to decrease the likelihood of failure of subsystems.
- **Increase components or systems reliability** - substitution of critical elements by more reliable ones, structural modifications of the systems or changes to the safety systems logics.
- **Increase components or systems effectiveness** - substitution or improvement of system elements by more efficient ones, including upgrading of technology.
- **Prevention of human error** – limiting the effects of a human error, namely by changing human-system interfaces (including changes in automation), changes in procedures (including changing in tasks) or changes in training.
- **Maintenance** – adequate preventive or corrective maintenance activities can reduce failure rates and consequently the likelihood of events.
- **Control systems** – detection of failure states, existence of unsafe conditions, by means of monitoring, testing or inspection, and actions to change the state of systems.
- **Accident mitigation** – safe shutdown, continuity in availability of utility's services, adequate confinement integrity and emergency preparedness.
- **Insurance and outsourcing** - the option of risk sharing with another party typically includes insurance and careful contract management, for instance, outsourcing.
- **Avoidance of a risk** – measures that involve deciding not to start or continue with the activity that gives rise to the risk, including not initiating or discontinuing an activity (e.g. water reuse for a certain purpose) or a technical process (not using a specific technical process).
- **Economic and accounting policies** – management practices including water tariffs and reserving money for provisions. Accounting policies could include e.g. a reserve fund to face events with high consequence but low likelihood available as resource for proper risk management. So a utility would have money ready to pay for instance for alternate water supply services in case of a total breakdown of the water supply system. These measures can be alternatives to making high investments into water supply systems reliability e.g. increasing redundancy. While events do not occur, money is not bound into illiquid assets (as it would be if it has been

spend for more system-redundancy) but is still liquid and monetary resources can be spend to face very different contingencies;

- **Adaptation of user and public behaviour** – changes in behaviour of system users or public in general allowing the risk reduction by decreasing the probability or the consequence of an event.

Some overlaps between these types of measures may occur, but are inevitable due to complexity.

Characterisation of each risk reduction measure should include information that can be classified in four main groups:

- Characterisation and applicability;
- Potential for risk reduction;
- Implementation strategy;
- Analysis of viability.

This information is essential to proceed with the assessment, prioritisation and, finally, selection of the measures to be implemented as well as to produce an adequate risk treatment programme.

The PREPARED RRDB was developed to support the application of this step and in the following description an illustration of its use is given.

Characterisation and applicability of each measure

The characterisation and definition of applicability conditions of each measure is essential. The items of information considered relevant for this purpose are:

- description of the measure;
- type of measure to reduce risk;
- contribution to primary aims of WCSP;
- application to level of analysis, system and subsystem;
- type of technical problems addressed;
- appropriate metrics for performance assessment;
- main advantages;
- main disadvantages.

The cost level that might be associated to the measure is not included in this part since it is considered in the criteria for the analysis of viability.

The description of the measure should be a concise explanation of what the measure is about, avoiding repeating information that can be included in the remaining items of this group. In the RRDB, generic descriptions are given; in a specific application, the description should also be concise but providing the necessary information to clearly characterise the measure, including specific location and system components.

The types of measures considered are those presented previously in this section.

Also relevant is the identification of the potential contribution of the measure to one or more WCSP primary aims, as appropriate. 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** and, in Table 4, the exposure modes are also identified. When applicable to more than one aim, the measure should be split in two, since some characteristics may differ. For instance, one measure may apply to reduce risk to public health and to the environment but the results obtained, as well as the actions required, often differ. These are especially relevant for finding appropriate measures.

Table 4 – 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 waters (water quality, ecosystems) (Soil) (Air)	Overuse of resources Pollution affecting ecological /chemical status of receiving waters

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

The RRDB catalogue of measures has an indication of the level of analysis, system and subsystem to which the measure can be considered to facilitate the selection of the measures for each specific event. Herein, subsystem is understood as those parts of the system that provide a specific function, and not necessarily geographically or physically associated parts of a system such as a demand management area in a drinking water system.

For selecting the measures applicable, a filter to the relevant system, subsystem or general, facilitates the task. The systems considered are catchment basin, drinking water, non-drinking water, wastewater, stormwater and receiving waters. The subsystems are those presented in Table 5.

Regarding the type of technical problem addressed, since different risks and events can have specific technical problems or performance deficiencies associated, selection of a measure needs to take into account what is the specific issue to be addressed by the measure. The directories of the RRDB, as well as the events described in the RIDB, provide information about this question.

Table 5 – Systems and subsystems in RRDB

System	Subsystems	
.1. Catchment basin	.1. Surface water catchment .2. Groundwater catchment	
.2. Drinking water	.1. Surface water reservoir .2. Groundwater reserves .3. Abstraction system .4. Groundwater recharge .5. Water treatment	.6. Transmission .7. Pumping stations .8. Storage .9. Distribution .10. Plumbing systems
.3. Non-drinking water	.1. Catchment system .2. Water treatment .3. Advanced wastewater treatment .4. Transmission	.5. Pumping stations .6. Storage .7. Distribution .8. Plumbing systems
.4. Wastewater	.1. Wastewater collection network .2. Interceptor system .3. Wastewater treatment .4. Combined sewer overflows	.5. Pumping stations .6. Storage structures .7. Infiltration systems .8. Outfalls
.5. Stormwater	.1. Urban catchments .2. Stormwater collection network .3. Infiltration systems .4. Source controls	.5. Stormwater treatment .6. Stormwater overflows .7. Pumping stations .8. Storage structures
.6. Receiving waters	.1. River .2. Estuary	.3. Lake .4. Coastal water

Considering all systems, the following types of technical problems addressed can be considered:

- **Hydraulic** – examples of hydraulic problems in sewer systems include limited or insufficient pipe flow capacity, high peak flows, high flow from illicit connections or sources that should not be directed to sewer, upstream network expansion, flow limited by downstream receiving water level (for instance, subject to tide dynamics) and sedimentation problems. In water supply systems, typical problems are associated with low pressure, undersized pipes, diameter reduction due to incrustations, and increase in water demand.
- **Environmental** – in wastewater and stormwater systems environmental problems include illicit polluted discharges to sewers, untreated discharges from CSO or SSO, exfiltration from sewers, low efficiency in treatment processes.

