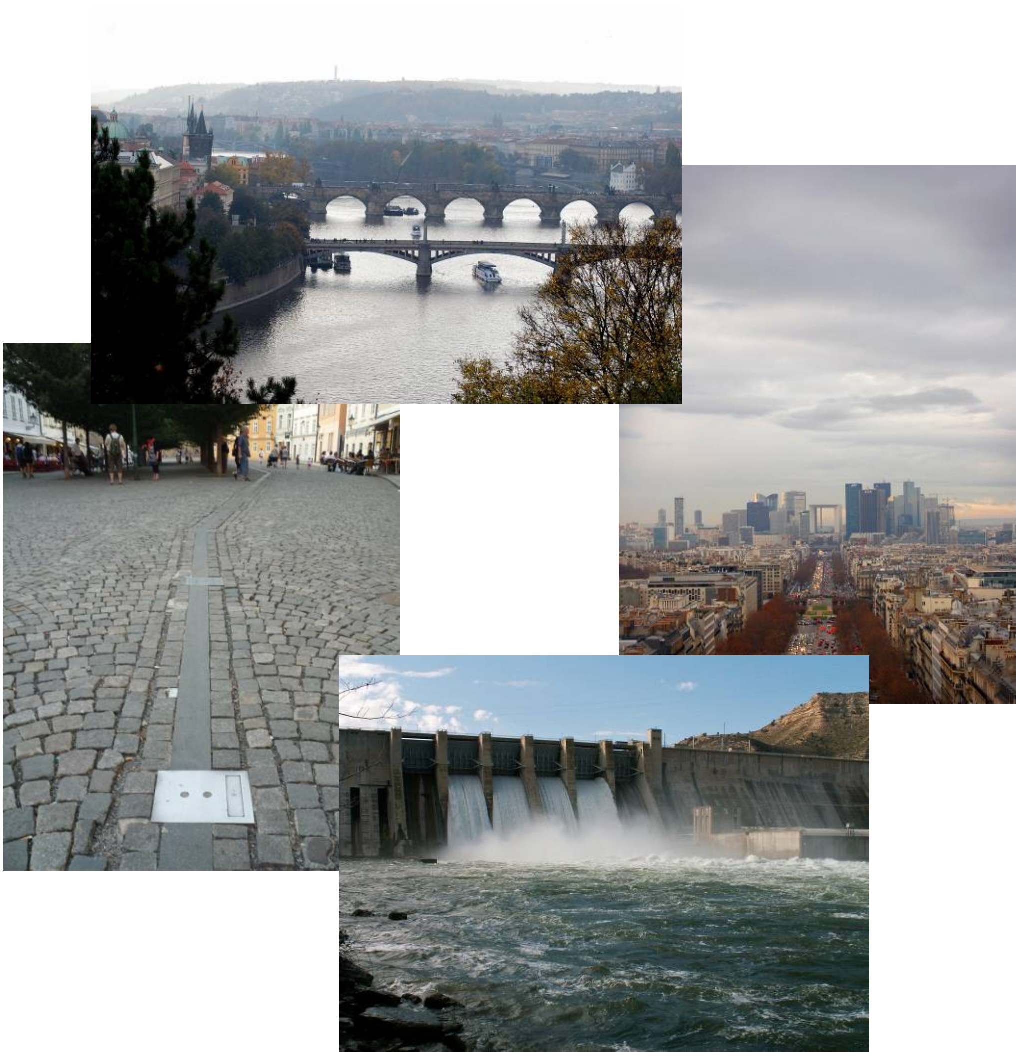
D1.1.1 Catalogue of European adaptive initiatives of the water sector to face climate change impacts



D1.1.1 Catalogue of European adaptive initiatives of the water sector to face climate change impacts V3 (Final version 2011)

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Summary

Water is one of the sectors where climate change will be most pronounced. While the extents of the impacts are not known yet, it is the right period to prepare the utilities to adapt to the global changes in an urbanising world. Adaptation to climate change, though not always perceived as such, is often already reality in the urban water sector. Several adaptation strategies have been tested to address the key questions: Adapt to what? What to adapt? How to adapt?

In this context, within the framework of the EU-project PREPARED, a tentative classification and catalogue of implemented initiatives in the water sector has been compiled. This catalogue is organised into four major categories of initiatives: (1) risk assessment and management, (2) supply-side measures, (3) demand-side measures and (4) global planning tools.

The document aims at providing examples on how utilities could go ahead into preparing their water supply and sanitation systems to climate change. Initiatives include various measures ranging from the promotion of active learning to the prevention of sewer flooding and water conservation measures.

Within PREPARED, this catalogue is supporting the development of solutions. Being a living document, it is updated regularly along the project when new solutions and initiatives are known. In addition, this work and the subsequent database of adaptation initiatives are accessible to a broader audience thanks to the web-based 'WaterWiki' of the International Water Association (IWA).

Key words:
adaptation, climate change, water utilities, floods, droughts, temperature rise, sea-level rise

Contents

A glossary of terms used in the context of climate change *is available online on the WaterWiki (http://www.iwawaterwiki.org) and the PREPARED project web sites (http://www.prepared-fp7.eu).*

1 Introduction

Adaptation to the impacts of climate change, as a global phenomenon with local impact, has become a reality for many water supply and sanitation utilities (Fluet, Vescovi et al. 2009). Among other parameters, the degree of development of societies of the 21st century will be measured by their capability to adapt to climate change (Iglesias, Garrote et al. 2009).

While water is one of the sectors where climate change will be most pronounced, it is also one of the sectors where there is the highest adaptation potential (Smith 1997). For regions already known for unfavourable climatic conditions, the increased frequency or duration of extreme weather events over recent years has already led to unprecedented actions to adapt water supply and sanitation systems. These actions are not always directly perceived as adaptation to global climate change. Examples of adaptation can be found all around the world, driven by utilities and others. In Australia, all major cities, facing depletion of surface supply reservoirs had to develop alternative sources within a few years in order to continue to supply millions of inhabitants. In total, Australia is investing AUD$ 12.9 billion (B) in adaptation of the water sector to climate change, the country's largest investment in climate change adaptation (Australian Government 2011).

In an urban world with an increasing number of megacities, supplying the population with potable water will be a major challenge for the 21st century. In Europe, on average, 18 percent of total water abstraction is used for urban needs (UNEP 2004). Most of this urban water consumption is for domestic use. Even without climate change and increased urbanisation, cities already suffer a number of threats pertaining to the water cycle, including pollution and deterioration of natural ecosystem functions. The global changes will accentuate these threats.

Despite a large set of evidence that current systems will continue to be challenged, water utilities where no impact has been perceived thus far, are facing the question of uncertainties. Hallegatte for instance, showed that precipitation patterns in France may differ by up to 30 percent depending on the climatic model used for the long-term forecast (Hallegatte 2009). Hence, uncertainty is inevitably part of the climate change issue. Rather than preventing action, uncertainty should be integrated into the decision process (Ferret 2009). While the extents of the impact are not yet known, it is the right time now to prepare the utilities for change.

Since the report of (EEA 2007) ('The cost of inaction and the cost of adaptation') and the famous 'Stern review' (Stern 2007), it is known that the cost of action may be twenty times less than the cost of inaction, with one percent of the global GDP being invested in mitigation and adaptation strategies every year. Most studies underline the vulnerability of the major sectors of our economies. Therefore, the question is not 'do we need to adapt?', but rather 'what and how do we need to adapt?' (Ferret 2009).

Thus, the basic questions for utility decision-makers are where to invest and what to invest in, while not knowing the type or extent of impact that can be expected. This calls for a prioritisation of actions (Smith 1997). In this situation, many utilities are researching 'no-regret' solutions that would prepare the utility for variability and uncertainties, while securing their investment.

This document provides examples as to how utilities have or expect to respond in preparing their water supply and sanitation systems for the impact of climate change. It is a living document that will be updated regularly during the project when new solutions and initiatives become known.

Building a catalogue of adaptive solutions requires as a minimum a classification and typology. But since the definition of 'adaptation' itself is still a subject under discussion (Smit, Burton et al. 2000; Levina and Tirpak 2006), the choice was made to go back to the basics and to organise this document around three main questions:

- Adapt to what?
- What to adapt?
- How to adapt?

'It is not the strongest of species that survive, nor the most intelligent, but the one most responsive to change' - Charles Darwin –

2 Classification and typology

Adaptation in the context of climate change is defined by the Intergovernmental Panel on Climate Change (IPCC) as 'the adjustment in natural or human systems in response to actual or expected climate stimuli or their effects, which moderates harm or exploits opportunities'[1].

Adaptation practices refer to adjustments, or changes in decision environments, which might ultimately enhance resilience or reduce vulnerability to observed or expected changes in climate (Adger, Agrawala et al. 2007). With climate change, in contrast to common climate variability, adaptation cannot rely on short-term strategies, but rather on long-term, continuous but flexible strategies (Mukheibir 2008).

Adaptation practices can be differentiated in many ways, here for example, in terms of several 'dimensions': by spatial scale (local, regional, national); by sector (water resources, agriculture, tourism, public health, and so on); by type of action (physical, technological, investment, regulatory, market); by actor (national or local government, international donors, private sector, NGOs, local communities and individuals); by climatic zone (dry land, floodplains, mountains, Arctic etc.); by baseline income/development level of the systems in which they are implemented (least-developed countries, middle-income countries, and developed countries); or by some combination of these and other categories (Adger, Agrawala et al. 2007).

From a temporal perspective, adaptation to climate risks can be viewed at three levels, including responses to current variability (which also reflect learning from past adaptations to historical climates); observed medium and long-term trends in climate; and anticipatory planning in response to model-based scenarios of long-term climate change. The responses across the three levels are often intertwined, and indeed might form a continuum (Adger, Agrawala et al. 2007).

2.1 Adapt to what?

The purpose of adaptation is to be able to face and mitigate the adverse effects of climate stressors for the water sector, which are complex and multiple. Climate change may, amongst other things alter (Arnell and Delaney 2006):

- the reliability of water sources by changing the frequency of low flows and recharge, increasing the frequency of floods which may inundate bank side facilities, increasing the frequency of highly turbid flows and threatening abstraction points with saline intrusion;

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[1]IPCC, 2001. Climate Change 2001: The Scientific Basis, Third Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge, United Kingdom.

- the ability to treat raw water to potable standards by changing the frequency of inundation of treatment works and by changing the quality of the abstracted water;
- the reliability of the supply infrastructure, by for example altering reservoir safety;
- the demand for water and the ability to distribute water to meet customers' needs, particularly at times of peak demand.

However, the different water sources will be challenged unequally: while surface waters and shallow aquifers will be highly impacted on, deeper aquifers will be less impacted on both concerning water quantity and quality at least in the short to medium term (Meier 2011).

Systems for management of water throughout the developed world have been designed and operated under the assumption of stationarity (idea that natural systems fluctuate within an unchanging envelope of variability) (Milly, Betancourt et al. 2008). This implies that any variable (e.g., annual stream flow or annual flood peak) has a time-invariant (or 1-year–periodic) probability density function, whose properties can be estimated from the instrument record. In view of the magnitude and ubiquity of the perceived hydro-climatic change now under way, however, we can assert that stationarity should no longer serve as a central, default assumption in water-resource risk assessment and planning (Milly, Betancourt et al. 2008).

Water infrastructure is a sector in which decisions should already take into account climate change, because they involve long-term planning, long-lived investments and some irreversibility in choices, and are exposed to changes in climate conditions (Smith 1997; Hallegatte 2009). In 2006, the annual global investment in water infrastructure exceeded USD$ 576 B (Ashley and Cashman 2006). Hence, regarding these huge investments, the implementation of adaptive measures should not be delayed.

2.1.1 Water scarcity

According to the European Commission (European Commission 2010), droughts have dramatically increased in number and intensity in the EU over the past thirty years. The number of areas and people affected by droughts went up by almost 20 percent between 1976 and 2006. At least 11 percent of the European population and 17 percent of its territory have been affected by water scarcity to date. Average summer flows in the rivers of Southern England may decrease by 30 percent by 2020 (Arnell and Delaney 2006), a similar reduction is forecasted for South Africa (Ludwig, Kabat et al. 2009), while average stream flow reduction in Ontario, Canada, could reach up to 40 percent (de Loë, Kreutzwiser et al. 2001). This may also have an influence on water quality during low flows (DEFRA 2007).

Water scarcity may be somewhat counterbalanced in Europe by the fact that the average water saving potential can be estimated between 18 and 47 percent (Dworak, Berglund et al. 2007).

The European Commission has identified eight main policy options to address water scarcity and drought (European Commission 2010):

- Putting the right price tag on water;
- Allocating water and water-related funding more efficiently;
- Improving drought risk management;
- Considering additional water supply infrastructure;
- Fostering water efficient technologies and practices;
- Fostering the emergence of a water-saving culture in Europe;
- Improve knowledge and data collection;
- Balancing ecosystem needs with human (habitats directive).

2.1.2 Sea Level Rise

In 2007, around ten percent of the world's population lived in coastal areas of low elevation (10m), with two-thirds of the world's largest cities (> 5 million inhabitants) at least partially located in these low areas (McGranahan, Balk et al. 2007).

The primary causes of sea level rise are the loss of land-based ice on Greenland and Antarctica and on mountains and the thermal expansion of oceans due to warming. As a consequence, the IPCC's 2007 report presented model results suggesting a global sea level rise of 18-59cm for 2090-99 compared with 1980-99. Recent studies suggest that IPCC projections of sea level rise by 2090–2099 are underestimated by roughly a factor of 3 (Grinsted, Moore et al. 2010).

Sea-level rise may have an effect on salinisation of coastal aquifers and lakes (Bonte and Zwolsman 2010), as well as on coastal settlements due the increased risk of sea-induced flooding.

2.1.3 Temperature changes

Globally, the world will get warmer. For Europe, climatic scenarios give estimates ranging from 1 to 5.5° Celsius by 2100 (Alcamo, Moreno et al. 2007). This will impact the biological and chemical processes driving water quality, as well as the anthropogenic interactions.

Records of Dissolved Organic Carbon (DOC) concentrations in 22 UK upland waters have shown increases of an average of 91 percent during the last 15 years. Increases have also occurred elsewhere in the UK, northern Europe and North America. From examination of recent environmental changes, spatial patterns in observed trends, and analysis of time series, it is suggested that DOC may be increasing in response to a combination of declining acid deposition and rising temperatures (Evans, Monteith et al. 2005).

In trend analyses of 62 streams of varying catchment size and characteristics in southern Sweden showed increasing total concentrations of Arsenic (As) and Vanadium (V) (Wällstedt, Björkvald et al. 2010). The authors suggested that the increasing trends of As and V are to a large extent due to increasing concentrations of colloidal Iron (Fe), which is stabilised by increasing concentrations of DOC – what could be called a 'snowball effect' from temperature rise and other factors.

Changes in water temperature may also impact water quality in reservoirs and removal efficiency in water treatment and wastewater treatment plants. Generally, an increase in water temperature is expected, changing for instance lake/reservoir stratification and mixing patterns that may result in complete oxygen depletion in the deep waters and an increase in sediment release of nutrients (Coats, Reuter et al. 2010). However, earlier snowmelt in some regions may also impact negatively the wastewater treatment processes (Plósz, Liltved et al. 2008).

Finally, temperature rise may also have a direct impact on the availability of surface and groundwater resources. With potentially increased mean annual temperatures, surface water reservoirs, canals and streams will have to face increased evaporation (Moore 2011), causing serious disruptions to regions relying essentially on surface water sources, while groundwater recharge will be poorer, threatening vulnerable aquifers. In parallel, the water demand of green areas and ecosystems will increase due to higher evapotranspiration, resulting in an additional demand.

2.1.4 What to adapt?

The 'targets' for adaptation are both:

- the technical equipment and other assets related to urban water supply and sanitation;
- the thinking and handling behaviour of the stakeholders, communities and individuals concerned, since water management concerns everyone.

Hence, the adaptation strategies may focus on:

- water utilities assets and infrastructure, such as pipes (leakage control) and production sites (adaptation to changed water quality, alternative sources, altered groundwater recharge etc.), much of which will be potentially exposed to increased flood damage;
- the management of water demand and supply (quantity, quality), including the balancing of environmental and human needs;
- the differentiation between the destinations of water (irrigation, household use, etc.), as well as their evolution (e.g. due to longer growing season for agriculture, heat waves and concomitant urban demand);
- the management of pollution risks, due to changes in water quality or due to changes in frequency and severity of rainfall events (sewer overflows);
- the enhancement of the natural assimilative capacity of water bodies receiving treated wastewater discharges.

2.2 How to adapt?

Ideally, adaptations strategies should be (de Loë, Kreutzwiser et al. 2001):

- 'no-regret' solutions – i.e. yielding benefits whatever the scenario, and potentially reversible or abandonable;
- effective;
- feasible;
- minimising environmental impact and not transferring impacts from one sector to another (e.g. water to air pollution);
- cost-effective;
- equitable;
- reducing the vulnerability (or at least, not increasing it).

Adaptation strategies do not always fulfil all the above mentioned criteria simultaneously. Being very diverse, the next subsections will begin to classify adaptation measures according to some major characteristics.

2.2.1 'Soft' versus 'hard' strategies

It is common to distinguish between 'soft' (governance, institutional, cultural, social and human capacity as a whole) and 'hard' (infrastructure and other engineering) solutions (Obeng 2008). These two concepts may also be classified as 'structural' and 'non-structural' measures (Ashley, Newman et al. 2008). More specifically, soft solutions include (Hallegatte and Dumas 2008; Hallegatte 2009):

- governance (laws, processes and arrangements) – mono or multi-level;
- planning , which includes studies of possible impact of climate change;
- water management;
- insurance and financial capacity of systems for resourcing change;
- emergency and warning systems;
- support to impacted population, etc.

In contrast, hard measures may be, for instance:

- water storage (increased reservoir capacity);
- alternative water sources;
- water and wastewater reuse, rainwater harvesting;
- water transportation;
- dikes, seawalls, reinforced buildings, etc.

Soft adaptation strategies are often better able to manage uncertainty than hard adaptation strategies, the latter being often related to long-term investments and locked-in technologies that dictate a certain technological pathway into the future (Walker 2000; Hallegatte and Dumas 2008; Brown, Ashley et al. 2011).

2.2.2 *'Demand-side' versus 'supply-side' strategies*

Another distinction can be made between 'demand-side' and 'supply-side' water adaptation measures (Arnell and Delaney 2006; Bates, Kundzewicz et al. 2008). Supply-side options generally involve increases in storage capacity or abstraction from water courses, whereas demand-side options aim at controlling or even decreasing demand, and achieving a balance between supply and demand (Kundzewicz, Mata et al. 2007; Bates, Kundzewicz et al. 2008). Supply-side options include (Arnell and Delaney 2006):

- finding new sources of water (reservoirs, groundwater development, transfers…);
- enhancing existing water sources (aquifer recharge and indirect potable reuse);
- improving the efficiency of resource utilisation.

On the other hand, demand-side measures may, for instance, be:

- reductions of leakages in water supply mains;
- use of water-efficient equipment and fittings;
- water reuse, rainwater or stormwater harvesting;
- promotion of water-sensitive behaviours.

While demand-side options may lack robust practical effectiveness because they rely on the cumulative actions of individuals, some supply-side options may also be environmentally unsustainable, such as additional abstractions from the environment (Kundzewicz, Mata et al. 2007; Bates, Kundzewicz et al. 2008). A combination of each types of strategy is usually the most effective, but in general supply-side options should only be implemented once all the opportunities for demand-side measures have been exploited (Arnell and Delaney 2006).

