Overview of climate change effects which may impact the urban water cycle

COLOPHON

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Summary

Climate changes can have impact in all areas of the water industry, including quality and availability of water sources and water infrastructure robustness. Water utilities will have to adapt to the impacts of climate change; the choices of today, particularly regarding investments in infrastructure, will significantly influence the ability of the water industry to react to the impact of climate changes of tomorrow. In addition to the need to plan investments, new issues related to water utilitiy services, health, safety and environmental protection will have to be accounted for.

This report brings into light the need for evaluating the relationship between climate changes and their impacts on urban water components, such as, river flow, groundwater level and salinity, reservoir level, water quality, demand for water and resilience of assets and infrastructures. For instance, it is envisaged that climate changes have a significant likelihood of influencing water quality, consequently acting in reducing the efficiency of current water treatment plants, affecting quality at the reservoirs, and during water transport.

In terms of receiving water bodies, increased rainfall intensity and rainfall amount, together with unfavourable runoff conditions can cause more frequent and longer CSO operation periods in combined sewer systems. On the other hand wastewater treatment plant discharges can be the majority of flow in streams and rivers, especially during droughts.

The impacts on the availability of the resource will be experienced at the catchment, reservoir and groundwater levels. Reliability during the transport of water or wastewater/stormwater will be reduced by factors that will accelerate the structural and operational urban water infrastructure deterioration. These factors, such as corrosion, breaks and blockages will consequently cause service failures, such as leakages, contamination and flooding.

In this report the impacts of the expected climate changes on the urban water cycle are characterised. This report is based on the climate change assessment carried out by SINTEF and LNEC within the PREPARED Work Area 2. The report starts by summarising the projected climate changes in four different European climate regions and their effects, regardless the specific impact on the water industry. After this first overview, the attention is driven to understanding how climate changes can impact urban water assets, both in generic terms, with a summary of the main impacts on the integrated water cycle, water supply (drinking and non-drinking water systems) and wastewater/stormwater systems, and in detail, describing impacts at single asset groups for each climate region.

This report aims to be a starting reference for PREPARED Work Areas 2, 5 and 6.

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1 Introduction

1.1 Purpose and scope of the report

The principal authority concerning the science of climate change is the *Intergovernmental Panel on Climate Change* (IPCC). In the "*Climate Change and Water*", Technical Paper VI IPCC, 2008, it is clearly stated that "water and its availability and quality will be the main pressures on, and issues for, societies and the environment under climate change". The paper addresses the issue of freshwater, under the light that climate, biophysical and socio-economic systems are interconnected in complex ways, and hence, a change in any one of these can induce a change in any other.

The main problems envisaged by IPCC (2007) are reduced water availability, water quality deterioration as result of flow variation and water quality impairment as result of higher temperatures, increased runoff and increased salinization. In addition, the global population movement towards cities and consequent high occupation densities are factors that tend to aggravate the problems mentioned above.

In April 2009 the European Commission presented a *White Paper on adapting to climate change* (European Commission, 2009) which presents the framework for adaptation measures and policies to reduce the European Union's vulnerability to the impacts of climate change. The White Paper highlights the need "to promote strategies which increase the resilience to climate change of health, property and the productive functions of land, inter alia by improving the management of water resources and ecosystems." As part of the actions included in the White Paper, Water Directors of EU Member States adopted in December 2009 a *Guidance document on adaptation to climate change in water management* to ensure that the River Basin Management Plans (RBMP) are climate-proofed. As a next step, the Commission will present by 2012 a '*Blueprint to Safeguard European Waters*', which, together with the analysis of all plans for 110 river basins, will perform a review of the Strategy for Water Scarcity and Droughts and of the vulnerability of water and environmental resources to climate change and man-made pressures.

Climate change can already be observed in Europe, and further changes in climate are projected to take place in the future. During the 20th century, Europe experienced an increase in average annual surface temperature of 0.8°C, with an increased rate of warming over time. The 1990s were the warmest on record (IPCC, 2007b and WMO, 2008). Warming has been stronger in most regions in winter than in summer. An increase in warm extremes has been observed rather than a decrease in cold extremes (IPCC, 2007b). Sea level has risen by 17 cm during the 20th century (IPCC, 2007a). In the past few years more frequent extreme weather conditions and a decline of the ice coverage in mountains and the Polar Regions have been reported.

Precipitation trends are more varied for regions across Europe. Trends in the 20th century showed an increase of precipitation in Northern Europe by 10-40% and decrease by up to 20% in average annual precipitation in some regions in Southern Europe. The intensity of rainfall has increased, even in some areas with decreased average annual precipitation (IPCC, 2007b).

The climate regions addressed in this report are the Atlantic, the Cold climate, the Continental and the Mediterranean European regions, as defined in the PREPARED DoW.

The changes of average temperature and precipitation are gradual over a long time period and they are affecting the four climatic zones differently (IPCC, 2007b). Cold climate Europe will face lower summer rainfall and an increased number of storms, for instance the Baltic regions will see higher coastal erosion due to more frequent and stronger winter storms. The average temperature increase in these regions will be relatively modest. Atlantic Europe will face increasing winter rainfall, dryer summers, more winter floods and higher risk of coastal erosion. Continental Europe will face increased winter rainfall, leading to winter floods and lower summer rainfalls with subsequent higher risk of summer droughts; temperature increase will be significant. Mediterranean Europe will face extreme temperature increase, continuous droughts and occasional flash floods. The main medium-term impact will come from a higher frequency of extreme weather events such as very hot summers with associated risk of water shortages, heavy rainfalls and storms with subsequent flooding consequences and coastal erosion.

Climate changes will affect all areas of the water industry including the quality and availability of water resources, the infrastructures, and the treatment that will be required to meet quality standards.

According to the changes affecting the different climate regions, different impacts on water resources availability and safety, water infrastructure reliability and water treatment efficiency will occur. The effects of the climate changes on the urban water cycle potentially leads to the occurrence of new hazards at health, safety and environmental level.

The ultimate purpose of this report is to provide a comprehensive understanding of the impacts of climate changes on the systems and subsystems of the urban water cycle, looking at different climate regions, based on published studies; the focus is on technical impacts expected for water utilities. The focus of the PREPARED WA6 is, on the other hand, on the institutional and organisational settings, delivering tools, knowledge and learning material for stakeholders, enabling them to acquire the capacity to manage the system using an adaptive approach, the so called Adaptive Water Sensitive City (AWSC).

Knowing the technical impacts is a useful guide to plan adaptation actions since current water management practices may not be robust enough to cope with the impacts of climate changes on water systems, which in turn, may affect public health, system's reliability, safety and environmental ecosystems. A risk-based approach seems to be an efficient way to identify risks, evaluate the level of risk and investigate mitigation measures. Key questions that should be addressed as part of a climate change risk approach are:

- What changes in climate are expected,

- How will these changes impact the environment in which water utilities operate,
- How vulnerable are communities and utilities to the changes in the environment, and
- What can and should water utilities do to manage their risks?

The outcomes of the report are as follows:

- Review of the global indicators of climate change at European level and in more detail in four different European climate regions;
- Highlight the impacts of climate changes at different levels of the urban water cycle: integrated water cycle level, water supply systems and wastewater and stormwater systems;
- Present the effects of climate changes potentially impacting the main systems and subsystems of the urban water cycle in the four climate regions.

The terminology adopted follows the one proposed by Almeida *et al.* (2010).

1.2 Structure of the report

In the introduction chapter the purpose and scope of the report are described. In Chapter 2, the expected changes in the basic climate variables, at European level are presented since any change in those variables will lead to direct or indirect impacts in the urban water cycle. The direct and indirect impacts are object of study in Chapter 3, first at urban water integrated level and then at the levels of water supply and of wastewater and stormwater systems. Detailed analysis of the expected effects of climate changes in the urban water cycle of Mediterranean region, in the Atlantic region, in the Continental region and in the Cold-climate region (Chapter 7) are presented respectively in Chapter 4, 5, 6 and 7. There are common effects for different Regions and subsystems; however it was decided to repeat them, accepting the risk of being redundant sometimes, in order to provide a complete checklist to guide the development of the risk database in WP 2.1. Appendix includes tables that summarise the expected effects of climate change in the different climate regions.

2 Trends in climate change and its effects in Europe

2.1 General

The climate change topic has been a prolific area of knowledge in the last decade in Europe and worldwide. Several European projects have been carried out to understand the climate changes and its effects, e.g. PRUDENCE (prudence.dmi.dk), STARDEX (www.cru.uea.ac.uk/projects/stardex/), ENSEMBLES (ensembles-eu.metoffice.com/), CECILIA (www.cecilia-eu.org) and CLAVIER (www.clavier-eu.org/).

These projects have provided a series of high-resolution climate change projections for 2071 and 2100 and have studied the impact of climate changes using an ensemble prediction system, given a systematic inter-comparison and evaluation of downscaling methods for the construction of regional scenarios extremes (European Commission, 2009).

Several emission scenarios have been used to project future climate change and associated climate change impacts. These scenarios form a basis for evaluating climate change analysis, namely climate modelling and the assessment of impacts, adaptation, and mitigation. A detailed description of the IPCC (Intergovernmental Panel on Climate Change) emission scenarios is presented in IPCC (2000).

It is noteworthy that most of the available climate change model results have low spatial resolution, i.e. the results are valid only for large regions. Moreover, the level of uncertainty associated with climate change model results is high.

In general terms, climate changes reported worldwide include the increase of the average surface temperature, rise of the sea level and retraction of Arctic sea ice, more extreme weather events and storm surges, altered precipitation (IPCC, 2007; Semenza and Menne, 2009; USEPA, 2010). These trends have also been observed in some regions of Europe.

Important information regarding climates change in Europe and its effects is presented in EEA (2008). That report provides up-to-date information for Europe with regard to both costs of inaction and costs of adaptation. General conclusions include the following:

- A wide range of economic effects is expected to result from climate changes in Europe;
- The observed and projected effects of climate change in Europe differ across regions and sectors. Many of the impacts are projected to be adverse and to lead to economic costs or losses, although economic benefits (gains) can also be expected;
- A significant trend towards more potentially adverse impacts are expected in south-eastern Europe and Mediterranean areas;
- In northern and Western Europe a more complex balance between negative and positive impacts is projected for moderate levels of

climate change in the coming decades, with potential benefits derived from new farming and tourism opportunities. As climate change continues, the negative impacts are projected to dominate;
- In addition to mitigation, it is essential to develop proportionate adaptive responses (adaptation) as a means of moderating damages or realizing opportunities associated with climate change. There is therefore also a need to consider the economic aspects of adaptation.

According to IPCC (2007), the projected regional impacts of climate change are as follows:

- Magnify regional differences in Europe natural resources, increasing the risk of inland flash floods and more frequent coastal flooding and increased erosion;
- Mountainous areas will face glacier retreat, reduced snow cover, winter tourism losses and extensive species loss;
- In southern Europe, climate changes are projected to worsen weather conditions (high temperatures and drought) in a region already vulnerable to climate variability, and to reduce water availability, hydropower potential, summer tourism and, in general, crop productivity;
- Climate change is also projected to increase public health risks due to heat and the frequency of wildfire.

Given the expected climate changes and the associated effects, it is fundamental that water utilities act accordingly in order to mitigate the effects of such changes. A recent study (Muthanna et al., 2010) shows that some of the main challenges faced by the water and wastewater sector as follows:

- Include adaptation to climate change in the county planning and zoning work;
- Secure and protect potable water sources against deterioration with respect to water quality, supply adequate water treatment and transport;
- Protect and secure technical infrastructure, and private and public properties against flood, raising sea levels and storm surges and erosion;
- Manage and handle extreme precipitation and snowmelt, including urban floodways, climate sensitive design criteria, and high resolution precipitation time series for the future 2071-2100, and advanced control and operation of the sewer network system;
- Clearly identified roles and responsibilities between local and regional authorities and other stakeholders;
- Build and secure knowledge and capacity for climate change adaptation.

The criterion to select the climate change indicators to consider in this report is associated with the potential impact of the climate changes on the urban water cycle. The indicators considered are as follows:

- Increase of air temperature;
- Increase of temperature variability;
- Increase of precipitation annual amount;

- Decrease of precipitation annual amount;
- Increase frequency of intense precipitation events
- Increase of winter precipitation;
- Decrease of summer precipitation;
- Changes in precipitation patterns;
- Increase of winter storms.

The general direct effects of climate change considered in this report are as follows:

- Increase of water temperature;
- Increase of sea temperature;
- Sea-level rise;
- Increase of river flows;
- Decrease of river flows.
- Changes in river flow pattern;
- Decrease of Arctic sea ice coverage;
- Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet).

Despite the direct climate change effects listed above, there are a few other indirect climate change effects that are caused by the first ones. These indirect climate change effects can, in some cases, be relevant for the urban water cycle systems, e.g. forest fires resulting by an increase in temperature and decrease in air humidity may have impact in the water quality in water reservoirs, increase in frequency of river flooding due to changes in precipitation patterns.

Among these climate change indicators and effects, air temperature increase, sea-level rise and sea temperature increase are common to the four European climate zones considered in this report (see Figure 1); all other indicators and effects considered to establish an overview of the climate changes effects on the urban water cycle systems are specific for more than one of the climate zones.

In this chapter, the observed and predicted trends in climate dynamics (indicators) and its effects are described.

2.2 European climate zones

For the purpose of the PREPARED project, four European climate zones are considered: Atlantic, Cold-climate, Continental and Mediterranean.

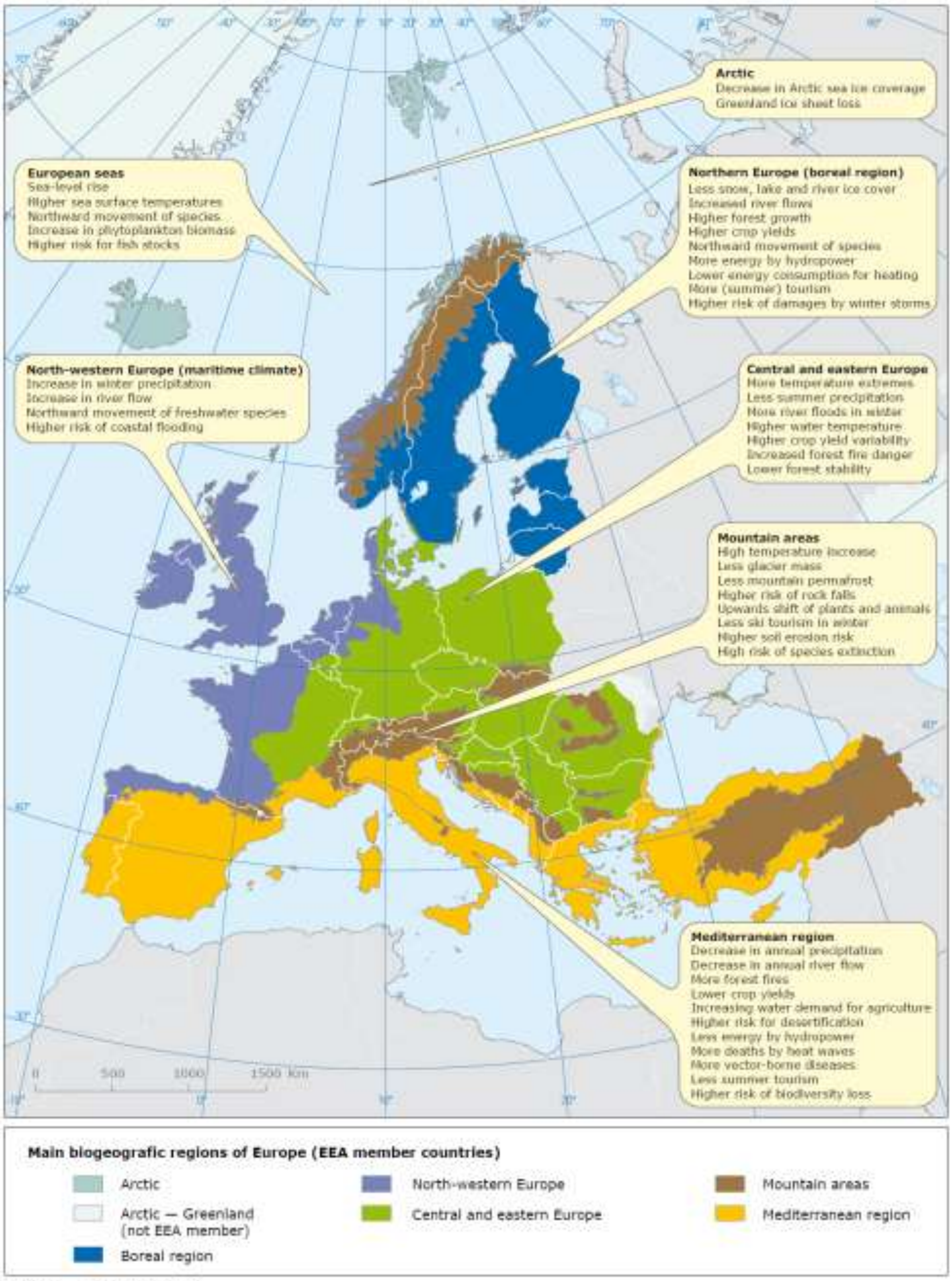
The **Atlantic zone** includes the UK, Ireland and north-west part of Europe. It is characterised by dense human occupation and associated infra-structures. Intensive agriculture is practiced in this region.

The **Cold-climate zone**, which includes the Alpine, Arctic and Boreal biogeographic regions (EEA, 2008), is experiencing changes in climate which may modify the conditions for biodiversity. It is characterised by the intense forestry practice and dense transport infrastructure. In some areas of the Cold-climate zone, tourism is present.

In the **Continental zone**, which comprises central and Eastern Europe areas, there is a significant exploration of the Natural resources, which in turn is directly linked to the development of several types of industries installed in this region. Similarly to the Atlantic zone, it has high levels of human occupation. These two characteristics might explain the relatively high levels of pollution of this region.

The **Mediterranean zone** is, perhaps, the world's most important tourism destination; therefore it experiences a high pressure from urbanisation in coastal areas. On the other hand, there is some land-abandonment in mid-mountain areas. The desertification phenomenon started to affect some areas of Mediterranean Europe.

In Figure 1 the European biogeographic regions are presented.



Source: IPCC, 2007; EEA.

Figure 1. European biogeographic regions (IPCC, 2007)

2.3 Climate change indicators

Increase of air temperature

The climate change prediction for the four climate zones in Europe, as identified in Section 2.2. of this document, corresponds to an increase of air temperature in all seasons (e.g. Alcamo *et al.*, 2007; Dankers and Hiederer, 2008; EEA, 2005; Parry, 2000); the temperature increase range is however different for each scenario due to different climate modelling results. Figure 2 shows the projected temperature variation in Europe up to 2080.

The magnitude of the temperature increase is not spatially uniform across Europe. Moreover it varies between seasons (Parry, 2000). In most parts of Europe the mean daily temperature increases by more than 2°C. The increase in the mean daily temperature is least in the north-west and more marked in areas bordering the Mediterranean basin, the Pyrenees and the Alps (around 4°C).

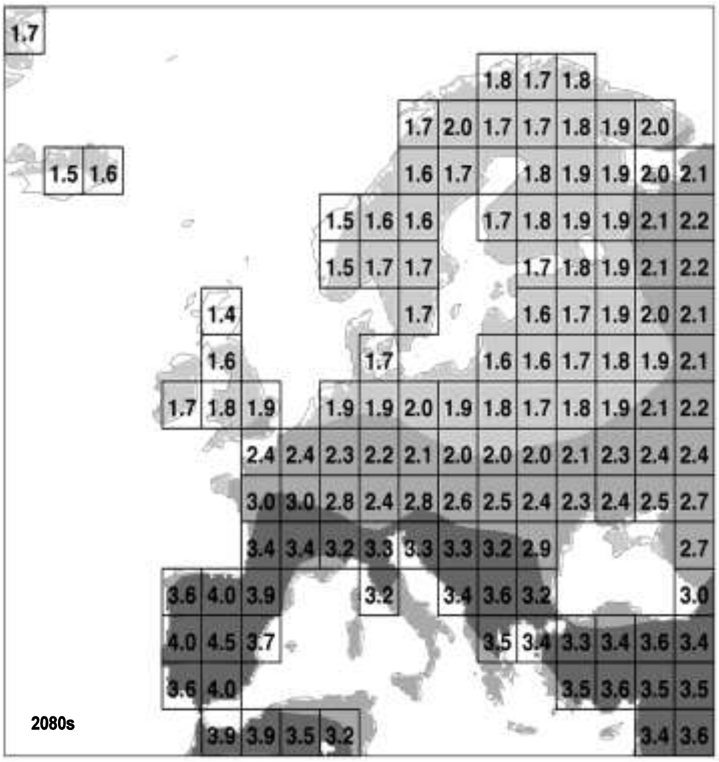


Figure 2. Projected temperature changes in Europe up to 2080 (Parry, 2000)

Increase of temperature variability

It has been widely accepted that Diurnal Temperature Range[1] decreased on a global scale during the second half of the twentieth century (Makowski *et al.*, 2009). In his work it is shown however that the long-term trend of annual Diurnal Temperature Range has reversed from a decrease to an increase during the 1970s in Western Europe and during the 1980s in Eastern Europe.

[1] *Diurnal Temperature Range: the temperature difference between the minimum at night (low) and the maximum during the day (high).*

Other authors (e.g. Klein Tank *et al.*, 2002) also reported the increase of daily temperature variability from 1977 to 2000. This is mainly due to an increase in warm extremes, rather than a decrease of cold extremes (Alcamo *et al.*, 2007).

Figure 3 presents the observed changes in warm spells and frost days indices between 1976 and 2006. These maps show the same trend as the trend observed by the authors mentioned above.

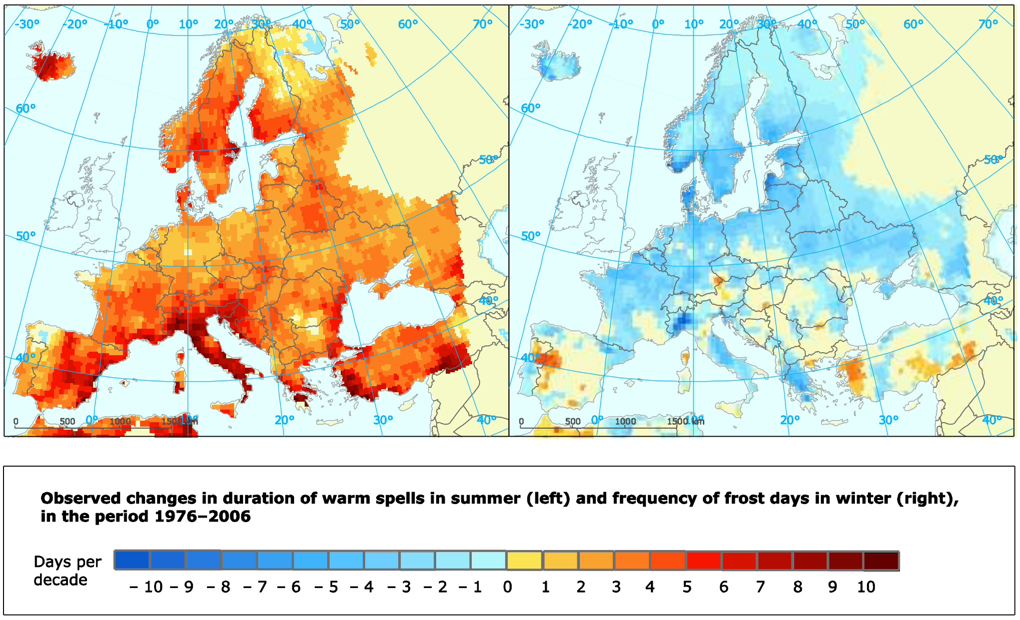


Figure 3. Observed changes in warm spells and frost days indices 1976-2006 (ENSEMBLES (http://www.ensembles-eu.org) and ECA&D (http://eca.knmi.nl) projects)

Changes in precipitation annual amount (increase and decrease of precipitation annual amount)

According to Norrant and Douguédroit (2006) (cited in Bates *et al.*, 2008) the Mediterranean annual precipitation trend over the period 1950–2000 was negative; this can be seen in Figure 4. Räisänen *et al.* (2004) found that summer precipitation can decrease significantly (in some areas up to 70% in emission scenario A2) in southern Europe. Giorgi *et al.* (2004) estimated that the decrease in precipitation can go up to 30-45% over the Mediterranean basin.

In some areas of the European cold-climate region (northern Europe) a relatively small increase (when compared with European overall precipitation increase) in annual precipitation is expected (see Figure 4). However, the general European trend can be considered a decrease of annual precipitation.

Both winter and summer changes were found to be statistically significant (very high confidence) over large areas of the regional modelling domain. Relatively small precipitation changes were found for spring and autumn (Kjellström, 2004 cited in IPCC, 2007; Räisänen *et al.*, 2004).

