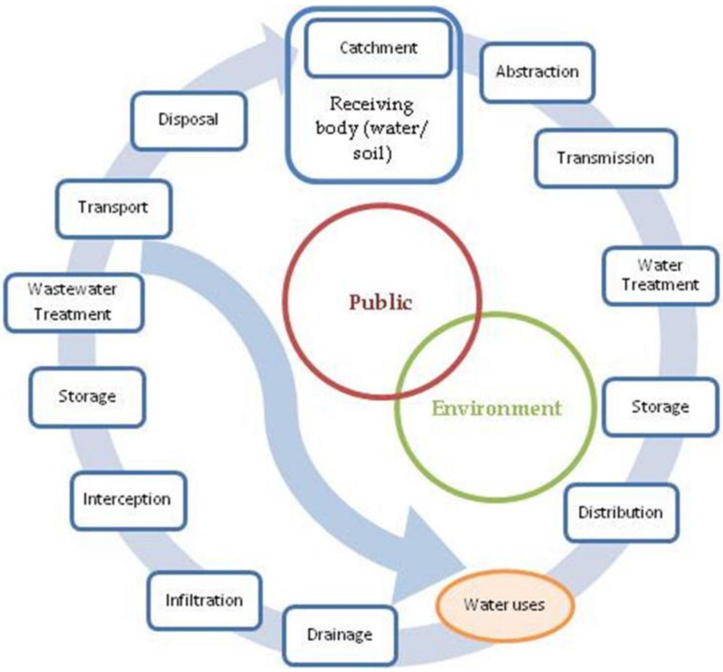
Water cycle safety plan framework

Demonstration in Eindhoven



SEVENTH FRAMEWORK PROGRAMME

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Summary

Climate change challenges in Eindhoven

Over the last 50 years, Eindhoven has developed from a settlement on the banks of rivers and stream into a densely populated area of over 200.000 inhabitants. Although once a city of heavy industry, Eindhoven has now become a city of innovation and R&D. During the growth of the city, the water infrastructure has not kept up with the expansion, nor the changes of industry and functions. As a result, Eindhoven is confronted with various shortcomings in the urban water system:

- old drainage systems have been removed;
- combined sewers were connected to surface water;
- wastewater treatment plant (WWTP) and sewerage capacity became insufficient.

In terms of the geohydrological situation, the city is situated in the valley of the river "De Dommel" which causes several problems. Lower parts of the city face high groundwater levels while the higher (green) areas around the city face drought. Groundwater levels are also impacted by local industrial and water supply abstraction.

The effects of climate change are likely to worsen the adverse effects of this geohydrological situation and the shortcomings of the urban water system (UWS). Intense rainfall will potentially increase the occurrence of water on streets leading to aggravation of health risks and reduction of public safety. Intense rainfall can also affect surface water quality through combined sewer overflows and poor WWTP performance. Prolonged drought periods affect natural areas.

The various stakeholders, including the Municipality of Eindhoven, the water supply company Brabant Water and the water board De Dommel need to work closely together to deal with these increased risks. All elements of the Eindhoven urban water cycle are closely connected, both to deal with water quantity and quality. Therefore, the city of Eindhoven needs tools to re-think the urban water system, solve current issues and increase system resilience to climate change.

Water cycle safety planning (WCSP) in Eindhoven

The WCSP framework developed in PREPARED provides a structured approach to assess risks and find solutions for the integrated urban water system (Almeida *et al.*, 2010). This was demonstrated in Eindhoven where the stakeholders worked together to prepare for climate change. Activities were organized around three workshops where strong interaction between stakeholders was initiated. Stakeholders also worked together in smaller meetings and on projects focusing on specific aspects. Some of these projects were part of PREPARED, such as the quantitative risk assessment study and the study on drinking water quality changes during distribution. Other projects were not part of PREPARED, for example the KALLISTO project on

improving the surface water quality, automated control of the sewage system and wastewater treatment (KALLISTO 2013). The demonstration made very clear that such complex issues cannot be dealt with within a single project but is part of a continuous process of assessments, plans and improvements.

Characterisation of the water cycle and initial risk inventory

The first workshop was dedicated to introduce the WCSP framework, to establish commitment from the stakeholders and to characterise the urban water cycle and make an initial inventory of risks. Both traditional maps and drawings and the use of the more modern GIS table were found to be useful in this phase. Stakeholders focussed on points of interaction between the various sub-systems (drinking water, sewerage, wastewater treatment and surface water). Doing this together from a risk point of view provided some new insights in how these components interact and impact each other. Since the source of drinking water is groundwater, interaction with other components is limited to flooding of well fields during extreme flood events.

Other important risks that were expected to increase by climate change were:

- untreated wastewater spilling into surface water causing decrease of ecological water quality and potentially impacting health through recreation (rainfall);
- low flow in the river Dommel, less dilution of treated wastewater and increasing temperature leading to low oxygen levels and other environmental effects;
- pluvial flooding of streets in specific areas, sometimes water entering properties (rainfall);
- fluvial flooding of streets, sometimes water entering properties (high river level);
- high groundwater levels affecting indoor climate of (old) houses and buildings;
- algal blooms during warm and dry periods leading to toxin and odour problems.

Risk analysis and risk treatment

Risks were mostly evaluated in studies outside the WCSP process. For example, the impact of wastewater and stormwater on river water quality was addressed in the KALLISTO study that focussed on improved control of the sewage and wastewater treatment system. The likelihood and consequences of pluvial flooding were assessed in the Wolk study (extreme rainfall) (Tauw 2013). These results were then used to quantify damage and the effect of risk reduction measures in the PREPARED QRA study (see D2.3.4). Remaining risks were analysed using a risk inventory form.

As many risks in Eindhoven, such as flooding, show a gradual increase of consequence and a decrease of likelihood, a stepwise approach was used to discuss the risk. Discussions focussed on the points where consequences suddenly increase, e.g. the rainfall event that causes properties to flood because the doorstep level is exceeded. Due to climate change the likelihood (or return period) of that rainfall event increases, but the consequence stays the same. By diverting water to unpaved surfaces and creating retention, the likelihood of floods exceeding the doorstep level decreases. An alternative measure would be to make the ground floor of those properties water-resistant, e.g. by tiling the floor and walls. This only reduces the consequence of the flooding, not the likelihood. The second measure is more favourable for individual properties, the first for an area of properties. This approach helped to clarify discussions on likelihood and consequence of events.