- **Structural** – in urban water systems structural problems are associated with physical deterioration of component, increasing likelihood of component collapse.
- **Operational** – extensive and expensive operations due to high maintenance, inspection or cleaning requirements, high energy and other resources consumption.
- **Water supply quality** – in water supply systems water quality problems include various possible causes of contamination at abstraction works, low efficiency at treatment works, low velocities causing long retention times and reduction of water quality, poor component condition may deteriorate water quality and poor hydrodynamics in storage tanks may also deteriorate water quality.
- **Water supply scarcity** – causes for water supply interruption can be due to failure of the performance of system components, high demand compared with source availability and water shortages due to low precipitation or contamination of water sources.

In the RRDB, the potential impact of the measures in existing technical problems is expressed using the ordinal scale presented in Table 6.

Table 6 – Measure potential for contributing to reduce technical problems

Class	Effect in technical problem
-2	Potential for severe aggravation of the problem
-1	Moderate aggravation of the problem
0	No significant effect
1	Potential for moderate improvement
2	Potential for major improvement

Selection of appropriate indicators for evaluating the measures is also important. These depend on the specific event to be dealt with but a first suggestion on indicators or other indexes for performance assessment can also be found in the RRDB. The evaluation of different risk reduction measures may benefit from using specific performance metrics. A minimum set of appropriate indicators or indexes for performance assessment of each specific measure should be selected, facilitating the following work of comparing, prioritising and selection of measures for implementation. For instance, in the case of a sewer system, for an environmental problem, indicators could include CSO number of discharges per year, CSO volume per year, CSO maximum peak flow per year, average concentration of parameter x in CSO discharge.

Finally, it may also be useful to check on RRDB main advantages and disadvantages of measures of interest.

Potential for risk reduction of measures

Information about potential for risk reduction is undoubtedly relevant to the selection of appropriate measures to carry out with risk treatment. In the RRDB the items of information included for this purpose are:

- type of risk reduction potentially achieved with the measure;
- risk reduction effectiveness;
- overall risk reduction cost efficiency.

For each event, measures sought might act on risk in the following ways:.

- **avoiding the risk,** by deciding not to start or continue with the activity that gives rise to the risk;
- **reducing the likelihood**, by removing the risk source, acting on relevant risk factors or causes;
- **reducing the consequences**, considering all potential dimensions of the consequence;
- **reducing the likelihood and the consequences**; and
- **sharing the risk** with another party or parties, including contracts and risk financing.

The type of risk reduction potentially achieved with a measure is also indicated for the RRMs included in the RRDB.

To determine the risk reduction effectiveness of a measure applied in a specific case, eventually together with other measures, it is necessary to proceed with a detailed analysis as described in section 2.4.

However, when identifying risk reduction measures to proceed with the selection of the appropriate measures for risk treatment, aspects that interest the analyst are the effectiveness of the measure, as an indicator of the achievement of the desired reduction of risk, and the efficiency, understood as the resource consumption for achievement of the desired effect.

In the RRDB, the effectiveness that can be expected in a typical situation for each measure is provided, using the scale presented in Table 7 as a first indication based either on experience or expert knowledge. The proposed 3-level scale is thus intended to give a general trend on the effectiveness of the measure. The three levels are associated with the usual risk matrix with three levels of risk.

Table 7 – Measure effectiveness

Class	Risk reduction expected
0	Minor reduction
1	Potential for moderate improvement
2	Potential for major improvement

The overall risk reduction cost efficiency, together with effectiveness, gives an indication of the efficiency, understood as resource consumption for achievement of the desired effect, and can be very useful to support selection of appropriate risk reductions measures in specific applications. The scale used (Table 8) is intended to give a general trend on the overall balance between costs and benefits for the risk reduction achieved with the measure.

Table 8 – Measure efficiency as an indicator per risk reduction level

Class	Cost per risk reduction level
0	Doubtful value
1	Justified
2	Highly worthwhile

Implementation strategy

The success of any risk reduction measure strongly depends on the adequacy of the implementation strategy, and actions of different types need to be considered. The strategy needs to clearly include, for each RRM or group of RRM, which type of actions is recommended for the implementation. Co-ordination and involvement of the different stakeholders (water cycle level or system level) should be considered in later stages of application of the WCSP framework. In the RRDB the types of actions that should be considered for adequate implementation and pertinent for cost evaluation are indicated.

For implementation, the types of actions to consider can be classified into the following categories (Almeida *et al.*, 2011a):

- **Design and construction:** for measures involving execution of works or structures, typical phasing is to be considered usually requiring the development of specific design, planning of the works, execution, and other related tasks.
- **Operation and maintenance:** Tasks of operation and maintenance can be necessary to the measures implementation. For instance, monitoring, testing and inspection, are often essential for providing the information required to potentially reduce the probability, and in some cases the consequences, of undesired events, in conjunction with alarm systems or other corrective actions.
- **Information and education:** The promotion and dissemination of information on the relevant issues is fundamental for the successful implementation of any measure. Different formats have to be used depending on the target group, which can be the general public or specific groups of professionals, among others.
- **Documentation, training and technical support**: Actions for improvement skills and aptitudes are often essential to increase technical competencies of personnel, without which proper implementation of measures can be compromised. Different formats and means can be used, such as, manuals, guidelines, training courses. Regarding personnel training, courses or other instruction programs allow improvement of knowledge, namely improving procedures and performance under all

operation conditions, thus reducing the probability or the consequences of an undesirable event.

