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**A**daptive **D**ecision **S**upport **S**ystem (**ADSS**) for the Integration of Stormwater Source Control into
Sustainable Urban Water Management Strategies

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# Whitepaper on Risk Perception, Risk Assessment and Risk Management in the DayWater Context

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# 1 Introduction

## 1.1 Objectives

*DayWater* is a direct translation of a Swedish word that basically means *surface runoff*. DayWater is also the acronym of a European research project aimed at developing an “adaptive decision support system (an ADSS) for the integration of stormwater source control into sustainable water management strategies”. The DayWater project, which runs from December 2002 to November 2005, is organised in seven work packages focused at different aspects of stormwater source control. Work package 4 – Risk and Impact Assessment – deals with the potential negative effects of handling stormwater locally, i.e. it aims at developing principles, procedures and tools for managing risks that can be realistically foreseen when implementing stormwater source control on top of traditional, basic urban water management.

The first task (T4.1) of work package 4 is entitled “Inventory and Characterisation of Risks”. The purpose is to prepare a “white paper” that defines how the DayWater project group will work with the concept of risk in relation to stormwater source control. In particular, the objectives of the white paper are to:

- Explain what risk is/means and what terminology we use when discussing risk issues
- Outline the relationship between real, estimated and perceived risk and how this relates to decision making
- Devise a framework for how the DayWater ADDS can assist the stormwater professional in managing risks
- Conduct an inventory of risks, problems and barriers associated with storm water source control

## 1.2 Work approach

It has been realised from the early start of the DayWater project that experts with varying professional as well as cultural background conceive risks and risk management related to stormwater source control differently. Therefore, it was considered important that most partners of the project contribute to this task, which will form a common basis for a substantial amount of further work in the project. The following approach was followed to allow integration of various partner’s contributions and points of view’s:

- First, an outline of the structure and content of the deliverable report was drafted by DTU and submitted to all contributing partners. This outline and the suggested contributions from each partner was discussed at a work meeting in Riksgränsen/Sweden and approved after minor revisions in early April 2003.
- Contributing partners submitted their work during spring an early summer and in parallel, DTU circulated “appetizers” (PowerPoint outline presentations) on various aspects of the risk white paper to stimulate discussions. DTU and TAUW met in Deventer/Holland in late June to discuss how to devise a framework for managing risks in urban stormwater management (USWM) based on the submitted contributions and subsequently, DTU made all pattner’s contributions available through the project’s BSCW server and circulated comments to the individual contributions.
- During July and early August DTU, TAUW and ENPC collaborated on defining how risk perception, risk assessment and risk management can be handled in the DayWater project, observing that major risk-related uncertainties exist. An “appetizer” on these issues were prepared by TAUW/DTU and circulated in late July.

- A draft version of the white paper, reflecting the work done by the middle of August was handed out during a work meeting in Prague in August. Several aspects related to uncertainty in risk management were discussed at the meeting, and it was subsequently decides to revise the white paper to reflect these discussions.
- This report is the main deliverable (D4.1) from task 4.1. It is prepared by DTU and TAUW based on contributions from these two institutions but referring also to contributions from other partners who prepared input on various aspects related to risk in USWM: ENPC, MU, NTUA, IPS, and LTU. The individual contributions from partners are listed in appendix 1.

## 1.3 Structure and content of the report

The report is organised in chapters aimed at elaborating the objectives outlined above.

Chapter 2 explains the basic scientific definition of risk, outlines the terminology chosen to describe the different aspects of risk and discusses how indicators of risk are sometimes used to simplify risks assessments and improve the communication of risk issues.

Chapter 3 explores the “space” made up of three important terms: actual risks, perceived risks and uncertainty – and discusses how these terms are related to risk management and decision-making.

Consequently, chapter 4 explains how the water professional dealing with stormwater source control can break the risk management task down into i) dealing with the perception of risks, ii) assessing the actual magnitude of risks (when needed), and iii) coping with uncertainty by either reducing uncertainty or initiating transition processes. Ways to simplify comprehensive risk assessments into analysing either hazards associated with the sources of risks or vulnerability of objects exposed to risks are discussed.

Chapter 5 reports on an inventory of risks related to stormwater source control based on questionnaire information from the end-users associated with the DayWater project. The inventory furthermore discusses regional risk aspects based on information from the partners of the DayWater project.

Finally, chapter 6 summarises the content of the report, and briefly outlines the way ahead for T4.2 and discusses possible integration issues with other work packages of the DayWater project.

## 2 What is risk ?

This chapter explains the basic scientific definition of risk, outlines the terminology chosen to describe the different aspects of risk and discusses how indicators of risk are sometimes used to simplify risks assessments and improve the communication of risk issues.

### 2.1 Basic scientific definition of risk

Many different definitions on risk can be found in the scientific literature. The most commonly used definition is:

$$\textbf{Risk = Probability * effect} \tag{2.1}$$

This means that risk is defined as the product of the probability of a certain unwanted event occurring and the effect of this unwanted effect occurring. Very often the word consequence is used synonymous for effect.

The effect is described by a description of 1) the objects exposed to the risk, 2) the severity of the effect and 3) the extent of the effect. Furthermore, an important element of risk assessment is a careful description of the actual situation that is being analysed; this includes specifying the circumstances including time, space, frequency, duration, exposure, etc.

The risk of fire in a single-family house can be used as an example to illustrate the basic terms:

- *Extent*: The part of the house that is affected by the fire, or the number of individuals affected by the fire.
- *Severity*: Does the affected part of the house burn completely down or does the smoke only damage it? Do the affected persons die, do they get burnt and how severely are they burnt: third, second or first degree, are they poisoned by the smoke or are they affected in any other way?
- *Probability*: The probability that the above effects (including their extent and severity) occur.
- *Analysis description*: This will include as much information as possible about the situation, e.g. what type of house (hard roof or thatched, number, type and age of electrical installations etc), and what inhabitants (how many, how many of those are smokers)?.

The product concept in eq. (2.1) can be understood within pure mathematical framework. Whenever the effect can be homogenously expressed (e.g. in unambiguous monetary terms), the expression in eq (2.1) yields the exact expectancy of the effect considered as a random variable. This can be utilised when comparing very different risks where both the objects of risks and the extent/severity of effects are different, and it may even open up for integrating the risk analysis with conventional cost-benefit analyses. Attempts have been made to work out such concepts for problems in urban water management (see e.g. Hauger et al., 2002), but it is a rather circumstantial and thus costly exercise and the validity of the analysis is difficult to communicate because the methodology may seem as a black-box concept to the decision makers.

Although such an interpretation sounds highly rational, risk will not be reduced to such a formula in the DayWater project, because the formula cannot be practically used in most situations. The beauty of mathematics has to face the imperfection of nature and society and risk assessment must cope with lots of uncertainties and imperfections. As will be shown in chapter 2.3, various and changing perceptions by different actors, of changing or undefined acceptability's (costs) for very rare and highly costly events, and high uncertainty of the probability distributions of effect (which generally result from many factors each of them with its own poorly known probability) make the formula unpractical.

Accordingly, we shall understand the concept of risk in a less formal manner than the product concept in eq. (2.1). Among many other definitions of risk we would like to mention one particular definition which is based on Hazard and Vulnerability concepts, both incorporated into French legislation into French legislation (Chabert, 2003):

$$\textbf{Risk = f (Hazard, Vulnerability)} \qquad (2.2)$$

This definition is fundamentally different from the first definition. Equation (2.2) basically means that both hazard and vulnerability must be studied for a comprehensive risk assessment. The relationship between hazard and vulnerability and their relation to risk assessment will be discussed in more detail later in chapter 4.1.

## 2.2 Most important terminology

One of the major problems that arise when the urban wastewater system is dealt with as an entity is that different types of risk have different methodologies and different terminology although the character of the problem can be quite similar. In the following section the most commonly used terminology within the different risk areas is presented. Some of the terms used in this report have many definitions dependent on the country and source of literature, but a common set of definitions can be very helpful while reading the report as well as in the further work with risk in DayWater across the traditional barriers between the different types of risk.

**Table 1. Risk related terms as defined by Christensen et al. (2002).**

| Term | Definition |
|---|---|
| Hazard | The inherent property of a risk source potentially causing consequences.<br>Note: Be aware that Hazard does not include the probability of an adverse outcome, which makes it fundamentally different from the term risk. |
| Uncertainty | Imperfect knowledge about the individual aspects of a system as well as the overall inaccuracy of the output determined by the system.<br>Note: Uncertainty can be divided into 1) model structure uncertainty, 2) data/parameter uncertainty, 3) inherent variability and 4) outcome uncertainty. |
| Probability | Two definitions are mentioned, 1) probability is an expected frequency and 2) probability is the expected fraction of a specific outcome in a population. |
| Frequency | An expression for the number of outcomes per time unit. |
| Risk Object | The exposed humans, environments and/or physical objects. |
| Risk Source | Activity, condition, energy or agent potentially causing unwanted consequences or effects. |
| Exposure | The extent to which an agent or energy reaches an object. |
| Effect / consequence / impact / damage | Results of a realized hazard that may be caused by exposure to an agent or energy. |
| Event | Isolated incident or a number of interrelated circumstances or incidents resulting in release of agents and/or energy. Events are typically acute or short-term whereas the exposure and the consequences may be acute or long term. |

The risk-related terminology used in DayWater is inspired by the work done by Christensen et. al. (2002) who base their definitions (Table 1) on a number of core references within risk literature. Common for these core references is that they all represent a professional area or an organisation and that they have all been dealing with the topic of defining basic terms within risk terminology. In addition to documents from the Danish Standard Organisation, the Seveso Directive I and 2 and ISO guidelines, the following references are mentioned:

- EU (2000): First report on the harmonisation of Risk Assessment Procedures. This report that can be downloaded from the Internet is the fist attempt from the EU to harmonize risk methodology in the European Union.
- UN/OECD (1999): Risk Assessment Terminology. Methodological considerations and provisional results. Report from a WHO experiment. This article is result of an interdisciplinary program between several organisations: UNEP, ILO, FAO, WHO, UNIDO, UNITAR and OECD. The article is considered the latest common terminology proposal from the involved UN–organisations.
- US-EPA (1997): Risk assessment and risk management in regulatory decision making. A report prepared for the Congress by the Commission on Risk Assessment and Risk Management.

A few additional definitions used in the report are shown in Table 2.

**Table 2. Other risk related terms used in the report.**

| Term | Definition |
|---|---|
| Perceived risk | People's perception of risk may differ substantially from the actual risk, which again may only be characterised with substantial uncertainty. |
| Load | The exposure that the pressuring part of a system puts on the receiving part of a system. |
| Carrying capacity | Capacity to absorb a given load without significant negative effects occurring, including long term effects. |
| Vulnerability | Inherent properties of a risk object that makes it sensitive to defined hazards. |
| Risk Indicator | A variable used to characterise a risk indirectly by either focusing on hazard or vulnerability. |

## 2.3 Indicators of risk

The intangible nature of risk can be handled by introducing indicators of risk instead of working directly with the fundamental definition. Indicators are used in a lot of risk analysis problems; in fact the majority of all risk analyses apply some form of indicators. The effects of introducing an indicator is of course that the analysis is easier to conduct, but the result is also a lot easier to communicate to a wider audience of interested actors. A few examples of indicators used in different areas of risk analysis are given in Table 3 below. These examples illustrate how different "schools of thought" make use of indicators crystallized from the original definition of risk (equation. 2.1).

Indicators are also used when society puts up limitations to the extent of risk it is willing to accept. The acceptable risk in a given situation is rarely formulated using the fundamental definition but using an indicator of the risk such as the number of traffic casualties instead of the societal cost or the water level instead of the economic loss associated with a flooding. The analysis carried out in practical risk management is then often a comparison of two values of an indicator: the load and the (politically defined) acceptable load.

The load is a calculated value defined as the exposure from the pressuring part of the considered system (under consideration of intensity, duration, frequency, accumulation over time and uncertainty). The acceptable load is defined as the amount of loading that we are willing to accept. The level of the acceptable load relies on a political decision, but in the process of making that decision the decision maker often looks at the receiving part of the system's carrying capacity. The carrying capacity is the capability to absorb a given load without significant negative effects occurring. Theoretically, the decision can be based on that the acceptance level should be below the carrying capacity, meaning that no detrimental effects or damage is accepted. But it must be realised that damage cannot realistically be avoided entirely i) the known types of damages cannot be avoided totally and ii) In the future damages that are not known today might be discovered. Then the politically defined acceptance level will be based on simplified options, and can be higher than the carrying capacity. The later is the case in the example in Table 3 with oxygen depletion, where dissolved oxygen concentration is used as indicator.

**Table 3. Examples of the use of indicators in risk analysis within four different risk areas. For each risk area the primary effect involved is indicated and the role of probability (P), frequency (F) or return period (T), and uncertainty (U) are briefly outlined. Furthermore, the used risk indicator is indicated followed by a short explanation of how it is analysed in practice.**

| Risk area | Primary effect | P, F/T, U | Indicator of risk | Practical analysis |
|---|---|---|---|---|
| Sewer flooding | Economic or socio-economic effects in urban area | P used to express F or T in design<br>Other types of U rarely included | T for defined water level (WL) or vice versa | $WL_T \leq WL_{accept,T}$ |
| Chemical pollution | Environmental effects | P chosen small and build into the estimation of PNEC*.<br>U accounted for by adding safety factor | PEC**/PNEC ratio | PEC/PNEC ≤ 1 |
| Oxygen depletion | Fish death | P used to express F or T<br>Other types of U rarely included | Concentration of dissolved oxygen (DO), sometimes as function of T | $DO_T \geq DO_{accept,T}$ |
| Microbiology | Casualties, illness<br>Simplifies to number of infected persons | P is predefined and build into acceptance level | Dose of organisms that the object is exposed to, or<br>Number of infections in a population | Calculated dose ≤ accepted dose<br>Number of infected ≤ accepted number |

* PNEC: Predicted No-Effect Concentration, ** PEC: Predicted Environmental Concentration.

The examples shown in Table 3 come from quite different fields of risk analysis. The common feature in all four examples is that the fundamental definition of risk (eq. 2.1) is forced into the background by a more clearly understandable indicator. The indicator is then again used in the final risk analysis where a calculated value of an indicator in all four examples is compared to an accepted level of that indicator. A common feature for all four examples is that simplifications are introduced with the introduction of risk indicators, but at the same time there is also a shift in the focus of the analysis.