In Eindhoven a pragmatic approach was chosen for adaptation of the water cycle. Given the current boundaries of existing infrastructure and annual investment plans, smart, no-regret improvements are being made, including:

- integrated control of the sewage system and wastewater treatment to avoid negative impact on surface water quality;
- raising (or re-installing) sidewalk curbs to create water buffering capacity in shopping centres;
- separate sewer systems for new developments and renovations;
- groundwater wells for drinking water production have been raised above ground level to prevent flooding of the construction;
- house owners are informed how to keep indoor air quality healthy even with high groundwater levels;
- creating 'cold zones' and experimenting with aeration in the river Dommel in case of CSO's. A pilot project is running since November 2013.

Management and communication

The WCSP activities in Eindhoven have enabled an integrated re-assessment of risks in the UWS. Communication lines between the stakeholders have been strengthened and risk management and communication protocols were updated. However, projects in the urban water cycle all have their own dynamics and issues. The WCSP demo in Eindhoven did not lead into a specific WCSP to be updated in the future. However, this does not mean that integrated risk management is off the agenda. The stakeholders in Eindhoven are committed to continue working together on relevant issues in the UWS.

Conclusions and recommendations

The Eindhoven UWS does not face high risks, nor is climate change expected to increase risks to a level where serious health or safety issues would occur. However, environmental risks for the river Dommel can be significant, and direct and indirect damage is expected to increase through climate change. The WCSP project allowed stakeholders to exchange knowledge and identify new risks. Good cooperation between stakeholders on the most important risks already existed. Criticism on the WCSP was that it was formal and required much time to complete all steps to the full extend. Since no mayor risks or investment decisions are at stake in Eindhoven, there were doubts if fully going through the steps would be efficient. Therefore, the WCSP philosophy was adopted in a more pragmatic way, using the benefits of interaction and systematic approach but being efficient in choosing which issues to address. The demonstration highlighted the challenges of performing integrated risk management between all the daily activities and disturbances.

Contents

1 Case study description

1.1 Eindhoven water history

Over the last 50 years, Eindhoven has developed from a settlement on the banks of rivers and stream into a densely populated area of over 200.000 inhabitants. Although once a city of heavy industry, Eindhoven has now become a city of innovation and R&D. Brainport Eindhoven now is one of the strongest economic regions in Europe. During these developments, water infrastructure has not kept up with the expansion, nor with the changes of industry and functions. As a result, Eindhoven is confronted with various shortcomings in the urban water system:

- Old drainage systems have been removed;
- Mixed sewerage was connected to surface water;
- Waste water treatment plant (WWTP) and sewage capacity became insufficient.

The geohydrological situation, the city is situated in the valley of the river "De Dommel", causes several problems. Lower parts of the city face high groundwater levels while higher areas around the city face drought of natural areas. Groundwater levels are also impacted through local industrial and water supply abstraction.

Table 1 – Key figures about Eindhoven

Country	Netherlands
Number of Inhabitants	220,000
Total area	89 km^2

1.2 Climate change challenges

The effects of climate change are likely to worsen the adverse effects of this geohydrological situation and the shortcomings of the urban water system. Intense rainfall will increase the occurrence of water on streets which leads to health risks and reduction of public safety. Intense rainfall will also affect surface water quality through combined sewer overflows and poor WWTP performance. Prolonged drought periods will affect the natural (green) areas.

The various stakeholders, including the Municipality of Eindhoven, the water supply company Brabant Water and the water board De Dommel need to work closely together to deal with this increased risk. All elements of the Eindhoven urban water cycle are closely connected, both in water quantity and quality. Therefore, the city of Eindhoven needs tools to re-think the urban water system, solve current issues and make the system resilient for climate change.

Figure 1 – Flooded street in Eindhoven

2 Water cycle level

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

2.1.1 *Project team*

The work in Eindhoven was conducted by several groups of people. Frank van Swol from the Municipality of Eindhoven was the demonstration manager. He was supported by Patrick Smeets from KWR that led the scientific development of the WCSP framework and tools. During the course of the project some team members changed, mostly due to a change of responsibilities or employment. Table 2 provides an overview of the representatives from the stakeholders in the urban water cycle.

Three levels of teams were initiated:

- Lead team, consisting of demonstration manager and scientific expert.
- Core team, consisting on one representative per stakeholder (per meeting).
- WCSP workshop team, consisting of approximately 5 representatives of each stakeholder in WCSP workshops.

Table 2 – WC level -Team composition

Name	Organization/ Department	Expertise	Responsibility in team	Team
Frank van Swol	Municipality of Eindhoven	Urban water and environment	Demonstration manager and team leader	Lead
Patrick Smeets	KWR Watercycle Research Institute	Urban water safety	Scientific expert	Lead
LuukPostmes	Municipality of Eindhoven	Urban water system (stormwater and drainage)	Expert	Core
Patrick van der Wens	Brabant Water Company	Strategy	Expert	Core
RoelDiemel	Brabant Water Company	Asset management infrastructure	Expert	Team
Mark Eck	Brabant Water Company	Water supply	Expert	Team
Melanie Tankerville	Brabant Water Company	Water supply	Expert	Team
GerRenkes	Municipality of Eindhoven		Expert	Team
Johan van Lijssel	Municipality of Eindhoven		Expert	Team
Jarno de Jonge	De Dommel Water Board		Expert	Team

Table 2 – WC level -Team composition (cont.)

Name	Organization/ Department	Expertise	Responsibility in team	Team
Erik van Kronenburg	De Dommel Water Board		Expert	Core
Bernard Raterman	KWR Watercycle Research Institute	GIS	Expert	Team
Dick Boland	De Dommel Water Board		Expert	Team
Eric Broers	Brabant Water Company	Water supply	Expert	Team
Michelle Berg	De Dommel Water Board		Expert	Team
Ruud van Nieuwenhuijze	Brabant Water Company	Water supply	Expert	Team
Stefan Weijers	De Dommel Water Board		Expert	Team

Table 3 – WC level - Stakeholder identification

Stakeholder name	Relationship to system
Municipality of Eindhoven	Responsible for sewerage, stormwater and drainage
Water board (Waterschap) De Dommel	Responsible for wastewater treatment and surface water quality and quantity
Drinking water company (Brabant Water)	Responsible for water supply

2.1.2 *Team coordinator*

The team was coordinated by the demonstration manager.

2.1.3 *Team modus operandi*

The demonstration manager and the scientific expert planned the WCSP demonstration activities. They identified primary stakeholders and invited them to participate in the WCSP process.

A core team was formed with one representative per stakeholder (representatives varied during the course of the demonstration). The core team discussed how the WCSP approach could be applied in Eindhoven. This led to the organisation of workshops with the whole WCSP team.

The WCSP team consisted of three to four representatives per stakeholder. Stakeholders were specialists on specific activities of the stakeholder such as production\treatment, transport or strategy.