Until the early 1990s, supply-side adaptation strategies dominated water resources planning ('predict-and-provide approach'). However, by the mid-1990s, and especially since the 2000s, much European legislation has urged a twin-track approach, considering both supply and demand (Arnell and Delaney 2006). This was due to:

- the very inefficient use of water in some areas; in particular, large proportions of the water being put into supply were being lost through leakage;
- the increasing difficulty to obtain approval for major works, such as reservoirs, both for environmental and local political reasons;
- a shift in resource management attitudes in general, which had changed away from the conventional predict and provide approach towards the management of demands, along with the growing importance of the concept of sustainability among stakeholders.

2.2.3 *Other possible classifications*

Several other classifications of measures are possible, for instance:

- 'Centralised' versus 'decentralised' measures: the measure can be implemented at one facility or place for a large area, or distributed around the entire area (Tjandraatmadja, Cook et al. 2009);
- 'On-site' versus 'off-site' measures: the measure can be local, at the impacted area, or include a delocalisation, e.g. by transportation of water to another site to be treated or discharged;
- 'Reactive' versus 'anticipatory' measures: measures can be taken in reaction to a consequence of climate change, or taken in advance, anticipating an event (Smith 1997);
- 'Planned' versus 'autonomous' adaptation: autonomous adaptation is frequently cited for the agricultural sector and in developing countries. In the urban water sector of developed countries, most adaptation initiatives are, to a certain extent, planned;
- 'Top-down' versus 'bottom-up' adaptation: top-down are approaches generally driven at a global or national level, are climate-scenario oriented, whereas bottom-up approaches are generally more local, participatory and solution-oriented approaches (Ludwig and Swart 2010). The two approaches generally use similar tools, but with different perspectives. While most countries have developed a national adaptation strategy, climate adaptation policies are mostly initiated and proposed at a regional or municipal level (Ferret 2009). The present catalogue will hence highlight examples of adaptations at various scales, with the most common examples being at a local (municipal) scale.

These classifications, which are oriented to focus on the methods or policies of adaptation rather than being effect- or result-oriented, will not be used here since they are not sufficiently characteristic and informative. Moreover, some criteria may be somewhat overlapping (e.g. decentralised measures are always 'on-site'; autonomous adaptation is often community-led, and hence a 'bottom-up' adaptation). Each initiative will, however, be rated regarding these criteria in the related database.

2.2.4 *Coping with uncertainties*

Adaptation strategies will need to address the inherent uncertainties of climate change. Infrastructure should be designed acknowledging (1) that it will need to cope with a larger range of climate conditions than before; and (2) that this range is and will remain highly uncertain (Hallegatte 2009).

Unfortunately, uncertainties tend to increase with decreasing scale – while small-scale is often the scale of action. Climate models may well be unable to provide the information current decision-making frameworks need until it is too late to avoid large-scale retrofitting of infrastructure (Hallegatte 2009). However, uncertainties need to be addressed and, as stated earlier, action is usually preferred to inaction from an economic point of view, although the value of doing nothing until more information is available should not be underestimated. 'Flexibility' is now being included as a key parameter in adaptation accounting (Ingham, Ma et al. 2007; Gersonius, Ashley et al. 2010).

Thus, it is possible for instance to base decisions on scenario analysis and to choose the most robust solution, i.e. the one that is the most insensitive to future climate and socio-economic conditions, instead of looking for the best choice under one scenario.

As water managers can no longer rely on past weather data to provide a good representation of future weather patterns, it becomes critical to replace historical weather characterisations with those that reflect possible changes in weather due to climate change (Groves, Knopman et al. 2008). Due to these uncertainties, there is as yet no unique or universal adaptation approach or remedy (Kabat, Schulze et al. 2002).

2.3 Scope and organisation of this catalogue

2.3.1 Climate change adaptation initiatives considered here

An initiative is defined by the Oxford Dictionary as 'an act or strategy intended to resolve a difficulty or improve a situation; a fresh approach to something' (http://oxforddictionaries.com/definition/initiative?view=uk). This general definition applies also to the context of this catalogue, with initiatives covering acts (structural or non-structural measures) and strategies (adaptation-oriented steering, planning, and investment strategies) intended to address the challenge of climate change in the urban water sector.

While addressing a wide range of initiatives in this report, the scope is constrained to adaptation in the urban water sector, with special focus on the European continent. However, due to the global nature of climate adaptation, examples from other regions which could be relevant for adaptation in Europe are also considered.

All examples of initiatives in the water sector that aim at coping with climate change are generally 'eligible' to be considered in this catalogue. A check-list of questions is considered before including examples in the catalogue, among them:

- is this example *specific to the urban water sector*? If not, does it however potentially *benefit the urban sector*?
- is this example an adaptation to *climate change*? If not, may it however enhance *adaptability to climate change*?
- is this example relevant in the *European context*? (temperate, Mediterranean, continental climates; comparable socio-economic conditions...)

This report may not of course be completely exhaustive. The inventory of initiatives is complicated by the fact that many adaptation measures are not perceived as 'adaptation to climate change', but as simple long-term evolutions of a given practice, or as adaptation in response to a catastrophe, circumstance or event that is not directly perceived as a manifestation of climate change.

In addition, the nature of adaptation is multiple, with some measures not *directly* aiming at adapting to *climate change*. For instance water plans or investment plans greatly enhance the ability of a community to adapt to climate change and its uncertainties, even if these are not explicitly climate-oriented. They thus represent initiatives that are potentially relevant to a wide range of communities for adapting to climate change.

This catalogue is built as a 'living document', since new initiatives for climate change adaptation are being initiated and taken at anytime and in any place. It is, per se, evolving and will be continuously improved and appended. All suggestions are thus welcome and should be directed to the Authors or to the PREPARED-Project Management Team.

2.3.2 Adaptation or maladaptation?

The question of climate change adaptation is inherently complex, related to significant uncertainties, and relatively recent. Strategies which are followed now may be criticised in ten or twenty years, as the development of science and technology, and the return on experience progresses ('trial-and-error' approaches).

Hence, difficulties and drawbacks *known to date to our best knowledge* will be indicated where relevant. These also include collateral or unintended impact, and some of these drawbacks may under certain circumstances threaten climate change adaptation – in this case they are examples of 'maladaptation'. Long-term effects of initiatives may be unknown at the time they are implemented, and thus flexible, adaptive and no-regret solutions should be favoured.

It is re-emphasised here that climate change adaptation is a complex topic, and *initiatives undertaken in a given context may not be relevant in another context*. Hence, *the reader is warned against following adaptation initiatives undertaken in another climatic, geographical, environmental, economic or political context*. This is similar to what we know about sustainability and sustainable development; where context is an essential consideration.

2.3.3 Structure –classification adopted

To organise the report, a distinction is made between
(1) risk assessment and management initiatives (Section 3);
(2) supply-side adaptation initiatives (Section 4);
(3) demand-side adaptation initiatives (Section 5);
(4) global planning initiatives (Section 6).

The links between these adaptation measures are illustrated in Fig. 1 on two levels: the measure implementation level and the global planning level. Measures can be implemented according to an overall adaptation strategy using global planning tools.

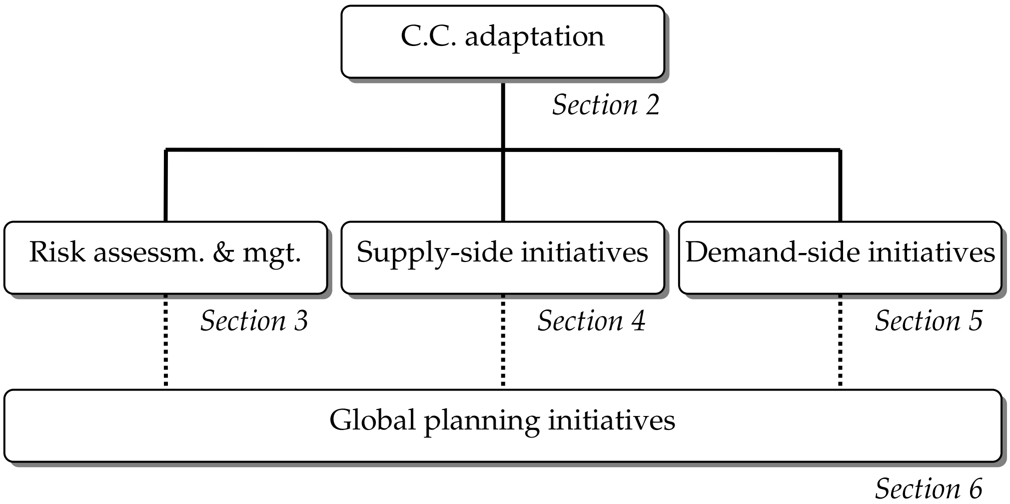

Fig. 1: different adaptation initiatives as organised in this report.

The initiatives considered in this catalogue have also been classified in terms of whether they are:

(1) initiatives at the stage of applied research or investigations, i.e. a small pilot project or the development of an assessment method;
(2) initiatives under development, i.e. a local/municipal/industrial-scale demonstration project or a measure that is currently being implemented;
(3) initiatives that have already been implemented for the purpose of climate change adaptation.

To identify these different types of initiatives visually, the following icons have been used:

 for a research investigation,

 for an initiative under development,

 for an implemented initiative.

2.3.4 *Interaction of this catalogue with other project deliverables*

The initiatives listed in this catalogue are also registered in a database in MS Excel. This dynamic database follows the structure of the report and lists, for each initiative:

- the initiative reference number;
- the initiative category, subcategory and name (identical to the ones in the report);
- the status of the initiative (research, under development or implemented);

- the geographical information (continent, country, region, city);
- supporting information (type of adaptation strategy, risk addressed, is it part of WSUD, is it centralised or decentralised, local or distant, soft or structural, reactive or anticipatory, top-down or bottom-up?).

Each initiative is identified using a unique reference number, marked in the text as follows (example for initiative number 1): [#001].

Within the FP7 EU-project PREPARED, this catalogue and the related database are complementary to the Deliverable D2.4.1. on Risk-Reduction Measures, which is focusing in detail on responses in the domain of risk management (PREPARED 2011).

Several other EU-funded projects have dealt with or are dealing with different aspects of adaptation to climate change for the urban water sector. For instance, reference is made to a relevant and completed FP6 EU-Project SWITCH, which provides general information and specific examples of adaptation in the urban water sector (SWITCH 2011). Several other EU-funded projects are completed or still in progress, especially concerning the vulnerability to floods in the context of climate change (e.g. FP7-CORFU, FP6-FLOOD*Site*, FP7-FloodProBE, FP7-SMARTeST, INTERREG-IVB FloodResilienCity, MARE, SAWA, SKINT).

3 Catalogue of risk assessment and management initiatives

Fig. 2 shows the different categories distinguished here between risk assessment and management initiatives, detailed in the following subsections.

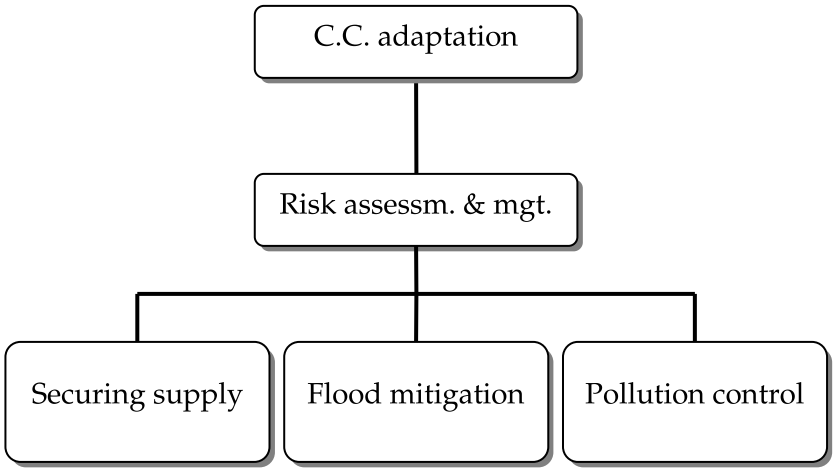

Fig. 2: different risk assessment and management initiatives.

3.1 Securing supply

Supplying safe freshwater is probably the most essential function of the water sector. The safe delivery of water under changing climate conditions can only be assured if adequate measures for risk assessment and management have been taken.

In this section, focus will be mostly given to adequate water quantity (related to drought risks and resource overexploitation), the hazards related to degradation of the water quality being addressed in the section on Pollution Control.

3.1.1 Diversification of water supplies

Principle and methods

- Diversifying water supplies prevents an overreliance on just one source and therefore reduce risks of water shortage (Ingham, Ma et al. 2007). The establishment of long-term water supply planning generally includes a survey of all potential sources and relying on at least two water sources.

Examples of initiatives

San Diego County Water Authority's long-term strategy focuses on diversifying the county's water supply to reduce the region's over-reliance on a single source of imported water. Several alternative water supplies are examined, including indirect and direct potable reuse of wastewater as well as desalination [#001].

➲ The Australian urban water sector is undergoing various institutional reforms under the direction of the National Water Initiative, and concurrently, state governments are revising water policies and plans to reflect the need for a greater diversity of supply sources (Brown and Farrelly 2007) [#002].

⚙ For the district of Melbourne, the diversification strategy includes a desalination plant, modernising irrigation infrastructure, expansion of the water grid, increased recycling and water conservation programmes (SWITCH 2010). Perth has a similar water diversification programme (Ludwig, Kabat et al. 2009) [#003] [#004].

⚙ In South Africa, several local authorities have diversified their water sources to include also more saline groundwater, which can be used for instance to flush toilets (Mukheibir 2008). These communities tend to rely on both surface and groundwater, driven by the increasing drought periods observed in the last decades [#005].

Potential difficulties, known drawbacks

None known to date.

3.1.2 Drought vulnerability assessment and modelling

Principle and methods

- Due to climate change, the number of regions facing droughts will be increasing, for instance in Mediterranean Europe (Alcamo, Moreno et al. 2007). The vulnerability of the water supply to droughts is modelled to assess the risks to which the system is exposed. To perform a preliminary risk assessment,
  - Average inflows to average water demand ratio,
  - Water demand to reservoir capacity ratio,
  - Reservoir capacity to average inflows ratio

  can yield essential information on the probability of system failure, the ability of the system to supply sufficient water, and ability of the system to overcome inflow irregularities such as droughts (Iglesias, Garrote et al. 2009).
- Risk analysis should include (1) the probability of failure occurrence, (2) the severity of failures, (3) the duration of failure, (4) the economic impact of failures (Iglesias, Garrote et al. 2009).
- Different thresholds for water scarcity can be defined: for instance in Spain, emergency scarcity (demand rationed to 80 litres per inhabitant and day and 50 percent of the demand satisfied for other activities), heavy scarcity (demand to be reduced by 26 percent) and severe scarcity (demand to be reduced by 9 percent) (Iglesias, Garrote et al. 2009). Accordingly, critical thresholds in the reservoirs and/or groundwater system can be calculated.
- A widespread method to assess drought risk is the Standardised Precipitation Index (SPI) (McKee, Doeskin et al. 1993), which enables the

calculation of drought vulnerability at different time scales (Iglesias, Garrote et al. 2009).
- Risk evaluation in water supply systems consists in identifying demands that may not be satisfied with available water resources during a shortage period, and quantifying the estimated impacts of water shortage (Iglesias, Garrote et al. 2009).

Examples of initiatives

In Potsdam, Germany, a groundwater scenario modelling has been conducted in order to assess the impact of climate change on the local groundwater resources. The model is used to adapt the city's strategy up to 2055 and to evaluate the need to search for alternative freshwater resources (Umweltbundesamt 2011) [#006].

In Berlin, Germany, in the framework of the water supply concept for 2040, climate change scenarios have shown that, by 2050, the discharge of surface water streams could be strongly affected during summers, with a proportion of treated wastewater which could be locally very high (Möller and Burgschweiger 2008). However, on the whole, the security of the supply was found to be secured even with an increase in water demand [#007].

In the U.S., (CERES 2010) has assessed the risks of shortage to which 8 public water utilities are exposed according to different scenarios of climate change. The assessment gives an overall risk score under baseline, supply reduction and storage reduction scenario by 2030, and evaluates the projected annual debt coverage based on current water rates and tariff structure [#008].

Potential difficulties, known drawbacks

- Difficulties associated with vulnerability assessment and modelling include the inherent difficulties of modelling complex natural processes, especially the fact that only known processes and parameters are included.

3.1.3 Drought management plans

Principle and methods

- Drought Management Plans (DMPs) are common in drought-prone areas and aim at organising and, if applicable, restricting the water supply during droughts. They are compulsory in some regions (e.g. Australia and some U.S. states). DMPs are flexible options to cope with increased drought risk induced by climate change, though per se not directly a climate change adaptation measure.

Examples of initiatives

The European Commission proposed general guidelines to develop DMPs in a Technical Report, defining the key indicators that shall be included, measures to be taken at the different drought phases to prevent further deterioration of water status, and the organisational framework to deal with drought (European Commission 2008). In the EU, drought management plans are not yet compulsory [#009].

Similarly, Queensland, Australia, has issued guidelines for the preparation of DMPs. In Queensland, DMPs are compulsory for water utilities, and contain (1) a service and system overview listing all facilities and infrastructure of interest, (2) the assessment of water resources and (3) an operational and management strategy (DERM of Queensland 2010) [#010].

Spain developed a National Hydrologic Plan in 2001, which obliged all basin authorities to develop special DMPs – a process which was finished in 2007 (Iglesias, Garrote et al. 2009; UN Economic Commission for Europe 2009). These plans include a drought monitoring system based on drought indicators and emergency drought plans for urban water supply systems (> 20,000 inhabitants). They include three alert thresholds: (1) pre-alert, (2) alert and (3) emergency, depending on the reservoir levels (Strosser, Kossida et al. 2007) [#011].

Several Sates of the U.S. have also developed their own drought management plans, for instance Tennessee proposed in 2010 an updated version of the first DMP of 1987, focussing on drought intensity determination, communication with the public, management of the resource, of wastewater discharges (DEC of Tennessee 2010) [#012].

Potential difficulties, known drawbacks

- Generally, DMPs are limited to reactive actions, and are not proactive.

3.1.4 *Sea-level rise vulnerability assessments*

Principle and methods

- Sea-level rise, caused by the melt of continental glaciers and by the thermal expansion of the oceans, is a consequence of climate change. It may become a hazard for coastal cities, and threaten the quality of coastal aquifers.
- Vulnerability to sea-level rise modelling may help to identify most critical areas prone to flooding, erosion or contamination of groundwater by seawater.

Examples of initiatives

Miami-Dade Water and Sewer Department initiated groundwater, salt intrusion and drainage/flooding consequences modelling in order to evaluate the necessary limitations in development of the most vulnerable undeveloped areas [#013].

Models have been developed and predict for instance that man-made freshwater lakes in the Netherlands, including the major Ijsselmeer Lake, could reach chlorine concentrations of 250 mg/L, which is above the maximum allowable concentration for drinking water (Bonte and Zwolsman 2010). Increased evaporation rates in the summer will even accelerate the phenomenon [#014].

The effect of sea-level rise and climate change on a coastal lake/aquifer system was studied in Denmark by (Sonnenborg, van Roosmalen et al. 2010). With mean sea level rise in the range of 0.5-1.0m, inflow of saltwater to the 6km-distant freshwater lake especially during late summer and autumn could threaten the ecosystem. The study concluded the necessity to take measures already at 0.5m sea-level rise, which is the maximum allowable rise to prevent inflows from seawater in the lake [#015].