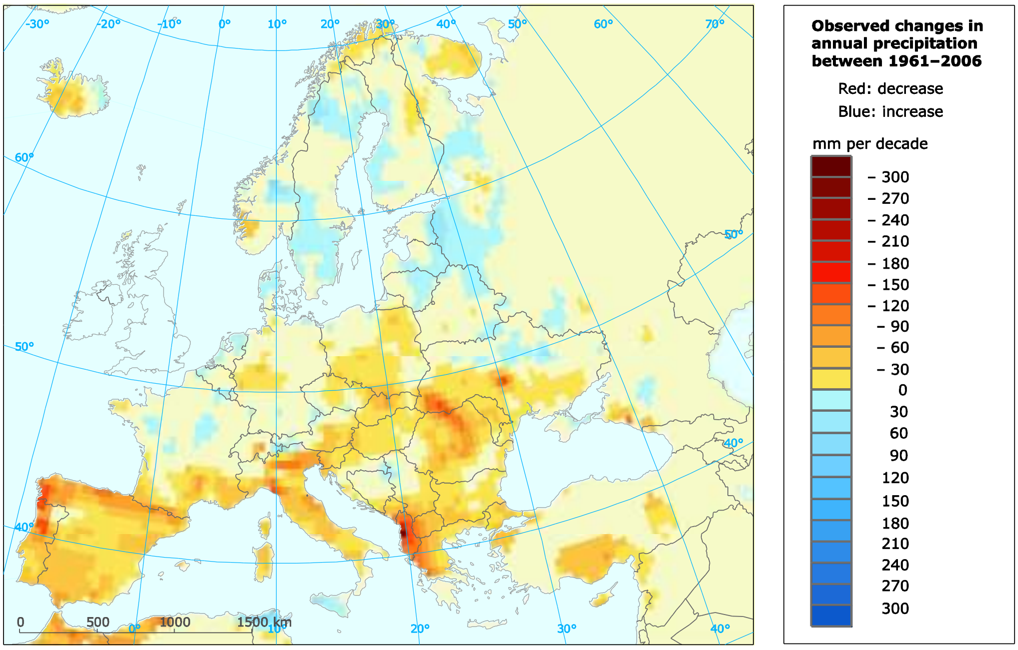


Figure 4. Observed changes in annual precipitation 1961-2006 (ENSEMBLES (http://www.ensembles-eu.org) and ECA&D (http://eca.knmi.nl))

Increase of frequency of intense precipitation events

The increased atmospheric water vapour and warmer air due to global warming suggests being associated with the recent increases of heavy daily rainfall.

In some areas where the trend of the total annual precipitation is decreasing, an increase of extreme precipitation events has been reported (Alpert *et al.*, 2001). Similarly, Klein Tank *et al.* (2002) found that an increase in mean precipitation per wet day is observed in most parts of Europe, even in the Mediterranean area, which is getting drier. Other authors (e.g. Christensen and Christensen, 2003; Giorgi *et al.*, 2004) also found a substantial increase in the intensity of daily precipitation events.

Increase of winter precipitation

As can be seen in Figure 5, for both B1 and A1B climate change simulation scenarios the precipitation in winter months (December, January and February) shows a slight increase in almost all European climate zones.

According to other studies (e.g. Dankers and Hiederer, 2008; IPCC, 2007; Klein Tank *et al.*, 2002; Schönwiese *et al.*, 2003) the precipitation amounts are also generally increasing, particularly in winter period (see Figure 6). In Figure 5 it can be seen that the precipitation amount during winter shows a strong increase (approximately +30% on average) over the Atlantic climate zone (+21% on average for most of Europe); this positive trend in winter precipitation is linked to a dramatic increase in the frequency of extreme wet months (Schönwiese *et al.*, 2003).

The increase in the mean winter precipitation across the Atlantic European climate zone should be interpreted, in part, in the context of winter North

Atlantic Oscillation (NAO) changes (Scaife *et al.*, 2005). This will, in turn, affect the river flows.

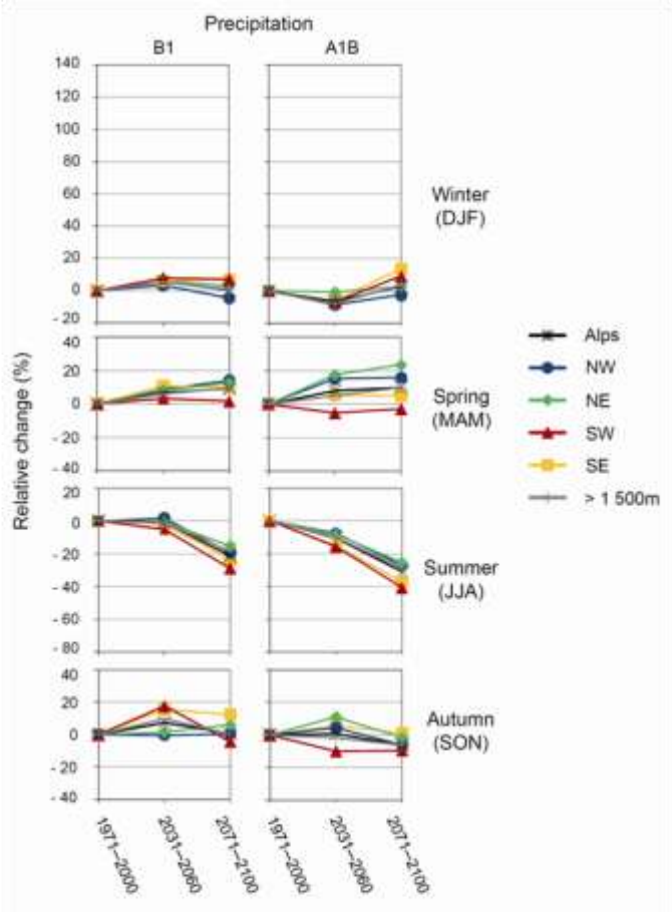


*Figure 5. Changes in seasonal precipitation according to different emission scenarios (*Lautenschlager *et al, 2008)*

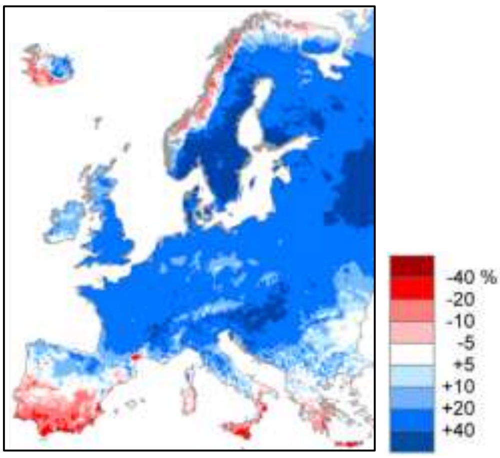
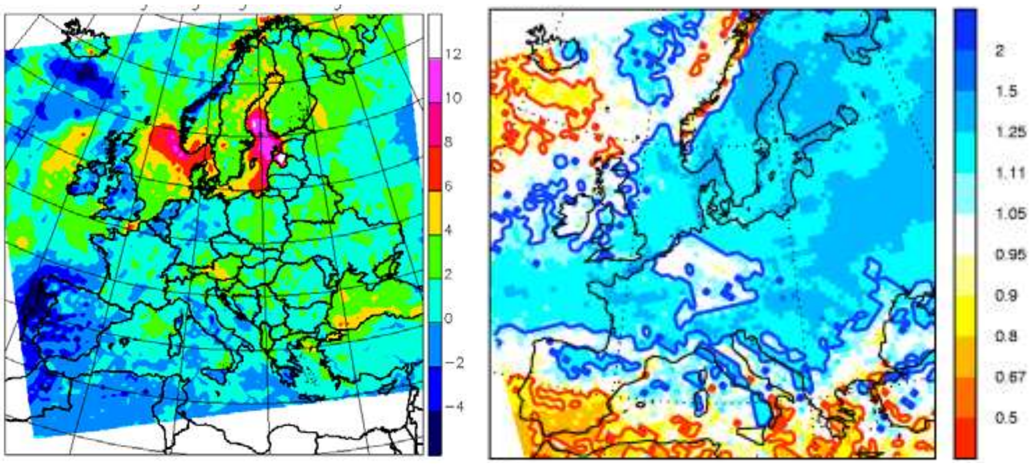


Figure 6. Relative change in the seasonal precipitation amounts in winter (December, January and February) (Dankers and Hiederer, 2008))

In addition to the seasonal increase of precipitation, other studies (e.g. Frei *et al.*, 2006) show that the results obtained from the simulation using six European Regional Circulation Models (RCM) indicate an increase of precipitation extreme events for north Europe, including the Atlantic climate zone. Figure 7 shows large parts of north-west Europe in green, yellow and reddish colours which indicate the expected increase of intense precipitation events due to climate change associated with the A2 and B2 emission scenarios (as simulated with the same HIRHAM model in the European PRUDENCE project).



(a) Change in days with heavy precipitation for the B2 emission scenario (Christensen, 2006)

(b) Ratio (SCEN: 2071-2100 / CTRL: 1961-1990) of the 5-year return value for 5-day precipitation intensity in winter (DJF). Results for the A2 emission scenario (Frei et al., 2006)

Figure 7. Change in intense precipitation in the Atlantic climate zone for A2 and B2 emission scenarios.

Decrease of summer precipitation

In summer, central and southern Europe may become up to 5 % drier per decade (Parry, 2000). In Figure 8 the forecasted change in summer precipitation in Europe is presented. As can be seen, the summer precipitation decreases in a large area of Europe, except for the northern part of Europe equivalent to the cold-climate climate zone.

Changes in precipitation patterns

Particularly in terms extreme weather events (droughts and floods), thus affecting all four regions in some way.

Increase of winter storms.

Especially in coastal areas higher exposure is expected to storms, especially in the context of increased sea level and of extreme weather events (Plan Bleu, 2008).

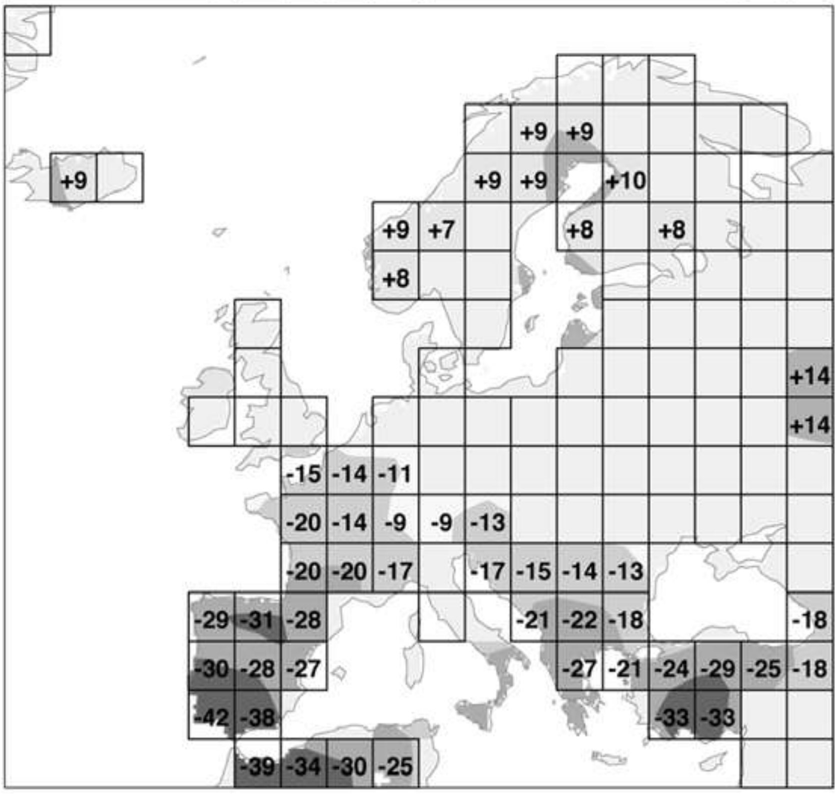


Figure 8. Projected change (%) in summer precipitation in Europe up to 2080 (Parry, 2000)

2.4 Climate change direct effects

Increase of water temperature

The increase of air temperature together with the increase inputs of heated cooling water from power plants are, probably, the main causes of the rise in temperature of some European rivers and lakes. During the last century the water temperature increased by 1–3°C in some rivers and lakes (EEA, 2008). Figure 9 presents the trend of water temperature increase of four European rivers in the 20th century.

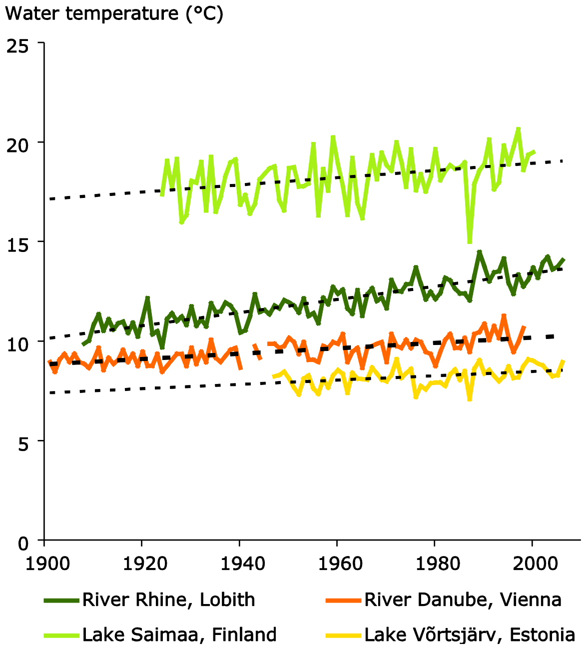


Figure 9. Water temperatures in four selected European rivers and lakes in the 20th century (EEA, 2008)

Increase of sea temperature

A slight increase of sea temperature is expected to occur in the four climate zones considered in this report. Figure 10 shows the temperature evolution since 1950 to 2000 in three European locations: the Norwegian sea, the Baltic sea and the west part of the Mediterranean sea, for both winter and summer conditions. The observed trend corresponds to a temperature increase in all three seas in the two conditions, except for the Norwegian sea during the winter period. These observations suggest a general increase of the sea temperature in all European regions.

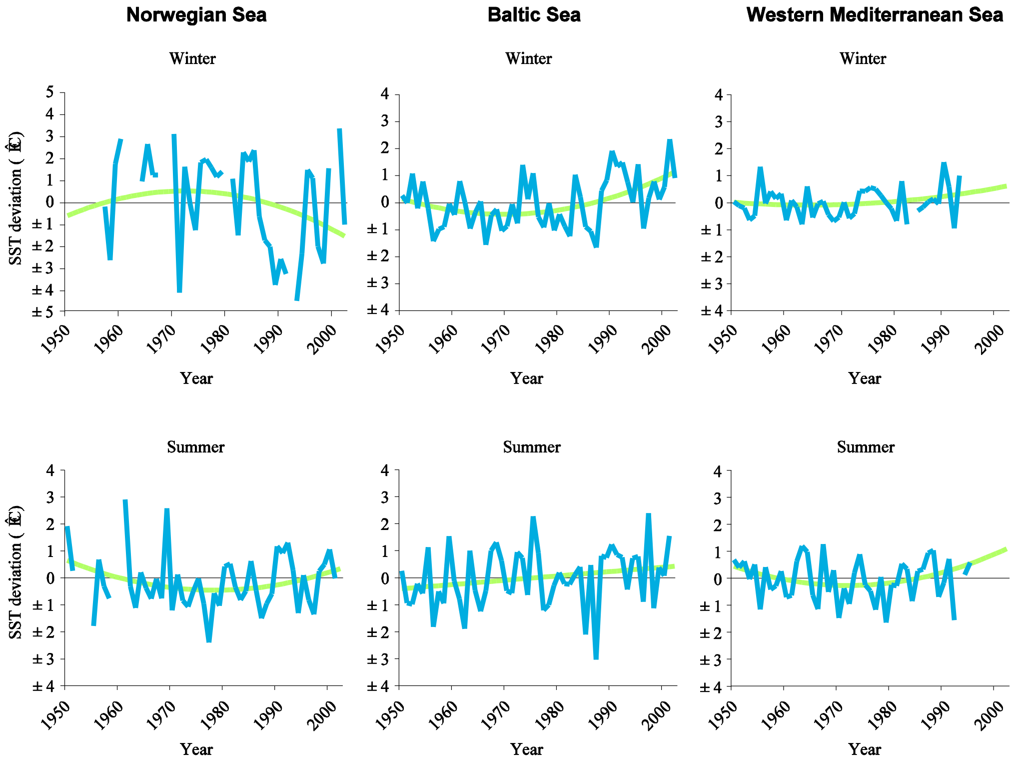


Figure 10. Sea surface temperature (SST) in winter and summer in the Norwegian, the Baltic and the western Mediterranean seas (Dooley, 2003)

Sea-level rise

As presented in many studies (e.g. Semenza and Menne, 2009), sea-level rise is being reported globally. In Europe, the rising rate is somehow different from place to place; Figure 11 illustrates the rising trend in four European cities (Stockholm in Sweden; Esbjerg in Denmark, and Brest and Marseille in France). The rising rate is higher for the two cities in the north of Europe (Stockholm and Esbjerg) when compared with the two other cities located in the south of Europe.

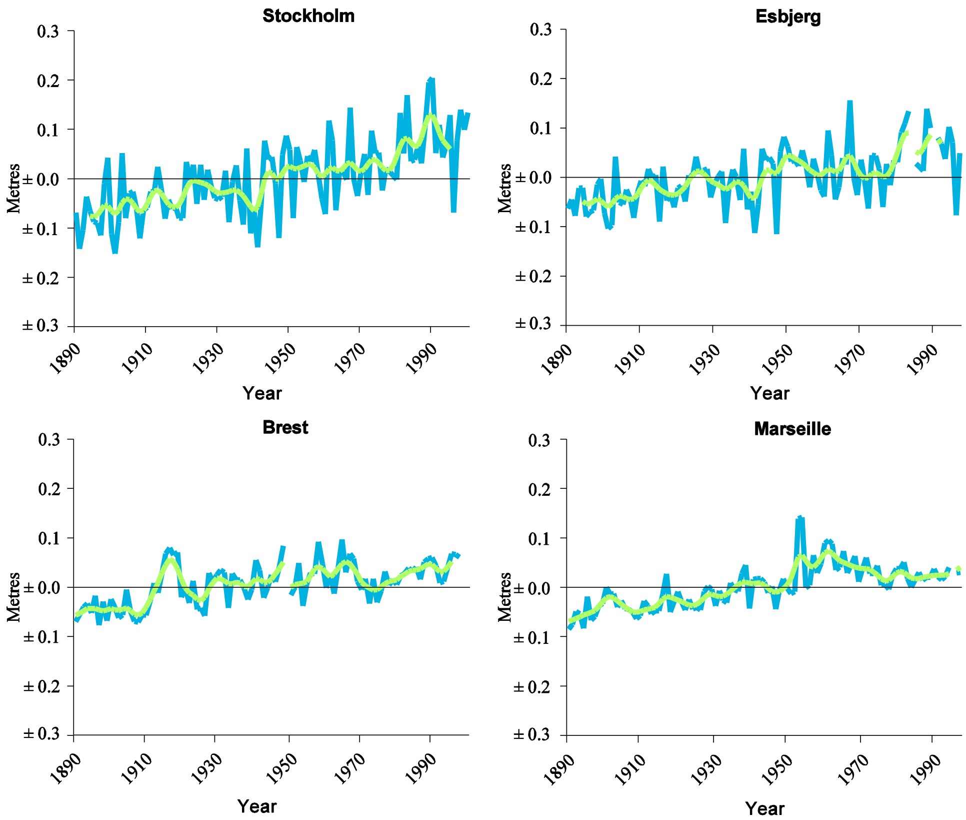


Figure 11. Sea level rise at selected European gauge stations (Liebsch et al, 2002)

Changes in river flow pattern (increase and decrease of river flows)

Some studies have detected significant trends in some indicators of river flow and have demonstrated statistically significant links with trends in temperature or precipitation (IPCC, 2007). Milly *et al.* (2005) presented the results from an ensemble of 12 climate models exhibiting qualitative and statistically significant ability in simulating observed regional patterns of twentieth-century multidecadal changes in streamflow. The results of the modelling project show a 10–40% increase in runoff in north Europe, as illustrated in Figure 12.

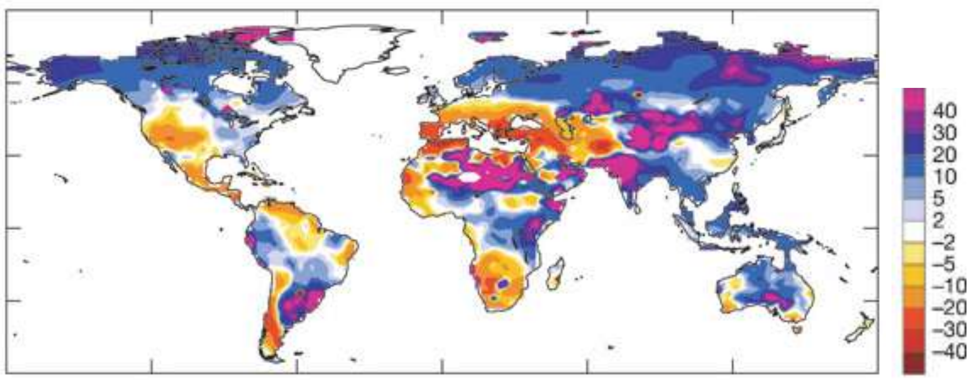


Figure 12. Ensemble (arithmetic) mean of relative change (percentage) in runoff for the period 2041–2060 (Milly et al., 2005)

Taking into account that the Atlantic climate zone is characterised by a densely human occupation, and that the forecasted increase of precipitation during the winter when the soil moisture level is high, the resulting higher runoff volumes can thus be high, and the river flows consequently larger.

Figure 13 presents the results obtained by running two climate models used to forecast the evolution of river flows: ECHAM4 and HadCM3 (Lehner *et al.*, 2001). As can be seen in this figure it is clear the significant increase in river flows in the North of Europe for the two models (forecasted for 2070). The increase in river flows varies between 10 and 50%, which is in agreement with the results presented by Milly *et al.* (2005).

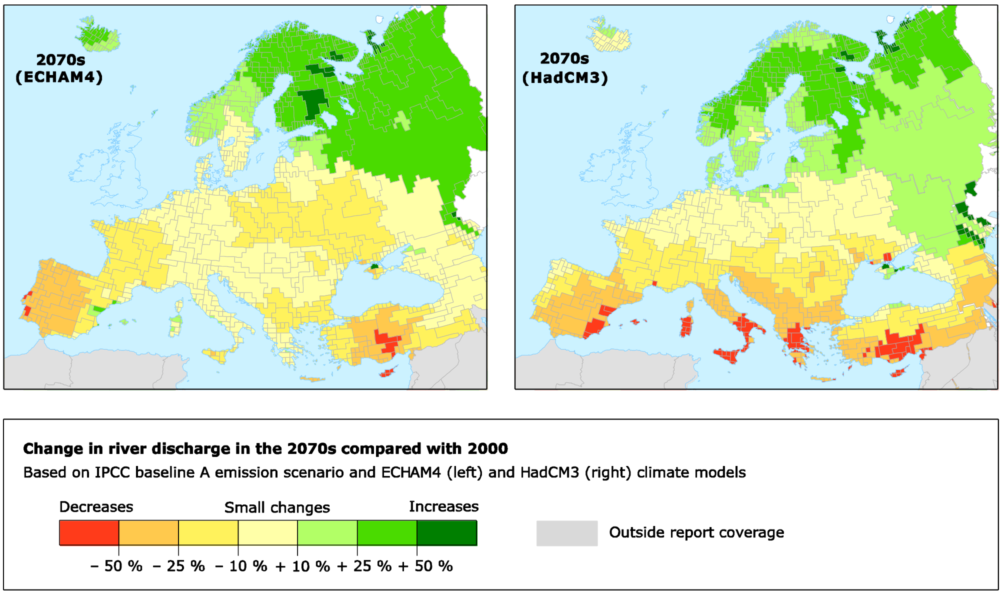


Figure 13. Projected change in annual average river discharges for European river basins in the 2070s compared to 2000 (Lehner et al., 2001)

On the other hand, and as a consequence of the drastic decrease in precipitation observed between 1961 and 2006 (see previous section) and forecasted, the expected river discharges are smaller than those of in mid-20th century for central and southern Europe. Nevertheless, absolute changes remain uncertain.

Regions in southern Europe which already suffer most from water stress are projected to be particularly vulnerable to reductions in water resources due to climate change. This will result in increased competition for available resources (EEA, 2008). *Figure 13***Error! Reference source not found.** presents the forecasted change in annual river discharge for Europe; in the Mediterranean climate zone (southern Europe) the river flow reductions can go down to -50%. The results presented in this figure were obtained using two climate models (ECHAM 4 and HadCM3) and show similar trends.

Decrease of Arctic sea ice coverage

The Arctic is one of the most vulnerable areas in terms of the decrease of the ice cover extent. This phenomenon can be explained by the global increase of air temperature and changes in precipitation pattern. In particular, the temperature has increased more than twice in the Arctic region when compared with the global temperature increase (EEA, 2008).

Error! Reference source not found. shows the evolution of the Arctic sea ice xtent along the year. As can be seen in the figure, the recorded Arctic sea ice extent has been always smaller in recent years (2006, 2007 and part of 2010) when compared with the average calculated for the period comprised between 1979 and 2000. In some cases, the sea ice extent is smaller than the average minus two standard deviations.

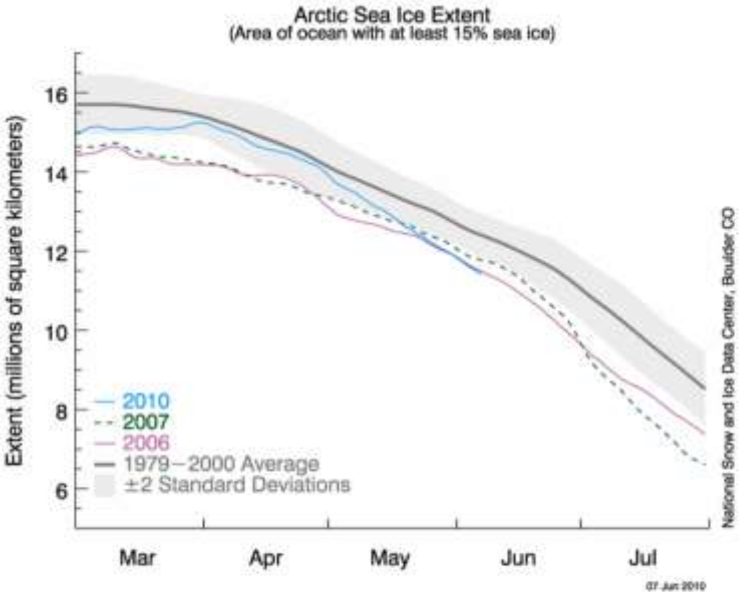


Figure 14. Daily sea ice extent as of June 7, 2010. (National Snow and Ice Data Center, 2010)

The reduction of the Arctic sea ice extent will inevitably lead to other phenomena/effects, such as increase of river flows, and may influence irrigation and power generation.

Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)

According to the conclusions presented in EEA (2008), snow cover in the northern hemisphere has fallen by 1.3% per decade during the past 40 years; the largest losses have been reported during spring and summer.

Results from models using a range of IPCC climate scenarios indicate that by the mid-21st century the permafrost area in the northern hemisphere is likely to decrease by 20–35%.

An indicator of the decreasing of snow coverage in Europe is the number of the day counting from the 1st January 2010 the ice breaks in rivers and lakes. The trend is clearly the decreasing in the number of days break in the ice occur, as presented in Figure 15**Error! Reference source not found.**. Around 1850 the number of days ice-break occurs was approximately 140 whereas in the year 2000 was approximately 125.

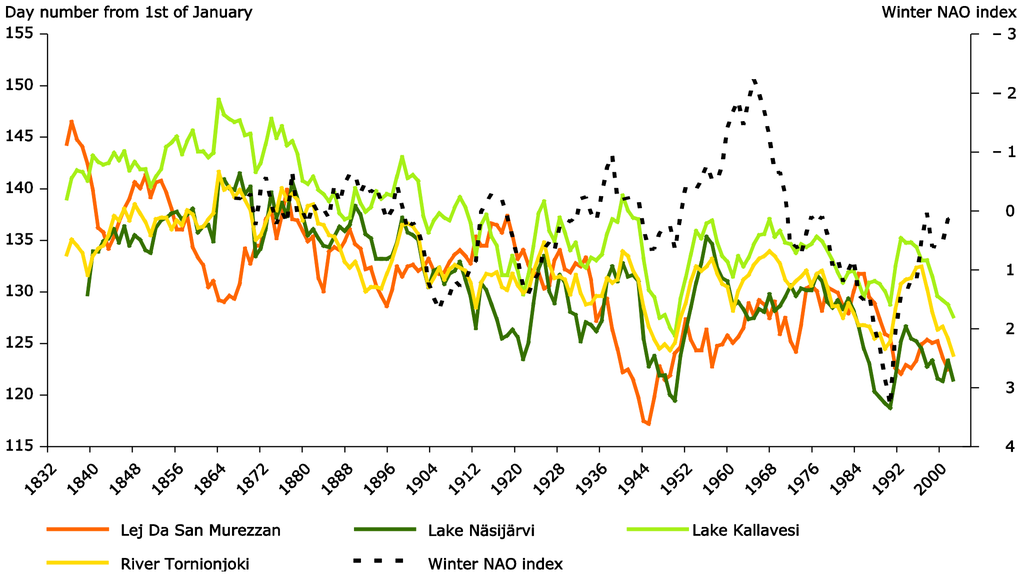


Figure 15. Ice break-up dates from selected European lakes and rivers (1835-2006) and the North Atlantic Oscillation (NAO) index for winter 1864-2006 (Benson and Magnuson, 2000)

2.5 Some indirect climate change effects

Increased frequency of coastal flooding events

The observed increase in precipitation intensity and other observed climate changes, such as the increase in westerly weather patterns during winter, leading to very rainy low-pressure systems indicate that climate change might already have an impact on the intensity and frequency of floods (IPCC, 2007a). Sea-level rising together with more likely storm surges is also expected to increase the frequency of coastal flooding (EEA, 2008).

From Figure 16 it is clear that European coastal areas will be more exposed to coastal flooding risks. However, it is evident that the more affected areas are in the Atlantic climate zone (e.g. UK, North of France) and also in some eastern parts of Mediterranean climate zone.

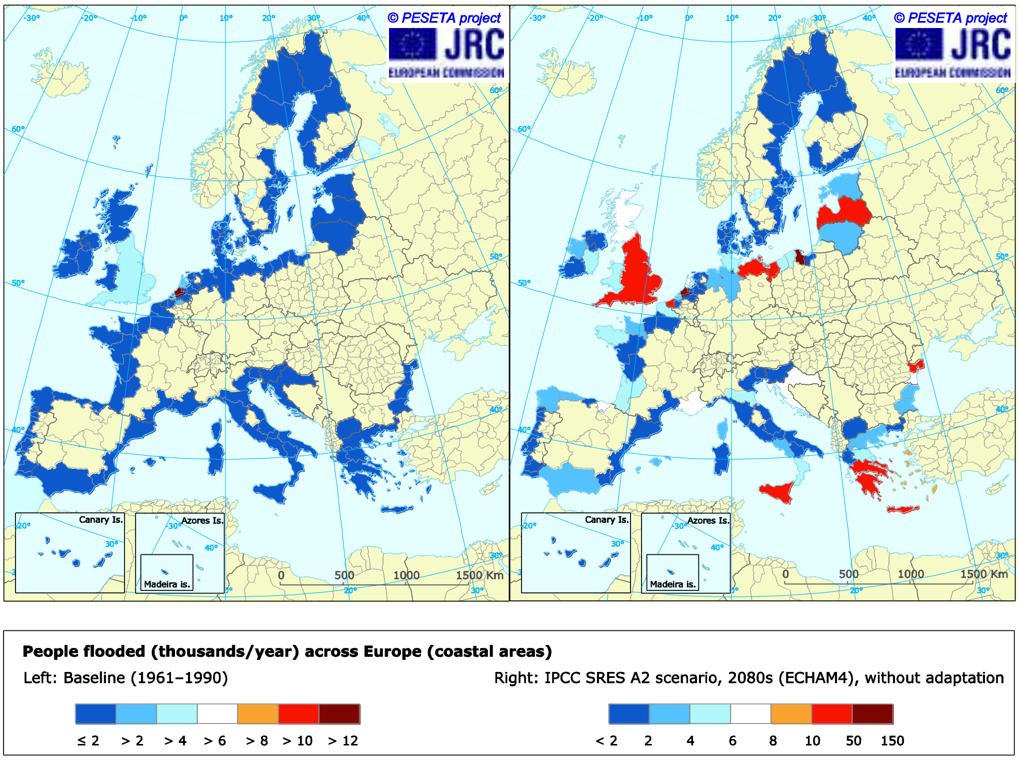


Figure 16. Number of people flooded across Europe's coastal areas in 1961-1990 and in the 2080s (JRC PESETA project[2])

Increased frequency of river floods

Recent floods in Continental European zone, such as the one in August 2002 in Austria, the Czech Republic, Germany, Hungary and the Russian Federation and the 2010 flood in Poland, are the evidence that river flood phenomenon can have a significant impact on society. The impact can go from light damage to properties to loss of lives. Climate changes, including the increasing intensity of heavy rainfall, are likely to make river floods more frequent in some areas of Europe, especially in the Continental climate zone, as reported in Ciscar (2009).

Figure 17 illustrates the change in the number of river floods expected for 2071-2100 using the IPCC SRES A2 scenario. The expected increase of floods caused by high river discharges can go up to 40% in some areas within the European Continental climate zone.

On the other hand, some areas of the Mediterranean climate zone can expect significant reductions in terms of damage caused by river flooding events.

[2] http://peseta.jrc.ec.europa.eu/docs/Costalareas.html

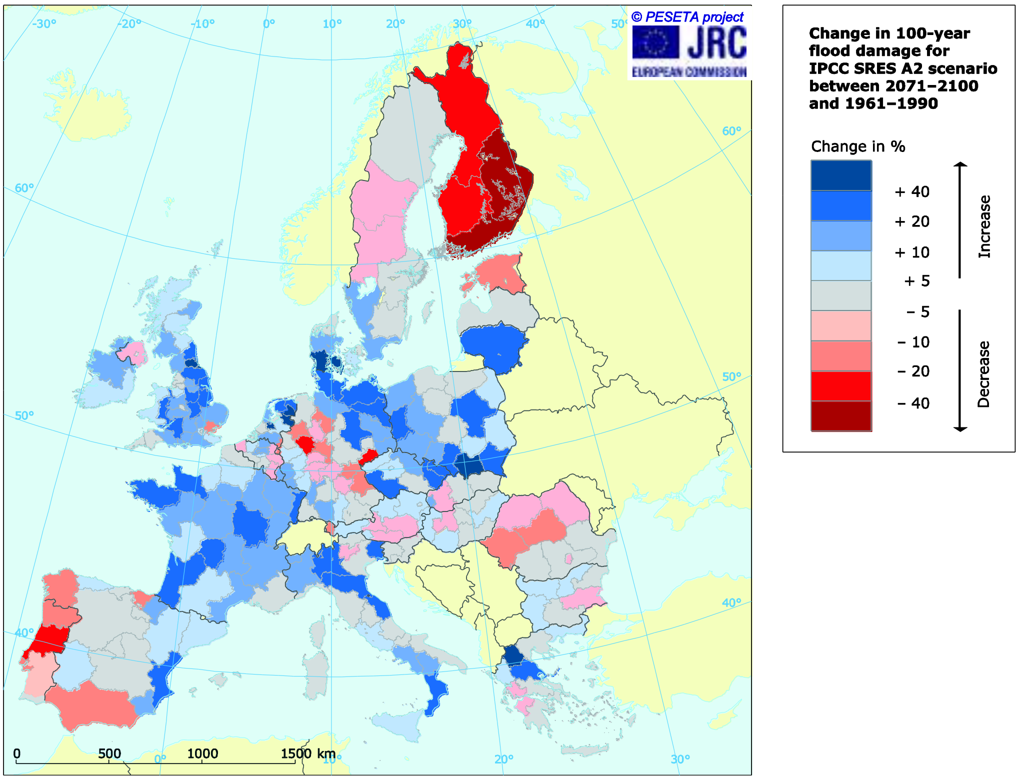


Figure 17. Projected change in damage caused by river floods with a 100-year return period between 2071-2100 and 1961-1990 (countries with light colour indicate no data).

3 General expected effects of climate change in the urban water cycle

3.1 Introduction

The ultimate goals of a water utility are: (i) providing high quality water in acceptable quantity and pressure to all customers, (ii) adequately collect and treat wastewater, and (iii) effectively collect, treat (when necessary) and dispose stormwater. These goals can be achieved by making the right decisions, i.e. solutions representing a good balance between internal resources and external threats and opportunities.

It is important to note that the activity of a water utility is not independent and is affected and may affect other activities within the urban water cycle. Therefore, utility activities should take into account the whole urban water cycle; an integrated approach, including safe and environmental safeguard of natural resources, efficient water supply procedures, optimal stormwater management, efficient wastewater treatment, is thus necessary in order to achieve the ultimate goals of a water utility. In addition, these goals should incorporate the right balance between risk, performance and cost for the overall urban water cycle.

One particular challenge in the efficient management of an urban water system is related to the ageing of infrastructure. Water supply and drainage systems face the problems associated with old and deteriorating assets, which are vulnerable to failure. It is a technological and financial issue to maintain and upgrade the systems so that the enough quantity of water with satisfactory quality is delivered to customers and wastewater is adequately collected and treated. There are also external global challenges, which include:

- Impacts of the external environment to the infrastructure;
- Impacts of the infrastructure to the external, and
- Man-made hazards as vandalism and terrorism.

Additional global trends, such as climate changes, changing demands, society, industry, agriculture and climate act as catalysts to system's degradation and associated system's inefficiency. As an example, forecasted climate changes will require adjustments in design and operational system procedures; as availability in water resources is predictable to decrease, need for increased protection of drinking water sources is expected; as an example of the application of the Water Safety Plans. Identifying the need to address these challenges and global trends is the first step effectively manage urban water systems' infrastructure and achieve sustainable water utility practices in terms of the three sustainability pillars: society, environment and economy. Sustainable solutions to the challenges mentioned above need thus to be sensitive to increasing energy prices, demands for low carbon intensity solutions, and the need to reduce greenhouse gas emissions from urban activities.

Water utility managers need to develop a long-term view of the organization (strategic level; e.g. 20 years) in order to achieve organization's objectives (Boseman and Phatak, 1989), and, at the same time, resolve the day-to-day (tactical; e.g. 5 years, and operational; e.g. 1 year, levels) management aspects. Water utility managers must also to pay attention to new issues, such as:

- Sustainable development;
- Asset sustainability as a consequence of global challenges, and
- Technological change and its impact on the type, range and life of assets

In addition, it is also important to have in mind the current economic and financial global context that becomes an extra issue to achieve the water utility goals.

Urban water utility managers should therefore implement Asset Management (AM) practices to face current and future challenges is becoming more and more urgent in order to be prepared for mitigation and adaptation to the impacts brought by changes. Asset management is a set of procedures operable at the strategic, tactical and operational levels, to assess the physical asset performance, associated risks and costs within its whole life-cycle; it combines engineering, management and data points of view (Alegre, 2007). An AM methodology should involve the following key steps:

1. Organisation of detailed information on the urban water cycle assets;
2. Company-wide integration of data and decision-making;
3. Definition of customer-focused level of service;
4. Condition assessment and monitoring routines both for networks and treatment plants;
5. Risk/criticality/vulnerability assessment with an integrated approach;
6. Life-cycle costing (LCC);
7. Define the asset plan including:
    a. Capital investment plan;
    b. Maintenance and operations plan;
    c. Disposal plan.
8. Standard and benchmarks;
9. Reporting and continuous improvement.

Making AM a reality requires information and analytical tools, existing and new technologies, operation and maintenance practices able to face the impacts of changes and new approaches to organizational communication and level of knowledge.

3.2 Water cycle components

Typically, the urban water cycle incorporates a number of different systems and subsystems (the same urban water cycle characterisation provided in the "Water cycle safety plan framework" document (Deliverable 2.1.1) is here applied (Almeida *et al.*, 2010). Climate change impacts not only each system or subsystem, but also the interactions and boundary conditions. The main systems and subsystems include the ones illustrated in Figure 18 (not exhaustive).

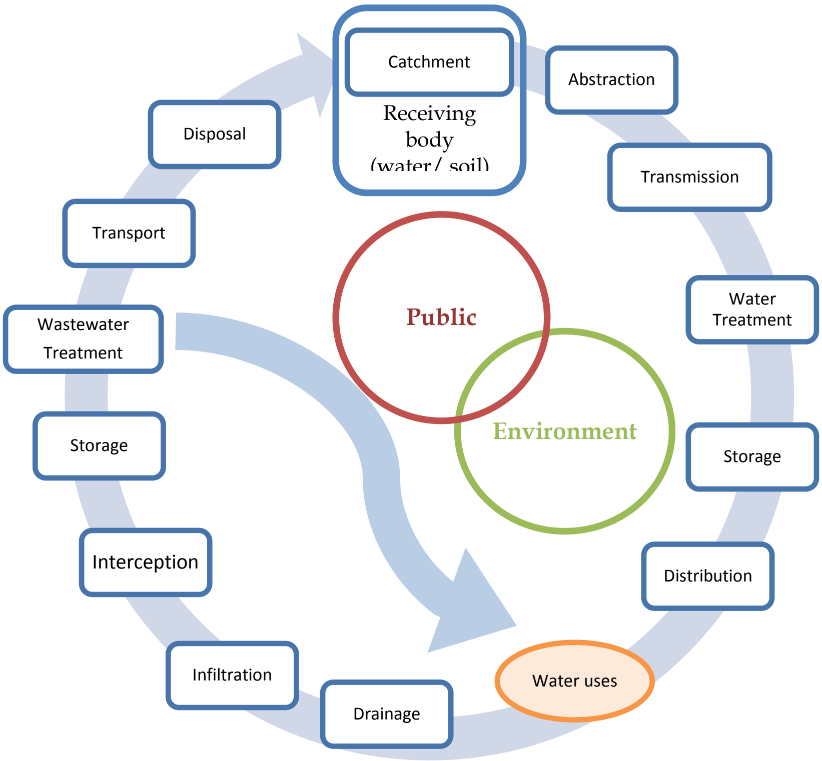


Figure 18 - Water cycle typical functional components

Catchment basin - surface water catchment; groundwater catchment.

Drinking water system - surface water reservoir; groundwater reserves; abstraction system; groundwater recharge; water treatment; transmission; pumping stations; storage; distribution; plumbing systems.

Non-drinking water system - catchment system; water treatment; advanced wastewater treatment; transmission, pumping stations; storage; distribution; plumbing systems.

Wastewater system - Wastewater system - wastewater collection network; interceptor system; wastewater treatment; combined sewer overflows; pumping stations; storage structures; infiltration systems; outfalls.

Stormwater system - urban catchments; stormwater collection network; infiltration systems; source controls, stormwater treatment, stormwater overflows; pumping stations; storage structures.

Receiving waters – river; estuary; lake; coastal water.

3.3 Overview of the effects

3.3.1 General

Climate changes will affect, directly or indirectly, the whole water cycle, including all its components. It is thus essential to identify which water cycle components (and their associated subsystems) will be affected, how they will affect and with what magnitude; it is also important to take into account potential cascade effects.

The urban water cycle is expected to be affected by both acute and slow developing climate change effects: the acute deals with acute events like flooding, whereas the slow developing leaves signs that something is happening, such as change in water colour. Both types of events will influence practice and methodologies to manage and operate the systems. The acute events should be faced and mitigated at planning and crisis management level, whilst the slow developing events should be dealt with at planning level.

3.3.2 Effects of climate changes at integrated water cycle level

One main concern related to effects of climate changes at the integrated water cycle level is the variation of water quality. Water quality is expected to change both as a direct and indirect climate change effects. Climate changes will directly affect the quality of raw water in reservoirs, groundwater and receiving water bodies. This will be caused, for example, by increased rainfall that will increase runoff in urban areas and due to increase of air and water temperature, leading to increased presence of algae, Natural Organic Matter (NOM) and particles.

Aquatic life may also be affected due to reduced water quality caused by low summer river flows, and aggravated by the higher temperature of wastewater treatment plant (WWTP) effluent. Warmer water temperatures will mostly occur in summer time, which in addition to the problems concerning the presence of algae and bacteria in drinking water reservoirs, is expected to increase the risk for biofilm growth in drinking water pipes, directly affecting water quality. This may have health and safety consequences and have some effect on the economy. In winter time, the water will be colder due to increased snow and ice melting and will reduce the efficiency of wastewater treatment and thus affect the quality of WWTP effluent.

Water quality will be indirectly altered by increased surcharge of sewer systems due to insufficient sewer hydraulic capacity, leading to more extensive problems concerning flooding in wastewater and stormwater systems and catchment areas. Immediate consequences of reduced water quality will have environmental, economic and health and safety impacts. Another impact linked to the reduction of water quality is the likely increased presence of microorganisms that can cause water related sickness outbreaks.

Rainfall and snow amounts and distribution will not be uniformly altered. The northeast countries will, in general, become wetter whereas the southwest countries drier. Because of these changes, areas with less rainfall are likely to experience drinking water supply difficulties: lower stream flow conditions and flooding events worsened by fires and consequent increased runoff.

Intense storms will occur more frequently with a greater percentage of annual precipitation occurring during intense precipitation events. The storms will mostly occur in winter periods, causing more often flooding events. Areas with greater precipitation will experience increasing runoff, more sewer overflows, and other infrastructure overloading. In particular, it is noted that the anticipated service life of infrastructure may need to be reviewed due to the anticipated climate changes.

Effects of changes in the precipitation patterns will also affect economy (damages) and environment (pollution of the surrounding areas).

Predicted changes in storm intensity and sea level rise create the need for integrated water, stormwater and wastewater systems infrastructure planning and better coordination among stakeholders.

3.3.3 Effects of climate changes on water supply (drinking and non-drinking) systems

Climate changes will impact the water supply systems by changing water availability and water quality, reducing systems' reliability. The impacts on the availability of the resource will be experienced at catchment, reservoir and groundwater levels.

Precipitation decrease, associated with increase of air temperature, can force drinking water utilities to seek additional water supply options to fill the gap between supply and demand. Increased evaporation due to higher air temperature will also lead to less available drinking water resources, especially in areas that have already to deal with water scarcity and drought.

Soil moisture content will vary due to climate changes and characteristics of soil. Water-holding capacity of soil will affect possible changes in soil moisture deficits; the lower the capacity, the greater the sensitivity to climate changes (IPCC, 2001). The amount of water stored in the soil also influences the rate of evaporation, groundwater recharge and runoff generation.

Increase of the demand is also another factor that needs to be taken into account in addressing the water availability; increase of temperature can lead to increased peaks of demand requiring greater storage requirement.

On the other hand, increased winter rainfall is likely to result in increased groundwater recharge. However, higher evaporation may mean that soil moisture deficits persist for longer and commence earlier. The way climate changes will influence groundwater recharge is not clear, unless climate variables change in the same direction towards reducing the resource availability. In addition, the recharge period may also be reduced, since future warmer climate leads to an increase of the length of the growing season; soils return to field capacity later in the autumn and start drying out sooner in the spring.

Climate changes have also a high probability of influencing water quality by reducing the efficiency of current water treatment plants, affecting quality at the reservoirs and during water transport. Treatment plants may thus need to be adapted and raise the standard of treatment. Raw water may be negatively affected by increased runoff in drainage area, increased water temperature, overload of wastewater systems, increased presence of birds and animals and the inclusion of new species in the drainage area and on reservoirs.

Deterioration of water quality will also be affected due to shorter times of stable stratification in lakes as a consequence of longer circulation periods. This will probably be caused by warmer weather, which will postpone or eliminate the freezing of lakes in cold climate areas.

The quality of raw water extracted from aquifer will also change due to sea level rise that may lead to saline intrusion.

If water treatment plants are not able to cope with the higher NOM levels expected in raw water, NOM will be transferred to the transport/distribution system. The NOM will work as food and facilitate the biological growth in the bulk flow of water and in biofilm media on the pipe walls.

The link between treatment and transmission/distribution system becomes even clearer; the problems of increased NOM and microbiological activity in raw waters emphasize the importance of dealing with optimized treatment so that problems related to these are not transferred to the drinking water network.

Water treatment plants, considering that all remediation actions have been made (pollution source reduction, runoff limitation, fertilizers and pesticides reduction management, etc.), must be adapted, envisaging better efficiency, particularly with regards to extreme events (heavy rainfalls and droughts). These measures integrate complementary treatment steps and process control even for small water supply systems. Moreover, water quality monitoring with analysis of micro pollutants among which emerging substances and treatment by products must be carried out, as well as health risk assessment following the water safety plan procedure (Delpha et al., 2009).

Contamination of the water delivered will happen along the transportation as an effect of a decrease of precipitation, leading to intermittent supplies: the depressurisation of pipelines leads to greater probability of external water entering the pipes, from groundwater but also from sewer in the countries where the pipes of the two services laid in the same ditch.

Due to increased precipitation and increased runoff and infiltration, the ground water table may rise; drinking water supply and sewer pipes will be more frequently in contact with the ground water table which will facilitate external corrosion problems. Pipes may experience increased break rates due to external corrosion caused by increasing acidity in the ground. The probability of breaks of pipes is also likely to increase due to intermittent supplies and pressure variations and, specifically in cold areas, more frequent cycles freeze/thaw will increase the mechanical stress of pipes due to soil movements.

Water supply will also be affected by reduction of reliability of pumping stations due to depressurisation of the supply system. This may lead to greater incidence of air blockages that stop pumps or cause the failure of real time control devices.

3.3.4 Effects of climate changes on wastewater and stormwater systems

Climate change will impact wastewater and stormwater systems on different fronts: economic, environmental and also safety level.

More heavy precipitation combined with increased population density and impervious areas in cities create the conditions for increase the risk of flooding in urban areas, and consequent the amount of damage. Flood protection measures will be needed to address flooding caused by intense rainfall events. Sea-level rise can aggravate this situation.

Systems that allow flow by gravity out to the discharge point may require pumping to discharge through outfalls due to the rising downstream water level with an increased energy demand. Reliability of pumping stations will be reduced due to increased volumes exceeding pump capacity and causing service failures; higher receiving water levels as well as increased volumes will also lead to increased pumping requirements causing accelerated asset deterioration and increasing energy use.

The increased problems associated with increased rainfall intensity, increased sewer blockages and lack of capacity of the sewer network to deal with the increased volume of rainfall will contribute to amplify the surface contamination when compared with today's conditions.

Expected extreme storm events and overall precipitation increase will drive the need for mitigation. Quality of receiving water will be affected due to variation in the frequency and volume of spills from Combined Sewer Overflows (CSO), and also from WWTP discharges of untreated effluent.

The wastewater treatment plant discharges can make up the majority of flow in streams and rivers especially during droughts. The higher effluent temperature may have effects on aquatic life; in addition, reduced summer rivers flow in many regions will increase the proportion of wastewater flow and may lead to stricter effluent water quality requirements. All this will require investments at the treatment plants. Moreover, for wastewater systems located near the coast, the effect of sea-level rise can cause inflow of salty water that requires higher treatment levels.

In an integrated management point of view, the wastewater system can contribute to addressing drinking water supply challenges throughout wastewater reuse (contemplating advanced treatment).

The increase of temperature (water and air) may increase treatment efficiency due to the associated increase in the biological processes rate; increased levels of septicity in received sewage may cause increased odour, promote growth of undesirable species and inhibit growth of normal aerobic heterotrophs. On the other hand, increased temperature also leads to lower oxygen transfer efficiency in secondary process affecting process performance.

On the other hand, sea level rise may cause backwater effects in the downstream of the sewer system. Such sewer pipes may get surcharged, i.e. pressure inside the pipe is higher than atmospheric pressure, and thus causes sewage from the system. The sewer will leak into the ground, the groundwater and to surrounding areas, rivers and waters, which may cause problems to, for example, the water supply system.

An increase of probability of sewer pipe breaks may be expected due to more frequent freeze/thaw cycles and consequent soil movements.

Table 1 provides an overview of climate impacts on the urban water cycle, per system according to the terminology introduced by the Water Cycle Safety Plan (D2.1.1). The list of climate change effects is here presented in the form of table to support and inspire the population of the risk identification (RIDB) database in WA2.

Table 1 - Overview of impacts on climate changes on urban water cycle systems

	Impact in terms of main aims of the WCSP		
System	**Public health**	**Public safety**	**Environment**
.1. Catchment basin	▪ Increase of temperature has detrimental effect on water quality at surface and ground waters ▪ Sea level rise may aggravate saline intrusion in ground waters ▪ Higher temperatures and droughts increase problems of water availability	▪ Increase in extreme events potentially increases the risks to public safety	▪ Increase of temperature has detrimental effect on water quality at surface and ground waters
.2. Drinking and non-drinking water supply	▪ Higher temperatures will impact treatment processes ▪ Increase of risk of contamination due to supply interruptions and potential for accelerated biological growth in water bulk and pipe walls	▪ Increase of rainfall may cause reservoir dam slippage; ▪ Increase of damage caused by equipment failure due to temperature increase and saline intrusion ▪ Increase of probability of pipe failure due to landslides, corrosion, etc.	▪ Increase of treatment and pumping requirements may increase energy consumption.