Looking at the fist example (sewer flooding, the first row in the table) what is really of interest is what the consequences are in terms of damaged infrastructure, ruined household contents, loss due to power failure, loss due to traffic not working, lost earnings during and after the flooding, etc. - and of course what the probability of experiencing these effects is. Eq. (2.1) can be used to estimate the expected consequences directly but such calculations are complex and uncertain so simplifications are made. It is instead chosen to focus on the water level instead of the socio-economic costs, which makes the analysis much simpler and more tangible. If the water level is chosen with some elegance a lot of information can be obtained about damage without actually estimating the damage directly. If for instance the critical water level is chosen to be at the top of the sewer pipes, it is known that damage is close to zero as long as the water stays below that level and that damage increases dramatically the moment the water rises above street level. Water level as indicator has the advantage that is easy to work with, models are available and results can be produced fast. Since the real object of interest is the cost of damage associated with a given water level, ideally the indicator should be cost. The only institution that has real information about what the cost is when flooding occurs is insurance companies and up till recently the have not been willingly to let others get access to their data. This encapsulates the whole purpose of indicators, that due to varies obstacles either with respect to data access, communication or other problems an perhaps not ideal but easier understandable and an indicator that is easier to handle is chosen

Furthermore, in the sewer flooding example probability is entirely focused on expressing the return period, or frequency, of event where water levels exceed the defined critical level. The risk indicator thus simplifies to the return period for exceeding a given water level, or to the water level obtained for a given return period. Using indicators of flooding expressed in this way makes it easier to communicate with the public, since most people can relate to such indicators. However, the backside is that the public and media tend to get confused when a water level estimated to be exceeded with a return period of 10 years is suddenly observed twice during the same summer, as it will occasionally. Return period expresses the average time between events above a certain magnitude, but the period between occurrences of such events may actually vary due to the inherent variation of the rainfall phenomenon, which media tend to forget or misunderstand. An other confusing element with respect to communication and public perception is that different properties of an event can have different return periods. A 10-year return period event regarding maximum intensity may be only a 1-year return period event regarding total volume for example. With respect to the communication with the public it is there for extremely important to specify which property the return period is associated with and not to focus on to many different properties.

The three terms probability, frequency/return period and uncertainty are clearly interconnected in a complicated way. This problem will be discussed further in chapter 3.2 on a theoretical level and in 4.3 in a more practical way.

## 2.4 What kind of risks?

In order to find out what types of risk are of concern two groups have been asked about their view on risk. The first group is group of core end users that is part of Daywater, the second group is a number of the experts working on Daywater. The answers was investigated for places were risks, barriers or problems in relation to storm water runoff was mentioned. The way the questionnaires and interviews were done is explained in detail in Appendix 1, where also the details of the results can be found.

Data were received from 14 core end users and three expert teams. The data was organised in a risk matrix were a distinction was made between seven different physical objects were risk could be located and seven different types of risk. The seven objects are: BMP’s, Pipe system, Basisns and overflows, Build environment, Natural environment and drinking water resource. The seven types of risk are: Chemical, Hydraulic/volume, Technical, Microbiology, Organisation, Economy, User perception/attitude. (For more details se Appendix 1).

Some highlights of the results from the end users are:

- 28% of the hits in matrix addresses “BMP’s”, All types of risk are mentioned but “organisation” and “users perception/attitude” are the most frequent types
- 28% of the hits address “the natural environment”, here it is especially the types “chemical” and “hydraulic/volume” that are pointed out.
- “chemical” and “hydraulic/volume” are the most mentioned types, together accounting for 44% of the hits. Within these two types it is especially “the natural environment” that is of concern to the end users.
- All types of risk have at least 5% of the hits. “Microbiology” and “Economy” is the types least frequently mentioned.

From the expert teams is worth noticing

- The experts focus on “hydraulic” and “technical” types of risk as the most important
- The only type that is mentioned significantly less than the others are “economy”, only one expert mention economy once.
- The most mentioned object is “natural environment” followed by “BMP’s”, “Basins and overflows” and “build environment”

Comparing the results there is a reasonable but not complete match between the results. Of the 12 cells in the matrix that the end users found most important, nine was also mentioned by at least two experts. On the other hand 12 cells that was not pointed out as important by the end users are also mentioned by at least two experts.

# 3 Exploring the risk space

Perception of risk is one of the basic dimensions of risk analysis since people's attitude in front of risk is evidently driven by their perceptions. The objective material on which the public can make his opinion is scarce and other items than reason more strongly come into play, and opinions become more versatile. Adding this new dimension introduces the concept of the risk space. The risk space is the space that is expanded by (actual) risks, perceived risks and uncertainty. This chapter explores this space by introducing a number of concepts that are essential in risk analysis and risk perception, before they are dealt with in depth in the next chapter.

Throughout the discussion of risk perception in section 3.1 below it is assumed that the risk – or the actual risk – is known to the water professional dealing with risk issues. This is not true; in reality we can only estimate the magnitude of the actual risk based on whatever information available. Risk assessment is a large field that sometimes make use of elaborate estimation methodologies based on monitoring data and simulation models. However, it is important to realise that estimates of risk are uncertain no matter how much effort is put into the analysis. In the same manner the risk perceived by a stakeholder involved in water management can only be judged with considerable uncertainty. Estimating the magnitude of the actual risk is a task that will be perused in more detail in a lot of the other activities that are a part of the Daywater project.

## 3.1 Risk Perception in USWM

### 3.1.1 The Public

Those exposed to risks can either be individuals or -usually in USWM-a group of individuals sharing a risk together. But in both cases each individual has unique characteristics resulting in unique behaviour towards any specific risk. Building a sociology regarding the perception of risk is a large and complicated task, it is not within the limits of this task to go into detail with that in stead we mention some of the factors that in combination forms the behaviour:

- Temperament
- Personal Values
- Social / Cultural Background
- Gender
- Decision Making Ability
- Education

Judgments the public make of risks can therefore differ infinitely between persons. But even the same person can have completely view of the same risk from one day to another. This is important to keep in mind at all times when communicating with the public and groups of individuals in the public.

### 3.1.2 Risk Identification

A person identifies something as a risk whenever it seems that a certain activity could have a negative impact on the personal health, the quality of life (including economy) or the quality of the personal environment or that of people considered to be in the circle of acquaintances.

However in USWM, activities are often unknown to the public and as a consequence their perceived risks do not yet 'exist'. Information provided by an authority or a contractor before and during the execution of a project can reveal a risk to the public. In other cases media discover a 'hidden' risk and provide the public with the information 'they deserve'. Sometimes this role is also played by neighbours or friends who inform and look for allies in a situation they already identified as potentially dangerous or otherwise carrying risk.

Risks can be very different in the way they are experienced by an individual or a group. Those characteristics of risks (see below) can have a huge impact on the way people feel about a certain activity and its possible influence on their lives. The shape in which a risk is experienced by the public depends mainly on the following (se also 3.1.4 about risk assaptance):

- Is it an individual risk or are more people (aware of one another's existence) undergoing the same risk?
- Is it a known risk, does the public have any past experience with this particular risk (including its consequences) or is it a risk unknown to the public, brought about by -for example- the media? For some fear of the unknown is worse than a known risk because some tend to overestimate risk they do not know the details of.
- Is it a voluntary risk an individual or a group takes or are they undergoing a certain risk implied by an activity they did not ask for and would definitely have avoided if they had had the choice?

### 3.1.3 Public Perception of Risk

***Factors influencing Risk Perception***

Which implicit information does the public have that could be of vital importance for a decision maker? And how can they access this important source of information when facing a more complex problem? It requires developing a genuine interest in the people affected by a certain activity or intervention with all its possible risks (however 'scientifically' small). Meanwhile bearing in mind the factors that largely determine how individuals perceive a certain risk by the public. which are:

- Lack of Knowledge
- Emotions such as: fear or suspicion
- Communication: for instance media attention
- Recent History
- The Possibility to Choose whether or not to be exposed to a certain risk and / or to control its consequences

***Emotionality vs. Rationality***

When making judgments of situations or activity in daily life an infinite range of approaches is possible, of which all exist between two extremes. There is absolute rationality, which is a theoretical approach based exclusively on scientific research and statistics that involve no emotions. On the other extreme is 'social rationality' or emotionality, which is only based on feelings and intuition without hardly any factual knowledge considered at all. Both types are quite idealistically and extreme represented here and neither of the two is very realistic compared to persons that can be found among living people in a case study, but they illustrate somehow the gap between experts and the public, and accordingly it is not hard to imagine how often both parties fail to communicate satisfactorily, let alone successfully.

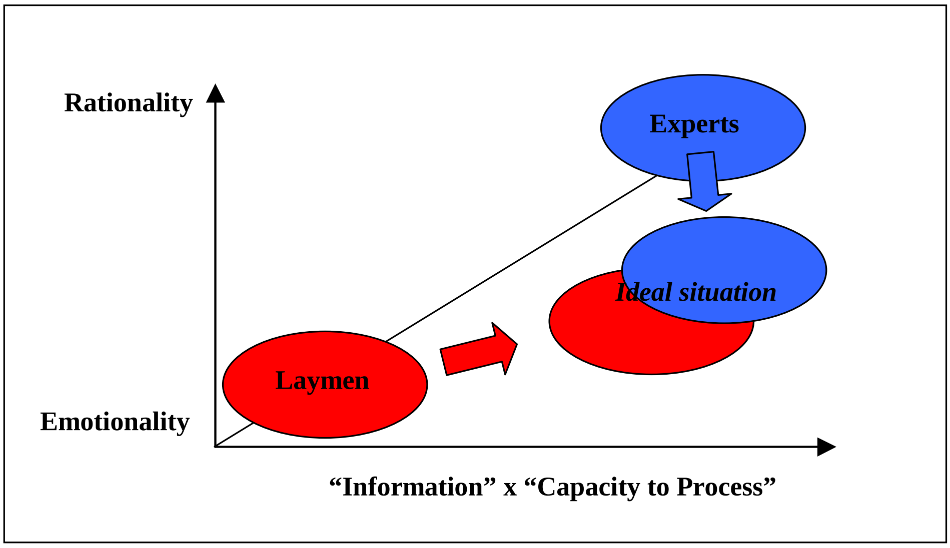


**Figure 1** ***Emotionality vs. Rationality***

It already became clear that public judgement of risks is not always straightforward and fixed, because the public usually depends on fewer and other sources of information than experts, and also because the public may be personally exposed to risk. Since the experts in general and in USWM in particular need the public to secure a successful execution of a project, it is in their interest to facilitate the right amount of factual information they have and to gather the implicit information that exists in the public - in order to make both parties approach one another on the 'rationality scale' towards the 'ideal situation'.

Figure 1 shows the position of both laymen and experts when considering risks. The above described distinction between rationality and emotionality can be found on the Y-axis. The X-axis represents a factor that can be attributed to either group, where a low value represents little information combined with little capacity to process and understand this information. A high value logically applies to the group 'experts', because they usually have access to more information sources and more means to interpret this often complex information.

### *Perception of Risk*

The way a person forms his or her opinion about the size of a risk and its possible consequences depends on two major inputs: the direct experience of the person involved and the words and deeds of influential others. These are persons in the near surroundings who's deeds, norms, values and words the person pays attention to and give weight. The perception of risk by a layperson is formed by those two quite 'personal' sources of information. On top of that a person can have acquired a certain amount of 'factual' information through media such as TV, Internet or newspapers.

And all this time the individual analyses the information he or she has about the potential hazard or danger. Parallel to that, he or she intuitively makes a judgment of the probability of occurrence and the severity or extent of the associated consequences. But yet without taking into account any possible benefits, these are only taken into account after the first evaluation of risk and consequences.

As a result of the above mentioned factors, persons can form very different opinions on the size of a risk they are running, based on different ideas of possible consequences and chances of occurrence (see below, Figure 2).

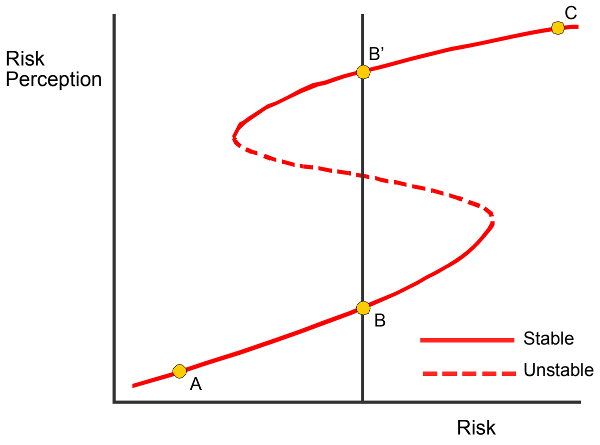


**Figure 2: Relation between risk perception and risk**

What can be read from Figure 2 is that the relation between actual and perceived risk - in contradiction with what is often assumed - is far from linear. Though in reality it turns out that at very high or very low risks (point A and C on the curve), the public perception (based on 'emotionality') is more in correspondence with the real estimated risk (based on expert's investigation and research) than at moderate risks (point B and B' on the curve), where individuals can have very different perceptions of the same risk.

However there still remains a large range of risks, for which the related perception shows a random character (the unstable zone, symbolised with a dashed line in Figure 2). Furthermore there is another phenomenon which is best described as ambivalence towards risks.

An individual could for instance be part of a 'bungee-jump' society, (he would be located on point B on the curve) in which anything has to be possible (in those societies authorities are often held responsible for any negative consequences of 'bungee-jump' behaviour) These types of societies underestimates risk, because individuals have the opinion that ' somebody else covers for me when it goes wrong –what ever happens'. Whereas in case B' risks are overestimated, resulting in excessive concern and rejection of some activities. The latter we refer to as the reflexive society. And there are again a number of perceptions are possible to fall into the unstable zone.

### *From Disharmony to Harmony*

An authority is better capable of approaching the public in a constructive way when it knows which problems and fears exist and when the behaviour of the public is consistent and more or less predictable. A situation where various inconsistent and fluctuating behaviours are determined is described as a situation of disharmony. And in order to be able to work together with the public it is therefore desirable to somehow make the transition to a more harmonious situation. This harmony should be seen as people being quite sure about their perception of a hazardous or dangerous activity, where the perception will be more or less consistent with the actual risk (a linear correlation). Instead of having to deal with sentiments, that vary from person to person and from day to day.