On the Azores Island, Portugal (Mollema, Antonellini et al. 2010) showed that, due to changes in precipitation patterns and sea-level rise, freshwater springs will disappear and the freshwater lens underneath the Terceira island will shrink. The modelling shows that SLR-related flooding of the low areas will cause surface and groundwater salinisation, and that up-coning of saltwater by pumping could also increase. Since import of water from the mainland is not possible, the study urges local water conservation and protection of existing sources [#016].

Potential difficulties, known drawbacks

- Sea-level rise is less uncertain than other water-related Nonetheless sea-level rise modelling suffers from the uncertainties of climate change models, and is unequally distributed over the planet. Safety margins should hence be included in any adaptation or other measures designed to cope with or live with future sea-level rise.

3.1.5 Barriers to sea water intrusion in aquifers

Principle and methods

- Due to climate change and decrease in precipitation rates during long and intense drought periods, sea water intrusion in coastal aquifers and coastal lakes is going to be a major concern.

Examples of initiatives

The Torreele reuse plant on the Flemish Coast in Belgium reuses wastewater effluent for groundwater recharge of an unconfined dune aquifer since July 2002. The injection of the treated effluent enabled to reduce by more than 60% the salinity of the dune aquifer, and led to higher groundwater levels. In addition, adapted ecological management enabled valuable species to return to the site (van Houtte and Verbauwhede 2008) [#200].

On the Maldives Islands, the groundwater becomes very saline due to insufficient aquifer recharge. It becomes even more saline in the dry periods as the demand for groundwater increases. Infiltration galleries are hence used to supply ground water in the Islands (MEC 2004) [#017].

In California, the first sea water intrusion barrier was built as early as 1960. Today, several in situ replenishment plant are in operation, with increased use of reclaimed water to protect the coastal aquifers from further sea level rise (Atwater 2011) [#018].

Potential difficulties, known drawbacks

- Building up a sea water intrusion barrier may have negative impacts on the environment if the water for the barrier is withdrawn from surface waters, or imported from remote locations. In addition, the equipment may have a high energy demand.

→ *See also Section 4.1.3 (Managed Aquifer Recharge) and Section 4.2.6 (Indirect potable reuse)*

3.2 Flood mitigation

Apart from securing the water supply, the role of urban water systems is also to prevent floods or mitigate their impacts in urban areas.
Storms and floods are the most frequent and costly extreme weather events occurring in Europe, representing 69 percent of the overall natural catastrophic losses between 1980 and 2006 (CEA 2007).
Among the urban responses to floods, several initiatives fall within the concept of Water Sensitive Urban Design (WSUD), which is the integration of urban planning and development with the management, protection and conservation of water within a consideration of the water cycle as a whole (ATSE 2004). It may help mitigate climate change-induced floods, and also offers benefits, notably concerning the heat island effect induced by more frequent heat waves.
This approach recognises the important role of the natural catchment but focuses primarily on artificial city catchment solutions (including features located on roads, roofs and impermeable surfaces) to reduce wastewater generation and lessen the impact of stormwater discharges on receiving waters. The approach seeks local solutions to achieve sustainable water management, and to reduce the reliance on one centralised water supply or treatment facility. They also aim to minimise environmental and social impacts (NYCGP 2010).

3.2.1 *Vulnerability to heavy rainfall and sea-level rise assessments*

Principle and methods

- Climate change will impact precipitation regimes in most regions of the world, with, for Europe, generally more rainfall in the Western and Northern part (Kundzewicz, Mata et al. 2007). This will add to sea-induced storm events, which might become more threatening in the context of sea-level rise.
- Several countries will have to face higher and more intense storm or rainfall events, which may have serious impacts on the water and urban infrastructures, and call for an upgrade in urban flood defences. The assessment of vulnerability to these events can support this adaptation usefully.

Examples of initiatives

In Manila, Philippines, Ho-Chi-Minh City, Vietnam, and Bangkok, Thailand, a recent flood risk report has highlighted that storms exacerbated by sea-level rise could cause damage equivalent to 25 percent of the metropolitan areas' GDP. Measures such as land planning, and vulnerability to sea-level rise zoning are to be developed in order to reduce the cities' vulnerability (McCann 2010) [#019].

The Massachusetts State's StormSmart Coasts programme is working with Boston to identify particularly vulnerable low-lying areas that can be protected (http://www.mass.gov/czm/stormsmart/) [#020].

In Hamburg and Paderborn, Germany, the URBAS-project aims at better understanding flash floods in urban areas. The project covers the whole chain of events (precipitation, runoff, type and trend of damage…). In particular, it will issue guidelines for protective mitigation measures and a disaster control plan in case of emergency (Umweltbundesamt 2011) [#021].

The State of Baden-Wurttemberg, Germany, has developed a downscaled climate change model ('NiedSim-Klima') to predict precipitation patterns up to 2050 and subsequently adapt the design of its sewage system to the increased amounts of stormwater (LUBW 2010). The model is freely available for authorities and communities of Baden-Wurttemberg [#022].

To raise public awareness and identify the most vulnerable basins, indexes such as the Flood Vulnerability Index, have been developed. The FVI proposed by the Japan Water Forum for instance takes into account a hydro-meteorological, a hydrologeological and a socio-economic component, as well as the countermeasures that have been implemented (Connor 2006). It is usefully applied in the Philippines by the Department of Public Works to prioritise action [#023].

Potential difficulties, known drawbacks
None known to date.

3.2.2 *Prevention of sewer flooding (-> WSUD)*

Principle and methods
- Sewer flooding is mainly caused by hydraulic overloading of storm sewer systems, when pipes exceed their capacity, become blocked, have their capacity limited by river flooding, or a combination of these factors (Wheater and Evans 2009).
- There is a trend of increasing number of sewer flooding events due to climate change and urbanisation (Sun 2010). High sea levels and heavy rains can also cause extensive flooding of streets and basements. Installing sewer backflow valves can efficiently prevent sewage overflow from entering residences.
- Rainwater disconnection, i.e. the separation of the sewage system from the rainwater discharge system, is also a solution to prevent sewer flooding. In particular, the two systems can be dimensioned to fit their respective nominal discharges. Rainwater disconnection is a frequent strategy in Water Sensitive Urban Design (WSUD), and also part, in the U.S., of the LID (Low Impact Development) and Green Infrastructure initiatives.

Examples of initiatives

In Helsingborg, Sweden, a study has shown that the separation from storm water and wastewater was an efficient adaptation solution for climate change (Semadeni-Davies, Hernebring et al. 2008). The current Combined Sewer Overflow (CSO) system would not be able to cope with the additional water volumes resulting from climate change [#024].

In Reiderland, The Netherlands, a 'smart drain' was installed to cope with higher rainfall intensities without flooding the homes and still maximising the treatment of wastewater. The rainwater is separated from the wastewater at the source point: existing wastewater pipes are used only for rainwater (which is filtered and infiltrated), while a new, smaller system is built for domestic wastewater. The decoupling of the systems prevents sewer flooding and discharge of polluted water to the surface water, while minimising investment costs (reuse of existing pipes) (SenterNovem 2006). This also prevented the replacement of leaking drains, since they now only convey 'clean' rainwater [#025].

In Stadskanaal, The Netherlands, a disconnection of the roofs and streets from the sewer system was implemented during major road construction. Only the first flow, usually the most polluted, is collected and treated (SenterNovem 2006) [#026].

Prague has equipped its major sewer pipes with flood gates, and retrofitted CSOs in order to prevent sewer flooding from the Rivers Vltava and Elbe as a response to the 2002 rainfall events (Thames Water 2010) [#027].

Potential difficulties, known drawbacks

- Rainwater disconnection can be a cost-intensive measure and needs to be integrated in urban planning and / or renewal.

→ *See also Section 4.2 (Water harvesting and recycling)*

3.2.3 Urban flood defences (-> WSUD)

Principle and methods

- The impact of floods in urban areas can be dramatic for the population, the buildings, but also the water supply and wastewater treatment facilities. In fact, floods may deteriorate the water treatment capacity of wastewater treatment plants, by disrupting some water purification steps durably (MUNLV NRW 2010). Among urban flood defences, permanent, removable and temporary defences can be distinguished.
- Permanent defences are integrated in the urban infrastructure and remain in place even without a flood.
- A removable defence is pre-installed using guides or sockets within a pre-constructed foundation, but requires operation during a flood event, (Environment Agency 2002). Demountable flood defences hence enable a flexible approach towards floods. They are generally used to defend critical infrastructure (McBain, 2010).

- Temporary flood defences are another type of defences, which are only used during the emergency, and fully removed after the flood event.

Examples of initiatives

Some flood protection initiatives focused on the critical infrastructure for water supply and sanitation. In New York, U.S., the critical control systems of the wastewater treatment plants were relocated to higher grounds or floors in response to major storms (i.e. 1992 storm in the Queens District), and flood walls were partially installed on other critical infrastructure (NYCDEP 2005) [#028].

In Tewkesbury, U.K., Severn Trent Water installed in 2007 a permanent flood barrier to protect a water treatment work, with total costs amounting to £ 5.5 M [#029].

Dordrecht, The Netherlands, is an example of a city which has retrofitted the entire downtown area with flood defence measures, including large-scale demountable flood walls and slot-in barriers to protect individual house doors as part of a multi-level safety approach which is pioneering in the Netherlands and is now included in Dutch policy (van Herk, Zevenbergen et al. 2011) [#030].

The city of Hamburg, Germany, also has implemented a system of watertight flood gates and barriers along the river Elbe, particularly since the 2002 flood [#031].

In Grimma, Germany, a 2km-long permanent flood wall was integrated in the city centre as a response to the flood of 2002. The construction of this wall altered the rainwater management system, which was adapted to discharge rainwater only downstream the city (IFOK 2010) [#191].

Several removable flood defences are available on the market, for instance with sand-filled Big Bags (http://www.mobiler-hochwasserschutz.org), demountable walls (http://www.floodcontrolam.com/), flip-up barriers (http://www.floodcontrol.co.uk/), or water-inflated temporary dams (http://www.ifdp.co.uk/products/demountableSystems.html). A broad use of removable flood defences has been reported in the U.K., the U.S., Germany, Austria, and several other EU Member States.

Potential difficulties, known drawbacks

- The integration of urban flood defences in urban design needs to be carefully planned in order to promote their public acceptance, especially if they are designed to be permanent.
- The costs for traditional urban flood defences can be high and depend upon the required degree of protection.

3.2.4 SuDS – Decentralised rainwater infiltration and evaporation solutions (-> WSUD)

Principle and methods

- Sustainable Drainage System (SuDS) is an umbrella term for local , decentralised rainwater management techniques, which, in general, prevent runoff water to enter the sewers ('keep water above the surface'), or delay its discharge into the sewage system (Digman 2010). SuDS should be easy to manage, requiring little or no energy input, resilient to use, and being environmentally as well as aesthetically attractive (CIRIA 2011). Green Infrastructure (GI) is also an umbrella term used for several measures that rely on and strengthen the natural support functions of natural ecosystems (Wikipedia, 2011:Green infrastructure). It is officially pursued by the European Union (Council of the European Union 2011).
- In the frame of SuDS and/or GI, a wide range of materials and techniques for paving roads, cycle-paths, car-parks and pavements that allow the movement of water and air around the paving material is available to avoid, store and/or delay the discharge of rainwater in the sewers. Large volumes of urban runoff cause serious erosion and siltation in surface water bodies, and permeable paving surfaces have been demonstrated as effective in managing runoff from paved surfaces (Scholz and Grabowiecki 2007).
- These solutions usually have the advantage to be implementable during urban renewal or new building construction, which lowers their costs and accelerates their implementation compared to classical, large-scale solutions (de Graaf and van der Brugge 2010).
- Beside from offering additional storage volumes for rainfall, permeable paving surfaces keep the pollutants in place in the soil or other material underlying the roadway. They capture the heavy metals usually originating from traffic, preventing them from washing downstream and accumulating inadvertently in the environment.
- In Germany, the Federal Environmental Agency has pledged for the use of roads (highways, major and secondary roads) and public car parks to store and infiltrate rainwater (Umweltbundesamt 2011).

Examples of initiatives

➡ In Essen, Germany, a programme has been launched to reduce by 15 percent the rainwater runoff in the sewer system by 2025 (Umweltbundesamt 2011). This will be achieved by increasing the infiltration of rainwater notably in parks and green fields [#032].

➡ In Nijmegen, Netherlands, a green roof programme has been launched with the explicit goal to slow down the water cycle and to infiltrate water locally whenever possible (Umweltbundesamt 2011) [#033].

➡ Similarly, in Toronto, Canada, urban regulation imposes since 2009 that every building exceeding 2000m^2 needs to include a 'green roof' capable of storing and delaying the flow of rainwater (Umweltbundesamt 2011) [#034].

Germany has rainwater harvesting economic incentive programmes running: rain taxes – taxes collected for the amount of impervious surface cover on the property that generates runoff and contributes to the local storm sewer. In the Emscher region, Germany, € 4.5 M were invested in RWH and infiltration projects up to 1999 for flood protection (so-called 'Rainwater Route'). A subsidy of € 5/m² of disconnected impervious surfaces was paid to 82 projects. A Geographical Information System (GIS) was used to identify easily disconnectible surfaces and to monitor project progress (Thames Water 2010) [#035].

In Rouen, France, a new climate-proof business park ('Luciline') has been built in 2009 along the Seine river in place of a former 12ha impervious area. The new business park enables an almost complete decentralised management of stormwater, with infiltration ponds, local excess water storage areas and several swales (Umweltbundesamt 2011) [#036].

In Fagnières, France, the new housing development 'Champs aux écrus' was constructed without rainwater collectors. The rainwater is only conveyed to swales, trenches and infiltration ponds which are integrated in the city's parks and lawns (Dehan 2010) [#037].

In Malmö, Sweden, the Bo01 district includes alternative rainwater practices, with green roofs installed on every building and a delayed discharge of stormwater in the nearby Öresund bay (ARENE 2006) [#038].

A similar rainwater management system was also installed in the sustainable district of Vauban in Freiburg, Germany. In particular, the paved areas are all connected to infiltration trenches and a recreational pond which is used for excess stormwater management (ARENE 2006) [#039].

In the Kronsberg sustainable district in Hanover, Germany, only 2 percent of the rainwater is discharged to the sewer system, while 45 percent of the water is infiltrated and 53 percent evaporates. This was possible thanks to a system of trenches, swales and ponds, the 'Mulden Rigoles' which was extended to the whole district. Connected to infiltration ponds, the system enables an effective recharge of the aquifer (ARENE 2006) [#040].

The Beddington zero fossil energy development (BedZED) is a mixed-use housing scheme in south London, where a large building complex was equipped with permeable parking areas in order to minimise surface runoff of these traditionally impervious surfaces (ARENE 2006) [#041].

In Rezé near Nantes, France, specially paved roads were used at the large scale of a suburb with positive effects, reducing sewer and street flooding significantly in this wet region (Wagner, Néron et al. 2006) [#042].

Potential difficulties, known drawbacks

- Some of these techniques are not completely commercially developed, and shall only be implemented once experience feedback is available.
- Infiltration solutions need adequate soil and aquifer characteristics. In Berlin, Germany, local infiltration solutions combined to high groundwater levels have lead to cellar flooding.

- Issued related to water quality have not yet been investigated thoroughly.

→ *See also Section 4.2 (Water harvesting and recycling)*

3.2.5 Flood resilient constructions (-> WSUD)

Principle and methods

- Climate change will increase the frequency of floods in many urban areas. Building 'flood-resilient' consists in constructing in such a way that minimises water ingress and promotes fast drying and easy cleaning, not causing any permanent damage (Tagg and Escarameia 2008). In such, this approach is quite opposite to resistance measures (e.g. building dikes, reservoirs, etc.), trying to keep the water out of the buildings.
- Alternatively, flood resilient structures may also float on the water surface when the water reaches a critical threshold.

Examples of initiatives

Rotterdam Water City 2025, the Netherlands, is an ambitious programme to address water storage and quality in the city centre through green roofs, water plazas and smart levees. The city is divided in three major districts, each of it having a different role and strategy towards water. Among them, City Port, built on reclaimed land outside the dykes, is a floating city concept (de Graaf and van der Brugge 2010) [#043].

In Melbourne, Australia, an ambitious Water Sensitive Urban Design (WSUD) programme is being implemented, including wetlands, rain gardens, storage tanks and permeable surfaces (NYCGP 2010). The programme also introduces changes to road maintenance, building and construction practices for conserving water, water harvesting, improving water quality, and improving the health of waterways. A sustainable building programme with the private sector to reduce energy and water use is also to be launched (1,200 Buildings Program) [#044].

In Maasbommel, the Netherlands, floating houses were built along the river Meuse. Equipped with a waterproof concrete casing, the houses float on water during flood events. The water and power supply, as well as the wastewater systems are designed to be flexible, in order to withstand flood events [#045].

In Hamburg, an entire new suburb, the HafenCity, is built in a flood-prone area, and no dike protection was constructed because of prohibitive costs. The planners preferred instead to enable floods to penetrate the suburb, but the buildings and critical roads are elevated on plinths 7.5 to 8m above sea level. During floods, the suburb will hence function as an 'island', isolated from the rest of the city (http://www.hafencity.com/en/) [#046].

Potential difficulties, known drawbacks

- None known to date.

3.2.6 Dual use of park and green fields for flood protection (-> WSUD)

Principle and methods

- To cope with frequent and intense rainfall events, existing parks and green fields can be used as storage ponds for rainwater either by an adapted initial design, or by retrofitting existing green fields.
- In the context of climate change combined with increasing urbanisation, this space-saving option both addressing more frequent and intensive rainfall events and the increase in temperature, by minimising the heat island effect (Digman 2010). The combination of recreational and flood control facilities saves costs and improves the aesthetics of stormwater detention facilities.

Examples of initiatives

In Saulxures and Pulnoy near Nancy, France, public parks were equipped in order to store up to 13,000 and 4,000m³ of rainwater respectively. In both basins, when the rainfall event exceeds a critical threshold, the basin stores excess water, and finally discharges the water at an acceptable flow rate for the downstream wastewater treatment plant (Wagner, Néron et al. 2006) [#047].

In Rotterdam, 'water plazas' have been designed to serve as playgrounds and water storage areas. These low-lying playgrounds may store excess water during extreme events, and slowly returns the excess water to the sewer system when the storm event is over (Umweltbundesamt 2011) [#048].

In Ceres, California, the dual use of a recreational and a flood control facility was integrated in the design of the West Landing Community Park. Passive recreational elements, such as trails, vegetation zones or open fields, are located on the lower elevated tier, while ball fields and soccer fields are located on intermediate elevated tiers and court games and picnic areas are located on upper elevated tiers (http://www.ci.ceres.ca.us/) [#049].

Potential difficulties, known drawbacks

- This dual use of parks and green fields for rainwater storage can cause depositions of sand, debris or trash which need to be removed. The design of the water channels and the preliminary screening of rainwater are essential.

→ *See also Section 6.2.4 (Enhancing the multi-functionality of equipments)*

3.2.7 Dual use of reservoirs for water supply and flood protection

Principle and methods

- Due to climate change, in most parts of the world, drought and flood events are going to be more frequent and to affect regions which were initially only impacted by one of these hazards.

- In this context, the dual use of reservoirs for water supply and flood protection is relevant. This needs, however, appropriate design and management. In fact, the structure needs to be able to adapt quickly to low and high water levels, and the management shall target optimum water volume to be stored for each period of the year.

Examples of initiatives

In New York, USA, a study has been launched to adapt the water supply reservoirs for a dual use as flood control facilities (NYCDEP 2005). To adapt the reservoirs, the dams' infrastructure and their operation need to be adapted. In particular, releases of water should be made in order to maintain a void in the reservoirs. An increased flexibility will be required in order to best adapt the reservoir levels to the seasonal demand and to expected or unexpected weather events [#050].

