Blenckner, Th. (2007): Climate-related effects on water quality. In: Lozán, J. L., H. Grassl, P. Hupfer, L.Menzel & C.-D. Schönwiese. Global Change: Enough water for all? Wissenschaftliche Auswertungen, Hamburg. 384 S. Online: www.klima-warnsignale.uni-hamburg.de

3.2.4 Climate-related effects on water quality

THORSTEN BLENCKNER

SUMMARY: *Many of the water quality problems we experience today are strongly influenced by global changes in climate. A higher surface water temperature in lakes increases the turnover of nutrients, in particular phosphorus. This in combination with a higher water temperature and the associated longer stratification period favours blooms of potentially toxic blue-green algae. Furthermore, long-term analyses of lake data indicate an increase of phosphorus released from the sediment in deep lakes. This climate-related eutrophication decreases the water quality of lakes and should receive special consideration in the European Water Framework Directive, which aims at achieving a good water quality status in European waters by 2015. Good co-operation between climatologists and water managers in an integrated system approach is therefore required.*

A number of scientific publications study the impact of climate on water quantity, while aspects of water quality often remain neglected. Changes in water quality are of distinct relevance mainly in areas, where drinking water beneath industrial and agricultural usage constitutes a considerable proportion.

In order to guarantee a good water quality in Europe for the long term, the European Water Framework Directive has been established. The directive implies that all EU member states shall meet the »good water quality« standard until 2015 (with few exceptions). Today, 20% of the European surface waters are seriously polluted. The Framework Directive reflects the growing importance attributed to water quality in various political contexts.

Water quality as such is defined by the concentration of diverse measurable substances. A negative impact is predominantly related to elevated anthropogenic nutrient inflows (especially nitrate), oil, fertilisers, hormones as well as salinisation, acidification and microbial contamination.

Inflows of phosphate and nitrogen originate especially from extensively used catchments such as large agricultural lands or industrial areas in close proximity to rivers and lakes. They can often lead to serious ecological consequences such as algae blooms, oxygen depletion, low water clarity, and fish death. Some algae species produce poisonous substances (toxins) and can thereby affect the taste and odour of the water, which constitutes a serious impact on water quality.

In this chapter, focus is put on lakes, as they constitute not only in Europe but also in large parts of the world relevant drinking water reservoirs. Moreover, the mechanisms developed to reach »good water quality« status can also be transferred to artificial water reservoirs in regions with highly varying precipitation rates.

Long-term measurements of water quality parameters in lakes have shown that, in addition to the above-named inflows, weather and climate change can also have a negative impact on water quality. As a result of the projected increase in the number of extreme weather events (droughts, floods) in the near future (IPCC 2001), studies on the effects of these changes have increased in importance as well. In the following section, a short introduction to the climate change during the last 100 years will be given; thereafter, the diverse impact of climate on water quality in different European lakes will be presented in more detail.

Climate

Natural climate change has always existed during the Earth's history. It is also thanks to this climate change that evolution could develop such a large diversity of organisms. However, during the last 20 years, there is growing evidence for an anthropogenic contribution to the most recent warming trend. World-wide, global air temperature has increased by 0.6 degree Celsius, though with large regional variations (IPCC 2001). During the 20th century, the temperature increase in Germany was above average, at 0.9 degrees. Furthermore, during the 1990s, winters were very mild and were followed by warm summers and a general increase in extreme climate events (floods, heavy rain, etc.). This was especially the case in 2002 and 2003, with severe flooding events in Europe along the river Elbe, destroying villages, housing and industry, and extreme drought in large parts of southern Europe, which cost human life. These two consecutive years exemplify the range of weather and climate variation which is predicted for the future.

Based on the purely physical fact that air with a higher temperature can hold more water vapour per unit volume than cold air, the water cycle intensifies with a general global warming. As a result, precipitation increases with heavy rain events during short time periods with high spatial variability. It is therefore crucial to clearly separate the general warming trend from the increase of variability, even if both phenomena appear to be directly linked.