- **Regulation, standardisation and legislation:** Development of documents regulating different aspects of the activities of water utilities, and of other agents influencing the levels of risk, can result in important benefits for risk reduction. These actions include licensing, banning of products or activities, wastewater discharge permits, and compulsory environmental impacts assessment. Certification of activities, firms and products can also bring improvements in the general performance of associated procedures leading to a safer and more reliable operation of water systems (e.g. ISO 22 000).
- **Economic and financial incentives or penalties:** The establishment of economic and financial incentives often is the best way to foster the application of a certain measure. However, the introduction of penalties can also be effective in some situations.
- **Research and development:** Despite existing knowledge and experience, there are open areas that need further research to improve the applicability, efficacy and viability of certain potential measures as well as development of technological innovations.
- **Social support to the population**: Tailored support actions to the population actions can prove to be very effective and are often disregarded or delayed. These are, especially directed at, but not restricted to, the most vulnerable groups such as elderly, lone parents and long-term sick (see Tapsell *et al.*, 2002, for the case of flooding).

Criteria for analysis of viability

The analysis of viability of the measures for each specific case should be carried out. Nevertheless, a preliminary indication of the viability of the measure provides useful information, even if only a general evaluation is possible since viability strongly depends on local conditions. In the RRDB, this preliminary indication is given using criteria for economic, technologic, functional, environmental impact and social acceptance. To all these criteria a qualitative evaluation is available in the RRDB, according to coding in Table 9.

Table 9 – Levels of viability

Code	Level of viability
5	High viability or not relevant
4	Moderate viability
3	Largely case dependent
2	Tends to be unviable
1	Impracticable

Economic viability is strongly dependent on local conditions. Therefore, in RRDB only the relative magnitude of required costs in capital expenditure (CAPEX) and expected magnitude of operational expenditure (OPEX) are indicated for an average situation. When carrying out the detailed analysis of the measures the analyst can conclude about the economic viability in specific local conditions and considering relevant economic scenarios.

The capital expenditures include payments for acquiring assets, fixing problems with existing assets, preparing assets to be used in business and costs for property. The sum of all these payments is called CAPEX and is the value which will be capitalized in terms of accounting and will be depreciated over the lifetime of the asset.

The capitalized expenditures will appear in the balance-sheet. But these capitalized expenditures (in sum) are usually no expenses in terms of the income-statement. Hence they do not affect the net-income, since they will not appear in the income-statement as expenses. Only the expenses for depreciation will appear in the income-statement of future periods. Thus, capital expenditures will not affect the net-income of a utility in the period where they are spend, but will affect the net-income of future periods with the depreciation.

Nevertheless, capital expenditures are affecting the statement of cash flows since the CAPEX are payments and therefore influencing the cash flow of investing activities.

The OPEX are the ongoing costs for a project or business. Operational expenditures do include payments for supplies and raw materials, maintenance and repair, administration, insurance, salary and wages, power and electricity and so on. OPEX are the sum of the project or business operating payments for a period of time, for instance a year. In terms of the income-statement these payments are also affecting the net-income since they will appear under expenses. All direct payments will also influence the cash flow statement and hence the cash flow from operating activities. Depreciation for the assets used for the project or business is not included here.

Both CAPEX and OPEX need to be regarded in a financial valuation of an investment project, like an investment into redundant water supply system parts to reduce the risk of infrastructure failure.

In the RRDB a general categorization scale is used to give an indication of the economic viability as presented in Table 10.

The CAPEX should be estimated in relation to the cash flow from investing activities in the cash flow statement of a utility. In Table 10 a code 5 in the RRDB means the CAPEX has a small value in comparison to a utility cash flow from investing activities. So the CAPEX payments are relatively small for the utility (also means potentially easy to afford).

The OPEX should be estimated in relation to the cash flow from operating activities. In Table 10 a code 5 means a relatively small value in comparison to the cash flow from operating activities of a utility.

Table 10 – Levels of economic viability

Code	Level of viability
5	High viability. OPEX/CAPEX has a small value in comparison to utilities' cash flow
4	OPEX/CAPEX has a moderate value in comparison to utilities' cash flow
3	OPEX/CAPEX in comparison to utilities' cash flow is largely case dependent
2	OPEX/CAPEX has a high value in comparison to utilities' cash flow
1	Impracticable OPEX/CAPEX has a very high value in comparison to utilities' cash flow.

The **technologic viability** corresponds to availability of technology in the market (e.g. products, equipment, methods required for implementation) or sufficient knowledge for the proposed measure. In some cases, further research or development might be necessary.

The **functional viability** corresponds to the evaluation in terms of added requirements for operation and maintenance or, when applicable, performing tasks or uses. When applicable, ease of use should also be considered.

Environmental viability represents the overall balance between environmental benefits and negative impacts. One measure may have some environmental benefits, for instance, reducing water demand, but implies higher energy consumption, thus the economic viability should consider both benefits and negative impacts.

Social acceptance represents the overall evaluation of expected acceptance, considering acceptability by stakeholders and the public. Even if in technical terms a measure is very promising, if it is not accepted by stakeholders or the public it will not be as effective as expected.

In Table 11 an example of risk reduction measures selected from the RRDB, for some relevant events, for further analysis (assessment, prioritisation and selection to implementation) are presented.