The WCSP team worked together in workshops to go through the steps of the WCSP framework. Actions were defined in the workshops to be performed by the representatives. Results were then included in the next workshop. The core team prepared the workshop presentations, activities and the workshop reports.

2.1.4 *Scope of WCSP*

The scope of the WCSP covers the urban water system of Eindhoven, which includes:

- surface waters (canals, river Dommel);
- groundwater;
- drinking water production and distribution;
- wastewater collection and transport;
- wastewater treatment.

The elements of the Eindhoven water system were defined in more detail in the description of the system. The geographical scope was set for effects and measures within the borders of the municipality, even though some systems extend beyond that. Origins of risks outside the municipality were included in the study. Both water quality and water quantity aspects were addressed.

The WCSP focuses on risks involving the urban water cycle that are impacted by climate change as described in various studies by the IPCC (intergovernmental panel on climate change, IPCC 2007) and other institutes such as the Dutch KNMI (royal Netherlands meteorological institute, KNMI 2009). The ultimate time horizon for the estimation of climate change effects was 2100 but varied between 2050 and 2100 in more detailed studies.

2.1.5 *Time frame to develop the WCSP*

Several PREPARED demonstration activities were planned in Eindhoven, of which the WCSP demonstration was one. General preparations for demonstrations were started on 4 May 2010 with a core team meeting of the stakeholders to discuss all demonstration activities.

The WCSP demonstration in Eindhoven kicked off on 7 October 2011 with the first WCSP workshop. The time frame was then set to have WCSP workshops in June, September and November 2011 with reporting finalised in December 2011. In reality this time frame was not kept due to various causes, such as the reorganisation of Eindhoven municipality. Table 4 shows the actual WCSP activities in Eindhoven.

Table 4 – WCSP activities in Eindhoven

Date	Activity
4-5-2010	Core team meeting 1
9-9-2011	Core team meeting 2
7-10-2011	WCSP workshop 1 - Introducing WCSP framework - Characterise UWS - Identify CC risks
1-12-2011	WCSP workshop 2 - Characterise identified risks - Prioritize identified risks
22-10-2013	WCSP workshop 3 - Integrate system safety plans - Check risks - Identify measures - Evaluate measures

2.1.6 *Formal requirements*

Formal requirements for the stakeholders consist of their legal responsibilities but also a wide range of legislations and plans which include political processes en public participation. This can be very complex and all stakeholders have specialists to stay updated. Collecting this within the scope of the WCSP would lead to extra work which could be rapidly outdated Therefore, stakeholders decided not to collect all these requirements within the WCSP framework. If any formal issues would arise, this would be looked into in more detail. In general, the stakeholders are used to working together to serve the public rather than focus on formal requirements.

2.1.7 *Water cycle safety policy*

The WCSP is not regarded as a goal in itself, but as a tool for decision making to achieve a climate resilient city. The WCSP policy, as described in the framework document, requires knowledge of what is expected in the WCSP process. Since there was no previous experience with WCSP, there were no examples of the types of outcomes. For example, setting acceptability targets for risks beforehand was not perceived as useful since the Eindhoven goal is to minimise risks with the available resources. The policy was communicated in the minutes of the WCSP core group and workshop meetings.

2.1.8 *Criteria for subsequent risk analysis*

Criteria were not set beforehand since this would take a lot of time and cannot be seen separately from the nature of the identified risks. Instead the group decided to first assess the risks in the Eindhoven system. See the discussion in paragraph 3.1.7.

2.1.9 *Difficulties*

- Since it was the first time that stakeholders went through a WCSP process, no one knew what to expect. It was very hard to formulate all aspects of the WCSP policy beforehand.
- The WCSP process can be very detailed and formal or more general and informal. It was clear that the stakeholders preferred to work together on an informal basis. However, it was harder to estimate the required level of detail to identify relevant risks and the effort required to do this.
- The stakeholders come from different backgrounds with different perceptions, terminology and focus. Some time is required to find a 'common language' between stakeholders.
- The WCSP process was not the only initiative related to the Eindhoven water cycle. Distinguishing between the different scopes was sometimes difficult since there was some overlap.

2.1.10 *Proposals for improvement of the WCSP framework*

- Make the framework less formal and more pragmatic. Stakeholders will get to know the approach as they go and then address any policy issues that arise.

2.2 WCSP ▸ 2. Urban water cycle characterisation

2.2.1 *Water cycle description and flow diagram*

At the first workshop the various stakeholders worked together to describe the urban water cycle of Eindhoven. Two groups were formed, both including participants from all stakeholders. One group used a simple flip-over board to sketch the general characteristics of the system and to highlight crucial interactions between the different sub-systems. The second group used a GIS-table on which available digital maps and GIS information could be combined to show the different systems and where they interact. Halfway the groups changed places.

Figure 2 gives an impression of the results of the 'sketching' group. The advantage of sketching was the more 'creative' process, allowing to clarify how different elements of the water cycle interact. The approach builds on the knowledge and the experience of the participants.

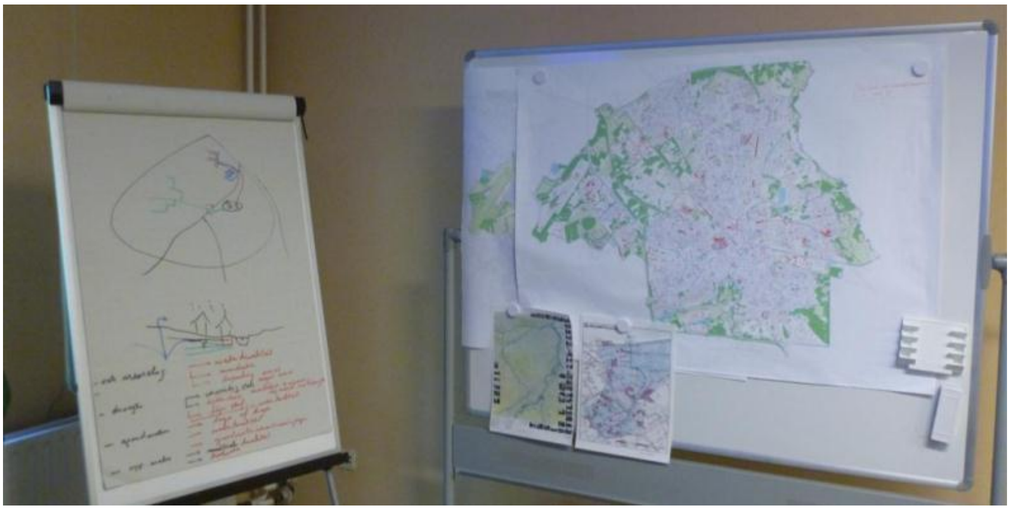

Figure 2 Example of 'sketching' the urban water cycle

Figure 3 gives an example of a group working on the GIS table. The advantage was that a lot of (detailed) information was readily available to work with. This information could be combined to identify potential issues. Expertise from the participating stakeholders was included typing in comments at specific geographical points or areas. Thus the assessed information was immediately digitized and comments were linked to geographical locations (Figure 4).