Potential difficulties, known drawbacks

- As flood control (i.e. retention of water) and controlled discharge of water (e.g. for urban or irrigation uses) impose, per se, different management schemes, the dual use of reservoirs may be sometimes difficult, or lead to the over-dimensioning of new constructions.
- The main challenge for this dual use remains a good forecast of seasonal hydro-climatic conditions. In particular, preventing flash flood events may still be very difficult, especially at the start of the dry season, when reservoirs are at the maximum water stage.

→ *See also Section 6.2.4 (Enhancing the multi-functionality of equipments)*

3.2.8 Natural system restoration in upstream catchments

Principle and methods

- Natural system restoration is the restoration or improvement of natural systems and functions in place before human intervention. In general, these natural systems are rivers or ecosystems related to surface waters (lakes, ponds, floodplains, estuaries…).
- It may consist in suppressing physical changes or barriers induced by urbanisation or hydraulic engineering (especially for channelised rivers) to re-allow river meandering, natural flood protection and natural filtration and purification processes.
- In addition to efficiently mitigating the adverse effects of floods, such measures can also contribute to enhance the resilience of natural systems to climate change.

Examples of initiatives

In North Rhine-Westphalia, Germany, natural system restoration is considered as one of the prioritary options for flood mitigation in the context of climate change (MUNLV NRW 2010) [#051].

In New York, USA, the 'Bluebelt project' on Staten Island allows the storage of excess stormwater. The project preserves natural drainage corridors, called Bluebelts, including streams, ponds, and other wetland areas. Preservation of these wetland systems allows them to perform their functions of conveying, storing, and filtering storm water. A surface of over 4,000ha is dedicated to these natural wetlands (NYCDEP 2005) [#052].

- In Tokyo, Japan, a watershed forest conservation plan was initiated since 2000 in order to maintain 22,000ha of forests (Yamamuro 2008). The objective is mainly to prevent heavy rainflows from eroding the soil and from resulting in mud accumulation in the water reservoirs, and also to prevent flood events [#053].
- Near Ingolstadt, Germany, natural river reaches from the Danube river will be restored over a distance of 20km in order to enhance natural flood mitigation and to protect the city of Ingolstadt (Umweltbundesamt 2011) [#054].
- In Alsace, France, the Erstein polder (600ha) was restored upstream of the city of Strasbourg to allow excess water storage during flood events on the river Rhine. The polder was hydraulically reconnected to the river, and the area is now protected from urbanisation [#055].
- In the Lower Danube Delta, Romania, Hungary, Moldova and Ukraine agreed to restore over 2,000km² of floodplain in order to attenuate floods and restore biodiversity (UN Economic Commission for Europe 2009) [#056].
- Similarly, on the Rhine River Basin, twelve flood alleviation measures were implemented by Germany and the Netherlands. These projects included for instance dyke relocations to enable a higher degree of hydro-morphological dynamics (UN Economic Commission for Europe 2009) [#057].

Potential difficulties, known drawbacks

- Natural restoration measures may be expensive, since they usually imply heavy construction measures. What is more, their public acceptance may sometimes be a serious problem, since they often mean 'deconstructing' former engineering equipments, constructed sometimes at high costs.

3.2.9 *Developing and adapting insurance*

Principle and methods

- Insurance of property is classically a soft adaptation measure, in such that it does not directly include hard – structural – adaptation measures, such as flood defences. The principle of insurance is the share of losses between different actors.
- In such, insurance may be a useful instrument to better recover from the effects of climate change.
- An insurance scheme that protects farmers against heavy losses when weather is unfavourable may be as efficient as hard adaptation options involving costly infrastructure (Hallegatte 2009).

- (CEA 2007) shows that, in Europe, almost half of the damages by climatic events in the last 20 years were not properly insured.

Examples of initiatives

The German insurance association, GDV, has launched its Project Climate Change in 2007, which aims, among other objectives, at preparing new products, services and incentives to cope with the changing conditions. An adaptation of the products in the field of flood insurance is about to be initiated, to encourage relocations of flood-prone assets (CEA 2009) [#069].

In Australia, in the aftermath of the 2010-2011 flood events, the insurance industry is considering adapting its products in order to cover all different natures of inundations (storm, flash flood or river flooding). The pricing of premiums is under discussion, in order to increase the number of insured assets on the one hand, while not increasing the insurance premiums disproportionally on the other hand, especially among flood-prone communities (Fraser 2011) [#070].

In the U.S.A., the National flood Insurance Program (NFIP) aims at developing insurance in flood-prone areas (http://www.floodsmart.gov/). The NFIP makes flood insurance available, but also supports local communities in their efforts to reduce the risk and consequences of serious flooding. In order to participate in the NFIP, a community must agree to adopt and enforce sound floodplain management regulations and ordinances. In exchange for these practices, flood insurance is made available to homeowners, business owners and renters in these communities [#071].

Potential difficulties, known drawbacks

- Insurance may be a relevant solution to face the aftermath of a disaster, but cannot be considered for addressing changes which would be persistent in time (i.e. the durable loss of a water source).
- Insurance costs may not bearable for all private companies or water utilities. Indeed, an increase in annual losses of 10 percent in the U.K. for instance would increase insurance prices by at least 14.7 percent as shown by the British Insurers (Association of British Insurers 2009). Depending on the climate scenario, insurance costs for floods for inland U.K. would ultimately rise by 12 percent to 47 percent.

3.3 Pollution control

Treating the urban water pollution is one of the roles of urban water systems, indirectly securing the water supply and directly minimising the impact of the urban area on the environment.

However, due to climate change, more sudden and intense rainfall events as well as increased mean temperatures may have an impact on the quality of surface and groundwater.

In this section, focus will be mostly given on water quality, the scarcity of the resource being addressed in the Section on Securing supply.

3.3.1 *Temperature-rise vulnerability assessments*

Principle and methods

- All climate change scenarios predict, globally, an increase in mean annual temperatures in Europe (Alcamo, Moreno et al. 2007). Hence, temperature-dependent processes in the water cycle will be impacted. Water quality will be altered due to changes in biological and chemical reactions, and to modification of precipitation and river flow regimes.

Examples of initiatives

- In Oslo, Norway, climate change impacts on wastewater treatment are being modelled in order to best design and adapt the treatment processes. It is expected that, with faster and more suddenly snow melting events, influent sewage flow rate may increase by 65 percent and average effluent temperature may drop by 2°C (Plósz, Liltved et al. 2008). This may both impact negatively the biological processes and the settling processes in the secondary solids-liquid separation [#062].
- The impact of rising temperatures on surface water quality due to climate change was extensively studied for the river Oder by (Schernewski and Janssen 2007). This region being potentially impacted more than average by global warming (+5°C), with mean annual precipitations decreasing sharply, reduced oxygen contents are expected, which will lead to an extension of anoxic conditions in the Oder region. This will have consequences for drinking water abstraction, as well as for the recreational use of the area on the long term [#063].
- With the Baltic sea already suffering from oxygen depletion, the region around the island of Funen, Denmark could be very strongly hit by climate change impacts on water quality, provoking a snowball effect on costal ecosystems and aquifers (Schernewski and Janssen 2007) [#064].
- In the Netherlands, an extensive assessment of the impact of climate change on surface water quality has been conducted by (RIVM 2010). It shows that the chemical quality of surface water will deteriorate and the concentration of oxygen will decrease. Salinisation, acidification, eutrophication and fragmentation of surface waters will increase, while higher temperatures may have consequences for public water supply because surface water may not be used as a source when temperature standards are exceeded. The report warns that the EU Water Framework Directive targets may become unfeasible as a result of the additional pressure caused by climate change. Furthermore, it recommends incorporating the possible impacts of climate change into existing policy and closer cooperation between authorities [#065].

Potential difficulties, known drawbacks

None known to date.

3.3.2 CSO management and containment of polluted stormwater

Principle and methods

- It is generally acknowledged that controlled Combined Sewer Overflows (CSO) are unavoidable on combined (wastewater and rainwater) sewer systems, as they represent a 'relief valve' during heavy rainfall events (PREPARED 2011).
- However, the frequency of discharge from CSOs into the receiving waters will be affected by climate change through changes in precipitation patterns, temperature increases as well as sea-level rise. Water utilities are hence adapting CSOs and building new containment capacities for polluted stormwater in dense urban areas.
- When sewers and/or stormwater systems are dependent on pumping stations, power backup systems are to be installed in order to guarantee a continuous operation despite power outages.

Examples of initiatives

London is consulting on a € 6 B scheme to build a 39km tunnel of 7m diameter at a depth of nearly 80m beneath the river Thames. It will track the course of the river from west to east London allowing the associated drop shafts to intercept combined sewer overflows on both banks (McCann 2008) [#058].

Berlin has partially achieved an extensive stormwater storage programme in its downtown area, already disposing in 2010 of a storage capacity of 213,000m^3. By 2020, thanks to the optimisation of existing pipe networks, the retrofitting of CSOs and the creation of new underground storage facilities, 302,000m^3 of stormwater will be storable (Rehfeld-Klein 2011). The entire project's cost is estimated € 140 M [#059].

Vienna inaugurated in 2006 a 3km long, 30m deep tunnel capable of storing up to 110,000 m^3 of stormwater underneath the river Wienfluss (Thames Water 2010) [#060].

Paris has inaugurated in 2009 Europe's largest underground stormwater storage tunnel to date, with a 1.86km long 30m deep tunnel of 6.80m diameter and a total capacity of 80,000m^3 (SIAAP 2009). Total investment was € 109 M for this tunnel, however the total stormwater management master plan cost could exceed € 4 B (Thames Water 2010) [#061].

Potential difficulties, known drawbacks

- Despite significant improvements in technology, CSO will always result in a punctual pollution of surface waters as long as combined systems are in place. Hence, CSO management must be accompanied by communication in order to ensure public acceptance of this limited, acceptable pollution.

3.3.3 *Deposits and corrosion control in sewers*

Principle and methods

- Different effects of climate change, like a shift in precipitation pattern, sea level rise, and the increase in temperature have impacts on in-sewer processes (PREPARED 2011). The introduction of sulphate-rich waters (e.g. sea water) and/or a decrease in sewage flow – connected with a higher degree of pollutant deposition - additionally enhance the emergence of emissions.
- Especially developments during the last 10 years, such as demographic changes, decrease in specific and industrial water consumption, or the renovation of leaky drainage channels to avoid infiltration are connected with the trend of decline in dry weather flow, which ultimately enhances deposits and corrosion problems in sewers (PREPARED 2011).
- Deposits may cause a first highly-polluted water "flush" during the next rainfall event, while corrosion may highly damage the sewer (IFOK 2010).

Examples of initiatives

In the region around Grimma, Germany, an assessment of the influence of low rainfall on deposition and corrosion in sewers has been conducted, and resulted in recommendations for the public water authorities, municipalities and private companies involved in the local water management (IFOK 2010) [#192].

Potential difficulties, known drawbacks

- The costs for rehabilitation of corrosion-affected sewers and operation costs for permanent countermeasures are generally very high.

3.3.4 *Decentralised wastewater management solutions (-> WSUD)*

Principle and methods

- Instead of being connected to the wastewater mains and treated in a centralised facility, wastewater can be collected at building- or suburb-scale and treated to be reused locally.
- This may minimise the risk of large-scale pollution due to intense storms or blackouts, while treating a more homogeneous pollution load locally. Globally, decentralised solutions increase the flexibility of urban water systems. Also, decentralised systems do not rely on ageing central sewers, which would require heavy investments to be renewed (Nelson 2009).
- Moreover, this measure may be energy-, water- and resource-efficient, and thus prevent additional indirect greenhouse gas emissions contributing to climate change. This has been for instance demonstrated for decentralised Membrane Bioreactor (MBR) solutions in Berlin, which would be, in this context, economically and environmentally inefficient (Stüber, Schallehn et al. 2010).

Examples of initiatives

- In the BedZED suburb in Sutton near London, UK, a decentralised waste water treatment called 'Living Machine' (LM) was installed in a greenhouse for the purpose of full on-site waste water treatment which shall (1) supply treated effluent for landscape irrigation and the sports field (2) supply treated effluent for reuse in the toilets in the clubhouse and elsewhere as appropriate (3) act as a small botanical nursery and an educational resource for the site and residents (iv) grow plants in the LM for the production of essential oils (ARENE 2006; Shirley-Smith and Butler 2008). However, the results are controversial [#066].
- An urban renewal programme in Vesterbro, Copenhagen, Denmark, included a rainwater collection system on the roofs. The water is then brought to a small-scale wastewater treatment plant in a dedicated building, 'the Green House', which treats the water to use it for the toilet flush in the building as well as for clothes washing (ARENE 2006) [#067].
- The residential Solaire building in Battery Park in south-eastern Manhattan, New York, has a membrane bioreactor-based wastewater and stormwater treatment unit in the basement. The facility enables non-potable reuse of water for toilet flushing (Nelson 2009) [#068].

Potential difficulties, known drawbacks

- Decentralised systems may be more difficult and costly to manage, operate and control. These measures need to be carefully monitored, with scheduled operation and water quality controls, in order to respect the same quality standards as state-of-the-art centralised wastewater treatment systems.

→ *See also Section 4.2 (Water harvesting and recycling)*

4 Catalogue of supply-side initiatives

Fig. 3 shows the different categories to be distinguished among supply-side initiatives, which are detailed in the next subsections.

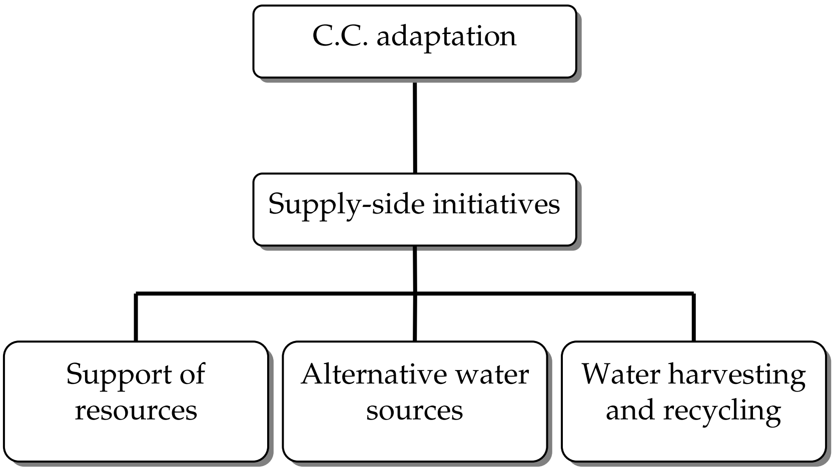

Fig. 3: different supply-side management initiatives.

4.1 Support of surface and groundwater resources

Both surface and groundwater resources constitute crucial 'reservoirs' of freshwater for several urban areas in the world. Climate change will increase the stress on these resources because of more irregular and, in general, lower rainfall, as well as diverse sources of pollution. Hence, these resources need to be protected and supported, or even augmented to cope with an increasing demand due to urbanisation.

The purpose of storage is to capture water when and where its marginal value is low—or, as in the case of floods, even negative—and reallocate it to times and places where its marginal value is high (Keller, Sakthivadivel et al. 2000).

Climate change will exacerbate more periods of droughts in many regions, and induce a higher variability in precipitation rates, thus making solutions aiming at supporting resources very relevant.

4.1.1 Augmentation of reservoir storage

Principle and methods

- The storage in reservoirs, dams or impounded rivers, is the most popular traditional option for large-scale storage options. Most of the largest reservoirs are used for irrigation, water supply as well as energy production (hydroelectricity).
- Increasing public pressure on major water dam projects make it more and more difficult to plan new projects in developed countries (Wasimi 2010),

and in some countries it is expected that there is no further potential for development of large-scale dams, like France.

- Fifty-five percent of the large dams are located in North America and Europe (Keller, Sakthivadivel et al. 2000). Whereas arid rich countries such as the United States and Australia have built over 5,000m^3 of water storage per capita, and middle-income countries like South Africa, China and Mexico can store about 1,000m^3 per capita, India by comparison can only store 200m^3 per capita (Ashley and Cashman 2006).
- By 1997, there were an estimated 800,000 dams in the world, 45,000 of which qualify as large dams, an estimated additional 1,700 large dams were under construction (Keller, Sakthivadivel et al. 2000). More than half of these large dams were constructed in the past 35 years. In 1998, the total water stored in reservoirs behind dams is estimated to be between 6,000 and 7,000km^3 in (Shiklamov 1998; Vapnek, Aylward et al. 2009).
- According to (Shiklamov 1998), of most importance for water supply is the base-flow runoff, a stable volume, varying little both during a year and from year to year, whose use is possible without artificial regulation. Its value is approximately 37 percent of the total volume of global river runoff, or about 16,000km^3 per year.

Examples of initiatives

(O'Hara and Georgakakos 2008) have proposed a method to estimate the impact of climate change on reservoir design, with application to the San Diego reservoir system. Taking into account climate change impacts, among others changing precipitation patterns and more intense evaporation from the reservoir, it was shown that climate change would result in important additional cost for the design and construction of the reservoirs [#072].

The Metropolitan Water District of Southern California, has already invested USD$ 5 B to increase its storage to 14 times its former capacity since 1996 by building new dams [#073].

In South-East England, seven large-scale water storage facilities are being considered to increase storage capacity by 2020 for a total cost of approx. 3,5 B£ (Strosser, Kossida et al. 2007). However, the increase in reservoir capacity is also accompanied by demand-side measures aiming at reducing demand [#074].

To support water supply in Queensland, Australia, a major dam (Traveston Crossing Dam) is to be constructed on the Mary River for a total of AUD$ 9.7 B. The option of building a large dam was preferred to desalination or a series of small dams based on a cost-benefit assessment, and the site was chosen after a review of 80 potential sites, on a hydrologically efficient catchment (receiving more rainfall than other candidates) (Wasimi 2010) [#075].

Potential difficulties, known drawbacks

- Dams may present various disadvantages, such as evaporation losses (about 2 m/year in warm, dry climates); sediment accumulation; potential of structural failure; increased diseases; and adverse ecological, environmental, and socio-cultural effects (Bouwer 2002; Wasimi 2010). Among these, entrapment of biomass within the reservoir volume may lead to considerable methane emissions, which is a greenhouse gas with high global warming potential.

4.1.2 Enhancing natural infiltration through adapted land-use management

Principle and methods

- Infiltration is possible on any type of soil, but infiltration rates may differ greatly depending on soil nature, its degradation state and the nature of the vegetal species.
- Climate change is challenging natural infiltration, since it will modify the intensity and frequency of rainfall events, and putting a greater stress on groundwater resources, which may be naturally more preserved from climate change impacts.
- Adapted land-use management can constitute a useful solution to preserve high infiltration capacities of natural grounds, sustaining urban water sources and reducing erosion that may be a consequence of high-intensity rainfall events driven by climate change.

Examples of initiatives

The German KLIWA-project (http://www.kliwa.de) specifically includes research on the impact of climate change on soil erosion. Erosion can be counterbalanced by adapted land management (i.e., choosing species that prevent erosion, adapting species to slopes…) and earlier sowing [#076].

In North Rhine-Westphalia, Germany, the forest conversion from conifers towards deciduous woodlands lowered the water demand of the forests and shows positive effects on natural groundwater recharge (MUNLV NRW 2010) [#077].