Table 11 – Examples of risk reduction measures identified for the Lisbon demo

Event ID	Event	Risk reduction measures
E1201.03	High velocity runoff in Luís de Camões street due to intense rainfall (RP = 10 years) and to insufficient sewers capacity resulting from high river or sea level, causing injuries to public, damages to property, disturbances in services and activities	▪ Establish land-use restrictions (such as in floodplain areas) ▪ Reduce catchment impervious areas ▪ River regulation ▪ Flow control within the drainage network, through the use of valves, weirs, gates, pumps, vortex controls ▪ Designing drainage networks for exceedance, e.g. transfer to nearby subsystems or streams ▪ Flood forecasting and warning ▪ Flood resilience measures (wet-proofing), e.g. flood resilient buildings and equipment ▪ Cleansing of urban surface and of systems components ▪ Adequate maintenance of equipment e.g. pumps in stormwater systems ▪ Cleaning of drains or sewer pipes ▪ Emergency response planning ▪ Inline/offline storage within the drainage network, such as oversized pipes, deep shafts, attenuation tanks, etc. ▪ Terrain surface modelling to modify overland flow paths
E1301.06	High depth flooding in public areas or private properties in Alcântara due to intense rainfall (RP = 100 years) and to insufficient sewers capacity resulting from high river or sea level, causing injuries to public, damages to property, disturbances in services and activities	▪ Establish land-use restrictions (such as in floodplain areas) ▪ Reduce catchment impervious areas ▪ River regulation ▪ Flow control within the drainage network, through the use of valves, weirs, gates, pumps, vortex controls ▪ Temporary flooding defences for protection in properties ▪ Designing drainage networks for exceedance, e.g. transfer to nearby subsystems or streams ▪ Flood forecasting and warning ▪ Flood resilience measures (wet-proofing), e.g. flood resilient buildings and equipment ▪ Cleansing of urban surface and of systems components ▪ Adequate maintenance of equipment e.g. pumps in stormwater systems ▪ Cleaning of drains or sewer pipes ▪ Emergency response planning ▪ Inline/offline storage within the drainage network, such as oversized pipes, deep shafts, attenuation tanks, etc.
E1705	Discharge of organics in the water cycle or soil due to discharge of untreated WW from wastewater system caused by failure in Alcântara WWTP for insufficient treatment plant capacity during peak flow causing damages to the environment	▪ Flow control within the drainage network, through the use of valves, weirs, gates, pumps, vortex controls ▪ Flood forecasting and warning
E0506	Extended periods without supply due to unavailability of surface water in Tagus river due to drought, affecting public health and causing disturbances in services and activities	▪ Use of alternative water sources in case of insufficient water quantity - reuse of treated wastewater from Alcântara WWTP ▪ Increase of raw water storage capacity ▪ Increase of use of water for supply by developing water allocation strategies among competing uses in Tagus river (priority to supply) ▪ Rationing schemes and restrictions on water use (consumer's)

2.4 Assessment, prioritization and selection of risk reduction measures

2.4.1 *General remarks*

In order to select the RRM that will be implemented, all previously identified RRM should be assessed by balancing the costs of implementation against the benefits (monetary as well as non-monetary) 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.

Several engineering tools (not always specific risk-related) are available for instance mathematical modelling, failure analysis and tools to support multicriteria decision making. These tools allow a detailed analysis of the potential effect of the measures and the use of a combination of criteria and metrics on performance, cost and risk. For instance, tools developed to support infrastructure asset management in projects such as AWARE-P (www.aware-p.org) or TRUST (http://www.trust-i.net), many of them open source and free (e.g. http://baseform.org/), can be of interest to this step.

This process should consider all dependent risks, or risks that can be modified by the measures being implemented.

After assessment, alternative RRM should be prioritised relatively to several criteria considered relevant by the utility and a decision be made on which RRM to implement. When RRM can impact on risks outside the utility, other relevant stakeholders should be involved in the decision process.

Cost and risk reduction efficacy as the two very important criteria for risk reduction measures assessment. Recommendations about how to quantify those criteria are discussed in chapter 2.4.2.

2.4.2 *Risk reduction efficacy and costs of risk reduction measures*

Risk reduction efficacy

To assess a RRM and decide if the measure is worthwhile or not, the **risk reduction efficacy** needs to be evaluated. Therefore quantification is usually necessary. As a generic rule the level of risk before and after implementing a RRM needs to be taken into account. The next paragraphs describe an analytical way to follow for quantification in general.

The outcome of the risk identification step of the WCSP leads to a set of identified risk events E_i for a water system. Each of these events can lead to different consequences c_j. The PREPARED approach differentiates the following consequence dimensions:

- Health and safety
- Financial impacts
- Environmental impacts

- Service continuity
- Liability, compliance, reputation and image
- Project development

To be able to assess the effect of risk reduction expectable from a RRM the level of risk before implementing the RRM needs to be defined at first. In general risk is a function of the likelihood of the event and the consequences. Since each risk event *(E_i)* can lead to more than one type of consequence *(c_j)* (respectively consequence dimensions) risk may be expressed as follows, for $i = 1 \ldots n$ events and $j = 1 \ldots m$ consequence dimensions:

$$r_{ij} = f(l_i, c_{ij}) \tag{1}$$

Analytically each event *(E_i)* is associated with one likelihood (l_i), but can be associated with more than one type of consequences (c_{ij}). The resulting risk level is defined as r_{ij}. Thus each risk event can lead to more than one risk, each in a different consequence dimension.

To assess the efficacy of a RRM the level of risk before implementing the RRM must be compared to the level of risk after implementation. Analytically this can be shown with equation No. 2 (Lindhe 2010, p. 72).

$$\Delta r_{ijk} = r_{ij} - \overline{r_{ijk}} \tag{2}$$

So the efficacy (respectively effect) of risk reduction *(Δr_{ijk})* of a measure *(k)* is defined as the difference between the level of risk before treatment *(r_{ij})* and the level of risk after treatment with the measure *($\overline{r_{ijk}}$)*. As a general rule the effect of risk reduction as described here can be defined as the benefit of a RRM. By assessing the effect of risk reduction the decision maker is able to check whether the level of risk after treatment with the RRM under assessment is reaching an acceptable level. If this can be expected, the measure is suitable to be implemented, at least from a risk reduction efficacy point of view.

Costs of risk reduction measures

The other main criterion relevant for any decisions on RRMs are the **costs**. Costs are an important decision criterion for different decision cases. For instance cost need to be taken into account for the **comparison** of alternative RRMs. Comparison is necessary when more than one RRM turn out to be able to reduce the risk to an acceptable level of risk. Also costs are an important criterion for **prioritisation** of RRMs. Budgets for risk reduction are usually limited, thus it is important to know which measures reduce risk levels with least costs. Thus it is recommended to calculate and compare costs for all alternative RRMs before measures are selected for the risk treatment programme.