Figure 3 Stakeholders discussing the Eindhoven water cycle over the GIS table

This was an advantage for recording the information from the WCSP process. Standing around the table created a more interactive environment than sitting behind a computer screen. A disadvantage is the potential lack of GIS information, resulting in focussing only on what is available and missing the rest. Some advanced combinations of maps were hard to implement on the spot and would require more time.

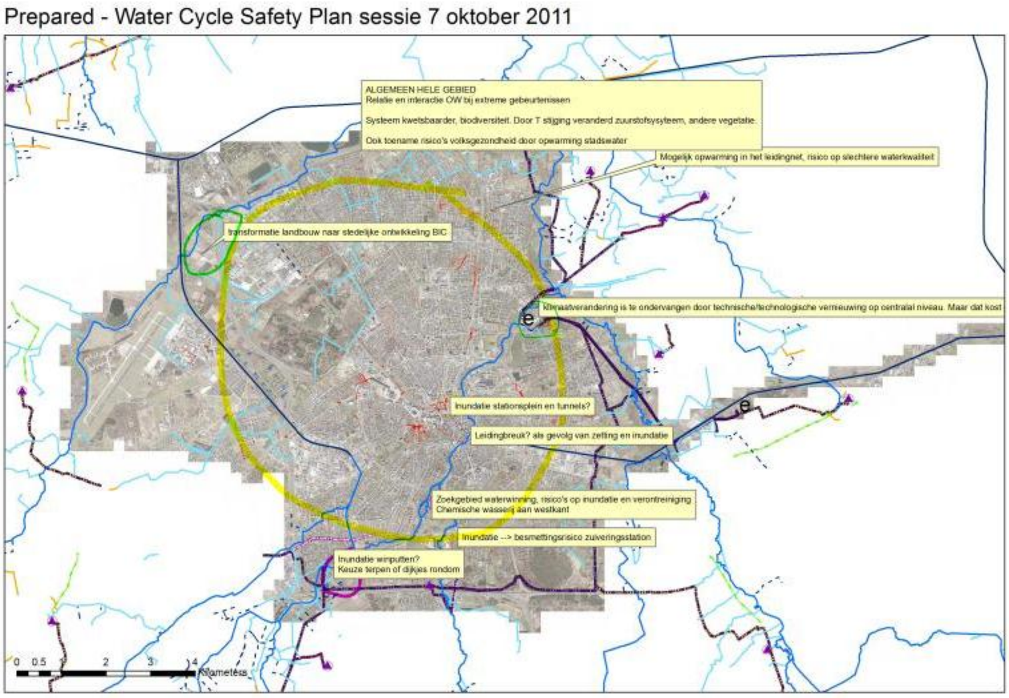

Figure 4 Example of a GIS table session outcome where points of interest in the Eindhoven water cycle are highlighted

Although the stakeholders regularly work together, this process did provide new insights for the various stakeholders. By overlooking the total system it became clearer how their sub-system was related to other sub-systems. During the process some potential risks were already identified.

2.2.2 *Objectives of the stakeholders*

The objectives of the stakeholders were very clear from the start:

Eindhoven municipality

- Safe environment for the population.
- Reduce nuisance for the population.
- Create an attractive living environment.
- Be efficient (costs, environment).

Water board De Dommel

- Protect/improve the ecological quality of the surface water, especially the river De Dommel.
- Prevent fluvial flooding.
- Be efficient (costs, environment).

Drinking water company Brabant Water

- Provide safe drinking water to the population.
- Be efficient (costs, environment).

2.2.3 *Criteria and targets for products and services*

The stakeholders have to comply with legal criteria that are often technical requirements. For example, the rainwater system must be able to process a once every two years rainfall event. Another target deals with the number of combined sewer overflows (CSO's) that is acceptable given a rainfall event with a given return time. These targets aim to protect the surface water quality; however, such technical requirements may not achieve this. Therefore, the Eindhoven stakeholders water board De Dommel and Eindhoven municipality have also set a target for the water quality targets of water board De Dommel to comply with swimming water quality. This allows for a more creative approach than the conventional technical requirements.

2.2.4 *Difficulties*

- Stakeholders work at different scales that don't overlap with the municipality boundaries. Defining the water cycle within the urban boundaries excluded upstream and downstream causes and solutions of risks. It was decided to only study effects and solutions within the municipality but to include risk causes outside that area.
- System characterisation and risk identification were not completely separated in the process. As interactions are discussed, risks become apparent.

2.2.5 *Proposals for improvement of the WCSP framework*

- The WCSP framework assumes a very elaborate approach to reach a complete overview. For a city like Eindhoven this would require much work with little added value, since details are well documented in the subsystem. A more efficient approach focussing only on interactions between sub-systems would be welcome.

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

2.3.1 *Climate change hazards and scenario's*

The identification of risks was partly performed together with the characterisation of the urban water system. Secondly, the potential effects of climate change on the water cycle were discussed focussing on four risk drivers:

- Rise of temperature;
- Long period without rainfall (drought);
- A wet winter (long rainfall period);
- Extreme rainfall events.

Hazards that could occur due to these risks were identified, resulting in 5 to 10 hazards for each driver. In a second session these were discussed in groups using a risk inventory form (Figure 5). The form was based on the preliminary risk identification database (RIDB) an included the topics (Almeida *et al.*, 2011b):

- Event ID and title;
- Description;
- Hazard;
- Risk source;
- Risk factor;
- Consequence dimensions;
- Climate change (indicators and direct effects);
- System/subsystem where risk occurs;
- System/subsystem where exposure occurs;
- Stakeholders involved;
- Scenario;
- Documentation;
- Measures (current, planned, ideas).

The groups also tried to relate the risks to the hazard descriptions in the preliminary RIDB. This proved to be time consuming also due to discussions on what was meant in the database and the fact that descriptions often didn't really cover the issues in Eindhoven.

Event ID and Title (Number and short title)
3 A winter with a lot of precipitation
3.1 Increase in runoff into surface water system, leads to inundation (upstream) of urban area and gives risks
3.1.1 Health problems due to hampered sewer drain is

Description (Describe what occurs, under what circumstances)
The water in the Dommel river is high and rainfall cannot reach the Dommel river through stormwater drains, resulting in water on the streets. The sewage drain is blocked and sewage surfaces to the street along with storm water.