Potential difficulties, known drawbacks

- Land-use management is a long-term adaptation policy, which goes beyond the borders of urban planning. Therefore, the implementation of this measure must rely on adequate global planning tools which shall promote an integrated approach

4.1.3 Managed Aquifer Recharge

Principle and methods

- Managed Artificial Recharge (MAR) of groundwater is achieved by adding surface water in basins, furrows, ditches, wells or other facilities where it infiltrates into the soil and recharges the aquifers (Bouwer 2002). As it percolates down into the aquifer, it is usually purified of biological pollutants (Keller, Sakthivadivel et al. 2000). In Aquifer Storage and Recovery schemes, which use injection wells, more than 75 percent of the injected volume can be recovered according to (Da Franca and Dos Anjos

1998). Being an underground storage solution, it does not require large surfaces of land as does reservoir storage.

- Water can be stored for years, with little or no evaporation loss, to be used in drought years as a supplementary source of water supply (Keller, Sakthivadivel et al. 2000; Moore 2011). Hence, MAR is particularly relevant to address climate change in areas with low natural recharge or surface water quality problems. MAR enhances the flexibility of water utilities concerning the increased risk of droughts due to climate change.
- Most states in the USA allow infiltration of recycled water (i.e., secondary treatment with basic disinfection of wastewater effluents) based on the proven ability of the surface recharge systems to provide additional treatment (U.S. Environmental Protection Agency 2004).

Examples of initiatives

In Delft, the Netherlands, underground storage and infiltration basins have been retrofitted to existing public spaces within the urban area (Digman 2010) [#078].

In the U.S. semi-arid state Texas, excess water from floods is used to recharge the stressed aquifer (Sheng 2011). The excess water is roughly pre-treated and directly pumped into the aquifer using existing wells from farmers or other users with own groundwater wells [#079].

In California, MAR has a long tradition (Atwater 2011). Since the 1960s, excess water has been stored during the winters in the Principal Aquifer (for instance at the Anaheim recharge facility in Orange County), and pumped during the summers. Thanks to this aquifer recharge, severe droughts in the last decades, which may be triggered by climate change, could be faced [#080].

Potential difficulties, known drawbacks

- MAR can only be implemented where suitable underground storage is possible. Infiltration basins may not be implemented directly in urban areas due to the pollution risk. Protection measures for the underground storage must be taken in order to preserve it.
- There is a lack of guidelines for the quality of infiltrated water, which is, to now, regulated locally by each authority.

→ *See also Section 4.2.6 (Indirect potable reuse)*

4.1.4 Dual use of flood defences for groundwater recharge

Principle and methods

- Flood defences, especially flood retention basins and ponds, naturally enhance the recharge of groundwater if they are constructed on permeable terrain. To increase flexibility of the water system, the dual use can be supported by construction measures in order to ameliorate the design and / or infiltration rates of the basins.

Examples of initiatives

In California, flood control facilities were converted into aquifer recharge facilities within a very short time in order to avoid the new construction of ponds and associated land use change (Campbell 2011). The combination of both flood control and aquifer recharge maximises the return on investment [#081].

Potential difficulties, known drawbacks

- Experience has shown that directly using existing equipments as multi-functional equipments without alteration is not directly possible, or may not completely fulfil requirements. In particular, the requirements in maintenance are higher due to important particle loads and waste materials carried by the flood storm water (Sheng 2011).

→ *See also Section 6.2.4 (Enhancing the multi-functionality of equipments)*

4.2 Water harvesting and recycling

Rainwater and stormwater (i.e. rainwater collected from a given infrastructure, such as a large building complex or a transportation infrastructure) harvesting enable to supply additional water without depriving existing surface or groundwater sources.

Water recycling encompasses the reuse of water as a potable or non-potable secondary source, after having been retreated accordingly. The main secondary water source concerned is treated wastewater. This measure addresses increasing water scarcity and irregularity in the natural water cycle induced by climate change. In 2001 already, more than 9 percent of the treated wastewater was reused in Australia (ATSE 2004).

The concept of Integrated Water Cycle Management (IWCM), where urban water supply, roof runoff, the recycling of sewage and stormwater are managed simultaneously, is gaining popularity (Ludwig, Kabat et al. 2009). This approach both integrates harvesting and recycling of water, mostly for non-potable reuses.

4.2.1 Non-potable use of rainwater / Rainwater harvesting (-> WSUD)

Principle and methods

- Rainwater harvesting (RWH) refers to the practice of collecting rainwater from roofs or other impermeable surfaces for future use. It is often considered as a part of Water Sensitive Urban Design (WSUD).
- RWH systems typically consist of a collection, a conveyance, and a storage system. In most cases a more or less simple water treatment is added – at least leaf screens or more elaborated filters (Li and Geiger 2006). RWH requires that tanks are installed to collect the runoff from the roof area; these tanks would be connected to indoor our outdoor end uses (Leflaive 2009).
- A simulation in Toronto showed that utilising RWH would supply between 59 and 76 percent of total demand for non-potable water, while diverting between 23 and 42 percent of annual precipitation on the roof

catchment area from storm sewers (Toronto and Region Conservation Authority 2010).

- In Germany, the Federal Environmental Agency encourages the harvesting of rainwater for garden use, but has warned that the indoor use may comprise health risks and be economically inefficient (Umweltbundesamt 2011).

Examples of initiatives

In France, RWH equipments installed in private homes can benefit from a tax refund of 25 percent of the investment since 2008. Local authorities sometimes provide additional financial helps for these equipments, for instance in the region Lorraine, 800 € help is provided for RWH tanks larger than 3 m^3 (Pierron 2010) [#082].

Seoul's Star City project consists of a department store and four apartment blocks, each of between 35 and 57 storeys. Overall there are 1,310 apartments providing accommodation for between 4,000 and 5,000 people (McCann 2008). Rainwater from all four roofs is piped to the RWH basement where there are three separate storage tanks each of 1,000m^3 capacity. Stored water is used for flushing the public toilets around the complex, for irrigating the greened and planted areas and for cleaning paved surfaces. To assure output quality the inlet line here is fitted with a self-cleaning filter (McCann 2008) [#083].

In Berlin, Germany, RWH is tested as a means to maximise evaporation and hence mitigate the heat island effect in dense urban areas. A pilot building was equipped with green facades, enabling a cooling of the entire building from up to 30°C down to 21-22°C (Schmidt, Reichmann et al. 2007) [#084].

In Germany, several cities have imposed 'precipitation fee'– a charge levied by the municipality at a given rate per m^2 of impermeable surface discharging stormwater to the public sewer (McCann 2008). These are already levied in Berlin and Bonn with costs around € 10-20/m^2 [#085].

In Berlin, Germany, the Potsdamer Square business district, equipped with more than 32,000m^2 of impervious roof surfaces, was equipped in the 1990s with a rainwater collection, treatment and recycling system, including a cleaning pond and 2,600m^3 of storage. The water is used for garden irrigation and reuse in toilets, enabling a save of 20,000m^3 freshwater per year (Kintat 2002). The remaining rainwater is discharged into a nearby canal [#086].

In the U.K., the BedZED RWH system drains surplus water into an underground tank under each of the 'blocks' of the development, which stores 35m^3 of water per block to supply the toilets and water the elevated 'sky' gardens for each of the elevated flats, adequate for approximately 11 weeks' supply (Shirley-Smith and Butler 2008) [#087].

At a 45-year-old apartment block in Muhlheim on Main, Germany, the landlord, the municipality, had installed 18 in-ground cisterns of between 7 and 11m^3 capacity close to each access into the four-storey building

(McCann 2008). All roof runoff is directed to the cisterns and these in turn are connected to washing machines in the basement, 176 machines in all [#088].

Potential difficulties, known drawbacks

- The benefits of utilising RWH to supplement mains water usage are highly variable. As an example, the retrofit of a RWH system to a block of 12 flats in Preston, UK resulted in only a 5.2 percent overall water saving, a report concluded that retrofitting should not be recommended due to the issues and costs encountered (Ward 2010).
- As demonstrated in a British study, although there is no doubt that RWH saves water, its massive use as an alternative to an existing reliable water mains supply may not be sustainable regarding carbon emissions (due to tank-embodied CO_2 as well as an unsatisfactory pump efficiency) (Way, Martinson et al. 2010).
- In terms of cost per unit of water, (Marsden and Pickering 2006) have shown that RWH is one of the most expensive water adaptation options for Australia.

→ See also Section 3.2.4 (SuDS – Decentralised rainwater infiltration and evaporation solutions (-> WSUD))

4.2.2 Non-potable use of storm water runoff / Stormwater harvesting (-> WSUD)

Principle and methods

- Storm water runoff harvesting (SWH) consists in collecting, storing and reusing stormwater collected from drains or creeks, on the contrary to RWH, where rainwater is directly collected from roofs. It may also be part of Water Sensitive Urban Design (WSUD). SWH is particularly common in Australia and New Zealand, while almost unknown in many other countries where RWH is preferred.
- As RWH, SWH offers an additional source of water, especially for water-stressed areas. What is more, by detaining and using urban runoff, there may be potential reductions in peak flow, annual runoff volume, and the frequency of runoff (Fletcher, Deletic et al. 2008).
- Urban storm water is generated in large quantities within short periods, and the nature of this pollutant source is diffuse. Treatments of stormwater include sedimentation in large open water bodies, filtration through soils (or any other filtration media), or biological uptake by plants and microorganisms (Fletcher, Deletic et al. 2008).

Examples of initiatives

In the Murray-Darling Basin, Australia, a AUD$ 200 M initiative was launched in 2009 to 'face climate change and less rain'. This funding is available for communities and local governments to implement local stormwater reuse initiatives. One of these is the collection of stormwater from the Adelaide airport, which is treated in nearby wetlands before it is used to recharge the depleted aquifer (Office of the Minister for Climate Change of South Australia 2009) [#089].

- In a survey of Australian stormwater runoff systems, (Fanner, Sturm et al. 2008) have shown that, on 7 sites, the collected runoff ranged from 20 to 100 percent, resulting in reduction of potable water demand from 17 to 65 percent. The presented systems were also efficient in reducing the concentration in Nitrogen of the collected rainwater, totalising savings in required storm water treatment of up to AUD$ 37,000/ha of wetlands [#090].
- In Australia, several commercial systems for sport fields, parking lots and parks to collect stormwater runoff are available. Atlantis® Water Management for instance proposes several tanks and purification systems for stormwater harvesting (http://www.stormwater-harvesting.com.au).

Potential difficulties, known drawbacks

- Despite several advantages, urban storm water remains a relatively neglected water resource, which needs further development (Thomas 1997).
- Urban runoff may be polluted with organic matter, pesticides or heavy metals, which effects and fate remain unknown.

→ See also Section 3.2.4 (SuDS – Decentralised rainwater infiltration and evaporation solutions (-> WSUD))

4.2.3 Non-potable use of raw water / Dual water supply (-> WSUD)

Principle and methods

- Raw, untreated water abstracted from surface waters or groundwater of lower quality can be used for street cleaning, irrigation of gardens and parks or other non-potable uses.
- In some cases, when a separate system supplying this lower-quality (simply treated or untreated) water is present, one speaks of dual water supply. This measure can provide a secondary source and lower the pressure on freshwater aquifers, but also diminish the environmental impact of water treatment, thus being a useful option in the context of climate change adaptation (WSA 2002).

Examples of initiatives

- In Paris, such a parallel distribution network with roughly filtered water from the Seine river is used for street and sewer cleaning for more than a 150 years [#091].
- In Wageningen, a dual water supply system was installed in 2000 to decrease the local pressure on groundwater systems (SenterNovem 2006) [#092].
- In Australia, several cities are equipped with dual water supply systems for irrigation and street water cleaning (WSA 2002) [#093].

Potential difficulties, known drawbacks

- The general decrease in water consumption and to the costs associated with the non-potable water networks are severe problems, and the city of Paris is considering the abandonment of this dual water supply.
- These dual systems bear the risk of wrong connections between the different supply systems, which can be a threat both to human health and the environment.

4.2.4 Non-potable reuse of wastewater (-> WSUD)

Principle and methods

- Non-potable water reuse can be based on greywater or various other waste water reuses. It reduces demand for fresh water resources, diversifies the water sources and reduces the volume of wastewater discharged into the environment. (O'Connor, Elliott et al. 2008) notes that guidelines for the reuse of degraded waters exist, especially in the U.S., but that standards vary from one country to the other.
- Greywater is residential wastewater originating from clothes washers, bathtubs, showers, and bathroom sinks and is distinguished from 'black water', which is the wastewater from toilets, kitchen sinks, and dishwashers (O'Connor, Elliott et al. 2008). USEPA defines greywater as non-drinkable water that can be reused for irrigation, flushing toilets, and other purposes (U.S. Environmental Protection Agency 2004). Greywater sources comprise about half of the total per capita residential water usage (O'Connor, Elliott et al. 2008; Iglesias, Garrote et al. 2009). Based on a survey of 12 North American Cities, of the total residential usage, the sources contributing to greywater are baths and showers (about 18 percent of total usage), clothes washers (22 percent), and some portion of faucets (16 percent) (Roesner, Qian et al. 2006).
- Directly reclaimed greywater is only intended to be used for non potable uses (e.g. irrigation, dust control, fire suppression) (Leflaive 2009). For purpose of recycling in households, primary treatment, biological treatment and disinfection as well as advanced processes for high quality reuse should be included (Li and Geiger 2006).

Examples of initiatives

The city of Osaka plans to reuse 30 percent of the treated wastewater by 2013 and 100 percent by 2030 for landscaping, heat-exchange source, fire mains, toilet flushing in public buildings and construction use (concrete batching) (ATSE 2004) [#094].

In Beijing, the water shortage is estimated to be 1.2-2.0 Bm^3 in 2010, while the municipal wastewater discharge is around 1.1-1.2 Bm^3, which makes reclaimed water use be a very relevant option for this city (Xin, Jia et al. 2006). A Geographical Information System (GIS) is used to control and plan the reclaimed water network, enabling to reach a reclaimed water reuse rate of 56 percent in 2010 [#095].

Cyprus has taken conservation measures at household level by encouraging the re-use of 'greywater' (i.e. from washing and washing machines) for watering gardens and flushing toilets, reducing per capita water consumption by up to 40 percent. In 2007, government subsidies covered 75 percent of the cost of the system (European Commission 2007) [#096].

- In London, UK, the Millennium Dome was the first major building receiving an in-building recycling scheme. A blend of greywater, rainwater and groundwater is used to flush over 400 WCs and 150 urinals on site (ATSE 2004) [#097].
- In Poitiers (France), the green areas are irrigated by the water of the public swimming pools (Lesquel 2007). Water savings up to 50 percent were achieved thanks to this measure [#098].
- In Japan, in 2003, 1,058 on-site individual buildings and block-wide wastewater recycling systems generated water toilet flushing in commercial buildings and apartment complexes (Funamizu, Onitsuka et al. 2008) [#099].
- According to (O'Connor, Elliott et al. 2008), Florida is a major degraded water reuser, and currently leads the nation in the reuse of wastewater effluent, representing ~50 percent of the state wastewater capacity. Reuse is dominated by urban applications, especially public access irrigation of golf courses and new housing developments (ATSE 2004) [#100].
- In Kuwait, around 25 percent if the agricultural and green areas are irrigated using reclaimed water from wastewater treatment plants (ATSE 2004) [#101].

Potential difficulties, known drawbacks

- Non-potable reuse of water often triggers public debates due to the lack of public acceptance. In general, it must be accompanied by adapted communication and consumer education.
- The quality of the non-potable water must be monitored, especially if it is used in homes or for agricultural uses. The development of greywater reuse is limited by planning regulation, norms for the quality of the product or service and by the norms on the techniques to be used (Leflaive 2009).
- What is more, systems preventing from backflow of non-potable water into the water mains must be installed to avoid contamination (generally air gaps or backflow valves).

4.2.5 Direct potable reuse of wastewater

Principle and methods

- Direct Potable Reuse (DPR) involves the reuse of treated wastewater without dilution with other sources or types of water.
- Per se, this method of water reuse is the most sustainable as the urban water cycle of tap water is managed as a (nearly) 'closed loop'. This allows for a complete securing of the supply source despite all possible effects of climate change.

- DPR, with a specific consumption of 0.7-1.2kWh/m^3 can be up to 4 times more energy-efficient than ocean desalination (3.0kWh/m^3), and 2 times more energy-efficient than importing water (2.0kWh/m^3), as shown on a Californian case study for the Orange County by (WateReuse Research Foundation 2011).

Examples of initiatives

In Cloudcroft, New Mexico, a small-scale plant for DPR is scheduled to operate from Fall 2011, delivering 400m^3/day of treated wastewater (28-50 percent of demand) using RO and UF techniques. This option was chosen in reaction to increasing drought periods, in order to augment the potable water system with a long-term alternative (WateReuse Research Foundation 2011) [#102].

The Colorado River Municipal Water District in Big Springs, Texas, will inaugurate in 2012 its large-scale DPR treatment plant with a capacity of 9,500m^3/day using an advanced treatment with MF and RO. The plant is part of the Water District's policy 'reclaim 100 percent of the water, 100 percent of the time' and is a response to recurrent droughts (WateReuse Research Foundation 2011) [#103].

In Windhoek, Namibia, due to local water scarcity and arid climatic conditions, a first experimental direct potable reuse plant was built in 1969. The plant was upgraded since with several treatments steps (including ultrafiltration) and delivers between 15,000 and 20,500m^3/day (~25 percent of the drinking water for the urban area) (Lahnsteiner and Lempert 2007). This is the only example of large-scale DPR worldwide currently in operation (NWRI 2010) [#104]. However, these examples shows that DPR may be a solution to address water scarcity induced climate change, since it is sustainable to reuse locally resources in a cycle-like approach.

Potential difficulties, known drawbacks

- Public acceptance is the major problem for DPR. The negative term 'toilet to tap' was born from a 2001, USD$ 55 M failed project for DPR in Los Angeles due to public revulsion. This explains why, to date, only one large facility for DPR is operating.

4.2.6 Indirect potable reuse of wastewater

Principle and methods

- Indirect Potable Reuse (IPR) involves the reuse of treated wastewater after dilution with other types of water (e.g. via a surface water reservoir, groundwater recharge etc.).
- It can be noticed that 'unplanned potable reuse' or 'de facto IPR' (i.e. the withdrawal of drinking water from rivers or surface water reservoirs that contain varying amounts of treated wastewater) is widely spread. It will not be considered here, since it is not a planned adaptation measure.

Examples of initiatives

- In Australia, early plans included IRP from the 1990s. However, due to public reluctance, most projects are still under development. Western Australia plans to apply a similar strategy of groundwater recharge to Orange County: a trial of reverse osmosis managed aquifer recharge (ROMAR) has been launched in 2008 and an industrial plant should be installed in Perth by 2015 (Marsden and Pickering 2006) [#105].
- Jordan is attempting to substitute reclaimed water and use it in other sectors for fresh water resources originally used for agricultural irrigation. In fact, reclaimed water is mixed with surface run-off water and stored in conventional reservoirs, prior to being used as a part of the freshwater resources of major cities, including Amman (Vallentin 2006). Quality standards for reclaimed water were recently set in collaboration between the Jordanian and German governments [#106].
- In Berlin, Germany, the municipal water supply relies for 70 percent on bank filtrate, with proportions of treated wastewater ranging from 10-30 percent in the drinking water (Möller and Burgschweiger 2008) [#107].
- In Orange County, California, USA, purified reclaimed water is used to recharge the depleted aquifer (Atwater 2011). The so-called Groundwater Replenishment System uses advanced water treatment techniques, as microfiltration, reverse osmosis and UV-disinfection are applied to the treated effluents from a closely located wastewater treatment plant prior to their injection in the groundwater [#108].
- In Singapore, reclaimed water is treated in a four-barrier process (including ultrafiltration and reverse osmosis) for indirect potable reuse since 2001 (ATSE 2004). The produced reclaimed water is called 'NEWater' [#109].
- In Israel, almost 100 percent of the purified wastewater is recycled for irrigation or indirect potable reuse. Most of the water used for IPR is recharged in the coastal aquifer for further treatment and storage (ATSE 2004). For instance, Tel-Aviv has a large aquifer recharge facility directly connected to the wastewater treatment plant [#110].

