Literature review on the potential Climate change effects on drinking water resources across the EU and the identification of priorities among different types of drinking water supplies

Annexes of the final report - ADWICE project

European Commission DG Environment
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Annex 1 – Drivers of climate change

1.1 Effects of CC on precipitation regime – regional examples

1.1.1 Decreased precipitation, especially in summer

Continental land

According to a study of the International Commission for the Protection of the Rhine, no considerable change is to be noted in summer precipitation in the entire Rhine river basin, until 2050 (compared to 1961-1990). The evaluations result in slightly differing findings for tributaries. For example, along the Moselle, a trend towards less summer precipitation is projected in 2050 and would reach -10 to -30% by 2100 (compared to 1961-1990) (ICPR, 2011).

According to the Austrian adaptation strategy to climate change, in Austria, the average summer precipitations will rather decrease in 2021-2050 (compared to 1976-2007) but a greater change is expected only after 2050. Small-scale changes in precipitation are also expected, but the current results are unreliable and contradictory. The average snow precipitation and snow cover duration will go on decreasing in 2021-2050 (compared to 1976 - 2007). This variation is strongly dependent on the sea level, not linear and presents large regional differences (BMLFUW et al., 2011).

In the Czech Republic, a hydrological model, used as part of the development of the national programme to tackle CC impacts (CC programme), predicts a decrease in average river flow rates of 15 to 40 % due to the effects of CC (15-20% under an optimistic scenario and 25-40% under a pessimistic scenario). Similar decreases are predicted with regard to minimum river flow rates and minimum groundwater outflow. This will lead to lower amounts of drinking water in reservoirs (up to 50% less water). The main driver is the increase in temperatures in winter, due to smaller amounts of snow and higher evaporation levels in spring and autumn. According to the CC programme, large groundwater stocks and man-made reservoirs are less exposed to the impacts of CC.

In Hungary, the forecasted change in precipitation does not show a uniform tendency between models; it is small and in most cases not significant (see Table 1) (Hungarian 5th National Communication to the UNFCCC, 2009). Even the direction of the change is uncertain as the intervals contain values equal to zero. For example, the annual change is expected to be between -40.8 mm and +2.4 mm in 2011-2040 compared to 1961-1990. Therefore, a slight drought effect

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is expected. Seasonal and annual interval values are minimal and maximal values expected. The width of the interval, i.e. the uncertainty, is minimal in autumn and maximal in winter.

### Table 1: Expected precipitation change for Hungary for the period 2021-2040

<table>
<thead>
<tr>
<th></th>
<th>Annual (mm)</th>
<th>Spring (mm)</th>
<th>Summer (mm)</th>
<th>Autumn (mm)</th>
<th>Winter (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average precipitation change</td>
<td>-40.8 / +2.4</td>
<td>-15.9 / +6.0</td>
<td>-15.0 / +3.0</td>
<td>-4.8 / +5.1</td>
<td>-22.8 / +10.8</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>43.2</td>
<td>21.9</td>
<td>18.0</td>
<td>9.9</td>
<td>33.6</td>
</tr>
</tbody>
</table>

### Northern Europe

In Latvia, a decrease in precipitations, especially in autumn, is forecasted when running the RCAO RCM (Rossby Centre Atmosphere Ocean Regional Climate Model) against IPCC scenarios; this decrease is estimated at 4-5% according to A2 and 2-3.5% according to B2 (Apsite et al., 2010).

### North Western Europe

For the Meuse river basin, a literature review shows that the expected summer precipitation is time scale dependent. The number of wet days will decrease, but the summer precipitation will decrease less significantly, remain constant or increase, depending on the study. Boukhris et al. (2007b) presents perturbation factors of 0.84, 0.98 and 1.09 respectively for the low, mean and high scenario, but only for the day, week and month time scales. The seasonally perturbation factors are 0.77 (low), 0.86 (mean) and 0.95 (high). This means less rainy days, but if it rains, it will be heavier than in the past. Similar results are obtained by the KNMI. The seasonally average precipitation amounts changes with -19% to +5.5%, the wet day frequency in summer changes with -1.6% to -19.3% and the precipitation on a wet day in summer changes with +0.1% to +9.1% (AMICE Project, 2010).

According to the French national adaptation strategy, optimistic and pessimistic scenarios show a decreasing trend in spring and summer precipitation. This decrease, significant only at the end of the century for the scenario B2 (rather optimistic), is earlier and of greater amplitude with the A2 scenario (rather pessimistic) with around -10% in 2050 and around -30% in 2090 for the summer season. The South West of France would be the region most affected by this reduction. (ONERC, 2011)

In the Seine river basin, the project GiCC - RExHySS had scattered results in terms of precipitation. All scenarios agree on a decrease in summer and autumn precipitation. However, the results are contrasted for winter and spring precipitations, some scenarios indicating an increase and other a decrease. In terms of annual precipitation, this leads to changes from +0.4% to -14% in 2050 (compared to 2011) and +4% to -24% in 2100 (compared to 2011). This decrease
in precipitation is irregular over the period 1960-2100 and is always accompanied by strong annual variations. (Agence de l'eau Seine Normandie et al., 2011)

**Mediterranean region**

In Spain, modelling exercises estimated a decrease in the water input in natural regime between 5 and 14% in 2030, considering a temperature increase of +1°C and an average decrease of precipitations by around 5%. In 2060, considering +2.5°C and a 8% decrease in precipitations, it was estimated that the water input would decrease by 17% (OECC - UCLM, 2005).

**Islands**

Islands face a number of specific challenges including their dependence on the availability, timing and amount of precipitation (Lange & Donta, 2005). For instance, a decrease in precipitation will impact on the availability of water resources in the Maltese Islands (Malta Resources Authority, 2010).

### 1.1.2 Increased precipitation, mostly in winter

**Continental land**

In the Rhine river basin, moderate increases in winter precipitation are projected in 2050, between 0 % and + 15%. Thus, the trends of changing precipitation established for the 20th century remain. The increase in precipitation during the winter months projected until 2100 for the entire Rhine mostly ranges between + 5% to + 20 %. It lies above the values pointed out for the near future. (ICPR, 2011)

In Austria, over the period 2021-2050 compared with 1976-2007, the average winter precipitation will rather increase, particularly north of the Alps. A greater change in precipitation is only expected after 2050. Small-scale changes in precipitation are also expected. The current model results are unreliable and contradictory (BMLFUW et al., 2011).

In Luxembourg, climate change will induce regional variations in precipitation from 0 to +25% in 2050 during the winter season compared to the period 1960-1990. Experts predict a likely increase in the frequency of natural phenomena such as intense rainfall and floods. The research conducted by the International Commission for the Protection of the Rhine (ICPR) also predicted these variations in the frequency and amounts of precipitation (AGE, 2011).

In Slovenia, according to Janža (2010), climate projections show an increase of the precipitation amount by 6% in 2011-2040, by 4% in 2041-2070 and by 2% in 2071-2100 compared to 1965-2005.

**Northern Europe**

According to the ASTRA project focusing on the Baltic Sea Region, climate change is already observable (Hilpert et al., 2007). For large areas in Sweden, Finland, Estonia, and the Gulf of Gdansk, an increase in the annual precipitation of approximately 10-50 mm was observed during

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* ASTRA project: ‘Developing Policies & Adaptation Strategies to Climate Change in the Baltic Sea Region’ (http://www.astra-project.org)
the 20th century. For Lithuania, eastern Germany, and western Poland, it became slightly dryer during this period. The projections show that this trend is likely to continue, implying a further increase in the annual precipitations in the Baltic Sea region (Figure 1).

**Figure 1:** Projections for the annual sum of precipitation from different models based on the SRES A2 forcing scenario (left: CSIRO2, middle: HadCM3, right: PCM)

The above maps display differences between 2100 and 2000. Blue colours mean a wetter, red a dryer climate in 2100. The average sum of annual precipitations (land/sea) is approximately 750 mm/yr, but with large differences.

Seasonally and spatially, these changes are very unevenly distributed across the Baltic Sea Region (Hilpert et al., 2007). While in winter an increase in precipitation of approximately 35% might be possible, in particular in the north, the summer will become dryer than today in the southern Baltic Sea region and only slightly wetter in the north. An example for such a scenario is shown in Figure 2. Although, overall, it will become wetter, in some years the water availability might be limited in certain regions due to higher temperatures and a higher rate of evapotranspiration. The spatial differences will also influence the run-off regimes.

**Figure 2:** Seasonal changes in precipitation between 2000 and 2100. Left: winter season (December to February); right: summer season (June to August), SRES A2 scenario, HadCM3

According to the Estonian Environment Information Centre (2003), all GCMs predict an annual increase in rainfall in 2100 in Estonia. This increase varies between 5-30%, with most cases ranging between 10-20%. Monthly changes in precipitation amounts range from -20% to +50% according to different models. In general, it is predicted that, during the cold half, the increase in precipitation is around +10-50% compared with the period from June to September during which precipitation is expected to change from -10% to +20%. According to Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), during the period 1961-2004, precipitation increased by over 45 mm. Moreover,
since 1966 precipitation series in Estonia have been homogeneous. They indicate an increase during the cold half-year and also in June. A significant increase in precipitation has occurred in winter period (29%).

In Latvia, an increase in precipitations in winter is forecasted when running the RCAO RCM (Rossby Centre Atmosphere Ocean Regional Climate Model) against IPCC scenarios; this increase is estimated at 7-9% according to A2 and 4-5% according to B2 (Apsite et al., 2010).

**North Western Europe**

In the Meuse river basin, the expected amount of precipitation during winter is dependent of the study. Towards 2100, an increase of 0%, 8% or 16%, respectively for the low, mean and high scenario is predicted. KNMI finds an average precipitation increase of 3.6% to 14.2% for 2050, while KUL shows that the rainfall factors are time scale independent. In other words, the perturbation factors for precipitation amounts averaged over day, week, month or the whole season are all the same, i.e. the rainfall peaks will be affected similarly as the low storms. Similar results can be deduced by the study of the KNMI, where the wet day frequency in winter will increase with 0.1% - 1.9% and the precipitation on a wet day in winter will increase with 3.6%-12.1% (AMICE Project, 2010).

In Belgium, the climate change will induce increased sea level rise, surges and potentially more intense and/or frequent storms. It is suggested that the recent increase in the amount of heavy rainfall, is caused by hydro-meteorological conditions that are less or as extreme as those observed during the 1960s. Of course, land use has changed significantly in the meantime (for example, urban areas have become larger with large-scale sewer networks constructed). Consequently, current hydrological impacts are very different from those of the 1960s. Over the past decade, the most pronounced changes have been during the winter (as is the case for precipitations). These changes are consistent with current temperature trends, which indicate warmer winters than previously observed. Various studies have also indicated that winters are likely to become milder in the future, which would imply that the evapotranspiration rate will increase. This would in part explain the increased precipitation during winter, given the larger quantities of water vapour in the atmosphere (National Climate Commission, 2010).

In Wallonia, there has been an increase of the average annual rainfall (+ 20% between 1951 and 2005 for different measuring station in Wallonia) and in heavy rains. An increase in rainfall volume, and in frequency and intensity of precipitation in winter is projected with high probability (Agence Wallonne de l’air et du climat, 2011).

In the French Adour Garonne river basin, climate change will induce an increase in winter precipitations (Agence de l'eau Adour Garonne, 2003).

### 1.1.3 Increased extreme precipitation events

**Continental land**

In Austria, over the period 2021-2050 compared with 1976-2007, the statement that extreme values of precipitation (due to the higher precipitation amounts in winter and its physical correlation with the expected temperature rise accompanying higher moisture content of the
atmosphere in summer) will increase is at present speculative, since the previous rainfall data to their spatial and temporal resolution and accuracy show no evidence of an increase in extreme precipitation (BMLFUW et al., 2011).

**Northern Europe**

According to the BaltAdapat project (2011a), in the Baltic Sea region, a general tendency in climate change scenarios is that heavy precipitation can increase in a warmer climate as a result of the larger water-holding capacity of the atmosphere. Such a tendency of increasing heavy precipitation events is projected also for the Baltic Sea basin for extreme events of sub-daily, daily and for precipitation integrated over a week. The tendency is evident both for relatively common extremes (e.g. events with a 1-year return period viz. events that takes place once a year in a statistical sense) and for rare events (e.g. events with a 30-year return period).

In Latvia, Apsite et al. (2010) also conclude that days with heavy rainfall will occur more frequently during the year.

**North Western Europe**

In the Meuse river basin, a study shows that extreme events will become more extreme. The perturbation factor depends on the considered return period. For example, the precipitation of the storm with a return period of 1 year will increase with a factor 1.13, while the factor is 1.16 for the storm with a return period of 10 years (AMICE Project, 2010).

1.2 Effects of CC on temperature and sea level – regional examples

1.2.1 Temperature rise

**Continental land**

According to a study of the International Commission for the Protection of the Rhine, in the entire Rhine river basin, there will be a continuous rise in temperature, reaching +1 to +2°C in 2021-2050 (compared to 1961-1990) and of + 2°C to + 4°C up to 2100 (compared to 1961-1990). This rise in temperature will be stronger in summer than in winter. These tendencies for 2050 and up to 2100 will differ regionally: temperature rise will be stronger in the south (Alps) than in the north (ICPR, 2011).

According to the Austrian adaptation strategy to climate change, the average air temperature will rise by about 1°C in 2021-2050 (compared to 1976-2007), the increase being stronger in summer than in winter (BMLFUW et al., 2011).

In Baden-Württemberg in Germany, according to the calculations of all scenarios, the average temperature will increase by 0.8 to 1.7 °C in 2050 and the hot days (daily maximum temperature of at least 30 °C) will be twice more likely. For example, this will increase the number of summer days, currently low in Karlsruhe, just less than 60 days, to more than 80 days in the middle of the century. In return, the frost and ice days will decrease considerably (Ministerium für Umwelt, Naturschutz und Verkehr Baden-Württemberg et al., 2010).
Annual temperatures in **Bulgaria** are to rise between 0.7° and 1.8°C in the 2020s. A warmer climate is also predicted for the 2050s and 2080s, with an annual temperature increase ranging from 1.6° to 3.1°C in the 2050s, and from 2.9° to 4.3°C in the 2080s (Alexandrov & Genev, 2003).

In **Slovenia**, according to Janža (2010), climate projections show an increase of the average temperature by 0.9°C in 2011-2040, by 2.3°C in 2041-2070 and by 3.8°C in 2071-2100 compared to 1965-2005.

In **Hungary**, all models forecast a significant rise in temperature (Hungarian 5th National Communication to the UNFCCC, 2009). The highest rise in the average seasonal temperature is expected to occur in summer (+1.45 °C for 2011-2040 compared to 1961-1990) and the lowest in winter (+1.0 °C) (see Error! Reference source not found.). The number of frosty days \((T_{\text{min}} < 0 °C)\) is expected to decrease in the period 2021-2040 compared to 1961-1990 in all parts of the country. The areas at higher altitudes are expected to show a larger reduction (more than 14 days in average), while the southern, lower areas are expected to show a smaller change.

<table>
<thead>
<tr>
<th></th>
<th>Annual</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Average</strong> temperature rise</td>
<td>0.8 - 1.8 °C</td>
<td>1.0 - 1.6 °C</td>
<td>0.5 - 2.4 °C</td>
<td>0.8 - 1.9 °C</td>
<td>0.8 - 1.2 °C</td>
</tr>
<tr>
<td><strong>Uncertainty</strong></td>
<td>1.0</td>
<td>0.6</td>
<td>1.9</td>
<td>1.1</td>
<td>0.4</td>
</tr>
</tbody>
</table>

**Northern Europe**

In **Latvia**, climate change scenarios forecast the most significant air temperature increases for the winter and autumn seasons: 4.1 to 4.9°C according to simulations running A2 scenario, and 3.0-3.4°C according to B2; this is expected to increase evapotranspiration (Apsite et al., 2010).

According to the ASTRA project in the **Baltic Sea Region**, empirical measurements for the 20th century show an increase in temperature of 1°C for the Baltic catchment (Hilpert et al., 2007). Simulation runs make it clear that until 2100 the increase will be spatially and seasonally very different. The increase in winter temperatures will be greater (at least 4-6 °C) than in summer (3-5°C). In some regions, e.g. in coastal and mountainous areas in Finland and Sweden, the temperature increases may even be higher (see Figure 3). Projected increases of mean summer temperatures are more moderate, ranging from about 2°C to 5°C in some coastal parts of Sweden, Finland, Estonia and Latvia. These strong changes are in line with general expectations that temperature increases are greater in higher latitudes. Projections for the whole of Europe show that, while summer temperature increase is higher in the Mediterranean, the winter temperature increase is higher in Northern and Middle Europe.
Averaging between different models show that an increase of 3-5 °C for the mean annual temperature in the Baltic Sea Region, by 2100, is very likely.

According to the climate model projections of the BaltAdapt project (2011b), temperatures in the Baltic Sea region are expected to increase with time, and the increase is generally greater than the corresponding increase in global mean temperature. This increase tends to accelerate with time, and after around 2040–2050 there is a marked difference between different emission scenarios with high-emission scenarios leading to significantly higher temperatures. The strong temperature increase in the region is to a large degree a result of a significant wintertime temperature increase, which is in turn a result of the feedback mechanism involving retreating snow and sea ice cover. These lead to even higher temperatures through an increased absorption of heat from sunlight and larger heat fluxes between the surface and the atmosphere in the absence of an isolating snow cover. The spatial pattern of warming in winter shows a larger increase in the north-eastern part of the region, which is again related to the interaction with snow as mentioned above. In summer, the spatial pattern of simulated climate change differs more between different RCMs and GCM combinations. In general, it is more uniform than the winter signal, but in some cases a stronger warming is simulated for the Baltic Sea and in some cases the strongest warming is seen in the southeast of the region. The absolute change in temperature differs between different simulations.

In Estonia, according to the Estonian Environment Information Centre (2003), the annual average temperature is projected to increase by 2.3-4.5 °C in 2100. The latest models give a smaller temperature rise. GCMs assume that the greatest warming will occur during the cold half of the year, especially in winter. The expected warming in the period from June to September is the smallest. Estonia's Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009) reports that, according to the IPCC, the territory of Estonia lies within the region where the most significant increase in air temperature has been observed over the past few decades. The annual mean air temperature in Estonia increased by 1.0-1.7 °C during the second half of the 20th century. Seasonality plays an important part in climate warming in Estonia. A statistically significant increase in the monthly mean temperature is present only during the period from January to May, with the greatest increase in
March (up to 4 °C). For the rest of the year, practically no change in the annual mean air temperature has been identified.

