Perspectives on water and climate change adaptation

Climate change and the water industry – Practical responses and actions

This Perspective Document is part of a series of 16 papers on «Water and Climate Change Adaptation»

'Climate change and adaptation' is a central topic on the 5th World Water Forum. It is the lead theme for the political and thematic processes, the topic of a High Level Panel session, and a focus in several documents and sessions of the regional processes.

To provide background and depth to the political process, thematic sessions and the regions, and to ensure that viewpoints of a variety of stakeholders are shared, dozens of experts were invited on a voluntary basis to provide their perspective on critical issues relating to climate change and water in the form of a Perspective Document.

Led by a consortium comprising the Co-operative Programme on Water and Climate (CPWC), the International Water Association (IWA), IUCN and the World Water Council, the initiative resulted in this series comprising 16 perspectives on water, climate change and adaptation.

Participants were invited to contribute perspectives from three categories:

1 **Hot spots** – These papers are mainly concerned with specific locations where climate change effects are felt or will be felt within the next years and where urgent action is needed within the water sector. The hotspots selected are: Mountains (number 1), Small islands (3), Arid regions (9) and 'Deltas and coastal cities' (13).

2 **Sub-sectoral perspectives** – Specific papers were prepared from a water-user perspective taking into account the impacts on the sub-sector and describing how the sub-sector can deal with the issues. The sectors selected are: Environment (2), Food (5), 'Water supply and sanitation: the urban poor' (7), Business (8), Water industry (10), Energy (12) and 'Water supply and sanitation' (14).

3 **Enabling mechanisms** – These documents provide an overview of enabling mechanisms that make adaptation possible. The mechanisms selected are: Planning (4), Governance (6), Finance (11), Engineering (15) and 'Integrated Water Resources Management (IWRM) and Strategic Environmental Assessment (SEA)' (16).

The consortium has performed an interim analysis of all Perspective Documents and has synthesized the initial results in a working paper – presenting an introduction to and summaries of the Perspective Documents and key messages resembling each of the 16 perspectives – which will be presented and discussed during the 5th World Water Forum in Istanbul. The discussions in Istanbul are expected to provide feedback and come up with sug• gestions for further development of the working paper as well as the Perspective Documents. It is expected that after the Forum all docu• ments will be revised and peer-reviewed before being published.

10 Climate change and the water industry – practical responses and actions

This paper has been prepared by the IWA Specialist Group on Climate Change (CCSG), on behalf of the IWA. The primary purpose of this paper is to communicate the IWA perspective and to trigger discussion at various events, including the 5th World Water Forum. It is not intended to provide a complete overview of the impacts of climate change on the water industry; rather it is a thought-provoking document.

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Climate change and the water industry – practical responses and actions

This paper outlines the key vulnerabilities of the water industry to climate change and the most important adaptation strategies, responses and actions. It has been prepared by the IWA Specialist Group on Climate Change (CCSG), on behalf of the IWA. The vulnerability of the water industry in terms of water security and water quality to the impacts of climate change is firmly established. Water professionals and utilities acknowledge that climate change is unequivocal, and shares an increasing concern of the need to take action now to mitigate and adapt.

1 Introduction

The impacts will exacerbate the increasing human pressures on water systems, and decision-makers and managers need to address the challenges in an integrated fashion. Impacts will be felt differently in different geographical regions. Here, climate change impacts are described according to different climatic conditions: a) Low lying countries and river deltas which are more prone to flooding and under threat of sea level rise; b) Mountainous regions, which will be affected by retreating glaciers and snowmelt; and c) Arid and semi-arid areas that will be impacted by less rain and increased evaporation.

This paper summarizes the potential impacts of climate change on the water industry, provides some examples of practical responses and actions (through the use of policies, tools and changed practices) and outlines some main recommended actions.

A primary challenge for the industry will be to enhance the capacity to cope with impacts on for example groundwater, surface water quality, flow seasonability, urban flooding, potable water supply, waste water treatment, ecosystems, social and economic activity etc. Adaptive management, flexible approaches, diverse portfolios of water sources and management strategies and an ability to move quickly to make and implement decisions will be imperative. Continuous monitoring and evaluation will be essential to underpin the knowledge of decision-makers. Adaptation strategies for drinking water supply should address both the demand and supply side. With increasing frequency of extreme events recommended interventions include early warning systems, improved physical defense for existing facilities and careful site selection for new facilities. The paper lists specific strategies for the different climatic regions. In regions affected by melting snowpack measures need to address a broad spectrum of interventions to address uncertainty and make staged investments that enhance system capacity. In low lying countries it is also important to reduce the vulnerability to flooding, where careful urban planning is required and future developments must take into account the safe provision of vital water services under future climate scenarios. In drying climates a proactive approach is needed to avoid sourcing reactive emergency supplies. Furthermore, it is of vital importance to diversify resources and building capacity especially in low- and middle-income countries. This paper also includes aspects of mitigation since it is linked to adaptation. Pursued climate change mitigation options should demonstrate co-benefits that facilitate climate change adaptation, such as constructed wetlands as well as reducing non-renewable water. Finally, the paper includes a section on recommendations for actions for governments, the water industry at large and individual utilities.

A longer version of this paper is available on www.iwahq.org (under Programmes and Climate Change).

2 Impacts of climate change on the water industry

The vulnerability of the water industry to the impacts of climate change is firmly established, impacting on both water security and water quality. The scale of the issue was identified by Howe et al. (2005) who identified over 100 potential impacts on the services provided by Melbourne Water in Australia.

2.1 Background – the need for adaptation in different geographical settings

The predicted changing climatic conditions will exacerbate the growing human pressures on water systems which include population growth, increasing urbanization, increased water demands, changing land use, intensive engineering works and so on. Over the past century, such changes have led to a general increase in the vulnerability of society to extreme hydro-meteorological events.

While the projected changes in precipitation are regionally specific and highly uncertain, there are some general patterns that are evident from the review of GCM output. These impacts will not be elaborated in this document, however, given the variability of impacts across regions, it is critical that the water sector is well informed of the nature and magnitude of projected impacts in the region where they operate.