Hazard (What is the risky situation that occurred? See checklist)
Presence of microbial pathogens (virusses, bacteria, protozoa and fungi) in floodwater that is accessed by humans

Risk source (What is the source of the risk?)
Pathogenic microorganisms in sewage
Or Flooding from combined sewers

Risk factors (What contributes to a risk?)
Exposure time (duration of rainfall)
Receiving water level (level of Dommel river)
Design related: Inadequate construction specifications

Consequence dimensions (What kind of consequences can occur? See list)
Health and safety
Reputation and image

Climate change
- **Indicators** (Global changes, see list) Increase of winter precipitation
- **Direct effects** (Consequence for the water system, see list) Increased river flow-> LEVEL
-

System/Subsystem where risk source occurs (Where the risk arises in the water cycle? See also list)
Catchment (upstream area caused high water level in the Dommel river)
Wastewater/storm water system (combined sewers)

System/Subsystem where exposure occurs (Where to find the place of exposure to the risk? See also list)
Urban Catchment? On streets, especially low parts

Stakeholders (Which stakeholders are involved, both inside and outside the WCSP team?)
Water board and municipality
Civilians, Health authority, Firefighters (pumping floodwater), Ministry\regulator, State water board

Scenario (Under which scenario occurs the risk?)
- Current estimate (1/100 year, no. 8 rainfall event) Very unlikely, these high elevations have not occurred as a result of a wet winter so far.
- Estimate climate change (scenario … year …)> 1/100 years
- Crossover points (at which the risk situation changes suddenly?)

When water in street occurs, when sewage comes up from the sewer, dry warm weather when street is still flooded (children play in the water)

Documentation (Relevant documents or information)
No

Figure 5- Example of a risk inventory form used to systematically describe risks

For one the characterisation made clear how complex urban water systems can be. Simply describing cause and effect often isn't possible since this depends on preconditions and coinciding events in the water cycle. The discussions did help to increase insight in the interrelationships between the subsystems.

2.3.2 *Difficulties*

- The complexity of the system is hard to capture in cause-event descriptions.
- Many risks have gradual effects, is water on street an event when it is 1 cm or 50 cm?
- Events in the RIDB were described with a certain system in mind. This is not always transferable to your own system. Some descriptions are hard to understand.
- The RIDB is in English and translating terminology from Dutch to English (and back) can be hard. The stakeholders don't regularly use English as a working language.
- Descriptions of events need to be concise, but short descriptions also lead to misinterpretation by others or when events are discussed again after some time.
- Sometimes it is hard to separate events completely. Often there are overlaps between events.

2.3.3 *Proposals for improvement of the WCSP framework*

The WCSP must be flexible enough to allow implementation in different contexts and cultures.

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

2.4.1 *Likelihood and consequences for each event*

The likelihood and consequences for events were discussed in the third WCSP workshop. Some types of consequences increase gradually, and then make a stepwise increase in consequence, e.g. a threshold level is exceeded causing damage. These are hard to capture in the current WCSP concept of likelihood and consequence. A large number of events would have to be defined for each combination of likelihood and consequence. An example is water on streets (due to various causes). A little water on the street is nuisance, but with increasing water depth the level of consequence increases. A one centimetre flood is more likely than a 30 cm flood but the latter has a higher impact. Thus the question rises which combination of flood level and likelihood should be considered an event. When the water exceeds the thresholds of houses, the consequences increase by a step as a lot of damage is caused etc. Currently for some events limits are set for design purposes (e.g. 1/20 year rainfall can cause houses to flood). This is illustrated in Figure 6.

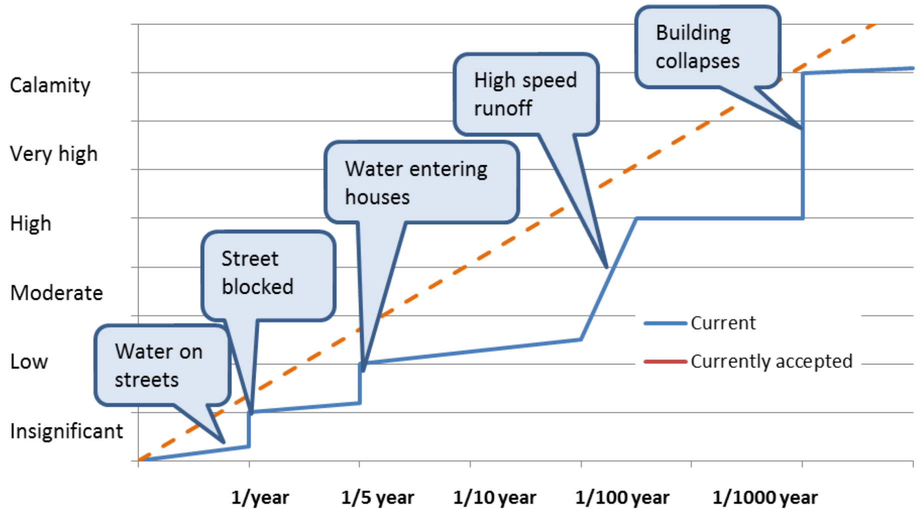

Figure 6 - Representation of gradual and stepwise increase of consequences for a flooding event

Climate change will change the likelihood of events occurring and thresholds being exceeded, not the thresholds themselves. This may lead to exceeding the acceptability (see Figure 7).

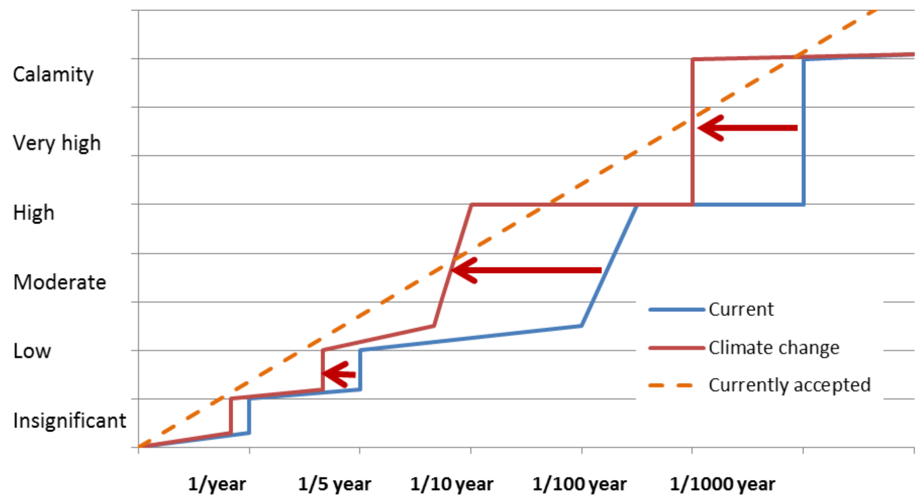

Figure 7 - Representation of how climate change can affect gradual and stepwise increase of consequences for a flooding event, exceeding the currently accepted situation

This representation helped the discussion on likelihood and consequence to focus on steps of increasing consequences. Still the discussions could become complex. Two examples are given here.