In spite of a persisting uncertainty, most climate

Thorsten.Blenckner@geo.uu.se

projections for Central Europe indicate for the coming 100 years a tendency towards milder winters and hot summers with less precipitation, as well as a general increase in extreme weather events (Räisänen et al. 2004).

In the following section, the impact of this changing climate on water quality shall be looked at more closely.

Physical impact

Generally, with only a few exceptions, the surface temperature of rivers and lakes is closely related to air temperature. Therefore, an increase in air temperature as observed during the 20^{th} century has lead to a shorter ice cover period and warmer water temperatures, in particular in freshwaters at high latitudes.

Ice cover periods have decreased considerably in Europe, as lakes freeze later and ice break-up occurs earlier (up to one month), or the lakes are totally free of ice. In particular, Arctic and Alpine lakes show a very strong response to the shortened ice cover period, as the intensity of the harmful UV-B radiation at 3000m height is 50 % stronger than at sea level (Psenner 2003).

This measured rise in water temperature has several consequences for the structure and function of lake ecosystems. Primarily, as a direct consequence, a number of lakes show an extended stratification period during summer. This stratification, also called summer stagnation, is characterised by higher temperature in the upper layer, which is clearly separated from the underlying cooler water in deeper layers. Very little exchange is possible between these two water bodies during this period. Prolonged summer stratification is especially relevant in deeper (more than 20 m), nutrient-rich lakes as the low exchange between the two water layers leads to a decrease in the oxygen concentrations in the bottom water. This can cause fish kills and further increases the release of nutrients from the sediment. This higher nutrient concentration in combination with higher water temperatures favours blue-green algae blooms during summer (Blenckner et al. 2002). However, the magnitude of this impact depends strongly on lake-specific characteristics, such as the morphometry of the lake.

Another direct impact of altered climate conditions consists in a general increase of heavy rainfall events while in Central Europe the general amount of precipitation during summer decreases. The inflow into the lake from the surrounding area (catchment), mainly controlled by the amount of precipitation, and the morphometry of the lake determine the water residence time (the average time the water spends in the lake). This time strongly drives the sensitivity of a lake to climate change. For example, in a deep lake with a long water residence time, the impact of a warm winter still can be observed in the following summer, e.g. due to persisting increased temperatures in the deep water layers. On the other hand, this effect is less persistent in lakes with a short water residence time (days or weeks) (Gerten &Adrian 2001).

The land use in the catchment of a lake determines the load of nutrients and other anthropogenic substances. Reduced summer precipitation can therefore reduce considerably the amount of water in rivers, leading to enhanced concentrations of substances and often reduced oxygen values. In more arid areas, for example Australia, these processes imply severe salinisation of soils and decrease the agricultural production largely. With more frequent heavy rain events, there will be an increasing risk for soil erosion in the catchment as well as point source pollution of surface waters with nutrients and pollutants such as pesticides. A further increase in temperature will diminish soil moisture and lead to a lowering of the groundwater table during periods of little precipitation.

Many of the above named impacts have so far only been attributed to regional climate anomaly events, such as the extreme warm summer in 2003 in Central Europe.

Today's knowledge indicates more clearly, however, that climate related changes in freshwater do not only occur due to local conditions but also due to regional and global circulations. In Europe, the impact of global circulation conditions is related to the North Atlantic Oscillation (NAO) and to the variation of the North Atlantic Ocean Current (extension of Gulf Stream) (George & Taylor 1995, Blenckner & Hillebrand 2002). These global to regional atmospheric circulations affect local lake ecosystems and are, therefore, of high relevance even with regard to lake management.

Impacts on water quality

As mentioned above, one of the main factors determining water quality is nutrient concentration. An increase in rainfall during mild winters, as projected by future climate models, could lead to a higher transport of nutrients from the catchment to lakes, depending on the land use in the particular catchment. In terms of the load of nitrogen, the main sources are from agricultural areas, industries and atmospheric deposition. In terms of the load of phosphorus, the main sources were previously industries and households, but both often have today substantially decreased emissions. However, soils still containing large amount of phosphorus from agricultural areas, which are released from the soil in a diffuse way, constitute one of the main sources today.