IWA has adopted the approach of analyzing impacts and responses divided in different climatic and geographical regions. The main categories that are used in this paper are:

- Low lying countries and river deltas
- Mountainous regions (retreating snowpack)
- Arid and semi-arid areas.

Low lying countries and river deltas

Low lying countries and deltaic regions are particularly vulnerable to the impacts of climate change as they are prone to flooding by both the sea and rivers.

Most of the research on climate change and water in low lying areas to date deals with flood risk assessment, especially in heavily populated coastal areas. Risks of droughts are also recognized, especially with regard to the effects on navigation, agriculture and energy production (specifically the availability of cooling water).

Mountainous regions (retreating snowpack)

Climate change is projected to have significant impacts on the hydrology of basins characterized by glaciers and the annual accumulation and melt of snowpack. Utilities that rely on mountain-based snowpack systems share some common vulnerability with respect to climate change. Increases in temperature will reduce the amount of snowpack that accumulates in the mountains above system reservoirs. Warmer temperatures may also affect the quality of the source water. The significance of these impacts may vary, however, both by region and by water supply system. Systems that have reservoirs versus those that rely on 'run of the river' diversions may experience different degrees of impacts. Regions where reduced snowpack is supplanted by increases in precipitation will likely face different impacts from those areas where reduced snowpack is accompanied by decreases in overall precipitation.

Arid and semi-arid areas

Climate effects in the arid and semi-arid countries of the world are expecting increasing temperatures, more extreme weather events, increased evaporation and sea level rise with accelerating rate in future. There is however a lack of consensus among the global climate change models as to what the likely changes in rainfall will be for certain areas. Figure 1 illustrates the projected patterns of precipitation change; the white area are where consensus is weak and the dot-patterned areas are where consensus is strong.

The most serious *effects* and resultant *impacts* for drying climates are:

- less rain which leads to reduced yields from surface water catchments;
- changed distribution of runoff which leads to much slower, less reliable and predictable groundwater recharge;
- more extreme events so that surface catchments are eroded with decrease in water quality and rivers provide less reliable supply;

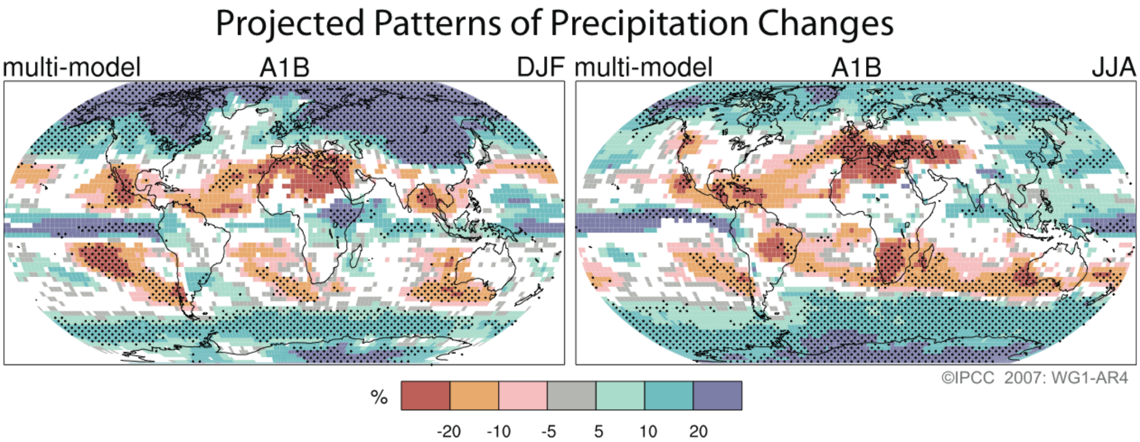

Figure 1: Projected patterns of precipitation changes (IPCC Working Group 1-AR4).

- increased evaporation through prolonged increase in temperature exacerbating water storage depletion;
- locally-specific changes in humidity levels with potential ecosystem impacts;
- water quality is impacted from all of these effects, including degradation of fisheries and potential wetland habitat loss;
- the combined effect of these impacts is very significant leading to whole communities becoming threatened and a broader impact of social defabrication in the most vulnerable drying climates.

3 Key vulnerabilities and main problems for the water industry

The water utility sector has a unique set of challenges ahead. A primary challenge for the water sector will be to enhance its capacity to cope with the impacts of climate change and these other human pressures on water systems while fostering greater resiliency to extreme hydrologic events.

The impact of climate change on drinking water resources and services is of increasing concern to a growing number of utilities worldwide. Driven by shareholder expectations, regulatory constraints, customers with their own set of growing expectations, and governments with responsibilities to deliver on both water quantity and quality objectives, these concerns present a future of increased risk across the climate, social and economic areas.

3.1 Impact on water resources

In addition to pressures from increasing demands and highly variable supplies, climate change also has the potential to influence water quality and the ability of the utility or catchment authority to meet (mandatory) ecological objectives. The response of water systems to changing meteorological conditions is highly dependent on a number of factors including: soil characteristics, topography, land use (urbanization, agricultural development), the presence of inundation areas and runoff management. Examples of some of the impacts of climate change on water resource management are given below:

Too little and/or saline groundwater

Groundwater dynamics are expected to change significantly due to climate change. During extended droughts, lowering of the groundwater table may have serious effects on terrestrial ecosystems, which are further exacerbated by the abstraction of groundwater for other purposes. In drought-sensitive areas, it will become increasingly difficult to combine ecological objectives (such as maintenance of biodiversity) and groundwater extraction, which endangers the license to produce drinking water. The anticipated effects are even more pronounced if increased agricultural and drinking water demands during heat waves and droughts are taken into account.

In areas where rainfall is reduced recharge is slower, but dryer conditions also lead to greater extractions and a lowering of water tables. Another aspect of groundwater mining or over-exploitation will be greater agricultural water usage under a future climate of higher temperature and evapotranspiration. Aquifers will need better management and strenuous efforts will be required to improve recharge.