Potential difficulties, known drawbacks

- Although public acceptance is higher than for DPR, IPR must also be accompanied by a consumer information and education campaign (Wilderer 2004). An illustration of this is provided by a referendum in Toowoomba, Australia, on the addition of purified water into Toowoomba's water supply: the referendum was rejected, as many residents perceived that they were being used as guinea pigs (Marsden and Pickering 2006).

→ *See also Section 4.1.3 (Managed Aquifer Recharge)*

4.3 Alternative water sources

Apart from classical surface and groundwater resources and water recycling, alternative or remote water sources may also be used. These mostly include waters of less raw qualities and the use of remote water sources.

4.3.1 *Sea water desalination*

<u>*Principle and methods*</u>

- Seawater contains 30 to 50 grams per litre (g/l) of salts and, with approx. 1.35 Bkm^3, is the most common form of water on the planet.
- Desalination is becoming an important component for augmenting and diversifying available national water sources in coastal regions. Overall, it is estimated that in 2007 over 75 million people worldwide obtain fresh water by desalination (Khawaji, Kutubkhanaha et al. 2008). Sea water desalination totalises around 60 percent of all desalinated water sources in the world in 2001.
- Seawater is separated into two streams: a freshwater stream and a concentrated brine stream. The most utilised desalination technologies are thermal distillation, membrane separation, freezing and electrodialysis (Khawaji, Kutubkhanaha et al. 2008). Reverse osmosis (RO) is the dominating membrane technology (Voutchkov 2011).

<u>*Examples of initiatives*</u>

On the Maldives Islands, solar desalination plants are being built to supply freshwater while decreasing the dependency on fossil fuels and GHG emissions. Another expected outcome is to mitigate the risk of diesel groundwater pollution (MEC 2004) [#111].

Several coastal cities of Europe, Northern America and Australia have included sea water desalination in their water management plans in order to diversify the supply options. Recently, some major desalination projects were finalised as responses to water shortages expected from climate change (all relying on RO):

- the Perth desalination plant in Kwinana, delivering from 140,000 up to 250,000m^3/day, was inaugurated in 2006 and is the major water source of the state of Western Australia (Ludwig, Kabat et al. 2009). The project's cost were around AUD$ 965M for the initial capacity. In 2011, an extension of the plant was planned for an additional AUD$ 450M to deliver up to 275,000m^3/day in reaction to persistent droughts in the Perth area (AAP 2011) [#112] [#198];
- to help reducing pressure on the local aquifer, the Tampa Bay seawater desalination plant was inaugurated in 2008 and is currently the largest seawater desalination facility in the U.S. with 95,000-190,000m^3/day. The project's total cost amounted to USD$ 158M (http://www.water-technology.net) [#113];
- the Hadera desalination plant, Israel, started operation in 2009 with a capacity of 348,000m^3/day (Wikipedia, 2011:Water desalination), for an investment of € 269M [#114];

- the London desalination plant in Beckton inaugurated in 2010 is the first desalination plant on mainland U.K., and produces up to 150,000m³/day in times of drought. The plant and pipes had a cost of £ 250M (http://www.water-technology.net) [#115].

Potential difficulties, known drawbacks

- The environmental impact of desalination is double: it consumes large amounts of energy and produces brine that needs to be discharged into the sea, potentially harming coastal and marine aquifers. Environmental assessments of desalination projects should be conducted to ensure that this option is the best option from a sustainability point of view. Desalination technologies when used inappropriately can in fact represent maladaptation (Barnett and O'Neill 2010).
- Although progress is made on technology, desalination costs may increase in the future because of project site location, environmental considerations and several other factors (Voutchkov 2011).
- A recent draft report from the Australian Productivity Commission (Australian Government 2011) warns that over-investments have been made in desalination, while techniques such as Indirect Potable Reuse (IPR) could have saved up to AUD$ 2.5 B.

4.3.2 Brackish water desalination

Principle and methods

- Brackish groundwater is generally defined as containing 500 to 30,000 milligrams per litre (mg/l) of salts.
- Desalination of brackish water bases in general on the same technology as seawater desalination, but usually uses water from deep saline aquifers, brackish springs, or other sources of brackish water, as a water source. Brackish water desalination totalises around 40 percent of all desalinated water sources in the world in 2001 (Khawaji, Kutubkhanaha et al. 2008).

Examples of initiatives

The city of Yuma owns North America's largest brackish water reverse osmosis desalination plant, with a total capacity of 273,000m³/day. The plant was initially completed in 1991, but not operated due to normal water supply conditions on the Colorado River. In 2010, the plant was restarted on a pilot run for one year (Wikipedia, 2011:Water desalination). Total costs amounted to now at approx. USD$ 150 M [#116].

El Paso brackish desalination plant, inaugurated in 2004, is currently the largest North American plant in full operation, with a production of 104,000m³/day of freshwater from a brackish groundwater supply. It supplies 25 percent of the local water demand [#117].

In Egypt and Jordan, brackish water desalination covers up to 10 percent of the total country's freshwater demand, and is used in priority for industrial and municipal uses (Talaat, Sorour et al. 2002) [#118].

Potential difficulties, known drawbacks

- Brackish water desalination may have the same adverse impacts as seawater desalination. Although it generally produces less brine, dealing with it in non-coastal regions may be a serious issue.

4.3.3 Water transportation

Principle and methods

- If no local water sources are available, or if they do not cover the local demand for water, water can be transported from a remote location either punctually (i.e. shipment of water) or continuously (i.e. via a pipeline).
- Water transportation is a traditional and ancient technique which is not primarily related to climate change adaptation; however the following examples are in response to climate change impacts.

Examples of initiatives

The Rhone-Catalonia aqueduct (France/Spain) aims at transferring a volume of 300 Mm^3 (10 m^3/s), in order to guarantee, both in quantity and quality, urban water supply to 5 million inhabitants. The works should be comprising an underground conveyor of 2.40m of diameter and 320km long (Desbordes, Brunel et al. 2003). Feasibility studies were undertaken since 1995, allowing to establish technical solutions which were cross checked by technical-economic studies [#119].

A AUD$137.9 M pipeline will be built to connect Geelong to Melbourne's water system by 2011. The 59km long pipeline will deliver 16 billion litres of water each year to Geelong, which is close to a 50 per cent boost for this important regional centre. The Victorian Government is also supporting a AUD$220 M plan to build the 'Goldfields Superpipe' totalising 155km length (Office of the Premier of Victoria 2006). (Marsden and Pickering 2006) have shown that the direct costs for water from long distance pipelines may be higher than any other water supply or demand option in the Australian context [#120] [#121].

While, to now, the Rhone-Catalonia aqueduct project has not been yet decided, Catalonia has imported freshwater from the Rhône (France) several times during intense drought periods since the 2000s. The water was shipped using tankers which did rotations up to six times a month [#122].

In the U.S., several states rely on aqueducts to secure the supply of major urban communities. One of the most famous examples is the Californian Aqueduct, built in 1963, totalising 1,129km in length and delivering to the urban areas of the Coast up to 370m^3/s (Atwater 2011). New York City relies on the Delaware Aqueduct to meet 50 percent of the city's demand [#123] [#124].

A U.S. company, S2C's, plan to use 10.9 Mm^3 of water each year from the Sitka reservoir in Alaska, which will then be pumped into a tanker and sent to a port south of Mumbai on the West coast of India to be bottled. (Arnell and Delaney 2006) also evoke the possibility to ship icebergs or large 'pouches' of fresh water from one water-rich region to a region facing a water crisis [#125].

Potential difficulties, known drawbacks

- Based on a large-scale study in Australia, (Marsden and Pickering 2006) have shown that long-distance pipelines are the adaptation measures with highest cost per unit of water.
- The import of remote water may deplete these resources and pose threats to the local environment. Aqueducts sometimes have high leakage rates, resulting in substantial waste of freshwater. It is also energy-intensive: the California Aqueduct as well as the Central Arizona Project aqueduct are the biggest electricity consumers of California and Arizona respectively (CERES 2010).
- Although the transportation of water is an adaptation option, it shall be considered only in some identified critical cases as a last resort option, since it generally does not fulfil the requirements of sustainability. The punctual shipment of water shall be considered only as an emergency option, for instance for countries facing a sudden water crisis.

5 Catalogue of demand-side initiatives

Fig. 4 shows the different categories which can be distinguished between demand-side measurement initiatives, and which are detailed in the next subsections.

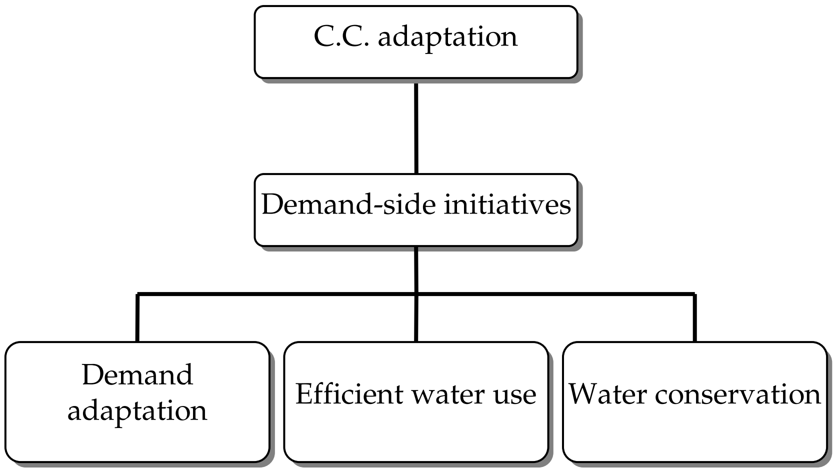

Fig. 4: different risk assessment and management initiatives.

5.1 Demand adaptation

Global change, including the demographical changes in urban areas and all implications of climate change, will impact the demand for fresh water. Therefore, to anticipate this, initiatives aiming at better understanding these changes are essential.

5.1.1 Assessment of global change impacts on demand

Principle and methods

- Water demand can be influenced by the customers' climate sensibility through their use. However, while scientists generally agree that weather-related variables may affect water demand, a consensus beyond this has yet to be reached (Klein, Kenney et al. 2007).
- A recent Dutch demand modelling study has shown increases in water demand during dry summers (Blokker and Vreeburg 2008). An extensive assessment on how climate may impact water consumption has been proposed by (Gutzler and Nims 2005) for New Mexico, U.S. Climate effects were shown to affect the demand rather on the long-term (e.g. from one year to another) than on the short term (e.g. during a season). Other U.S. studies showed similar patterns (Klein, Kenney et al. 2007). This strong relationship is related to outdoor water uses, which are extremely climate-dependent and more elastic than indoor water uses (Olmstead and Stavins 2009).

- The monitoring of water demand at a German water utility from Saarland has shown that temperatures were not the most critical factor influencing water demand, but the length of the heat period. Heat waves of 2-5 days (T>30°C) had no influence on water demand, while a heat wave of 20 days (T>30°C) triggered increases in water demand of up to 20 percent (Meier 2011).

Examples of initiatives

To better understand the impacts of climate change on local demand, Canal de Isabel II in Madrid, Spain, undertakes research on micro-use to develop reliable scenarios about the effect of temperature and daily rainfall on water consumption in individual homes. Results can be seen by specific use – showers, washing machines, toilets, faucets, dishwashers, irrigation, swimming pools and leaks – to identify customers' climate sensibility through their end uses. The information is applied in designing and implementing water infrastructure action plans with climate change aspects [#126].

The City of Berlin, Germany, has assessed the predicted changes in water demand by 2040, taking into account both changes in demography, living standards and influence of climate change (Möller and Burgschweiger 2008). Three scenarios for demographic and economic development and an average climate change scenario for the region have been considered. On the whole, both the annual as well as the daily peak water demand shall stay at the same level or decrease (with, in general, a stagnation or decrease of the demography in this region) [#127].

A study of the water demand in New York City has shown that water use in New York increases by 11 litres per degree centigrade once temperatures go above 25°C (SWITCH 2010) [#195].

Potential difficulties, known drawbacks

None known to date.

5.2 Efficient water use

Efficient water use targets the maximisation of the efficiency in water use, and corresponds to the adage 'for every drop the maximum'.
Efficient water use differs from water conservation in that it focuses on reducing waste. A proposition is that the key for efficiency is reducing waste, not restricting use (Wikipedia, 2011:Water efficiency).
In the context of climate change, this enables to address local water scarcity in drought-prone regions, and also contributes to an efficient use of resources. Water efficiency measures are, per se, 'no-regrets' adaptation measures (Council of the European Union 2011).

5.2.1 Leak detection and repair

Principle and methods

- In areas where losses of water in the distribution network reach significant percentages, leak detection and repair will support efficient water use to achieve that every produced m^3 of water is delivered and sold to the final customer.

- A major difficulty is in defining what levels of leakage may be acceptable from 'public' mains. In England, Wales and the U.S., Economic Level of Leakage (ELL) is used to specify targets for the water companies (U.S. Environmental Protection Agency 2010). ELL represents an agreed leakage rate above which it is believed economic to tackle the problem and below which it would supposedly cost more than it would save to deal with. Typical agreed ELL are of the order of more than 20 percent (Ashley and Cashman 2006).
- Water loss levels in the public water network are highly variable. According to (VEWA 2006), they are estimated at 7.3 percent for Germany, 19.2 percent for England/Wales and 28.5 percent for Italy. In Ireland, losses from 16.8 percent to 58.6 percent have been reported (Walsh 2010).

Examples of initiatives

In Ireland, the investment in replacing water mains has increased five-fold for the period 2010-2013 in order to achieve the renewal of the main water networks of the country (Walsh 2010) [#128].

In France, according to (SoeS 2010), the water losses were already reduced on average from 23.7 percent in 2004 to 21.9 percent in 2008 due to pipe replacements and an earlier detection and control of leaks. With 3.5 percent, Paris is one of the best examples, but some cities have up to 41 percent of losses, especially in the South of France [#129].

In Tokyo, Japan, an extensive Water Leak prevention programme is in operation. In addition to routine checks and repairs, renewal of aged pipes and replacement of lead feeder pipes with stainless steel pipes is a major priority for the water utility (Kakehi 2010). Leaks are detected by using electronic leak detectors. The potential leakage quantity is estimated by using night flow measurement tools. The K-Zero project (for 'zero aged pipes') has been in place since 2002, and in 2008, 99 percent of the old pipes have been replaced. Tokyo reduced leakage levels from 20 percent (1956) to 10 percent (1992) and finally 3.1 percent (2008) (Yamamuro 2008; Kakehi 2010). This was achieved by exchanging cast iron for ductile iron pipes (from 1960 on), and by using the latest electronic equipment to track leakage points on the existing infrastructure [#130].

Potential difficulties, known drawbacks

- As reported earlier, the targets for the acceptable leakage levels may vary for each utility. The concept of ELL suffers from the notorious difficulty of assigning economic and marginal costs and is a highly contested concept.

5.2.2 *Pressure management*

Principle and methods

- Pressure management involves reducing the pressure of the water supplied to consumers, either durably for customers receiving constantly high pressures (for instance higher than 15-50m water column), or during off peak periods to reduce water leakage and levels of wastage in the water distribution system. The latter case is a dynamic pressure management, since pumps are adjusted to the actual demand.
- In such, it is complementary to leak detection and repair to reduce losses of freshwater. An advantage of this system is also that it provides a constant water pressure at consumer, and also extends the service life of distribution pipes (U.S. Environmental Protection Agency 2010).

Examples of initiatives

In Sydney, Australia, a water pressure management coupled to leakage detection programme was initiated in 2006 and shall save 33 Mm^3 of water per year by 2015. It consists in the use of pressure regulating valves and system monitoring points to achieve more consistent and lower water pressure levels at the distribution points where very high pressure is measured (Sydney Water 2006) [#131].

In the cities of Campbeltown, Tarbert and Inverness, Scotland, pressure control devices have been installed in order to cut down water losses. In Inverness, pressure was reduced downtown from 175m down to 17.5m at night for an investment of € 850,000. The effectiveness of the pressure control programme was assessed thanks to the collected data from flowmeters: at night, the flows could be halved. The payback period was estimated to be approximately 1.75 years (Naveh, Wiltshire et al. 2008) [#132].

In Lima, Peru, a joint German-Peruvian pressure management programme has been initiated in 2008. Modern pressure regulating valves, which adjust the water pressure according to demand via a central control system have been installed, reducing water losses in SEDAPAL's supply sector by 11 percent on a long-term basis, which has led to an annual cost saving of roughly € 97,000. Thus 1,329m^3 of water are saved daily, which corresponds to the average use of around 11,100 people [#133].

In Cape Town, South Africa, a township of 450,000 inhabitants was equipped with pressure reduction devices, enabling to save 25,000m^3 per day (40 percent of water). Similar projects in other cities of South Africa also yielded savings of 5,000-35,000m^3 per day (for cities with 450,000 inhabitants near Johannesburg and Cape Town) (McKenzie and Wegelin 2009) [#134].

Potential difficulties, known drawbacks

- Dynamic pressure management usually requires the investment in up-to-date pumping and monitoring systems, which are costly.

- A minimum pressure of 15m water column for the customers, or even higher pressures for fire fighting must remain.

5.2.3 *Efficient indoor water use (fixtures and appliances)*

Principle and methods

- The use of water-conserving fixtures and appliances, such as low-flow showerheads, faucet aerators, water-efficient dishwashers, and clothes washers supports reduction of water consumption.
- In households, water is mainly used for toilet flushing (33 percent), bathing and showering (20-32 percent), and for washing machines and dishwashers (15 percent) (UNEP 2004). Toilets and bathroom equipments hence offer the highest saving potentials. Following (Dworak, Berglund et al. 2007), up to 25 percent savings can be obtained by improving the technological performance of household devices.
- One of the means to support the use of water efficient appliances is through water efficiency labelling to influence purchase decision, or financial incentives for the purchase and installation of high-efficiency water fixtures (e.g. rebates on water saving products).

Examples of initiatives

In the U.S. , modern fixtures (post-2000) may reduce water consumption by up to 90 percent in home appliances (Federal Energy Management Program 2002). This is now encouraged by the EPAct which set new standards in order to benefit from these technological evolutions [#135].

New innovations are appearing on the market claiming even larger saving (up to 80 percent) by integrating a almost direct recycling scheme such as toilets where water used for hand washing is re-used for flushing, as used in Japan and the U.S. (for instance, project 'Eco Bath' or for example the AQUS ™ Greywater System commercialised in the USA for USD$ 300 - http://www.yankodesign.com/2009/05/21/use-your-water-twice/).

According to (Poquet and Maresca 2006), the water consumption of washing machines was divided by 3 between 1983 and 2000, while the one of dish machines was reduced by 4 between 1970 in 2000, showing that major progress has been achieved in this field. In Germany, a total of 18 percent savings was achieved between 1991 and 2004 due to the replacement of toilet flushing systems (Roth and Wagner 2011) [#136].

The 2011 adopted French National Adaptation Plan targets a 20 percent reduction in water losses by 2020. The Plan supports utilities both financially and technically to attain this objective , focused, among others, on a systematic tracking and repairing of leaks in water supply networks (MEDD 2011) [#196].

In the U.S., Southern Nevada Water Authority offers free fixture retrofit kits that include faucet aerators, leak-detection tablets, toilet flappers, and low-water-use showerheads for homes built before 1989 (Cooley 2007) [#137].