**North Western Europe**

According to the French national adaptation strategy, a scenario rather optimistic (B2) leads to an increase in temperature by about 2 ° to 2.5 ° C in the end of this century (compared to the late twentieth century). The increase is about 2.5 ° to 3.5 ° C for a more pessimistic scenario (A2). Warming is similar for both scenarios in 2030 and 2050, ranging between approximately 0.5°C and 1.5°C (compared to the late twentieth century). However, it is slightly higher for the A2 scenario in 2050. After 2050, the difference between the "optimistic" and "pessimistic" scenarios is growing significantly (ONERC, 2011).

In France, the changes in heat extremes appear mixed. However, when a trend is present, it is of greater amplitude for the A2 scenario. For example, the extreme daily maximum temperature in 2050 (compared to the late twentieth century) in the Southwest would increase by 2.7 ° C with the optimistic scenario and by 3.7 ° C with the pessimistic scenario. In 2090, the corresponding deviations would be respectively 4.8°C and 6.7°C. Both scenarios show an increasing trend in the frequency and intensity of hot extremes. The annual number of days with an abnormally high daily maximum temperature will rise sharply. For example, this number of days is currently 36 (annual average), and would be increased from 8 to 38 days in 2030. (ONERC, 2011)

In the Seine river basin, the project GICC-RExHySS predicted a temperature increase from 1.5 to 3 ° C in 2050 (compared to 2011) and from 2 to 4.5 ° C in 2100 (compared to 2011) (Agence de l'eau Seine Normandie et al., 2011).

In the Netherlands, according to the river basin management plans, climate change will induce a rise in average temperature of +1 ° C to +2 ° C in 2050 (compared to 1990) in the four river basins of the country (Ministerie van Verkeer en Waterstaat et al., 2009-a, b c and d).

**Mediterranean countries**

In the Alps, the highest temperature increases will be in the western parts of the Alps, reaching more than 4.5 ° C 2071-2100 (compared to 1971-2000). The warming gradually decreases towards the north: it ranges from +4.9 ° C in Nice (France) to +2.8 ° C in Bolzano (Italy). According to the results of Regional Climate Models (RCM), average temperatures could rise in the Alps of 3 ° C to 5 ° C maximum in winter and 4 ° C to 6 ° C in summer, by the end of the 21st century, compared with average temperatures of the 20th century (ONERC, 2008).

1.2.2 Increased evapotranspiration

**Continental land**

According to the Austrian adaptation strategy to climate change, the average potential and actual evapotranspiration will increase in 2021-2050 (compared to 1976-2007) but the magnitude of this change is uncertain. (BMLFUW et al., 2011)

**North Western Europe**
For the **Meuse** river basin, the CCI-HYDR project predicts towards 2100 a perturbation factor for the winter potential evapotranspiration of 1.00 (low scenario), 1.13 (mean scenario), 1.27 (high scenario). The summer potential evapotranspiration will increase with a factor 1.10, 1.16 or 1.29, respectively for the low, mean and high scenario. These factors are time scale independent. In other words, they are almost the same for daily, weekly, monthly or seasonally averages. The KNMI expects an increase in potential summer evapotranspiration by +3.4% to +15.2% towards 2050 (AMICE Project, 2010).

In **Belgium**, as a general rule, since the 1980s a trend towards increased evapotranspiration has been observed in every season. Increased evaporation due to temperature change is a fact (National Climate Commission, 2010).

In the **Seine** river basin, the project GICC-RExHySS predicted an increase in potential evapotranspiration from 10 to 25% in 2050 (compared to 2011) and 15 to 35% in 2100 (compared to 2011). This increase is quite regular over the period 1960-2100 (Agence de l'eau Seine Normandie et al., 2011).


### 1.2.3 Disappearing glaciers

**North Western Europe**

A research team of the Laboratory of Glaciology and Geophysics of the Environment (Laboratoire de Glaciologie et de Géophysique de l'Environnement, LGGE) developed a model to estimate the evolution of the Saint Sorlin glacier (**France**) in the context of the climate change. Scenarios project a reaction of the glacier more or less marked, but it is very likely that the Saint Sorlin glacier will disappear by the end of the 21st century (ONERC, 2008).

### 1.2.4 Reduced snow cover

**Continental land**

In the **Struma river basin** in **Bulgaria**, projections for the year 2085 under climate change scenarios suggest that the snow cover would disappear in most parts of the western basin at the end of spring, versus significant snow cover in the same area under the baseline climate. In sum, the reduction of snow storage results in increased runoff during the winter and early spring months and decreased runoff during the summer months. This result implies that the basin will be changing into a more Mediterranean climate with more distinctly dry summers and wet winters. The results also suggest that reduced snow accumulation accompanied by higher winter precipitations and warmer temperature would increase early spring floods and lower summer flows (Chang et al., 2002).

**Northern Europe**

According to the **Estonia's** Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), the duration of the time period with snow...
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cover and sea ice decreased significantly during the second half of the 20th century. Over this period, the date by which sea ice appears has been very consistent, but it disappearing at the end of winter has occurred earlier. The end of winter and the start of spring occur much earlier than before (19–39 days earlier).

North Western Europe

In the French Alps, Météo France calculated the response of snow cover with a temperature increase of 1.8 °C. This temperature increase had much more pronounced impact on areas of low and medium altitudes than of high altitude (> 2500 m). At high altitude, the impact of climate change on snow cover is negligible. Conversely, at low altitude (1500 m), the average snow cover is reduced by more than one month and the average height of snow is reduced by about 40 cm in the northern Alps (transition from 1 m to 60 cm) and 20 cm in the Southern Alps (transition from 40 cm to 20 cm) (ONERC, 2008).

1.2.5 Sea level rise

Northern Europe

In Latvia, data from the LEGMA5 coastal observation stations on the long-term sea level changes led to the conclusion that the water level of the Baltic Sea has been rising between the end of the 19th century and the beginning of the 21st century (1875 – 2000). In line with the expected changes induced by climate change, extreme values for the sea level have been observed more frequently. In the latest water level rise observed in January 2005 during a storm, the sea level rapidly rose in all observation stations, and the maximum water level in the stations of the western coastal area of the Gulf of Riga (Mersrags, Roja, Kolka) exceeded the respective maximum values observed during previous similar events in 1969 and 1967. The main threats for the coastal area of Latvia are the relatively frequent and severe South-West, West and North direction storms that cause considerable drifts of the Baltic Sea water mass in the coastal zone, with relative sea level rises of 1.7 to 2 m or even higher. This leads to the flooding of low altitude coastal territories including the dunes, populated territories, buildings, roads, forest and agricultural areas (VARAM, 2006).

According to the Estonia’s Fifth National Communication (Estonian Ministry of the Environment & Estonian Environment Information Centre, 2009), Estonian tidal measurements over the period 1842–2005 suggest a mean sea level rise (adjusted to account for land uplift) of 1.5–2.1 mm/year over the last century. The trend in Pärnu County (2.3–2.7 mm/year) is greater than the estimated mean global sea level rise. The excessive rise in both the mean and the maximum sea level can be accounted for by the local sea level response to the changing regional wind regime and the intensification of cyclones.

In the Baltic Sea region, the BaltAdapt project (2011c) analysed the effect of regional climate change on sea surface height (not considering the effect of land lift and global sea level rise). Between the periods 2070–2099 and 1969–1998, the change in the annual sea surface height is largest in the Gulf of Finland, the Gulf of Riga, and the Bothnian Bay and along the Finnish coast.

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5 Surface water monitoring programs of Latvia
in the Bothnian Sea. When looking at the different seasons, highest values are found in autumn, when the winds are strongest, followed by winter, while spring and summer are less affected.

**North Western Europe**

According to the Dutch river basin management plans, the sea level will rise of 0.85 m to 2100, with a lower limit of 0.35 m (Ministerie van Verkeer en Waterstaat et al., 2009-a, b, c and d).

In the UK, sea level rise is an issue along the east coast and in the Broads (UK Environment Agency, 2009e). Saline incursion is an issue along the east coast and in the Broads (UK Environment Agency, 2009e).

In Belgium, an effect of sea level rise is the erosion of sand dunes, reducing the natural protection against flooding from the sea (National Climate Commission, 2010).

**Mediterranean countries**

While some publications report that the Mediterranean region is among the areas that will be most affected by coastal flooding, in a contribution provided in 2002 by ENEA (Italian National agency for new technologies, Energy and sustainable economic development) to the third National communication to the UN-FCCC, it is reported that the Mediterranean sea level will not rise as much as that of the oceans, probably because of anomalies in the atmospheric dynamics and in the whole hydrologic cycle of the Mediterranean basin. The same contribution also reports that the Mediterranean sea level rise due to CC is expected to be between 18 and 30 cm by 2090 (apart from subsidence phenomena that are different for different Italian coastal areas). According to a study of the NASA-GISS, around 4500 km² of Italian coastal areas are liable to flooding. Their distribution has been projected as reported below:

- 25.4% in Northern Italy (mainly Northern Adriatic coasts);
- 5.4% in Central Italy (mainly Central Adriatic and some zones of the Tyrrhenian coasts);
- 62.6% in Southern Italy (mainly gulfs of Manfredonia and Taranto);
- 6.6% in Sardinia (mainly western and Southern coasts).

The Italian coasts do not seem to be among the most critical areas from the point of view of number of people that may be affected by flooding. The main issue is reported to be vulnerability with regard to sea water intrusion in the coastal aquifers caused by sea level rise, together with a decrease in beach solid debris replenishment, caused by low river flows. The importance of the phenomenon can be better understood considering that, in Italy, drinking water is mainly withdrawn from groundwater (with a considerable contribution from artificial reservoirs in Southern Italy).
Annex 2– Case studies

The vulnerability assessment builds on case studies. Each investigates the vulnerability of different types of water resources to climate change. A synthesis is available in the main report, and details are presented in this section.

2.1 Case study of an endorheic lake: Lake Neusiedl

Key Points

- **Location**: endorheic lake located at the Austrian and Hungarian border
- **Climate**: The future climate will consist of an increase of the annual average temperatures up to 2.5°C in 2050 in the lake area and of greater uncertainties in precipitation patterns, along with a slight decrease.
- **Findings**: impacts on the water level. Increase of the frequency of low water levels from and increase in the average duration of these periods
- **Implications**: impacts on key socio-economic sectors such as tourism, retail sales and agriculture. Potential impacts on biodiversity.

2.1.1 Location

Lake Neusiedl, located at the Austrian and Hungarian border is a hydrological system that is particularly sensitive to climate change. Indeed, this endorheic lake has no natural drain and its water level is mainly determined by precipitation and evaporation. The whole lake area has been declared as UNESCO World Cultural Heritage Area due to its outstanding geomorphological and ecological diversity.

The lake has a total area of about 320 km² of which 180 km² are covered by reed. It is considered as shallow with an average depth of 1.2 m and among the driest areas of Austria with an annual precipitation of 500-700 mm. In the recent years, the significant deficiency in precipitation and the high evapotranspiration which is characteristic for this region have lead to low lake water levels, as seen in Figure 1.

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6 [www.climateadaptation.eu/austria/en/#fresh-water-resources](http://www.climateadaptation.eu/austria/en/#fresh-water-resources)
According to Eitzinger et al. (2005), an increase of the annual average temperatures of 1.9°C for the 2010-2030 period and of 2.5°C for the 2030-2050 period is expected in the lake area, compared to the period 1961-1990. With regard to precipitation changes, greater uncertainties are estimated with a bandwidth of -20% to +20%. Yet, within the last 15 years, a slight decrease of annual precipitation has been observed (-5%).

The observed increase of temperature and also sunshine duration within the last decades enhanced the lake evaporation by 10% for the period 1991-2004 compared to 1961-1990. A further increase of the lake evaporation by 15% could be achieved considering a temperature increase of 1.8°C until 2050. The return period for reaching critical lake levels for sailing has changed from around 30 years in 1961-1990 to 12 years in 1991-2004 (Eitzinger et al., 2005).

2.1.2 Results

2.1.2.1 Impacts on water levels

Climate change is likely to impact the water level of the endorheic lake.

Schönerklee et al (2007) identifies four characteristic water levels for Lake Neusiedl:

- 115.50 m a.s.l.: average lake water level during the time period (1965-2005)
- 115.20 m a.s.l.: feasible starting level of artificially supplying water to the lake
- 115.00 m a.s.l.: level which is slightly below the minimum lake water level of the driest year 2003 (115.06 m a.s.l.)
- 114.70 m a.s.l.: extreme event

Table 1 presents the estimated occurrence probabilities and average duration of periods below the considered water levels for the past period (1991-2004) and for the projected scenarios (2010-2030) and (2030-2050), assuming a precipitation decrease of 5%.
Table 1 – Occurrence of low lake water levels, Schönerklee et al (2007)

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Climate change (compared to period 1961-90)</th>
<th>Lake water level 115.20 m a.s.l.</th>
<th>Lake water level 115.00 m a.s.l.</th>
<th>Lake water level 114.70 m a.s.l.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Occurrence probability</td>
<td>Average duration of periods below level</td>
<td>Occurrence probability</td>
<td>Average duration of periods below level</td>
</tr>
<tr>
<td>Past period</td>
<td>T: + 0.7°C Prec.: ± 0 %</td>
<td>12.2 years</td>
<td>138 days</td>
<td>71.4 years</td>
</tr>
<tr>
<td>Scenario</td>
<td>T: + 1.9°C Prec.: - 5%</td>
<td>2.6 years</td>
<td>191 days</td>
<td>6.9 years</td>
</tr>
<tr>
<td>2010-2030</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Scenario</td>
<td>T: + 2.5°C Prec.: - 5%</td>
<td>1.8 years</td>
<td>223 days</td>
<td>3.5 years</td>
</tr>
<tr>
<td>2030-2050</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

2.1.2.2 Implications

An economic analysis of the lake area highlights that the local gross value added and employment situation is related to the good state of the lake. Low lake water level scenarios would mainly affect the following sectors:

- Tourism: hotel business, restaurants, water sports
- Retail sales
- Agriculture

Schönerklee et al (2007) estimates a decrease of gross value added of approximately 13 Mio € and employment decrease of 476 full-time equivalents for the region for the scenario leading to a water level of 115.00 m a.s.l. This corresponds to a decrease of 0.5% for the total economic situation of the region. The economic impacts are more significant when considering the scenario leading to a water level scenario of 114.70 m a.s.l., with a loss of 41 M€ for the total gross value added of the region and 1,271 full-time equivalents.

Figure 5 quantifies the economic impacts for both scenarios by sector.
2.1.3 Conclusions

**Endorheic lakes** like Lake Neusiedl, at the Austrian and Hungarian border) are particularly sensitive to CC because their water level is only determined by precipitations and evaporation. There is no natural drain to recharge the lake and sustain the water level.

The possible effect of climate change on Lake Neusiedl has a high priority for regional authorities (Federal Ministry, 2010) because of its high socio-economic implications (costs and employment). In addition, the lake is a famous European bird breeding region and low water levels may have important impacts on the European fauna.

Figure 5 - Expected total decrease of gross value added for the lake level scenarios 115.00 m a.s.l. and 114.70 m a.s. l. (average scenarios), Schönerklee et al (2007)
2.2 Case study: Impact of climate change on large lakes – the Lake Balaton

Key Points

- **Location**: shallow lake located in Western Hungary
- **Climate**: the precipitation regime is expected to become drier, with fewer rainy days. The temperatures may increase in average of 1.4 to 1.6°C, with smaller changes in spring (0.8 to 1.2°C) compared to other seasons (1.5 to 2°C).
- **Findings**: Lake Balaton - due to its remarkable shallowness- is deemed to be sensitive to climatic variations. Because of increased temperature and decrease in precipitation patterns⁷, climate change may impact the evaporation and recharge of the Balaton lake, with subsequent impacts on the water level and related socio-economic activities in the area. Yet, the extent of the impacts of climate change on the lake water level is still debated.
- **Implications**: The modification of water levels can have great impacts on water supply. It can also have great impacts on water quality and therefore on public health. This is particularly remarkable for shallow lakes, which are confronted with decreased dilution rates and increased water temperatures, and are therefore vulnerable to pollution and eutrophication. Although water-level fluctuations are natural patterns which are necessary for the survival of many species and support biodiversity, too low water levels and/or supplementation may disturb the overall ecological balance of the lake. Through lower water levels, CC may also have implications on socio-economic activities like tourism and require water supplementation from foreign sources.

2.2.1 Location

Lake Balaton is located in Western Hungary (Figure 6). It is the largest lake in Central and Western Europe and its drainage basin covers about 20% of Hungary (together with the Sió Canal) (Bartholy et al., 2004). Its surface area covers 593 km², with a length of 77 km and width of up to 15 km. It is one of the shallowest large lakes in the world (ALM, 2008). It lies 104 m above mean sea level and has an average depth of 3.2 m (Figure 7). The southern shore of Lake Balaton is extremely shallow, the average depth only being reached at a distance of 500 to 1,000 m (1,600 to 3,300 ft) from the shore (International Lake Environment Committee, Unknown). The main inflow, the Zala River, empties into the southwestern end of the lake, while the Sio-canal drains the water from the eastern basin into the River Danube.

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⁷ Uneven distribution and increased deviation of precipitation was found to be an important climatic factor from the aspect of low waters.
Little is known about the regional effects of climate change. Yet, downscaling from global atmospheric models shows that in Western Hungary:

- the precipitation regime is expected to become drier, with fewer rainy days (Figure 8 presents the precipitations in 2006 in Hungary, Figure 9 presents the changes expected in a changing climate) (Bartholy et al., 2004),
- the temperatures may increase in average of 1.4 to 1.6°C, with smaller changes in spring (0.8 to 1.2°C) compared to other seasons (1.5 to 2°C) (Max Planck Institute for Meteorology, 2009). Figure 8 presents the current temperatures (in 2006) in Hungary.
2.2.2 Results

2.2.2.1 Impacts of climate change on the lake water level

From an ecological and economical perspective, recent changes in the lake water levels have alarmed both regional authorities and local stakeholders. Lake Balaton - due to its remarkable shallowness- is deemed to be sensitive to climatic variations (Honti & Somlyódy, 2009) (Figure 5). During last decades strong decreases in surface inflow occurred because of dry conditions, resulting in significant drops in the lake water level (e.g. period 2000 – 2003). On the other hand, in case of abundant precipitations, rapid rises can also occur (e.g. period 2005 – 2006) (Max Planck Institute for Meteorology, 2009).