The link between climate and water quality impacts induced by nutrients is rather complex and both lake and catchment specific. For example, in Finnish lakes, an enhanced nitrate concentration directly after mild winters has been found due to an increased discharge during the snow melt period. In English lakes, on the contrary, nitrate concentration after mild winters was much lower compared to colder winter periods, probably due to an enhanced nitrate uptake by plants in the catchment, as this region seldom is snow covered (GEORGE et al. 2004). This illustrates that a holistic view integrating climate, land use and water management is very important.

The climate-induced phosphate concentration in lakes can increase substantially. A recent study from Swedish lakes shows that a higher water temperature in spring and summer, associated with a longer and stronger stratification period and oxygen depletion in the bottom water, resulted in large phosphorus releases from the sediment, leading to an internal eutrophication (MALMAEUS et al. 2004). Lakes with a long water residence time (longer than one year) and without any changes in the supply of nutrients from the catchment are especially at risk for a deterioration of the water quality. The frequency of heavy rain events, which could flush more nutrients into the lake, could intensify this climate-induced eutrophication.

In lakes with a short water residence time, such an effect could not be shown (see *Fig 3.2.4-1*). However, in these mostly shallow lakes, the warming effect is relatively strong, which intensifies the microbial mineralisation activity (enhanced nutrient recycling) and leads to a generally higher biomass production with changes in species composition towards higher water temperature adaptation.

An increase in water temperature and stratification strength during summer favours algae blooms in nutrient rich lakes, in particular blue-green algae (or more correctly cyanobacteria) visible as surface scums with a blue to green colour. Some of these blooms are toxic and harmful to humans, causing stomach and intestinal problems, breathing problems, allergic responses, skin irritation, liver damage and neurotoxic reactions, such as tingling fingers and toes. Treatment of lake water for human consumption can vastly reduce toxin levels. Thus, the greatest public health concern focuses on recreational use of contaminated waters. Many lakes are thus monitored intensively in order to reduce any risk for human health. Due to the warmer climate in the last decade, some algae species moved northwards, for example the normally tropical to sub-tropical toxic cyanobacterium *Cylindrospermopsis raciborskii*, which occurs today even in lakes in Hungary, Germany, France, Portugal and North America and can cause severe toxic blooms.

In addition to changes in water quality due to nutrients, the water colour can also be strongly effected. During the last decade, an increase in water colour in English and Scandinavian rivers and lakes was observed. A high variability in soil moisFRture (from relatively dry to wet) of organic rich soils increases the dissolved organic carbon in rivers, leading to an increase in water colour, with consequences for drinking water treatment in particular, as a higher concentration of dissolved organic carbon clearly enhances treatment costs.

And with increased frequency of heavy rainfalls with associated flooding, enhanced microbial contamination with faecal coliform bacteria leads to symptoms including watery or bloody diarrhoea and abdominal cramps (ROSE et al. 2000).

Conclusion

All in all, only a selection of risks for induced changes in water quality is presented. To summarise, the direct effects of climate change on freshwater are