Table 1 - Overview of impacts on climate changes on urban water cycle systems

	Impact in terms of main aims of the WCSP		
System	**Public health**	**Public safety**	**Environment**
.3. Wastewater and stormwater	▪ Increase of odours and levels of septicity due to temperature increase;	▪ Increase of levels of septicity due to temperature increase; ▪ Increase of frequency and magnitude of coastal, river and urban flood events due to sea-level rise, changes in flow pattern and rainfall increase.	▪ Increase pollution on urban surface due to flooding from drainage systems; ▪ Surcharged sewers (domestic and combined systems) may contaminate soil, groundwater, etc.; ▪ Increase of frequency of discharges (WWTP and CSO) to rivers and receiving water bodies due to increase precipitation; ▪ Increase of energy demand due to increase of pumping requirements and larger amount of WWTP inflow
.4. Receiving waters	▪ Health issues may result from discharges of non-treated wastewater to receiving water bodies with recreational use.	▪ Settlement conditions may occur due to changes in rainfall and river flow pattern, causing flood issues with high flow velocities.	▪ Pollution of receiving water bodies due to wastewater and stormwater discharges

4 Expected effects of climate change in water systems in the Mediterranean region

4.1 General

In addition to the general climate change indicators and impacts expected for the whole Europe, such as the increase of air temperature and the increase of sea level, this climate zone is also expected to experience decrease in annual precipitation and decrease in river flows.

The climate change impacts and indicators expected for this climate zone may affect the majority of the components comprising the urban water cycle systems. The catchment will probably face increased soil erosion problems due to changes in rainfall patterns. Water scarcity problems associated with water quality problems are also expected due to changes in the rainfall pattern (decrease of annual precipitation) and also due to a general increase of air temperature – drought events.

On the other hand, collection and transport system hydraulic capacity is expected to be reached more often due to changes in rainfall patterns - an increase in operation of CSO and in the frequency of flooding events is also expected to occur. Consequently, this may have a negative impact on the water quality of the receiving water bodies. Sea-level rise can also contribute to have impacts on systems hydraulic capacity.

Raw water and wastewater treatment components may be affected by the expected increase of air temperature. Biological activity increase due to the expected increase of air temperature will influence water retention time in the treatment facilities causing problems in the treatment capacity and, ultimately, affecting the quality of the water for supply and the environmental conditions of receiving water bodies.

Details on how climate changes will affect urban water systems in the Mediterranean European climate zone are presented in the following sections.

The analysis only presents the systems and subsystems for which climate effects were considered to be relevant.

4.2 Catchment basin

4.2.1 Surface water catchment

Water scarcity due to evaporation increase

Evaporation is expected to increase due to the expected increase of air temperature. Increased evaporation will then lead to less available drinking water resources in areas that already have to deal with water scarcity and in areas experiencing drought. Higher evaporation rates will add problems to the already limited available amounts of water.

The rate of evaporation will depend upon a number of factors. Evaporation rate increases when temperatures are higher; as an example, an increase of temperature of 10°C will approximately double the rate of evaporation. The humidity of the surrounding air will also influence evaporation; drier air has a greater "thirst" for water vapour than humid (moist) air. Wind is another factor that influences evaporation rate; on still days, water evaporating to the air remains close to its source, increasing local humidity. As the moisture content of the air increases, evaporation will decrease. If, however, an air stream exists to remove the newly formed vapour, the air surrounding the water source will remain dry and evaporation rate is higher (ARIC, 2010).

Drought and water scarcity due to changes in rainfall pattern

Increased temperature and evaporation may increase drought event frequency in areas that are already experiencing this type of events. Therefore, in these areas water scarcity events are expected to be experienced more often.

Earth loses annually about 200,000 km^2 of productive land due to lack of water. This number will probably increase due to even higher expected water scarcity. The earth also experiences desertification of about 60,000 km^2 of land each year, and the number is expected to increase. Nowadays, 30 - 40% of the earth's surface is already suffering from water scarcity (Pokorny *et al.*, 2009).

Mediterranean areas are expected to experience a temperature increase and less rainfall which will aggravate the water scarcity problem. This can affect the water supply and food production industries.

Increase of soil erosion due to drought events

Regular drought events can lead to desertification. Consequently, soil sediments can be transported after (intense) rainfall events (runoff) causing soil erosion. Soil erosion is influenced by land use and rainfall intensity (Govers *et al.*, 2010). Changes in rainfall pattern and intensity expected for the Mediterranean climate zone, associated with long drought periods, can accelerate the soil erosion process.

Shorter catchment time of concentration due to drought events

Frequency of drought events leading to desertification is expected to increase in the Mediterranean climate zone. This phenomenon can reduce significantly the time of concentration of the catchment i.e. the time a water particle takes to go from the upstream part of the catchment to its outlet. Reduced time of concentration increases the probability of flash floods, as the catchment's hydraulic response can be altered significantly. Thus, the more frequent drought events caused by temperature increase and changes in rainfall pattern and intensity can create flooding problems in the catchment.

4.2.2 Surface water reservoir

Water quality issues due to warmer water in summer periods

According to several authors (e.g. Delpla *et al.*, 2009), higher water temperature will promote the growth of blue-green algae and increased microbiological growth in surface water reservoirs. Blue-green algae present in raw water not removed by water treatment plants may reach the consumers. Cyanotoxins from these algae are also of concern. Growth of bacteria and other microorganisms, including pathogens, will also increase due to the expected higher water temperature. Higher levels of microorganisms will lead to increased control levels to assure water quality.

Treatment processes may need to be upgraded to cope with the new conditions (higher level of algae and microorganisms).

Increased Total Suspended Solids due to drought

Another consequence of more prolonged drought events and changes in rainfall intensity and pattern, which is associated with soil erosion processes, is the increase of total suspended solids that are transported over the catchment.

The changes of rainfall pattern and intensity expected for the Mediterranean climate zone, associated with the drought events, can increase the amount of soil sediments that is transported through runoff process. This will increase the total suspended solids amount arriving to the surface water reservoirs. The amount of total suspended solids can then affect the biodiversity of the surface water reservoirs and, ultimately the quality of raw water for drinking water production.

Water quality problems due to more frequent discharges caused by intense rainfall events

Operational conditions of CSO and WWTP are one of the expected changes due to the alterations in rainfall pattern and intensities forecasted for the Mediterranean climate zone (Kleidorfer *et al.*, 2009). An increase in the number of discharges is expected and consequently water pollution problems in the receiving water bodies will be more likely to occur.

The water quality problems in the receiving water bodies can affect their recreational uses. More intense rainfall events can load the receiving water bodies with pathogens, nutrients and toxic chemicals that may create public health problems (such as gastroenteritis and respiratory infections) and/or affect aquatic life, i.e. the environment (Semenza and Menne, 2009).

4.2.3 Groundwater reservoir

Groudwater availibity issues due to drought and rainfall variability

Groundwater availability may decrease in areas experiencing water scarcity and drought on areas with expected high rainfall variability (Hetzel *et al.*, 2008).

In areas experiencing drought and water scarcity problems, groundwater table level can decrease since groundwater is not supplied with water from infiltration. This may cause drinking water scarcity if the groundwater aquifer is used as drinking water source.

Groundwater reservoirs are expected to be more slowly affected by climate changes when compared with surface water, e.g. rivers. This is explained because rivers get replenished in a shorter time scale, and drought and floods are quickly reflected in surface (river, for example) water levels. Only after long-lasting droughts groundwater levels will show a declining trend.

Groundwater level variation and possible ground settlements due to changes in rainfall pattern

The variation of groundwater table level can affect structures and infrastructures. Settlements in the ground due to variation of the groundwater level can thus affect water supply and wastewater system networks, increasing therefore the frequency of structural pipe failure.

4.3 Drinking water system

4.3.1 Abstraction system

The effects of climate change in the abstraction system are similar to those described for catchment and reservoir components.

4.3.2 Groundwater recharge

The effects of climate change in groundwater recharge are similar to those described for catchment and reservoir components.

4.3.3 Water treatment

Raw water quality problems due to runoff increase and changes in air temperature

Raw water is expected to worsen due to climate changes so that treatment plants must adapt and increase the efficiency level of the treatment (Albert, 2008; Aaheim *et al.*, 2009). Raw water will be negatively affected by increased runoff in drainage area, increased water temperature, overload of wastewater systems, increased presence of birds and animals and the inclusion of new species in drainage area and reservoirs. The reduced effect of stratification in water supply reservoirs will reduce the protection of water intakes. Deterioration of water quality will probably occur due to shorter times of stable stratification in lakes as a consequence of longer circulation periods, which will increase the risk of water pollution to reach the water intake of treatment plants (Vevatne *et al.*, 2007).

Treatment plants must be adapted in order to improve the ability to remove microorganisms, NOM, environmental toxins, algae, etc. Bomo *et al.* (2008) state that the water treatment processes must be adapted due to climate changes.

Water treatment issues due to sudden variations in raw water quality

Sudden variations in raw water quality create additional difficulties in the operation of water treatment plants; it becomes increasingly difficult to predict the required dose of chemicals, for example. Operation of treatment plants are based on the raw water quality and when it is unstable and vary over time it is difficult to obtain a stable and good drinking water quality.

The variation of raw water quality requires continuous monitoring of the raw water in order to be able to detect changes in water quality at any time. Water treatment plants must be adapted and be flexible to take into account the variation of the raw water quality and optimise the treatment processes accordingly. Treatment processes should also be prepared to respond to the changes quickly. The changes in raw water quality may seriously affect water treatability by different technologies, treatment costs, water treatment process selection and treatment process design and operation (Eikebrokk *et al.*, 2004).
Groundwater may need improved treatment due to changes in raw water quality

Like for surface water, in some instances improved and extended treatment of groundwater will be needed due to the changed conditions of groundwater caused by climate changes.

In many places, groundwater wells are already contaminated, unprotected or close to becoming dysfunctional due to a lowering of the groundwater table close to or below the bottom of the well.

4.3.4 *Transmission*

Increase of biological growth in biofilms and in suspension in water in pipes due to higher NOM levels in water

If water treatment plants are not able to cope with the higher NOM levels expected in raw water, NOM will be transferred to the transport system. Natural Organic Matter will act as food source and will facilitate the biological growth in the water bulk flow and in biofilm media on the pipe walls.

The link between treatment and transmission/distribution system becomes clearer; the problems of increased NOM and microbiological activity in raw waters emphasise the importance of dealing with optimised treatment so that problems related to these are not transferred to the drinking water network.

Increased water temperature in pipes during the summer months can also contribute to a higher level growth of microorganisms in the network components (Bruaset, 2008; Tryland, 2009).

Increase of chlorine demand due to temperature increase

Temperature increase can affect bacterial growth rate, which is then associated with an increase in chlorine demand to maintain the level of chlorine constant. Chlorine decay in these conditions is then faster and if no action is taken, bacteria regrowth can happen within the water bulk.

4.3.5 *Storage*

Increase of instability of high water tanks in areas with drought due to lower groundwater level

The expected lower groundwater level due to the rainfall pattern changes and temperature increase in the Mediterranean climate zone may create structural stability problems in storage components, such as elevated water tanks. The foundations of the water storage components can thus be affected, creating problems in water supply systems.

Increase of bacteriological growth due to temperature increase

Warmer water can contribute to faster growth of microorganisms; this can then create additional water quality problems that need to be addressed by water utilities.

4.3.6 *Distribution*

Risk of pumping stations to stop due to power failure caused by severe weather events

Extreme weather increases the risk for power failure which can affect the serviceability of pumping stations (Vevatne *et al.*, 2007). If power supply fails and the pumping station has no backup power supply, an interruption in the water supply may occur. This will decrease the serviceability of the water company. Another side effect of a stopped pumping station is that pipes might lose the pressure and be vulnerable to the ingress of contaminants during that period. Continuity of pumping is therefore important for both serviceability and safety of the drinking water.

Since the risk for power failure is higher during extreme weather situations, which are expected to occur more often due to climate changes, it is important to have back up power supply available at all important pumping stations. This will increase the reliability of the system and therefore reduce the risk of break up in the water supply.

Increase of bacteriological growth due to temperature increase
Expected similar effects to those described for the storage component.

4.3.7 *Plumbing systems*

Increase of bacteriological growth due to temperature increase
Expected similar effects to those described for the storage component. This is especially relevant when there are residential water supply storage reservoirs.

4.4 Wastewater system

4.4.1 *Wastewater collection network*

Backflow issues in low lying sewer systems along the shoreline due to sea level rise
A rising sea level can result in backwater situations in the sewer system leading to basement flooding and damages on buildings and other infrastructure (Vevatne *et al.*, 2007).

Low-lying CSO in the network will be affected by sea water inflow if these CSO are not removed or moved higher above sea level.

Limited hydraulic capacity due to more frequent and intense rainfall events
During heavy rainfall events it will be crucial to use the whole capacity of the existing sewer network, together with implementing cost-effective elements in the network like detention ponds. To reduce the amounts of water into the sewer systems, more surface water should be infiltrated to the ground (Lindholm *et al.*, 2005) or detained in open ponds and open water routes on the surface (Vevatne *et al.*, 2007).

Old manholes are often bottle necks in terms of capacity in the networks. Old networks can therefore be made more efficient by for example rehabilitating the manholes so that flow capacity is increased (Lindholm, 2009). The lack of capacity related problems can lead to flooding events in urban areas, both in house basements and on infrastructure. It is therefore important to upgrade the systems to cope with the increasing capacity problems.

Increase of probability of urban flooding from combined sewer networks due to heavy precipitation events
More heavy precipitation combined with increased population density in cities generates the conditions to increase the risk for flooding in urban areas (Vevatne *et al.*, 2007). Heavy rainfall over impervious city surfaces cannot infiltrate into the ground. All water will flow over the surface causing large runoff peaks which sewer networks cannot handle (Vevatne *et al.*, 2007).

There is often a strong non-linear connection between increase in precipitation and resulting increase in number of flood-related damages to buildings (Vevatne *et al.*, 2007). It is economically unjustifiable to design sewer systems to handle all heavy rainfall events so that there will be always situations where flooding cannot be avoided. Flood prevention, development of flood plans and creation of flood mitigation conditions should be considered and implemented (Vevatne *et al.*, 2007).

The effect of more impervious surfaces can be counteracted by implementing new methodologies for reduce flooding. Such methodologies include taking care of surface water at the site, including infiltration and detention. Safe flood routes for excess water during heavy rain periods can be constructed in order to cause the least damage (Vevatne *et al.*, 2007).

Increase of urban surface pollution on due to flooding in combined sewers networks

Combined sewer networks might experience lack of hydraulic capacity resulting in backflow and urban surface flooding. Urban surface is hence expected to experience contamination from sewage, including phosphorous, nitrogen and microbiological contamination.

Odour and corrosion issues due to temperature increase and precipitation decrease

Temperature increase results in higher microbiological activity. Together with low concentrations of dissolved oxygen in the wastewater, the potential for occurrence of anaerobic conditions in sewers increases. Subsequently, the formation of odorous and of corrosive substances in sewers is likely (Thistlethwayte, 1972).

4.4.2 Interceptor system

The effects of climate changes in interceptor system are similar to those described for the wastewater collection system and described in Sub-section 4.4.1.

4.4.3 Wastewater treatment

Reduction of hydraulic detention time in treatment plant due to Wastewater treatment plant inflow increase

Increased inflow sewage volume to Wastewater Treatment Plants (WWTP) can reduce the hydraulic detention time in treatment (Plósz and Ratnaweera, 2007). This can result in more direct discharges to receiving water bodies if inflow exceeds the WWTP capacity. Reduced detention time may result in lower treatment efficiency. Therefore, quality of treated wastewater may decrease or even not comply with water applicable regulations.

Increase of biological activity due to water temperature increase

The expected increase in water temperature will accelerate the biological processes. Design of wastewater treatment takes into account the time of retention and the rate of biological processes. If one of these two factors changes, the level of treatment is changed, resulting in an insufficient level of wastewater treatment. In order to solve this expected problem, end-users may need to improve/alter their treatment processes, which can involve significant costs.

4.4.4 Combined sewer overflows

More frequent operation of combined sewer overflows due to precipitation and runoff increase

Increased rainfall intensity and unfavourable runoff conditions (large city impervious areas) can cause more frequent and longer periods of operation of CSO. For CSO there is a strong non-linear relationship between increase of precipitation intensity and discharge quantities (Vevatne *et al.*, 2007). If no measures are taken into account, some studies indicate that discharges from CSO might double during the next 50 years (Madsen, 2007; Semadeni-Davies *et al.*, 2006).

4.4.5 *Pumping stations*

Risk of pumping stations stopping due to power failure caused by an extreme weather event

Extreme weather increases the risk of power failure which will affect the serviceability of pumping stations (Vevatne *et al.*, 2007). It is therefore important to have backup power supply available at all important pumping stations. This will increase the reliability of the system and reduce risk of direct discharges to receiving water bodies.

If power supply fails and pumping stations have no backup power supply, direct discharge of sewage to the water receiving body will occur. The risk of contamination of the receiving water body is therefore high.

4.4.6 *Infiltration systems*

Higher infiltration rate due to drier soil conditions (positive impact)

Moisture soil conditions in the Mediterranean climate zone can change due to the changes forecasted for the rainfall pattern and air temperature (less rainfall and higher temperatures). Consequently soil moisture will decrease and therefore soil infiltration rate increase. This increase of the infiltration capacity of soil can have a positive impact in operating and managing wastewater treatment solutions based on infiltration; this can be seen as a positive impact. Nevertheless, such wastewater treatment solutions are no longer accepted as appropriate solutions due to groundwater contamination problems and, for this reason, tend to be abandoned.

4.5 Stormwater system

4.5.1 *Stormwater collection network*

Sediment issues due to drought and lack of soil moisture and vegetation

The expected changes in rainfall pattern and intensity may increase the amount of sediments that enter into the stormwater system. This can in turn cause sedimentation problems that can reduce the hydraulic capacity of a sewer pipe (partial blockage) or completely block a sewer pipe. Blockage sewer pipe events can therefore become more frequent and require additional investments by the end-users in order to maintain the stormwater system fully operational.

4.5.2 *Infiltration systems*

The effect of climate changes on infiltration component of stormwater systems is similar to the one described in the infiltration component of wastewater systems.

4.6 Receiving water body

The climate change effects expected for the receiving water bodies can be considered similar to those described for the catchment basin, namely, the surface water reservoir (see section 4.2.2).

5 Expected effects of climate change in water systems in the Atlantic region

5.1 General

In addition to the climate change indicators and effects that are common to all four European climate zones, as described in this report, in the Atlantic climate zone, two other climate change indicators/ effects are also expected: increase in winter precipitation and increase in river flows. These indicators may affect several of the urban water systems' components.

Increase of precipitation during the winter period may lead to increase of runoff, and consequently increase of flooding events in urban areas. Together with increase of river flows, and sea-level rise, the likelihood of river and coastal floods is also expected to increase.

Associated with the increase in terms of precipitation and temperature, surface water quality can be affected. The processes involved in the treatment may need to be adjusted to the new climate conditions.

In terms of drainage and wastewater treatment systems, the expected increase in precipitation during winter may affect the hydraulic performance of the collection and transport components; floods are thus more likely and can have a significant impact in terms of surface and receiving water bodies' pollution (affecting recreational uses, for example). It is also expected an increase in the number of CSO and WWTP direct discharges, which can affect the water quality of the receiving water bodies.

Wastewater treatment can also be affected by the increase in precipitation during winter and sea-level rise as the treatment is based on the volume that needs treatment and the time of retention.

The effects of climate changes on the urban water systems located in the European Atlantic climate zone are described in detail in the following sections. The analysis only presents the systems and subsystems for which climate change impacts were considered are relevant.

5.2 Catchment basin

5.2.1 Surface water catchment

Increase of runoff and flooding due to precipitation increase

Due to the expected increase of precipitation (especially during winter months) in the Atlantic climate zone, runoff is expected to increase in both intensity and total amount. Heavier rainfall over longer periods of time will saturate the soil and consequently lead to further increase of runoff. In addition, during winter the increased changes between cold and mild periods will lead to multiple situations of rainfall on top of ice and snow; such conditions may increase runoff peaks and total amount of surface water. In some instances, flooding can occur in the catchment due to the increased precipitation.

More nutrients, microorganisms and NOM in receiving water bodies due to runoff increase

Runoff is linked to the precipitation, especially in cities where large part of the catchment is impervious. Therefore, an increase in precipitation corresponds to an increase in runoff, which in turn represents an increase in available nutrients and NOM in the receiving water bodies. More available nutrients and NOM are conditions that favour the development of microorganisms. In addition to more available nutrients, the expected increase in air and water temperature can also favour the microorganisms' activity.

More microorganisms are likely to aggravate pollution problems or create new ones, which can then have impact in the water uses (e.g. recreational, water supply).

Raw water contamination due to precipitation increase

Increased precipitation and consequently runoff may lead to water quality problems such as higher NOM water content, higher number of microorganisms in the water and other contamination related problems (e.g. eutrophication).

Water quality issues due to new species living in the catchment

Warmer climate can bring along longer periods of non-frozen lakes and ponds (ice-free periods) during winter (Zwolsman *et al.*, 2007). This makes water easily accessible for animals and birds, allowing new species to live in and around water sources.

The presence of a larger number of animals and birds for longer periods of time in the catchment areas raise the risk for microbiological water contamination. Therefore, raw water treatment may need to be improved due to this factor.

Raw water quality changes due to development of march areas

Increased precipitation and wet climate promote the development and expansion of marches. Marches are wet areas in which trees and animals have difficulty to live in. The biodiversity of such areas (effects on animals, insect, trees and plants species) will change and consequently may affect the raw water quality (Zwolsman et al., 2007).

Water pollution events due to WWTP direct discharges

As mentioned earlier, WWTP inflow is expected to increase due to the expected increase in precipitation and sea level rise (back water inflow phenomenon). This will create hydraulic capacity problems to WWTP and, in extreme cases, lead to more direct discharges of non-treated wastewater to the receiving water bodies/catchment basin, causing water pollution problems.

The discharges and pollution associated can have a direct impact in the environmental conditions of the water (e.g. effects on fish resources) and on the possible water uses (e.g. recreational).

5.2.2 *Groundwater catchment*

The impacts of Climate Change in the groundwater catchments in the European Atlantic climate zone are considered similar to those described for the surface water catchment (Atlantic climate zone).

5.2.3 *Surface water reservoir*

Likelihood of microorganisms in raw water due to air temperature increase

Air temperature increase is expected in Europe, including the Atlantic climate zone. This will lead to warmer weather and less ice on reservoirs, and consequently animals and birds can stay for longer periods of time. These circumstances will attract new species which altogether will increase the microbiological strain in the catchment area and consequently in the reservoir. Water sources will experience higher contamination load and worse raw water quality.

Intense and strong rainfall will lead to increased runoff from areas containing storage of natural fertilizers, areas with spread fertilizers, natural habitats and grazing land. This will contaminate the surface water reservoirs with pathogenic microorganisms (e.g. bacteria, virus and parasites). Increased supply of nutrients to the surface water reservoirs will further assist the reproduction of such pathogenic organisms (Tryland, 2009).

In addition, warmer water will also contribute to the increase of the growing rate of such microorganisms.

Increase of evaporation due to air temperature increase

The rate of evaporation depends on a number of factors. When air temperature is higher the evaporation rate is also higher (an increase of 10°C will approximately double the evaporation rate). Surrounding air humidity also influences evaporation; drier air has a greater "thirst" for water vapour than humid, moist air.

Although the effect of the increased evaporation rate in the Atlantic climate zone is expected to be not as important as in the Mediterranean climate zone, higher evaporation rates can also create problems of water availability in this zone.

Maximum capacity of surface water reservoirs reached more often due to precipitation increase

The increase in rainfall amount may fill surface water reservoirs close to their maximum capacity. This can therefore cause flooding in surrounding areas during rainfall events. Nevertheless, more water available in the reservoirs can have positive effects; more water is available to supply the drinking water reservoirs which may postpone the need for new water sources within the next 40-50 years (Vevatne *et al.*, 2007).

Raw water contamination due to birds and other animals living more time in surface water reservoir surroundings

Climate changes can create conditions better suited for many types of animals, among them birds, to live longer time in surface water reservoir surroundings. These new species may contribute to contaminate the water with faeces and thus increasing the number and type of pathogenic microorganisms.

The potential risk for microbiological contamination may require new water quality monitoring measures.

Water quality issues due to warmer water

Higher water temperature will promote the growth of blue-green algae. Warmer water also facilitates microbiological growth in the reservoirs.

Blue-green algae present in raw water not removed by water treatment plants may reach the consumers. Cyanotoxins from these algae are also of concern.

5.2.4 *Groundwater reservoir*

High level of groundwater table due to precipitation increase
In areas where increase in precipitation is expected, infiltration is also expected to increase and therefore the groundwater table is expected to ascend.

High groundwater table levels might create problems to water supply and wastewater systems. For water supply systems a high level of groundwater constitutes a risk for groundwater intrusion into a pipe when the pressure inside the pipe is low; the infiltration of groundwater into water supply pipes may contaminate the drinking water.

Wastewater sewers can often have cracks and if the sewer is within the groundwater table relatively large volume of water can enter to the sewer through cracks. Increased amounts of water in wastewater pipes can lead to increased costs associated with the wastewater treatment.

On the positive side, high groundwater table will contribute to more available drinking water.

Decrease of soil infiltration due to high groundwater table
When groundwater reservoirs are full, soil infiltration is expected to be lower and therefore increase runoff. This can lead to flood problems, especially in areas built following the LID (Low Impact Development) concept in which infiltration of water to ground is part of the solution to take away flood water.