In many coastal regions, groundwater resources are increasingly vulnerable to salinisation due to sea level rise. Overconsumption or unregulated extraction of groundwater exacerbates the problem. Coastal rivers are likely to be threatened by the creep of saltwater wedges upstream. A combination of sea level rise and reduced river flows will lead to increased seawater intrusion into river mouths, limiting the use of the water for irrigation and drinking water production.

Reduced surface water

In drying climates reduced yield from surface catchments (watersheds) is complex, exaggerated by normal hydrologic processes, which mean that dryer soils take up more water before any net runoff occurs, so the percentage reduction in runoff typically substantially exceeds the percentage precipitation reduction. Increased evaporation from storages reduces the yield from a catchment further. Evapotranspiration also increases with temperature, exacerbating reduced runoff. Each situation has to be modeled for its local circumstances, but a minor rainfall reduction can translate to a catastrophic drop in yield.

Rivers which receive less runoff tend to dry out more frequently, and in arid climates they are often ephemeral. Water extractions from rivers, for irrigation and urban water supply purposes, increase during dry periods placing even greater stress on ecological health. Even where net extractions do not increase, the proportion of natural flow extracted is higher under low-flow conditions. Under normal conditions, many rivers gain water from aquifers in certain reaches, and lose water to aquifers in others. During climate induced aridity, the tendency is for there to be greater losses and less inflow, exacerbating other river problems.

Shift in flow seasonality and water availability

Snowpack and glaciers have a large impact on water storage and flow seasonality, and with global warming, vanishing glaciers and diminishing snowpacks potentially pose a major threat to the water availability in the regions identified in figure 1. In a warmer world, a smaller proportion of winter precipitation falls as snow and the melting of winter snow occurs earlier in spring (Eckhardt and Ulbrich, 2003; Vanham et al., 2008a).

Even without any changes in precipitation intensity, both of these effects lead to a shift in peak river runoff in winter, out of summer and autumn when demand is highest (Barnett et al., 2005). Where storage capacities are not sufficient, much of the winter runoff will be lost to the oceans.

Climate change will alter the behaviour of river runoff including the probability of flooding. In regions where most of the winter precipitation currently falls as snow, the seasonality of river flows will become less pronounced. Spring discharges will decrease due to reduced or earlier snowmelt, and winter flows will increase. This has been observed in the European Alps, Scandinavia and around the Baltic, Russia, the Himalayas, and most of North America. The increased winter flow in some areas will enhance the threats of greater winter floods caused by ice jams. In regions with little or no snowfall, changes in runoff are much more dependent on changes in rainfall than on changes of temperature. Most studies in such regions (e.g. the monsoon region) project an increase in the seasonality of flows, often with higher flows in the peak flow season and either lower flows during the low-flow season or extended dry periods.

As a result of climate change, the water retention characteristics of river basins are likely to change due to the change in ecosystems in mountainous regions resulting in faster collection time and a lower time-gap for organizing flood defense measures.
Figure 2 shows the contribution of specific mountain systems to lowland water resources (Viviroli et al., 2007). It can be seen that mountainous snowpacks and glaciers have high contributing potential to several dry regions in the world (the blue regions in the figure) including the North American coastal region west of the Rocky Mountains (e.g. Los Angeles) the mountainous sources of the Tigris and

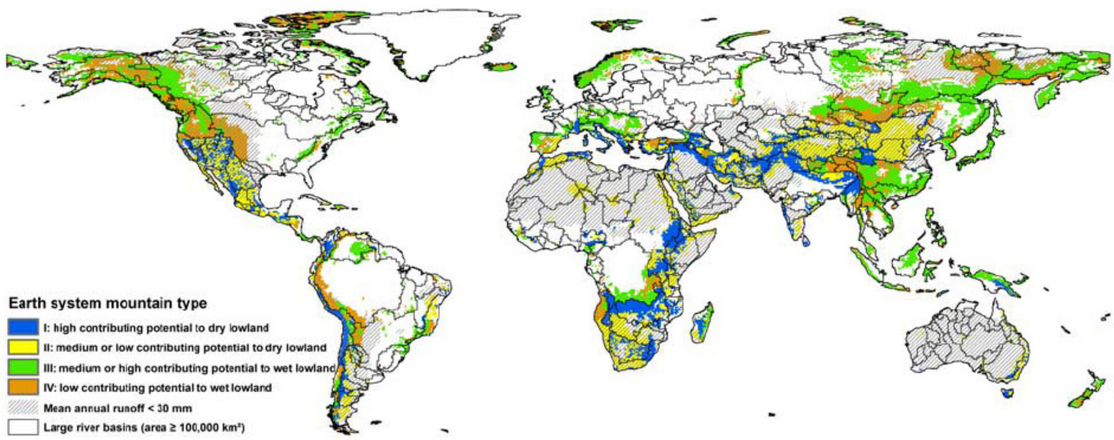

Figure 2: Earth system mountain types – contributing water to lowland (Viviroli et al. 2007).

Euphrates Rivers, the Hindu-Kush-Himalaya mountain range for the river basins of the Indus and Ganges-Brahmaputra and the Andes glaciers for cities like Quito. The green regions show areas with medium to high contributing potential to wet lowlands (including the Alps in Europe which feed into river basins like the Rhine, Danube, Po or Rhone, and the snowpacks in Japan on which cities like Tokyo depend for their water supply.

Surface water quality

The projected trend towards more frequent and extended droughts will also affect the water quality of surface waters (Murdoch et al., 2000; Van Vliet & Zwolsman, 2008), threatening the functions assigned to water systems (agriculture, recreation, drinking water). Low river discharges are generally associated with a decreased dilution capacity for point source pollutants, resulting in higher concentrations of contaminants in the water. Increased precipitation variability may lead to longer periods of low flow followed by high flow events which result in high concentrations of pollutions from diffuse pollutant sources (Thorne, 2008).

Increasing temperatures and an increase in the frequency and/or intensity of drought also have the potential to increase the occurrence of algal blooms in lakes and reservoirs. The occurrence of potentially toxic blue green algae (cyanobacteria) which take advantage of high water temperatures are of particular concern, both to ecosystem functioning and to water services. Changes to meteorological conditions have also been linked to changes in the concentrations and characteristics of natural organic matter in drinking water sources.