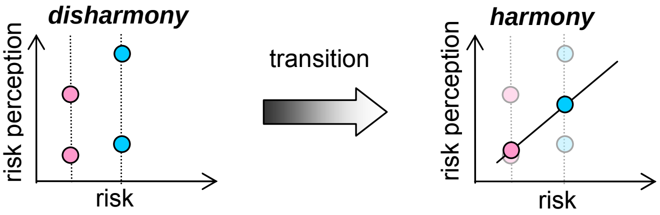


**Figure 3: Transition to achieve harmony**

Often authorities try to change people's perception of risk by providing more information about it. In doing that they underestimate the other factors influencing risk perception, which are: emotions (fear or suspicion), communication, recent history and the possibility to choose (see 3.1.3 Public Perception of Risk). In paragraph 4.2 will be described how to bring a better approach of the public into practice, by understanding that other factors than just the lack of information make up the way people perceive risks.

### 3.1.4 Public Acceptance of Risk

Once a person has formed an idea of an actual risk and its possible consequences, the next step is the subjective process in which a person considers potential benefits of the same activity or resulting activities and of the final situation obtained. And it turns out to be ascertaining for the eventual behaviour of a person towards authorities, to which extent he or she experiences benefits from their decisions.

As an example to illustrate the difference between risk perception and risk acceptance, we think of for instance mountain climbing. Both experienced climbers as well as laypersons are very much aware of the dangers involved in climbing at high altitude, especially because the yearly numbers of deaths and casualties are known to most people and easy to understand, regardless education or intelligence. Nevertheless thousands of climbers choose to run the risks of mountain climbing every year because the benefits they have from their activity apparently surpass these risks. One could even claim that to some people the risks involved in an activity add to the excitement experienced by it. The same applies to, for example skiing, deep-sea diving and paragliding, but also non-leisure activities can be brought up as examples.

People living on volcanoes, in river deltas or on polluted soils, often have good reasons to live exactly there, because they experience a great benefit from their living on that specific location. These benefits are mostly economic, but also other issues such as a great view or lots of space can be reasons to accept a high risk when choosing a place to live.

Two persons can agree on an actual risk and its consequences, but at the same time disagree on the extent to which that particular risk is acceptable. And that is where there lies another interesting aspect, which can be useful for authorities to keep in mind when dealing with the public in case of activities involving risk.

## 3.2 Uncertainty

Digging deeper into the subject of uncertainty reveals a need to clarify both the types of uncertainty, the sources of uncertainty and how these can be dealt with. Walker et al. (2002) describes a comprehensive framework of how to do define uncertainty in model based decision support. This framework is adapted to fit the urban stormwater source control system in a more general way than just focusing on modelling as Walker et al do, by the authors of this report. For further explanation of the terminology used in the following see Walker et al. (2002).

The whole definition of uncertainty is based on three key words, or dimensions:

- Location of uncertainty
- Level of uncertainty
- Nature of uncertainty

### 3.2.1 Location of uncertainty

Location of uncertainty identifies where in the urban stormwater system the uncertainty is located or manifested. We see a logical division of the urban stormwater system into three sub-systems as it can be seen on Figure 4: the social, the technical and the environmental sub-system (Mikkelsen et al., 2001).

- **Social system**. Covers all actors (individuals or institutions), the behaviour and interaction between them, the social processes going on between the end-users when they are influenced by stimuli from each other and from the outside.
- **The technical system**. Covers the hardware of the system, the pipes, the ponds, the treatment facilities etc. But also processes occurring inside these technical elements are part of the technical system
- **Environmental system**. Covers the surrounding environment, especially the recipients, the soil, the atmosphere and the natural processes such as meteorological and aquatic processes taking place the above-mentioned locations.

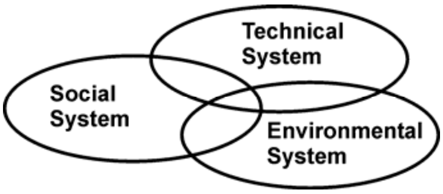


**Figure 4 Three subsystems of the urban stormwater source control system**

These three systems are, as it will be explained later quite different with respect to both the level and the nature of uncertainty. In particular there is a difference between the technical and natural system on the one hand and the social system on the other hand; a difference also apparent from the fact that the first template of the structure of the DayWater ADDS makes a clear distinction between the “system” consisting of the technical and natural sub-systems in Figure 4 and the “context”, which is similar to the social sub-system in Figure 4 (see Tauw 2003 B).

### 3.2.2 Level of uncertainty

The level of uncertainty deals with the fact that some things are very well known, some things are totally unknown and the vast majority is something in-between. To distinguish the levels of uncertainty in-between the well known and unknown the scale in Figure 5 is proposed by Walker et al. (2002). Below, we present a very short description of the terminology involved.

- **Determinism**. The left extreme of the axis. The ideal situation where everything is known accurately. This is however only obtainable in theory
- **Statistical uncertainty**. Uncertainty that can be described adequately in statistical terms. The most obviously example is the measurement uncertainty, stemming from the fact that a measurement is never perfectly true to the item measured. Statistical uncertainty has traditionally in the natural science been referred to as “uncertainty”. Statistical uncertainty assumes the functional relationships of the phenomena studied to be reasonably well understood, and/or that vast amounts of data are available.
- **Scenario uncertainty**. Scenario uncertainty is represents uncertainty at a level beyond statistical uncertainty. Scenario uncertainty means that a range of possible outcomes (scenarios) con be postulated or predicted, but the functional relationships of the processes in the studied system are not well understood and therefore it is not possible to formulate the statistical probability of any specific outcome. Scenarios do not forecast the future, they indicate what might happen, a scenario is a possible future. Dependent on the level of available information scenarios can be anything from very wake to very detailed in the way they are formulated, but in the process of formulating scenarios one has to considerer a lot of details in order to create an overview over what might happen.
- **Recognised ignorance**. This is fundamental uncertainty about the functional relationships being studied. Neither functional relationships nor statistical properties is known, even the basis for choosing scenarios is week. Uncertainty stemming from ignorance can further be divided into reducible and irreducible ignorance but this will not be further discussed here.
- **Indeterminacy**. The other extreme on the scale, beyond that there is only:
- **Total ignorance**. This is the deepest level of uncertainty, which implies uncertainty to the extent where it is not even known what is unknown.

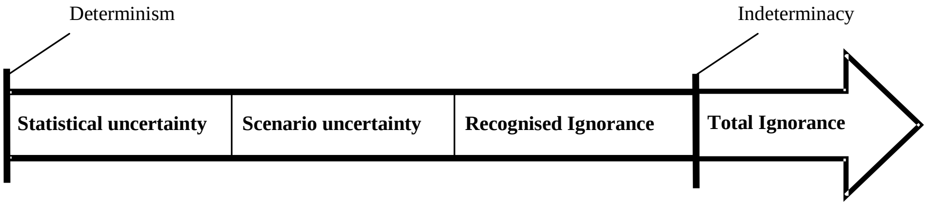


**Figure 5** ***Transition between different levels of uncertainty. From walker et al. (2002).***

### 3.2.3 Nature of uncertainty

Last of the three dimensions is the nature of uncertainty. Here we simply distinguish between:

- **Reducible uncertainty**. Uncertainty that is due to imperfections in our knowledge.
- **Irreducible uncertainty**. Inherent variability of the phenomena described.

The description of the nature of uncertainty is a subject that has been addressed in literature under many different terms. As already mentioned reducible uncertainty is characterised by lack (imperfections) of knowledge, and based on this reducible uncertainty is also referred to as epistemic uncertainty, a term taken from the philosophical terminology. Since reducible uncertainty is due to some sort of imperfections in the knowledge, the way ahead to reduce this type of uncertainty is to increase the level of knowledge - for instance by gathering more data. Irreducible uncertainty is sometimes referred to as ontological uncertainty, based on philosophical terminology or aleatoric uncertainty, which stems from natural science. Irreducible uncertainty has two fundamentally different elements. Inherent irreducible, which is stochastic variablity in natural phenomena and practical irreducible, which is phenomena that are chosen to be treated as stochastic because no methods are currently available to reveal the cause effect relationship or that the cause effect relation ship is so complicated that it for reason of simplicity is chosen to treat it as a stochastic process

Rainfall can be used as an example to distinguish between reducible and irreducible uncertainty. Most people watching daily television weather reports will agree that it is difficult to say exactly how much it will rain the next day let alone the next hour or minute. The ability to issue weather forecasts has however improved considerably over the past decades due to better and more monitoring data, more sophisticated simulation models and larger computers. Thus, although weather reports are still uncertain, the uncertainty has been reduced over the past decades. On the other hand, rainfall is an inherently variable phenomenon. Assuming a stationary rainfall process, the inherent variability cannot be reduced no matter how much data is recorded. At maximum we can hope to describe the statistical distribution of rainfall more accurately.

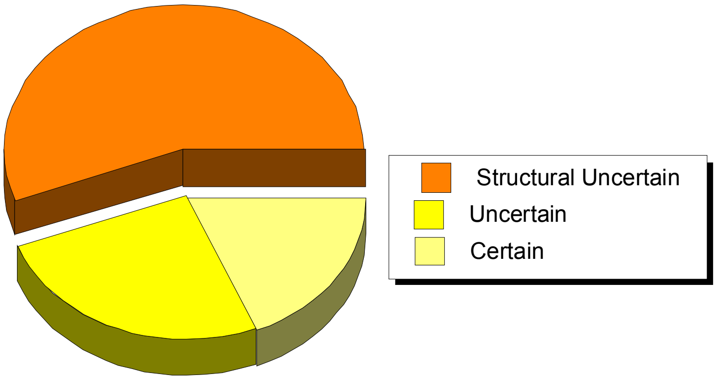


**Figure 6 Three degrees of uncertainty in cause and effect relationships**.

A similar distinction is made by Walker (2000) and Geldof (2003), however using a different terminology. They talk about structural uncertainty (se Figure 6) when it is impossible to reduce the uncertainty. For example, it is very hard to predict how people will react to an integrated water plan, as it is difficult to model public and political support. On top of that, social systems often show a deterministic chaos. As a result it is impossible to predict long-term future behaviour, even if we have a perfect model. Other processes are easier to predict. For example, when we double the pump capacity of a pond system it is easy to predict the effects on surface water level variation; there are no significant uncertainties in comparison with the above. However, when we increase the storage capacity within a sewer system it is difficult to predict the effects on the pollution load of the surface water. We know that the larger the storage the smaller the pollution load. But, predictions of the effects are often inadequate – only more research and application of better models can reduce these non-structural uncertainties.

Even though we introduced this alternative terminology illustrated in Figure 6 the rest of the report we use the terminology illustrated in the previous section and illustrated in Figure 5.

# 4 Risk management in the DayWater context

## 4.1 Assessing the actual magnitude of the risk

### 4.1.1 A unified framework for risk assessment in the Daywater context

In the process of starting a risk assessment the fist thing to consider is if it is necessary at all to start the comprehensive and time-consuming task that a complete risk assessment in fact may be. Thus, for preliminary analysis of potential risks, it may be wise to start by focusing on the hazards related to risk sources or the vulnerability related to risk objects.

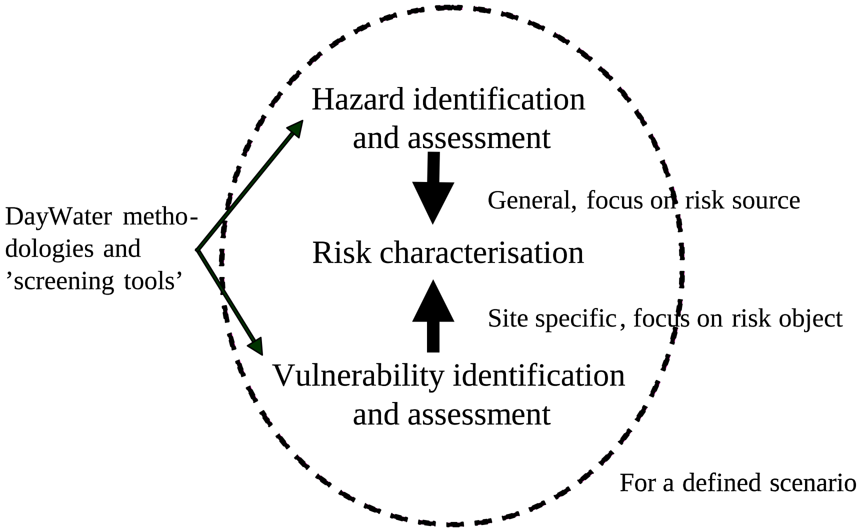


**Figure 7. Relationship between hazard identification/assessment, risk characterization and vulnerability identification/assessment as defined in the DayWater project.**

Figure 7 shows a simple sketch of how the risk assessment terminology in DayWater is defined. Hazard identification or assessment, vulnerability identification or assessment, and risk characterization are related methodologies that make up a whole. Hazard or vulnerability identifications are initial steps prior to a more detailed assessment of hazards and vulnerabilities, and both may be followed risk characterization depending on the risk in question and if judged necessary.

Identification and assessment of hazards is used for answering questions focused at the risk source such as: Are earthquakes or flooding known regularly to affect the area where I intend to build my house? Will copper from copper roofs be a problem when washed out with stormwater? Vulnerability identification is conversely used for answering questions focused at the risk object, which may e.g. be a site/location or a person: Will the newly built house be damaged if there is a flooding, does it for example have stone or wooden floors? Is the ecosystem of the local stream likely to be affected by urban drainage discharges?

Since the same hazard will not produce the same effect on all systems, vulnerability is introduced as a system dependant property to be the link between the hazard and the effect;

the combination of the occurrence of a hazard and of the vulnerability of the system results in the effect. But making a clear distinction between hazard and vulnerability is not always easy.

As a rough, general rule we can define hazard as being external to the system and is applied to it and vulnerability as being inside the system. This means that all types of damage lowering measures that have character of a barrier between the outside and inside of the system, such as building dikes and treatment plants are measures directed towards hazards. Accordingly, measures pointing directly at a risk object, such as securing buildings against earthquake, using stone floors to prevent flood damage or retrofitting rivers receiving urban drainage discharges can be classified as measures aiming at lowering the vulnerability of an object.