In 2005, in Australia, the government provided a legal framework for a Water Efficiency Labelling and Standards (WELS) Scheme. In the U.S., the WaterSense label from the Environmental Protection Agency (EPA) was created to identify products and programmes that meet the U.S. Environmental Protection Agency's (EPA) criteria for water efficiency and performance [#138].

In the region Bretagne, France, an extensive water saving programme was initiated in the 1990s. Households were equipped with water efficient fixtures, yielding 30 percent water savings (Bozec and Benot 2010) [#139].

The city of Austin, Texas, funded a 'free toilet programme' to replace toilets built before 1991, and a 'WashWise' programme to subsidise the purchase of efficient clothe washers (City of Austin 2005). Several other programmes have been launched in the U.S. by water utilities in the form of financial incentives to purchase water-efficient technologies (Klein, Kenney et al. 2007) [#140].

Potential difficulties, known drawbacks

- Policies to subsidise the equipment in water efficient fixtures require expenditures, and if they succeed in reducing demand, they could reduce revenues for the water utilities, generating water utility budget deficits (Olmstead and Stavins 2009).
- Hence, paradoxically, efficient indoor water use may not induce net savings for households, as the water price per unit could increase as less water is sold. Increases up to 5 percent per year could be expected in the coming years in some major European cities according to (Poquet and Maresca 2006). Communication on the benefits of water savings seems unbearable to increase public acceptance that these may not decrease their costs.
- Water conservation may have impacts on odours and corrosion of household systems as well as sewer system due to the lower flows and the concentrated pollutant load.

5.2.4 Efficient outdoor water use (-> WSUD)

Principle and methods

- The primarily outdoor water use is for watering lawns and gardens (Antoniou 2010). Other uses include outdoor cleaning and car washing.
- Water saving can be obtained via outdoor conserving technologies – which can be often seen as a part of Water Sensitive Urban Design (WSUD) – or changes in behaviour.
- Examples of technologies include drip irrigation systems that are 90 percent efficient or smart irrigation controllers which adjust watering based on local weather. The use of native low water demand plants can also support reducing water consumption (Antoniou 2010).

Examples of initiatives

In a 5 years study in Nevada, (Sovocool, Morgan et al. 2006) homes that converted from turf grass to low water demand plants saved 30 percent of the yearly total household water use [#141].

In Sydney (Australia), an Irrigation and Landscape Efficiency Assessment was conducted in order to rationalise irrigation of public sport fields. A simplified microclimatic modelling is made in order to best estimate watering requirements (Bryce and Porter 2010). Guidelines were derived from this assessment in order to list the best practices for the management of public sport fields [#142].

In Brest and Quimper, France, retrofitting of old sprinkling equipments enabled to save 60 percent of the irrigation water (Bozec and Benot 2010). In Poitiers, France, new "intelligent" sprinklers, designed to take into account the local soil humidity, enabled to save 20 percent of water (Lesquel 2007) [#143].

Potential difficulties, known drawbacks

- None known to date.

5.3 Water conservation

Water conservation measures are measures aiming at minimising / diminishing water consumption, i.e. via restrictions on the use or changes in the behaviour of customers.
Hence, water conservation focuses on the reduction in use (in general), and not on reducing waste (or use per unit final product), on the contrary to water efficiency (Wikipedia, 2011:Water conservation).
Water conservation measures contribute to adaptation to climate change in such that they help lowering pressure on water resources which will be impacted by climate change.

5.3.1 Voluntary and mandatory water-use restrictions

Principle and methods

- Water restrictions are enforced to reduce human demand for potable water supplies. Voluntary restrictions generally involve requests to limit outdoor watering to a particular schedule (i.e. on some specific days or time of the days) but without any enforcement mechanism.
- Mandatory restrictions, on the other hand, require that customers follow a watering schedule and impose penalties, usually in the form of fines, for known violations. Mandatory restrictions may also involve quantity limitations (Klein, Kenney et al. 2007).
- U.S. experience so far has shown that mandatory outdoor water restrictions are more effective than voluntary restrictions, which often produce little savings (Klein, Kenney et al. 2007). These may include restrictions on watering lawns, using sprinkler systems, washing vehicles, hosing in paved areas and refilling swimming pools.

- Following (Kenney, Goemans et al. 2008), the literature is consistent in showing significant (sometimes 30 percent or more) savings from mandatory restrictions.

Examples of initiatives

In a study during drought periods among Colorado's Front Range municipalities, water savings measured in expected use per capita ranged from 18 to 56 percent with mandatory restrictions (Kenney, Klein et al. 2004) [#144].

The effect of Drought Management Programs in Virginia in 2002 was studied by (Halich, Stephenson et al. 2005), the overall reductions in water use ranged from 0-7 percent for voluntary restrictions and from 4-22 percent for mandatory restrictions [#145].

In Sydney, Australia the 'Water Wise Rules' define behaviours to be followed for outdoor water use (Sydney Water 2011) [#146]:

- Watering, including with sprinklers and irrigation systems, is allowed any day before 10 am and after 4 pm;
- All hand held hoses must have a trigger nozzle;
- Cars shall be washed over lawns whenever possible;
- Fire hoses may be used for fire fighting activities only.

Potential difficulties, known drawbacks

- Voluntary restrictions show contrasted results, and even sometimes increases in consumption due to customers' expectations to be potentially cut off water later if mandatory restrictions apply (Klein, Kenney et al. 2007).

5.3.2 Water metering

Principle and methods

- Most water meters have the potential to generate significant reductions in the demand for water, by providing a price signal against which to compare consumption (Environment Agency 2007).
- About two-thirds of OECD member countries already meter more than 90 percent of single-family houses, however metering is not applied globally even in the most developed countries (Ashley and Cashman 2006).
- The literature indicates that installation of water meters typically may reduce consumption in the range of 10 to 40 percent and sometimes as much as 50 percent (Maddaus 2001 ; Terrebonne 2005; Friesen 2008). More specifically:
    - According to Environment Canada data from 1999, Canadians paying flat or fixed rates used 70 percent more water than those under a volume-based structure (Friesen 2008).
    - According to (Environment Agency 2008), in England and Wales, people living in metered properties use, on average, 13 percent less water than those in unmetered homes.

- ❑ According to (Lallana, Krinner et al. 2001), the immediate savings from the introduction of revenue-neutral metering in Europe are estimated to be about 10–25 percent of consumption.

Examples of initiatives

The Lille Metropolitan Area promoted, via its local climate agenda, the implementation of individual meters in all housing buildings (Lille-Métropole 2003) [#147].

New York City Department of Environmental Protection introduced automated meter reading to enable enhanced monitoring of water use – from four readings per year to four per day (NYCDEP 2005). This completed metering programme and incentives for installation of water efficient equipment by consumers resulted in the total water saving of nearly 17 percent for the city (Danilenko 2010) [#148].

In the BedZED suburb near London, U.K., easy-to-read water meter (together with an electricity meter) was provided in a small glass-fronted cupboard in the kitchen of all residential units at eye level. A decrease of 50 percent of the water consumption has been achieved (ARENE 2006), although the remotely read water meters did not work as expected (manual reading still required) (Shirley-Smith and Butler 2008) [#149].

Potential difficulties, known drawbacks

- Installing individual meters is costly, both in investment and maintenance. These costs are usually – at least partially – born by the end-user, which requires at least adapted communication.

5.3.3 Consumer education to enhance water conservation

Principle and methods

- Public information campaigns through advertisements or targeted marketing continue to be the most popular means of encouraging urban water users to adopt water conservation behaviours during drought (Dziegielewski 1991).
- In general, the following stages of concern are observed concerning water conservation (Howarth and Butler 2003):
  - ❑ Ignorance of the need to reduce water,
  - ❑ Awareness of the need to reduce water,
  - ❑ Interest in reducing water use,
  - ❑ Desire to take action to reduce water use,
  - ❑ Action to reduce water use.
- Educating the consumer to water conservation is essential, to ensure his support of conservation programmes. While the consumer is asked to do some efforts to conserve water, paradoxically this generally results in an increase of the price per unit of water (Frérot 2009). This matter of fact is driven by the important fixed costs embedded in the price of water (80 percent).
- Reviews of public communication campaigns found e.g. in (Klein, Kenney et al. 2007; Kenney, Goemans et al. 2008) concluded that education

campaigns can result in up to 25 percent water savings in short-term or crisis situations, but that their long-term effectiveness has not yet been shown. Further, the studies reviewed found that written material, alone, is unlikely to be effective.

Examples of initiatives

(Howarth and Butler 2003) reviewed some positive examples of public campaigns in Copenhagen and Singapore have demonstrated that communication programmes can also influence water using behaviour. Education programmes in schools were found to be more effective than large public information campaigns (Howarth and Butler 2003; Klein, Kenney et al. 2007) [#150] [#151].

Potential difficulties, known drawbacks

- None known to date.

5.3.4 *Pricing as a tool to enhance water conservation*

Principle and methods

- Pricing is a method used to encourage consumers to reduce water consumption.
- The end-user usually pays only a portion of the real costs induced by the water and wastewater services due to large subsidies. In some U.S. regions where water is very scarce, like Las Vegas, the water is typically billed less than USD$ 0.80/m^3 (2010), while it is billed more than USD$ 2.0/m^3 (2010) in the water-abundant region of Seattle (CERES 2010).
- In principle, change in pricing creates financial incentives for consumers to use less water, and higher prices are believed to fight against the 'myth of abundance' (Friesen 2008). Economists are measuring the responsiveness of water usage to water price with the 'water price elasticity of demand'. It represents the percentage change in quantity demanded resulting for a 1 percent change in price (with an elasticity of -0.5, a 10 percent increase in price nets a 5 percent decrease in consumption).
- With an elasticity of -0.4, if a water utility wanted to reduce demand by 20 percent (not an uncommon goal during a drought), this could require approximately a 50 percent increase in the marginal water price (Olmstead and Stavins 2009). Many studies of elasticity have been carried out, often in the U.S. They show that water demand in the residential sector is sensitive to price, but the magnitude of the sensitivity is small. Typical elasticity values ranging from -0.1 to -1.0 (Lallana, Krinner et al. 2001) from -0.11 to –1.59 (Brookshire, Burness et al. 2002).

Examples of initiatives

Full cost pricing is aiming at recovering the full cost of water and wastewater services. In Greece and Spain for example, water is priced at some 25-30 percent of the true costs, and in the United Kingdom at about 90 percent (Ashley and Cashman 2006). In Australia the costs for water supply are covered by 50-85 percent (Marsden and Pickering 2006). In France, the principle that "water pays water" was introduced in order to ensure that the water services are financed by the end-users (companies, public clients and domestic users). The European water framework directive is supposed to ensure that the full economic costs of water services are passed on to the users by 2015 [#152] [#153] [#154] [#155] [#156] [#157].

In Ardèche, France, a public water utility imposed a very high price in a rural district of Southern France (201 percent of the average French water price), but the effects were mixed since this has led people not to pay their bills – therefore, no elasticity exists (Strosser, Kossida et al. 2007). Other utilities in the same sector, applying 'average' French water prices, have shown a sounder elasticity of -0.31 [#158].

(Blokker and Vreeburg 2008) propose to use time-dependent tariffs in order to better manage peak demands during dry summers. This is already been done, e.g. in Austin, U.S., where a peak-tariff is used from July to October (City of Austin 2005). However, the peak tariff corresponds only to an increase of 10 percent of the water price [#159].

In Australia, the National Water Initiative, agreed by all Australian states latest in 2006, achieved the introduction of two-parts tariffs in which users pay a fixed charge as well as a charge for the volume of water used (Ludwig, Kabat et al. 2009) [#160].

In Cape Town, South Africa , a progressive tariff for water is used: while the first 6 m^3 per year are for free, the higher the water consumption, the higher the unit price per m^3. During a severe drought in 2005, the highest tariff for the highest step was significantly increased to curb excessive water use (from € 1.72 to 5/m^3) (Mukheibir 2008) [#161].

Potential difficulties, known drawbacks

- The question of water pricing is a very sensitive question, since water utilities – and especially private companies – are always suspected of maintaining high prices on purpose. Adapted communication campaigns on the price of water are essential to accompany such measures.
- Higher water prices may be bearable for the major part of the population, but not for low-income categories. Hence, several countries, such as France progressively since 2010, introduce social tariffs for water, and special incentives for low-income families to buy water-efficient fixtures.

5.3.5 *Water rights trade as a means to enhance water conservation*

Principle and methods

- Market-based water rights trading is the transfer of rights to abstract water from one person to another. It involves the trading of rights only, not the trading of actual water. The transferred rights are set out in a new abstraction licence (Environment Agency 2011).

- Water rights trade already took place in ancient times. Nowadays, trade is regulated by national or international agreements or law, but the trading itself remains – at least partially – independent of state intervention.
- Water rights trade can contribute to lower the pressure on water resources in water-scarce regions, or regions with predicted degraded quality or quantity in the context of climate change (Luo, Maqsood et al. 2003).

Examples of initiatives

In England and Wales, water trade rights are already in operation since 2001 in regions where water is scarce. A limited number of licences for given water abstraction quantities have been issued, and trading mechanisms have been in operation for several years; however to now only the trading of licences is permitted (Environment Agency 2011) [#162].

Regional trading systems were introduced since 1994 in Melbourne, Australia, to allow market mechanisms to develop a market-based reduction of water demand. The principle is based on transferrable water rights owned by major water consumers (e.g. agriculture, industry), similarly to CO_2 emission rights. This has led to massive investment in newer, water efficient technologies, with subsidies from local governments (Grefe and Young 2011) [#163].

Among other U.S. states, California has been participating in State regulated water trading since 1914. Water rights are shared by the State and specific agricultural use must be requested by application to the State Water Board (Hodgson 2006). These water rights permits are then awarded over a quantity-based period during which the bodies of water may be used (Wikipedia, 2011:Water trading) [#164].

Potential difficulties, known drawbacks

- Actual trade volumes have been relatively low in most water markets where water rights have been introduced. A 'modern' water rights system still needs to be invented (Hodgson 2006).
- Transferrable water rights may pose problems for the market concurrence if they are only adopted by some countries, or with very different allocation schemes. The return of experience from the difficult start of the CO_2 emission rights must also be considered if transferrable water rights are to be implemented.

6 Catalogue of global planning initiatives

Fig. 5 shows the different categories of initiatives which can be distinguished between global planning initiatives, and which are detailed in the next subsections.

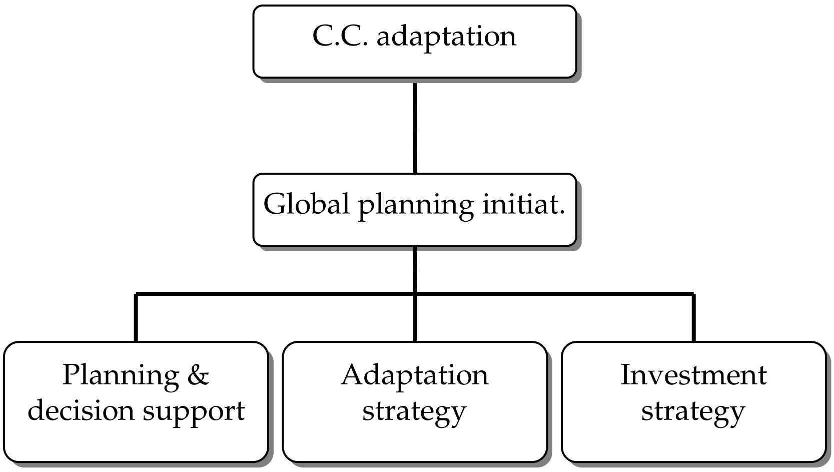

Fig. 5: different global planning initiatives.

6.1 Planning and decision support

Every adaptation strategy implies critical decisions, which need to be supported by planning and decision-support tools.

6.1.1 Climate change modelling and vulnerability assessments

Principle and methods

- The better the prediction and knowledge of climate change, the more relevant the adaptation policy.
- One of the major stakes for climate change prediction is the dealing with General Circulation Model (GCM) simulations, which cannot be directly used to assess local changes in climate due to their coarse resolution models (Easterling 1999). To obtain a much finer spatial resolution, downscaling approaches still need to be implemented and tested.
- In addition to studies dedicated to climate impacts, vulnerability studies enable to focus on the major vulnerabilities of cities facing climate change.

Examples of initiatives

The Danish Hydraulic Institute, DHI, has developed a Climate Change Tool for the MIKE numerical modelling software, classically used by several utilities or planners. This tool bases on GCMs for future precipitation and temperature scenarios, taking them into account for the modelling. Hence, this facilitates assessments and screening studies of the vulnerability to climate change (DHI 2011) [#165].

Within the framework of the 2011 adopted French National Adaptation Plan, the Explore 2070 project aims at quantifying the impacts of climate change on the water resources and usages by 2070. Climate change modelling will be used as a base for different regional scenarios for changing environmental conditions. The project will result in an assessment of the vulnerability of surface and groundwater resources, as well as the opportunities to protect them (MEDD 2011) [#197].

The Seattle Public Utilities (SPU) uses an Adaptation Value Chain that goes from GCMs, runs through downscaling, hydrology model and decision support to propose adaptation options. Since 2002, SPU has funded key downscaling studies related to water supply, as well as dynamical downscaling for urban drainage and downscaled GCM outputs to a regional scale [#166].

A nationwide U.S. study driven by the NRDC has screened the vulnerability of twelve major U.S. cities to climate change impacts for the water sector. The report summarizes the expected impacts of climate change according to over 75 studies in terms of sea-level rise, increased or decreased precipitation, increased flooding, saltwater intrusion or coastal erosion. For each city, the likelihood of these impacts is discussed, hence providing a tool for decision support concerning the various impacts of climate change (NRDC 2011) [#199].

Potential difficulties, known drawbacks

- The uncertainty related to climate change models and downscaling studies should not be underestimated. Hence, outputs of climate change models shall always be interpreted with care and safety margins as well as flexible or 'no-regret' options are to be favoured.

6.1.2 Adaptation databases

Principle and methods

- Several databases list examples of adaptations which can be useful for stakeholders to develop an own strategy. The databases are established and updated either on a voluntary, participative basis, or by a specific scan of specialised publications and on the Internet.
- Databases are especially of interest given the nature of climate change: a global effect, but with multiple, contrasted local effects. Interestingly are also the databases including examples which shall not be followed, for instance for being not cost-effective, such as provided by (SenterNovem 2006).

Examples of initiatives

In Germany, the Federal Environmental Agency (UBA) established a database of implemented solutions, TatenBank, with a fact sheet for each solution and details on how to contact the local manager (Umweltbundesamt 2011). The database collects examples mostly from Germany and Europe [#167].

The Adaptation and Database Planning Tool (ADAPT) was proposed by the International Council for Local Environmental Initiatives (ICLEI). ADAPT walks users through the process of assessing community vulnerabilities, setting resilience goals, and developing effective strategies that integrate into existing local planning efforts (ICLEI 2011). In the U.S., Climate Resilient Communities™ (CRC) is a national climate adaptation programme tailored to local governments to increase their resilience to climate change impacts and based on the ADAPT tool [#168].

Potential difficulties, known drawbacks

- Large adaptation databases sometimes omit explaining the difficulties for implementing solutions. They may also give the impression that any solution is adaptable to any context, which is wrong. Adaptation databases shall be considered with care, especially if they have been built up on a voluntary basis.