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Source: Szegedi et al., 2006

Source: Bartholy et al., 2004

Figure 8: Hungarian climate in 2006

Figure 9: Anomalies of the amount of precipitation on rainy days for the watershed of Lake Balaton simulated by a stochastic embedded model for 2×CO₂ climate.

8 Precipitation changes associated with a doubling of the concentration of carbon dioxide in Earth’s atmosphere
Because of increased temperature and decrease in precipitation patterns\(^9\), climate change may impact the evaporation and recharge of the Balaton lake, with subsequent impacts on the water level and related socio-economic activities in the area. A sensitivity analysis showed that the sensitivity of the lake increases with the amplitude of climate change. Yet, the extent of the impacts of climate change on the lake water level is still debated.

The evaporation for the next 40 years (until 2050) was estimated based on the combination of two methods:

- the monthly derivated estimation of long-term water balance (Figure 11); and
- the use of regional climate model outputs (REMO) as inputs for the evaporation estimation models (based on historic data (for 1960 – 2000) and an A1B scenario).

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\(^9\) Uneven distribution and increased deviation of precipitation was found to be an important climatic factor from the aspect of low waters.
According to the results, no significant changes in mean annual lake evaporation can be expected under the A1B scenario: for the 50-year time period the expected mean annual evaporation rate is 888 mm, which is only a 1-mm increment when compared to the water balance value for 1951-2000 and only a mere 3 mm (~1/3 of a percent relative increase) when compared with the same water balance value for the 1961-2000 period. The Morton model with REMO 5.7 inputs and no tunable parameters yielded 773 mm/year for 1951–2000 and 785 mm/year for 2001-2050, both a significant underestimation, yet the evaporation increase again is under 2% (being close to the limit of error)(Figure 11). These results concerning the phenomenon of evaporation are confirmed at the lake’s water balance level by RMA model simulations by Honti & Somlyódy (2009), which show that the lake is not endangered under the expected climate changes.

However, Nováky B. (2008) showed that an increase in annual temperature by 2.8 °C coupled with a decrease in precipitation by 10% could turn Lake Balaton into a closed lake without outflow. These changes would be more drastic than those described in section 1.2. Yet, the same study shows that an increase in annual temperature by 1.5 °C and decrease in annual precipitation by 5% could already lead to significant decreases in water recharge of lake (Nováky, 2008).
2.2.2.2 Impacts of water-level fluctuations on the ecology of the lake

Water-level fluctuations are natural patterns which are necessary for the survival of many species and support biodiversity (Gafny et al., 1992; Gafny, S. & A. Gasith, 1999; Wantzen et al., 2002). Only extreme or untimely floods and droughts have deleterious effects for both biota and man (Sparks et al., 1998; Bond et al., 2008). For example, the drought in 2003 was shown to disturb the populations of zebra mussels as well as plankton community including the planktonic larvae of Dreissena polymorpha (Wantzen et al., 2008). In this context, the supplementation of Balaton lake from outside sources to sustain the lake water level, which prevent water fluctuations and allows the introduction of foreign organisms, may disturb its ecological balance.

Decreases in water level and increases in water temperature may favour the intensification of biological metabolic processes, such as primary production and bacterial decomposition, and therefore favour eutrophication, which the lake is already sensitive to due to its shallowness and the loading of nutrients. The phenomenon of eutrophication may also be intensified by the reduced runoff, which affects the relative proportions of nutrient pollution from concentrated and diffuse sources (Szilagyi & Somlyody, 1991). Eutrophication may then affect the phytoplankton structure, crustacean plankton and benthic invertebrates’ populations, with further impacts on fish populations.

2.2.2.3 Socio-economic impacts of water-level fluctuations: tourism

Lake Balaton, in Hungary, is the second most popular touristic destination of the country, after Budapest. By offering a picturesque landscape and a water environment that is ideal for swimming and other water sports, it attracts 2 million tourists every year (International Lake Environment Committee, unknown). This highly seasonal tourism can temporarily triple the area’s population (ALM, 2008). Touristic activities, which include water skiing, sailing, swimming and fishing, require a proper lake water level. Changes in the number and types of tourists during

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20 www.cost869.alterra.nl/Hungary/Istvanovics.pdf
periods of lower water levels were observed between 2002 and 2003 (Bizikova & Pintér, 2009). These touristic activities may increase in response to the changing climate in the region, with increased heat stress. Should the water level of the lake need to be artificially maintained for these activities because of too high evaporation, the water supplementation from outside sources can be envisaged, resulting in potential ecological changes in the lake fauna and flora.

2.2.3 Conclusions

Lake Balaton - due to its remarkable shallowness- is deemed to be sensitive to climatic variations. Because of increased temperature and decrease in precipitation patterns, climate change may impact the evaporation and recharge of the Balaton lake, with subsequent impacts on the water level in the area. Yet, the extent of the impacts of climate change on the lake water level is still debated. The modification of water levels can impact water supply. It can also have great impacts on water quality and therefore on public health. This is particularly remarkable in the case of shallow lakes, which are confronted with decreased dilution rates and increased water temperatures, and are therefore vulnerable to pollution and eutrophication. Although water-level fluctuations are natural patterns which are necessary for the survival of many species and support biodiversity, too low water levels and/or supplementation may disturb the overall ecological balance of the lake. Through lower water levels, CC may also have implications on socio-economic activities like tourism and require water supplementation from foreign sources.

11 Uneven distribution and increased deviation of precipitation was found to be an important climatic factor from the aspect of low waters.
2.3 Case of an artificial reservoir (the Netherlands)

Key Points

- **Location**: artificial freshwater reservoir in the Netherlands
- **Climate**: The Royal Netherlands’ Meteorological Institute (KNMI) formulated four scenarios in 2006, which assumes a maximum temperature increase of 2°C by 2050
- **Findings**: Under normal circumstances, the water system works well but under extreme events, problems such as water shortages, flooding, waterlogging, salinisation and water pollution may take place.
- **Implications**: Because they present a better thermal buffering capacity and water capacity, deep lakes are less vulnerable to CC than other typologies of water bodies. However, these lakes, which can be used as reservoirs (e.g. Lakes IJsselme and Markermeer in the Netherlands), often have to face intensive abstraction to meet water demands, which increases the overall sensitivity of these water bodies. CC may have significant impacts on both the quality and quantity of drinking water of the reservoir.

2.3.1 Location

Lake IJsselmeer and Lake Markermeer in the Netherlands form the largest artificial freshwater reservoir in north-western Europe (see Figure 13). It is primarily fed by the Rhine River and stands as an important source for drinking water production, as well as agriculture and industry. It notably functions as a buffer, which can supply water to many of the northern parts of the Netherlands during potential periods of drought.

From April to September, the target level on these lakes is 0.20 m below mean sea level (m.s.l.), while during the rest of the year a level of 0.40 m below m.s.l. is maintained. There is usually enough water to maintain this level. In the winter months, Lake Markermeer discharges the majority of its excess water into Lake IJsselmeer, while in the summer most of it flows westwards to flush the Noordzeekanaal. In spring and autumn the direction of the water discharge changes depending on the weather conditions and the water levels (Zwolsman et al., 2011).
The Royal Netherlands’ Meteorological Institute (KNMI) formulated four scenarios in 2006, which assumes a maximum temperature increase of 2°C by 2050. In a worst-case scenario, the summers will become considerably dryer as well, which will have an impact on river discharges, moisture deficit and salinisation. (Van Den Hurk et al., 2006).

Figure 13 – Map of the area (Zwolsman et al., 2011)

2.3.2 Results

- River discharges
  All scenarios envisage that the average discharge of the Rhine will increase in winter (up to +12% and decrease in summer (up to –23%). The same applies for the Meuse, with a maximum increase of 5% in winter and a maximum decrease of 20% in summer.

- Moisture deficit and drought
  If easterly winds prevail, it is estimated that rainfall could easily decrease by 10 to 19% in the area. Aside from this, the chance of extreme drought is greater because at high temperatures, the evaporation rate is higher.

- Salinisation
  The combination of sea level rise and lower river discharges in summer will lead to increased salinisation. The saltwater will go inland and the number of days that freshwater inlet points cannot be used for abstraction will increase.
Pollution by chloride

Peak chloride concentrations close to 200 mg/l occurred in the Rhine at the Dutch-German border during periods of low river flow, e.g. summer-autumn 2003 (Zwolsman & Van Bokhoven, 2007). With an expected increase in the frequency and duration of such low flow as a result of climate change, water supply in the Netherlands may be at risk as chloride can only be removed by desalination systems such as reverse osmosis.

2.3.3 Conclusions

Under normal circumstances, the water system works well but under extreme events, problems such as safety concerns, water shortages, flooding, waterlogging, salinisation and water pollution may take place. By 2050, assuming the present conditions of water-level regime, as well as a current land uses, in an extremely dry year (occurring once every 100 years), only 70% of the water demand could be met. In order to ensure a sustainable supply of water resources, close cooperation between different areas within the Delta Programme is necessary: the IJsselmeer (water level ordinance), the Rhine estuary (effectiveness of measures to counter salinisation), the river Rhine (discharge distribution between the IJssel and the Waal) and the south-west delta (fresh versus saline water) is advocated (PBL, 2011).
2.4 Impact of climate change on Lake Bolsena (Central Italy)

Key Points

- **Location**: volcanic lake located in Central Italy. It is located at 305 m a.s.l., while its watershed has a mean height of 490 m and a maximum height of 690 m a.s.l., in the north-western part of the watershed.

- **Climate**: Expected rainfall decrease up to 20-30% for the next 50 years, in the Western Mediterranean area and the Italian peninsula (Dragoni, 1998), with current negative trends in some stations.

- **Findings**: In order to investigate the impact of climatic variations on the lake regime, a monthly lake level simulation model was developed and applied. For a 30% decrease from the current rainfall there would be a decrease in the lake level of up to 3 meters compared to the 1948-1985 levels. With the decrease in levels, there would also be a strong decrease in the outlet flow.

- **Implications**: environmental and economic problems due to low water level and decrease in the outlet flow. Unless water withdrawals are reduced, the impacts of CC could quickly worsen the situation at the lake. A strong lake management action, aimed at cutting water use, at finding alternative water sources and at tuning water licenses according to rainfall, is needed.

2.4.1 Location

The case study refers to Lake Bolsena, located in Central Italy (Figure 14). It is the largest European volcanic lake, has a surface of approximately 114 km², a maximum depth and an average depth of 151 m and 81 m respectively. It is located at 305 m a.s.l., while its watershed has a mean height of 490 m and a maximum height of 690 m a.s.l., in the north-western part of the watershed.
The catchment basin (273 km², including the lake) lies mainly over Pleistocene volcanites that form a phreatic aquifer that, together with few and localized torrents, feed the lake. The hydrogeological basin (350 km²) is larger than the catchment basin, as resulting from several piezometric investigations (Dragoni et al., 2002), see Figure 15.

The main climatic parameters of the Lake Bolsena basin are reported in Table 3.
Table 3: Main climatic parameters of the Lake Bolsena basin (after Dragoni et al., 2002)

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean annual temperature (°C)</td>
<td>13.6</td>
</tr>
<tr>
<td>Mean temperature of the coldest month (Jan), (°C)</td>
<td>5.9</td>
</tr>
<tr>
<td>Mean temperature of the hottest month (Aug), (°C)</td>
<td>22.3</td>
</tr>
<tr>
<td>Mean annual rainfall on the lake (mm)</td>
<td>938</td>
</tr>
<tr>
<td>Lowest mean monthly rainfall on the lake (July), (mm)</td>
<td>29</td>
</tr>
<tr>
<td>Mean annual rainfall on the basin (mm)</td>
<td>956</td>
</tr>
<tr>
<td>Highest mean monthly rainfall on the lake (Nov), (mm)</td>
<td>127</td>
</tr>
</tbody>
</table>

Marked variations were observed in the winter temperature of the lake water; from 1969 to 1998, there was a mean increase in the water temperature from 7.4 to 8.4 °C (Ambrosetti et al. 2003). A further worrying variation from the 60’s has become apparent for the hydrology of the lake. Due to the tapping of groundwater for irrigation and domestic use, water withdrawals increased from around $5 \times 10^6$ m$^3$ y$^{-1}$ during the period 1960-2000 (Pagano et al. 1998; Dragoni 1998). There has also been a slight decrease in the quantity of precipitation over the last four decades, while air temperature has increased of about one degree during the last hundred years (Dragoni et al., 2002).

The lake has only one outlet, River Marta that in the 60’s had a flow of approximately $100 \times 10^6$ m$^3$ y$^{-1}$ that corresponds to a retention time of 120 years. Nowadays, as a consequence of the above mentioned increased withdrawals and climatic variations, River Marta flow is less than $25 \times 10^6$ m$^3$ y$^{-1}$ on average, the lake level has fallen markedly and the lake retention time is approximately 300 years. This very long water renewal time makes the lake very susceptible to pollution, demanding higher care in sewage disposal and water use. In Figure 16 some of the above described variations are reported.
Literature review on the potential climate change effects on drinking water resources across the EU and the identification of priorities among different types of drinking water supplies – ADWICE project

Final report - Annexes

**Figure 16**: Evolution of annual precipitation, of the River Marta discharge and of the lake level (1960-2000)

About 22,000 people live in the watershed, increasing to 35,000 in the summer period. The sewage reaching the lake was untreated until 1996, after which a pipeline was constructed to convey sewage from the main population centres to a treatment plant located about 3 km from the lake, along the outflow. Further sources of pollution are the fertilisers derived from agricultural runoff. The total amount of N and P applied as fertiliser has been evaluated to be 950 and 450 t/y respectively (Associazione Lago di Bolsena 2003).

Notwithstanding the above mentioned pressures, the lake is characterized by an almost uncontaminated natural environment and is one of the few almost fully suitable for bathing Italian lakes. The very good water quality allowed an extraordinary biodiversity development, with very rare animal and plant species. Due to this characteristic in 2005 the lake has been
candidate to be a Special Area of Conservation, according to the EU Habitats Directive (92/43/EEC).

It has been reported that water balance referred to 1960’s shows that evaporation from the lake surface equaled rain directly fallen on the lake surface. Neglecting water withdrawals, during the 60's water flow into the lake equaled River Marta outflow ($100 \times 10^6 \text{ m}^3 \text{ y}^{-1}$) (Busatto et al., 2009).

According to present water balance, evaporation greatly exceeds rainfall, with a $20 \times 10^6 \text{ m}^3 \text{ y}^{-1}$ deficit. Also the basin inflow to the lake decreased from 100 to $85 \times 10^6 \text{ m}^3 \text{ y}^{-1}$ because of rainfall scarcity. According to these values, climate is responsible, on the whole, of a $35 \times 10^6 \text{ m}^3 \text{ y}^{-1}$ loss. Another $35 \times 10^6 \text{ m}^3 \text{ y}^{-1}$ deficit have been ascribed to water withdrawals.

Water withdrawals from Lake Bolsena basically belong to three kind of uses: drinking, agricultural and domestic (withdrawals from wells for domestic uses in isolated rural houses).

On the whole it has been estimated that drinking water withdrawals from the lake approximate $19 \times 10^6 \text{ m}^3 \text{ y}^{-1}$, which correspond to around 19 cm of the lake level. Overall lake Bolsena basin in the present climatic condition provides $35 \times 10^6 \text{ m}^3 \text{ y}^{-1}$. Greater withdrawals would unavoidably produce environmental damages. Future climatic trends in the area would further worsen the already existing pressure on the lake ecosystem.

In particular, with reference to Lake Bolsena, apart from the rainfall decrease up to 20-30% expected for the next 50 years, in the Western Mediterranean area and the Italian peninsula (Dragoni, 1998), the rainfall over the entire basin currently shows a slight decrease which is statistically not significant. However, some of the stations in the basin individually show significant negative trends (a rainfall decrease of 2.19 mm y$^{-1}$ resulted investigating the period 1903-1997, with reference to Bolsena municipality). This suggests that if the regional trends common to all of Central Italy continue, in the next few decades a variation in the lake regime has to be expected.

### 2.4.2 Results

In order to investigate the impact of climatic variations on the lake regime, a monthly lake level simulation model was developed and applied. This model is a variation of a series of models that have already been worked out to simulate the rainfall – runoff transformation of some basins in Central Italy. (Dragoni et al., 2002). Details of the mentioned model that can be found in Cambi et al., 2001.

After the model was calibrated, a series of assumed rainfalls and temperatures were inserted in order to simulate the effects of rainfall decreases and temperature increases on lake levels. Restrictions were also inserted in the model to control the flow from the outlet, since this is currently regulated artificially according to the lake level: when the simulated level goes below the minimum value measured in the 1948-1985 period, the flow from the outlet is decreased until it reaches a zero value for the lowest levels; in the other cases, the flow corresponds to the average value measured in the studied period. Figure 17 shows the simulations obtained for various decreases in rainfall; in particular, the graph illustrates what the average lake level would
be in the case of a 10, 20 or 30% decrease in rainfall compared to the recorded rainfalls. These decreases are consistent with those to be expected should the present climatic trends continue.

The fluctuations in the level reflect the variance in the original rainfall series. The tests carried out indicate that for a 30% decrease from the current rainfall there would be a decrease in the lake level of up to 3 meters compared to the 1948-1985 levels. This may seem surprising, but it should be noted that in the past there have been periods with levels lower than the current ones. For example, an ancient coastline dated about 1000 BC lies about 5 m below the present level. Along with the decrease in levels, there would also be a strong decrease in the outlet flow, with all the related environmental and economic problems (Dragoni et al., 2002).

### 2.4.3 Conclusions

Lake condition is weighty, but not dramatic yet. It is common opinion that unless water withdrawals will be reduced below $25 \times 10^6 \text{ m}^3 \text{ y}^{-1}$, it will quickly worsen. To avoid this, a strong lake management action, aimed at cutting water use, at finding alternative water sources and at tuning water licenses according to rainfall, is needed.
2.5 The GLOWA project: climate change impacts on water resources in the Upper Danube

**Key Points**

- **Location**: river basin of the Upper Danube, in the Alps.
- **Climate**: the annual mean temperature in the Upper Danube will increase from 3.3 to 5.2°C in the end of the century. There will be an increase in winter precipitation from 8 to 47% and a decrease in summer precipitation from 14 to 69%. The annual precipitation sum will decrease from 3.5 to 16.4%.
- **Findings**: The modifications of the water resources in the Upper Danube predicted by the chosen scenarios lead to a decrease in the available water resource, so that water will become rarer, but not rare in the future. The share of snow in run-off will lower significantly, and will disappear between 2040 and 2050. In addition, the runoff maximum will advance from summer to spring.