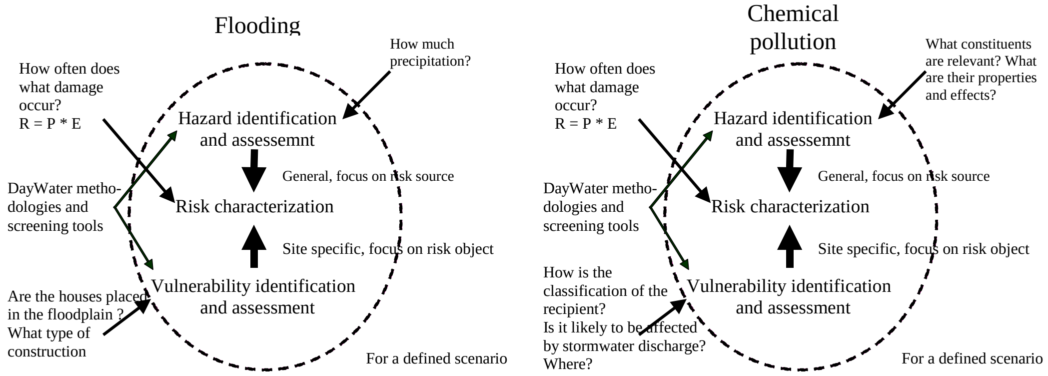


**Figure 8. Two exemplifications of Figure 7: flooding and chemical pollution. The needed tool depends on the question asked and the problem analysed.**

Figure 8 shows two examples where Figure 7 has been elaborated for risks relevant to the DayWater project: Flooding of urban areas and pollution with chemical substances.

In hazard identification and assessment focus is on the risk source. For flooding the risk source is precipitation and thus, hazard identification can be skipped leading directly to hazard assessment, which is concerned with analysing the question: how much precipitation falls within or upstream from the catchment in question? Vulnerability identification is focused on the risk object, i.e. the object that would be damaged in case of a flooding. The risk object could be many different things; the urban planner would normally focus on something being a part of the build environment (houses, roads, bridges, electricity etc.) but humans could also be the risk object. A vulnerability assessment could therefore be analysing questions like; are there any houses placed in the floodplain, or how many people would be affected by a flooding with a given recurrence interval?

For chemical stormwater pollution the risk source is the chemical substances in stormwater runoff from urban areas. Hazard identification is therefore devoted to identifying the relevant chemical constituents and finding information about their properties and effects, and developing a tool able to do exactly that will be one of the main products of WP4. Hazard assessment is concerned with predicting concentrations of these substances and comparing with predicted no-effect concentration threshold levels (estimating the so-called PEC/PNEC ratios). Vulnerability identification should preferably be concerned with identifying other potential sources of risk that may affect the surface water that receives runoff containing chemical pollutants (for example high flows giving rise to erosion of the river bed), while vulnerability assessment could aim at developing heuristic rules for the resulting effect to how surface waters from various risk sources (chemical pollution, erosion, etc.), taking recipient classifications defined by the Water Framework Directive as a starting point.

As shown in Figure 7 and Figure 8 the results from the hazard and the vulnerability assessment can, if the assessment reveals that there is a need for more elaborate analysis, be used as an input to a more thorough risk characterization, where the aim is to quantify the risk as defined in chapter 2 (equation 2.1). However, this level of detail is not addressed in the DayWater project.

### 4.1.2 DayWater risk screening tools

The risk assessment tools provided by DayWater will be but tools that can assist screening either the hazard or the vulnerability in relation to stormwater runoff. The screening tools will focus specifically on screening of chemical hazards and vulnerability to environmental impacts. The tools developed will, however not include methods for full risk characterisation.

The developed tools will provide assistance for two fundamentally different problems.

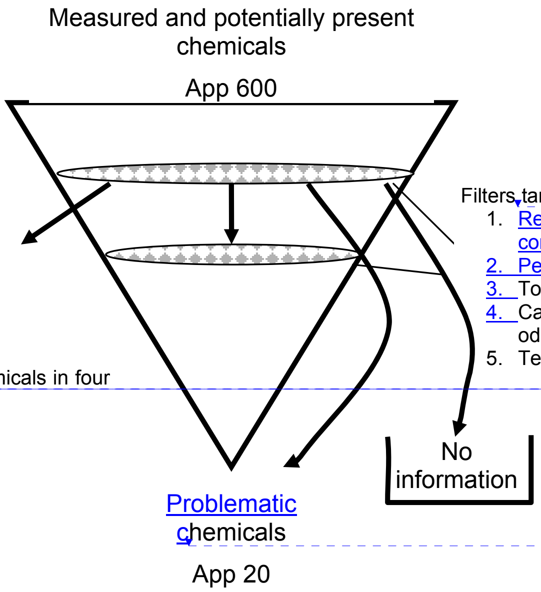
1. Screening large databases of potential stormwater pollutants for hazardous properties, and based on that filtering and condensing information about the pollutants to create a base list potential stormwater priority pollutants (PSPP).
2. Screening information about environmental systems to assess their vulnerability to stormwater discharges, and presenting such information in GIS interfaces with the purpose of creating overview.

The primary outcome of task 4.2 and 4.3 will be a tool aimed at (1) above, whereas task 4.4 as well as tasks in other WP's will be focused on (2).

The Daywater “chemical hazard screening tool” will be a method to narrow down the number of chemical substances potentially present in stormwater runoff. According to Eriksson et al. (2003) stormwater can potentially contain up to 600 different chemical constituents, and dependent on the scenario the number may be even higher. This is far to high a number of constituents to use in an risk characterisation, so an important process prior to a full risk assessment is to narrow down these 600 potentially present pollutants to a more manageable number of chemicals, something in the vicinity of 15-20 substances.

Figure 9 illustrates the risk screening tool that will be an outcome of task 4.2 and 4.3. The tool can be visualised as a funnel. At the top of the funnel is the gross list of 600 potentially present stormwater pollutants, derived partly from a literature study covering what has been measured in stormwater and partly from studying sources of stormwater pollutants in the urban environment (roofs, roads, special activities etc.). A specific scenario that is up for analysis may cause an increase in the number of chemical substances in the gross list. If for instance the analysed location is a golf course and it is discovered (by looking in the green keepers shed) that a number of pesticides that are not on the gross list are used in the particular golf course, the list should be expanded correspondingly.

Between the top and the bottom of the funnel there are several filters. Currently we operate with 5 filters as the figure shows. In the initial filtering the environmental compartments of relevance are identified by inherent physical-chemical properties of the pollutants. A pollutant entering at the top of the funnel can be classified as water (e.g. surface or groundwater) and/or solid phase (e.g. soil and sediments) problems and will belong to one out of four groups: “not problematic”, “maybe problematic”, “problematic”, or “information not available to conduct hazard/problem identification”. Three groups of criteria are used in the filters: long-term human health hazards, environmental hazards (short- and long-term) and technical damage. The considered human health hazards are carcinogenic, mutagenic and, reproductive/endocrine effects. The environmental hazards considered are persistence to degradation, bioaccumulation and toxicity. The technical problems considered are among other things precipitation in installations, corrosion, discolouring and odours.



Filters targeting properties such as
1. Relevant environmental compartment
2. Persistence/bioaccumulation
3. Toxicity
4. Carcinogenic/mutagenic/reproductive effects
5. Technical problems

The filters sort the chemicals in four categories:
1. Not problematic
2. Maybe problematic
3. Problematic
4. Information missing

**Supprimé :** Persistence/bioaccumulation

**Supprimé :** ¶
Phase

**Mise en forme :** Puces et numéros

**Supprimé :** Each

**Supprimé :** s

**Supprimé :** hazardous

**Supprimé :** hazardous

**Supprimé :** Hazardous

**Supprimé :** Hazardous c

**Figure 9. Outline of chemical hazard screening tool.**

The filters are organised in a way that no chemicals that are "cleared" by one filter would have been found problematic by another filter. Chemicals where it is impossible to find suitable information to conduct the hazard/problem identification are put in a special category that should be studied further. For some of these chemicals estimation of properties (e.g. by quantitative structure activity relationships, QSAR) may lead to classification using the chemical hazard screening tool. The literature study, that forms the background for the gross list, reveals that insufficient information was available about approximately half of the chemicals (Ledin et. al, 2002).

It must be emphasized that the classifications are specific for USWM and for the environmental compartments considered. There are hazardous chemicals that will be classified as "non-problematic" in water due to that fact that they will bind to sediments. In the hazard identification carried out for sediments these chemicals will, however, be classified as "problematic". Chemicals that are found maybe problematic are passed on to another filter. The final outcome of the chemical hazard screening tool are list of "non-problematic" and "problematic" chemicals (for chemicals for which sufficient data is available).

The above described screening method is meant to be applied on one location at the time. On an even higher screening level, for instance in the process of selecting the locations for further investigations, geographical information systems (GIS) can be helpful tools. Here many types of information can be presented simultaneously, creating an overview. Types of information of relevance could be: discharge points, location of industry and main roads, location of recreational areas, classification of recipients, land use, population density, catchment boundaries etc.

In the same way GIS could possible also be used when screening vulnerability. By selecting the right type of information useful information about the vulnerability could be generated. Coupling information about the location of the discharge points and the volume of discharges with information about recipients could for example be very interesting. A small recipient with a highly varied aquatic life that receives large discharges is very vulnerable whereas a large recipient that receives small discharges shows much smaller vulnerability.

Vulnerability towards flooding can be analysed and communicated to others by making maps of simulated flooding and information about the area. The GIS map shown in Figure 10 is an example of a flooding vulnerability assessment. The map shows how large a part of an area that will be affected by a flooding corresponding to different return periods (based on simulations). If such a map is studied in detail an estimate of the cost of a flooding could be made beforehand. This estimate would be quite uncertain, but nevertheless an estimate.

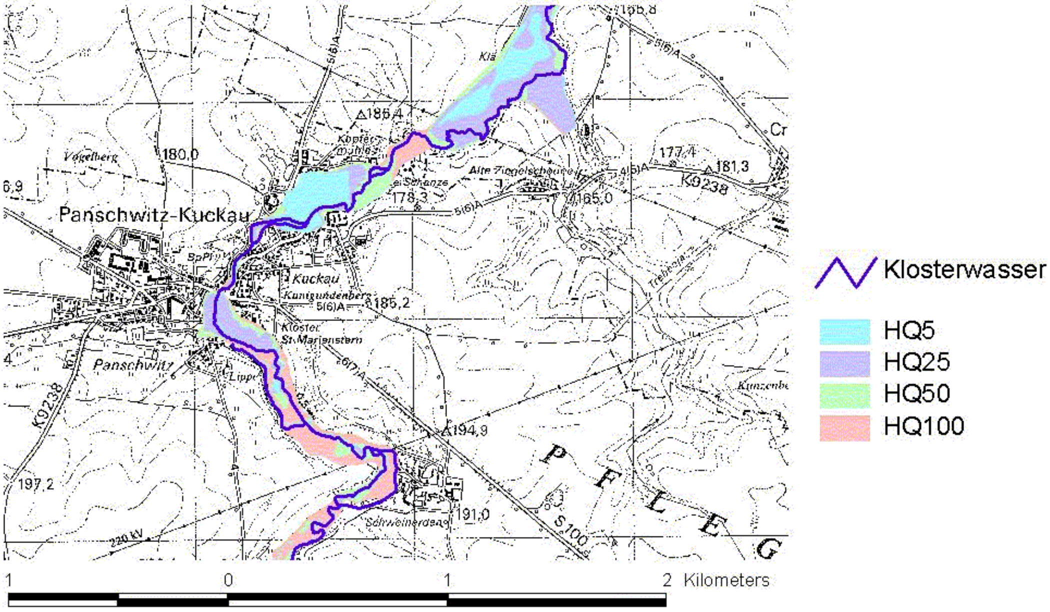


**Figure 10 Example of vulnerability map showing how large a fraction of a town will be flooded at different return periods. (Sieker 2003)**

## 4.2 Coping with risks perception

### 4.2.1 Categories of USWM Risks

In USWM there are three major categories of risks that might affect the public. They are described in Table 4 together with some of the causes that may result in that particular risk.

The risks in the different categories vary tremendously in location (impact of consequences) and therefore accordingly in their related risk perception (see section 4.2.2 below). Those differences in location of USWM risks are due to the following characteristics:

- Frequency of Occurrence (every decade or weekly)
- Duration of Occurrence (continuous or short term)
- Aspects of life affected (life comfort or life expectancy)

**Table 4 USWM risk categories and examples of their possible causes.**

| Category | Possible causes (examples) |
|---|---|
| Flooding | Overflowing rivers<br>Urbanisation<br>Straightening of rivers<br>Heavy rainfall<br>Pump failure in polders |
| Deterioration of water quality | (Illegal) waste dumps or discharges<br>Leakage of pesticides and other chemicals<br>Water borne diseases (Botulism, Giardia etc) |
| Deterioration of the water environment | Illegal waste dumps<br>Elimination of natural river banks through construction |

### 4.2.2 Public Perception of USWM Risks

As in section 4.2.1 the public perception of risk will be described concerning the same three categories (Table 5). First of all the table does not contain all possible perceptions of USWM risks. It shows merely a few general examples, and it is advisable in real projects to make an inventory of risks perceived by the public by interviewing or surveying those possibly affected. However the mentioned perceptions cover most of which can be expected in USWM.

**Table 5 USWM risk categories and examples of their possible perception**

| Category | Possible perception (examples) |
|---|---|
| Flooding | Loss of life<br>Damage (with major economic consequences)<br>Loss of earnings |
| Deterioration of water quality | Disease (short term and long term)<br>Decline of biodiversity in water<br>Devaluation of property |
| Deterioration of the water environment | Loss of enjoyment<br>Decline of neighbourhood<br>Devaluation of property<br>Disturbance of routines |

### 4.2.3 USW Risk Management

Throughout Europe very different practices can be found in USW Risk Management. Practice varies from highly developed to non-existent. Even in highly developed situations the context (covering all non technical factors involved in USWM, such as the public, their social networks and their living environment) is often neglected in the design and decision making process.

Risks are usually considered as statistically determined values and even then ordinarily not seriously taken into account when design processes take place. As long as norms are not exceeded any other consideration remains undone. This is also a consequence of the fact that rules and regulations have been designed over the past decades in such a way that there is not much room for creative solutions anymore.