6.1.3 Integrated water management plans

Principle and methods

- Per se, water management plans are no climate change adaptation measures, but they clearly support decisions to be taken on the long term to face the consequences of climate change. Different types of integrated water management plans have emerged in the last decades, Integrated Water Resource Management (IWRM) being probably the most popular concept.
- IWRM is a cross sectoral approach for coordinated management and development of land, water and other related resources in order to maximise the resultant economic and social welfare in an equitable manner without compromising ecosystem sustainability (GWP 2000). IWRM establishes goals and monitors the processes' progress (van der Keur, Henriksen et al. 2008). The concept of IWRM is supposed to be mostly a bottom-up rather than a top-down approach (Figuères, Tortajada et al. 2003; van der Keur, Henriksen et al. 2008).

Examples of initiatives

In England, Water Resource Planning (WRP) is used to plan the actions to take in order to maintain security of water supply every 5 years for the next 25 years on a given geographical area (Dessai and Hulme 2007). These plans include water demand, water supply, as well as "headroom" or buffer between supply and demand. In south-East England, WRP enabled to identify the most relevant options for water management in the context of climate change, namely leakage reduction and securing of supply (Dessai and Hulme 2007) [#169].

In Perth, Australia, the Integrated Water Supply Scheme (IWSS) (which can be considered to be an IRP) is a useful tool for climate adaptation (Ludwig, Kabat et al. 2009). This water management scheme integrates different supply options (dams, surface water, groundwater, desalination) and enhances the flexibility of options, both on the short- and long-term [#170].

In the U.S., Integrated Resource Planning (IRP) is a popular planning tool. IRP examines all types of water supplies and conservation in a holistic and interconnected manner. In the Metropolitan Water District of Southern California, the 1996 IRP provided a 20-year resource plan that emphasised a balance between locally developed resources and imported supplies. Prior to the IRP, the region was heavily dependent on water imported from the Colorado River and Northern California. The new IRP goes through 2035 and emphasises investments in water conservation, recycling, storage and water transfers. Through 2008, this has included 59 recycling, 21 groundwater recovery, and 5 desalination projects [#171].

Similarly, the California Water Plan provides a framework to consider options and make decisions regarding California's future water supply. The Plan evaluates every five year the water needs and supply options, and also identifies and evaluates existing and proposed state-wide demand management and water supply augmentation programmes and projects to address the State's water needs [#172].

In South Africa, Water Resources Adaptation Plans are used by utilities to assess the vulnerability of the resource, propose and prioritise actions. Finally, these are implemented, monitored and reviewed in a process similar to IWRM (Mukheibir 2008) [#173].

In Singapore , the IWRM concept has been adopted since the early 2000s, integrating five major aspects of urban water management: (1) the protection of water resources, (2) the more efficient treatment of water, (3) the minimisation of pipe losses, (4) enhanced water conservation and (5) 'closing the water loop' thanks to water reclamation (Wu 2010) [#194].

Potential difficulties, known drawbacks

- IWRM may sometimes be inefficient due to the inherent uncertainties of water planning with climate change. In particular, system understanding and boundary conditions might be difficult to define (van der Keur, Henriksen et al. 2008).

→ *See also Section 6.2.1 (Flexible and reversible strategies)*

6.1.4 Capacity building and active learning

Principle and methods

- Although climate change is already a reality in most countries, 'thinking adaptation' is not always intuitive. Local authorities are therefore in need of further support regarding capacity building so that they can develop adaptation actions and strategies for reducing the severity of the impacts.
- Adaptation measures may not be implemented due to the lack of training of local staff. For example, in Egypt, the lack of highly-trained staff is identified as one major limitation for the broad use of desalination technology (Talaat, Sorour et al. 2002). Rather than developing own 'trial-and-error'-approaches, the exchange of expertise between senior and

young experts, and the training of the next generation of planners should prove to be an efficient adaptation method.

- Capacity building shall not be merely an academic exercise: actively involving the 'learners' – i.e., here, the stakeholders – in the learning process is the basic principle of active learning (Wikipedia, 2011:Active learning). In the context of climate change adaptation, it may be a convenient way to continually reappraise the performance of services and infrastructure and respond to changing risks (Ashley, Newman et al. 2008).

Examples of initiatives

➡ In the Economies in Transition (mostly countries of Eastern Europe), several capacity building programmes on climate change adaptation have been launched since the 1990s. These programmes include bilateral or multilateral assistance, or training via international institutions (OECD 2002) [#174].

➡ In South Africa, climate change capacity building forums have been launched starting from 2009 provide essential background and information to assist the South African public and private sectors to define their role in the context of climate change (van der Merwe 2009) [#175].

➡ In Alberta, Canada, a Municipal Climate Change Action Centre (MCCAC) was developed based on the principle that all municipalities must be part of the climate change solution. The role of the MCCAC is to provide capacity building support to the municipalities so that they can directly implement measures in their own operations and communities (AAMDC and AUMA 2009) [#176].

Potential difficulties, known drawbacks

None known to date.

6.1.5 Early-warning systems

Principle and methods

- An Early-Warning System (EWS) is a network of sensing devices, system or procedure designed to warn of a potential or an impending hazard. EWSs are important tools for governments and local authorities to protect the population and the infrastructure. Indeed, while hydro-meteorological hazards may take but a few hours, days, or weeks to occur, their adverse consequences can derail development efforts for years to come.
- EWSs are composed of four main elements, (1) risk knowledge, (2) monitoring and predicting, (3) disseminating information and (4) response (UNEP 2009).
- Most climatic and environmental EWSs were developed as a response to a major catastrophe. In the water sector, EWSs mostly concern flood, pollution (both considered ongoing and rapid/sudden-onset events) and drought threats (considered a creeping/slow-onset event). Hence, they shall both combine short-term weather forecasting, seasonal to inter-

annual climate prediction, as well as long-term climate prediction to include the effects of climate change (UNEP 2009).

Examples of initiatives

- In Lisbon, Portugal, an EWS is being currently developed within the European Research Project PREPARED to warn from health risks from faecal contamination of combined sewer overflows in recreational waters. The EWS is based on a coupled hydrodynamic-faecal contamination model and on real-time monitoring of the CSOs (PREPARED 2009) [#177].
- Also in Lisbon, a pilot EWS for water quality in the water supply system will be tested in the framework of the PREPARED project [#178].
- Several countries have developed an EWS for floods based on real-time monitoring of water stages and / or meteorological warnings. Among them, some provide complete public information, such as the 'VigiCrues' alert website in France (MEDD 2003) [#179].
- The Joint Research Centre of the European Commission has developed a European Flood Alert System (EFAS) in order bridge communication between authorities across European borders. The flood forecast information is provided twice a day to national flood warning systems, and flood information is provided up to 10 days in advance for the major European river basins (JRC 2010) [#180].
- The U.S. has developed an early warning system for droughts. The website proposes a national drought monitor, as well as regional Drought Early-Warning Systems (DEWS) for the Colorado and Apalachicola-Chattahoochee-Flint basins, as well as for the State of California (NIDIS 2011). Based on the climatic data, five key climatic indexes are calculated, and the basins are ranked in five categories, from 'abnormally dry' (D0) to 'exceptional drought' (D4) [#181].

Potential difficulties, known drawbacks

- Although flood EWSs are relatively widespread, drought and pollution EWSs are still lacking in several countries.
- Early warning systems need to be highly flexible and capable of adapting to the arrival of new information, and updated regularly (Hallegatte 2009), which is a technical challenge.

→ *See also Section 3.1 (Securing supply) and Section 3.2 (Flood mitigation)*

6.1.6 Legislation and guidelines revision

Principle and methods

- Adaptation strategies can hail from local initiatives, but can also be the result of legal incentives – hence in this case it is the policies which adapt to climate change, and private companies and utilities simply comply to the new policies. Climate change issues are gradually being mainstreamed into policies, plans and strategies for development and management in most developed countries.

- This traditional 'top-down' approach has proven to be efficient for instance in the EU with the European Directives, which drive the environmental policy of EU Member States.

Examples of initiatives

- In the U.S., the Energy Policy Act (EPAct) set water efficiency standards for several domestic fixtures by January 1994 (faucet, showerhead, toilet, urinal, clothes washer) (Federal Energy Management Program 2002). New domestic fixtures should comply with the new standards, reaching water savings of 50-75 percent compared to the pre-1990 usages. Another American example of policy adaptation is given by the U.S. Army Corps of Engineers, which has released a new policy requiring that sea level rise be taken into consideration in any new work of the Corps [#182].
- In New Zealand, the Coastal Policy Statement included consideration of sea-level rise, the Resource Management (Energy and Climate Change) Amendment Act 2004 made explicit provisions for the effects of climate change, and the Civil Defence and Emergency Management Act 2002 requires regional and Local Government Authorities (LGAs) to plan for future natural hazards (Hennessy, Fitzharris et al. 2007) [#183].
- In Australia, climate change is included in several environmentally focused action plans, including the National Agriculture and Climate Change Action Plan and the National Biodiversity and Climate Change Action Plan. A wide range of water adaptation strategies has been implemented or proposed, including USD$1.5 B for the National Water Fund from 2004 to 2009 and USD$1.7 B for drought relief from 2001 to 2006 (Hennessy, Fitzharris et al. 2007). The National Water Initiative, agreed by all Australian states latest in 2006, aims at promoting the 'efficient use of recycled water and stormwater' as well as 'increased water-use efficiency in domestic and commercial settings' (Ludwig, Kabat et al. 2009). This initiative sets the framework for Australia's water policy [#184].

Potential difficulties, known drawbacks

- These traditional 'top-down' approaches are not always well perceived by local authorities and by the public, as they are not directly involved in the decision-making process.
- An example from the Netherlands shows that top-down political approaches may not always be the most relevant. According to (de Graaf and van der Brugge 2010), the project Rotterdam Water City 2035 succeeded because it was a non-official policy process. The nonofficial status decreased the political risk. However, possible drawbacks of non-official policies are low status and low priority (de Graaf and van der Brugge 2010).

6.2 Adaptation strategy

The question 'how to adapt' to climate change must be answered by a list of measures that fit in a coherent and sound strategy.

6.2.1 *Flexible and reversible strategies*

Principle and methods

- Climate change is a highly uncertain challenge, especially at the local scale. Hence, the idea is to favour strategies that are reversible and flexible over irreversible choices (Smith 1997; Hallegatte 2009). The aim is to keep as low as possible the cost of being wrong about future climate change.
- The valuation of reversibility, through the option value concept or through multi-criteria decision-making frameworks, have thus to be applied to the comparison of adaptation strategies with different 'irreversibility levels'. An example is restrictive urban planning: when deciding whether to allow the urbanisation of an area potentially at risk of flooding if climate change increases river runoff, the decision-maker must be aware of the fact that one answer is reversible while the other is not (Hallegatte 2009).
- To protect against urban floods, cities may build removable and 'easy-to-retrofit' flood defences with pre-installed guides or sockets, within a pre-constructed foundation, that enable to adapt to different flood water stages depending on the severity of the expected flood (Environment Agency 2002).

Examples of initiatives

Legislations and guidelines which are re-evaluated frequently are examples of flexible and reversible measures. For instance, in The Netherlands, the design water levels for flood management are re-evaluated every 5 years to deal with uncertainties (Hoekstra and De Kok 2008) [#185].

A flexible – but not really reversible – strategy is followed in the Netherlands and parts of Germany for dike construction in such that their foundations are usually dimensioned strong enough to carry a future larger dike than the actual one (which has a limited lifetime), thus enabling the later construction of higher defences (Dessai and van der Sluijs 2007) [#186].

The diversification of water supplies to include more than one unique source of water, enhances the flexibility of the urban water system to adapt to future uncertainties, as proposed in the Integrated Water Supply Scheme of Perth, Australia (Ludwig, Kabat et al. 2009) [#004].

Additional examples are detailed in Sections 3, 4 and 5.

Potential difficulties, known drawbacks

- Flexibility and reversibility may induce supplementary costs for structural measures (reversible design, maintenance…). The benefits of such approaches hence need to be well communicated to the stakeholders.

→ See also Section 6.2.2 ('No-regret' strategies) and Section 6.2.3 (Soft adaptation strategies)

6.2.2 'No-regret' strategies

Principle and methods

- As stated earlier, uncertainty in future climate may complicate the decision-making process, or the design of structural measures. 'No-regret' measures, which yield benefits even in absence of climate change, constitute a valuable strategy to adapt to these uncertainties (Hallegatte 2009).

Examples of initiatives

- Controlling leakages in water pipes is almost always considered a very good investment from a cost–benefit analysis point-of-view, even in absence of climate change (Hallegatte 2009).
- Land-use policies that aim at limiting urbanisation and development in certain flood-prone areas (e.g., coastal zones in Louisiana or Florida) would reduce disaster losses in the present climate, and climate change may only make them more desirable (Hallegatte 2009).
- Most of the river restoration measures, which create or recreate natural flood expansion basins or plains, are also beneficial to the riverbank and floodplain ecosystems, help maintaining a certain degree of biodiversity, and add recreational value to the sites, hence representing a 'no-regret' solution even if floods are less frequent than expected (UN Economic Commission for Europe 2009).
  Additional examples are detailed in Sections 3, 4 and 5.

Potential difficulties, known drawbacks

None known to date.

6.2.3 Soft adaptation strategies

Principle and methods

- Technical and structural solutions are not the only way of adapting to climate change. Institutional, educational or financial tools can also be efficient and very cost-effective. Key advantage of 'soft' adaptation options is that they imply much less inertia and irreversibility than hard adaptation: an insurance scheme can be adjusted every year, unlike a water reservoir (Hallegatte 2009).
- In hurricane-prone regions, it may be more efficient to implement an efficient warning and evacuation system combined with strong (possibly expensive) insurance scheme and recovery plan than to protect all populations with seawalls and dikes (Hallegatte 2009).

Examples of initiatives

Water plans are typical examples of soft adaptations. For instance, in the framework of the California Water Plan, all water suppliers that provide water to more than 3,000 customers in California have to carry out, every 5 years, a 25-year prospective of their activity, including the anticipation of future water demand, future water supply sources, and 'worst-case' drought scenarios (Hallegatte 2009) [#172].

Additional examples are detailed in Sections 3, 4 and 5.

Potential difficulties, known drawbacks

- Soft adaptation measures may sometimes not seem as 'reassuring' as do hard (technical) measures, especially to decision-makers having a long experience with hazard 'resistance' approaches. Adapted communication with all stakeholders is hence essential.

6.2.4 Enhancing the multi-functionality of equipments

Principle and methods

- Climate change will induce changes in the precipitation regimes, river flows and temperature. Instead of building new structures capable of adapting to these new conditions, the principle of multi-functionality, i.e. several functions covered by one equipment, is promising in the water sector, where investments are generally relatively costly. It is a way to keep investment costs acceptable by covering several functions with one equipment.
- This approach is promising since, if well planned, it requires less additional investment than building multiple single-use equipments, and saves space – which is essential in urban areas (Digman 2010).

Examples of initiatives

The multi-functionality of equipments is at the heart of Water Sensitive Urban Design (WSUD), which proposes the integration of urban planning and development with the management, protection and conservation of water within a consideration of the water cycle as a whole (ATSE 2004). For instance, existing playgrounds may be retrofitted to be submersible, and offer additional stormwater storage capacities in highly urbanised areas (Umweltbundesamt 2011). Similarly, large parks located upstream of a dense urban area may be used as retention ponds (Pierron 2010).

Several measures of WSUD may also benefit to the urban environment in general, and cool down the heat island effect, which is expected to be significant due to climate change. Several structures can be adapted for dual use, as it will be shown in the next sections.

Additional examples are detailed in Sections 3, 4 and 5.

Potential difficulties, known drawbacks

- Multi-functionality may induce additional costs for the initial design or adaptation of the equipments.

- Although it may sometimes seem counterintuitive, usually a direct multi-functional without alteration of the initial equipment is not directly possible, or may not completely fulfil requirements. For instance, flood defences did not prove, as is, to be efficient recharge ponds and needed to be adapted (Sheng 2011).

→ See also Section 3.2.7 (Dual use of reservoirs for water supply and flood), Section 3.2.6 (Dual use of park and green fields for flood protection (-> WSUD)) and Section 4.1.4 (Dual use of flood defences for groundwater recharge)

6.3 Investment strategy

Climate change adaptation implies in most of the cases costs and investments in new equipments and technologies. Therefore, the investment strategy is a key element of the adaptation to climate change.

6.3.1 Buying "safety margins" in new investments

Principle and methods

- Uncertainties in climate change make it difficult to predict precisely the required degree of protection. Often, when it is cheap, it is sensible to add 'security margins' to design criteria, in order to improve the resilience of infrastructure to future (expected or unexpected) changes. This is also known as 'conservative design', and accounts for statistical uncertainty and unrecognised ignorance (Dessai and van der Sluijs 2007).
- Cheap safety margins can be introduced in many existing adaptation options, to take into account climate uncertainty. Making drainage infrastructures able to cope with more water than we currently expect is a 'safety margin' strategy that makes this adaptation measure more robust (Hallegatte 2009).

Examples of initiatives

In the Netherlands, very high flood design standards are applied, though there is limited knowledge of floods for long return periods. Hence, the consideration of very long return periods for the design encompasses important safety margins (Hoekstra and De Kok 2008). For dikes and walls, construction costs alone are often manageable, and the marginal cost to build a higher dike is small compared to its total cost (Hallegatte 2009) [#187].

To adapt drainage infrastructure, water managers in Copenhagen now use run-off figures that are 70 percent larger than their current level. According to (Hallegatte 2009), this 70 percent increase has not been precisely calibrated, because such a calibration is made impossible by climate change uncertainty, but it represents a conservative safety margin [#188].

A survey made in Germany among utilities has shown that they generally tend to increase the size of rainwater pipe systems as an explicit adaptation to climate change induced heavier rainfall. However, this is generally done using an empirical safety margin that is not the result of precise climate change impact modelling (Umweltbundesamt 2010) [#193].

<u>*Potential difficulties, known drawbacks*</u>

- Safety margins are perceived as a synonym of additional costs, and deservedly so. The benefits of including these however largely exceed the additional costs, which needs to be communicated adequately.
- In the design of flood protections, the use of safety margins is rather out-dated, and tools to better estimate uncertainties are preferred (Dessai and van der Sluijs 2007).

→ *See also Section 6.2.1 (Flexible and reversible strategies)*

6.3.2 *Climate-change oriented investment planning*

<u>*Principle and methods*</u>

- Investment planning can contribute to the flexibility of chosen options, which is a key element of adaptation to climate change. For instance, planning can help:
  - ❑ Reducing the lifetime of investments, which is an option to reduce uncertainty and corresponding costs (Hallegatte 2009).
  - ❑ Planning a staged investment (i.e. where only a portion is initially invested and the remaining amount is invested over time based upon the achievement of agreed upon objectives, or adjusted climate simulations). This technique is generally employed by investors in order to protect against future loss and uncertainties.

<u>*Examples of initiatives*</u>

In Berlin, the investment in the rainwater system to allow storage and treatment of urban rainwater is a typical example of staged investment, with a total of € 140 M invested until 2020 in new storage areas. The investment plan focused first on the most efficient investments, i.e. the storage options having the highest effectiveness/cost ratio, and scheduled cost-intensive measures for the last investment phases (Rehfeld-Klein 2011) [#189].

Queensland considers staged investment through the strong advocating of decentralised systems, enabling investment throughout the life of the asset (Tjandraatmadja, Cook et al. 2009). Sydney Water follows a similar planning approach [#190].

<u>*Potential difficulties, known drawbacks*</u>

- Stakeholders may be tempted to reduce time horizons in order to reduce investment cost – and quality.
- Staged investment requires adequate planning and a long-term strategy, to which local stakeholders might sometimes not be inclining.

7 Geographical index of initiatives

8 References

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