These changes to water quality have the potential to adversely impact on the treatment of water for potable use and may result in taste and odour problems, ineffective treatment processes (such as coagulation and chlorination) and unacceptably high levels of disinfection by-products in distribution systems.

Depending on the extent of the changes and the site-specific water treatment processes, poor raw water quality may ultimately result in elongated intake stops.

In addition to concentrating pollutant loads from wastewater treatment plants during prolonged dry periods, climate change can also lead to increases in raw water turbidity and natural organic matter, including disinfection by-product precursor concentrations. In recent years some regions have reported an increase in high flow events (e.g. the Schoharie Creek watershed which is part of the New York City Catskill watershed). These elevated flows have eroded stream banks and have led to an increase in raw water turbidity levels. Increases in raw water turbidity are a concern to water suppliers for several reasons: interference in the disinfection process, increased coagulant doses and costs, overloading process functionality, increased solids handling costs and increased public health threat – especially for supplies that do not filter.

Climate change can also lead to longer-term changes in the quantity and character of natural organic matter. Many utilities in the northeastern US and northern Europe have noted increases in raw water color and disinfection by-product levels (especially haloacetic acids). This change is thought to be associated with warmer temperatures and decreased snowpack leading to increased microbiological activity.

3.2 Sea level rise and flood protection

The main structural defense against sea level rise in developed countries will continue to be dykes and other hard engineering measures. Improved public and scientific awareness will also play an important role in the development of shoreline management plans which may include plans for retreat and relocation in addition to physical defenses. Such strategies have already been developed in parts of Europe.

Sudden shifts in population (away from flood prone regions) will also provide challenges. Special attention must be paid to waste water treatment plants located in zones of potential inundation as flooding of such facilities can have serious public and environmental health consequences.

3.3 Disaster prevention and resilience to extreme events

Extreme weather events – risk of death and health, and damage to infrastructure

Another aspect of climate change relevant to water utilities is the projected increase in extreme weather conditions, such as tropical cyclones, storm surges and rainstorms. This may cause mass destruction of the infrastructure and changes in flood risk, including flash flooding and urban flooding. However, there may be some reductions in the risk of spring snowmelt floods and ice jam floods in certain areas. Floods have a considerable impact on health in terms of number of deaths, disease burden, and also in terms of damage to infrastructure. While the risk of infectious disease following flooding is generally low in high-income countries, populations with poor infrastructure and high burdens of infectious disease often experience increased rates of diarrhoeal diseases after flood events. There is increasing evidence of the impact that climate-related disasters have on mental health, with people who have suffered the effects of floods experiencing long-term anxiety and depression.

Urban flooding

The design of urban drainage systems is often based on critical 'design storms' that are determined through analysis of historical precipitation statistics and described by Intensity-Duration-Frequency (IDF) curves. Other design approaches include the use of hydrodynamic models which utilize long time series to represent precipitation variability. However, both methods lack the ability to represent future climatic conditions. Alternative design methods are required to ensure that the system can continue to function as designed even under future climate scenarios.

Urban drainage and waste waster treatment

Surcharge of drainage systems – The topography of deltaic countries is flat which leads to minimal slopes in gravity drainage systems. Sewers carrying rainwater tend to behave like a sponge which gradually fills. The transport capacity is maintained by pumping stations. Further compounding the problems is the character of the soil in these areas which is typically constituted of fine materials such as clay and silt, thus ruling out the use of infiltration to increase drainage capacity of the system.

With increased rainfall intensities, surface runoff peaks increase as well. This creates the danger that runoff volumes may exceed either the capacity of sewer entries (gullies) or the design discharge of sewer reaches[1].

Combined sewer overflows – Heavy rainstorms may challenge the capacity of the sewer system to deal with large amounts of water in a short period of time. If the capacity of the sewer system is exceeded, polluted water may be discharged into surface water (sewer overflows), causing water quality deterioration, both chemical and biological (pathogens), and incidental fish kills. Moreover, water from the sewer system may flush back to street level during rainstorms, posing a threat to human health and wellbeing. The increase in rain events also leads to ele-

[1] Preliminary assessment of small catchment shows, that a change from 3-year design storm to intensities of current 5-year design storms lead to a 10% to 15% increase in the discharge peak (Staufer et al., 2008). The impacts of rare events are probably more severe.

vated raw water turbidity levels which are especially problematic for unfiltered supplies such as New York City.

As for the shift of the water balance from the drier part of the year (northern hemisphere summer) to the wetter part, heavy rainfall coincides with long dry weather periods, which increase the loads spilled by combined sewer overflows (cso)[2].

Waste water treatment – Waste water treatment plants are endangered by flooding from both rivers and the sea. The emission of the bacteria and pollutants stored within the biological treatment risk public health, water supply and aquatic life (Pinnekamp et al., 2008).

3.4 The provision of potable water supply

Climate change will impact on the ability of water utilities to meet potable water demand in many regions around the world. Increasing source variability and declining raw water quality, combined with increased demands and increased competition between different water users (municipal, agriculture, industry, ecology) will create challenges for providers of potable water.

- Sea level rise will result in saline intrusion into coastal aquifers, affecting the suitability of the water for potable use. This is particularly an issue in areas where ground water is the sole source of drinking water (e.g. a case in the dunes area of the Province of West Flanders in Belgium).
- In drying climates potable water sources can be impacted by more concentrated pollution, higher temperatures, increased carbon dioxide levels and higher turbidities. This affects waterway health, especially for lakes and reservoirs. Algal blooms can be expected to increase, with attendant problems. Treating blended or compromised water sources to service a given community imposes greater challenges.
- Infrastructure for water utilities will become more difficult and costly to manage in drying climates. Water mains and sewers are structurally challenged by drying and hence shrinking soils, so they can crack, leading to increased infiltration and exfiltration, which in turn exacerbate treatment and groundwater or stormwater contamination problems. Similar problems can arise with stormwater drains. Corrosion increases in sewers – thanks to the combined effects of higher temperatures, increased strengths, longer retention times, and stranding of solids – shorten asset life and increase maintenance demands.