### 4.2.4 Communication

#### *Identifying the Public*

Before good risk communication can be initiated it is very important to identify the public, in order to ensure that the right groups are informed. Also an inventory of their needs can be a useful tool as it may require a very different approach to inform a small group of lower educated people than for instance a large group of academics. Furthermore it can be useful to know who are considered as ‘respected leaders’ in a group. These leaders often have access to a lot of implicit information which is indispensable in order to understand the public’s needs. And at the same time they can function as ‘interpreters’ when experts and public turn out to speak ‘different languages’.

#### *Information*

In communication with the public authorities should be aware of the information they are providing. Even when not communicating at all, they generate a source of information to the public, which can best be described as ‘attitude-information’, giving someone information about the availability of someone else to participate in communication.

When an authority decides to open up towards the public, several different sources of information next to the above mentioned ‘attitude-information’ can be distinguished, according to the nature of the communication.

Those types of information connected to the two major types of communication are:

1. One way information providing, involves possibly:
    - Scientific information (surveys, scientific papers, statistics etc.)
    - Common knowledge (assumptions of the authority about what that is can be very far from reality, however)
    - Information about plans made and/or decisions already taken by the authority.
2. Dialogue
    - All the above mentioned sources.

    plus

    - Scientific information 2nd opinion (surveys, papers and statistics generated by a professional different from those consulted by the authority)
    - Written non-scientific information (surveys, neighbourhood inquiry).
    - Implicit information existent among the public (sentiments, historical events)

#### *Characteristics of Good Risk Communication*

The public in general has a much more positive perception of risks when they feel they have a choice or a means to control the risk itself or its impacts, as opposed to when the risk is forced upon them with no options to choose from. Since these are the two aspects that can be influenced, it seems obvious that in order to improve public opinion and perception, one should try to increase both:

- The Freedom to Choose
- The Ability to Control

This sounds quite easy to do, however in reality the possibilities to change those aspects in complex situations are often limited. It therefore requires a large amount of creativity to invent new ways to involve the public as far as possible in the decision making, by for example:

- Interviewing a random sample of the public on their point of view specifically, and
- Asking them to express more hidden concerns that might be contributing to their resistance or concern, and
- To invent new ways to involve the public in management or maintenance, by for example: asking them for suggestions (design, constructions, locations), making them participate in easy to manage construction activities etc.

This could be a major challenge for most engineers and policy makers, being very often quite ‘far’ away from the public and preferring as little interference as possible. What should be clear for everybody at all times is: who is in charge of a project, i.e. who carries supervision and responsibility for what. It is not necessarily best to centralize this ‘decision making power’, in fact it seems to be very helpful to give individuals small responsibilities they can handle, in order to make them feel involved.

The most important conclusion so far should be, that just providing as much information as possible is not good enough and often not even desirable.

## 4.3 Coping with uncertainty

By exploring the risk space, we discover different processes. With reference to Figure 4 we can distinguish processes in the technical system, the environmental system and the social system. Using the terminology developed the ADSS template (TAUW, 2003b) we can distinguish physical processes (in the technical and environmental systems) and social processes (in the social system) Physical processes influence social behaviour, people influence risks. The interactions between technical/environmental system and the social system are complex by nature. People are interacting with the subsystems continuously.

When water professionals handle a risk problem, they have to know what the risk is and how it can be reduced. By intervening, they expect that something will change for the better. These interventions can be in any of the three sub-systems, and both probabilities and effects related to risks might be reduced.

In the relationships between goals and measures and between cause and effect, we meet uncertainty (see also 4.3.4). Sometimes it is possible to predict the effects of different interventions in the system. However, there are a lot of cases where the outcome could be a surprise, either because the circumstances are poorly defined, because there is no good overview of the significant uncertainties, or because it is not realised that the nature of uncertainty plays a role for how uncertainty can be dealt with. These issues are discussed further in the following sections.

### 4.3.1 Defining the circumstances: an integrated urban wastewater example

The example shown in Figure 11 illustrates the earlier mentioned three subsystems integrated into each other. The technical system in this example consists of the pipe system, the storage structures, the treatment facilities, the overflow structures, the infiltration devices and any type of monitoring/control that might be installed. The environmental system is made up by the river and the soil/groundwater that act as recipients for stormwater runoff. The elements in the social system are the different types of stakeholders in the system. In this example we have four different types of stakeholders. The property owner owns a piece of property that discharges stormwater into the technical and/or the environmental system and hence he/she has strong economic and personal interests in any changes occurring close to his property. The general public consists of people not owning property or not living in the catchment. The general public also have some interests in what is going on because changes in the technical system can influence them economically, for instance through their tax bill. The utilities are responsible for operating and maintaining the technical system. In some countries this function is outsourced or privatised to a company, but the function remains the same; operating the technical system. The last types of stakeholders are the authorities, responsible for making the rules on how the system should be run, the demands it should fulfil, pricing etc. Some rules are given on an international level, others at a national or municipal level.

All of the above examples are tangible elements in the urban stormwater system; in addition there are also a number of intangible elements, or processes, that belong to the three sub-systems. All processes occurring in the technical part of the system are also part of the technical system; this is transport, removal and degradation processes occurring both in the pipe system and in the treatment facilities. In the same way all processes that occur in the elements of the environmental system are also part of that particular subsystem. These processes are meteorological processes, such as rain and temperature, and it is chemical, physical and biological processes in the receiving water and in soil/groundwater and air. Also in the social system there are numerous processes, i.e. all the social processes that drive the behaviour of the four types of actors described above.

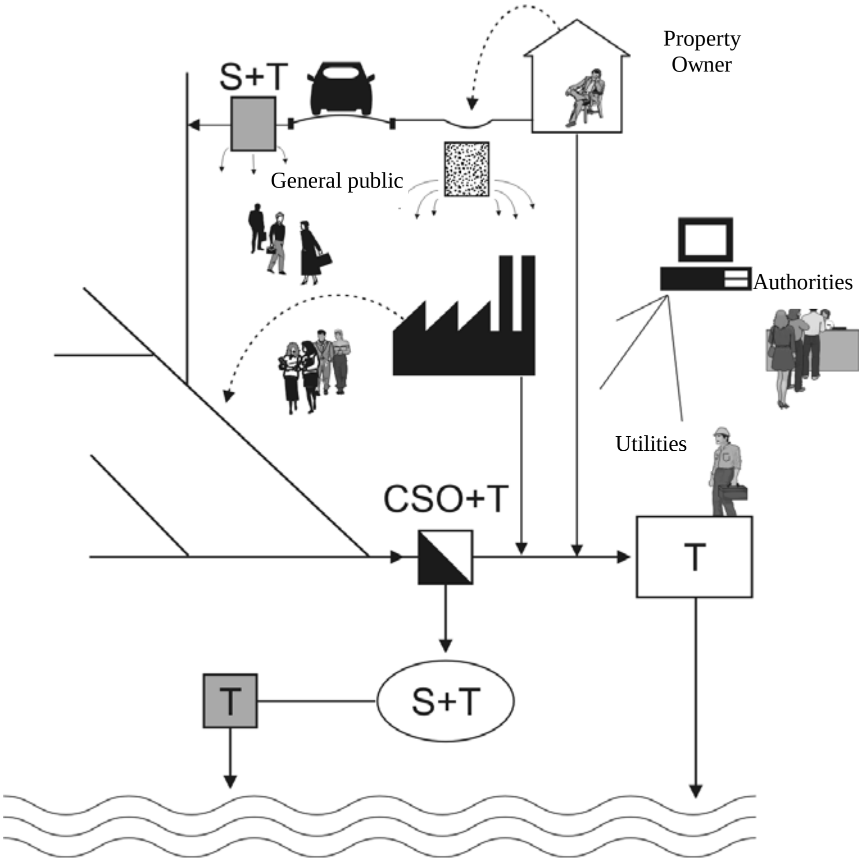


**Figure 11 Illustration of the urban stormwater system. T in this figure means treatment, S means storage.**

Surely there is, as also Figure 4 indicates some overlap between the sub-systems. As an example of this overlap pollution transport can be mentioned. First the extent to which a substance is used and the chosen method of treatment is a result of processes and decisions in the social system. Secondly, from the moment the pollutant enters the urban stormwater system it undergoes and interacts in numerous processes; they start inside the technical part of the system and continue when the pollutant reaches the environmental elements of the system, in this example the river. This example illustrates that pollution transport is spread out over all three systems. Therefore, when discussing uncertainties related to the different subsystems, it is important that it is clearly defined what is considered to be in what system. In other words; an important first step of an analysis of the uncertainty in a system is a good description of the three sub-systems.

### 4.3.2 Getting an overview of uncertainties

To provide an overview of the essential features of uncertainty an “uncertainty matrix” has been introduced (Walker et al., 2002; Harremoës, 2003). The basic idea of using the uncertainty matrix here is to identify the location, level and nature of the uncertainty associated with the urban stormwater system in the hope that it clarifies and thereby encourages to deal with the important elements of uncertainty. The matrix will be elaborated below for two examples, first for the whole integrated urban stormwater system and secondly for selected parts of the system.

***Overall uncertainties in the integrated urban stormwater system***

Among the three subsystems introduced in Figure 4 and illustrated in Figure 11, the best understood is the technical system. The technical system has been subject to research and modelling for decades. Many important processes in the technical system are well understood and can be described in detail, and even processes that are not very well understood can be described statistically when a large amount of data is available. Therefore, the majority of the uncertainty in the technical system is statistical uncertainty, although some scenario uncertainty also exists (see Figure 12). The nature of the uncertainty is primarily reducible but there will always be a minor residual that can not be reduced due to measurement uncertainty and difficulties with allocating resources to monitoring programmes.

The environmental system is somewhat more influenced by ignorance, cf. Figure 12. Some processes are relatively well understood, but many of the processes in the environmental system are only understood at the level of scenarios and some processes are not understood at all (ignorance). The impacts on the environmental system have not been subject to detailed studies to the same extent as the technical system itself. This, together with the fact that the number of interacting processes is much larger makes the uncertainty higher in the environmental system than in the technical system. The nature of the uncertainty is distributed evenly between reducible and irreducible uncertainty. Thus, putting an effort into understanding the environmental system by collecting data through systematic monitoring can reduce a large part of the uncertainty, but an evenly large part cannot be reduced.

The most complex of the three systems is the social system. The social system is composed of a very high number of interacting processes that cannot (at least in a practical context) be described mathematically. The most well understood processes are understood at the level of scenarios and many of the processes and interactions in the system cannot even be described with scenarios. Thus, the majority of he uncertainty in the social system is at the level of ignorance (cf. the M in column three in Figure 12) although some of the uncertainty is the level were scenarios can be formulated. The majority of the uncertainty in the social system is irreducible uncertainty, but some of the uncertainty may be reduced if an effort is put into it employing some of the possible actions mentioned in section 4.2: Coping with risks perception.

| **Location** | **Level** | | | **Nature** | |
|---|---|---|---|---|---|
| | Statistical | Scenario | Ignorance | Reducible | Irreducible |
| Technical | M | s | | M | s |
| Environmental | s | M | M | M | M |
| Social | | s | M | ? | M |

**Figure 12 The uncertainty matrix for the integrated urban stormwater system illustrated in Figure 11. "M" indicates where the majority of uncertainty within a subsystem is located, "s" indicates where some uncertainty is located, and "?" indicates where uncertainty (of unknown magnitude) may be located.**

It is tempting based in the matrix shown in Figure 12 to compare the level of uncertainty present in the three subsystems. However, the matrix should be read horizontally in rows, meaning that the M under ignorance in the social system cannot be compared directly with the M under ignorance in the environmental system. The relative magnitude and importance of uncertainty in the three subsystems depends entirely on the type of risk or problem in question.

### *Examples of uncertainties at the process-level*

Figure 13 contains three small examples of processes or phenomena where it could be relevant to analyse the uncertainty, one example for each sub system. The example from the technical system is estimation of the concentration of a pollutant in stormwater. This is a problem that has been studied for quite a long time and therefore a reasonably large amount of data from measurements exists (e.g. USEPA, 1983; Tasker & Driver, 1988; Arnbjerg-Nielsen et al., 1999). If we use the most frequently studied constituent, COD (Chemical Oxygen Demand), as example it is possible to describe quite well the variation from rain event to rain event within the same catchments in statistical terms. The uncertainty becomes larger when it comes to describing the variation between catchments; here we are at the level of scenario uncertainty because only a little can be explained and it is poorly understood how the concentration is correlated to characteristics in the catchments.

| **Location** | **Level** | | | **Nature** | |
|---|---|---|---|---|---|
| | Statistical | Scenario | Ignorance | Reducible | Irreducible |
| Technical:<br>**Concentration of pollutant** | M | s | ? | s | M |
| Environmental:<br>**Rainfall process** | M | s | ? | s | M |
| Social:<br>**Perception of pollution** | | M | ? | ? | M |

**Figure 13. Characterisation uncertainties at the process-level for examples form each of the three subsystems in the integrated urban stormwater system. "M", "s" and "?" is explained in the caption of Figure 12.**

A question mark has been added under ignorance since it is unknown how the cities will develop in the future and even more uncertain how this development will affect pollution concentrations. The distribution between statistical and scenario uncertainty depends on the pollutant in question because some have been studied a lot and some very little. Generally it can be said that the more they have been studied the larger part of the uncertainty is statistical. The majority of the uncertainty is irreducible because we are dealing with stochastic phenomena, which have an inherent variation that cannot be reduced. See also 3.3.3 where practical and inherent reducible is explained However, some of the uncertainty is reducible; more and better data from a larger number of catchments combined with refinements of the measurement methods could reduce some of the uncertainty.

The second example, the one from the environmental system is description of the rainfall process. The majority of the uncertainty is statistical; the rainfall process has been studied for decades in many countries and vast amount of data exists, which makes it possible to a large extent to describe the rainfall in statistical terms. Some of the uncertainty is, however, scenario uncertainty; the potential effect of global warming on rainfall can only be described in scenario terms. The implications of extreme climate change such as the Gulf Stream turning is at the ignorance level, it is at the moment not possible to forecast what will happen to rainfall in such extreme scenarios. But this field is an area of intense study and the scenarios are improving all the time. Most uncertainty associated with rainfall is irreducible with the same argument as in the previous example: there are many stochastic phenomena included which have an inherent variation that cannot be reduced. But some of the uncertainty can be reduced, especially concerning the scenarios. Looking back at climate change scenarios, the scenarios have improved quite a lot since the first scenarios were postulated –not including rainfall at all, to the scenarios used today that predict different changes in rainfall patterns in different regions of Europe (DMI, 2003). Improving a scenario is also a way of reducing uncertainty.