Since RRM are supposed to reduce the level of risk in the future it is essential to account the cost of a measure for future periods. A common way to account for future costs of a new investment is to use the present value method. It is recommended to use this method to account the costs of RRMs. To calculate the present value of costs for a specific measure the lifetime of this measure needs to be defined at first. The lifetime is usually the time horizon *T* for which costs are accounted on an annual basis. In simple terms, to calculate the present value the costs of each year of the time horizon are estimated and summed up. Two general types of costs need to be considered in the analysis (see also the section on "economic viability" in chapter 2.3 for explanations):

- Capital expenditures (CAPEX)
- Operational expenditures (OPEX)

CAPEX include payments for acquiring assets, fixing problems with existing assets, preparing assets to be used in business and costs for property. CAPEX are spent before a new measure is "working". They can be interpreted as **investment** at the beginning of a project. OPEX are the **ongoing costs** for a measure. They include payments for supplies and raw materials, maintenance and repair, administration, insurance, salary and wages, power and electricity and so on.

Since costs are accounted for multiple future periods in the present value method**, inflation** needs to be taken into consideration. For instance the OPEX needs to be inflated over the whole time horizon of the analysis. Therefore the costs in future periods defined on the basis of today's price levels need to be multiplied with the so called inflation factor (*IF*). Assuming e.g. today to be the basis, each following periods costs must be multiplied with the inflation factor which is depending on the period *t* of the analysis and the assumed inflation rate (*IR*). The inflation factor is calculated according to equation No. 3.

$$IF_t = (1 + IR)^t \qquad (3)$$

Commonly future costs are given a lower weight than costs today. The rationale behind is simply the further in the future costs occur, the lower the weight aligned to it. This is called discounting. Since for the present value method costs are accounted for multiple future periods, all costs need to be discounted. The nature of discounting implies an exponential growing discount factor. The formula for the discount factor (respectively weight *w*) is shown in equation No. 4.

$$w_t = \frac{1}{(1+r)^t} \qquad (4)$$

Here r is the discount rate, t the future period and w_t the discount factor for any costs assumed for the period t (Pearce et al. 2006, p. 184). The Intergovernmental Panel on Climate Change (IPCC) suggests to use discount rates around 4-6 % for developed countries and 10-12 % for developing countries to assess climate change mitigation policies (Halsnæs et al. 2007). The rule to calculate the present value of costs ($PV(c)_k$) for a RRM with the discount rate r is shown in equation No. 5.

$$PV(c)_k = \sum_{t=0}^{T} \frac{c_t}{(1+r)^t} \qquad (5)$$

Here all costs (c) are discounted for each period of the time horizon (T).The sum of all discounted costs is the present value $PV(c)_k$ of the measure k. Costs in periods with $t > 0$ should be inflated cost values. To compare different RRMs this calculation needs to be done for all measures. The measure k with the lowest $PV(c)$ can be assumed to be the cheapest one in the long run.

Additional accounting for social costs of greenhouse gases

Implementation and operation of RRMs to mitigate the risk from climate change dynamics itself do lead to additional greenhouse gas (GHG) emissions. Thus the cost assessment of RRMs to reduce the risk aligned to climate change dynamics may not only cover cost for RRMs itself. If the decision frame is not a local but a global one, also social cost of additional greenhouse gases originating from the RRM should be regarded. This is true for decision cases in risk reduction where the objective of the decision maker is to reduce risk levels with minimum internal *and* social costs. For those cases social costs of greenhouse gases originating from implementing and operating a RRM need to be estimated. These social costs must subsequently be added to the internal costs to implement and operate the RRM (CAPEX and OPEX).

Social costs of greenhouse gases are usually defined as damages to global economy on a 100 year time frame per incremental tonne of CO_2 emission equivalent (CO_2-eq.). Commonly those costs are called "social costs of carbon" (SCC) in literature (Tol 2008). Different studies tried to estimate a monetary value for SCC. Unfortunately it is a complex and hard task to estimate monetary damages globally per tonne CO_2 emission. Tol (2008) analysed in a meta-study 211 estimations for SCC from 47 studies. According to his findings the mean value for SCC is \$127/tCO_2 (94€ at 2014-02-04), the median value \$74/tCO_2 (55€ at 2014-02-04) and the modal value \$35/tCO_2 (26€ at 2014-02-04).

In order to be able to account for SCC deriving from a RRM the carbon footprint (CF) of the measure must be calculated beforehand. The CF of a RRM covers all emissions resulting during implementation and operation of a RRM. So far there is no binding standard to calculate the CF in the water industry. Still in the UK the "Publicly Available Specification 2050:2008 - Specification for the assessment of the life cycle greenhouse gas emissions of goods and services" was developed to recommend a guideline for carbon footprint assessments (Sinden 2009). This can also serve as a basis scheme to calculate the CF of a RRM.

In general a four stage process to calculate the CF should be followed, as show in Figure 6 (Rohn and Merkel 2013). In the first step, system boundaries of the RRM have to be set. This is especially relevant for RRMs which include new water infrastructure assets. Also the time horizon needs to be specified here. For instance if the RRM incorporates a new water infrastructure asset, the lifetime of this asset can be defined as time horizon. At the next stage all processes involved within these boundaries needs to be defined. Especially when comparing different RRMs, it is important to use the same system boundaries and processes for the CF of each measure. Looking e.g. at a new exploited ground water source to reduce the risk of water scarcity, relevant processes are water abstraction, transport and pumping. In the following, all material and energy flows going into, out of and being used in the system have to be determined. This is the basis to identify all direct and indirect emissions. Direct emissions are defined as emissions originating from the processes themselves. Looking at the example of the new ground water source, this could be e.g. CH_4 emitting during abstraction. Indirect emissions in contrast are emissions released during the production or the transport of involved goods during operation of the RRM as well as the emissions released during the generation of the consumed energy necessary to operate the RRM. At the last stage all identified emissions need to be summed over the whole lifetime of the RRM and thus calculated as CF in tCO_2-eq. By calculating the CF in CO_2-eq. and multiplying it with a monetary value of the SCC in €/t CO_2-eq. the social costs of greenhouse gases can be incorporated in a cost comparison of alternative RRMs.