Additional water detention structures should be considered in order to cope with the increased amounts of runoff.

5.3 Drinking water system

5.3.1 *Abstraction system*
The problems associated with climate changes that may affect the abstraction component of water supply systems are similar to the problems described for surface and groundwater reservoirs/catchments. As mentioned before, these problems are mainly linked to water quality problems.

5.3.2 *Water treatment*

Additional water treatment requirements due to microorganisms in raw water increase
More precipitation and more runoff will result in more microbiological activity in the drinking water reservoirs. Water treatment plants will probably have to deal with more microorganisms in water, including parasites (Delpla *et al.*, 2009; Hunter, 2003; Vevatne *et al.*, 2007), due to the following causes:

More precipitation leads to more runoff from the drainage area of reservoirs. This will bring more microorganisms to the drinking water sources;

Warmer climate will lead to the presence of more animals and birds for a longer period of time (also over winter). This will increase the supply of faeces and microorganisms, including parasites;

Warmer water could also be viewed as another main factor affecting microorganism activity rate and other physic-chemical and biological reactions (Delpla *et al.*, 2009);

The stratification layers of the surface water reservoirs will function less as hygienic barriers due to changes in water temperature, less freezing of water in winter time and more wind on the surface which will create more circulation in the water.

Due to the presence of more microorganisms in the raw waters, water treatment processes will have to be implemented in order to reduce the risk for microbiological contamination of drinking water. Implementation of early detection tools is beneficial.

Higher amounts of algae and toxins are expected in surface water reservoirs due to warmer weather, more precipitation, more runoff and more strain on the wastewater system. Warmer water and increased access to light during winter months will boost the growth of algae in reservoirs (Aaheim *et al.*, 2009; Albert, 2008; Hunter, 2003).

5.3.3 Transmission

Increase of risk of infiltration of contaminated water into water supply systems due to groundwater rise

Increased precipitation may raise the groundwater table; if it reaches the level where water supply pipes are installed there is risk of infiltration of groundwater into the pipes.

In some countries water supply system pipes and wastewater system sewers are laid down in the same ditch. The pipes for water and wastewater in such systems go through the same manholes. During extreme weather situations such manholes can be submerged in sewer combined with surface water. Drinking water pipes will then be surrounded by contaminated water. In such situations it is very important that positive pressure occur within the water supply system pipes (Vevatne *et al.*, 2007).

Increase of biological of growth in biofilms and in suspension in water in pipes due to higher NOM levels in water

The increase in air and water temperature can contribute to the growth of biofilm in the drinking water system components, namely the transmission system components. These conditions can then affect water production for drinking purposes.

Increase of chlorine demand due to temperature increase

Chlorine decay increase is also expected to affect the transmission, storage, distribution and plumbing systems due to the increase of microbiological activity associated with the increase in temperature (air and water).

5.3.4 Storage, distribution and plumbimg systems

The climate change effects described for the transmission system are also applicable to the storage, distribution and plumbing systems in the European Atlantic climate zone.

5.4 Wastewater system

5.4.1 Wastewater collection network

Backflow issues in low lying sewer systems along the shoreline due to sea-level rise

A rising sea level will result in backwater situations in the sewer system leading to basement flooding and damages on buildings and infrastructure. (Vevatne *et al.*, 2007)

Low lying CSO in the network will take in sea water if these CSO are not removed or moved to higher locations, above sea level

Limited hydraulic capacity due to more frequent and intense rainfall events

During heavy rainfall events it will be crucial to use the whole capacity of the existing sewer network, together with implementing cost-effective elements in the network like detention ponds (Lindholm, 2007). To reduce the amounts of water into the sewer systems, more surface water can be infiltrated to the ground (Lindholm *et al.*, 2005), and surface water can be detained in open ponds and open water routes on the surface (Vevatne *et al.*, 2007).

Old manholes are often bottle necks in terms of capacity in the networks. Old networks can therefore be made more efficient by, for example, rehabilitating the manholes so that flow capacity is increased (Lindholm, 2009).

The capacity problems will lead to flooding events in urban areas, both in house basements and on infrastructure. It is therefore important to upgrade the systems to cope with the increasing capacity problems. The problem can be solved by either increasing the diameter of sewer pipes, to use particle separating overflows during the extreme weather events or to build in detention pools in the system.

Increase of probability of urban flooding from combined sewer networks due to heavy precipitation events

More heavy precipitation combined with increased population density in cities generates the conditions for increase the risk for flooding in urban areas (Vevatne *et al.*, 2007).

Heavy rainfall will fall on impervious city surfaces and thus water cannot infiltrate into the ground. All the water will flow on the surface which will cause large runoff peaks in which the sewer network cannot handle (Vevatne *et al.*, 2007). Such situations can cause flooding in urban areas, especially if surface flow has no flood attenuation areas to run into.

There is often a strong non-linear connection between increase in precipitation and resulting increase in number of flood-related damages to buildings (Vevatne *et al.*, 2007). It is economically unjustifiable to design sewer systems to handle all heavy rain events so that there will be always situations where flooding cannot be avoided. Flood prevention, development of flood plans and creation of flood mitigation conditions should be considered and implemented (Vevatne *et al.*, 2007).

Climate changes will lead to more water on the surface and in the sewer network. This will cause more frequent and larger floods in urban areas. Damages caused by flooding are also expected to increase due to climate changes.

The effect of more impervious surfaces can be counteracted by implementing new methodologies for reduce flooding. Such methodologies include taking care of surface water at the site, including infiltration and detention. Safe flood routes for excess water during heavy rain periods can be constructed in order to cause the least damage (Vevatne *et al.*, 2007).

Increase of urban surface pollution on due to flooding in combined sewers networks

Combined sewer networks might experience lack of hydraulic capacity resulting in backflow and urban surface flooding. Urban surface is hence expected to experience contamination from sewage, including Phosphorous, Nitrogen and microorganisms type of contamination.

The increased problems of increased rainfall intensity, increased sewer blockages and lack of capacity of the sewer network to deal with the increased volume of rainfall will contribute to increase the surface contamination when compared with today's conditions.

Increase of probability of basement flooding due to limited sewer system capacity

The increased amount of water in the combined sewerage systems raises the probability for sewer blockages, backflow of water and consequent basement flooding. Basement flooding occurs mainly when a blockage in the sewer system makes the water flow backwards and into basements. Such basement flooding can amount to a large sum of money in insurance payments. With climate changes, basement flooding can occur more often, increasing the damages caused by these events.

According to Vevatne *et al.* (2007), some studies have demonstrated that separating sewer and stormwater in some combined sewerage systems can lead to a reduction in the number of basement flooding.

5.4.2 Interceptor system

Backflow issues in low-lying sewer systems along the shoreline due to sea-level rise

The increase of the sea level can create problems of backwater inflow. This phenomenon will mainly be located in low-lying coastal areas. As a consequence, lack of hydraulic capacity problems can be reported, which can then affect the water quality of receiving water bodies.

In addition, backwater inflow phenomena can influence the performance of WWTP, as large volumes of sea water can be transported to these treatment infrastructures.

5.4.3 Wastewater treatment

Wastewater treatment plant capacity issues and increase of use of chemicals due to inflow increase

The expected increase in rainfall in the Atlantic climate zone will increase the soil moisture, which in turn can contribute to an increase of sewer system infiltration. This infiltration can then create problems in terms of wastewater treatment due to the limited treatment capacity of WWTP.

Associated with the increased inflow in WWTP is the increased use of chemicals to treat wastewater, which can represent a significant additional operational cost to the end user.

5.4.4 *Combined sewer overflows*

More frequent operation of combined sewer overflows due to precipitation and runoff increase
Increased rainfall intensity and unfavourable runoff conditions (large city impervious areas) will be the cause of more frequent and longer periods of operation of Combines Sewer Overflows (CSO) in combined systems. For CSO there is a strong non-linear relationship between increase of precipitation intensity and discharge quantities (Vevatne *et al.*, 2007). If no measures are taken against this, some studies indicate that discharges from CSO might double during the next 50 years (Madsen, 2007; Semadeni-Davies *et al.*, 2006).

5.4.5 *Pumping stations*

Pumping stations and discharge issues due to sea-level rise
The inflow to pumping stations can be higher than the pumping station peak flow due to sea-level rise, which may originates backwater phenomena. Seawater has different characteristics when compared with wastewater; thus, pumping stations components, namely, pump sumps, can be affected by sea water (e.g. corrosion).

Higher inflow volumes can also increase the number and volume of overflows; these overflows can then generate environmental problems associated with the pollution of receiving water bodies (e.g. rivers, coastal areas).

5.4.6 *Infiltration systems*

Reduction of infiltration rate due to high level of soil moisture caused by precipitation increase
Although no longer common in the European Atlantic climate zone, infiltration-based wastewater treatment systems (e.g. septic tanks) can be affected by the increase in soil moisture content due to increase in precipitation. This can then create operational and maintenance problems, and in extreme cases, pollution problems.

5.5 Stormwater system

5.5.1 *Stormwater collection network*

Reduction of infiltration rate due to high level of soil moisture caused by precipitation increase
Although no longer common in the European Atlantic climate zone, infiltration-based wastewater treatment systems (e.g. septic tanks) can be affected by the increase in soil moisture content due to increase in precipitation. This can then create operational and maintenance problems, and in extreme cases, pollution problems.

System hydraulic capacity reached more often due to precipitation increase and sea-level rise
Sea level rise and increased precipitation can lead to reach stormwater system hydraulic capacity more often. Flooding events are then expected to be more frequent, causing increased damage and pollution-associated problems.

5.5.2 Infiltration systems

Reduction of infiltration rate due to high level of soil moisture caused by precipitation increase
Infiltration rate is expected to decrease due to the high levels of soil moisture caused by the increase of precipitation. This can make, for example, SUDS less effective and therefore increase the probability of surface flooding.

5.5.3 Storage structures

Stormwater storage structures capacity issues due to intense precipitation increase
The hydraulic capacity of existing stormwater storage structures can become insufficient due to the expected increase in precipitation for the European Atlantic climate zone. As consequence, these structures will have a limited effect in controlling flooding events, which are thus likely to become more frequent.

5.6 Receiving water body

The climate change effects expected for the receiving water bodies can be considered similar to those described for the catchment basin, namely, the surface water catchment and surface water reservoir (see sections 5.2.2 and 5.2.3).

6 Expected effects of climate change in the Continental region

6.1 General

Continental Europe will face higher winter rainfall, more winter floods, and lower summer precipitation with subsequent higher risk of summer droughts. Temperature increase will be significant.

As consequences of these expected changes water availability will be affected by changing weather patterns and it could be necessary to build additional infrastructure, for example winter storage capacity. Reservoirs will be impacted in terms of operation, quantity, quality and structure. Demand for water is likely to increase.

The rise in sea level will have many implications for the natural environment: there are impacts on groundwater quality and coastal habitat. Pipe systems for both drinking water supply and sewerage will be more prone to cracking as climate changes lead to greater soil movement as a consequence of wetting and drying cycles. Existing sewerage systems were not designed to take climate change into account. This means that more intense rainfall is likely to exceed the capacity of parts of the network and cause local flooding. Dams will be more prone to siltation resulting from increased soil erosion, and the slippage risk to soil dams from intense rainfall events will also increase. Lower river flows will reduce the dilution of wastewater effluent. We may need additional treatment to meet higher standards, which are likely to be achievable only by using energy intensive processes, with all that means for greenhouse gas emissions. Colour and odour problems will result from higher temperatures and more intense rainfall events.

According to the expected effects of climate indicators for the Continental areas, in the following paragraphs the impacts on different assets of the water cycle are presented. The analysis lists only the systems and subsystems for which climate effects are relevant or related studies have been considered in this report.

The effects of climate changes on the urban water systems located in the European Continental climate zone are described in detail in the following sections and in the Appendix, Table 12 - Table 16

The analysis lists only the systems and subsystems for which climate effects are relevant or related studies have been considered in this report.

6.2 Catchment basin

6.2.1 *Surface water catchment*

Decrease of summer precipitation and of temperature:

Spanning the centre of continental Europe, the Alps play a crucial role in accumulating and supplying water to the continent. Recognised as the 'water towers of Europe', the mountains host most of the headwaters of the rivers Danube, Rhine, Po and Rhone. The alpine climate has changed significantly during the past century, with temperatures increasing more than twice the global average. This makes alpine mountains especially vulnerable to changes in the hydrological cycle and decreases in snow and glacier cover, which are already occurring. Projected changes in precipitation, snow-cover patterns and glacier storage will further alter run-off regimes, leading to more droughts in summer, floods and landslides in winter and higher inter-annual variability. Projected water shortages and more frequent extreme events, combined with increasing water demand (for irrigating agriculture or tourist influxes, for example), are likely to have severe adverse effects on ecosystem services such as the provision of drinking water (EEA, 2009).

Raw water contamination due to runoff increase

Increased precipitation and consequently runoff may lead to water quality problems such as higher Natural Organic Matter (NOM) water content, higher number of microorganisms in the water and other contamination related problems (e.g. eutrophication).

Water quality issues due to new species living in the catchment

Warmer climate can bring along shorter or periods of non-frozen lakes and ponds (ice-free periods) during winter (Zwolsman *et al.*, 2007). This makes water accessible for animals and birds, allowing new species to live in and around water sources.

The presence of more animals and more birds for a longer period of time in the catchment areas raise the risk for microbiological water contamination. Therefore, raw water treatment may need to be improved due to this factor.

Formation of marches due to precipitation increase

More precipitation and wetter climate facilitate the formation and expansion of marches. March lands will therefore expand in areas where more precipitation is expected. Marchland is wet and makes it difficult for trees and animals to reside in. The biodiversity of such areas will change according to the changed living conditions for animals, insects, trees and plants. (Zwolsman *et al.*, 2007).

6.2.2 Groundwater catchment

Very little research exists on the potential effects of climate change on groundwater. Available studies show that groundwater recharge and discharge conditions are a reflection of the precipitation regime, climatic variables, landscape characteristics and human impacts such as agricultural drainage and flow regulation (Allen *et al.* 2004; De Wit 2001). Hence, predicting the behaviour of recharge and discharge conditions under future climatic and other changes is of great importance for integrated water management. For instance, substantial reductions in groundwater recharge near Grenoble, France, simulated by Bouraoui *et al.* (1999), was almost entirely attributed to increase in evapotranspiration during the recharge season under CO2 doubling scenarios. A study by (Brouyère *et al.* 2004) for the Geer basin in Belgium shows mostly a decrease but also some slight increase of recharge for climate scenarios derived from several general circulation models (GCM). According to Sandstrom (1995), a 15% reduction in rainfall, with no change in temperature, results in a 40–50% reduction in recharge, inferring that small changes in rainfall can lead to large changes in recharge and, hence, in groundwater resources

Saline intrusion due to sea-level rise

Sea level rise, combined with changes in rainfall patterns and increased demand for water, will increase the risk to coastal aquifers of saline intrusion and consequent variation of water quality characteristics.

6.2.3 *Surface water reservoir*

Water quality issues due to summer precipitation decrease

Lower river flow increases demand on existing storage and causes reduction in safety of supply (UKWIR - http://www.ukwir.org/lib/90857/)).

Surface water capacity reduction due to temperature (water and air) increase

Increased evaporation and evapotranspiration reduce yield of surface reservoirs and increases demand on groundwater recharge (UKWIR - http://www.ukwir.org/lib/90857/)). Higher evaporation rates can therefore create problems of water availability in this zone.

Higher water temperature is better suited for growth of blue-green algae. Warmer water also facilitates microbiological growth in the reservoirs.

Growth of blue-green algae is something that first and foremost affects the bathing water quality since these algae can easily be removed in the water treatment plants.

Maximum capacity of surface water reservoirs reached more often due to precipitation increase

The increase in rainfall amount may fill surface water reservoirs close to their maximum capacity. This can therefore cause flooding in surrounding areas during the rainfall event.

Water quality issues due to new species living in the catchment

The new climate is better suited for many types of animals and among them birds will expand their residence time in many reservoirs. This will increase the risk of contamination from faeces.

6.2.4 *Groundwater reservoir*

Reduction of borehole yelds due to temperature (water and air) increase

Increased evaporation and evapotranspiration reduce infiltration and so borehole yields (UKWIR - http://www.ukwir.org/lib/90857/).

Water availability variation due to precipitation increase

In areas where increased precipitation is expected, infiltration is also expected to increase and therefore the groundwater table is expected to ascend.

High groundwater table levels might create problems to water supply and wastewater systems as described for the Atlantic climate zone.

On the positive side, high groundwater table will contribute to more available drinking water. When the ground water reservoirs are full there is limited possibility for infiltration which will cause more of the surface water to runoff on the ground surfaces (Hetzel *et al.*, 2008): this will lead to more flood problems.

6.3 Drinking water system

6.3.1 Abstraction system

Water quality issues due to sumer precipitation decrease

Lower flow rates cause deposition, which reduces raw water quality.

6.3.2 Groundwater recharge

Changes in length of the recharge period and water avalability due to temperature (water and air) increase and changes in precipitation trends

Effective rainfall, rivers and lakes generally replenish aquifers. This water may reach the aquifer rapidly, through macro-pores or fissures, or more slowly by infiltrating through soils and permeable rocks overlying the aquifer. A change in the amount of effective rainfall will alter recharge, but so will a change in the duration of the recharge season. Increased winter rainfall generally is likely to result in increased groundwater recharge. However, higher evaporation may mean that soil deficits persist for longer and commence earlier. Various types of aquifer will be recharged differently. The medium through which recharge takes place often is poorly known and very heterogeneous, challenging recharge modelling. In general, there is a need to intensify research on modelling techniques, aquifer characteristics, recharge rates, and seawater intrusion, as well as monitoring of groundwater abstractions.

The warmer future climate leads to an increase in the length of the growing season, so that the region's soils return to field capacity later in the autumn and start drying out sooner in the spring. This leads to a reduction in the length of the recharge period.

6.3.3 Water treatment

Sedimentation and water quality issues due to summer precipitation decrease

Lower flows lead to greater sedimentation, with blockages causing service failure.

Reduced raw water volumes reduce dilution and increase drinking water quality risk.

Changes in treatment efficiency and processes due to temperature (water and air) increase

Higher temperature impacts treatment process because of increased planktonic species, of NOM and also changes in water colour.

Increased algae growth and risk of microscopic organism within the water supply system.

Discolouration and odour problems caused by the biological consequences of higher temperatures.

High sediment level and water quality risk due to river flooding events during winter

Greater sediment levels increase drinking water quality risk.

Saline intrusion and need for improvement of groundwater treatment due to sea-level rise

Saline intrusion decreases yield causing service loss and reduction in safety of supply

6.3.4 Transmission

Microbiological growth due to temperature (water and air) increase
Increased rate of micro-biological growth increases risk of residual chlorine depletion and contamination of supplies

Water quality issues due to river flooding events during winter
Flooding causes contaminants to enter pipelines increasing drinking water quality risk

Increase of external corrosion due to higher groundwater table and higher soil accidity
Due to increased rain and increased runoff and infiltration, the ground water table will be higher. This will cause the drinking water and sewer pipes to more frequent be in contact with the ground water table which will facilitate external corrosion problems. It is also probable that pipes will have increased break rates due to external corrosion caused by increasing acidity in ground (Vevatne *et al.*, 2007).

6.3.5 Storage

Increase of risk of contamination due to summer precipitation decrease
Intermittent supplies leads to contamination from accumulated silt and debris being flushed out of service reservoirs and towers (increasing drinking water quality risk)

Water quality issues due to river flooding events during winter
Flooding cause contaminants enter underground storage tanks

Reduction of water supply safety due to temperature (water and air) increase
Increased peaks of demand lead to greater storage requirements reducing safety of supply

6.3.6 Distribution

Risk of water contamination due to summer precipitation decrease
Intermittent supply increases risk of external contaminants entering the pipelines (increased drinking water quality risk)

Depressurisation of pipelines leads to greater incidence of pipe failure and resulting contamination during re-pressurisation.

Intermittent supplies leads to increased risk of mechanical asset failures.

Increase of rate of contaminant growth due to temperature (water and air) increase
Increased rate of microbiological growth increases risk of residual chlorine depletion and contamination of supplies (increasing water quality risk)

Water quality issues due to river flooding events during winter
Floodwater infiltration into pipelines increases drinking water quality risk

Increase of external corrosion due to higher groundwater table and higher soil accidity
Due to increased rain and increased runoff and infiltration, the ground water table will be higher. This will cause the drinking water and sewer pipes to more frequent be in contact with the ground water table which will facilitate external corrosion problems. It is also probable that pipes will have increased break rates due to external corrosion caused by increasing acidity in ground (Vevatne *et al.*, 2007).

Increase of service failure of pumping stations due to summer precipitation decrease
Depressurisation of the supply system leads to greater incidence of air blockages causing service failure.

Failure of pumping stations due to scada & telemetry/ electrical supply/ buildings/ security/ mobile plant can be damages
Higher temperatures cause increased vegetation growth at sites damaging equipments
Direct asset flooding cuts access to assets.
Direct flooding leads to submersion of electrical assets.
Saline intrusion degrades infrastructure causing accelerated asset deterioration

6.4 Wastewater system

6.4.1 *Wastewater collection network*

Increase of flood probability from combined sewer systems due to river flooding during winter increase
Increased volumes in combined sewers exceed sewer capacity and causes flooding in basements. Also more and larger floods in urban areas are expected with also consequent increase of pollution on urban surface.

Impacts on environmental and health due to sea-level rise
Saline intrusion and subsequent H_2S formation in sewer creates environmental health risk

Increase of septicity levels ue to temperature (water and air) increase
Increased level of septicity cause accelerated asset deterioration and increased odour

Increase of leakage from sewer network due to precipitation increase and sea- level rise and consequent surcharge of combined sewer network
More precipitation and more runoff will cause the combined sewer network systems to run full and pressurize. The sea level rise will cause backflow of sewer water, which will also pressurize the system (Vevatne *et al.*, 2007). Such sewer pipes will have a pressure gradient, which will cause sewer water to leak/ exfiltrate from the system. The sewer will leak into the ground, the groundwater and to surrounding areas, rivers and waters.

6.4.2 *Wastewater treatment*

Treatment efficiency reduction due to temperature (water and air) increase
Increased levels of septicity in received sewage causes increased odour

Higher rate of biological activity causes change to process efficiency

Increased of septicity levels promote growth of undesirable species and inhibit growth of normal aerobic heterotrophs affecting process performance efficiency.

Increased septicity in sewers/primary tanks leads to poor primary settlement and increased load onto secondary process affecting process performance efficiency.

Increased temperature may lead to lower oxygen transfer efficiency in secondary process affecting process performance efficiency.

Increase of sewage salinity due to sea-level rise

Saline intrusion increases sewage salinity which impacts on H_2S formation, reduces primary and FST (final settlement tanks) sludge settleability, reduces dewaterability of SAS (Surplus Activated Sludge). Potential impact on ASP (Activated Sludge Process) microbiology due to rate of salinity change dissolved oxygen saturation causing accelerated asset deterioration and reduced performance.

6.4.3 *Combined sewer overflows*

Water quality issues due to river flooding events during winter

Higher winter flows dilute and reduce the effects of spills, reducing the impact of spills and improving receiving water quality. However, increased rainfall intensity and unfavourable runoff conditions (large city impervious areas) will be the cause of more frequent and longer periods of operation of Combines Sewer Overflows (CSO) in combined systems.

Increase of probability of flooding from combined sewer networks due to sea level rise

Costal CSO discharges become tide locked, hindering free discharge and causing customer flooding and reducing received water quality.

6.4.4 *Pumping stations*

Pumping station performance issues due to temperature (water and air) increase

Increased levels of septicity affect pumping regimes and causes accelerated asset deterioration and increased odour

Changes in pumping station requirements due to sea-level rise

Higher receiving water levels leads to increased pumping requirements causing accelerated asset deterioration.

Pumping system failures due to Scada & telemetry/ electrical supply/ buildings/ security/ mobile plant damages

Higher temperatures cause increased vegetation growth at sites damaging equipments
Direct asset flooding cuts access to assets.
Direct flooding leads to submersion of electrical assets.
Saline intrusion degrades infrastructure causing accelerated asset deterioration

6.4.5 *Outfalls*

Changes in river flow pattern due to summer precipitation decrease

Lower river flows mean effluent is required to maintain river flows, reducing flexibility and increasing the risk of pollution incidents.

High risk of pollution events due to temperature (water and air) increase

Reduced oxygen saturation as water temperature increases, increasing the risk of pollution incident

Increased level of septicity leads to increased toxicity reducing receiving water quality and increasing odour.

Risk of pumping stations to stop due to power failure caused by severe weather events
Higher peak levels at the discharge change outfall hydraulics and back up pumps causing service failure.

Health and safety issues due to sea-level rise
Higher sea level affects dispersion characteristics leading to Health and Safety risk.

6.5 Stormwater system

6.5.1 Stormwater collection network

Flooding issues due to summer precipitation decrease
Lower precipitation leads to lower average and peak flows, resulting in greater deposits and more frequent blockages causing flooding.

Drainage systems surcharge issues and consequent urban flooding due to river floods during winter
Increased run off leading to flooding and surcharge related problems.

Increase of exfiltration from stormwater system due to system surcharge, caused by precipitation increased and sea level rise
More precipitation and more runoff will cause the stormwater network systems to run full and pressurize. The sea level rise will cause backflow of sewer water which will also pressurize the system (Vevatne *et al.*, 2007). Such stormwater pipes will have a pressure gradient which will cause sewer water to leak / exfiltrate from the system. The water will leak into the ground, the groundwater and to surrounding areas, rivers and waters.

6.5.2 Stormwater treatment

Treatment operation issues due to summer precipitation decrease
Lower average and peak carry flows lead to settlement in the system with shock loads affecting process regimes and causing accelerated asset deterioration and Health and Safety risk.

Lower average and peak carry flows reduce volumes received at WWTP and affects process regimes

Lower average and peak carry flows reduce wetting rates into process requiring minimum hydraulic loading rate (HLR) increasing the need for recirculation pumping.