The last example is from the social system and concerns people's perception of pollution. How people perceive and react to pollution can as the situation is today at best be described with scenarios. Most sociologists would probably agree that not all human reactions and behavioural patterns are known and thus, elements of ignorance are clearly also involved. Most of the uncertainty is irreducible, the scenarios cannot be formulated with great detail and it is not likely that human perception of pollution can be so well described that it can be quantified statistically. But some of the uncertainty can be reduced by gathering data. Two types of data are relevant here; surveys asking people how they will react in different situations, and learning from the past. There are already quite a number of cases of pollution, large and small around the world, and it is likely that useful information can be achieved by studying these cases.

Comparing the level and nature of uncertainty as indicated in Figure 12 and Figure 13 reveals some differences. For example, the nature of uncertainty is said to be mainly reducible for the technical subsystem generally, although the pollutant's concentration example showed that the uncertainty is mainly irreducible. This emphasizes the need for clearly defining the circumstances when discussing the location, level and nature of uncertainties.

### 4.3.3 Reducing uncertainty or initiating transitions?

As explained in section 3.2.3 and illustrated in Figure 12 and Figure 13 we can distinguish between uncertainties with different nature: irreducible and reducible uncertainty, or structural and non-structural uncertainty. Thus, there are basically two different strategies for coping with uncertainty:

A. Try to reduce it.

B. Accept it and see it as a pre-condition for change (a transition).

The strategy of reducing uncertainty (A) is to avoid deterministic chaos and structural uncertainty. Structural uncertainty are to a large extent avoided by the way the system boundaries are chosen and assumptions about the system. Interventions are focused on cause and effect relationships that can be described very well and exhibit little uncertainty (primarily on the form of statistical uncertainty). In practice this means that mostly processes in the technical and to some extent the environmental system are taken into account and that the interaction between water and society are taken for granted. Society is considered to be in equilibrium. This strategy is useful for assessing the variant risks in the ADSS, i.e. to compare different possible technical solutions to a well-defined problem. The assessment part of the ADSS will focus on the cause and effect relationships that can be described with limited uncertainty. The pros and cons of the different variants can be clarified.

The interactions between technology/the environment and society are complex by nature. They can be described as produced by a complex adaptive system, a system that learns and evolves. When a complex adaptive system shows stable behaviour, it is locked-in in a basin of attraction of an *attractor*. An attractor is a state of preference. An attractor works as a magnet on the system state and ensures that structural changes cannot simply be passed on. Complex adaptive systems often have many attractors, which exist side by side.

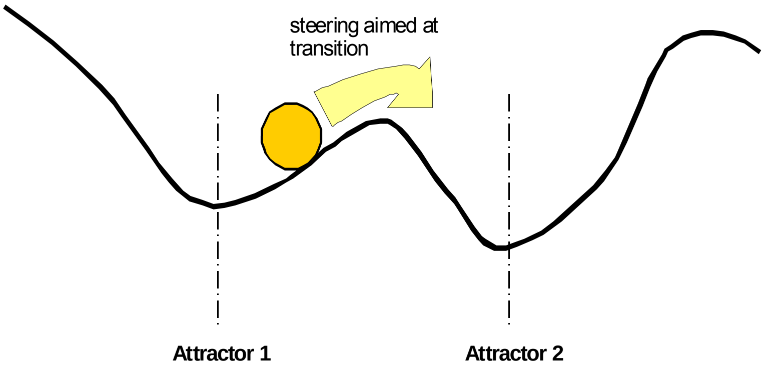


**Figure 14. Schematic reproduction of a complex adaptive system with two attractors**

The system state is close to only one of the attractors. The effects of attractors are schematically described in Figure 14, in a marble diagram. Here, the state space is schematised as a hilly landscape and the system state as a marble in this landscape. In the landscape the valleys are attractors. If the landscape stays the same and no force is exerted on the marble, the system behaviour is maintained around the ruling attractor. However, through adaptation the landscape changes (valleys and hills on the figure changes) continuously and through interventions, symbolised with the arrow, the marble rolls towards another attractor.

A *transition* is an attractor change, and to change system behaviour (striving for a transition), the area of structural, or irreducible, uncertainty offers the best prospects. The reason is that the associated processes have the highest degree of freedom. In order to bring a transition about (strategy B), insight is needed into the various attractors available and the resisters, which are the factors that form the “hills” between two different attractor basins that have to be overcome in order to enter another attractor’s basin of attraction. Many opportunities lie in the unknown and the future may reveal change that coincides with a shared vision on sustainable water management. The interactions between all three sub systems are taken into account and interventions are carried out all over the system. To cope with the structural uncertainty, the strategy includes empirical iterative design, also referred to as adaptive management. Over the course of time, we learn and adapt.

In the ADSS it is important to take risk perception into account and to look at the interactions between the technical/environmental and the social system. This will not be included in the assessment part of the ADSS, but in illustrated road maps which are supplementary tools to the

ADSS (TAUW, 2003b). Road maps will describe the necessary steps to cope with the interaction between risk and risk perception and to organise a transition process. These road maps will be illustrated by examples from practice.

In principle there are two basic paradigms for science: positivism and constructivism. From these two paradigms uncertainty is approached differently. Positivistic scientists are looking for the truth. Within boundaries they look at cause and effect relationships that describe the situation, as it is, as precisely as possible. They produce objective knowledge. Constructivists accept that there is not one single truth. Everybody is limited in his or her way of observing processes in this world and out of this limited knowledge they construct “a truth”. They look for knowledge that has value for life and they claim that they produce subjective knowledge. Objective knowledge does not exist.

In practice both positivists and constructivists will use the ADSS. Positivists are more interested in the cause and effect relationships and the way to reduce uncertainty. Constructivists have more interest in structural uncertainty and the ways to organise a transition process.

### 4.3.4 The role of uncertainty in risk management

Figure 15 below illustrates how decisions can de divided into four “typical situations” based on two dimensions; goals and technology (Christensen, 1985). The horizontal axis distinguishes situations where there is agreement or disagreement about the goals of a decision, and the vertical axis distinguishes situations where technology needed to achieve a goal is either known or unknown.

As it will be illustrated in the following these four situations are very different with respect to the dominant type of uncertainty, the type of person (water professional or other stakeholder) involved in decision making and the tools he or she needs to support decisions. In the following technology should be interpreted broadly as the knowledge, analysis tools or means of how to do something. Also goal should be interpreted broadly as the purpose or the desired outcome of a decision.

| | **Goals** | |
| --- | --- | --- |
| **Technology** | **Agreed** | **Not agreed** |
| **known** | **Agreed goal**<br>**Known technology** | **Not Agreed goal**<br>**Known technology** |
| **unknown** | **Agreed goal**<br>**Unknown technology** | **Not-agreed goal**<br>**Unknown technology** |

**Figure 15. Four different regimes of decisions, dependent on the agreement about goals and the knowledge about technology (adapted from Christensen, 1985).**

The dominant category of uncertainty changes depending on the situation, as illustrated in Figure 16. In situation 1 were there is full agreement about both the goals and the technology needed to achieve the goals things are generally well known, and the uncertainty will probably mostly be non-reducible statistical variation that can be quantified. In situation 2 where there is no agreement about the goals, the uncertainty increases and scenario uncertainty becomes the dominating type of uncertainty. Often there will be a range of competing goals present in situation 2 and a possible range of scenarios could be: our goal is goal A, our goal is goal B, or our goal is partly A and B. Similarly situation 3 is also dominated by scenario uncertainty. Either there is no know technology available to reach the goals or the available technologies have not yet proven their reliability or trustworthiness in that specific field. Scenarios are formulated as a number of technologies that might solve the problem. I situation 4 ignorance dominates, the technology is unknown and there is disagreement about the goals. In a regime like that it is very difficult, if not impossible to set up scenarios, which means that uncertainty can be classified as ignorance.

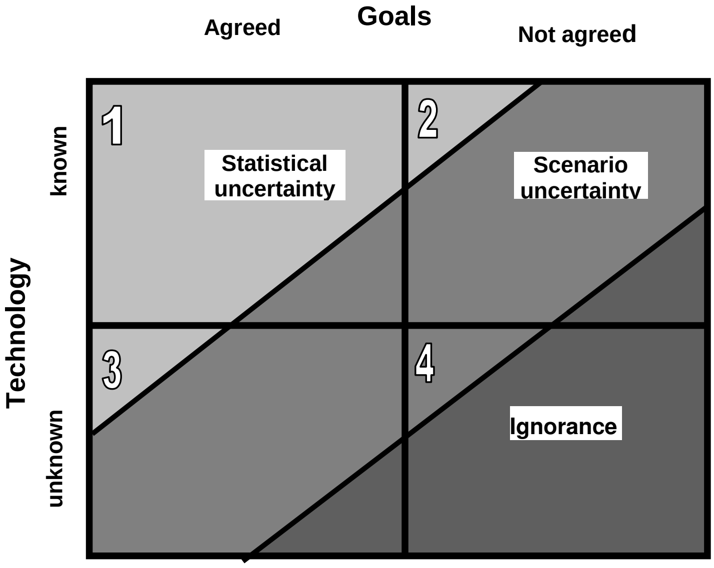


**Figure 16. The inter-dependency between agreement on goals, knowledge about technology and the level of uncertainty in decision making.**

These great differences in level of uncertainty, agreement on the goal and confidence in technology calls for a large range of working methods and tools, but also a large variety of different professionals are needed in the 4 different situations, as illustrated in Figure 17.

Situation 1 where the goals are well defined and the technology needed to reach the goals is well-proven the tools are also relative straight forward. The working methods are following rules, programmes or procedures and the professionals working here are regulators and administrators following procedures and administrating rules and programmes. Not much surprise is expected here because the uncertainty is relatively low, and therefore predictive design methods relying heavily on simulation models where the whole design is predicted and later implemented in one operation can be used in this type of situation. Stochastic methods become increasingly relevant as uncertainty increases, for example by building return-period considerations into the engineering design or by accounting for uncertainty in measurements by adding a safety margin, but this still corresponds to the level of statistical uncertainty. When decisions are complex multicriteria decision aid (MCA or MCDA) tools can be applied to “optimise” decisions and make them more transparent. Generally situation 1 is where rationalistic planning is relevant and where the traditional engineer has his working area (Christensen, 1985).

In situation 2 the technology is known but there is disagreement about the goals. Therefore the problem is either to find agreement about the goals or to reach a compromise. There are different ways to do this. First and foremost there are bargaining and consensus, in which case MCA/MCDA techniques may sometimes be used to clarify the goals of different stakeholders by manipulating the scoring and weighting used. However, there may be situations where agreement on one goal or on a compromise cannot be reached. In these situations either restructuring the problem into a number of smaller problems, or allocating resources into a number of competing goals can be the solution. The yearly negotiation about the state budget that takes place in many countries is a good example of allocating resources. The types of persons operating here are bargainers when it is a matter of defining a goal or compromise. When it is a matter of competing goals advocates and lobbyist represent each goal in order to achieve as much as possible. When different groups present a number of competing goals the mediator seeks to reach consensus or find a compromise. This corresponds quite well to the situation at the municipal level when politicians allocate funds for very different competing purposes such renovation of public schools and restoration of natural watercourses.

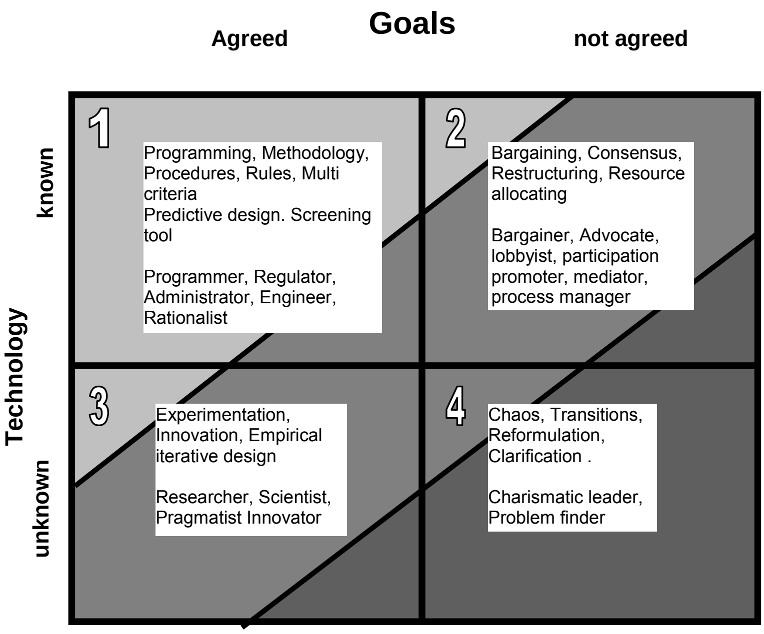


**Figure 17. Overview over the different tools used and the types of persons operating based on knowledge about technology and agreement on goals.**

In situation 3 the goals are known and agreed on but how to get there is not known. The problem is to develop methods to get to the goal. The regime is characterized by innovation; new solutions are needed, so the people working under these conditions have to be innovative.

The design methods can be characterised as empirical iterative and experimenting methods, where the experiments are constructed stepwise with continuous feedback about the experiments as they develop. This regime is the area where researchers and scientists operate, either to unveil new cause-effect relationships or to develop new technologies (e.g. improved simulation models).

In the 4th situation uncertainty is very large, there is nothing to fall back on, neither the goals nor the technology is known. In this situation we have chaos. What might help is to reformulate and clarify the problem. Another possibility could be to strive for a transition, find the goal and the technology in the region of a completely different attractor. The type of person needed in this chaotic situation is either a charismatic leader who is able to steer the boat through the difficult waters or a problem finder; the brilliant person with the brilliant idea.