High groundwater level

High groundwater levels during a wet winter can lead to water in the ventilation space beneath houses and to water rising through the walls. This can result in an unhealthy interior climate. However, indoor climate is also impacted by the behaviour of the house owner. Sufficient ventilation can prevent issues. Also proper house construction will prevent these issues. Therefore the groundwater level itself is not a good indication of consequence. Rather than taking expensive measures to reduce groundwater levels, house owners are educated about their responsibility to create a healthy in-door living environment.

Surface water quality

The continuous efforts to improve surface water quality have led to increased recreational use of surface waters. This trend is expected to continue as water quality increases and climate change leads to warmer summers. However, the surface water quality is vulnerable to different risk scenarios. Increased water temperatures leading to cyanobacteria blooms, periods of drought reduces refreshment and wastewater spills and CSO's due to heavy rainfall events. Since water is now used for recreation, the consequences of poor water quality also increase. So by improving water quality, consequence levels also change, whereas keeping current poor water quality would prevent these consequences. Such interaction is hard to include in a frequency and consequence evaluation.

2.4.2 *Level of risk for each event*

For Eindhoven the WCSP team decided not to try a semi-quantitative risk assessment. This would require an extensive amount of time and was expected to provide a false sense of accuracy. None of the consequences identified were substantial, generally limited to nuisance, water damage to individual properties or increased risk of diarrhoea. Likelihoods were in the range of a few times per year for small consequences to less than once per 100 years for serious consequences. After all, that is how the system has been designed and operated so far, and climate change may affect the frequency, but the relative occurrence of events is not expected to change much (a 10 cm flooding will still be more likely than a 50 cm flooding). So it was expected that extensive studies would not impact prioritisation.

The studies therefore focussed more on event location. Given the different scenarios, where would events occur? Extensive studies on rainfall patterns and the effect on sewers, CSO's, wastewater treatment, runoff on streets and flooding areas were performed. Thus, priority areas were identified rather than priority risks.

2.4.3 *Risk evaluation for each event*

As explained above, the risk evaluation was not performed by comparing risk estimates to targets. The studies focussed more on identifying critical aspects of identified risks in order to target risk management. The philosophy was not whether a certain situation complied to a risk target, but to identify what causes consequences to occur. This insight was used to design measures within the current constraints of budget and time.

2.4.4 *Difficulties*

- Good assessment of events requires time and resources. Most risk studies were performed outside the scope of the WCSP process.
- For many consequences no clear target can be set as acceptability is also influenced by current conditions and the resources needed to improve the situation.

2.4.5 *Proposals for improvement of the WCSP framework*

- A pragmatic approach can be added to separate relevant risks with serious consequences from less substantial risks. Less relevant risks often don't need explicit evaluation.

2.5 WCSP ▸ 5. Development of System Safety Plans (SSP)

Risk management for the different sub-systems has been on-going for ages (literally). This has led to the current state of the system and risk management strategies by the stakeholders. Therefore, the WCSP process in itself was not the initiator for the 'system safety plans'. The stakeholders were asked for their recent activities with regard to system safety and climate change.

Drinking water

The drinking water company Brabant Water has developed a water safety plan for one of its systems (not Eindhoven). Lessons learned from this approach were applied to the Eindhoven water supply system. Since this is a groundwater system, focus is on potential groundwater pollution, abstraction well integrity and protection of water quality during treatment and distribution. Hygiene codes have been developed by the joint drinking water industry as operational guidance for safe repair and works in distribution, treatment and abstraction. Brabant Water participates in several projects dealing with risks from climate change (Deltaplan hoge zandgronden, 2013; kennis voor klimaat, 2013).

Sewerage and waste water treatment

The water board De Dommel and Eindhoven Municipality worked together to reduce risks from sewage for ecological quality of the river Dommel in the KALLISTO project. This project addressed the effect of CSO's, treatment bypass and treated effluent quality on the water quality and related ecological effects. It focussed on active control of both the sewage network and the wastewater treatment to minimise the total impact. The integrated approach provided new insights resulting in strategies beyond simply increasing capacity. Instead measures focussed on exploiting current capacities by better (automated) control of the total system.

Pluvial flooding in the city

The municipality of Eindhoven conducted extensive studies to get insight in the risks of pluvial flooding. This required modelling of rainfall events, sewage capacity, surface flows and flooding areas. This included hydraulic studies like the WOLK GIS application (Tauw 2013). This provided insight under which conditions flooding of would occur and what damage might be expected (see Figure 8 and Figure 9).