[2] The effect of the shift from summer to winter precipitation was investigated with a hydrological model for a catchment with a single storage tank. The results emphasize an increase of mean annular pollutant loads of 10% although total annular precipitation remained constant (Staufer et al., 2008). Butler et al. (2007) gained results from a case study that in London the number of storm events filling the storage tank rise by 35% and conclude that 57% additional storage volume would be necessary.

3.5 Effect of climate change on ecosystems

Climate change may have adverse effects on the ecology of mountains, which in turn can have an indirect impact on water supply systems. Forested watersheds could be more susceptible to pest infestations and diseases, which could lead to deforestation and impacts on water quality. Higher temperatures, coupled with weakened forest health, could increase the likelihood and severity of forest fires, which can also impact quality and quantity.

Wetlands come under pressure as water becomes more scarce, so habitats are lost and trees which rely on periodic watering begin to die. In coastal regions, wetlands (and estuaries) can become more saline, impacting on mangroves, invertebrates and other species which rely on particular ranges of salinity. Owing to saltwater intrusion, coastal areas could be challenged by the need to relocate water intakes further upstream, resulting in more disruption of wetlands.

Fisheries are threatened by lower flows, changing salinity, change of stream flow seasonality, loss of habitat and increasing fishing effort as economic pressures narrow choice for economic activity.

3.6 The human dimension

Large-scale climate change forces people to move from low lying coastal regions to resettle in areas with available water resources and safety from sea level rising. Many of these target areas for relocation are floodplains. Resettlement also results in losses in local knowledge, which is an important factor when people move to high-risk locations. Such improperly prepared resettlements may rise the possible costs, and even the death tolls of flood events. Thus, growing population density in high risk locations, such as riverine neighbourhoods, is very likely to increase the vulnerability of societies to climate change. This mass relocation has already occurred in a number of small island developing nations such as Tuvulu, which is currently assessing options for relocating the country's entire population.

This migration also creates pressures for water utilities which must be able to provide services to these regions of rapidly growing population.

Social and economic impacts will be perhaps the most challenging for drying climates as:

- Communities in regional areas, especially those dependent on agriculture, could be threatened by reduced water availability. For the water industry, this poses risks in terms of the long-term viability of systems and the size of treatment units. A conventional water treatment plant, designed for stable or growing population levels, might end up as a stranded asset.
- Managing water in times of scarcity is more complex and exacting, which imposes greater demands on human and other resources, and the skills of staff involved. Water theft has been tolerated in many communities, but a drying climate makes issues like theft much harder to ignore. More accurate water accounts will have to be kept and, to support it, better metering will be demanded.
- Water demands will increase. A good indicator for dry climates is the increasing proportion of water used for irrigated agriculture. Tensions over water allocation become more severe as the supplies become more scarce.
- Reduced crop production and food security are very significant downstream. Vulnerable communities face under an uncertain and worsening water resource regime, and food security has already demonstrated that it will impact developing nations severely in the very short timeframes.

4 Practical responses of water utilities to climate change adaptation

4.1 General responses

Adaptive management holds the key to survival for arid areas under the influence of climate change. Flexible approaches, diverse portfolios of water sources and management strategies and an ability to move quickly to make and implement decisions will be imperative. Continuous monitoring and evaluation will be essential to underpin the knowledge of decision-makers.

At the level of utilities, the awareness, impacts and response to climate change is diverse and locally specific. Yet, it is imperative that the water sector take measures and actions to respond to a changing climate in combination with other relevant pressures (e.g. population growth, urbanization).

The EC (DG Env) Communication on Water Scarcity and Drought and associated action plan is under preparation. Climate change impacts and adaptation are key considerations. Its 'water hierarchy' approach sets out the need to **prioritize water savings/water efficiency** before looking at other alternatives.

Potable water supplies

Adaptive strategies for drinking water supply should address both the demand and supply side.

Demand strategies may both apply to water allocation issues between sectors (agriculture, industry, drinking water, ecology) and to a reduction in water consumption. In warm climates, agriculture is by far the largest user of fresh water (e.g. 80% in Spain), so reduction of water losses by agriculture should be top priority. Technological innovation (e.g. improved irrigation techniques) may make this possible. With respect to public water supply, increasing public awareness of water scarcity and water saving is needed as a first step, although mandatory measures may be necessary in times of water crisis. Possible measures include public information campaigns, introduction of progressive water tariffs, and setting of specific regulations regarding the use of drinking water during periods of water scarcity (e.g. a ban on private car washing or watering the garden). In recent years, mandatory water restrictions have been used to successfully reduce domestic water demand in Australia during drought periods.

Supply strategies aim to increase water resources availability. Relevant aspect of such strategies are costs, customer perception and environmental sustainability. Worldwide, studies have focused on the exploitation of sea water, precipitation, brackish ground water and domestic wastewater, using innovative treatments, such as membrane technology, as alternatives to commonly applied water resources. Some concepts are already widely applied in specific regions. For example, desalination is a commonly applied technique in (semi) arid areas, like the Mediterranean countries. Drawbacks of this technique are the high investment costs and energy consumption (opposing CO_2 mitigation targets).

Flexible water resources management is a promising concept to guarantee the continuity of drinking water production and supply at acceptable costs. Application of the 'Flexwater concept' is based on large treatment systems, designed for constant production, combined with local sources to deal with peak demands. The use of locally available water resources is an essential element of this concept. The Flexwater concept is expected to be cost efficient in remote areas and newly developed urban areas. For instance, the 'closed city concept' is based on the use of local rainfall for drinking water production in urban areas. During dry periods recycled waste water treatment plant effluent and regional surface water may be used as supplementary sources to create a more flexible system (provided appropriate treatment techniques are available). This can reduce the vulnerability of urban areas to water scarcity. Another example of the Flexwater concept is the use of excess rain water or pretreated surface water as additional sources for drinking water or for non-potable uses (e.g. flushing toilets) in combination with temporary storage in aquifers, and the excess water is then recovered during dry periods. At several locations in the world (e.g. USA, Canada, UK, Israel, Australia), this concept is already applied. It should be mentioned that this technique may have serious implications for the quality of the injected water (e.g. mobilization of arsenic).