Lower average and peak carry flows increases retention times in settlement tanks leading to increased septicity and odour problems

Treatment efficiency reduction due to temperature (water and air) increase
Higher rate of biological activity causes change to process efficiency

Lower summer precipitation and reduced freezing frequency lead to increased insect issues and create an environmental health risk.

Increased temperature leads to lower oxygen transfer efficiency in secondary process affecting process performance efficiency.

Treatment efficiency issues due to river flooding events during winter
Increased flushing effect leads to higher loads to be treated, affecting process performance efficiency and causing service failure

Longer retention of water in storm tanks leads to increased septicity and operational problems affecting process performance efficiency and increased odour.

6.5.3 *Pumping stations*

Asset deterioration accelaration due to summer precipitation decrease
Lower average and peak carry flows lead to settlement in the system affecting pumping regimes and causing accelerated asset deterioration.

River floods during winter may cause pumping station service failure
Increased volumes exceed pump capacity causing service failures.

Increased volumes requires increased pumping, causing accelerated asset deterioration.

Increase of pumping requirements due to sea-level rise
Higher receiving water levels lead to increased pumping requirements causing accelerated asset deterioration and increasing energy use.

Pumping system failures due to Scada & telemetry/ electrical supply/ buildings/ security/ mobile plant damages
Higher temperatures cause increased vegetation growth at sites damaging equipments
Direct asset flooding cuts access to assets.
Direct flooding leads to submersion of electrical assets.
Saline intrusion degrades infrastructure causing accelerated asset deterioration

6.5.4 *Storage structures*

Stormwater storage structures capacity issues due to intense precipitation and runoff increase
During heavy rain periods it is possible that the storage structures and detention ponds built within the stormwater system might go full. This is due to increased rain and runoff.

In such instances it will be important to build in spillways for the stormwater (i.e. overflows) to avoid flooding of surface ground, houses and infrastructure.

6.6 Receiving water body

Increase of risk of pollution due to changes in precipitation patterns
Higher storm intensity means CSO spill more frequently impacting on receiving water quality

Lower river flows mean effluent is required to maintain river flows, reducing flexibility and increasing the risk of pollution incidents.

Risk of pollution events due to temperature (water and air) increase
Reduced oxygen saturation as water temperature increases, increasing the risk of pollution incident

Increased level of septicity lead to increased toxicity reducing receiving water quality and increasing odour.

Increase of service failures due to river floods during winter
Increased flood incidence increases the risk of failure of spills per bathing season.

Increase of health and safety risks due to sea-level rise
Higher sea level affects dispersion characteristics leading to Health and Safety risk.

High rainfall and high tides affect CSO discharges reducing receiving water quality.

7 Expected effects of climate change in the cold-climate region

7.1 General

Cold climate regions will face overall more precipitation and larger variation in the precipitation patterns. This will result in periods of rain with high intensity which will cause flooding in the sewer network and in the drain water system. Basement flooding and flooding on urban surfaces will be more common.

Variable temperatures in the winter will cause rain to fall on frozen ground to increase the amount of runoff and facilitate flood problems in winter time.

General water quality of raw water will be worse due to increased rain and higher water temperature. Increased rain leads to more runoff which results in higher amount of NOM values in water and more presence of micro biological contamination of the drinking water. Drinking water treatment plants will therefore have to deal with rising problems in the raw water.

Due to warmer climate, new species will reside in the catchment of reservoirs and further increase the risk for micro biological contamination.

The analysis lists only the systems and subsystems for which climate effects are relevant or related studies have been considered in this report.

The effects of climate changes on the urban water systems located in the European Cold Climate zone are described in detail in the following sections and in the Appendix, Table 18 - Table 21 .

The analysis lists only the systems and subsystems for which climate effects are relevant or related studies have been considered in this report.

7.2 Catchment basin

7.2.1 Surface water catchment

Increase of flood events frequency due to changes in precipitation

The normal patterns which have been used to create curves to describe the link between intensity, duration and frequency of precipitation will change during the next decade. The intensity, duration and frequency will all increase. Heavy rains over a very short period of time which will create larger floods will be more normal. The change in pattern will also create higher run-off peaks in the catchment areas which will contribute to bigger flood problems (Alfnes and Førland, 2006; Benestad and Hanssen-Bauer, 2009; Holvik, 2010; Lindholm *et al.*, 2003; Mamen and Iden, 2010).

High intensity precipitation will constitute a larger fraction of the total precipitation, and low intensity precipitation will constitute a reduced fraction of the total precipitation (Gutowski *et al.*, 2007; Holvik, 2010).

Increase of runoff due to precipitation increase

Precipitations have increased and will increase more with the effect of increased runoff in the drainage area of the reservoirs. The runoff will increase in intensity (higher runoff peaks) and total amount of water. Heavier rain over longer periods of time will make the ground water aquifers more saturated and lead to further increase of the runoff.

In winter periods, the more frequent change between cold and mild periods will lead to multiple situations of rain on the top of ice and snow. Such instances increase the intensity of the peak run-off. The runoff will lead to flooding in the surrounding areas of the reservoir and will increase the problems with eutrophication, NOM and microbiological activity in the drinking water reservoirs.

Increase of runoff during winter due to snow (and glacier) melting increase

Higher air temperature will increase the melting of snow and glaciers with the effect of elevated runoff problems in winter periods. Runoff will happen on top of ice and snow which will increase the amount and intensity of the runoff. In winter months, the sewer network is less accessible due to snow and ice, making the amount of runoff on the surface very high. The infiltration potential is almost non-existent in winter (in cold climate) due to frozen grounds and will be another reason that runoff will increase. This can cause large floods in urban areas. The increased snow melt reduces the temperature of the sewer water so that cleaning efficiency in the treatment plants is reduced (Vevatne *et al.*, 2007).

Risk of contamination due to precipitation increase

With increased precipitation and runoff the probability of higher NOM values (Aaheim *et al.*, 2009), higher number of microorganisms in the water (Hunter, 2003; Vevatne *et al.*, 2007) and other problems related to contamination will increase. Restrictions as regards to settlements in catchment areas are by health authorities considered important to reduce risk of contamination (Vevatne *et al.*, 2007).

Water quality issues due to new species living in the catchment

New species (or more presence of existing species, such as beavers) will reside in the catchment areas of drinking water sources due to warmer climate and ice-free water during winter time (Zwolsman *et al.*, 2007). The warmer climate will result in shorter or no periods of frozen lakes and ponds and make the water more accessible during winter months for animals and birds. This means that both the animal and plant biodiversity will change (Vevatne *et al.*, 2007). The presence of more animals and more birds for a longer period of time in the catchment areas raise the risk for micro biological contamination of reservoirs (Hunter, 2003).

Larger march areas due to precipitation increase

More precipitation and wetter climate facilitate the formation and expansion of marches. March lands will therefore expand in areas where more precipitation is expected. Marchland is wet and makes it difficult for trees and animals to reside in. The biodiversity of such areas will change according to the changed living conditions for animals, insects, trees and plants (Zwolsman *et al.*, 2007).

7.2.2 *Groundwater catchment*

High risk of pollution and microbial activity due to precipitation increase

With increased precipitation and runoff and the presence of new species the probability of higher number of microorganisms in the catchment (Hunter, 2003; Vevatne *et al.*, 2007) and other problems related to contamination will increase. Restrictions as regards to settlements in catchment areas are by health authorities considered important to reduce risk of contamination (Vevatne *et al*., 2007). Floods may bring contamination into catchment areas of groundwater reservoirs (Hetzel, 2008).

High runoff peak due to changes in precipitation patterns

Rain patterns will change and create higher runoff peaks in the catchment areas which will contribute to less infiltration and more runoff. This is due to the infiltration capacity of the soil being exceeded during high intensity rain (Alfnes and Førland, 2006; Benestad and Hanssen-Bauer, 2009; Lindholm *et al.*, 2003; Mamen and Iden, 2010).

7.2.3 *Surface water reservoir*

High likelihood of microorganisms due to runoff increase

There's a higher likelihood of microorganisms in drinking waters due to increased runoff from the catchment areas (Vevatne *et al.*, 2007). Increased runoff results in the surface water containing more microorganisms from the ground and from faeces of birds and animals in the area (Hunter, 2003).

Climate change will lead to warmer weather and less ice on reservoirs so that animals and birds can reside for a longer period. These conditions will also attract new species which altogether will increase the micro biological strain in the catchment area and in the reservoir. The water sources will experience weakened barrier efficiency, larger contamination loads and worse raw water quality (Vevatne *et al.*, 2007). It is registered increased occurrence of salmonella during warm periods, which is expected to further increase (Aaheim, 2009).

Increase of evaporation due to air temperature increase

Evaporation of surface water will increase due to higher temperatures, (Nie *et al.*, 2009) but will not affect cold climate regions as much as other regions in Europe.

Maximum capacity of surface water reservoirs reached more often due to precipitation increase

More precipitation will lead to fuller surface and ground water reservoirs and may postpone the establishment of new water sources with 40-50 years (Vevatne *et al*., 2007). In some instances, when reservoirs become too full during heavy rain, it might cause flooding in surrounding areas, especially in reservoirs with large catchment areas.

High likelihood of NOM due to runoff increase

An increase in colour and total organic carbon (TOC) has been observed in surface waters in recent years (Nie *et al.*, 2009; Vevatne *et al.*, 2007). It is expected that these values will be even higher due to more runoff from drainage areas and increased water temperatures. It is observed that heavy rains can give a rapid increase in colour and TOC in surface waters (Vevatne *et al.* 2007). Colour and TOC gives a measure of natural organic matter (NOM) in the water. Increased NOM in drinking water reservoirs can give amplified taste and odour of the water. If it is not removed properly in the water treatment it will give a high risk for chlorination bi-products, it will reduce the effect of disinfection and it will increase the possibility for biofilm growth in the network (Vevatne *et al.*, 2007).

Reduced time of frozen cover and longer ice-free periods due to temperature increase
The warmer weather will postpone or eliminate the freezing of lakes. This will expand the circulation periods and result in shorter duration of stable layers in the reservoirs.(Nie *et al.*, 2009). Heavy winds during winter time will enhance the mixing of surface water in the deeper layers of lakes. This will reduce the effect of deep water intakes as a hygienic barrier (Tjomsland and Rohrlack, 2008; Vevatne *et al.*, 2007).

The longer ice-free periods will lead to increased access to light and algae flourishing, more birds in the area of reservoirs and increased over wintering of these birds. New species of animals will also reside in the reservoir areas during winter time due to accessibility of water (Vevatne *et al.*, 2007).

Longer circulation periods due to changes in freeze/ thaw periods
Delayed or lacking ice cover on lakes together with increased wind speeds can bring along longer circulation periods, and the whole winter can be a circulation period (Vevatne *et al.*, 2007). Large lakes may cool down much slower than rivers and result in longer periods when the rivers can dive down into the deep of the lakes resulting in circulation and mixing of surface waters containing particles in the deep water (Vevatne *et al.*, 2007). Tjomsland and Rohrlack (2008) have looked at the effects of rising temperatures in the surface water in Norwegian lakes. Rising temperatures lead to a changed pattern in the water circulation because the water reaches its highest density in other points in time than earlier.

Increase of the number of birds and new species may reside in the reservoir due to warm climate
The new climate is better suited for many types of animals and among them birds will expand their residence time in many reservoirs. The reservoirs will over a longer time be residence for more birds, and new species may settle in the area (Vevatne *et al.*, 2007). This will increase the risk of contamination from faeces. Temperatures will increase and decrease the length and degree of freezing periods making the surface waters available for birds over a longer period of time, even throughout the whole year in many northern areas. Seabirds like ducks and swans may use open lakes as wintering residue (Vevatne *et al.*, 2007).

Increase of circulation due to wind power increase
Heavier winds on the reservoir surfaces will lead to more circulation of the water and cause increased intermixture of surface water in deep water inlets (Vevatne *et al.*, 2007). The heavier winds will increase the circulation speed and reduce the extent and duration of stable layers in reservoirs (Vevatne *et al.* 2007). It will therefore lead to more contamination from the surface of the reservoirs being brought down to the bottom. Circulation will happen faster, more often and over a longer period of time. Normally there are stable conditions in the stratification of reservoirs in the winter months, but the

circulation in reservoirs will be extended to that period also. Because of this the effect of layers in the reservoirs as a hygienic barrier is reduced (Vevatne *et al.*, 2007).

Warmer water in summer periods due to air temperature increase
Warmer temperatures will lead to warmer water all year, but especially in summer months. At higher water temperatures the conditions are better suited for growth of blue-green algae, however, the higher colour, which will occur in the waters due to climate changes, will prevent the growth of blue-green algae (Aaheim, 2009). Warmer water will also facilitate microbiological growth in the reservoirs, including pathogens. Warmer water will also lead to increased oxygen demand in the deep, which can give increased problems with iron and manganese (Vevatne *et al.*, 2007). Positive effects of increased water temperatures are more stable stratification of reservoir layers and longer stagnation in summer months (Vevatne *et al.*, 2007).

7.2.4 *Groundwater reservoir*

High likelihood of microorganisms due to runoff increase
There is a higher likelihood of microorganisms in groundwater due to increased runoff from the catchment areas and higher presence of animals and birds (Hunter, 2003; Vevatne *et al.*, 2007).

Changes in groundwater table due to changes in precipitation patterns
Increased variability in rainfall may decrease groundwater recharge in humid areas because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff (Hetzel, 2008). In cold climate areas, which will normally experience more rain, but changed precipitation patterns, there is a probability that the groundwater table will be lower with less water available for extraction. However, this will depend on the overall rainfall through a year and due to increased precipitation some parts can probably experience higher groundwater tables.

Salinity problems in coastal areas due to sea level rise
Projected sea level rise and excessive groundwater extraction in coastal areas (in cold climate regions where groundwater is used for water supply) combine to increase the risk of salinity problems in water supplies (Hetzel, 2008).

Groundwater quality issues due to precipitation increase
Water quality is controlled by land surface characteristics, vegetation cover and soil properties, which may change due to climate changes (Hetzel, 2008). For example increased precipitation and wetter climate will facilitate the formation and expansion of marches, which will affect the water quality in such areas (Zwolsman *et al.*, 2007).

Limited water supply in times of disaster and emergencies due to lower groundwater table
A lowering of the groundwater table may make the groundwater wells dysfunctional or contaminated and will not be able to deliver water to the public in times of disasters or emergencies. Such wells may be contaminated by floods (Hetzel, 2008).

7.3 Drinking water system

7.3.1 *Abstraction system*

Increase of risk of contaminants and microorganisms in or near abstraction point of surface waters due to more circulation

Heavier winds on the reservoir surfaces will lead to more circulation of the water and cause increased intermixture of surface water in deep water inlets (Vevatne *et al.*, 2007). The heavier winds will increase the circulation speed and reduce the extent and duration of stable layers in reservoirs (Vevatne *et al.*, 2007). It will therefore lead to more contamination from the surface of the reservoirs being brought down to the bottom and to the inlets for drinking water. Because of this the effect of layers in the reservoirs as a hygienic barrier is reduced (Vevatne *et al.*, 2007).

Weaken hygienic barrier of deep water inlets due to longer circulation periods

Delayed or lacking ice cover on lakes together with increased wind speeds can bring along longer circulation periods and the whole winter can be a circulation period (Vevatne *et al.*, 2007). Large lakes may cool down much slower than rivers and result in longer periods of time when the rivers can dive down into the deep of the lakes resulting in circulation and mixing of surface waters in the deep water (Vevatne *et al.*, 2007). These rivers often contain large amounts of particles which will be transported to the lower layers of the lakes and possibly enter the drinking water inlets. Reduced stratification of the deep lakes will give a reduced benefit and effect of the deep water intake as a hygienic barrier (Vevatne *et al.*, 2007). More pollution will reach shallow and deep water intakes and increase the demand for better monitoring and optimised water treatment.

Increase of risk of contaminants and microorganisms in or near abstraction point of surface waters due to reduction of frozen cover and longer ice-free periods

The warmer weather will postpone or eliminate the freezing of lakes. This will expand the circulation periods and result in shorter duration of stable layers in the reservoirs (Vevatne *et al.*, 2007). Heavy winds during winter will enhance the mixing of polluted surface water in the deeper layers of lakes. This will reduce the effect of deep water intakes as a hygienic barrier (Tjomsland and Rohrlack, 2008; Vevatne *et al.*, 2007).

The longer ice-free periods will lead to increased access to light and algae flourishing, more birds in the area of reservoirs and increased over wintering of these birds. New species of animals will also reside in the reservoir areas during winter time due to accessibility of water (Vevatne *et al.*, 2007).

7.3.2 *Groundwater recharge*

High likelihood of microorganisms due to runoff increase

There's a higher likelihood of microorganisms in groundwater recharge sites due to increased runoff from the catchment areas and higher presence of animals and birds (Hunter, 2003; Vevatne *et al.*, 2007).

Changes in groundwater table due to changes in precipitation patterns

Increased variability in rainfall may decrease groundwater recharge in humid areas because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff. (Hetzel, 2008)

The rain available for recharge will be available in larger amounts and in shorter periods of time, which will make the groundwater table, decrease if the water is not detained in for example ponds. However, this will depend on the overall rainfall through a year and due to increased precipitation some parts can probably experience higher groundwater tables.

Salinity issues in coastal areas due to sea level rise
Projected sea level rise and excessive groundwater extraction in coastal areas (in cold climate regions where groundwater is used for water supply) combine to increase the risk of salinity problems in water supplies (Hetzel, 2008).

Groundwater quality issues due to precipitation increase
Water quality is controlled by land surface characteristics, vegetation cover and soil properties, which may change due to climate changes.(Hetzel, 2008). For example increased precipitation and wetter climate will facilitate the formation and expansion of marches, which will affect the water quality in such areas (Zwolsman *et al.*, 2007).

7.3.3 Water treatment

Worse raw water quality due to catchment runoff increase
There will be a generally and overall worse raw water quality of surface and ground water due to climate changes (Albert, 2008; Aaheim *et al.*, 2009). The raw water in reservoirs will be negatively affected by increased runoff in drainage area, increased water temperatures, diminished stratification layers in reservoirs, less ice cover, overload of wastewater systems, increased leaks of sewer pipes, increased presence of birds and animals and the inclusion of new species in catchment areas and on reservoirs (Hunter, 2003; Vevatne *et al.*, 2007). The raw water quality will be worse in terms of lower oxygen saturation, increased supply of nutrient salts, more algae, more NOM, more micro biological activity, increased oxygen demand, more toxins and problems with odour and taste and increased risk of saltwater intrusion and contamination due to sea level rise (Aaheim *et al.*, 2009; Albert, 2008; Hunter, 2003; Vevatne *et al.*, 2007).

Treatment operation issues due to large (seasonal) variation of raw water quality
Because of climate change drinking water treatment plants will have to be adaptable to changes in raw water quality. Extreme events, like flooding, will instantly affect the drinking water supply (Slavik and Uhl, 2009). Water bodies' quality is subjected to weather seasonality, which results in large seasonal variations in raw water quality (Delpla *et al.*, 2009).

Variations in the raw water quality makes it difficult for operators of treatment plants to predict the need for dose of chemicals etc. and it may be difficult to get a stable and good, clean water quality.

High likelihood of NOM due to runoff increase
A strong increase of colour in drinking water resources have been registered during the later years, as can be seen in Figure 19. Increased rain and runoff and higher water temperatures will lead to higher colour, organic carbon and ultimately NOM values in the raw waters (Vevatne *et al.*, 2007).

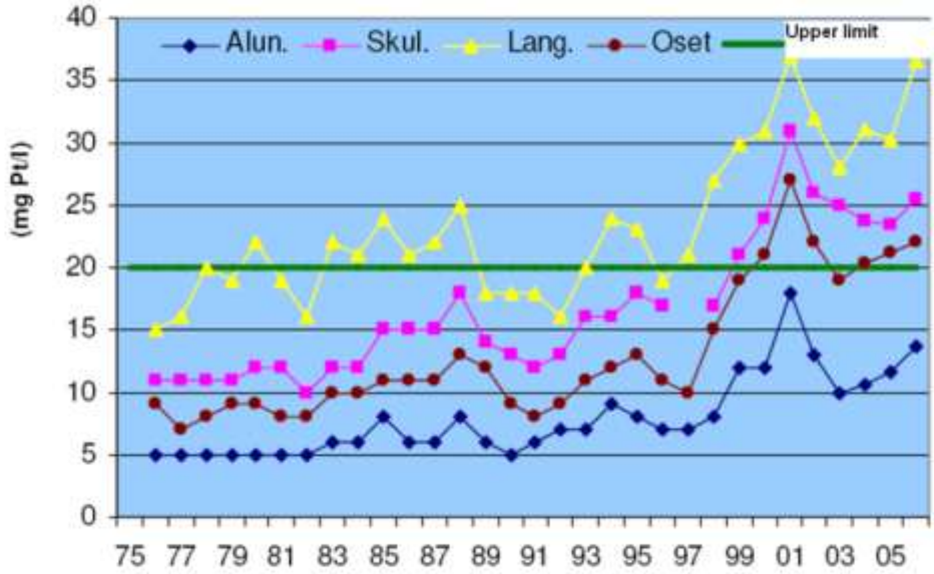


Figure 19 - NOM increase in the water sources of Oslo from 1974-2007. Annual mean based on monthly measurements. (Wold, 2010)

Increase of microorganisms in raw water, including parasites, due to precipitation and temperature increase

More precipitation, more runoff and higher temperatures will result in more micro biological activity in the drinking water reservoirs. The treatment plants will have to deal with more microorganisms in the water, including parasites (Aaheim *et al.*, 2009; Hunter, 2003; Vevatne *et al.*, 2007) due to more precipitation, more runoff, hotter climate, more presence of animals and birds, diminished stratification layers, less ice cover, more wind and more and longer circulation of reservoirs.

High amounts of algae and environmental toxins in raw water due to warmer climate

Higher amounts of algae and algal toxins are expected in surface water reservoirs due to warmer climate, more precipitation, more runoff, more nutrients and more strain on the wastewater system (Aaheim *et al.*, 2009; Albert, 2008; Hunter, 2003). Higher water temperatures and increased amounts of nutrient will boost the growth of algae in reservoirs (Albert, 2008; Hunter, 2003; Maier and Dandy, 1997; Jacoby *et al.*, 2000; Saker and Griffiths, 2001). Problems associated with algae blooming are taste and odour and algal toxins (Albert, 2008).

Need for improved groundwater treatment

Like for surface water, there will in some instances be a need for improved and extended treatment of ground water due to the changed conditions for groundwater caused by climate change. In many places, groundwater wells are already contaminated , unprotected or close to becoming dysfunctional due to a lowering of the groundwater table close to or below the bottom of the well or due to low and poor maintenance (Hetzel *et al.*, 2008).

Extended use of chemical due to NOM, algae, etc. increase

Increased colour and NOM values in raw water means that there will be increased coagulant doses, increased sludge production and reduced length of filter cycles in the water treatment, which can be seen in Figure 20 and Figure 21.

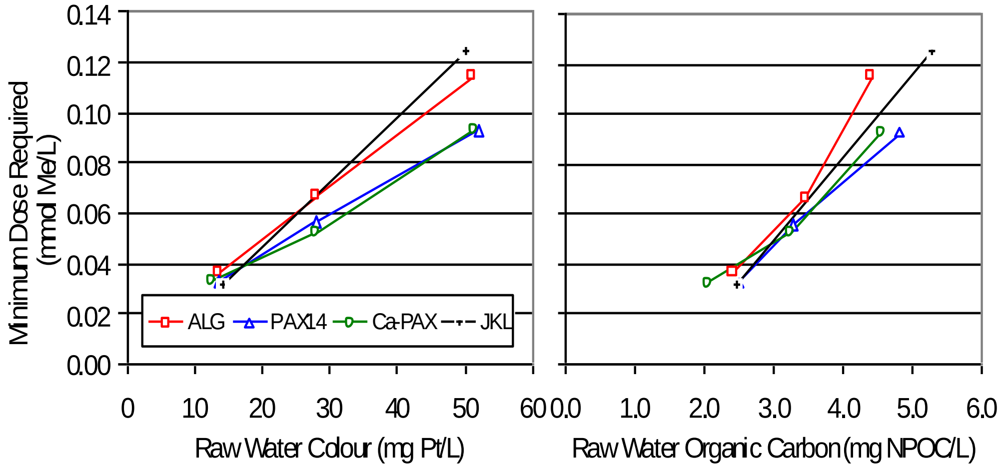


Figure 20 - Increasing need of coagulant dose with increasing raw water colour (Eikebrokk, 2000)

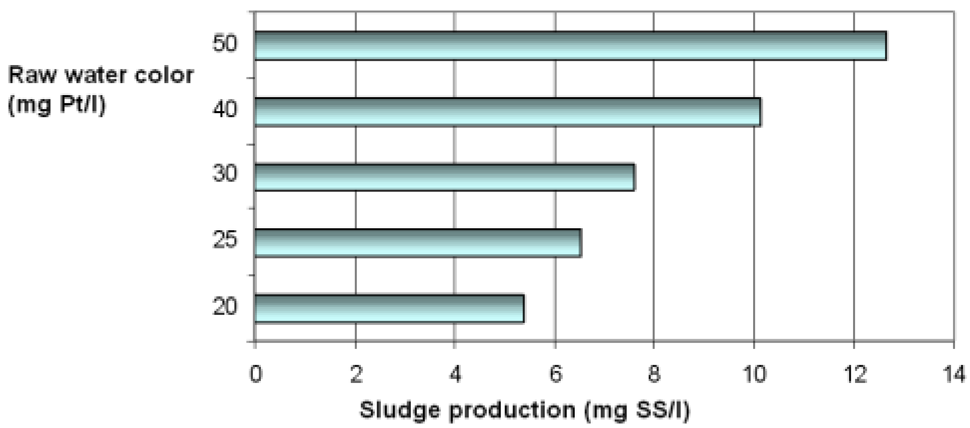


Figure 21 - Sludge production versus raw water colour (Eikebrokk, 2006)

7.3.4 *Transmission*

Increase of risk of infiltration of contaminated water into water supply systems due to high groundwater table

In some countries where water and sewer pipe is in the same ditch, the risk is higher for contamination from sewer due to generally higher flow in sewer pipes. Also, more rain will in some places raise the ground water table and increase the risk for ingress into water pipes. Risk of ingress is especially high during reparations of water pipes or other incidents when pressure might be reduced (like leaks) (Bruaset, 2008).