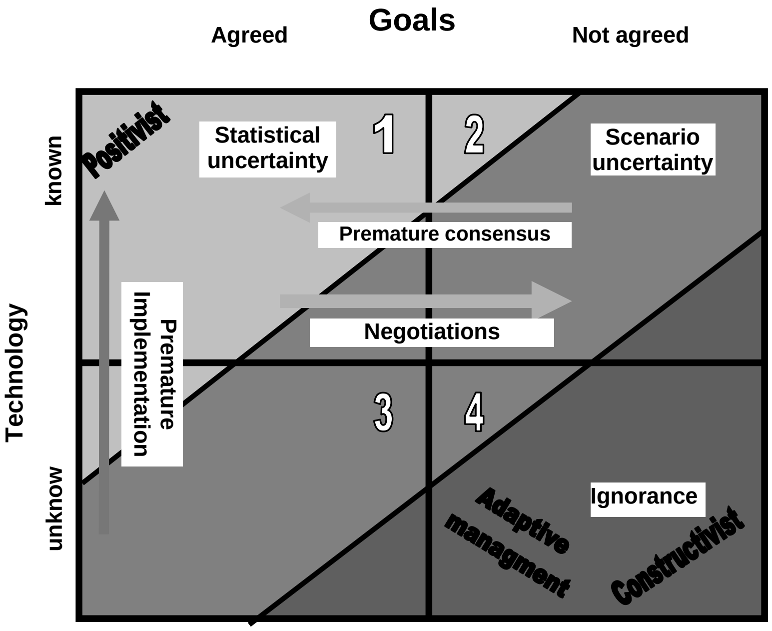


**Figure 18. Positivism vs. constructivism and movement between decision-situations.**

Dependent on where a planner operates in this matrix of decision situations there is difference in the scientific paradigm applied in his/her work. Planers working in the area with the lowest uncertainty apply a positivistic approach in their planning. There is one truth and they strive to describe the cause and effect relationship as precisely as possible. (Situation 1, Figure 18) Planners operating in the most chaotic and uncertain situations apply a constructivistic approach; there is no single truth and the observer is limited in his way of observing (which might be a reason for conflicting goals) because of his or her location of observation. Based on the acceptance that their knowledge is limited they construct a version of the truth, and based on that they seek decisions. (Situation 4, Figure 18). In a regime where uncertainty (i.e. ignorance) is so dominating it would be advisable to make decisions 'gently' meaning that the implications of a wrong decision should not be too large. Adaptive management (Holling, 1978) is a principle based on doing exactly that. When applying adaptive management decisions should be taken in small steps and between each step there shall be evaluation of and learning from the decision. Based on that the decision maker adapts and takes the next step, or the constructivist gathers more information and constructs a new version of the truth based on which he or she makes a new decision and so forth.

From time to time decisions are moved from one part in the matrix to another, from one regime of decision to another. On the technology axis the system is likely to engage into premature planning or implementation. This is when new and unproven technology is chosen and then implemented through prescribed procedures and programmes as if the technology had already proven its worth. On the figure this means that a decision is moved from situation 2 to situation 1 and thereby prematurely implemented. While doing that the uncertainty is being misjudged or underestimated, since the decision is moved from a regime with dominantly scenario uncertainty to a regime with dominantly statistical uncertainty.

On the goal axis movement in both directions occur. There can be a tendency that decisions are either taken at to early a stage and somebody uplifts a solution proposal to a decision before it is fully debated, or that political choices and tradeoffs are not treated as such but as acceptable solutions. By doing this, the decision is moved from situation 2 to situation 1 as premature consensus, the situation is moved but there is in reality still not agreement about the goals. As with premature implementation the uncertainty is underestimated or misjudged in this movement process. The reverse process might also take place that already agreed goals are questioned, by starting up negotiations again after a decision has been made. It can be a healthy process to revise the goals from time to time because in general the world changes and consequently goals have to be questioned every now and then to see if they fit the standards of the time.

The DayWater project contains work related to all four decision-situations discussed in this section.

- The “risk screening tools” developed in WP4 (Risk and Impact Assessment) and discussed in section 4.1.2 are both examples of tool development (innovation) aimed at moving decisions from situation 3 to situation 1 or 2. The hazard screening tool aims at providing scientific evidence so that further detailed investigations on risks associated with potential stormwater priority pollutants can be focused on a limited (realistic) number of relevant substances. The vulnerability screening tool aims at providing information about the spatial location of potential negative impacts from stormwater discharges into the environment. Most activities in WP5 (Multi Criteria Assessment of BMP’s) and WP6 (Sources and Flux Models) aim at developing technology much in the same way as in WP4. Thus the tools developed in WP4-6 will enable decision makers to employ rationalistic planning principles to deal with some decision situations that fall into category 2 at the present.
- WP3 (Urban Dynamics) is less devoted to technology development but instead focuses on providing aid (“soft” tools such as roadmaps and mental maps) to guide decision makers when they find themselves in situation 2 or 4, and to identify useful tools that are already available and that may be incorporated into the DayWater ADSS
- WP2 (Adaptive Decision Support System) aims at developing the DayWater ADSS, which will be partially tested in WP7 (Field Testing). Thus, these two work packages should preferably address all the four decision situations discussed in this section.

# 5 Summary and conclusions

## 5.1 Executive summary

This report has been prepared as part of task 4.1 of the research project DayWater, funded by the EC under the 5th Framework Programme for Science Research and Technological Development. The report is a "whitepaper" on risk perception, risk assessment and risk management as they are seen in the context of the DayWater project. The purpose of the white paper is to define how the DayWater project group will work with the concept of risk in relation to stormwater source control.

In chapter 2 the definition of risk, which is the basis for the whole report is introduced. To provide a common understanding for the readers the most important terminology is defined. It is discussed that the formal scientific definition of risk can be difficult to use operationally, and as a consequence the use of risk indicators is introduced in many types of risk assessment, to ease both the risk assessment and the risk communication.

The risk space is the space that is expanded by the actual risk, the perceived risk and the uncertainty of both. In chapter 3 this space is explored. A number of influencing factors and concepts are presented. It is illustrated that uncertainty, perceived risk and actual risk are strongly linked. It is emphasized that the public's perception of risk is important when communicating about risk to a broader audience. Individuals' perception of the same risk varies a lot from members of the "bungee-jump society" who consequently underestimate risks to members of the "reflexive society" who overestimate risks. It also illustrated that uncertainty can be divided into three dimensions, location, level and nature of uncertainty. Location deals with where in the urban water system the uncertainty is located, we distinguish between three sub-systems; the technical system, the environmental system and the social system. At the level of uncertainty we operate with a scale from statistical uncertainty in one end over scenario uncertainty to ignorance in the other end. The nature of uncertainty is divided into reducible uncertainty and irreducible uncertainty.

Risk management in the DayWater context is explored in chapter 4. We present a frame for risk analysis that also explains how we interpret the relationship and gradual transition between hazard and vulnerability identification and/or assessment to risk characterisation. The screening tools that will be developed in Daywater will provide assistance with two different types of problems; screening of large databases of chemicals and presentation of information in GIS interfaces with the purpose of creating overview. A draft outline of the tool for screening of potential stormwater pollutants is presented. These tools will have potential applications both within hazard and vulnerability identification and assessment.

Coping with uncertainty in risk management is of the uttermost importance. The three dimensions of uncertainty are used to construct a matrix for analysing the uncertainty of decision situations present in urban stormwater management. This matrix is beneficial when discussing and creating overview of a problem. Finally in this chapter we show that decisions can be divided into 4 different regimes based on agreement/disagreement about the goal and knowledge about the technology needed to achieve the goals. Each regime is characterised by being dominated by a certain level of uncertainty (statistical uncertainty, scenario uncertainty and ignorance), as well as by special groups of professionals and typical working methods. That different tools are suited for different regimes, or decision situations, is important to keep in mind in the work in DayWater, which is aimed at developing an adaptive decision support system that can guide the decision maker to the right tools depending n the situation.

Chapter 5 presents the results of an inventory made on the background of 14 end user questionnaires and reports from partners. The results are presented in a matrix dividing the urban stormwater system into seven different risk objects and seven different types of risk. The inventory shows a reasonable correspondence in what combinations of object/type the end-users and the experts find the most problems. The most frequent object among the experts was the natural environment, the most mentioned type of risk was hydraulic and technical risk. The end users pointed out the natural environment and BMP’s as the objects with most risks involved. The most often mentioned types of risk were chemical and hydraulic risks.

## 5.2 What happens next in DayWater ?

The white paper summarizes the work conducted in task 4.1: "Inventory and characterization of risks". Preliminary versions were discussed at work meetings in Riksgränsen/Sweden (April 2003), Deventer/Holland (June 2003) and Prague/Check Republic (August 2003), as well as via bilateral phone and e-mail discussions with different partners. The report seeks to bridge several aspects of the content of the DayWater project and the DayWater ADSS which is yet to be developed and tested in an iterative manner during the project.

On the one hand, the white paper suggests a way to link Risk Management, and in particular Risk and Impact Assessment (WP4), with planning principles based on Urban Dynamics (WP3). On the other hand, it suggests a well-defined terminology and procedure for risk assessment that may be a key to interfacing the work conducted on Risk and Impact Assessment (WP4) with the work on Multi-Criteria Analysis of BMP's (WP5) and Sources and Flux Models (WP6).

The contents and suggestions of the final white paper will be presented and discussed among project partners at the first annual meeting of the DayWater project, taking place in Athens/Greece during 16-17 October 2003. Here, a detailed plan for further work and integration between tasks in WP4-6 will also be suggested. The outcome of these discussions will be reported in the next deliverable of WP4, D4.2: "Methodology for assessing environmental risks to surface water, soil and groundwater".

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# Appendix 1: Inventory of risks in stormwater management

This chapter is an inventory over risks/barriers and problems seen from the end users point of view and from an expert point of view. Section 0 explains the method of the inventory which is split in to an end user point of view and an expert point of view. Section 0 presents the end users point of view. All core end users associated with the Daywater project have in an other work package been asked to complete a comprehensible questionnaire about them selves. This was done in collaboration with other work packages, were more information about end users can be found (TAUW 2003 A and Carré et al 2003). The questionnaires have been searched for anything resembling either a risk, a barrier or a problem within the urban storm water system, and these data are the background for the results shown in section 0. In section 0 we present the expert point of view. Daywater partners from Sweden, Greece and UK have written contributions about stormwater risks as they see them in their countries or regions, these texts have been searched in the same way as the questionnaires. Finally we compare the two points of view.

## Method for generation of inventory

It has to be mentioned that the questionnaires used in this inventory, were not designed for this purpose but for use in WP3 for creating on overview over the core end users that will be used later to select which end users that are going to be selected as cases later on in DayWater, nevertheless we think the statements in the questionnaires serves as a very good first answer to the question whether or not Daywater delivers a product (ADSS) were there is a demand for such a product. To get a better data material questionnaires specially designed for this purpose have to be applied. DTU plan to at a later stage apply a new set of questionnaires to a group of Danish end users.

All questionnaires have been scanned for risk/problems and barriers. For each questionnaire a table is made with all the mentionings of risks barriers and problems. Table 6 below is an example of such a list from one of the questionnaires. In total in all 14 questionnaires there is 295 listings.

To create an overview over the long list the information have been organized in a matrix like the one in Table 7. The information has been organized according to the following procedure. For nearly all listed risks/barriers/problems it has been possible to identify 1) an object and 2) a type of risk/barrier/problem. This has been used to place each listing in the matrix that can be seen below in Table 7.

### Objects and Types.

With object we mean physical objects that can be found somewhere in the water cycle. Objects are organised as rows in the matrix in Table 7. We have found 7 different objects:

- **BMP'S:** anything that has to do with stormwater source control, local retention or infiltration, special structures and rainwater reuse.
- **Pipe system:** Everything connected with the pipes in the sewer system
- **Basins and overflows:** Everything that has to do with detention basins and overflow structures and similar structures in the sewer system.
- **Built environment:** Everything that is a part of the built environment such as streets, houses, bridges etc.
- **Natural Environment:** all types of recipients, rivers, lakes, coastal water and soil including groundwater.
- **Drinking water resource:** Everything where drinking water has been mentioned (ground- or surface water) explicitly.

**Table 6 Risk/barriers and problems mentioned in the questionnaire from Nejmigen.**

| | Risk/barrier or problem | Mentioned in Question | Mentioned on page |
|---|---|---|---|
| 1 | During heavy rain: flooding of lower parts of the city | B-3 | 13 |
| 2 | During heavy rain: untreated discharge | B-3 | 13 |
| 3 | Combined sewer overflows, emissions from | B-4 | 13 |
| 4 | Difficult to fit the wastewater system into the landscape (hills that slopes away from a river | B-4 | 13 |
| 5 | Water quality in recipient | B-4 | 13 |
| 6 | Soil pollution (pesticides) | B-4 | 13 |
| 7 | GW pollution (pesticides) | B-4 | 13 |
| 8 | False connections (sewers) | C-3 | 17 |
| 9 | Wash-off from roads pollute the stormwater system | C-3 | 17 |
| 10 | False connections in Rainwater harvesting constructions causes health risks | C-8 | 19 |
| 11 | Discussions about water quality of harvested rainwater – can children play with it<br>- Health risk | C-9 | 19 |
| 12 | Discussions about water quality of harvested rainwater -- Health risk | C-9 | 19 |
| 13 | Can rainwater be used in ponds, does it live up to regulations for surface water? | C-10 | 19 |
| 14 | Can rainwater be used in ponds, does it live up to regulations for soil? | C-10 | 19 |
| 15 | Acceptance by users<br>Willingness to participate | C-11 | 20 |
| 16 | Acceptance by users<br>Large information requirement | C-11 | 20 |
| 17 | Acceptance by users<br>Financial means | C-11 | 20 |
| 18 | Water quality in recipients, especially ponds | D-3 | 25 |
| 19 | Illicit connections, | D-3 | 25 |
| 20 | Careless behaviour of inhabitants no examples) | D-3 | 25 |
| 21 | Water quality, pollution from surfaces, car wash, walking dog etc. | D-3 | 25 |
| 22 | Need for control on a household level | F-1 | 31 |
| 23 | Water quantity –floodings | F-9 | 32 |
| 24 | Water quality – physical constituents | F-9 | 32 |
| 25 | Water quality –, chemical, constituents | F-9 | 32 |
| 26 | Water quality – biological constituents | F-9 | 32 |

Types refer to the type of problem or risk. Types are organised as columns in the matrix in table Table 7. We have found 7 different types of risks or problems:

- **Chemical:** Everything that addresses chemical and toxic aspects of flooding, infiltration, stormwater, wastewater treatment, transport and discharge etc.
- **Hydraulic/volume:** All listings that addresses hydraulic and volume aspects –Flooding is the major risk of this type
- **Technical:** Technical malfunctioning such as illicit connections
- **Microbiology:** All listings that mentions living organisms (bacteria, protozoa, etc).
- **Organisation:** Everything that addresses organisational aspects, such as planning and legal aspects
- **Economy:** Everything that addresses economical aspects
- **Users perception/ attitude**: Everything that addresses the users perception and attitude towards all 7 objects. Users in this context are people that live close to or nearby the structures in question and who are users of the urban water, the urban space or some other related aspect.