Extreme events

Water utilities should work closely with the developers of shoreline management plans as in low lying and deltaic regions it is likely that their infrastructure will be vulnerable to flooding, compromising their ability to provide necessary services. Possible measures to protect against such disasters could include early warning systems, improved physical defence for existing facilities and careful site selection for new facilities.

Extreme hydrological events pose a big challenge to water utilities' daily operations. Demand patterns and flows in water mains and sewers will become more dynamic as a result of rainstorms and droughts. Treatment works will be challenged with more variable sewage flows, either diluted (rainstorms) or concentrated (droughts), sewers may not be able to cope with rainstorms, leading to sewer overflows and backflushing of sewage to street level, etc. This may lead to serious public health issues. Knowledge and models are needed to understand and assess the consequences of extreme weather (rainstorms, heat waves, droughts) on the entire urban water cycle and on the interaction between the urban water cycle and the hydrological cycle, aiming to develop best management practices at local level. We need smart and robust monitoring systems with sensors and communication tools for early warning of **rainstorms** and associated pollution events and for remote control of supply and sewer systems. These systems should contain 'control handles' to enable more flexible operations and adaptation to extreme weather conditions. We need more knowledge and technologies (such as toxicity assays and sensors) to assess public health effects of urban flooding and controlled sewer overflow events. **Droughts** will increasingly cause imbalance between water demand and supply. On the one hand this asks for smart technologies and communication strategies to save or reuse water in households, industries and agriculture, and on the other hand it calls for innovative technologies to exploit alternative and non-conventional resources such as brackish groundwater, sea water, greywater and treated wastewater. And we should further develop technologies and approaches to store and recover water in local aquifers (ASR), taking account of possible adverse impacts on water quality (e.g. mobilization of arsenic). We have to assess and monitor the microbiological risks of high temperatures in water mains and plumbing systems (e.g. *Legionella*). The hydraulic functioning of the sewer system and the purification performance of waste water treatment facilities during rainstorms and droughts is another issue at stake.

There is also a major challenge related to mitigation. To ensure that adaptation strategies do not contribute to further global warming, the water sector must aim to lower its energy demand and GHG emissions and introduce energy recovery and renewable energy systems. Research and technology development is needed to support the water sector in this ambition. Further discussion is provided in Chapter 5 of this document.

Capacity-building

A general concern is the need for capacity-building for adaptation through a knowledge exchange between countries and to showcase adaptation examples worldwide. Toolkits need to be developed in different areas and sharing of knowledge and best practice needs to be facilitated.

4.2 Adaptation responses and strategies in deltaic countries

Adaptation to climate change in low lying and deltaic countries will rely on a combination of physical defence and careful development of response strategies and disaster action plans. To reduce the vulnerability of communities to flooding, careful urban planning is required, and future developments must take into account the safe provision of vital services (including water) under future climate scenarios.

Adaptation to reduced sea level rise/storm surge

This section mentions some of the measures not previously under extreme events.

The building and strengthening of dikes will protect land from being inundated by the sea. Reforestation and coastal vegetation (mangroves) can act as natural barriers to erosion and destructive storms. However, with sea level rise saline waters will be entering the ground and surface waters with implications for agriculture and water production. At the same time adaptations have to target increase of pollutant concentrations in rivers during low flows (micro pollutants EDS's/ PPCPS's, organic material, etc.) and the subsequent impact on drinking water treatment, ecology, swimming water, etc. Alternative sources of water have to be considered such as desalination or use of rainwater harvesting, filtered pond water, etc.

Adaptation to flooding

Other than building embankments, there are other approaches in learning how to live with floods and develop flood resilient systems, landscapes and infrastructure. This includes flood proof storage of chemicals/ fuel. River flooding will increasingly affect agricultural areas and adaptation may be carried out through 'floating crop beds' and hydroponics.

In general there will be a need for expenditure on maintenance and repair, for example, improved infrastructure engineering and design to protect underground assets due to changing soil conditions.

Adaptation of urban drainage and waste water treatment in deltaic countries

The increasing impact of rainstorms on sewer systems can be dealt with by creating more open water, underground storage, and a separate collection of rainwater and sewage, but these are costly measures and there may not always be enough space to implement them, especially in urban areas.

Adaptation of drainage systems has to aim at different levels which are separated by the return period of a rain event. With respect to sustainable development of urban areas, adaptation has to be based on an integrated approach that minimizes the number of end-of-pipe measures, thus focusing on source control.

Long droughts and the increasing number of formerly very rare events will cause the operation of drainage systems to act more decentralized.

If flood protection is established or enhanced, waste water treatment plants should not be forgotten. If necessary, additional pumping stations for high water times are needed that ensure the operation during this time.

4.3 Adaptation responses and strategies in mountainous regions

Current water management practices may not be robust enough to cope with the impacts of climate change on water and will need strengthening. Moreover, current water management practices are not flexible enough to cope with the seasonal contrast of floods and drought at the same geographical location, especially in lowland plains. Climate change challenges the traditional assumption that past hydrological experience provides a good guide to future conditions, and new approaches have to be made. The consequences of climate change may alter the reliability of current flood defence systems and infrastructure.

A portfolio approach to climate change adaptation

Given the uncertainty associated with the possible impacts of climate change, it is critical that utilities pursue adaptation strategies that enable them to make staged investments that enhance their system capacity in a financially sound manner. An initial area of focus is system operations: utilities should analyze how to enhance the operations of their existing utility system as it may lead to greater knowledge of their system at low to no cost. In assessing the possible impacts of climate change on its water supply system using three climate scenarios, Seattle Public Utilities was able to offset all the projected reductions of supply in 2050 in two of the three scenarios through low cost, operational adjustments. While changes in system operations will be a critical component of water managers' responses to climate change, it is also critical for water managers to think more expansively and consider portfolios of adaptation strategies that operate in multiple realms to enhance the coping capacity of their system and the communities they serve. A partial list and description of these realms is given below.