The GLOWA project has been launched by the German Ministry for Education and Research (Bundesministerium für Bildung und Forschung) in order to analyse the regional consequences of climate change on water resources.

**2.5.1 Location**

The study area is the river basin of the Upper Danube. It has more than 10 million inhabitants and a surface of 77,000 km² and represents the biggest and most important river basin in the Alps, at the limits between Austria, Czech Republic, Germany, Italy and Switzerland (Figure 18). The river basin comprises both glaciers and areas intensively used for agriculture. There is various and intensive use of water resources for electricity production, for agriculture (e.g. possibly irrigation in the future) and for tourism (e.g. snow guns).

![Figure 18: The study area, the Upper Danube](image-url)
According to the chosen scenarios, the annual mean temperature in the Upper Danube will increase from $3.3$ to $5.2^\circ C$ in the end of the century.

There will be an increase in winter precipitation from $8$ to $47\%$ and a decrease in summer precipitation from $14$ to $69\%$. The annual precipitation sum will decrease from $3.5$ to $16.4\%$.

In the past, there has been a clear decrease in the share of snow precipitation in annual precipitation sum. This trend will be reinforced in the future (see Figure 19).

![Figure 19: The evolution of the annual precipitation sum (solid line) and of the share of snow precipitation in annual precipitation sum (dotted line) in the river basin of the Upper Danube (from 1970 to 2060)](image)

Due to the decrease in the share of snow precipitation in annual precipitation sum and due to the increase in temperature, the mean snow cover duration will decrease by 30 to 60 days at all altitudes, so that snow, which could be found at altitudes around 1000m above sea level will be found at 2000m above sea level in the future.

The expected increase in temperature will also lead to an increase in evapotranspiration sum from $10$ to $25\%$.

### 2.5.2 Results

Due to the increase in evapotranspiration and due to the evolution of the precipitation, water will become rarer in the Upper Danube. In Achleiten, at the exit of the Upper Danube, according to the GLOWA-Danube scenario, there will be a decrease in runoff from $5$ to $35\%$ in 2060. When looking at regional predictions, this trend of a decrease in river runoff is particularly important in the northern edge of the Alps (see Figure 20).

On the one hand, the northern edge of the Alps is the location where precipitation decreases most and on the other hand, where evapotranspiration increases clearly due to a longer growth period. On the contrary, locally in the northern regions of the river basin of the Upper Danube,
there may be a slight increase in water availability. In these cases, the change in annual precipitation sum is small, but the increase in water availability comes from water stress which reduces evapotranspiration.

Figure 20: Evolution of the annual precipitation sum, of the evapotranspiration and of the river runoff in the river basin of the Upper Danube (REMO regional baseline scenario, 2036-2060 compared to 1971-2000)

When looking at the annual evolution of the runoff in the Upper Danube in Achleiten, there is a clear advance of the runoff maximum from summer to spring (see Figure 21 on the left). Since the precipitation sum during summer maximum runoff keeps the same (see Figure 21 on the right), this decrease is due to the modification of the snow precipitation and to the increased summer evapotranspiration.

A detailed analysis of the evolution of the river runoff dynamic is given in Figure 22. It shows the decadal evolution of the monthly river runoff in Innsbruck and the share of the glacier runoff in it. The runoff maximum is clearly advanced from summer to spring. There is also a decrease in the share of the glacier runoff in the river runoff. It is due to the increasing temperature and to the consequently earlier snow melting, so that there is an increase in the duration of exposition of the glacier. Initially, this share decreases and then rapidly completely disappears between 2040 and 2050.
2.5.3 Conclusions

The modifications of the water resources in the Upper Danube predicted by the chosen scenarios lead to a decrease in the available water resource, so that water will become rarer, but not rare in the future. The share of snow in run-off will lower significantly, and will disappear between 2040 and 2050. In addition, the runoff maximum will advance from summer to spring.
2.6 Impacts of climate change on the water regime of the Rhine watershed

Key Points

- **Location**: glacier-supported low base-flow index river in Rhine catchment
- **Climate**: With regard to precipitation patterns, monitoring data show that, in all regions of the Rhine watershed, an increase of precipitation is observed in winter while in large parts of the Rhine watershed (in particular in the south), and the amount of precipitation decreases in summer. During the 20th century, a significant rise of the mean annual temperature has been recorded with +0.5°C to +1.2°C.
- **Findings**: Low base-flow index rivers (e.g. Rhine catchment) are likely to be more vulnerable to drought in summer than high base-flow index rivers (e.g. Seine river basin), which have higher support from groundwater to buffer water level fluctuations in dry periods. The Rhine catchment, with low base-flow index, would present a high vulnerability to CC if higher temperatures and significant decreases in precipitations in summer (mostly by -10 % and -30 % in 2050) were not compensated in the short term by the increased meltwater contribution to the river flows. Currently with a medium vulnerability, the Rhine catchment will show an increased vulnerability to CC with time with the decrease of snow stock leading to a decreased contribution of meltwater.

The International Commission for the Protection of the Rhine (ICPR) performs a comprehensive work on the impacts of climate change on the water regime of the Rhine watershed and commissioned an expert group - KLIMA - to study these issues. The section presents the main outcomes from a literature evaluation (ICPR, 2009) and a scenario analysis (ICPR, 2011).

2.6.1 Location

The Rhine catchment with a size of approximately 185,000 km² has a high population density and a high level of economic activity. The river flows in 9 countries and is navigable from Basel in Switzerland to Rotterdam in the Netherlands, which is one of the largest harbours in the world.

The land use along the basin varies according to the climate, as well as the suitability of the soil. The hydrological regime of the Rhine basin is expected to shift from a combined snowmelt-rainfall regime to a more rainfall dominated regime because of climate change. Land use changes can reinforce the effects of this shift through urbanisation.

The impacts of climate change in the Rhine watershed are already detectable in precipitation and temperature monitoring data.

With regard to precipitation patterns, monitoring data show that, in all regions of the Rhine watershed, an increase of precipitation is observed in winter while in large parts of the Rhine
watershed (in particular in the south), and the amount of precipitation decreases in summer (see Figure 23).

During the 20th century, a significant rise of the mean annual temperature has been recorded with +0.5°C to +1.2°C (see Figure 23). This is slightly above the global mean value of +0.56 to +0.9°C/100 years. Due to rising temperatures, glaciers are retreating in Switzerland. Additionally, investigations into snow parameters reveal a decrease in the average depth of snow, although it mainly depends on the altitude.

2.6.2 Results

2.6.2.1 Current hydrologic situation

Currently, all discharge parameters MQ\textsuperscript{12} and NM\textsubscript{7Q}\textsuperscript{13} at the gauging stations along the main stream of the Rhine tend to increase (mostly +10 to +15 % for MQ; +15 to +20 % for NM\textsubscript{7Q}). During summers, MQ and NM\textsubscript{7Q} decrease by up to 8 %. Mainly, this is an effect of rising temperatures (more evaporation) combined with stagnating precipitation and coincident reduced snow volume in the Alps. The flood discharge (MHQ) evaluated for entire hydrological years (November to October) indicates an increase by about +10 %. A more close consideration of data shows that this is not due to an increase of extreme peak flows but due to frequent moderate and great floods.

At the gauging stations Würzburg and Trier the development of parameters is different, sometimes opposite and can neither be aligned with the changes in the hydrometeorological constraints nor with the discharge pattern at other gauging stations. This is also true of the inconsistent development of some parameters of the Rhine gauging stations Cologne and Lobith and requires further investigation.

\textsuperscript{12} Mean flow
\textsuperscript{13} Lowest mean value of flow rate in the seven months with the higher natural discharges
Figure 23 - Observed changes in precipitation and temperature in the Rhine watershed during the 20th century

2.6.2.2 Development until 2050

Available climate projections in the Rhine watershed relate to the GCM ECHAM4 using the emission scenario B2.

According to 2050 projections, the temperature will continue to rise for the period 2021 to 2050 and will amount to an average of +1 to +2°C for the entire Rhine catchment, compared to the 1961-1990 reference period. In the south (Alps) it will tend to be greater than in the north. As far as precipitation is concerned, no considerable changes are to be noted in summer. For the winter, moderate increases are projected which, for the entire Rhine, will vary between 0 % and +15%. Thus, the trends of changing precipitation established for the 20th century remain.

These developments are accompanied by mostly moderate changes of the discharge pattern. The models used to simulate runoff in the Rhine watershed were Rhineflow, HBV (both combined with the flood-routing model SOBEK), LARSIM and WaSIM-ETH (ASGi). Compared to the present situation, the mean and lower discharges (MQ and NM7Q) in summer will remain almost unchanged. However, increased precipitation in winter which, due to rising temperatures increasingly occurs as rainfall, will lead to a rise of the mean discharges and low flow in winter by about 10 % (0 % to +20 % for MQ and 0 % to +15 % for NM7Q). Due to deficits in methods, no statements are made for Basel, Maxau, Worms.
2.6.2.3 Sensitivity analysis up to 2100

Under the assumption of continued increasing atmospheric greenhouse concentrations until the end of the 21st century, changes compared to the present (1961-1990) will be obvious and the Rhine catchment will be more vulnerable to the impacts of climate change. A rise in temperature of +2°C to +4°C (until 2100) is projected. The regionally differing tendencies - stronger rise in temperature in the south than in the north – will remain unchanged compared to the 2050 perspective. Also, the rise in temperature is stronger in summer than in winter. Unlike the changes in precipitation stated until 2050, precipitation in the Rhine catchment will considerably fall during the summer months, mostly by -10% and -30%. On this basis, falling mean runoff and low flow in summer is simulated in comparable orders of magnitude. The increase in precipitation during the winter months projected until 2100 for the entire Rhine mostly ranges between +5% to +20%, leading to a comparable increase of the mean runoff and of low flow in winter. As far as flood parameters are concerned, many projections indicate rising levels for the gauging stations downstream of Kaub (up to +30%). However, some projections also indicate opposite developments, so that a significant ranges of variation result for the entire catchment (Trier: -20% to +45%).

2.6.3 Conclusions

Low base-flow index rivers (e.g. Rhine catchment) are likely to be more vulnerable to drought in summer than high base-flow index rivers (e.g. Seine river basin), which have higher support from groundwater to buffer water level fluctuations in dry periods. The Rhine catchment, with low base-flow index, would present a high vulnerability to CC if higher temperatures and significant decreases in precipitations in summer (mostly by -10% and -30% in 2050) were not compensated in the short term by the increased meltwater contribution to the river flows. Currently with a medium vulnerability, the Rhine catchment will show an increased vulnerability to CC with time with the decrease of snow stock leading to a decreased contribution of meltwater.
2.7 Impact of climate change on a high baseflow index river – the Seine river

Key Points

- **Location:** high base-flow river in the Seine river basin
- **Climate:** current climate is said « pluvial océanique », with maximal flow in winter when evapotranspiration is low and minimum flow in summer, when evapotranspiration is high. In the future, systematic and statistically significant increase in temperatures are expected (3.1°C in average, with a standard deviation of 1.55°C), along with increase in precipitations in winter and decrease in summer. Unlike the trends reported at the global scale in the context of the IPCC, regional simulations show a clear decrease in average yearly precipitations with CC.
- **Findings:** the Seine river, high base-flow index river, benefits from the drainage of numerous aquifers that are regularly recharged through infiltration of precipitations. Because of the support from groundwater, the Seine river has a low vulnerability to drought. Risks of water shortages are significantly limited in dry seasons, although CC may eventually provoke severe low flows possibly requiring an adaptation of dams management and design. The impact of climate change on high base-flow index rivers is more likely to be due to increased water temperatures (inducing bacteria development and oxygen depletion) than changes in river flows.
- **Implications:** possible implications of low water levels, on pollution dilution, water retention and sedimentation processes, with significant impacts on water quality supplied to cities.

2.7.1 Location

The hydrological regime of the Seine river basin is said to be “pluvial océanique”, with maximal flow in winter when evapotranspiration is low and minimum flow in summer, when evapotranspiration is high (e.g. In the city Poses, the Seine average flow is about 240m³/s in summer and 805m³/s in winter). These average seasonal flows mask a high intraseasonal variability. Overall, the Seine river flows are quite low comparatively to other rivers, which originate from higher mountainous regions.

The Seine is a high baseflow index river\(^1\). The river flows are regulated by the combination of:

- a good soil water retention capacity (the soils mostly consist of silt and quaternary clay),
- the drainage of numerous aquifers (which forms the baseline for the flows), and

\(^1\) Baseflow index consists of the ratio of mean annual baseflow to mean annual flow
regular precipitations throughout the year (in average, precipitations of 750mm/yr, out of which 500 are evaporated and 250 infiltrate or flow).

Because of its geological and soils characteristics, the Seine river is more prone to floods than water shortages.

In the GICC Seine project (Ducharne et al., 2004), 8 global climatic models were forced with 1 or 2 scenarios of greenhouse gas emissions (GES) to generate 12 simulations of impact of climate change on precipitations and temperature on the Seine river basin.

Table 4 summarises the key findings of these 12 simulations in terms of precipitations and temperature.

Table 4: Statistics of the 12 simulations of Climate Change, in terms of temperature and precipitations

<table>
<thead>
<tr>
<th></th>
<th>Température (°C)</th>
<th>Précipitations (mm/j)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moyenne annuelle de référence (1985-1991)</td>
<td>9.27</td>
<td>2.08</td>
</tr>
<tr>
<td>Moyenne annuelle sous CC (12 scénarios)</td>
<td>12.37</td>
<td>2.06</td>
</tr>
<tr>
<td>Impact moyen (moy. 12 scénarios - RCF)</td>
<td>3.10</td>
<td>-0.08</td>
</tr>
<tr>
<td>Ecart-type de l’impact (12 scénarios)</td>
<td>1.55</td>
<td>6.13</td>
</tr>
<tr>
<td>Impact minimal (12 scénarios) (LMDG)</td>
<td>1.65</td>
<td>-0.40 (CCSR/NIES)</td>
</tr>
<tr>
<td>Impact maximal (12 scénarios) (CCSR/NIES)</td>
<td>6.88</td>
<td>+0.03 (CCCMa)</td>
</tr>
</tbody>
</table>

All the simulations show a systematic and statistically significant increase in temperatures (3.2°C in average, with a standard deviation of 1.55°C). Precipitations tend to increase in winter and to decrease in summer, throughout the 12 simulations, although the important dispersion of data in winter highlights major uncertainties. Unlike the trends reported at the global scale in the context of the IPCC (Le Treyt et MacAveney, 2000), these simulations show a clear decrease in average yearly precipitations with climate change. Figure 24 shows the variables used in the CaB models, based on the 12 simulations of climate change.

Legend: The black curve corresponds to the current values (August 1985-July 1991), the blue curve corresponds to the average of the 12 simulations, and the dot curves to the standard deviation. The blue area represents the variation range of the 12 simulations.

Figure 24: Synthesis of the 12 scenarios of climate change on precipitations and temperatures used in the model CaB for the Seine river basin.

Among 2 scenarios from IPCC (A2 and B2) and a scenario of CO2 increase by 1% per year since 1990
2.7.2 Results

2.7.2.1 Impacts of climate change on the Seine river flows

Based on the 12 simulations of climate change of the GICC-Seine project, hydrological models (MODCOU and CaB) were run to generating quantified and spatial projections of the impacts of climate change on ETP at the river basin level and on river flows. The combination of the results of MODCOU and CaB models allow capturing the range of uncertainties linked to climate change scenarios.

Precipitations and temperature patterns directly impact the evapotranspiration and infiltration rates, which impacts the hydrological functioning of the basin and subsequently the variation of piezometric level of aquifers and the flows of water streams within the river basin (Figure 25). Over the year, simulations also show an increase in evaporation.

![Figure 25: Synthesis of the impacts of the 12 scenarios of climate change obtained with the model CaB for the Seine river basin. The black curve corresponds to the current values (August 1985-July 1991), the blue curve corresponds to the average of the 12 simulations, and the dot curves to the standard deviation. The blue area represents the variation range of the 12 simulations.](image)

No significant impacts were observed regarding the variation of piezometric level of aquifers, unlike the Seine river flow.

Although results show that contrasted situations are observed upstream and downstream the river basin (see Figure 26), the overall results show that there will be an intensification of seasonal contrasts in river flows, with more significant low flows in summer and much higher river flows in winter (up to almost 50% compared to the current situation) (see Illustration 5). The significant decrease in the river flow is systematically observed in summer, when the decrease in precipitations is combined with a decrease in humidity. The increase in the river flow is less obvious in winter (half of simulations showing an increase during certain months), in particular due to the higher uncertainties in terms of precipitations.

Combined with the decrease in precipitations, the increased evaporation may induce a decrease of the total humidity in the non-saturated zone of the soils. Although the increase in transpiration from the plants is considered negligible since it is significantly limited in case of drought and hydric stress, this decrease in the humidity of the soils is likely to increase water demand to meet new irrigation needs and therefore indirectly to exacerbate the possible impacts of climate change on low flows.
Despite its dams and its current high baseflow river index, climate change may pose significant issues in summer with severe low flows possibly requiring an adaptation of the dams management and design (ClimAware, 2010).

2.7.2.2 Impacts of changes in river flows on water quality

By impacting the processes of dilution, retention and sedimentation, river flows may have significant impact on water quality, e.g. with remarkable consequences on water supplies to densely populate cities and on ecosystems through eutrophication (Billen et Garnier, 1997). When flows are low, the pollution through agricultural and industrial activities as well as through increasing urbanisation is all the more important since pollutants are more concentrated and
remain longer in the environmental compartment (lower speed with lower flows). On the other hand, higher flows may compensate the likely increase in nitrate concentration due to increased temperatures through high dilution.

Yet, Ducharne et al. (2004) highlight that the impact of climate change on the Seine water resources is more likely to be due to increased water temperatures (inducing bacteria development and oxygen depletion) than changes in river flows.

### 2.7.3 Conclusions

The treated surface water from the Seine and the Marne, its affluent, represents 50% of drinking water, distributed to Paris, with the other 50% being represented by the water abstracted from groundwater bodies. With 3 million consumers, 550 000 m$^3$ of drinking water are used every day in Paris. The Orly treatment plant (the only one on the Seine river) could ensure the production of 300 000 m$^3$ of drinking water/day (Eau de Paris, 2010). The impact of abstraction, to sustain urbanisation and economic activities$^{16}$ on the Seine river flows, are not likely to be crucial because the Seine benefits from the drainage of numerous aquifers that are regularly recharged through infiltration of precipitations. This process tends to support the Seine river flows even during the dry season, therefore reducing the risks of water shortages. Furthermore, the development of dam-reservoirs upstream the Seine, following dramatic flood events, that originally allowed reducing the risk of floods also allows supporting the possible low flow levels in the end of summer and in fall in the Parisian area (doubled during dry years), where pressures in terms of water demand can be quite high (Meybeck et al., 1998). The uncertainties regarding the extent, frequency and duration of extreme events (floods or low level flow) may question in the near future the dimensions and management of these dams. They may indeed present a risk of overflow in case of increased magnitude, frequency and duration of precipitations in winter.