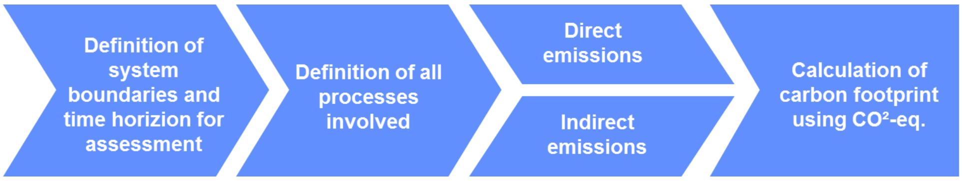


Figure 6 – Process to calculate the carbon footprint of a risk reduction measure

2.5 Assessment of residual risk

The nature and extent of residual risk remaining after selected risk treatment should then be assessed, using similar approaches and criteria as in risk assessment. As appropriate, the residual risk can be estimated per measure but, if a set of measures is to be implemented, analysis should also be carried out for the set since results do not necessarily correspond to the sum of results for individual measures.

This assessment should be as comprehensive as possible to allow detecting risks that can be modified by the measures being implemented in the sense of aggravation. The assessment needs to consider all dimensions of consequence under analysis.

Assessment of residual risk per implementation phase or for the whole programme can also be necessary. This residual risk should be subjected to monitoring, review and, if necessary, further treatment.

2.6 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 coordinating its implementation;
- proposed actions and, for each action, implementation schedule, responsibilities and priorities;
- necessary resources for the programme implementation;
- reporting and monitoring requirements.

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, thus, require the involvement of other stakeholders. These situations should be dealt with at the water cycle level.

3 Example for risk reduction in Eindhoven

3.1 General

Eindhoven is facing the growing challenge of pluvial flooding. Pluvial flooding originates from extreme precipitation in urban areas, where e.g. limited sewer capacity and paved areas lead to water on streets and flooding of properties. Climate dynamics may aggravate the risks from pluvial flood events. Extreme precipitation can happen more often or with a greater intensity due to climate change. Therefore, a collaborative case study on pluvial flood risk was conducted by Eindhoven municipality, University of Exeter and IWW Water Centre. One objective was to compare different RRMs. Therefore the costs and the risk reduction efficacy of each RRM were compared. Costs and risk reduction efficacy were calculated as explained and recommended in chapter 2.4.2 and have been integrated into a cost-benefit analysis (CBA) for risk reduction in Eindhoven. The next sections describe the approach, procedure and results of the application in Eindhoven. More details are explained in Strehl *et al*. (2013), PREPARED deliverable 2.4.2.

3.2 Application using a quantitative approach with cost-benefit analysis

To compare alternative RRMs a cost-benefit analysis (CBA) can be used. To conduct a CBA the costs as well as the benefits of each RRM need to be estimated.

The benefit of a RRM can be defined as the effect of risk reduction (Δr_{ijk}) aligned with a measure k for event E_i in a consequence dimension j as shown in chapter 2.4.2. If the consequence dimension "financial consequences" is relevant, a CBA can be a straightforward method to quantify the effectiveness of the RRM k. Therefore the effect of risk reduction needs to be expressed in monetary terms. For example the reduction of expected annual flood damage costs can be defined as monetary benefit for flood alleviation measures. Here the benefit equals to the prevented flood damage in future periods.

The costs for RRMs need to be expressed as the sum of two basic figures. These are the capital expenditures (CAPEX) for a measure and the ongoing operational expenditures (OPEX) for that measure, as already explained in chapter 2.4.2.

By simple means the Procedure to assess a measure following a CBA approach is to subtract the sum of costs (to implement and operate a RRM) from the sum of benefits (e.g. prevented damage in monetary units) for a specific time horizon. If the result of this calculation is a positive monetary value, then benefits outweigh costs and the measure for itself is worthwhile. If the result is negative, the measure is not worthwhile from a financial point of view. By comparing the outcome of CBA of different RRMs the ranking of alternatives is straightforward.

To conduct a sophisticated CBA for one or a set of risk reduction measures some further financial-mathematical rules have to be followed and important financial variables have to be included in the calculation. Details can be found in Strehl *et al*. (2013). A comprehensive overview of the generic rules for CBA can be found e.g. in Pearce *et al*. (2006).

3.3 Procedure and results for the cost-benefit analysis of risk reduction in Eindhoven

3.3.1.1 Risk identification

Considering the WCSP for Eindhoven's sewer and storm water system, one risk event found in the RIDB is "Flooding in public areas or private properties" due to insufficient combined sewer systems capacity. Eindhoven's mostly combined sewer system is overloaded from time to time by extreme precipitation leading to water on streets. It was found necessary to reduce this risk of flooding. Here financial consequences, especially for private property owners in Eindhoven, were in focus. This is because pluvial flood events did cause damage in the past to buildings and content values of Eindhoven's citizens and is likely to do so in future, eventually to a larger extend.

3.3.1.2 Risk assessment

The risk itself was expressed as expected annual flood damage in € (EAD). The risk *(r)* equals the EAD which is calculated for one event *(E_i)* "Flooding in public areas or private properties" and the consequence dimension *(j)* "financial consequences". This is shown in equation 6.

$$r_{ij} = f(l_i, c_{ij}) = EAD \quad (6)$$

To analyse the risk event "Flooding in public areas or private properties", n = 3 rainfall events were considered with three different annual return periods (T) and different one-hour rainfall profiles. The rainfall profiles where taken from Dutch Standards (Rioned 2004). Here the likelihood can be expressed as concrete probability of each rainfall event. The probability equals the reciprocal of its return period (1/T). For all three rainfall event sewer network simulations, the software SOBEK (www.deltaressystems.com) was used in combination with GIS analysis and an historic data from a Dutch insurer's damage database for pluvial flood events, to calculate damage costs to private properties. For the results presented here, the assumption was to account for damage to building and content value each time a property is flooded above 10 cm of flood water depth (assumed threshold of the average doorstep height).