Increase of risk of biological growth in pipes due to higher NOM levels in water

If treatment plants are not able to cope with the high NOM levels in the raw water, this will be transferred into the transport and distribution system. The NOM will work as food and facilitator for biological growth in the bulk flow of water and in biofilm media on the pipe walls. In the pipe network it will be a cause for extended growth problems (Vevatne *et al.*, 2007). Increased water temperature in the pipes in the summer months can also contribute to a higher level growth of microorganisms in the network. High water temperatures will facilitate bacteria growth (Bruaset, 2008;Hunter, 2003).

Increase of risk of pipe failure due to landslides

An increased number of large precipitation events in steep terrain indicate increased risk of landslides (Holvik, 2010). Incidents have occurred where heavy rainfall resulted in landslide with casualties (Roald, 2008¨).

Such incidents may cause water pipes to break and fail and cause leakages.

Increase of external corrosion due to higher groundwater table

Differential aeration cell corrosion occurs when the supply of oxygen at the surface of the pipe varies. Such conditions can occur when a pipe is in the level of the groundwater or is passing through the groundwater table (Sægrov, 2007).

Due to increased rain and increased runoff and infiltration, the ground water table will in some places be higher. This will cause the drinking water and sewer pipes to more frequent be in contact with the ground water table which will facilitate external corrosion problems. It is also probable that pipes will have increased break rates due to external corrosion caused by increasing acidity in ground (Vevatne *et al.*, 2007).

Increase of probability of pipe failure (pipe burst) due to more often freeze/ thaw cycles

More frequent freeze/thaw cycles will be a cause for greater strain on the pipes in ground and might increase the pipe breakage rate (Vevatne *et al.*, 2007). The municipality of Oslo, Norway has registered that an increased frequency of freezing/thaw cycles, with belonging movements in the ground (during bare ground with no snow), can lead to increase break rates on water pipes in certain problem areas (Vevatne *et al.*, 2007).

7.3.5 Storage

Storage capacity exceedance due to increase in precipitation

Water tanks for storage are kept in the water distribution system to balance the daily and hourly consumption of water, for emergency water use and for extra water during fire-extinguishing. The changed precipitation patterns due to climate change have impacted the at all time available water resources. Changed precipitation patterns will cause alot of rain to fall in short periods of time, while there will be longer periods without rain (Holvik, 2010). Such conditions put a higher importance on being able to store enough water for the periods of drought, when there will be no rain. In these periods, alot of municipalities will have to rely on available stored water for water supply.

7.3.6 Pumping stations

High risk of pumping stations to stop due to power failure caused by severe weather events

Extreme weather increases the risk for power failure, which will affect the serviceability of pumping stations. The risk for pumping stations stopping is therefore higher (Vevatne *et al.*, 2007). The risk for power failure often coincides with times when the amount of water is high, so a failure to run pumping stations at those times will result in large amounts of sewer discharge via CSO.

7.3.7 *Distribution*

Increase of risk of infiltration of contaminated water into water supply systems due to high groundwater table

In some countries where water and sewer pipe is in the same ditch, the risk is higher for contamination from sewer due to generally higher flow in sewer pipes. Also, more rain will in some places raise the groundwater table to raise the risk for ingress into water pipes. Risk of ingress is especially high during reparations of water pipes or other incidents when pressure might be reduced (like leaks) (Bruaset, 2008).

Increase of risk of biological growth in pipes due to higher NOM levels in water

If treatment plants are not able to cope with the high NOM levels in the raw water, this will be transferred into the transport and distribution system. The NOM will work as food and facilitator for biological growth in the bulk flow of water and in biofilm media on the pipe walls. In the pipe network it will be a cause for extended growth problems (Vevatne *et al.*, 2007). Increased water temperature in the pipes in the summer months can also contribute to a higher level growth of microorganisms in the network. High water temperatures will facilitate bacteria growth (Bruaset, 2008; Hunter, 2003).

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7.4 Wastewater system

7.4.1 *Wastewater collection network*

Low lying sewer systems along the shoreline issues due to sea-level rise

The future sea level is expected to rise in cold climate regions. A rising sea level will result in backwater situations in the sewer system leading to basement flooding and damages on buildings and infrastructure (Vevatne *et* *al.*, 2007). Low lying CSO in the network will take in sea water which will fill the sewer pipes and then cause basement flooding. Many CSO in the shoreline today are vulnerable for backflow of sea water and will cause backwater in the network.

Increase of leakage from sewer network due to precipitation increase and sea- level rise and consequent surcharge of combined sewer network

More precipitation and more runoff will cause the combined sewer network systems to run full and pressurize. The sea level rise will cause backflow of sewer water, which will also pressurize the system. (Vevatne *et al.*, 2007). Such sewer pipes will have a pressure gradient, which will cause sewer water to leak/exfiltrate from the system. The sewer will leak into the ground, the groundwater and to surrounding areas, rivers and waters.

Limited hydraulic capacity due to more frequent and intense rainfall events and alternating temperatures in winter months

More rain, more runoff and more melting of snow all results in more water in the sewer system and on the surface. Frequent changes in winter between periods of frost and mild temperatures lead to heavy rain falling on frozen ground when there is no way for surface water to infiltrate the ground. All the rainwater will then run off the ground and many times surpass the amount of water in which the sewer network is designed for (Vevatne *et al.*, 2007). Most of the existing sewer systems are not capable of handling these amounts of water. The capacity problems will lead to flooding events in urban areas, which will damage building basements, warehouses and infrastructure (Vevatne *et al.*, 2007).

Increase of probability of urban flooding from combined sewer networks due to heavy precipitation events

Higher intensity precipitation and more snowmelt in winter combined with increased population density in cities increase the risk for flooding in urban areas (Vevatne *et al.*, 2007). High intensity rainfalls will fall on impervious city surfaces whereas little of the water infiltrate into the ground. The water will flow on the surface which will cause large runoff peaks in which the sewer network cannot handle (Vevatne *et al.*, 2007). Such situations can cause flooding in urban areas. Increased precipitation and changes between cold and mild weather can lead to more often and greater damage from floods to basements, warehouses, infrastructure and other buildings.

Increase of pollution on urban surface due to flooding in combined sewer systems

Combined sewer networks will experience lack of hydraulic capacity resulting in backflow and urban surface flooding (Vevatne *et al.*, 2007). Urban surfaces will therefore also experience more contamination from sewage, including Phosphorous, Nitrogen and microorganisms.

Increased amounts of wastewater due to more precipitation and more unfavourable runoff conditions will also give increased frequency and longer periods with overflow from combined sewer networks which will contribute to pollution of urban surfaces and water courses (Vevatne *et al.*, 2007). Studies indicate that the overflow discharges might more than double until the middle of the century unless measures are taken against it (Madsen, 2007; Semadeni-Davies *et al.*, 2006; Vevatne *et al.*, 2007).

Increase of probability of basement flooding due to limited sewer system capacity
The increased amount of water in the combined sewer systems raises the probability for sewer blockages, backflow of water and succeeding basement flooding (Vevatne *et al.*, 2007). Heavy rain events may bring small stones, gravel, branches and other undesirable elements into the wastewater system, which can lead to blockages (Vevatne *et al.*, 2007). Separating sewer and storm water in existing combined sewerage systems has led to a reduction in number of basement flooding (Vevatne et al., 2007). Increased precipitation and changes between cold and mild weather in winter months can also lead to basement flooding due to capacity problems in the wastewater network.

Increase of probability of pipe failure (pipe burst) due to more often freeze/ thaw cycles
More frequent freeze/thaw cycles will be a cause for greater strain on the pipes in ground and might increase the pipe breakage rate (Vevatne *et al.*., 2007). The municipality of Oslo, Norway has registered that an increased frequency of freezing/thaw cycles, with belonging movements in the ground (during bare ground with no snow), can lead to increase break rates on pipes in certain problem areas.(Vevatne *et al.*, 2007).

Increase of risk of pipe failure due to landslides
An increased number of large precipitation events in steep terrain indicate increased risk of landslides (Holvik, 2010). Incidents have occurred where heavy rainfall resulted in landslide with several casualties (Roald, 2008). Such incidents may cause pipes to break and fail and cause leakages.

7.4.2 *Interceptor system*

Backflow issues in low lying sewer systems along the shoreline due to sea level rise
The future sea level is expected to rise in cold climate regions (Holvik, 2010). The rising sea level will result in backwater situations in the sewer system leading to basement flooding and damages on buildings and infrastructure (Vevatne *et al.*, 2007). Low lying CSO in the network will take in sea water which will fill the sewer pipes and then cause basement flooding. Many CSO in the shoreline today are vulnerable for backflow of sea water and will cause backwater in the network.

Increase of pollution on urban surface due to flooding in combined sewer systems
Combined sewer networks will experience lack of hydraulic capacity resulting in backflow and urban surface flooding (Vevatne *et al.*, 2007). Urban surfaces will therefore also experience more contamination from sewage, including Phosphorous, Nitrogen and microorganisms.

Increased amounts of wastewater due to more precipitation and more unfavourable runoff conditions will also give increased frequency and longer periods with overflow from combined sewer networks, which will contribute to pollution of urban surfaces and water courses (Vevatne *et al.*, 2007). Studies from Helsingborg and Bergen indicate that the overflow discharges might more than double until the middle of the century unless measures are taken against it (Madsen, 2007; Semadeni-Davies *et al.*, 2006; Vevatne *et al.*, 2007).

Increase of probability of pipe failure (pipe burst) due to more often freeze/ thaw cycles
More frequent freeze/thaw cycles will be a cause for greater strain on the pipes in ground and might increase the pipe breakage rate (Vevatne *et al.*,

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An increased number of large precipitation events in steep terrain indicate increased risk of landslides (Holvik, 2010). Incidents have occurred where heavy rainfall resulted in landslide with several casualties (Roald, 2008).

Such incidents may cause pipes to break and fail and cause leakages.

7.4.3 *Wastewater treatment*

Reduction of hydraulic detention time in treatment plant due to wastewater treatment plant inflow increase

Increased inflow sewage volume to the WWTP can lead to reduced hydraulic detention time in treatment (Vevatne *et al.*, 2007). This can result in more direct discharge to receiving water body if inflow exceeds WWTP capacity, or in reduced hydraulic detention time in treatment plant. Reduced detention time means that treatment efficiency is reduced and the quality of treated wastewater is diminished.

Increase of chemicals use due to wastewater treatment plant inflow increase

In chemical wastewater treatment, the use of chemicals must be adjusted according to the amount of sewer water. The increased amounts of wastewater will lead to more use of chemicals.

Reduction of treatment efficiency due to sewer water temperature decrease during winter months

The temperature of sewer water decreases in winter months due to more melting of snow. Plósz and Ratnaweera (2007) (cited in Vevatne *et al.*, 2007) compared data from Bekkelaget wastewater treatment plant in Oslo with metrological data and found that the temperature of sewer water got colder in winter months due to more snow melting. The colder water leads to reduced efficiency of the wastewater treatment due to processes going slower.

7.4.4 *Combined sewer overflows*

More frequent operation of combined sewer overflows due to precipitation and runoff increase

Increased rainfall intensity and unfavourable runoff conditions (large city impervious areas) will be the cause of more frequent and longer periods of operation of Combines Sewer Overflows (CSO) in combined systems. For CSO there is a strong non-linear relationship between increase of precipitation intensity and discharge quantities (Vevatne *et al.*, 2007). If no measures are taken against this, some studies indicate that discharges from CSO might double during the next 50 years (Madsen, 2007; Semadeni-Davies *et al.*, 2006).

More frequent operation of combined sewer overflows due to snow melting increase (during winter)

Frequent changes in winter between periods of frost and mild temperatures lead to heavy rain falling on frozen ground when there is no way for surface water to infiltrate the ground. In addition, melted snow will contribute to extended amounts of water on the ground. All the water will run off the ground and many times surpass the amount of water in which the sewer network is dimensioned for (Vevatne *et al.*, 2007). Most of the existing sewer systems are not capable of handling these amounts of water, which will result in more operation of CSO and large amounts of water being discharged to surrounding areas and water courses.

Pumping stations and discharge issues due to sea-level rise
The future sea level is expected to rise in cold climate regions. A rising sea level will lead to seawater coming into pump sumps. This will result in increased energy costs for pumping seawater and increased costs for treating the seawater in treatment plant. It will also cause increased operation of overflow when the pump sump is full of seawater.

7.4.5 Pumping stations

Pumping stations and discharge issues due to sea-level rise
The future sea level is expected to rise in cold climate regions. A rising sea level will lead to seawater coming into pump sumps. This will result in increased energy costs for pumping seawater and increased costs for treating the seawater in treatment plant. It will also cause increased operation of overflow when the pump sump is full of seawater to contaminate and pollute the recipient even further.

Increase of energy costs associated with pumping larger wastewater volumes
The increased precipitation and runoff will lead to more storm water in combined sewer networks. Sea level rise and more snow melting in winter months will contribute to more amounts of water in the sewer system (Nie *et al.*, 2009 ; Holvik, 2010; Vevatne *et al.*, 2007). Heavier rain can make the ground more saturated with the effect of a higher ground water table (Hetzel *et al.*, 2008). This will make it possible for water to infiltrate from the ground water into the sewer pipes. All these factors contribute to more water in the network and increased costs for pumping of wastewater.

High risk of pumping stations to stop due to power failure caused by severe weather events
Extreme weather increases the risk for power failure, which will affect the serviceability of pumping stations. The risk for pumping stations stopping is therefore higher (Vevatne *et al.*, 2007). The risk for power failure often coincides with times when amount of water is highest, so a failure to run pumping stations at those times will result in large amounts of sewer discharge via CSO.

7.4.6 Storage structures

Storage capacity exceedance due to increase in precipitation
Changed precipitation patterns will lead to large amounts of water over short periods of time, which will result in a lot of storage capacity in the sewer network being exceeded.

7.4.7 *Infiltration systems*

Infiltration delay due to longer frost periods during winter

Frequent changes in winter between periods of frost and mild temperatures lead to heavy rain falling on frozen ground when there is no way for surface water to infiltrate the ground. In addition, melted snow will contribute to extended amounts of water on the ground. All the water will then run off the ground and many times surpass the amount of water in which the sewer network is dimensioned for (Vevatne *et al.*, 2007).

Infiltration capacity exceedance due to high soil moisture content caused by precipitation increase

Increased variability in rainfall may decrease infiltration capacity in humid areas because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff (Hetzel, 2008).

7.4.8 *Outfalls*

Overflow discharges into surface water due to sea-level rise

If the outfall pipe also leads stormwater, it is usually large variation in the water flow and overflows are often used. With elevated sea levels there will be more discharge of water through overflows due to elevated water level in the discharge manholes/overflows.

7.5 Stormwater system

7.5.1 *Stormwater collection network*

Increase of pluvial flood events frequency due to high intensity precipitation events and alternating temperatures in winter months

More rain, more runoff and more melting of snow all results in more water in the stormwater system and on the surface. Frequent changes in winter between periods of frost and mild temperatures lead to heavy rain falling on frozen ground when there is no way for surface water to infiltrate the ground. All the rainwater will then run off the ground (Vevatne *et al.*, 2007) and enter the storm water systems. The total amount of surface water can lead to capacity problems and flooding of urban surfaces, infrastructure and houses.

Increase of probability of pipe failure (pipe burst) due to more often freeze/ thaw cycles

More frequent freeze/thaw cycles will be a cause for greater strain on the pipes in ground and might increase the pipe breakage rate (Vevatne *et al.*, 2007). The municipality of Oslo, Norway has registered that an increased frequency of freezing/thaw cycles, with belonging movements in the ground (during bare ground with no snow), can lead to increased break rates on pipes in certain problem areas (Vevatne *et al.*, 2007)

Increase of risk of pipe failure due to landslides

An increased number of large precipitation events in steep terrain indicate increased risk of landslides. Incidents have occurred where heavy rainfall resulted in landslide with several casualties (Roald, 2008). Such incidents may cause pipes to break and fail and cause leakages.

Increase of exfiltration from stormwater system due to system surcharge, caused by precipitation increase

More precipitation and more runoff will cause the stormwater network systems to run full and pressurize. The sea level rise will cause backflow of sewer water, which will also pressurize the system (Vevatne *et al.*, 2007). Such stormwater pipes will have a pressure gradient which will cause stormwater to leak/exfiltrate from the system. The water will leak into the ground, the groundwater and to surrounding areas, rivers and waters.

7.5.2 Infiltration systems

Infiltration delay due to longer frost periods during winter

Frequent changes in winter between periods of frost and mild temperatures lead to heavy rain falling on frozen ground when there is no way for surface water to infiltrate the ground. In addition, melted snow will contribute to extended amounts of water on the ground. All the water will then run off the ground and many times surpass the amount of water in which the sewer network is designed for (Vevatne *et al.*, 2007).

Infiltration capacity exceedance due to high soil moisture content caused by precipitation increase

Increased variability in rainfall may decrease infiltration capacity in humid areas because more frequent heavy rain will result in the infiltration capacity of the soil being exceeded, thereby increasing surface runoff (Hetzel, 2008).

7.5.3 Stormwater treatment

Reduction of hydraulic detention time in treatment plant due totreatment plant inflow increase

Storm water is treated on-site or in wastewater treatment plants. Both the mechanical treatment on-site and the treatment in treatment plants are dependent upon hydraulic detention time since most of the pollution is attached to particles (Thorolfsson, 2007). Increased runoff during heavy rains, when the pollution of surface water is highest, leads to decreased detention time in ponds, which again diminishes the cleaning efficiency.

7.5.4 Stormwater overflows

More frequent operation of combined sewer overflows due to precipitation and runoff increase

Increased rainfall intensity and unfavourable runoff conditions (large city impervious areas) will be the cause of more frequent and longer periods of operation of overflows in stormwater systems.

More frequent operation of combined sewer overflows due to snow melting increase (during winter)

Frequent changes in winter between periods of frost and mild temperatures lead to heavy rain falling on frozen ground when there is no way for surface water to infiltrate the ground. In addition, melted snow will contribute to extended amounts of water on the ground and result in more operation of CSO.

7.5.5 *Pumping stations*

Increase of energy costs due to pumping more
The increased precipitation and snow melt in winter time will lead to more storm water in storm water networks (Nie *et al*., 2009 ; Holvik, 2010; Vevatne *et al*., 2007) which contribute to increased costs for pumping of water where pumping is necessary.

High risk of pumping stations to stop due to power failure caused by severe weather events
Extreme weather increases the risk for power failure, which will affect the serviceability of pumping stations. The risk for pumping stations stopping is therefore higher (Vevatne *et al*., 2007). The risk for power failure often coincides with times when amount of water is highest, so a failure to run pumping stations at those times can result in flooding of the urban surfaces.

7.5.6 *Storage structures*

Stormwater storage structures capacity issues due to intense precipitation and runoff increase
During heavy rain periods it is possible that the storage structures and detention ponds built within the stormwater system might go full. This is due to increased rain and runoff.

7.6 Receiving water body

Increase of direct discharges from wastewater treatment plants due to inflow increase
Increased inflow sewage volume to the WWTP can lead to reduced hydraulic detention time in treatment (Vevatne *et al*., 2007) and more direct discharge to receiving water body if inflow exceeds WWTP capacity. Reduced hydraulic detention time in wastewater treatment plants will also reduce the treatment efficiency and deteriorate the quality of treated water. These aspects contribute so that recipients will be polluted.

More frequent operation of combined sewer overflows due to precipitation and runoff increase
Increased rainfall intensity and unfavourable runoff conditions (large city impervious areas) will be the cause of more frequent and longer periods of operation of Combined Sewer Overflows (CSO) in combined systems. This will affect the recipients.

More frequent operation of combined sewer overflows due to snow melting increase (during winter)
Frequent changes in winter between periods of frost and mild temperatures lead to heavy rain falling and melted snow on frozen ground when there is no way for surface water to infiltrate the ground. All the water will then run off the ground and many times surpass the amount of water in which the sewer network is designed for (Vevatne *et al*., 2007). This will result in more operation of CSO and large amounts of water being discharged to recipients.

Increase of pollution from surface water runoff
More precipitation will lead to more runoff of surface water. The surface waters will include more contamination from the ground, which will enter the recipients. The increased contamination in surface water includes environmental toxins like heavy metals, PAH, PCB, dioxins etc.

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8 APPENDIX

Table 2 - Expected effects of climate Change in the 'Mediterranean' Region – Catchment Basin

Expected effects of climate Change in the 'Mediterranean' Region			Catchment basin			
			surface water catchemt	Groundwater Catchment	Surface Water reservoir	Groundwater reservoir
Climate variables	Climate change factors	Climate impacts				
TEMPERATURE						
INCREASE	Air temperature increase		Projected water scarcity and more frequent extreme events. Increased evaporation of surface water. New species in catchment.	Projected water scarcity and more frequent extreme events. Increased evaporation of surface water. New species in catchment.		
	Increase of temperature amplitude					
		Increase of water temperature			Water quality issues like increased growth of blue-green algae and micro organisms	
RAIN						
INCREASE	Increase frequency of intense precipitation events		Less infiltration, more water scarcity	Less infiltration, more water scarcity	Water quality contamination from increased discharge from CSO	Water scarcity. Increased ground water level variation. Ground settlements affecting water and wastewater infrastructure.
DECREASE	Decrease in summer precipitation		Water scarcity. Decreasing ground water table	Water scarcity. Decreasing ground water table		Water scaricty
	Decrease in annual precipitation		Water scarcity. Decreasing ground water table	Water scarcity. Decreasing ground water table		Water scaricty. Ground settlements affecting water and wastewater infrastructure.
		Droughts	Water scarcity. Decreasing ground water table. Increase of soil erosion. Can create flood problems and reduced infiltration.	Water scarcity. Decreasing ground water table. Increase of soil erosion. Can create flood problems and reduced infiltration.	Increased amount of total suspended solids in water due to increased soil erosion,.	

Table 3 - Expected effects of climate Change in the 'Mediterranean' Region – Drinking water system

Expected effects of climate Change in the 'Mediterranean' Region			Drinking water system							
			abstraction system	GW recharge	Water treatment	Transmission	Storage	Pumping stations	Distribution	Plumbing system
Climate variables	Climate change factors	Climate impacts								
TEMPERATURE										
	Air temperature increase		New species. Water scarcity.	Projected water scarcity and more frequent extreme events. Increased evaporation of surface water. New species in catchment.	Water quality problems, worse raw water quality. Increased micro bioligical presence	Increased biological growth in biofilms and in suspended water	Increased biological growth in biofilms and in suspended water		Increased biological growth in biofilms and in suspended water	Increased biological growth
INCREASE	Increase of temperature amplitude									
		Increase of water temperature		Water quality issues like increased growth of blue-green algae and micro organisms	Increased chlorine demand	Increased chlorine demand. Increased micro biological growth	Increased micro biological growth		Increased micro biological growth	
RAIN										
	Increase in Winter precipitation				Water quality problems, worse raw water quality. Increased micro bioligical presence					
	Increase of winter storms							Risk of pumping stations stopping due to power failure caused by extreme weather events.		
INCREASE	Increase frequency of intense precipitation events		Water scarcity	Less infiltration, more water scarcity. Water quality contamination from increased discharge from CSO	Water quality problems, worse raw water quality. Increased micro bioligical presence. More algae and algae toxins. Water treatment issues due to sudden			Risk of pumping stations stopping due to power failure caused by extreme weather events.		

Expected effects of climate Change in the 'Mediterranean' Region			Drinking water system							
			abstraction system	GW recharge	Water treatment	Transmission	Storage	Pumping stations	Distribution	Plumbing system
Climate variables	Climate change factors	Climate impacts								
					variations in raw water quality.					
		Increase of frequency of river floods, especially during winter						Risk of pumping stations stopping due to power failure caused by extreme weather events.		
	Decrease in summer precipitation		Water scarcity	Water scarcity. Decreasing ground water table						
DECREASE	Decrease in annual precipitation		Water scarcity	Water scarcity. Decreasing ground water table		Ground settlements can effect transmission	Ground settlements can effect tanks		Ground settlements can effect pipes	
		Droughts	Water scarcity. Increased amount of suspended solids in the water due to increased soil erosion.	Water scarcity. Decreasing ground water table. Increase of soil erosion. Can create flood problems and reduced infiltration.	Increased amount of total suspended solids in water due to increased soil erosion,.					

Table 4 Expected effects of climate Change in the 'Mediterranean' Region – Wastewater system

Expected effects of climate Change in the 'Mediterranean' Region			Wastewater system (WW)					
			WW collection Network	Interceptor system	WW treatment	CSO	pumping station	Infiltration systems
Climate variables	Climate change factors	Climate impacts						
TEMPERATURE								
	Air temperature increase							
INCREASE	Increase of temperature amplitude							
		Increase of water temperature	Increased odour and corrosion problems.	Increased odour and corrosion problems.	Increased biological activity			
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)						
		Sea level rise	Backflow of sea water	Backflow of sea water		Backflow of sea water		
RAIN								
	Increase in Winter precipitation				Reduced hydraulic detention time resulting in reduced treatment efficiency.			
	Increase of winter storms						Higher risk of stopping due to power failure	
INCREASE	Increase frequency of intense precipitation events		Limited hydraulic capacity. Increased probability of urban flooding. Increased pollution on urban surfaces.	Increased probability of urban flooding. Increased pollution on urban surfaces.	Reduced hydraulic detention time resulting in reduced treatment efficiency.	More frequent operation of CSO		
	Decrease in summer precipitation		Increased odour and corrosion problems.	Increased odour and corrosion problems.				Higher infiltration rate
DECREASE	Decrease in annual precipitation		Increased odour and corrosion problems.	Increased odour and corrosion problems.				Higher infiltration rate

Table 5 Expected effects of climate Change in the 'Mediterranean' Region – Stormwater systems

Expected effects of climate Change in the 'Mediterranean' Region			Stormwater systems (SW)					
			SW collection system	Infiltration systems	SW treatment	SW overflows	Pumping stations	Storage structures
Climate variables	Climate change factors	Climate impacts						
TEMPERATURE								
INCREASE	Air temperature increase							
	Increase of temperature amplitude							
RAIN								
INCREASE	Increase in Winter precipitation							
	Increase of winter storms							
	Increase frequency of intense precipitation events							
DECREASE	Decrease in summer precipitation			Higher infiltration rate				
	Decrease in annual precipitation							
		Decrease in river flow		Higher infiltration rate				
		Droughts	Sedimentation problems caused by increased amount of suspended solids in the water due to increased soil erosion.					