Overall, the impact of climate change on this high base-flow index river is more likely to be due to increased water temperatures (inducing bacteria development and oxygen depletion) than changes in river flows.

Changes in river flows occurring in the context of changing climate are likely to increase the sensitivity of the drinking water resources to climate change by impacting dilution, retention and sedimentation processes.

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$^{16}$ 20 million inhabitants in 2005 (i.e. about 30% of French population), amongst which more than 10 million live in Parisian urban centre, and 40% of domestic industrial activities.
2.8 Case Study – river bank filtration

Key Points

- **Location:** River bank filtration site in the lower Rhine valley, supplying the city of Dusseldorf in North-West Germany
- **Climate:** analogues used, based on unusually low river Rhine water levels (about 2 metres below the mean water level) for several weeks during the dry summer of 2003 and flood event in the winter of 2003/04
- **Findings:** insignificant impacts of low water events on the abstraction capacity of the well field; anaerobic conditions appeared within the aquifer in the summer, but iron and manganese did not appear in the abstracted water; the high removal capacity of RBF for E. coli was maintained during summer, but E. coli breakthrough was observed in the well during the flood event in 2003
- **Implications:** anticipated lower river flows/levels and warmer river temperature during the summer, and increased flooding during the winter associated with climate change will make the management of river bank filtration waterworks more challenging

2.8.1 Location

About 600,000 inhabitants of the city of Dusseldorf in North-West Germany are supplied with treated bank filtrate by four waterworks in the lower Rhine valley. The four waterworks include vertical wells and horizontal collector wells and abstract raw water from a Quaternary aquifer with a proportion of 50 to 90% of bank filtrate. A water demand of about 60 million m³/year and up to 210,000 m³/day has to be provided, but this represents only around 2 m³/s out of the mean discharge of the Rhine at Dusseldorf is 2,200 m³/s, increasing up to 10,000 m³/s during flood events.

A test site was installed at one of the waterworks, which consisted of two multi-level wells which are situated between the river Rhine and the production well (Figure 28). The raw water is abstracted by a network of 55 siphon wells. In a siphon well system a delivery height of less than 7 m, representing the height difference between the water level within the well and the siphon tube, has to be maintained, which is dependent on the river water level and the abstraction rate at the central well - the lower the river level and higher the abstract rate, the greater the delivery height. Furthermore the water level should not drop below the top of the filter screen to avoid qualitative impacts.

Past hydrological conditions as an analogue of future performance of RBF: The summer 2003 was extraordinarily dry in Central Europe and often serves as an example of climate change for the area. In 2003, water levels in the Rhine were unusually low, being about 2 metres below the mean water level for several weeks. Eckert et al. (2008) report the effects of these low water levels on the RBF performance and the water quality of the river, bank filtrate and the extracted
raw water. In contrast to the horizontal wells at the other well fields, the capacity of siphon wells (because of their delivery height limitation) is more vulnerable with regard to low water levels.

However, despite the low river levels at around 28 m asl, the desired maximum capacity of 50 m$^3$/h could be realised without problems demonstrating that insignificant quantitative impact of low water events on the capacity of the well field (Figure 29). This is a consequence of good design, with the well screens and the siphon tube connecting the individual wells being constructed deep enough to allow for the low river water levels.

![Cross section of the river Rhine and the adjacent aquifer and monitoring and production well](from Eckhert et al., 2008).

![Graph showing water level and pumping rate](content)

Figure 28: Cross section of the river Rhine and the adjacent aquifer and monitoring and production well (from Eckhert et al., 2008).
The low rate of river discharge associated with the low river water levels resulted in decreased river water quality. Comparison of the river and bank filtrate water during summer 2003 showed that:

- the temperature of the bank filtrate never exceeded 20°C (compared to the maximum river temperature of over 25°C), indicating the thermal absorption capacity of the aquifer (Figure 30);
- Biological activity was sufficiently high that anaerobic conditions appeared within the aquifer over a period of nearly three months (Figure 30);
- Iron or manganese, which can be mobilised in their reduced form, did not appear in the abstracted water;
- Despite E. coli counts of between 100 and 10,000 in the river water, no E. coli were observed in the well demonstrating the high removal capacity of RBF (Figure 30).
2.8.2 Conclusions

Although this case study demonstrated that the RBF had a good buffering effect to the impacted river water quality during this warm, low flow period, this was in part due to the improved river water quality which is a consequence of the water quality improvements made over the past 30 years. The anticipated lower river flows/levels and warmer river temperature during the summer, and increased flooding during the winter associated with climate change will make the management of river bank filtration waterworks more challenging.
2.9 Case Study – lake bank filtration

Key Points

- **Location**: Lake bank filtration sites at lakes Tegel in Berlin (Germany) and Lake Nainital (northern India)
- **Climate**: historical. Investigation in Lake Nainital under monsoonal and non-monsoon conditions
- **Findings**: acceptable water quality was maintained through monsoon and non-monsoon conditions in India; decreasing nitrate concentrations and increasing ammonium, soluble manganese (Mn2+) and iron (Fe2+) concentrations were found with increasing temperature due to increased anoxic processes in the porewater
- **Implications**: Surface water warming is likely to represent a more important potential threat to the lake bank filtration processes than changes in the precipitation-excess. Increased development of anaerobic conditions in bank filtration zone may lead to reduced self-purification potential and require the installation of additional conventional treatment to secure acceptable drinking water quality.

2.9.1 Location

Given the paucity of published studies on lake bank filtration sites and their possible vulnerability to climate change, studies from two lake bank infiltration sites have been used.

Lake bank filtration has been used for drinking water supply in Berlin, Germany, for more than 100 years. Approximately 70% of the drinking water supplied to the 3.4 million inhabitants of Berlin comes from lake bank filtration and artificial groundwater recharge. Large capacity waterworks are located at lakes Müggelsee, Tegel and Wannsee.

Lake bank filtration has been in use at Nainital in northern India for more than 15 years. Seven tube-wells (depths 22.6–36.7 m) located at a distance of <100 m from the lake are being used to abstract 24.1 ML/day.

2.9.2 Results

The performance of the lake bank filtration site at Lake Nainital was investigated under monsoonal and non-monsoon conditions (Dash et al 2008), thereby providing an indication of the climatic (precipitation-excess) sensitivity of such systems. Although the lake water at Nainital is not potable due to unacceptable levels of organic matter in terms of Chemical Oxygen Demand/COD (~44 mg/L), coliforms (~15.6 x 10^4 MPN/100 mL) and nutrients, coliform bacteria and COD have not been detected in any samples from the tube-well which are located <100 m from the lake. The tube-well water when compared with lake water showed 5.2 log removal of total coliform, 4.2 log removal of fecal coliform, 1.4 log removal of turbidity and 1.6 log removal...
of organics (in terms of COD), with little differences between monsoon and non-monsoon conditions. Nitrate levels in bank filtrate increased from 0.2–0.3 mg/l in the lake water to an average of 3.5 mg/l in both monsoon and non-monsoon conditions, which might be ascribed to mineralisation of organic matter under oxic conditions (Dash et al., 2008). The lake water component in the water pumped from the bank filtration wells is lower in the non-monsoon season (25–40%) compared to the monsoon season (80%).

Surface water warming is an important potential threat to the lake bank filtration processes, because most infiltration occurs in the shallow zones. Often the lake bank/beach is the main infiltration area as it is continuously cleaned by the action of waves, whereas infiltration through thick organic deposits at the lake bottom is limited (Grischek and Ray 2009). Increasing water temperatures will lead to a decrease of oxygen concentrations (due to the intensification of metabolic processes) and the probability of increased anaerobic conditions in bank filtration zone. Aerobic microorganisms are the active components of self-purification processes in bank filtration, as the anaerobic microbial community is less effective, and metabolic processes are slower.

The effect of climate change on the water purification processes acting within lake bed infiltration was examined at Lake Tegel in Berlin, using the significant increase in the recorded near-surface water temperature of 2.4°C within the last 30 years (Gross-Wittke et al. 2010). They found decreasing redox potentials with increasing temperature and depth, indicating the utilisation of oxygen for microbial respiration and the development of anoxic (no oxygen) conditions at shallow depth, despite a high infiltration flow velocity of oxygen-rich lake water of 0.5 m/d. This was associated with decreasing nitrate concentrations and increasing ammonium, soluble manganese (Mn²⁺; Figure 32) and iron (Fe²⁺) concentrations with increasing temperature due to anoxic processes in the porewater. Iron in the bank filtrate from the lake Vihnužiärvi in Finland is removed in post treatment in the Nokia waterworks. There was no evidence of significant sulphate reduction leading to the development of hydrogen sulphide at Lake Tegel.
site which would be unacceptable for the drinking water purification process, although some highly localised pyrite crystallisation was observed (Gross-Wittke et al. 2010).

The efficiency of bank filtration systems at lakes strongly depends on the type of deposits in the lake. A change in lake level due to climate change may lead to short-term changes in lake infiltration until wave action has removed accumulated deposits.

### 2.9.3 Conclusions

Surface water warming is likely to represent a more important potential threat to the lake bank filtration processes than changes in the precipitation-excess. This is because most infiltration occurs in the shallow zones of highest water temperature and which strongly affects the development of anaerobic conditions in bank filtration zone, leading to reduced self-purification potential and higher dissolved manganese, iron and (potentially) hydrogen sulphide concentrations. This may require the installation of additional conventional treatment to secure acceptable drinking water quality.
2.10 Case Study – Unconfined aquifer - Coastal/island

Key Points

- **Location**: unconfined aquifers within the island of Cyprus
- **Climate**: historical climate, with significant reductions (~17%) in annual precipitation since 1970s
- **Findings**: coastal aquifers are over-exploited with significant areas of declining groundwater levels, including levels below mean sea level; increased saline intrusion is predominantly a consequence of reduced groundwater recharge (due to climate and unintended surface water measures) and over-abstraction.
- **Implications**: coastal and island aquifers can highly vulnerable to saline intrusion arising changes to the aquifer waterbalance as a consequence of natural or man-made changes to recharge, over-abstraction and relative sea level rise. Changes in water management (supply-side and demand-side) may be more important than climate change for future drinking water resources

2.10.1 Location

Cyprus is the third largest island of the Mediterranean. It is classified as one of the “water poor countries” in Europe, with the most acute shortage: it has Europe’s highest Water Exploitation Index (WEI), exceeding 40% since the late 1990s. Most of the Island aquifers are unconfined/phreatic, developed in river or coastal alluvial deposits, with half of the 20 groundwater bodies having a connection with the sea and 13 of them have been placed under protection for drinking use (Water development Department, 2011). Recharge comes from precipitation, artificial recharge and river leakage, but the latter has been significantly reduced since the 1960s due to the damming of the major rivers. This report focuses on the Acrotiri and Kokkinochoria aquifers (Figure 33), although it places them in the context of the island’s waterbalance.
2.10.2 Results

Decreased precipitation caused the mean annual inflow to dams decrease by around 40%, causing severe water shortage. In response to the water balance shortfall from dams, aquifers were overexploited, although they were already at stress due to lower natural and artificial recharge (Demetriou & Georgiou, 2004). The situation was further compounded when the government prioritised drinking water supply, resulting in reduced water availability for irrigation and illegal groundwater abstraction and overpumping for irrigation.

The most recent detailed available study concerning groundwater balance covers the period 1991-2000 dates, and shows a net extraction of 15.3 million m³ per year, despite saline intrusion of 12.8 million m³ per year (Table 5). Today, although extraction for drinking water purposes has been reduced from 24.7 x 10^6 m³ to 11.8 x 10^6 m³ per year, aquifers are still overexploited by around 40% of their sustainable exploitation.

Table 5: Annual groundwater balance of Cyprus averaged over period 1991-2000 – Adapted from Water Development Department, 2002 (cited in Demetriou & Georgiou, 2004).

<table>
<thead>
<tr>
<th>Aquifer replenishment (10^6 m³)</th>
<th>Outflow from aquifer (10^6 m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rainfall</td>
<td>Domestic water abstraction</td>
</tr>
<tr>
<td>River flows / Groundwater inflows</td>
<td>Irrigation</td>
</tr>
<tr>
<td>Return from irrigation / Domestic /</td>
<td>Industry</td>
</tr>
<tr>
<td>Dam losses</td>
<td>Total natural recharge</td>
</tr>
<tr>
<td>Artificial recharge</td>
<td>Total extraction</td>
</tr>
<tr>
<td>Sea intrusion</td>
<td>Groundwater outflow</td>
</tr>
<tr>
<td><strong>TOTAL RECHARGE</strong></td>
<td><strong>TOTAL OUTFLOW</strong></td>
</tr>
</tbody>
</table>
The over-exploitation of groundwater resources is apparent in the hydrographs of coastal aquifers (see example on Figure 34), in which the water table has dropped below Mean Sea Level (MSL) over extensive areas (Figure 35). This deficit in groundwater makes coastal aquifer vulnerable to seawater intrusions, despite upward tectonic movements in the Island offsetting potential sea level rise.

Figure 34: Hydrograph of borehole 749 of the Akrotiri Aquifer
Figure 35: Contour map of groundwater levels in the (upper) Akrotiri aquifer and (lower) Kokkinochoria aquifer in autumn 2011, with pink/red indicating areas with groundwater levels below mean sea level (Source: Water Development Department, 2012)

2.10.3 Conclusions

Coastal aquifers can be highly vulnerable to saline intrusion arising changes to the aquifer waterbalance as a consequence of natural or man-made changes to recharge, over-abstraction and relative sea level rise. In Cyprus, tectonic uplift is counter-acting sea level rise, so the increases in saline intrusion are predominantly a consequence of reduced groundwater recharge and over-abstraction. From the perspective of the groundwater resources, the damming of the surface waters as a response to drought represents an unintended negative impact. The Water Development Department has adopted a series of supply-side (seawater desalination for drinking water, utilisation of recycled wastewater for irrigation) and demand-side (to alleviate demand to aquifers from agriculture and households) measures to reduce their coastal aquifers’ vulnerability to climate change.
2.11 Case Study – Unconfined aquifer - Inland - high storage rock aquifer

Key Points

- **Location:** unconfined chalk aquifer in the Geer basin in eastern Belgium
- **Climate:** baseline, together with various timeslice and transient regional climate model scenarios. The future climate of the Geer basin will consist of warmer, wetter winters and much hotter, drier summers, with a more pronounced annual cycle of temperature and precipitation
- **Findings:** Large uncertainties in the direction of change for both surface flow rate and mean groundwater hydraulic head during 2011–2040, but a significant decrease in groundwater levels and flow rate is projected by 2041–2070 and 2071–2100, such that mean groundwater levels are expected to decrease by 2–8 m by 2071–2100.
- **Implications:** Reduced river flows in the low flow discharge period and lower groundwater levels may necessitate a change in the groundwater extraction policy in the basin, which mostly utilises galleries, rather than boreholes

2.11.1 Location

The Geer sub-catchment is located in eastern Belgium, northwest of the city of Liège, and covers approximately 480 km² on the west bank of the Meuse River (Figure 36). The main aquifer in the region is the chalk which is unconfined over most of the basin. It is underlain by impermeable clays and overlain by a thick layer of loess and locally sand lenses.

The chalk has a total porosity of around 44%, enabling the storage of large quantities of groundwater, while fast preferential flow occurs through fractures. The saturated zone is usually exclusively within the chalk, with the overlying loess layer controlling the infiltration to the chalky aquifer, resulting in smoothed recharge fluxes at the groundwater table. The ‘aquifer is heavily exploited for drinking water, primarily through more than 40 km of pumping galleries below the chalk water table.

The impact of climate change on the Geer basin has been the subject of extensive groundwater modelling studies, using GCM 30-year timeslices for an unspecified emissions scenario (Brouyère et al., 2004), using six regional climate model scenarios for 30-year timeslices for the A2 (medium-high) emissions (Goderniaux et al. 2009) and using transient stochastic scenarios based on six regional climate model scenarios (Goderniaux et al. 2011).

The climate change scenarios for the 2071–2100 time period (Goderniaux et al. 2009) show a general increase in temperature throughout the year (with the largest increases during summer and the smallest increase during late winter/early spring), and an annual mean temperature increase ranging from 3.5 - 5.6 °C. The RCMs consistently project a decrease in annual precipitation but there is a large range from -1.9 % to -15.3 %, with large decreases during summer months and smaller increases in winter precipitation.
2.11.2 Results

No clear changes compared to the baseline were identified by Goderniaux et al. (2009) during 2011–2040 (Figure 37), with large uncertainties in the direction of change for both surface flow rate and mean groundwater hydraulic head. However, by 2041–2070 and 2071–2100, a significant decrease in groundwater levels and flow rate is projected, such that mean groundwater levels are expected to decrease by 2–8 m depending on location in the Geer basin by 2071–2100.

These values are similar to those given by Brouyère et al. (2004), who suggests that the thick unsaturated zone will smooth out the seasonal changes in percolation, making it difficult to observe any clear variation in seasonal changes of groundwater levels between the baseline and the climate change simulations. Given the spatially variable changes in projected groundwater levels, Brouyère et al. (2004) suggested that groundwater levels might locally decline below the base level of the southern pumping gallery (Figure 36).
2.11.3 Conclusions

The projected declines in groundwater level, by up to 8m, would represent a major impact on groundwater abstraction and the requirement for a reconsideration of the groundwater extraction policy in the basin. This might necessitate a decrease or a cessation of water abstraction in the southern gallery and a possible transfer of the water production to the northern gallery.
2.12 Case Study – Confined aquifer - inland

Key Points

- **Location**: confined chalk aquifer within the south east of UK
- **Climate**: palaeoclimate, historical climate, baseline climate, and ensemble of GCM outputs for A2 emission scenario for the 2080s
- **Findings**: The effect of the climate change scenario-induced reductions in recharge on the simulated groundwater levels at a borehole located in the confined part of the aquifer were much smaller than for those in the unconfined part. Analyses of groundwater collected within the confined portion of the chalk aquifer within the London Basin indicate that recharge occurred during much cooler periods around 18,000 years Before Present.
- **Implications**: Groundwater levels within the confined areas are less sensitive and slower responding to changes in climate than in the unconfined recharge area due to the limited groundwater flow in the confined aquifer, compared to the unconfined aquifer.