Now taking all three rainfall events into account, the EAD was calculated as follows. Defining *i* as rainfall event with a specific probability *(p)* and aligned damage costs *(COST)* the EAD was calculated as:

$$risk = EAD = \sum_{i=1}^{n} (p_i * COST_i) \quad (7)$$

For practical reasons, only the three indicative rainfall events for return periods of 2, 5 and 10 years where included in the EAD calculation. Including more events would certainly alter results. But Eindhoven was most interested in results using those three events with low return periods. This is because those were the events to be expected to happen in the short-term as well as to happen a lot of times in the long-term, potentially cumulating considerable amounts of damage.

3.3.1.3 Risk treatment

Two possible generic risk reduction measures have been selected from the RRDB:

- Rebuilding of combined sewer systems to separate sewers;
- Flood attenuation (retention or detention systems) such as ponds, basins, constructed wetlands.

Adapted to Eindhoven, these measures resulted in three possible risk reduction alternatives. The first one is to separate a part of the combined sewer system into separated sewer and storm water networks in the city (measure "Separation"). The second is to reopen and restore the formerly channelized river Gender, which flows through the city, for flood retention increase (measure "Gender"). The third scenario incorporates the realisation of both measures (measure "Separation+Gender"). In fact Eindhoven's municipality has plans to implement these measures already.

To compare all three alternatives against the 'do nothing option' or baseline situation, a CBA was conducted. Benefits were defined as 'saved damage' from flood attenuation in the city, preventing private properties from flooding with one or both of the proposed measures. For the Eindhoven case study the effect of risk reduction was defined as shown in equation 8.

$$\Delta r_k = r - \overline{r_k} = \Delta EAD_k = EAD - \overline{EAD}_k \qquad (8)$$

Here *k* stands for the risk reduction scenario to be compared. Deviating from equation 2 in chapter 2.4.2 the indices *i* and *j* are dropped since the case study just took one risk event and one consequence dimension into account.

3.3.1.4 CBA of risk reduction and climate change scenarios

To compare all three risk reduction alternatives, a CBA was conducted as outlined in chapter 3.2. As decision criterion the net-present value (NPV) was calculated for all alternatives. The NPV equals the difference between the present value of costs and the present value of benefits. For Eindhoven a time horizon of 50 years was used. Annual costs were summed over 50 years up to the present value of costs. Costs include the CAPEX and OPEX for each risk reduction alternative. The calculation for present values included inflation and discounting. The same was done for the benefits.

Additionally, the NPVs were not only calculated for the 'status quo' but also for two different situations with assumptions on future climate change. Since rainfall events were used as major input for the analysis, a change due to climate change assumptions in their frequency (here annual return periods of rainfall events) does also change results for the CBA and NPV calculations. Thus, the NPV for each risk reduction scenario was not only calculated once, but three times. As 'best case scenario' the NPV was calculated for the 'status quo' of rainfall event return periods. For the 'mid case scenario' the NPV was calculated for 'moderate climate change' assumptions on rainfall event return periods, and for the 'worst case scenario' calculations 'extreme climate change' assumptions on rainfall event return periods were incorporated. As a general rule, return periods were assumed to be lower in climate change scenario calculations, leading to increased damage frequency in the simulation.

3.3.1.5 *Results and conclusion*

The results of the CBA allowed comparing all three risk reduction scenarios by their NPVs (Figure 7). Considering only private properties and possible flood damage to them, all risk reduction measures are not 'no regret options'. This means they do not pay off in case of no change in rainfall events' severity due to climate change. In fact, results showed that all three risk reduction scenarios would pay off only in a situation with extreme climate change in Eindhoven.

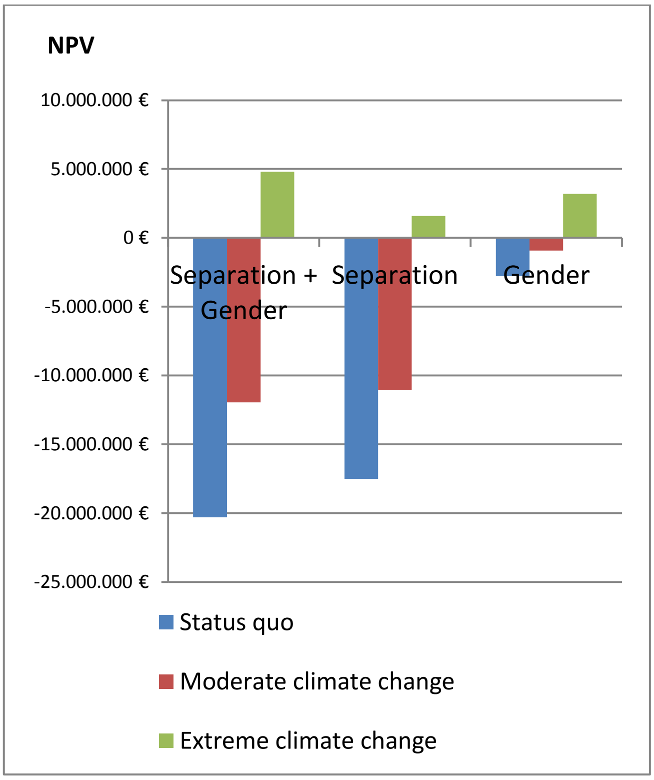


Figure 7 – Net-present value calculations for all risk reduction scenarios

Another conclusion drawn was that the measure of 'reopening the river Gender' was the better measure compared to the measure 'separation of sewer system' in terms of NPV. The separation of the sewer system did save more buildings from being flooded in the analysis and thus 'saved' more damage costs but did also cost much more than the Gender measure in the simulation. Thus, the net effect is better for the Gender only scenario, although in a situation assuming extreme climate change, the combination of both measures results in the highest NPV.

It should be noted, that this case study did only consider damage to private properties for a limited set of possible rainfall events in Eindhoven in the future. Taking other damage categories like interruption of traffic and business, damage to public and business properties, damage to cellars and so on into account, would change results. Also, the inclusion of more than three possible rainfall events would change results.