Table 6 Expected effects of climate Change in the ' Mediterranean ' Region – Receiving water bodies

Expected effects of climate Change in the 'Mediterranean' Region			
Climate variables	Climate change factors	Climate impacts	Receiving water body
TEMPERATURE			
INCREASE	Air temperature increase		
	Increase of temperature amplitude		
		Increase of water temperature	Water quality issues like increased growth of blue-green algae and micro organisms
RAIN			
INCREASE	Increase frequency of intense precipitation events		Water quality contamination from increased discharge from CSO
DECREASE		Droughts	Increased amount of total suspended solids in water due to increased soil erosion,.

Table 7 - Expected effects of climate Change in the 'Atlantic' Region – Catchment Basin

Expected effects of climate Change in the 'Atlantic' Region			Catchment basin			
			surface water catchemt	Groundwater Catchment	Surface Water reservoir	Groundwater reservoir
Climate variables	Climate change factors	Climate impacts				
TEMPERATURE						
INCREASE	Air temperature increase				Higher likelihood of micro organisms. Increased evaporation.	
	Increase of temperature amplitude					
		Sea temperature increase				
		Decrease in Arctic sea ice coverage				
		Increase of water temperature			Higher likelihood of micro organisms. Growth of blue-green algae. Cyanotoxins from the algae.	
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)				
		Sea level rise				
RAIN						
INCREASE	Increase in Winter precipitation		Increased runoff and flooding. Raw water contamination. Wet climate facilitates expansion of marches resulting in water quality changes. Expected pollution events from direct discharge from WWTP and CSO.	Increased runoff and flooding. Raw water contamination. Wet climate facilitates expansion of marches resulting in water quality changes. Expected pollution events from direct discharge from WWTP and CSO.	More nutrients, microorganisms and NOM in water. Raw water contamination, more presence of animals. Expected pollution events from direct discharge from WWTP and CSO. Possible flooding of reservoirs.	
	Increase frequency of intense precipitation events		Increased runoff and flooding. Raw water contamination. Wet climate facilitates expansion of marches resulting in water quality changes. Expected pollution events from direct discharge from WWTP and CSO.	Increased runoff and flooding. Raw water contamination. Wet climate facilitates expansion of marches resulting in water quality changes. Expected pollution events from direct discharge from WWTP and CSO.	More nutrients, microorganisms and NOM in water. Raw water contamination, more presence of animals. Expected pollution events from direct discharge from WWTP and CSO. Possible flooding of reservoirs.	Will affect the level of groundwater table., it will increase or decrease depndent on local conditions. If ground water table increases it might reduce soil infiltration and cause more flooding on the surface.

Table 8 - Expected effects of climate Change in the 'Atlantic' Region – Drinking water system

Expected effects of climate Change in the 'Atlantic' Region			Drinking water system						
			abstraction system	GW recharge	Water treatment	Transmission	Storage	Distribution	Plumbing system
Climate variables	Climate change factors	Climate impacts							
TEMPERATURE									
INCREASE	Air temperature increase				Higher risk of microorganisms. More blue- green algae and toxins	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.
		Increase of water temperature			Higher risk of microorganisms. More blue- green algae and toxins	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.	Increased growth of biological growth due to increased NOM levels. Increased chlorine demand.
RAIN									
INCREASE	Increase in Winter precipitation		Raw water contamination. Higher risk of micro organisms in the water.		Higher risk of microorganisms				
	Increase frequency of intense precipitation events		Raw water contamination. Higher risk of micro organisms in the water.		Higher risk of microorganisms. More blue- green algae and toxins	Increased risk of infiltration if ground water rises. Increased growth of biological growth due to increased NOM levels.	Increased risk of infiltration if ground water rises. Increased growth of biological growth due to increased NOM levels.	Increased risk of infiltration if ground water rises. Increased growth of biological growth due to increased NOM levels.	Increased risk of infiltration if ground water rises. Increased growth of biological growth due to increased NOM levels.

Table 9 Expected effects of climate Change in the 'Atlantic' Region – Wastewater system

Expected effects of climate Change in the 'Atlantic' Region			Wastewater system (WW)					
			WW collection Network	Interceptor system	WW treatment	CSO	pumping station	Infiltration systems
Climate variables	Climate change factors	Climate impacts						
TEMPERATURE								
INCREASE	Air temperature increase							
	Increase of temperature amplitude							
		Sea temperature increase						
		Sea level rise	Backflow of sea water	Backflow of sea water			Backflow of sea water.	
RAIN								
INCREASE	Increase in Winter precipitation		Limited hydraulic capacity. Increased probability of urban flooding. Increased pollution on urban surfaces. Increased probability of basement flooding in houses.		Capacity problems and reduced treatment efficiency. Increased use of chemicals.	More operation of CSO	Increase of discharge through CSO	Reduction of infiltration rate due to high level of soil moisture
	Increase of winter storms						Power shutdown may lead to stop of pumping station and discharge via CSO.	
	Increase frequency of intense precipitation events		Limited hydraulic capacity. Increased probability of urban flooding. Increased pollution on urban surfaces. Increased probability of basement flooding in houses.		Capacity problems and reduced treatment efficiency. Increased use of chemicals.	More operation of CSO	Increase of discharge through CSO	Reduction of infiltration rate due to high level of soil moisture

Table 10 Expected effects of climate Change in the 'Atlantic' Region – Stormwater systems

Expected effects of climate Change in the 'Atlantic' Region			Stormwater systems (SW)		
			SW collection system	Infiltration systems	Storage structures
Climate variables	Climate change factors	Climate impacts			
TEMPERATURE					
INCREASE	Air temperature increase				
	Increase of temperature amplitude				
		Sea temperature increase			
		Decrease in Arctic sea ice coverage			
		Increase of water temperature			
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)			
		Sea level rise	Hydraulic capacity can be exceeded.		
RAIN					
	Increase in Winter precipitation		Hydraulic capacity can be exceeded.	Reduction of infiltration rate due to high level of soil moisture	Capacity can be exceeded, so there is need for larger volume of storage.
INCREASE	Increase frequency of intense precipitation events		Hydraulic capacity can be exceeded.	Reduction of infiltration rate due to high level of soil moisture	Capacity can be exceeded, so there is need for larger volume of storage.

Table 11 Expected effects of climate Change in the 'Atlantic' Region – Receiving water bodies

Expected effects of climate Change in the 'Atlantic' Region			
Climate variables	Climate change factors	Climate impacts	Receiving water body
RAIN			
	Increase in Winter precipitation		More nutrients, microorganisms and NOM in water. Raw water contamination. Expected pollution events from direct discharge from WWTP and CSO. Possible flooding.
INCREASE	Increase frequency of intense precipitation events		More nutrients, microorganisms and NOM in water. Raw water contamination. Expected pollution events from direct discharge from WWTP and CSO. Possible flooding.

Table 12 - Expected effects of climate Change in the 'Continental' Region – Catchemtn Basin

Expected effects of climate Change in the 'Continental' Region			Catchment basin			
			surface water catchment	Groundwater Catchment	Surface Water reservoir	Groundwater reservoir
Climate variables	Climate change factors	Climate impacts				
TEMPERATURE						
INCREASE	Air temperature increase		Projected water scarcity and more frequent extreme events. New species will reside in catchment.	Projected water scarcity and more frequent extreme events. New species will reside in catchment.	Reduced surface water reservoir capacity	Iincreased evaporation and reduced amount of infiltration. Increased demand on groundwater resources.
	Increase of temperature amplitude					reduced yield of surface reservoirs and increased demand on groundwater recharge
		Sea temperature increase				
		Decrease in Arctic sea ice coverage				
		Increase of water temperature				
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)				
		Sea level rise		increases the risk of of saline intrusion to coastal aquifers		Increased risk of saline intrusion in coastal areas
RAIN						
INCREASE	Increase in Winter precipitation		More winter floods. Expansion of marches.	More winter floods	Possible raw water pollution and contamination. More NOM (and micro organisms in raw water.	Increased runoff and reduced amount of infiltration.
	Increase of winter storms		More winter floods	More winter floods		
	Increase frequency of intense precipitation events		Less infiltration, more floods	Less infiltration, more floods		Less infiltration. Ground water table will drop.
		Increase of Coastal flooding				Higher risk of intrusion of saline water along coast
		Increase in river flows	More Flooding			More recharge from rivers
		Increase of frequency of river floods, especially during winter	More winter floods		Increased risk of contamination	Increased risk of contamination
DECREASE	Decrease in summer precipitation		Decreasing ground water table	Decreasing ground water table	Reduced security of water supply.	
	Decrease in annual precipitation		Decreasing ground water table	Decreasing ground water table		
		Decrease in river flow			Increases demand on existing storage and causes reduction in security of supply. Reduces ground water table.	Increases flow from groundwater to river. Decreases groundwater table.
		Droughts			Reduces ground water table. Projected water scarcity.	Reduces ground water table. Projected water scarcity. May lead to pollution of groundwater wells.

Table 13 - Expected effects of climate Change in the 'Continental' Region – Drinking water system

Expected effects of climate Change in the 'Continental' Region			Drinking water system						
			abstraction system	GW recharge	Water treatment	Transmission	Storage	Pumping stations	Distribution
Climate variables	Climate change factors	Climate impacts							
TEMPERATURE									
INCREASE	Air temperature increase			Influences the length of the recharge period and water availability	Impacts treatment efficiency and processes	May increase micro-biological and biofilm growth	Reduced security of supply		Increased rate of contaminant growth. May damage pumping station equipment. Increased biofilm growth.
	Increase of temperature amplitude								
		Sea temperature increase							
		Decrease in Arctic sea ice coverage							
		Increase of water temperature			Impacts treatment efficiency and processes				
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)							
		Sea level rise			Higher risk of saline intrusion and need of improved groundwater treatment				Saline intrusion degrades infrastructure causing accelerated asset deterioration
RAIN									
INCREASE	Increase in Winter precipitation		Increased risk of drinking water contamination. Increased asset deterioration due to increased pumping.						May damage pumping station equipment. Increased asset deterioration.
	Increase of winter storms		Increased risk of drinking water contamination					Increased risk of power failure and stopping of pumps	
	Increase frequency of intense precipitation events			Influences the length of the recharge period and water availability					
		Increase of Coastal flooding							
		Increase in river flows							
		Increase of frequency of river floods, especially during winter			Greater sediment level in raw waters and risk of worse raw water quality	May influence water quality	May reduce water quality		May reduce water quality
DECREASE	Decrease in summer precipitation		Reduced raw water quality	Influences the length of the recharge period and water availability	Risk of service failure and contamination		May increase risk of contamination		May induce service failure of the network pumping stations
	Decrease in annual precipitation		Reduced raw water quality		Risk of service failure and contamination				

Table 14 Expected effects of climate Change in the 'Continental' Region – Wastewater system

Expected effects of climate Change in the 'Continental' Region			Wastewater system (WW)				
			WW collection Network	WW treatment	CSO	pumping station	outfalls
Climate variables	Climate change factors	Climate impacts					
TEMPERATURE							
INCREASE	Air temperature increase		Increased level of septicity cause accelerated asset deterioration and increased problems with odour	May reduce treatment efficiency		Affects pumping station performance. Causes damages to pumping station assets.	
	Increase of temperature amplitude						
		Sea temperature increase					
		Decrease in Arctic sea ice coverage					
		Increase of water temperature					
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)					
		Sea level rise	May impact environmental health risk. Increased leakage from sewer network due to backflow of sea water.	Increases salinity of sewage water	More backflow of sea water through CSO and more discharge from CSO	Increased pumping requirements. Saline intrusion degrades infrastructure causing accelerated asset deterioration	
RAIN							
INCREASE	Increase in Winter precipitation		Increased leakage from sewer network			Causes damages to pumping station assets.	
	Increase of winter storms					Increased risk of power failure and stopping of pumps	
	Increase frequency of intense precipitation events		Increases the probability of flooding from combined sewer networks		May influence water quality thorugh more frequent discharge from CSO		Higher peak levels at the discharge change outfall hydraulics and may cause service failure of back up pumps
		Increase of Coastal flooding					
		Increase in river flows					
		Increase of frequency of river floods, especially during winter	Increases the probability of flooding from combined sewer networks		May influence water quality through more frequent discharge from CSO	Increased risk of power failure and stopping of pumps	
DECREASE	Decrease in summer precipitation						
	Decrease in annual precipitation						

Table 15 Expected effects of climate Change in the 'Continental' Region – Stormwater systems

Expected effects of climate Change in the 'Continental' Region			Stormwater systems (SW)			
			SW collection system	SW treatment	Pumping stations	Storage structures
Climate variables	Climate change factors	Climate impacts				
TEMPERATURE						
INCREASE	Air temperature increase			May affect efficiency of processes. Higher rate of biological activity causes change to process efficiency	Causes damages to pumping station assets.	
	Increase of temperature amplitude					
		Sea temperature increase				
		Decrease in Arctic sea ice coverage				
		Increase of water temperature				
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)				
		Sea level rise	Increased leakage from storm water network due to backflow of sea water		Increased pumping requirements. Saline intrusion degrades infrastructure causing accelerated asset deterioration	
RAIN						
INCREASE	Increase in Winter precipitation		Increased leakage from storm water network		Causes damages to pumping station assets and may cause service failure	Storage capacity can be exceeded
	Increase of winter storms					
	Increase frequency of intense precipitation events				May cause service failure	Storage capacity can be exceeded
		Increase of Coastal flooding				
		Increase in river flows				
		Increase of frequency of river floods, especially during winter	May lead to surcharging problems and urban flooding	May affect efficiency of processes. Increased flushing effect leads to higher loads to be treated, affecting process performance efficiency and causing service failure	May cause service failure	Storage capacity can be exceeded
DECREASE	Decrease in summer precipitation		Lower precipitation lead to lower average and peak flows, resulting in greater deposits and more frequent blockages causing flooding.	Will affect treatment processes	May accelerate asset deterioration	

Table 16 Expected effects of climate Change in the 'Continental' Region – Receiving water bodies

Expected effects of climate Change in the 'Continental' Region			Receiving water body
Climate variables	Climate change factors	Climate impacts	
TEMPERATURE			
INCREASE	Air temperature increase		May increase risk of pollution
	Increase of temperature amplitude		
		Sea temperature increase	
		Decrease in Arctic sea ice coverage	
		Increase of water temperature	
		Decrease of snow, lake and river ice cover (including loss of Iceland ice sheet)	
		Sea level rise	Higher sea level affects dispersion characteristics leading to Health and Safety risk. High rainfall and high tides affect CSO discharges, thus reducing the receiving water quality.
RAIN			
INCREASE	Increase in Winter precipitation		May increase risk of pollution
	Increase of winter storms		
	Increase frequency of intense precipitation events		May increase risk of pollution
		Increase of Coastal flooding	
		Increase in river flows	
		Increase of frequency of river floods, especially during winter	May cause service failures
DECREASE	Decrease in summer precipitation		May increase risk of pollution
	Decrease in annual precipitation		May increase risk of pollution

Table 17 - Expected effects of climate Change in the 'Cold Climate' Region – Catchemtn Basin

Expected effects of climate Change in the 'Cold Climate' Region			Catchment basin			
			surface water catchemt	Groundwater Catchment	Surface Water reservoir	Groundwater reservoir
Climate variables	Climate change factors	Climate impacts				
TEMPERATURE						
INCREASE	Air temperature increase		Higher intensity rainfalls and more winter runoff. New species will reside in area.	Higher intensity rainfalls and more winter runoff. New species will reside in area.	Increased evaporation. More blue-green algae.	
	Increase of temperature amplitude		More winter runoff			
		Sea temperature increase				
		Decrease in Arctic sea ice coverage				
		Increase of water temperature	Higher presence of animals and new species.			
		Decrease of snow, lake and river ice cover (increased ice and snow melt)	Higher presence of animals and new species.		More circulation. Presence of new species.Higher presence of animals	
		Sea level rise		Increased risk of saline intrusion in coastal aquifers		Increased risk of saline intrusion in coastal areas
RAIN						
INCREASE	Increase in Winter precipitation		Increased runoff, flood problems. Increased NOM values. Higher risk of contamination. Expansion of marches.	Increased runoff, flood problems. Increased NOM values. Higher risk of contamination. Expansion of marches.	Higher risk of contamination. More water in reservoirs. Higher NOM values.	Higher risk of contamination. More water in reservoirs. Higher NOM values.
	Increase of winter storms				Risk of flooding. Higher risk of contamination.	
	Increase frequency of intense precipitation events		Increased runoff during periods of heavy rain, flood problems. Increased NOM values. Higher risk of contamination. Expansion of marches.	Increased runoff during periods of heavy rain, flood problems. Increased NOM values. Higher risk of contamination. Expansion of marches.	Higher risk of contamination. More water in reservoirs. Higher NOM values.	Higher risk of contamination. Higher groundwater table. (Higher NOM values)
		Increase of Coastal flooding				Higher risk of saline intrusion in coastal areas.
		Increase in river flows	Increased risk of flooding areas.	Increased risk of flooding areas.	Increased risk of contamination. Increased risk of contamination.	Increased recharge from rivers. Increased risk of contamination.
		Increase of frequency of river floods, especially during winter	Increased risk of flooding areas.	Increased risk of flooding areas.	Increased risk of contamination. Increased risk of contamination.	Increased recharge from rivers. Increased risk of contamination.
DECREASE	Decrease in summer precipitation					
	Decrease in annual precipitation					
		Decrease in river flow				Less recharge from rivers during times of drought
		Droughts			Due to changed precipitation patterns, there can be times of drought leading to water scarcity and higher risk of drinking water contamination and pollution	Due to changed precipitation patterns, there can be times of drought leading to water scarcity and higher risk of drinking water contamination and pollution

Table 18 - Expected effects of climate Change in the 'Cold Climate' Region – Drinking water system

Expected effects of climate Change in the 'Cold Climate' Region			Drinking water system						
			abstraction system	GW recharge	Water treatment	Transmission	Storage	Pumping stations	Distribution
Climate variables	Climate change factors	Climate impacts							
TEMPERATURE									
INCREASE	Air temperature increase								
	Increase of temperature amplitude					Increased risk of pipe failure due to increased frequency of freeze/thaw cycles.			Increased risk of pipe failure due to increased frequency of freeze/thaw cycles.
		Sea temperature increase							
		Decrease in Arctic sea ice coverage							
		Increase of water temperature			More algae and more algae toxins.				
		Decrease of snow, lake and river ice cover (increased ice and snow melt)	Higher risk of contamination. Weakened barrier efficiency of deep water inlets due to more cicrulation.						
		Sea level rise							
RAIN									
INCREASE	Increase in Winter precipitation								
	Increase of winter storms							Higher risk of power failure and stopping of pumps	
	Increase frequency of intense precipitation events			Higher risk of contamination. Higher NOM values.	Worse raw water quality. Higher NOM values. More micro organisms. More algae and algae toxins.	Increased risk of infiltration and contamination. Increased biofilm growth. Increased risk of pipe failure and external corrosion.	Periods of water scarcity.	Increased risk of power failure	Increased risk of infiltration and contamination. Increased biofilm growth. Increased risk of pipe failure and external corrosion.
		Increase of Coastal flooding							
		Increase in river flows							
		Increase of frequency of river floods, especially during winter		Higher risk of contamination. Higher NOM values.	Worse raw water quality. Higher NOM values. More micro organisms. More algae and algae toxins.	Increased risk of contamination and pollution of drinking water		Increased risk of power failure	Increased risk of contamination and pollution of drinking water
DECREASE	Decrease in summer precipitation	Droughts	Higher risk of contamination	May lead to periods of drought and water scarcity. Higher risk of drinking water contamination and pollution			Increased demand on storage during times of water scarcity		

Table 19 Expected effects of climate Change in the 'Cold Climate' Region – Wastewater system

Expected effects of climate Change in the 'Cold Climate' Region			Wastewater system (WW)						
			WW collection Network	Interceptor system	WW treatment	CSO	pumping station	storage structures	Infiltration systems
Climate variables	Climate change factors	Climate impacts							
TEMPERATURE									
INCREASE	Air temperature increase								
	Increase of temperature amplitude		Increased risk of pipe failure due to increased frequency of freeze/thaw cycles.	Increased risk of pipe failure due to increased frequency of freeze/thaw cycles.					Decreased infiltration capacity in winter time with increased runoff.
		Sea temperature increase							
		Decrease in Arctic sea ice coverage							
		Increase of water temperature							
		Decrease of snow, lake and river ice cover (increased ice and snow melt)			Decreased treatment efficiency due to lower water temperature.	Increased operation of CSO's in winter time.			
		Sea level rise	Increase of sea water backflow.	Increase of sea water backflow.		Backflow into overflow and increased overflow discharge.	Increased overflow discharge		
RAIN									
INCREASE	Increase in Winter precipitation		Increased leakage from network. Under capacity (hydraulic) in network. Increased risk of flooding urban areas and basement flooding. Increased pollution on urban surfaces. Increased risk of pipe failure.	Higher risk for under capacity. Increased risk of pollution on urban surfaces and in recipients. Increased risk of pipe failure.	Reduced treatment efficiency. Increased use of chemicals.	Increased overflow discharge.	Increased energy costs due to more pumping. Increased risk of power failure. Asset deterioration	Risk of under capacity	Decreased soil infiltration.
	Increase of winter storms						Higher risk of power failure and stopping of pumps		
	Increase frequency of intense precipitation events		Increased leakage from network. Under capacity (hydraulic) in network. Increased risk of flooding urban areas and basement flooding. Increased pollution on urban surfaces. Increased risk of pipe failure.	Higher risk for under capacity. Increased risk of pollution on urban surfaces and in recipients. Increased risk of pipe failure.	Reduced treatment efficiency. Increased use of chemicals.	Increased overflow discharge.	Increased energy costs due to more pumping. Increased risk of power failure. Asset deterioration	Risk of under capacity	Decreased soil infiltration.
		Increase of Coastal flooding	Increased risk of flooding urban areas. Increased risk of pipe failure.	Increased risk of pipe failure.	Reduced treatment efficiency.	Increased overflow discharge. Possibility of backflow of sea water into WW system.	Increased costs for pumping of sea water.		
		Increase in river flows	Increased risk of flooding urban areas. Increased risk of pipe failure.			Increased overflow discharge. Possibility of backflow of sea water into WW	Increased costs for pumping due to increased amounts of surface water.		

						system.			
		Increase of frequency of river floods, especially during winter	Increased risk of flooding urban areas. Increased risk of pipe failure.	Increased risk of flooding urban areas. Increased risk of pipe failure.	Reduced treatment efficiency.	Increased overflow discharge. Possibility of backflow of water into WW system.	Increased costs for pumping of surface water. Asset deterioration.	Risk of under capacity during river floods	Decreased soil infiltration.

Table 20 Expected effects of climate Change in the 'Cold Climate' Region – Stormwater systems

Expected effects of climate Change in the 'Cold Climate' Region			Stormwater systems (SW)					
			SW collection system	Infiltration systems	SW treatment	SW overflows	Pumping stations	Storage structures
Climate variables	Climate change factors	Climate impacts						
TEMPERATURE								
	Air temperature increase							
	Increase of temperature amplitude		Increased risk of pipe failure due to increased frequency of freeze/thaw cycles.	Limited possibilities for infiltration.				
INCREASE		Sea temperature increase						
		Decrease in Arctic sea ice coverage						
		Increase of water temperature						
		Decrease of snow, lake and river ice cover (increased ice and snow melt)						
		Sea level rise						
RAIN								
INCREASE	Increase in Winter precipitation		Risk of under capacity. Increased risk of pipe failure. Increased probability of urban flooding.	Decreased infiltration capacity of soil.	Reduced efficiency of treatment.	More overflow discharge		Increased risk of flooding
	Increase of winter storms							
	Increase frequency of intense precipitation events		Risk of under capacity. Increased risk of pipe failure. Increased probability of urban flooding.	Decreased infiltration capacity of soil.	Reduced efficiency of treatment.	More overflow discharge	Increased risk of power failure and stopping of pumps	Increased risk of flooding
		Increase of Coastal flooding						Increased risk of flooding

		Increase in river flows	Risk of under capacity. Increased risk of pipe failure. Increased probability of urban flooding.			More overflow discharge		Increased risk of flooding
		Increase of frequency of river floods, especially during winter	Risk of under capacity. Increased risk of pipe failure. Increased probability of urban flooding.	Decreased infiltration capacity of soil.	Reduced efficiency of treatment.	More overflow discharge	Increased risk of power failure and stopping of pumps	Increased risk of flooding during storm events

Table 21 Expected effects of climate Change in the 'Cold Climate' Region – Receiving water bodies

Expected effects of climate Change in the 'Cold Climate' Region			Receiving water body
Climate variables	Climate change factors	Climate impacts	
TEMPERATURE			
INCREASE	Air temperature increase		
	Increase of temperature amplitude		
		Sea temperature increase	
		Decrease in Arctic sea ice coverage	
		Increase of water temperature	
		Decrease of snow, lake and river ice cover (increased ice and snow melt)	Increased pollution from CSO's
		Sea level rise	
RAIN			
INCREASE	Increase in Winter precipitation		Increased pollution. Increased discharge from overflows. More pollution from surface water runoff.
	Increase of winter storms		
	Increase frequency of intense precipitation events		Increased pollution. Increased discharge from overflows. More pollution from surface water runoff.
		Increase of Coastal flooding	
		Increase in river flows	
		Increase of frequency of river floods, especially during winter	Increased pollution. Increased discharge from overflows. More pollution from surface water runoff.
		Droughts	