Operational

Water managers should develop flexible operational strategies that are dynamic and responsive to real time conditions. Water managers should test their systems to identify latent system flexibility that could be deployed as needed to accommodate variability that may be amplified by climate change. Utilizing observational networks to enhance access to real time information that informs operational decisions should be evaluated. Aggressive leak reduction strategies should be deployed in order to reduce system withdrawals and reduce vulnerability to drought events.

Structural

The projected hydrologic impacts of climate change, as well as the GHG emissions associated with different options, should be factored into decisions about system expansion or additions. Reservoirs are often operated, or are expected to be operated, for multiple purposes that often have competing objectives, e.g. water supply and flood retention. System operations and expansion should recognize these sometimes competing objectives of water system management and attempt to enhance system flexibility through strategic investments that are staged appropriately and pursued in tandem with other strategies.

Sociological

Demand management strategies, such as conservation programmes and tiered pricing, can be instrumental in helping to maintain or increase the gap between supply and demand. Behavior modification and social marketing strategies can be pursued to assist in redefining people's relationship to water. Meaningful outreach and involvement strategies with citizens can enhance a community's water intelligence and enable water utilities to access tacit knowledge in the community about water.

Technological

As 'water smart' technologies continue to advance and decentralized approaches to water provision become more acceptable and safe, it would be advantageous to water managers to develop integrated water management approaches that support hybrid strategies of decentralized and centralized strategies, e.g. rainwater harvesting that complements traditional centralized water supply systems. Such approaches can add resiliency and diversity to water supply portfolios. If lacking such pro-active approaches, technological advancements could lead to outcomes that are disruptive to current utility business models.

Political

Water managers may want to engage in discussions about water allocations between sectors of society and be active in issues, such as decisions about which types of new energy generation facilities are developed that have implications for the withdrawal and use of limited water resources. Identifying and implementing water use efficiencies in the agricultural sector should be top priority, since this sector consumes most of the fresh water resources globally. Collaborating with other utilities to share best practices, jointly advocate for resources that would enhance adaptive capacity, such as the establishment or expansion of observation networks, and fund research that enhances knowledge and addresses issues of common concern, should be considered.

Technical

Water managers should be engaged in helping to shape and frame the climate change research agendas of governments and research institutes so that the research is addressing the needs of user communities and generating research products that can be used by water utilities to enhance their understanding of the impacts of climate change and develop appropriate adaptation strategies.

Institutional

Building institutional capacity within utilities to operate and think strategically across these realms is critical if utilities are to pursue a broad-based approach to developing adaptation options and capitalize on opportunities beyond the traditional domain. Evolving conditions and uncertain futures merit the evaluation of institutional capacity to respond to them.

4.4 Adaptation responses and strategies in drying climates

Because of the effects of prolonged droughts in many semi-arid and arid nations there has been a realization that water resource management including planning and investment in infrastructure must be underpinned by sustainability principles, which incorporates social and economic aspects together with the engineering.

Introduction to water utility issues (drying climates)

For utilities in drying climates climate information is critical to ensure there is adequate lead time to source alternative supplies, assess the suitability for potable use and put in place management or treatment options. For developing country utilities, it is critical to have this information to break the cycle of sourcing reactive, emergency supplies. Furthermore, the water utility structure in both developed and developing nations face existing and growing pressure of industry capacity and capability.

Asset management

Emergency management, resilience planning, flood warning systems and predictive modeling all form important pillars for both developed and developing nations. These systems will be a small yet important step in assisting developing nations in escaping a reactive cycle when water resources become scarce in a short period of time or when a village is relocated due to floods for instance.

Water resources management including developing a diverse water resource portfolio:

- **Water efficiency and demand management** are important when water is scarce and, in many cases, they have no impact on the quality of life of consumers, but enable communities to use much less water. These are also generally the most cost effective measures to cope with reduced supplies, particularly for developed countries.
- **Pricing signals** should reflect more accurately the cost of securing and delivering safe potable water.

- **Mapping and predicting groundwater resources** needs to be further developed, particularly as the resource itself becomes more unreliable from a quality and quantity point of view. Any tools that can be implemented to assist communities manage surface and groundwater resources will help to address the potential for social dislocation in remote and rural areas.
- **Desalination** of sea water and brackish water is truly climate independent and it profoundly affects the risk management dimension for water utilities. The use of desalination also acts to disconnect cities from water systems in a positive way. The externalities associated with water extractions from natural systems can be avoided when desalination is employed. There are now innovations available for desalting saline groundwater that are more appropriate for developing nations without the resources or expertise available to operate heavy engineering type processes.
- **Reuse of water** (recycling) at scales ranging from on-site to metropolitan and for purposes ranging from agriculture to drinking water, enables arid areas to drive every litre of water further. An entirely closed loop is impractical, but many communities in arid areas already recycle anywhere from 50% to 100% of their used water.
- **Aquifer storage and recovery (ASR)** techniques have a lot to offer under the right conditions, and are likely to be more widely used than they have up to now. If suitable aquifers are accessible, ASR has many benefits when compared to other storage options. ASR can be applied to both recycled water and to stormwater.
- **Stormwater harvesting** will become more attractive, for the dual purposes of supplementing other sources and managing the impacts of storm runoff, which is likely to increase in some areas. The methods will include water sensitive urban design (WSUD), best management practices (BMPs) and a general move towards lower impacts. The cost of storages is a major hurdle for stormwater capture projects, but it is still an approach to try.
- **Reservoir management** needs to be more sophisticated to maximize yield from a given catchment and storage combination; the desire to minimize evaporative losses, and the demand for optimum water quality outcomes. Techniques such as destratification, selective draw-off, and manipulation of multiple, linked storages, need to be applied where feasible.

Capacity-building for water management

Most arid countries (both developing and developed, but especially developing) will need to build human capacity to cope with the challenges, ranging from water treatment plant operators in the field, climate change modelers and politicians and bureaucrats who will need to make complex decisions.

There is also a need to build capability in the agricultural sector for water resource planning and, while in the direct remit of a typical water utility as pressures for a diminishing resource increase, more indirect planning documents such as land use planning may need to be considered.