2.12.1 Location

The Chalk is an important groundwater source for public water supply both in the United Kingdom (UK) and in nearby parts of Europe, and it is the most important aquifer in England. The Chalk is a dual-porosity aquifer which stores relatively immobile water in the fine-grained porosity of the matrix but transmits water via a more conductive fracture and fissure system. The aquifer is underlain by, and is generally in hydraulic continuity with, the Upper Greensand (Lower Cretaceous) aquifer. Up to 70 m of Gault Clay (Lower Cretaceous) forms the basal aquitard for both aquifers. The confined chalk aquifer system is overlain by up to 150 m of low hydraulic permeability Eocene clays (London Clay).

In the London Basin of SE England, progressive increase in groundwater abstraction since the late 1800s led to aquifer overexploitation, such that groundwater levels in the centre of the Basin fell by as much as 70 m. However, in recent decades less water has been pumped from the Chalk beneath Central London, and water levels in the region are gradually recovering (Wilkinson and Brassington, 1991; Lucas and Robinson, 1995). Groundwater recharge occurs on the northern and southern Chalk outcrops, and in the London Basin the general flow is towards discharge areas in the Lower Thames Valley (Fig. 1), although recent water resource developments of the Chalk and Tertiary Sands through pumped wells has intercepted the natural discharge, and these abstractions are now the main outlet for the confined area.

2.12.2 Results

This study by Jackson et al. (2011) used outputs from 13 GCMs to calculate changes in groundwater recharge and then groundwater levels. The decrease in potential recharge is...
greater than 10% for the majority of GCMs across east of the study area whereas in the central and western region, generally less than one-third of the GCMs predict a decrease greater than 10% (Figure 38). However, these changes in recharge lead to spatially different responses in groundwater level (Figure 39), with the modelled groundwater heads at sites close to the unconfined/confined boundary (Manton House Farm) and within the confined aquifer (Great Park Farm) being much reduced. The effect on the groundwater level at the Great Park Farm is small because this is located in the confined part of the aquifer, where groundwater flow is limited, and suggests the lower sensitivity of groundwater levels in the confined aquifer to climate change.

Figure 38: Distribution of the number of GCM scenarios in which more than a 10% decrease in potential recharge is simulated (from Jackson et al., 2011) [Areas with 0 GCMs cover the confined part of the aquifer]
Figure 39: Change in mean groundwater level at observation boreholes for each GCM [Great Park Farm is within the confined aquifer; Manton House Farm is located close to the confined/unconfined boundary] (from Jackson et al., 2011)

Elliot et al. (1999) sampled groundwater along two approximate flowlines (S-N and W-E) from Chalk outcrop to the centre of the London Basin. Given a current mean annual air temperature at Kew Garden in London of 10.5°C, significantly cooler recharge temperatures, determined from the concentration of noble gases within the groundwater, occur downgradient towards the centre of the London Basin. Despite the over-exploitation of the chalk aquifer in the London Basin in the 19th and early 20th centuries, their analyses of the groundwater hydrogeochemistry indicates that the in-situ groundwater in the confined area of the London Basin was recharged under a colder climate than present occurring around 18,000 years Before Present (BP).

2.12.3 Conclusions

The combination of the small changes in simulated groundwater levels within the confined areas and the estimated recharge age of the groundwater demonstrates that confined aquifers can be less sensitive and slower responding to changes in climate than in the unconfined recharge area due to the limited groundwater flow in the confined aquifer.
2.13 Case Study – Unconfined aquifer - Inland - karstic or hard rock aquifers

Key Points

- **Location**: shallow aquifer zone with fractured crystalline rock aquifer in the Bohemian Massif, Czech Republic
- **Climate**: recent climate analogues together with groundwater model under conditions of 25% reduction in infiltration
- **Findings**: crystalline shallow aquifer in the Bohemian Massif is very vulnerable to a decline in atmospheric precipitation and infiltration; significant spatial differences in observed watertable decline, of up to 10m in the recharge areas (interfluves) and steep slopes and only around a metre in the discharge zone (valley bottoms), causes greater reductions in groundwater body thickness away from local streams
- **Implications**: horizontal wells or drains may be required due to the reduced groundwater body thickness; increase groundwater recharge from surface water courses; manage vegetation to reduce evapotranspirative losses

2.13.1 Location

The study was performed in two catchments in the Bohemian Massif in the Czech Republic. The area is composed of metamorphic and plutonic rocks that form around three-quarters of the area of the Bohemian Massif. Groundwater storage and flow in the Bohemian Massif typically occurs in a relatively shallow aquifer zone formed by weathered rocks containing open fractures, which locally reach up to several tens of meters in thickness. Groundwater storage and flow tend to decrease with depth in the groundwater body.

Two pairs of shallow (10m deep) and deep (25m deep) boreholes were installed and monitored in the recharge and discharge areas of two catchments over three years. A MODFLOW groundwater model was applied to one of the catchments to simulate changes in spatial groundwater levels.

2.13.2 Results

Observed seasonal ranges in groundwater level were greater in the recharge areas than the discharge areas, being 5.5-7.5 m in the recharge areas compared to less than 2m in the discharge areas. Figure 40 shows the rapid, but transient, response of the watertable to precipitation, particularly in the monitoring wells in the recharge zone (H3 and H4). Groundwater levels in the discharge areas (H1 and H2) during periods of low recharge were relatively constant, indicating an important surface water control on groundwater levels.

Having calibrated their groundwater model to the observed watertable levels, they simulated groundwater levels during a twelve-month period of in which recharge was reduced by 25%
compared to the mean. The spatial map of groundwater-level fluctuation (Figure 41) shows the importance of the landscape position of abstraction points in hard rock aquifers, with boreholes and wells located in discharge areas, close to the valley, being much less vulnerable to climate change than those located in recharge areas, on slopes and near groundwater divides.

Figure 40: Observed groundwater levels and precipitation (2004-2006) within a hard rock aquifer

Figure 41: Spatial map of groundwater-level fluctuation.
2.13.3 Conclusions

The low storage capacity of such shallow hard rock aquifers makes their groundwater levels highly sensitive to changes in the amount and/or timing of groundwater recharge. Reductions in the amount of recharge or increasing seasonality to the recharge will lead to greater reductions in the thickness of the groundwater body in the recharge areas compared to in the discharge areas where groundwater levels can be controlled by the local surface water network.

Reducing groundwater body thickness has significant implications for groundwater abstraction from wells and boreholes. Hrkal et al. (2009) suggest three possible adaptation options in such environments: (1) increase use of horizontal wells or linear drains to abstract groundwater; (2) river restoration to slow rivers and increase the potential for recharge during periods of high river water levels; and (3) management of vegetation cover to reduce evapo-transpiration (although not at the expense of increased runoff and flood risk).

2.14 Case Study – Confined aquifer - Coastal

Key Points

- **Location:** Confined alluvial multi-aquifer system within the lowlying coastal Dutch Delta
- **Climate:** baseline (2000) climate and climate change scenarios for 2100 of 0.85m and 2.0m sea level rise with wet (increasing precipitation in both summer and winter) and dry (decreasing precipitation in summer), together with large increases in evapotranspiration;
- **Findings:** Coastal groundwater systems can be impacted by both climate change and sea level rise, although the latter may be more important in systems with strong surface water level management. However, they can also be adversely affected by ongoing autonomous salinization associated with past and ongoing processes (such as lake reclamation, water level management and land subsidence). The propagation of future sea level rise into these coastal aquifers is determined by the geohydrological setting - where the confining layer is thin and permeable, the effects are strongly attenuated as the increase in pressure due to sea level rise can easily be released resulting in locally high (brackish) seepage rates and also in a small zone of influence..
- **Implications:** Procedures for coping with water shortages during summer droughts are needed in order to avoid resource degradation in these vulnerable systems. Countermeasures to prevent or to retard the salinization process can be ineffective and that there is probably no measure effective enough to be used...
under all conditions, with a combination of different interventions needed to decrease the future salt load

2.14.1 Location

Oude Essink et al. (2010) studied the Dutch Delta groundwater system, covering an area of around 100 km by 92.5 km in the southwest of the Netherlands in the delta of the rivers Rhine, Scheldt and Meuse (Figure 42). This coastal area is the most densely populated part of the Netherlands, with more than 8 million people, and includes Amsterdam, Rotterdam, The Hague and Utrecht. The area is characterized by a diversity of land types, including the dunes, polders and peatlands.

The area contains a multi-layered aquifer system consisting of 4 aquifers and 5 aquitards (lower permeability layers), with the top confining layer consisting of poorly permeable Holocene clay and peat deposits, except for the dunes where it consists of sand. Large amounts of groundwater are extracted from the coastal dunes in the west, where the watertable can rise to more than 7 m above msl, and from the eastern part of the study area to supply the demand for drinking water. The landward side of the dunes consists of deep polders, or reclaimed lake areas, where surface water levels are controlled by pumping at between −4 m to −7 m msl, leading to upward groundwater seepage from the first aquifer under these deep polders.

The authors constructed a regional three-dimensional density-dependent groundwater model with model cells of 250 × 250 m² and 40 layers, to deal with the complex geology and complex distribution of fresh, brackish and saline groundwater, giving four million cells. 5772 chloride concentration measurements over the period 1867–2001 A.D were used to help define the baseline groundwater salinity distribution (Figure 42). After calibration against 395 groundwater level measurements, the median of the difference between the calculated minus measured freshwater groundwater level was only 0.17 m. Oude Essink et al. (2010) used four climate scenarios for which sea level rise and precipitation surplus differed, based on data from KNMI. They used a realistic estimation of sea level rise of 0.85 m in 2100 A.D and also more extreme, but possible, sea level rise of 2.0 m. These were combined with a “wet climate scenario” with increasing precipitation in both summer and winter and a “dry climate scenario” with decreasing precipitation in the summer, with both having a large increase in evapotranspiration.
2.14.2 Results

The groundwater levels within the upper aquifer increased due to sea level rise in all of the climate scenarios, although the increases were limited to a zone of influence within 10km of the coastline and main rivers. By 5km from the coast, the rise in groundwater levels was reduced to an average of about 40% of the sea level rise. Inland of this zone, the combination of continuing land subsidence and decreasing recharge in the “dry climate scenario” caused groundwater levels to decline by up to 1m.

Present groundwater seepage occurs in 40% of the study area (Figure 43), characterized by low-lying polders where hydraulic heads in the first aquifer exceed the shallow watertable and surface water levels. Seepage fluxes are significantly changed by climate change, ongoing land subsidence and sea level rise, because these processes cause hydraulic heads and phreatic water levels to change. These effects on salt loads for the “wet climate scenario” with 2m sea level rise in the year 2100 A.D. are shown in Figure 44. The large increase of salt loads in the southwestern part of the study area is caused by sea level rise, whereas land subsidence (due to continuing drainage) is the main cause of increasing salt loads in the rest of the study area.
Literature review on the potential climate change effects on drinking water resources across the EU and the identification of priorities among different types of drinking water supplies – ADWICE project

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Figure 43: Calculated present salt loads to surface water systems in 2000 A.D.

Figure 44: Change in salt loads in 2100 A.D. for the "wet climate scenario" with 2m sea level rise.

The effect of the changing precipitation surplus within the climate change scenarios recharging the groundwater system is small and local, as the polder water levels are mainly controlled by weirs and pumps, although it will affect surface water salinity due to changed dilution. The fresh groundwater volume is projected to decrease in percentage terms by less than 1%, this represents a loss of between -200 and -2750 million m³ of fresh groundwater. This may be compounded by upconing of deeper and more saline groundwater arising from large extractions for drinking water (Figure 45).
The implications of the changes in hydraulic heads, seepage fluxes and salt loads arising from future sea level rise, climate change and land subsidence for the urban and agricultural parts of the delta areas are summarized in Table 6.

Table 6: Possible socioeconomic impacts in coastal groundwater systems (after Oude Essink et al., 2010)

<table>
<thead>
<tr>
<th>Sector</th>
<th>Groundwater-related problems</th>
<th>Physical cause</th>
</tr>
</thead>
<tbody>
<tr>
<td>Public safety/flood risk management</td>
<td>Failure of dykes</td>
<td>Change in hydraulic head</td>
</tr>
<tr>
<td>Freshwater supply</td>
<td>Shortages in drinking water and industrial water supply</td>
<td>Decreased fresh water resources</td>
</tr>
<tr>
<td>Environment</td>
<td>Damage to groundwater-dependent terrestrial ecosystems and aquatic ecosystems</td>
<td>Decreasing hydraulic head; saline seepage</td>
</tr>
<tr>
<td>Agriculture</td>
<td>Shortage of fresh water for irrigation; salt damage to crops</td>
<td>Saline seepage and cracking of Holocene confining layer</td>
</tr>
<tr>
<td>Infrastructure and urban areas</td>
<td>Instability of underground infrastructure; rotting poles and building subsidence</td>
<td>Change in hydraulic head</td>
</tr>
</tbody>
</table>
2.14.3 Conclusions

Coastal aquifers can be sensitive to change but also exhibit delayed impacts due to significant lags in response. The present salinity distribution in this groundwater system has not yet reached dynamic equilibrium, as a result of hydrogeological events over the past hundreds of years such as transgressions, land subsidence, land reclamation and groundwater extraction. Although managing flood risk is the most important water management issue for the Dutch government, fresh water supply is second given the challenge of maintaining high quality fresh water in this lowlying coastal nation. The Dutch Water Management Act states the priority for fresh water users in the case that there is a water shortage during a summer drought in order to avoid resource degradation, with the order of preference for use being (1) stability of embankments, shrinkage and oxidation of peat, sensitive nature reserves; before (2) domestic water supply and power generation; before (3) industry and sprinkling water of expensive crops (horticulture); before (4) other end users such as agriculture, nature, industry, recreation, navigation.

The propagation of future sea level rise into these coastal aquifers is determined by the geohydrological setting, in particular by the sequence of aquifers and aquitards and their hydraulic properties. The transmissivity of the first aquifer, and thickness and vertical hydraulic conductivity of the top Holocene confining layer, are the dominant factors that determine the zone of influence of sea level rise. Since the composition of the Holocene confining layer is spatially highly variable, effects are strongly attenuated in areas with a thin and highly permeable Holocene confining layer, as the increase in pressure due to sea level rise can easily be released resulting in locally high (brackish) seepage rates and also in a small zone of influence.

Six technical countermeasures to prevent or to retard the salinization process were considered (Oude Essink, 2001c): (1) freshwater injection barriers through injection of fresh (purified sewage) water near the shoreline; (2) extraction of saline and brackish groundwater; (3) modifying pumping practice through reduction of withdrawal rates or relocation of extraction wells; (4) land reclamation and creating a foreland where a freshwater body may develop which could delay the inflow of saline groundwater; (5) increase of (artificial) recharge in upland areas to enlarge the outflow of fresh groundwater through the coastal aquifer; and (6) creation of physical barriers, such as sheet piles, clay trenches and injection of chemicals. Oude Essink et al (2010) demonstrate that countermeasures can be ineffective and that there is probably no measure effective enough to be used under all conditions, with a combination of different interventions needed to decrease the future salt load.

2.15 References for the case studies

ALM Project Profile 2008 - Lake Balaton Integrated Vulnerability Assessment, Early Warning and Adaptation Strategies. Available at: www.adaptationlearning.net/category/tags/lakes

Literature review on the potential climate change effects on drinking water resources across the EU and the identification of priorities among different types of drinking water supplies – ADWICE project


Klijn, F., J. Kwadijk, K. de Buijn & J. Huinink (2010), Overstromingsrisico’s en droogterisico’s in een veranderend klimaat. Verkenning van wegen naar een klimaatveranderingsbestendig Nederland, rapportnummer 100265-000, Delft: Deltares.


PBL Netherlands Environmental Assessment , 2011, Climate Adaptation in the Dutch Delta. Strategic options for a climate-proof development of the Netherlands


Water Development Department, 2012

Zwolsman et al. (2011), Water for utilities: climate change impacts on water quality and water availability for utilities in Europe, WATCH, FP6

3.1 Water Framework Directive

The Water Framework Directive establishes a strategic framework for the protection of all water bodies, i.e. rivers, lakes, coastal waters and groundwater in a highly integrated manner. As the cornerstone of EU water policy, the Water Framework Directive requires that all water bodies must meet the standard of “good status” as a rule by the end of 2015. The Water Framework Directive (WFD) streamlines and simplifies the existing body of EU legislation by repealing several EU water acts as from December 2013.

Under the WFD, bodies of water used for the abstraction of drinking water are identified and regularly monitored. They must meet the WFD quality requirements (good ecological status and good chemical status) as well as the DWD quality requirements under water treatment regime. Water bodies used for abstraction for human consumption have to be protected with the aim of improving water quality and reducing necessary water treatments. Designated protected areas shall be mapped and added to a national register of protected areas which is kept up to date and under review.

Under the WFD, if there were adverse effects on DW supply in the case of changes to achieve good ecological status, the concerned water bodies would be considered heavily modified water body (to be protected, enhanced and restored according to Article 4.1):

- **Article 4 - Environmental objectives**

  3. Member States may designate a body of surface water as artificial or heavily modified, when:

  (a) the changes to the hydro-morphological characteristics of that body which would be necessary for achieving good ecological status would have significant adverse effects on:
  
  - activities for the purposes of which water is stored, such as Drinking-water supply, power generation or irrigation;
  - water regulation, flood protection, land drainage, or
  - other equally important sustainable human development activities;

  (b) the beneficial objectives served by the artificial or modified characteristics of the water body cannot, for reasons of technical feasibility or disproportionate costs, reasonably be achieved by other means, which are a significantly better environmental option. Such designation and the reasons for it shall be specifically mentioned in the river basin management plans required under Article 13 and reviewed every six years.
MS have to identify, register and monitor (cf Annex V) water bodies for drinking purposes:

**Article 6 – register of protected areas**

1. Member States shall ensure the establishment of a register or registers of all areas lying within each river basin district which have been designated as requiring special protection under specific Community legislation for the protection of their surface water and groundwater or for the conservation of habitats and species directly depending on water. They shall ensure that the register is completed at the latest four years after the date of entry into force of this Directive.

2. The register or registers shall include all bodies of water identified under Article 7.1 and all protected areas covered by Annex IV [DWD, BWD, UWWTD, ND...]