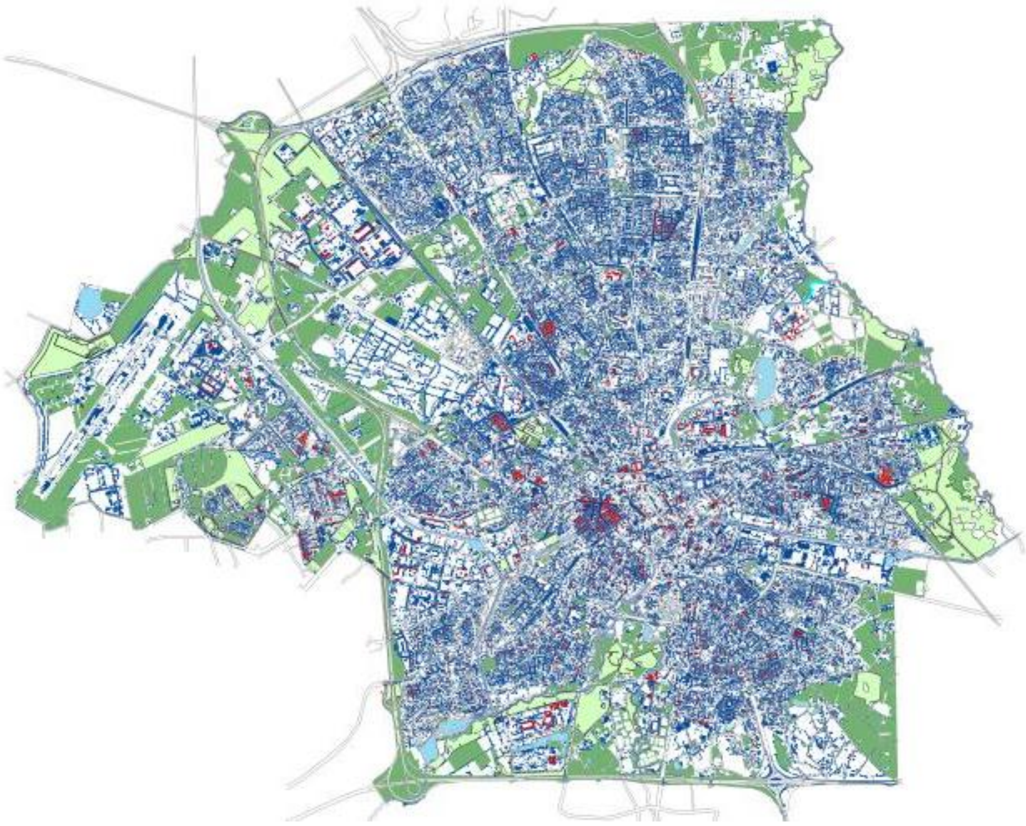

Figure 8 - WOLK simulation of water levels in streets after a rainfall event

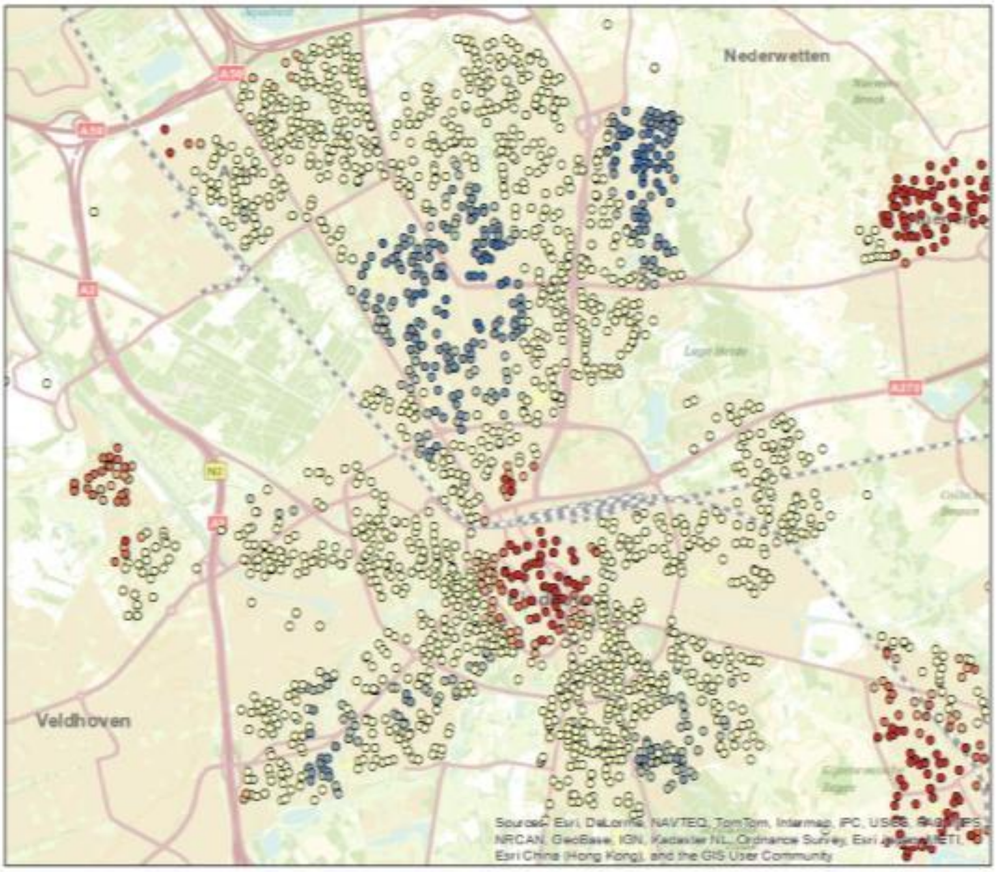

Figure 9 - Estimated damages from rainfall events

Fluvial flooding

The level of the river Dommel can rise significantly due to upstream events and operations. The effect of a 'flood wave' passing through Eindhoven was studied by simulations. This led to plans, including measures to protect specific vulnerable elements like groundwater abstraction wells and the Van Abbe museum. Other studies focussed on the total Dommel basin and how flooding events (in the city) could be prevented by controlled, designated water storage areas.

Cyanobacterial bloom

Risks for cyanobacterial blooms and measures to prevent them were studied. This resulted in plans for prevention and response.

2.6 WCSP ▸ 6. Integrated risk analysis and evaluation

2.6.1 *Aggregation of information from system safety plans*

The abovementioned studies and plans generally involved two or more stakeholders in Eindhoven already. These results were brought together during the WCSP workshops.

2.6.2 *Comparison and reassessment of estimated risks*

Several of the studies mentioned under 'system safety plans' ran parallel to the WCS process. Information was therefore exchanged throughout the process and findings at the system level were integrated at the WCSP level. Therefore a reassessment was not needed.

2.6.3 *Difficulties*

- Several similar projects can run at the same time. Challenge is not to duplicate work.

2.6.4 *Proposals for improvement of the WCSP framework*

- Allow for other structures of system safety planning to incorporate on-going activities.

2.7 WCSP ▸ 7. Integrated risk treatment

2.7.1 *Risk reduction measures*

Measures can be directed at reducing the likelihood of exceeding a threshold or reducing the consequence. Goal of measures is to retain a system that is acceptable for the population. This is illustrated in Figure 10. In some cases however the acceptability may also change.

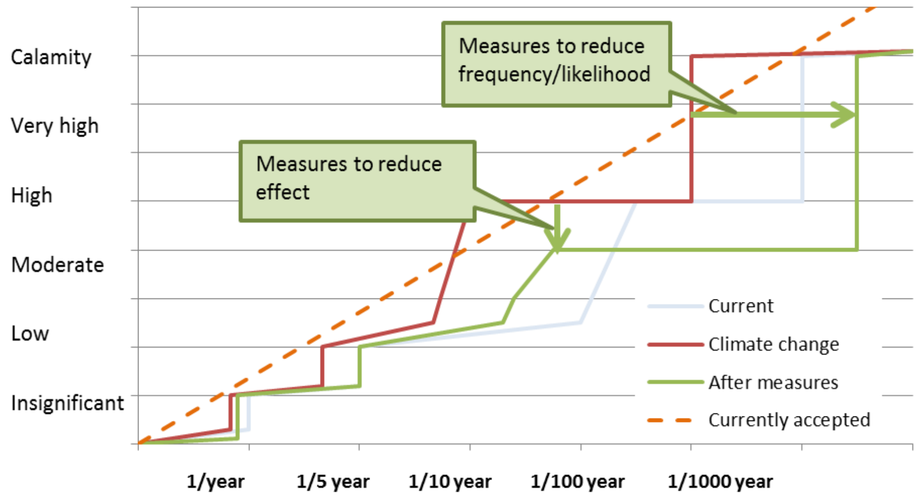

Figure 10 - Illustration how measures can reduce the likelihood or the effect of events occurring