Type have some resemblance to the way risk is normally categorised. chemical risk= “chemical”; technical risk= “Technical” or “Hydraulic/volume”; Microbial risk = “Microbiology” etc. The only type that does not correspond to a traditional risk discipline is users perception/attitude.

It should be mentioned that some of the risks found in the questionnaires are placed in more than one cell in the matrix. The argument for placing a listing in more than one cell can be either because of the formulation or of the type of listing. For example (line 23 in Table 6): ‘Water quantity –floodings’ can be placed in the ‘hydraulic/volume’ column in Table 7, but also in both the ‘built environment’ and the ‘natural environment’ rows. In total this means that the 295 listings become 453 hits in the matrix. How the information is distributed in the matrix can be seen in Table 7.

### End users point of view on what is the problems/risks and barriers within stormwater source control

In total we have access to 14 questionnaires from 14 end users across Europe. The end users are companies or organisations, public as well as private who have the thing in common that at least one of their tasks is dealing with water in some way.

**Table 7 Matrix for organisation of risk inventory. Percentage of total. End user view. Cells in greyscale are Cells that contains more than 2,5 % of the hits. Cells without greyscale are Cells with less than 2,5 % of the information. Empty cells are cells with no listings.**

| Type<br>**Object** | **Chemical** | **Hydraulic/ volume** | **Technical** | **Micro-biology** | **Organisation** | **Economy** | **Users perception / attitude** | **Sum object** |
|---|---|---|---|---|---|---|---|---|
| **BMP’s** | 2,2 | 1,1 | **4,2** | 1,6 | **8,5** | 2,2 | **8,0** | 27,9 |
| **Pipe system** | 0,2 | 1,1 | **6,7** | 0,0 | 1,6 | 0,7 | | 10,3 |
| **Basins and overflows** | **2,7** | 2,0 | 2,0 | 0,2 | **3,1** | 0,2 | 1,3 | 11,6 |
| **Waste water treatment plant** | | 0,2 | 0,9 | | | 0,2 | | 1,3 |
| **Build environment** | 0,7 | **7,4** | **2,9** | | 1,8 | 1,8 | **2,9** | 17,4 |
| **Natural environment** | **13,2** | **10,3** | 0,7 | **3,1** | 0,4 | | 0,7 | 28,3 |
| **Drinking water Resources** | 2,0 | 0,7 | | 0,2 | 0,4 | | | 3,3 |
| **Sum Type** | 21,0 | 22,8 | 17,4 | 5,1 | 15,8 | 5,1 | 12,9 | 100 |

In the matrix the following points are worth noticing:

- 28% of the hits address the object BMP’s, especially the types “organisation” and “users perception/attitude” are mentioned, but no types are left unmentioned.
- Also 28% of the hits concern the natural environment, especial the types chemical and hydraulic/volume.
- The most frequent types mentioned are “chemical” and “hydraulic/volume”, in total these two objects accounts for nearly 44% of the hits. Within these two types it is especially the natural environment that is of concern to the end users.
- The third most mentioned object is the built environment that account for 17% of the hits. Especially Hydraulic aspects are mentioned here, but also technical and user aspects have many hits
- All types of risks have at least 5% of the hits. With “Microbiology” and “Economy” being the ones with fewest hits – 5% each
- Two objects have less than 5% hits, that is wastewater treatment plant and drinking water resource

Seen as a total the core end users see risk barriers and problems of many different types and related to many different objects. Daywater is a project focusing on stormwater and the risk screening tool that will be part of the ADSS will focus primarily on chemicals. Based on the findings in this inventory the Daywater project in general and the chemical risk screening tool in particular falls in an area were there is a need for help, 28% of the hits in the matrix concerns BMP’s and 22% is concerned with chemicals. Of the cells with more than 2,5% of the hits 5 out of 12 is either type chemical or the object BMP’s. So there is a quite good chance that the users will find a chemical risk screening tool as well as an ADSS a useful set of tools.

In the list below is a limited selection of what has been mentioned in the cells with the highest density of information.

**Table 8 Selected risks barriers and problems, in the cells of the matrix containing more than 2,5% of the information**

| Object | Type | Risk/Barrier/Problem |
|---|---|---|
| Bmp’s | Technical | • Infiltration structures takes up space<br>• Discussions about water quality of harvested rainwater – Health risk<br>• Discussions about fences around ponds<br>• Ice blockage |
| Bmp’s | Organisation | • Authoritative reluctance to rainwater reuse<br>• Technicians have to change mentally, some are not ready for this yet<br>• Local BMP’s Legislative problems Legislation is creating obstacles (laws are old fashion)<br>• GW abstraction enforce restrictions on infiltration of storm water and wastewater<br>• Can rainwater be used in ponds, does it live up to regulations for soil?<br>• Urban STWM low rank in urban planning<br>• Operation Maintenance and control of BMP's requires revision of management structure<br>• Conservatism among city planners and the company's designers |
| Bmp’s | User perception /attitude | • Public reluctance to rainwater reuse<br>• Lack of maintenance after some time (lost interest or lack of knowledge)<br>• Willingness to participate<br>• BMP's are space demanding<br>• Concern/worry for safety among public<br>• Public is per instinct negative towards BMP's<br>• New solutions require a lot of time to dialogue |

| | | |
|---|---|---|
| Pipe system | Technical | • Disconnection of roof runoff because of illicit connections<br>• Illicit connections<br>• Poor constructions (leaky pipes and joints)<br>• GW infiltrating into sewers causing capacity problems<br>• Technical risks - wrong design<br>• Neglected maintenance<br>• Ice blockage |
| Basins and overflows | Chemical | • Sewage overflows<br>• Water quality in river due to polluted overflow water.<br>• During heavy rain: untreated discharge<br>• Major input of heavy metals to receiving water comes from storm water |
| Basins and overflows | Organisation | • Bathing water classification<br>• Administrative responsibility<br>• It is a problem to communicate the 'big picture'<br>• Politicians are hesitant to test projects that are costly in the short term<br>• The (relatively well-functioning) existing system is a large barrier |
| Build environment | Hydraulic /volume | • Floods<br>• Basement flooding<br>• A risk that water ends up in water in normally dry places<br>• High GW tables during floods causing problems with basements<br>• Urban retention reservoirs is an ecological concern since they represent an important modification in the natural river course<br>• Flooding hazard makes certain activities impossible |
| Build environment | Technical | • Infiltration structures takes up space<br>• Infiltration structures might cause local flooding because of malfunctioning in the melt season in areas with cold climate<br>• Infiltration of road runoff problematic due to space limitations |
| Build environment | User perception /attitude | • Public do not accept modifications of their town<br>• Need for control on a household level<br>• Public suspicious towards risk management policy<br>• Concern that BMP's might increase the risk of local flooding<br>• Flooding hazard makes certain activities impossible |
| Natural environment | Chemical | • Chemical pollution<br>• Eutropication<br>• Water quality during low flow periods<br>• Wash off from surfaces both urban and rural<br>• Infiltration of road runoff problematic due to salt from de-icing<br>• Waste water becomes a large fraction of the flow in the streams during low flow periods<br>• Pesticides infiltrating into groundwater<br>• Soil pollution (pesticides)<br>• High presence of nitrate in the aquifer<br>• High concentrations of heavy metals in bottom sediments |
| Natural environment | Hydraulic /volume | • Soil erosion<br>• Fish mortality<br>• Flooding caused by USW<br>• Surface system often in lack of water (streams and lakes inside Copenhagen)<br>• Pulse impacts on streams from separate rainwater overflows – Flooding of stream banks,<br>• Water quality – physical constituents<br>• Hydraulic overloading in smaller rivers<br>• Life steeling flash floods<br>• Urban retention reservoirs is an ecological concern since they represent an important modification in the natural river course |
| Natural environment | Microbiology | • Health risk when bathing (banned since 1970)<br>• Health risk with the Drinking water<br>• Water quality, pollution from surfaces, car wash, walking dog etc.<br>• Water quality –biological constituents<br>• Concerns over drainage into environmentally sensitive rivers<br>• Discharge of sewage to recreational, and vulnerable areas |

The questionnaires was also compared regionally with the purpose of investigating weather it was possible to locate any regional differences or differences between countries by comparing the questionnaires from end users from the same country with end users from other countries. However the authors of this report did not find any significant differences between different regions, apart from the obvious that Swedish end users mention ice blockage of BMP-s and de-icing problems and Greek end users are more focused heavy intense rainfall effects, there was no interesting findings in the regional analysis. The reader also has to keep in mind that every country participates with 1-3 end users, so the data material are very limited.

### Summary of various contributions from other partners about risk perception/assessment/management (expert point of view)

This section represent the expert view on were the risks barriers and problems are within the urban storm water system. Three Daywater partners have been asked to make contributions about risk, barriers and problems in their particular region:

- Luleå University of Technology (LTU) (SE) has made a contribution with special emphasis on cold climate. (LTU, 2003)
- Urban Pollution Research Centre at Middlesex University (MU) (UK), have made a contribution about risk related to stormwater management in the UK (MU, 2003).
- Finally have Department of Water Resources Hydraulic and Maritime Works at National Technical University of Athens (NTUA) (GR) contributed with three documents concerning stormwater risk with focus on Mediterranean conditions. (Noutsopoulos et al., 2003; Tarnaras and Aftias 2003; Papavasiliou and Aftias 2003).

The numbers in the matrix does not refer to how many times a certain cell have been mentioned, but how many of the above three experts that have mentioned something that belongs to a given cell. Due to the limited number of data (statement from three partners only) a quantitative inventory were not found relevant. The shaded cells are the cells, that were found in section 0 to contain more than 2,5% of the information. This is done to indicate overlap between perception of risks, barriers and problems among experts and end users.

Even though the three expert teams were asked to look at urban storm water risks seen from the perspective of their own region, there is remarkable agreement about where there is a risk and where not. 21 cells have references from 2 or three partners and 17 cells have not been mentioned by any of the three partners only 11 cells have reference from one expert only.

- The experts have focused on hydraulic and technical types of risk as the most important.
- “chemical”, “microbiology”, “organisation” and “users perception/attitude” are also mentioned often but a little less than the two previous.
- Only one type of risk is significantly less mentioned than the others, “economy” is only mentioned once by one expert.
- The most mentioned object is “natural environment” followed by “BMP’s”, “Basins and overflows” and “built environment”
- The least mentioned object is “waste water treatment plant, even though all three expert mentions hydraulic overloading of the treatment plant.

**Table 9 Expert point of view. Matrix with risk barriers and problems. Percentage of total. Grey cells are cells that were found significant**

| Type<br>**Object** | **Chemical** | **Hydraulic/ volume** | **Technical** | **Micro-biology** | **Organi-sation** | **Economy** | **Users perception / attitude** | **Sum object** |
|---|---|---|---|---|---|---|---|---|
| **BMP's** | **1** | **2** | ▨ **2** | **1** | ▨ **2** | **1** | ▨ **1** | 10 |
| **Pipe system** | | **1** | ▨ **2** | | **2** | | **1** | 6 |
| **Basins and overflows** | ▨ **1** | **2** | **2** | **2** | ▨ | | **2** | 9 |
| **Waste water treatment plant** | | **3** | | **1** | | | | 4 |
| **Build environment** | | ▨ **3** | ▨ **2** | | **2** | | ▨ **2** | 9 |
| **Natural environ-ment** | ▨ **3** | ▨ **3** | **2** | ▨ **3** | **1** | | **2** | 12 |
| **Drinking water Resources** | **3** | **2** | **1** | **1** | | | | 7 |
| **Sum Type** | 8 | 14 | 11 | 8 | 7 | 1 | 8 | |

Comparing to the end user point of view there is a quite good correspondence. Of the 12 cells that the end users found to be the important (cells in greyscale), 9 of them are mentioned by at least two experts. The three cells under natural environment that the end users found to be significant all three experts mention all three cells. In the build environment there is also three significant cells, all three experts mention one, and the other two are mentioned by two experts. On the other hand there is 12 cells outside the cells that the end users found to be the most important that are mentioned by two or more experts.

In conclusion it could be stated that the experts focuses some more on “microbiology” an less on “organisation”, “economy” and “users perception” or in other words the experts pays less attention to the social system. With respect to types the experts pays some more attention to drinking water and less attention to BMP’s.

# Appendix 2

The following list contains documents prepared by DayWater partners as part of task 4.1. They have all somehow been part of the basis for preparing this report and are cited accordingly in the text.

Chabert, L., 2003. Report on Inventory and characterisation of risks: Draft contribution to DayWater Task 4.1.

Luleå University of Technology (LTU), 2003 Special Concerns Cold Climate, Draft contribution to DayWater Task 4.1.

Mouchel, J. M., 2003. Draft contribution to DayWater Task 4.1 Personnel communication and notes about vulnerability.

Noutsopoulos, C., Hatzibiros, K., Andreadakis, A., Aftias, E., 2003, Report on environmental risks related to urban stormwater management, focus on the Mediterranean area, Draft contribution to DayWater Task 4.1.

Sieker, H., 2003. Flooding and surcharge problems, Draft contribution to DayWater Task 4.1.

Urban Pollution Research Centre at Middlesex University (MU), Perceived risks relating to stormwater management in the UK , Draft contribution to DayWater Task 4.1.

Tarnaras, I.; Aftias, E. 2003, The risk of flooding, Draft contribution to DayWater Task 4.1.

Papavasiliou, C., Aftias, E. 2003, Erosion sediments and solid transport in urban runoff – risk analysis, Draft contribution to DayWater Task 4.1.