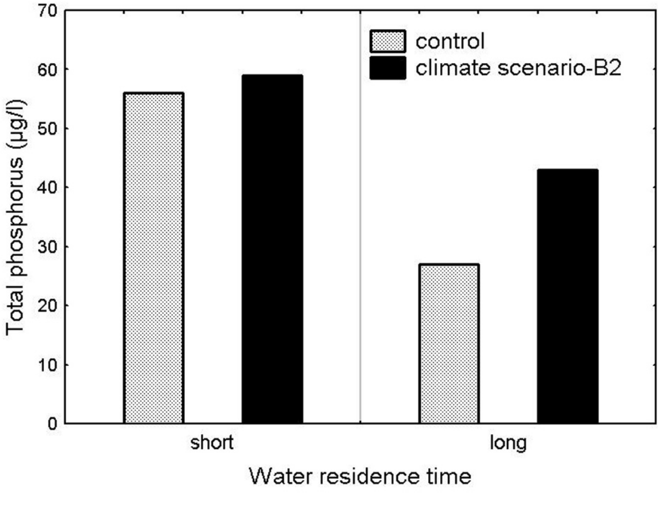

Fig. 3.2.4-1: Comparison of total phosphorus at today's climate (1960–1990, control) and in future (2071–2100, B2) in two Swedish lakes with a different water residence time (modified from MALMAEUS et al. 2004).

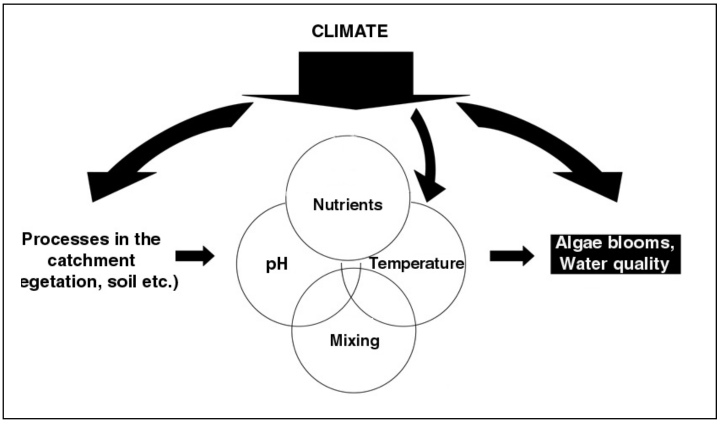

Fig. 3.2.4-2: Climate impact on processes in catchment and lakes as well as their interaction (modified from ANDERSON 2000).

- shorter ice cover period or no ice cover at all
- higher variability of some climate parameters
- increase in risk of droughts and floods
- increase in water temperature
- prolonged summer stratification period

This has profound consequences for water quality such as
- decreased oxygen concentration in deep waters
- enhanced internal release of phosphorus from the sediment
- increased frequency of summer blooms of potentially toxic cyanobacteria
- increase in brown water colour
- high frequency of microbial contaminations

However, it is important to mention that most of the published studies only focus on single effects or single study sites. Therefore, more integrated approaches are necessary to understand the mechanisms leading to changes in water quality, and which consider changes in land use, climate and other anthropogenic factors such as pollutants. In this context, a comparison to human health is interesting, as we can diagnose symptoms but often, the underlying causes remain uncertain or too complex. Therefore, only the most commonly found results from long-term analyses and model simulations are presented in this chapter in order to provide a more objective view. However, a review of climate-related effects on lakes indicates that the increase in temperature is general but the responses in different lake systems are more specific or individual (BLENCKNER 2005).

The schematic *Fig 3.2.4-2* synthesises that changes in climate directly influence the catchment by the length of the vegetation period or soil moisture. Furthermore, climate affects the lake directly through water temperature, mixing in the water column and nutrient supply. In addition, discharge into the lake determines pH and nutrient concentration. Only a combination of these direct impacts and results from the indirect impacts (see above) determine the overall impact on water quality, with aspects such as blooms in future.

In order to prevent a further deterioration of today's water quality, the following action needs to be taken: A reduction of diffuse nutrient load to freshwater systems after changes in land use and riparian buffer strips can reduce leakage of nutrients. In combination with a long-term water management plan, state-of-the-art future climate projections and assessment of the sensitivity of the water body to climate, risk calculation of extreme weather events (droughts or floods) and/or water quality changes (internal eutrophication, summer blooms) will be possible.

Conclusively, as climate change and variation strongly affect water quality, both factors (long-term change and short-term variability) should be considered more strongly in integrated water management, hence should be included into the European Water Framework Directive ♦