Drinking water bodies must meet the general environmental objectives (Article 4) and the DWD requirements under water treatment regime. MS also have to protect DW sources to improve quality and reduce water treatment:

**Article 7 - Waters used for the abstraction of Drinking water**

1. Member States shall identify, within each river basin district:
   - all bodies of water used for the abstraction of water intended for human consumption providing more than 10 m³ a day as an average or serving more than 50 persons, and
   - those bodies of water intended for such future use.

Member States shall monitor, in accordance with Annex V, those bodies of water which according to Annex V, provide more than 100 m³ a day as an average.

2. For each body of water identified under paragraph 1, in addition to meeting the objectives of Article 4, in accordance with the requirements of this Directive, for surface water bodies including the quality standards established at Community level under Article 16, Member States shall ensure that under the water treatment regime applied, and in accordance with Community legislation, the resulting water will meet the requirements of Directive 80/778/EEC as amended by Directive 98/83/EC.

3. Member States shall ensure the necessary protection for the bodies of water identified with the aim of avoiding deterioration in their quality in order to reduce the level of purification treatment required in the production of Drinking water. Member States may establish safeguard zones for those bodies of water.
Water pricing policies should take into account climatic conditions:

**Article 9**

1. Member States shall take account of the principle of recovery of the costs of water services, including environmental and resource costs, having regard to the economic analysis conducted according to Annex III, and in accordance in particular with the polluter pays principle L 327/12 EN Official Journal of the European Communities 22.12.2000.

Member States shall ensure by 2010:

that water-pricing policies provide adequate incentives for users to use water resources efficiently, and thereby contribute to the environmental objectives of this Directive,

an adequate contribution of the different water uses, disaggregated into at least industry, households and agriculture, to the recovery of the costs of water services, based on the economic analysis conducted according to Annex III and taking account of the polluter pays principle.

Member States may in so doing have regard to the social, environmental and economic effects of the recovery as well as the geographic and climatic conditions of the region or regions affected.

Measures to protect drinking water sources are considered basic measures (i.e. they are part of the minimum requirements to be complied with):

**Article 11 - Programme of measures**

3. Basic measures are the minimum requirements to be complied with and shall consist of:

[...]

(d) measures to meet the requirements of Article 7, including measures to safeguard water quality in order to reduce the level of purification treatment required for the production of Drinking water;

Drinking water sources need to be protected from pollution by individual pollutants or groups of pollutants.
Areas designated for the abstraction for DW must be included and mapped in the register of protected areas:

ANNEX IV - PROTECTED AREAS

1. The register of protected areas required under Article 6 shall include the following types of protected areas:
   - areas designated for the abstraction of water intended for human consumption under Article 7;
   - [...]
Surface drinking water bodies shall be monitored at determined frequencies:

<table>
<thead>
<tr>
<th>Community served</th>
<th>Frequency</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;10 000</td>
<td>4 per year</td>
</tr>
<tr>
<td>10 000 to 30 000</td>
<td>8 per year</td>
</tr>
<tr>
<td>&gt;30 000</td>
<td>12 per year</td>
</tr>
</tbody>
</table>

3.2 Drinking Water Directive

The Drinking Water Directive requires MS to meet binding quality standards to ensure safe drinkable water from the tap, to monitor whether the standards are complied with and to inform consumers and the public accordingly.

It sets Criteria for a clean and wholesome water: no parasites, micro-organisms or hazardous substances, and compliance with requirements set out in Annex (microbiological and chemical parameters).
Final report - Annexes

The quality requirements set out in the DWD are minimal and MS have to set applicable values that cannot be less stringent than those set out in Annex:

**Article 4 - General obligations**

1. Without prejudice to their obligations under other Community provisions, Member States shall take the measures necessary to ensure that water intended for human consumption is wholesome and clean. For the purposes of the minimum requirements of this Directive, water intended for human consumption shall be wholesome and clean if it:

   (a) is free from any micro-organisms and parasites and from any substances which, in numbers or concentrations, constitute a potential danger to human health, and

   (b) meets the minimum requirements set out in Annex I, Parts A and B; and if, in accordance with the relevant provisions of Articles 5 to 8 and 10 and in accordance with the Treaty, Member States take all other measures necessary to ensure that water intended for human consumption complies with the requirements of this Directive.

2. Member States shall ensure that the measures taken to implement this Directive in no circumstances have the effect of allowing, directly or indirectly, either any deterioration of the present quality of water intended for human consumption so far as that is relevant for the protection of human health or any increase in the pollution of waters used for the production of drinking water.

**Article 5 - Quality standards**

1. Member States shall set values applicable to water intended for human consumption for the parameters set out in Annex I.

2. The values set in accordance with paragraph 1 shall not be less stringent than those set out in Annex I. As regards the parameters set out in Annex I, Part C, the values need be fixed only for monitoring purposes and for the fulfillment of the obligations imposed in Article 8.

Drinking water quality must be regularly monitored through monitoring programmes that meet requirements set out in Annex:
In the case water quality is not satisfactory; MS should identify the causes and make sure the quality is restored. Supply constituting a potential danger for human health is prohibited or restricted:

**Article 8 - Remedial action and restrictions in use**

1. Member States shall ensure that any failure to meet the parametric values set in accordance with Article 5 is immediately investigated in order to identify the cause.

2. If, despite the measures taken to meet the obligations imposed in Article 4(1), water intended for human consumption does not meet the parametric values set in accordance with Article 5, and subject to Article 6(2), the Member State concerned shall ensure that the necessary remedial action is taken as soon as possible to restore its quality and shall give priority to their enforcement action, having regard inter alia to the extent to which the relevant parametric value has been exceeded and to the potential danger to human health.

3. Whether or not any failure to meet the parametric values has occurred, Member States shall ensure that any supply of water intended for human consumption which constitutes a potential danger to human health is prohibited or its use restricted or such other action is taken as is necessary to protect human health. In such cases consumers shall be informed promptly thereof and given the necessary advice.
Water quality reports are published every three years:

> Article 13 - Information and reporting

1. Member States shall take the measures necessary to ensure that adequate and up-to-date information on the quality of water intended for human consumption is available to consumers.

2. Without prejudice to Council Directive 90/313/EEC of 7 June 1990 on the freedom of access to information on the environment (1), each Member State shall publish a report every three years on the quality of water intended for human consumption with the objective of informing consumers. The first report shall cover the years 2002, 2003 and 2004. Each report shall include, as a minimum, all individual supplies of water exceeding 1 000 m³ a day as an average or serving more than 5 000 persons and it shall cover three calendar years and be published within one calendar year of the end of the reporting period.

### 3.3 Groundwater Directive

This Directive aims to protect Groundwater against pollution and deterioration. Its context presentation establishes a direct link between groundwater and drinking water, although the directive itself does not refer to drinking water. The GWD establishes groundwater quality standards, threshold values for groundwater pollutants and indicators of pollution, and make compulsory the reversal of trends which present a significant risk of harm to ecosystems, to human health or to uses of the water environment.

The GWD establishes criteria for groundwater quality, and sets measure to protect groundwater bodies from deterioration

> Article 1 - Purpose

1. This Directive establishes specific measures as provided for in Article 17(1) and (2) of Directive 2000/60/EC in order to prevent and control groundwater pollution. These measures include in particular:

   (a) criteria for the assessment of good groundwater chemical status; and

   (b) criteria for the identification and reversal of significant and sustained upward trends and for the definition of starting points for trend reversals.

2. This Directive also complements the provisions preventing or limiting inputs of pollutants into groundwater already contained in Directive 2000/60/EC, and aims to prevent the deterioration of the status of all bodies of groundwater.

Threshold values chosen for classification of chemical status take into account potential use as drinking water and are therefore based on human toxicology (among others).
The chemical status of groundwater bodies must be assessed, and a body of GW cannot be considered to have a good chemical status if it is not able to support human uses. Furthermore, bodies of groundwater with good chemical status must be protected to ensure potential human use:

**Article 3 - Criteria for assessing groundwater chemical status**

1. For the purposes of the assessment of the chemical status of a body or a group of bodies of groundwater pursuant to Section 2.3 of Annex V to Directive 2000/60/EC, Member States shall use the following criteria:

   [...] 

   The threshold values applicable to good chemical status shall be based on the protection of the body of groundwater in accordance with Part A, points 1, 2 and 3 of Annex II, having particular regard to its impact on, and interrelationship with, associated surface waters and directly dependent terrestrial ecosystems and wetlands and shall inter alia take into account human toxicology and ecotoxicology knowledge.
Article 4 - Procedure for assessing groundwater chemical status

1. Member States shall use the procedure described in paragraph 2 to assess the chemical status of a body of groundwater. Where appropriate, Member States may group bodies of groundwater in accordance with Annex V to Directive 2000/60/EC when carrying out this procedure.

2. A body or a group of bodies of groundwater shall be considered to be of good chemical status when:

   [...] 

   (c) the value for a groundwater quality standard or threshold value is exceeded at one or more monitoring points but an appropriate investigation in accordance with Annex III confirms that:

   [...] 

   (iv) the ability of the body of groundwater or of any of the bodies in the group of bodies of groundwater to support human uses has not been significantly impaired by pollution.

   [...] 

5. If a body of groundwater is classified as being of good chemical status in accordance with paragraph 2(c), Member States, in accordance with Article 11 of Directive 2000/60/EC, shall take such measures as may be necessary to protect aquatic ecosystems, terrestrial ecosystems and human uses of groundwater dependent on the part of the body of groundwater represented by the monitoring point or points at which the value for a groundwater quality standard or the threshold value has been exceeded.
Article 5 states that deterioration of groundwater bodies shall be reversed to eliminate risks to human health:

> **Article 5 - Identification of significant and sustained upward trends and the definition of starting points for trend reversals**

1. Member States shall identify any significant and sustained upward trend in concentrations of pollutants, groups of pollutants or indicators of pollution found in bodies or groups of bodies of groundwater identified as being at risk and define the starting point for reversing that trend, in accordance with Annex IV.

2. Member States shall, in accordance with Part B of Annex IV, reverse trends which present a significant risk of harm to the quality of aquatic ecosystems or terrestrial ecosystems, to human health, or to actual or potential legitimate uses of the water environment, through the programme of measures referred to in Article 11 of Directive 2000/60/EC, in order progressively to reduce pollution and prevent deterioration of groundwater.

Risks from pollutants to groundwater abstracted for human consumption must be assessed:

> **ANNEX III – Assessment of groundwater chemical status**

4. For the purposes of investigating whether the conditions for good groundwater chemical status referred to in Article 4 (2)(c)(ii) and (iii) are met, Member States will, where relevant and necessary, and on the basis of relevant monitoring results and of a suitable conceptual model of the body of groundwater, assess:

> 

> (e) the risk from pollutants in the body of groundwater to the quality of water abstracted, or intended to be abstracted, from the body of groundwater for human consumption.

### 3.4 Bathing Water Directive

This Directive lays down provisions for the monitoring and classification of bathing water quality, the management of bathing water quality and the provision of information to the public about drinking water quality, with the aim of preserving, protecting and improving the quality of the environment and of protecting human health.

No reference is made to drinking water of human consumption, nor to climate change. However article 8 and 9 deal with some phenomena associated with water temperature increase and change in chemical composition, i.e. cyanobacterial development and algal proliferation.
The Bathing Directive requires that measures are taken to prevent exposure of bathers to health risks in case of cyanobacterial proliferation or algal bloom:

**Article 8 - Cyanobacterial risks**

1. When the bathing water profile indicates a potential for cyanobacterial proliferation, appropriate monitoring shall be carried out to enable timely identification of health risks.

2. When cyanobacterial proliferation occurs and a health risk has been identified or presumed, adequate management measures shall be taken immediately to prevent exposure, including information to the public.

**Article 9 - Other parameters**

1. When the bathing water profile indicates a tendency for proliferation of macro-algae and/or marine phytoplankton, investigations shall be undertaken to determine their acceptability and health risks and adequate management measures shall be taken, including information to the public.

### 3.5 Urban Wastewater Treatment Directive

The Urban Waste Water Treatment Directive is a key element of EU water policy for achieving the Water Framework Directive environmental objective of good status. It requires that wastewater generated by agglomerations is collected and made subject to secondary treatment before being discharged into the natural environment. More stringent treatment must be applied when wastewater is discharged into so-called sensitive areas.

No direct reference is made to drinking water, but the Directive seeks to prevent potential contamination of freshwater resources with urban wastewater, by imposing urban wastewater collection and treatment.

Articles 3 and 4 require that urban waste water must be collected and go through a secondary treatment before being discharged into the environment.
Article 3

1. Member States shall ensure that all agglomerations are provided with collecting systems for urban waste water,
   - at the latest by 31 December 2000 for those with a population equivalent (p.e.) of more than 15,000, and
   - at the latest by 31 December 2005 for those with a p.e. of between 2,000 and 15,000.

For urban waste water discharging into receiving waters which are considered ‘sensitive areas’ as defined under Article 5, Member States shall ensure that collection systems are provided at the latest by 31 December 1998 for agglomerations of more than 10,000 p.e.

Article 4

1. Member States shall ensure that urban waste water entering collecting systems shall before discharge be subject to secondary treatment or an equivalent treatment as follows:
   - at the latest by 31 December 2000 for all discharges from agglomerations of more than 15,000 p.e.,
   - at the latest by 31 December 2005 for all discharges from agglomerations of between 10,000 and 15,000 p.e.,
   - at the latest by 31 December 2005 for discharges to freshwater and estuaries from agglomerations of between 2,000 and 10,000 p.e.

Urban wastewater being discharged into sensitive areas (including surface freshwater intended for the abstraction of drinking water) shall be subject of more stringent treatment:

Article 5

1. For the purposes of paragraph 2, Member States shall by 31 December 1993 identify sensitive areas according to the criteria laid down in Annex II.

2. Member States shall ensure that urban waste water entering collecting systems shall before discharge into sensitive areas be subject to more stringent treatment than that described in Article 4, by 31 December 1998 at the latest for all discharges from agglomerations of more than 10,000 p.e.
Climate is a parameter to take into account for treatment plant design and operation. Although this is not explicit in the text, changes in “seasonal variations of the load” can be induced by a change in precipitation patterns and subsequent modifications of stormwater runoff.

**Article 10**

*Member States shall ensure that the urban waste water treatment plants built to comply with the requirements of Articles 4, 5, 6 and 7 are designed, constructed, operated and maintained to ensure sufficient performance under all conditions. When designing the plants, seasonal variations of the load shall be taken into account.*

DW abstraction sites are potentially sensitive areas for wastewater discharge:

**ANNEX II**

**CRITERIA FOR IDENTIFICATION OF SENSITIVE AND LESS SENSITIVE AREAS**

**A. Sensitive areas**

A water body must be identified as a sensitive area if it falls into one of the following groups:

[...]

(b) surface freshwaters intended for the abstraction of drinking water which could contain more than the concentration of nitrate laid down under the relevant provisions of Council Directive 75/440/EEC of 16 June 1975 concerning the quality required of surface water intended for the abstraction of drinking water in the Member States (1) if action is not taken

### 3.6 Floods Directive

The Floods Directive requires Member States to assess flood risks and to establish flood risk management plans by 2015, with the aim to reduce flood risk for human health, economic activity, the environment and cultural heritage.

Unlike the WFD, the Floods Directive explicitly acknowledges the importance of climate change as a factor increasing the risk of floods and makes provision for a detailed study of CC impacts on flood risk. In addition, for the implementation of the Floods Directive, co-ordination with the implementation of the WFD is required by its article 9 from the second cycle of the WFD river basin management plans (RBMP) onwards. There is an opportunity through alignment to deliver alternative more cost-effective and sustainable catchment based approaches that deliver multiple benefits for flood risk management, water scarcity and drought management and river basin management outcomes. The requirement to coordinate the two Directives therefore
establishes an appropriate framework for implementation, so that differing and conflicting interests can be properly balanced and maximum synergies gained.

The rationale acknowledges that climate change is likely to increase the likelihood of occurrence and adverse impacts of floods. It states that these must be dealt with in a new directive:

Whereas:

2. Floods are natural phenomena which cannot be prevented. However, some human activities (such as increasing human settlements and economic assets in floodplains and the reduction of the natural water retention by land use) and climate change contribute to an increase in the likelihood and adverse impacts of floods.

4. [...] reducing the risk of floods is not one of the principal objectives of [the WFD], nor does it take into account the future changes in the risk of flooding as a result of climate change.

14. Flood risk management plans should focus on prevention, protection and preparedness. With a view to giving rivers more space, they should consider where possible the maintenance and/or restoration of floodplains, as well as measures to prevent and reduce damage to human health, the environment, cultural heritage and economic activity. The elements of flood risk management plans should be periodically reviewed and if necessary updated, taking into account the likely impacts of climate change on the occurrence of floods.

The scope and potential impacts of climate change are to be taken into account for flood risk assessment:

Chapter II – Preliminary Flood Assessment

Article 4

Based on available or readily derivable information, such as records and studies on long term developments, in particular impacts of climate change on the occurrence of floods, a preliminary flood risk assessment shall be undertaken to provide an assessment of potential risks. The assessment shall include at least the following:

(d) an assessment of the potential adverse consequences of future floods for human health, the environment, cultural heritage and economic activity, taking into account as far as possible issues such as the topography, the position of watercourses and their general hydrological and geomorphological characteristics, including floodplains as natural retention areas, the effectiveness of existing manmade flood defense infrastructures, the position of populated areas, areas of economic activity and long-term developments including impacts of climate change on the occurrence of floods.
The impacts of Climate Change must be explicitly mentioned in the reports and reviews of flood risk assessment, flood hazard maps, and flood risk management plans:

Chapter VIII - Reviews, reports and final provisions

1. The preliminary flood risk assessment, or the assessment and decisions referred to in Article 13(1), shall be reviewed, and if necessary updated, by 22 December 2018 and every six years thereafter.

[...] 

3. The flood risk management plan(s) shall be reviewed, and if necessary updated, including the components set out in part B of the Annex, by 22 December 2021 and every six years thereafter.

4. The likely impact of climate change on the occurrence of floods shall be taken into account in the reviews referred to in paragraphs 1 and 3.

Article 16

The Commission shall, by 22 December 2018, and every six years thereafter, submit to the European Parliament and to the Council a report on the implementation of this Directive. The impact of climate change shall be taken into account in drawing up this report.

3.7 Sustainable Use of Pesticides

The Directive stresses that pesticides may contaminate water resources and have adverse effects on drinking water quality. It states that MS must take appropriate measures to protect drinking water supplies from the impacts of pesticides through a number of selected measures. In particular, pesticides cannot be used or stored in areas used for the abstraction of drinking water.