5 Climate Change Mitigation in Water Utilities

Adaptation strategies are required to ensure that water utilities can continue to provide services in the face of changing climates. However, mitigation is equally as important to ensure that solutions do not further exacerbate the problem. This chapter addresses several issues related to climate change mitigation in water utilities (i.e. green house gas emission reduction efforts).

5.1 Research on climate change mitigation in water utilities

Worldwide many water utilities are engaging in visionary efforts to reduce carbon and energy footprint in their operations. Water supply and wastewater treatment are energy intensive industries.

Within the research community, the research effort towards a better understanding of the relationship between the water industry and climate change is staggering. As more research results become available, we observe with increasing frequency that commonly accepted engineering practices may be associated with severe impacts on the surrounding environment.

Enhanced wastewater treatment levels are now been reassessed *vis-à-vis* CO_2 emissions related to higher water quality standards. A balance between these two aspects is most needed.

Mathematical modeling of wastewater treatment plants is currently being upgraded to provide for a better estimation of N_2O and CH_4 emissions.

5.2 The link between mitigation and adaptation

Mitigation measures can reduce the magnitude of impacts of global warming on flood disasters, in turn reducing adaptation needs. However, mitigation can have considerable negative side effects if projects are not sustainably allocated, designed and managed.

Pursued climate change mitigation options should demonstrate co-benefits that facilitate climate change adaptation. In many cases climate change will increase current risks for utilities such as extreme flooding events. Utilities need to investigate existing response plans or risk management plans that identify vulnerabilities in the utility system. Climate change mitigation measures that increase the efficiency of a utility can be applied to vulnerable infrastructure and demonstrate co-benefits by providing hazard mitigation against extreme events.

An example of a programme that links climate change mitigation and adaptation is the regional wetland assimilation system planned for New Orleans. The planned implementation of the largest wetland assimilation system in the world will utilize natural wetlands to assimilate over 4.4 m^3/s (100 MGD) of secondarily treated, disinfected municipal effluent to restore approximately 12,000 ha of critical cypress wetlands. Currently nutrient rich effluent from both parishes is discharged to the Mississippi River where it contributes to the hypoxia of 13,000 km^2 in the Northern Gulf of Mexico. Rerouting the effluent will allow the nutrients to be used to replenish the wetlands, rather than increasing damage to the coastal environment. Furthermore, it was proven during Hurricane Katrina that wetlands are effective for climate change adaptation, since they dissipate surge and wave energies, thereby protecting levees from breeching and failure. An additional climate change benefit of wetland assimilation is that almost 1 million tons of CO_2-e a year are reduced through biosequestration and burial. Wetland restoration is an important climate change adaptation-mitigation measure for combating CO_2 emissions, increased tropical storms, and relative sea level rise (Nolasco, 2003 and 2004).

5.3 Mitigation and wetlands

Treatment wetlands have emerged as a viable option for wastewater treatment, especially for tertiary or polishing applications. One of the key collateral benefits of treatment wetlands is the low energy requirement, which includes the elimination of chemical additions to accomplish treatment. Land area and energy input from the sun are substituted for the normal energy inputs required to operate a wastewater treatment system. The total carbon footprint of all potential treatment processes needs to be understood, including that of treatment wetland systems. The key GHG issue for treatment wetlands is the balance between net carbon sequestration in wetland sediments and the emission of CO_2, CH_4, and N_2O. These fluxes are comparatively well understood for natural wetland systems. However, much less is known about GHGs and treatment wetlands, where loading rates tend to be considerably higher. Initial comparisons of advanced wastewater treatment with treatment wetland systems suggest that the carbon footprint of a typical treatment wetland system designed to accomplish a similar level of treatment will be considerably less than conventional tertiary treatment. Especially when considering alternatives such as treatment wetlands, carbon footprint is an inadequate criterion, in that a full life cycle analysis that includes aspects such as net environmental benefits (e.g. habitat restoration) will provide a more robust assessment.

6 Recommendations for actions

Governments (political messages):

- Take adequate steps to model climate change;
- Monitor and evaluate unfolding climate and its impacts;
- Develop nimble, adaptive management strategies;
- Ensure that all personnel employed in the field of water are adequately educated and trained;
- Establish and provide access to data monitoring and observational networks and support needs-

driven climate research that is developed with the involvement of the water sector;
- Pursue climate change mitigation options that demonstrate co-benefits with climate change adaptation;
- Adaptation in the water sector should be part of the discussion in multi-lateral talks for the successor to the Kyoto Protocol and a focal point for the Adaptation Fund that is being created.

The water industry:

- Close the gaps in impact data;
- Promote the development of adaptation plans for the water industry and put in place measures to provide assistance as required;
- Provide information sharing mechanism (IWA);
- Development of successful case studies on adaptation, mitigation, and mitigation-adaptation projects through websites/web portals, workshops and reports;
- Practitioners in water need to take personal responsibility for being up to date and proactive in their work. One way to achieve this is to be actively engaged with IWA and local water associations;
- Adopt of energy recovery and energy efficient technologies for the water sector;
- Support evidence-based research on the pollution potential of and mitigation options for N_2O;
- Develop collaborative partnerships between the research community and the water utility community for the development and application of applicable climate research.

Individual utilities:

- Engage with the research community to better understand the projected hydrologic impacts of climate change in the region where they operate;
- Conduct vulnerability assessments to better understand the specific attributes of the system they are responsible for managing and what the implications are given the projected hydrologic impacts in the region where they operate;
- Foster discussions and knowledge transfer between developed and developing countries;
- Broaden the discussion on the multi-shift usage of the aquatic environment with respect to water quality, heat loads and (decreasing) biodiversity;
- Participate as stakeholders, e.g. in EU or (inter)national projects on climate change (impacts, adaptation, mitigation) and water availability;
- Bridging the technology gap between the North-South divide by raising climate change adaptation and mitigation awareness and building partnerships with all stakeholders through mutual sharing of information among the utilities (e.g. Water Operator Partnership (WOP) networks).
- Develop water loss reduction programmes (unaccounted-for water reaches 30% and up to 70% in developing countries, i.e. a huge waste of resources and an unnecessarily large C footprint).

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