Risk reduction measures were generally identified in the system studies. Bringing the measures together in the WCSP helped to check for any overlap or conflicting measures. In general, the proposed or implemented measures already take other effects into account. Some examples of measures are:

- Integrated control of sewage and wastewater systems to avoid negative impact on surface water quality. Using weather predictions, rainfall radar, current water levels in the sewer system, available capacity in treatment and operational conditions, valves in the sewer system are operated. Thus, the storage capacity in the sewer can be optimised to prevent overloading the wastewater treatment. Also water can be directed towards CSO's that have least negative impact. At the same time treatment is operated to be prepared for predicted changes in inflow volume or quality.

- Raising (or re-installing) sidewalk curbs to create water buffering capacity in shopping centres. Thus, the risk of water entering shops and properties after heavy rainfall is reduced. Similarly 'exit ways' were created where water can leave the overflowing streets and flow onto unpaved surfaces in areas that were prone to flooding.
- For new developments and during renovations separate sewer systems are built. Rainwater is generally diverted to local surface water to reduce wet weather flow. This process takes a lot of time though and positive effects will become apparent in the coming decades.
- Groundwater wells for drinking water production have been raised above ground level to prevent flooding of the construction. Communication protocols between the water board De Dommel and water company Brabant Water are in place. Thus, the water company can control the quality of the abstracted water during high water events and continue to guarantee drinking water safety.
- Groundwater levels during winter are kept below ground level. However, with traditional house building in the Netherlands this can lead to flooding of the ventilation space under the ground floor of houses. House owners are often concerned about moisture in poorly constructed houses, leading to health risks. The Eindhoven municipality has, together with the Dutch house owner association, started an information campaign to educate house owners how to prevent or remediate such moisture problems. This is regarded more efficient than large investments to control winter groundwater levels.
- The river De Dommel was adapted at some locations to create 'cold zones' where fish and other aquatic life can migrate to when water temperatures become too high in hot and dry periods. Also experiments with aeration of the river water after wastewater spills are conducted to prevent oxygen levels below ecological targets.

2.7.2 *Comparison, prioritization and selection of risk reduction measures*

The WCSP framework suggests a purely technical and very formal comparison and selection of risk reducing measures. In practice, such choices are driven not only by technical aspects, but also by politics, feasibility of implementation, financial planning, public opinion and recent events. The WCSP approach allows for inclusion of such aspects and this is also addressed in the viability of risk reduction measures in the database. However, the Eindhoven WCSP team did not attempt a multi-criteria evaluation to support evaluation and choice of measures. Instead a more pragmatic approach was chosen in Eindhoven. Given the current boundaries of existing infrastructure and annual investment plans, smart, no-regret improvements are made. Examples are mentioned under 3.7.1.

The current risks from the water cycle in Eindhoven are not very significant, mostly resulting in nuisance or limited damage. Current infrastructure and operation is also expected to be sufficient to prevent major consequences under climate change conditions. As a consequence there is no incentive for large scale investments to deal with risks. Therefore prioritization is not so much an issue. Risk reduction measures are more in the line of non-regret measures and using available opportunities to improve the resilience of the system.

2.7.3 *Risk treatment program*

The WCSP process did not lead to a new risk treatment program. The knowledge gained in the process is used to test new developments and to support decisions. Actual programmes of change are dealt with between the involved stakeholders, mostly the Eindhoven Municipality and water board De Dommel. Some of the risk reduction measures have been embedded in other programmes, e.g. re-introduction of sidewalk curbs has been implemented in the design guidebook for public spaces in Eindhoven.

2.7.4 *Assessment of residual risk*

Residual risk can remain mainly in nuisance or small damage. Information and education can lead to increased acceptability. Incidental nuisance is more acceptable when your monthly taxes are lower and incidental damage can be insured.

2.7.5 *Difficulties*

Developers often don't take rare events into account and may build for example in flood-prone areas. Once the properties are handed over to the owner, the developer is no longer responsible. The owner has to deal with the consequences when the risk event occurs.

2.7.6 *Proposals for improvement of the WCSP framework*

The WCSP framework should allow for opportunities that are beneficial even though they may not have the highest risk score.

2.8 WCSP ▸ 8. Management and communication programs and protocols

2.8.1 *Communication programs and protocols*

Communication between stakeholders takes place regularly in terms of public service cooperation and in specific projects. Communication with the public takes place through information campaigns using letters, the internet, community meetings, local interest groups and technical visits.

2.8.2 *Management programs and protocols*

Management programs and protocols are in place to inform relevant stakeholders and others in case of events. One example is the communication protocol of the water board during a potential fluvial flooding event. For each (predicted) water level at specific vulnerable points in the city it is defined who needs to be contacted. This can be the water supply company when well fields may be flooded or the municipality when the museum is threatened.

2.8.3 *Difficulties*

Communication during an event needs to be prompt and adequate. The events and potential responses may not be clear beforehand.

2.8.4 *Proposals for improvement of the WCSP framework*

None.

2.9 WCSP ▸ 9. Monitoring and review

2.9.1 *Tasks and responsibilities*

For Eindhoven, the WCSP project did not result in a specific plan that needs to be monitored and reviewed. Developments will continue in various cooperative efforts and projects related to the water cycle. The stakeholders in Eindhoven don't see the added value of centralising these developments.

2.9.2 *Difficulties*

Projects in the urban water cycle all have their own dynamics and issues. Bringing these together in a WCSP concept is generally regarded as an extra effort with little added value.

2.9.3 *Proposals for improvement of the WCSP framework*

None.

3 Conclusions

The Eindhoven UWS does not face high risks, nor is climate change expected to increase risks to a level where serious health or safety issues would occur. However, environmental risks for the river Dommel can be significant, and direct and indirect damage is expected to increase through climate change. The WCSP project allowed stakeholders to exchange knowledge and identify new risks. Good cooperation between stakeholders on the most important risks already existed. Criticism on the WCSP was that it was formal and required much time to complete all steps to the full extend. Since no mayor risks or investment decisions are at play in Eindhoven, there were doubts if fully going through the steps would be efficient. Therefore the WCSP philosophy was adopted in a more pragmatic way, using the benefits of interaction and systematic approach but being efficient in choosing which issues to address. The demonstration highlighted the challenges of performing integrated risk management between all the daily activities and disturbances.

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