The rationale states that pollution of water bodies should be avoided, and that the use of pesticides near drinking water abstraction sites should be reduced or eliminated.
Under Article 11, MS have to protect drinking water supplies from the impact of pesticides, through adoption of a series of measures that include use of non-dangerous pesticides, efficient application techniques, establishment of buffer zones and reduction or elimination of pesticide use in sensitive areas. In addition, pesticides must not be used or stored in areas used for the abstraction of DW.

**Whereas:**

\[\ldots\]

15. The aquatic environment is especially sensitive to pesticides. It is therefore necessary for particular attention to be paid to avoiding pollution of surface water and groundwater by taking appropriate measures, such as the establishment of buffer and safeguard zones or planting hedges along surface waters to reduce exposure of water bodies to spray drift, drain flow and run-off. The dimensions of buffer zones should depend in particular on soil characteristics and pesticide properties, as well as agricultural characteristics of the areas concerned. Use of pesticides in areas for the abstraction of drinking water, on or along transport routes, such as railway lines, or on sealed or very permeable surfaces can lead to higher risks of pollution of the aquatic environment. In such areas the pesticide use should, therefore, be reduced as far as possible, or eliminated, if appropriate.

**Article 11 - Specific measures to protect the aquatic environment and drinking water**

1. Member States shall ensure that appropriate measures to protect the aquatic environment and drinking water supplies from the impact of pesticides are adopted. Those measures shall support and be compatible with relevant provisions of Directive 2000/60/EC and Regulation (EC) No 1107/2009.

2. The measures provided in paragraph 1 shall include:

\[\ldots\]

(c) use of mitigation measures which minimise the risk of off-site pollution caused by spray drift, drain-flow and run-off. These shall include the establishment of appropriately-sized buffer zones for the protection of non-target aquatic organisms and safeguard zones for surface and groundwater used for the abstraction of drinking water, where pesticides must not be used or stored;

(d) reducing as far as possible or eliminating applications on or along roads, railway lines, very permeable surfaces or other infrastructure close to surface water or groundwater or on sealed surfaces with a high risk of run-off into surface water or sewage systems.
Training for pesticide users, distributors and advisors must cover topics concerning risks to water resources and the influence of climate on risks.

ANNEX I - Training subjects referred to in Article 5

7. Risk-based approaches which take into account the local water extraction variables such as climate, soil and crop types, and relies.

8. Procedures for preparing pesticide application equipment for work, including its calibration, and for its operation with minimum risks to the user, other humans, non-target animal and plant species, biodiversity and the environment, including water resources.

10. Emergency action to protect human health, the environment including water resources in case of accidental spillage and contamination and extreme weather events.

3.8 Environmental Quality Standard Directive

Environmental Quality Standards Directive (EQSD) establishes the standards which constitute the chemical status criteria for the Water Framework Directive. Concerning drinking water, it states that Member States have to “manage the surface water bodies used for abstraction of drinking water in accordance with Article 7 of [the Water Framework Directive]. This Directive [i.e., the EQSD] should therefore be implemented without prejudice to those requirements which may require more stringent standards.”

3.9 Nitrates Directive

The Nitrates Directive is an important instrument which deals with the relationship between agriculture and water quality. In order to reduce and prevent water pollution caused by nitrate pollution originating from agricultural sources, Member States must monitor both groundwater and surface waters, designate so called nitrate vulnerable zones and then adopt and implement action programmes and codes of good agricultural practices with the aim of improving fertiliser management and reducing nitrate leaching towards waters. Monitoring programmes are required to be set up to assess the efficiency of these action programmes.

MS must identify water bodies that could be affected by nitrate pollution, in particular those used or intended for abstraction of drinking water. All zones that contribute to pollution should be designated as vulnerable zones.
Vulnerable zones shall be dealt with using action programmes including measures such as prohibiting or limiting the land application of fertilizers, ensuring storage capacity for livestock manure, etc:
3.10  White paper on Climate Change adaptation

The White Paper on Climate Change adaptation presents the framework for adaptation measures and policies to reduce the European Union’s vulnerability to the impacts of climate change. It 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.”

The White Paper argues that adaptation is already taking place in a piecemeal manner across Europe, therefore a more strategic approach is needed to ensure that timely and effective adaptation measures are taken, ensuring coherency across different sectors and levels of governance. Next to a number of other fields, the proposed EU framework of the White Paper includes objectives and actions to increase the resilience of EU water systems. Specific emphasis is given to the proper implementation of the WFD, the Floods Directive as well as the Water Scarcity and Droughts Strategy for the delivery of adaptation measures with regard to water.
The White paper stresses that the Common Agricultural Policy (CAP) must take into account the impacts of agriculture on water resources, in terms of quality and quantity. Requirements will be integrated into CAP instruments and water efficiency will be promoted:

More generally, consideration should be given to the CAP providing an adequate framework for sustainable production, thereby enabling the agricultural sector to deal with the challenges posed by changing climatic conditions. This will involve, inter alia, assessing which water quantity and quality requirements should be further integrated into relevant CAP instruments as well as improving the efficiency of water use by agriculture especially in water stress regions. A reflection on possible support for farms which are particularly vulnerable to the impacts of climate change could also be undertaken. Further details are provided in a specific working document on agriculture and adaptation to climate change. In any case, the possible contribution of the CAP to adaptation to climate change will also have to be examined in the context of the review of the CAP after 2013.

It also acknowledges that guidelines and a set of tools are developed to ensure that RBMPs are climate proof, that MS should ensure Climate Change is taken into account in the implementation of the flood directive. The EC will assess the need for further measures for water efficiency, and explore the potential for policies and measures to boost ecosystem storage capacity.

Regarding water, a number of existing EU policies contribute to adaptation efforts. In particular, the Water Framework Directive establishes a legal framework to protect and restore clean water across Europe by 2015 and to ensure the long-term sustainable use of water. The River Basin Management Plans due in 2009 under the Directive will take into account the impacts of climate change and the next generation of plans due in 2015 should be fully climate-proofed. In addition, climate change must also be properly integrated in the implementation of the Floods Directive. Full implementation of this Directive by the EU Member States will help increase resilience and facilitate adaptation efforts.

For water scarcity, the Commission will assess the need to further regulate the standards of water using equipment and water performance in agriculture, households and buildings. When reviewing in 2012 the implementation of the Water Framework Directive and the Water Scarcity and Droughts strategy: options for boosting the water storage capacity of ecosystems to increase drought resilience and reduce flood risks should be evaluated. A more detailed account of water issues is provided in the accompanying document.
3.11 Water blueprint preparatory documents

3.11.1 Communication on Water Scarcity and Droughts

The European Commission’s official Communication regarding water scarcity and droughts aims to further develop adaptation measures to address expected increasing impacts of water scarcity and droughts in next decades. The Communication presents a range of possible options for managing the problems of water resource scarcity and drought, and stresses that water saving should become the priority. Furthermore, it recommends drafting Drought Management Plans, provides support to establish a European Strategy, proposes to establish a European Drought Observatory and introduces the possibility of using European funds for countries suffering prolonged droughts.

The Communication recommends that all possibilities to improve water efficiency must be explored, and that policymaking should be based on a clear water hierarchy, i.e. additional water supply infrastructures should be considered as an option when other options (water saving, water pricing policy etc.) have been exhausted. It also insists that addressing the consequences of climate change is one the priorities of the EU, and that investments in infrastructure related to water management, clean and water-efficient technologies as well as risk prevention measures are provided by the new legislative framework. Tackling climate change through an effective strategy towards water efficiency is also considered a precondition for sustainable economic growth in Europe.

3.11.2 Fitness check final report

The Fitness check analyses the EU Freshwater policy to identify excessive burdens, overlaps, gaps, inconsistencies and/or obsolete measures which may have appeared over time.

In particular, relevance is assessed and it is deemed that “the body of EU water law is largely complete and relevant to the issues that need to be addressed. Furthermore, for many issues stakeholders view current EU water policy as well designed for its purpose”17.

Some gaps are mentioned:

- An issue raised concerning both the UWWTD and WFD concerns combined sewer overflows and whether the costs of bring storm water within the treatment requirements of the UWWTD need to be better integrated into the ecological objective setting of the WFD
- There are also concerns from some stakeholders that the WFD lacks clarity on some details and leaves a lot of room for diverging interpretation of action requirements (such as on the concept of water services in relation to cost recovery). This may make it difficult to ensure that policy objectives are being

met, while at the same time allowing the flexibility to help Member States choose the most locally cost-effective measures to deliver those objectives.

- While the WFD requires action to address water availability and tackle water demand, there is concern that quantitative objectives are not clear for surface waters. EU Member States enjoy considerable autonomy and flexibility with regard to issues such as adequate pricing of water use. Flexibility allows Member States to adopt measures adapted to their own specific circumstances. However, economic instruments focusing on efficiency in water supply are not widely used in Europe. An effective approach to better integrating water concerns into key sectoral policies is still missing, particularly with regard to increasing the efficiency of using water in agriculture and buildings. A prioritisation of competing water uses would be helpful, but is missing. The principle of cost-recovery remains widely and controversially discussed, as it has not been sufficiently defined.

- Water scarcity and droughts are under-addressed within EU legislation. Efficiency standards for water use in building offer prospects for future savings. Furthermore, development of water accounting would provide a stronger basis for effective and targeted water protection measures. There is no consensus and no clear majorities for future regulatory action on droughts, but widespread agreement on the need for increased “soft” policy coordination. While EU water policy provides a basis for tackling critical quantitative issues of scarcity and drought, the policies do not provide a sufficient strong basis for action. Objectives are not fully clear, processes such as water accounting and target setting are not explicit and measures to deliver targets are not sufficient. Furthermore, water policies do not address the prioritisation of water uses.

- The drafting of flood risk management plans would benefit from a much stronger link to integrated land use management. The approach taken so far is rather reactive, in that it focuses on better preparing for floods rather than on mitigating their causes.

**Consultation results** - A public consultation was carried out to support the EC in developing the Fitness Check of EU Freshwater Policy: an internet questionnaire was developed to provide an opportunity for the public across the EU to comment on issues of relevance to the Fitness Check.

Regarding climate change, respondents were divided in their opinions on how well the current policy framework can accommodate climate adaptation needs. However, there was consensus that in addressing climate challenges, the main necessity is the flexibility to act at the level where the pressures are the greatest and to balance water availability with changing pressures.

The most common comment was that much water legislation was written before climate change issues had begun to be included into policies. Consequently there is a gap in integrating climate change adaptation through the existing policies. The Communication on Water Scarcity and Droughts and the White Paper on climate adaptation do address climate change, but the fact that these are non-binding documents is seen as a drawback by some.
Comments were made that some existing instruments are unable to address climate challenges. For example, the Urban Waste Water Treatment Directive does not take into account the carbon implications (energy use) of secondary or tertiary treatment and whether these may, in some instance, outweigh the environmental benefits of this additional treatment.

Most respondents considered that the Floods Directive was the best adapted to climate change. This Directive was more recently adopted and specifically includes a requirement to take account of potential climate change in its provisions (Chapter II – Art.4).

On the Water Framework Directive, one respondent remarked that the intercalibration exercise, which helped in establishing the reference conditions, was a one-off. However, climate change, increasing temperatures and changes in precipitation patterns will invalidate the boundary setting and the values for biological quality elements which is the basis for the definition of good ecological status.

A uniform, one size fits all approach was widely criticised in particular in relation to floods, droughts and water scarcity. Industry respondents stated that solutions need to be developed at local and regional level. One respondent noted that at the moment the only answer to droughts is to set up kilometres of pipes for water transfer, which increases social and regional strife. Several respondents also called for the contribution from hydropower to flood and drought protection to be acknowledged through the River Basin Management Plans.

It was suggested by some respondents that an essential adaptation to climate change requires having an economic approach to water scarcity by taking further steps towards recognising the value of water (which is different from the value of the service of providing water).

For an industry association, the main challenges are in relation to sewage sludges which should be pro-actively managed as a resource for energy production. The issue of waste water storm overflow was also raised by two industry respondents. The increase of extreme weather events from climate change will increase the strain on sewerage systems and most Member States do not have the infrastructure to address this.

Finally some respondents stated that there was no need for more legislation, the existing framework being sufficient to address climate change, which will essentially only necessitate managing the changing pressures on the environment.

### 3.12 WHO – Protecting Groundwater for Health

The World Health Organisation (WHO) issued a report on groundwater protection for health in 2006. It gives a number of key ideas for groundwater quality protection.

The document details methods to delineate protection zones, using various criteria (fixed radius, travel time, vulnerability assessments, risk assessments...). It also details how land use and human activities are managed and restricted in protection zones in those countries. It is supported by numerous examples of European and non-European countries which have established groundwater protection zones in their respective national legislations.

Table 7 presents a few of those examples and compares the different zones and the way they are defined. In most cases there are three zones, defined in terms of distance to wellhead or water
travel time. The closer to the abstraction point (or the shorter water will take to reach the abstraction point), the more activities are regulated, as illustrated in Table 8.

Table 7: Comparative table of examples of protection zone dimensions (WHO, 2006)

<table>
<thead>
<tr>
<th>Country</th>
<th>Wellhead protection zone or inner zone</th>
<th>Middle zone</th>
<th>Outer zone</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Travel time and/or radius of zone</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Australia</td>
<td>50 m</td>
<td>10 years</td>
<td>Whole catchment</td>
</tr>
<tr>
<td>Austria</td>
<td>&lt;10 m</td>
<td>60 days</td>
<td>Whole catchment</td>
</tr>
<tr>
<td>Denmark</td>
<td>10 m</td>
<td>60 days or 300 m</td>
<td>10-20 years</td>
</tr>
<tr>
<td>Germany</td>
<td>10-30 m</td>
<td>50 days</td>
<td>Whole catchment</td>
</tr>
<tr>
<td>Ghana</td>
<td>10-20 m</td>
<td>50 days</td>
<td>Whole catchment</td>
</tr>
<tr>
<td>Indonesia</td>
<td>10-15 m</td>
<td>50 days</td>
<td>Whole catchment</td>
</tr>
<tr>
<td>Ireland</td>
<td>100 days or 300 m</td>
<td>-</td>
<td>Whole catchment or 1000 m</td>
</tr>
<tr>
<td>Oman</td>
<td>365 days</td>
<td>10 years</td>
<td>Whole catchment</td>
</tr>
<tr>
<td>Switzerland</td>
<td>10 m</td>
<td>Individually defined</td>
<td>Whole catchment of middle zone</td>
</tr>
<tr>
<td>United Kingdom</td>
<td>50 days and 50 m</td>
<td>400 days</td>
<td>Whole catchment</td>
</tr>
</tbody>
</table>

Table 8: Priorities among different types of drinking water supplies (ADWICE project)
Table 8: Examples of activities controlled in water protection zones in Germany

(Who, 2006, based on GGWG, 1995)

<table>
<thead>
<tr>
<th>Zone type</th>
<th>Zone category</th>
<th>Controlled or prohibited activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wider protection</td>
<td>Zone III B</td>
<td>Industrial estates</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Pipeline systems for the conveyance of substances constituting a hazard to water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Central sewage treatment plants, release of waste water to the ground</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Waste disposal facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Agriculture (animal husbandry, application of fertilizers and pesticides)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Air fields, Military facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Sites for freight handling (freight railway stations, trackheads)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use of leachable substances constituting a hazard to water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Mining</td>
</tr>
<tr>
<td></td>
<td>Zone III A</td>
<td>Hazards listed for Zone III B, plus:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Local sewerage systems</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Discharge of waste water into surface waters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transportation systems, unless waste water generated by these systems is piped out of Zone III A</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Petrol stations, motor racing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Extraction of minerals and rock (near-surface resources)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Penetration of strata overlying ground water (e.g. civil engineering excavations), drilling operations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use of pesticides on road and railway areas</td>
</tr>
<tr>
<td>Outer zone</td>
<td>Zone II</td>
<td>Hazards listed for Zone III A, plus:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Roads, railway lines and similar facilities for transportation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transportation of radioactive or other substances constituting a hazard to water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Storage of fuel oil and diesel fuel, storage of fertilizers and pesticides</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Construction sites</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Livestock grazing</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Transportation of sewage or waste water</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Contaminated surface waters</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Release of storm water to the ground</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Swimming and camping facilities</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Shooting and blasting operations</td>
</tr>
<tr>
<td>Inner zone</td>
<td>Zone I</td>
<td>Hazards listed for Zone II, plus:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Any type of traffic (whether vehicle or pedestrian)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use for agriculture or forestry</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Use of fertilizers and pesticides</td>
</tr>
</tbody>
</table>
3.13 EU Water Initiative

At the 2002 World Summit on Sustainable Development (WSSD), European leaders decided to support the water-related Millennium Development Goals (MDGs):

**Target 7.C:**

_Halve, by 2015, the proportion of the population without sustainable access to safe drinking water and basic sanitation_

- The world is on track to meet the drinking water target, though much remains to be done in some regions
- Accelerated and targeted efforts are needed to bring drinking water to all rural households
- Safe water supply remains a challenge in many parts of the world
- With half the population of developing regions without sanitation, the 2015 target appears to be out of reach
- Disparities in urban and rural sanitation coverage remain daunting
- Improvements in sanitation are bypassing the poor

This commitment led to the launching of the “European Union Water Initiative” (EUWI), which aims to “create the conditions for mobilising all available EU resources (human & financial) and to coordinate them to achieve the water-related MDGs in partner countries”. The EUWI seeks to deliver effective development assistance by improving international coordination. It takes a partnership approach to mobilise a wide range of social actors (e.g. government, civil society, NGOs, donors, water industry, private sector, etc.) and encourages cooperation within partner countries through national policy dialogues.

Its key objectives are:

- The reinforcement of political commitment towards action and innovation oriented partnership
- The promotion of improved water governance, capacity-building and awareness
- Improved efficiency and effectiveness of water management through multi-stakeholder dialogue and coordination
- Strengthened cooperation through promoting river basin approaches in national and transboundary waters
- Identification of additional financial resources and mechanisms to ensure sustainable financing
To achieve those goals, the EUWI is organized in working groups that have either a regional focus (e.g. Africa, Mediterranean, EECCA-Eastern Europe Caucasus and Central Asia and Latin America) or concentrate on a cross-cutting issue (e.g. Research, Finance). EUWI members’ work has been leading to high-level declarations 1) improving commitment to Water Supply and Sanitation (WSS) and water management; 2) influencing Poverty Reduction Strategies and allocation of resources18.

18 http://www.euwi.net/policy