A more detailed description of the case study, especially on the CBA calculations and included (financial) variables, can be found in Strehl *et al*. (2013). Additional information for QRA and uncertainty analysis of the Eindhoven case can be found in Sušnik *et al.* (2013).

4 Final remarks on data for risk treatment

The identification of measures adequate to reduce risks and the estimation of the effects, positive and negative, of those measures for specific events can benefit from data collected and stored in an appropriate data structure. Often measures are already in place but estimation of the metrics of interest a posteriori is, frequently, not viable.

Therefore, it is recommended a proactive action from water utilities in adopting procedures that facilitate the gathering of data to support the analysis of viability and the comparison of alternative RRM. Furthermore, divulging of results allows other utilities to obtain valuable information.

Considering the RRDB data structure, five main groups of data can be of interest: economic, technologic, environmental and social acceptance.

For instance, the economic viability, data on capital and on operational expenditures, costs for implementation of specific actions (e.g. for education, information or training; operation and maintenance of measurement systems) and corresponding benefits (e.g. cost of water saved due to leakage control or reduction in consumption); cost of construction of new facilities (e.g. a new dam for flood control) are useful to support a first identification of measures and also to validate the qualitative assessment included in the catalogue of RRM included in the RRDB. For the remaining groups, similar considerations can be made, for instance the technologic limitations of a certain measure might not be evident a priori but practice can reveal limitations not previously foreseen. An example is the promotion of efficient appliances for households – experience in the USA has showed that without recognised certification of the devices the result can be reduced efficiency in water use, leading to increase in consumption and loss of willingness from the consumer to adhere to changes in their practice.

References

Almeida, M.C., Cardoso, M.A., Vieira P., Ugarelli, R., Leitão, J.P. (2013b). *State of the art water cycle risk identification database RIDB with focus on climate change*. Deliverable D2.2.5. PREPARED number 2013.026. PREPARED project. MS Excel Database.

Almeida, M.C., Strehl, C., Leitão, J.P. (2011a). *Risk reduction measures. Supporting document for RRDB structure*. Deliverable D 2.4.1. PREPARED Report number 2011.025. PREPARED project. 38 p.

Almeida, M.C., Ugarelli, R., Leitão, J.P., Vieira P. (2011b). *Risk identification database. Supporting document for RIDB definition of contents and data structure.* Accompanying document to deliverables D2.2.2 and D2.2.3. PREPARED Report number 2011.022/2011.023. PREPARED project. 35 p.

Almeida, M.C., Ugarelli, R., Vieira P., Cardoso, M.A. (2013a). *Guidance on RIDB hazard selection and use in the WCSP*. Deliverable D2.2.4. PREPARED Report number 2013.001. PREPARED project. 80 p.

Almeida, M.C., Vieira, P., Cardoso, M.A., Strehl, C., Mälzer, H.-J., Leitão, J.P. (2013c). *Catalogue of risk reduction measures (Risk Reduction Measures Database)*. Deliverable D 2.4.2. PREPARED Report number 2011.027. PREPARED project. MS Excel database.

Almeida, M.C., Vieira, P., Smeets, P. (2013d). *Water cycle safety plan framework. Final*. Deliverable D 2.1.4. PREPARED Report number 2013.025. PREPARED project. 102 p.

Halsnæs K, Shukla P, Ahuja D, Akumu G, Beale R, Edmonds J, Gollier C, Grübler A, Ha Duong M, Markandya A, McFarland M, Nikitina E, Sugiyama T, Villavicencio A, Zou J (2007). *Framing issues.* In: Climate Change 2007: Mitigation. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, IPCC (Ed.), Cambridge University Press, Cambridge, 118-167.

Lindhe A (2010). *Risk Assessment and Decision Support for Managing Drinking Water Systems.* Dissertation an der Chalmers University of Technology. Chalmers, Gothenburg, 121 p.

Pearce D, Atkinson G, Mourato S (2006): *Cost-Benefit Analysis and the Environment - Recent Developments*. OECD Publications, Paris, ISBN/ISSN 92-64-01004-1, 316 p.

Price R, Thornton S, Nelson S (2007): *The Social Cost of Carbon and the Shadow Price of Carbon.* Department for Environment, Food and Rural Affairs London, 23 p.

Rioned (2004): *Rioleringsberekeningen, hydraulisch functioneren.* Leidraad Riolering C2100. p.

Rohn A, Merkel W (2013): *Carbon Footprint von Wasserversorgungsunternehmen*. gwf-Wasser Abwasser, 2013(2), 2-9.

Sinden G (2009): *The contribution of PAS 2050 to the evolution of international greenhouse gas emission standards*. The International Journal of Life Cycle Assessment, 2009(14), 195-203.

Strehl, C., Mälzer, H.-J., Almeida, M.C., Vieira, P., Sušnik, J., Vamvakeridou-Lyroudia, Lydia S., Postmens, L. (2013). *Quantification of risk reduction measures: framework, methods and examples for quantification from the risk reduction measures database.* Acompanying report to Deliverable D 2.4.2. PREPARED Report number 2011.027. PREPARED project.

Susnik J, Strehl C, Postmes L, Butt T, Vamvakeridou-Lyrouda L S, van Swol F, Savic D A, Kapelan Z, Mälzer H-J (2013): *Methodology for the stochastic quantitative risk assessment models in PREPARED*. EU, 21 p

Tapsell, S.M., Pennig-Rowsell, E.C., Tunstall, S.M., Wilson, T.L. (2002). Vulnerability to flooding: health and social dimensions. *Phil. Trans. R. Soc. Lond. A* 2002 **360**, 1511-1525.

Tol, Richard S. J. (2008): *The Social Cost of Carbon: Trends, Outliers and Catastrophes*, in: Economics – The Open-Access, Open-Assessment E-Journal, Vol. 2, 2008-25,p. 1-10.

Ugarelli, R., Leitão, J.P., Almeida, M.C., Bruaset, S. (2011). *Overview of climate change effects which may impact the urban water cycle*. Deliverable D 2.2.1. PREPARED report number 2011.011. PREPARED project. 118 p.