MSc Program
Environmental Technology & International Affairs

The Protection of Lakes in the Face of Climate Change Challenges Regarding the Preservation of the "Good Water Status" - Explained on the Examples of Lake Constance and Lake Neusiedl

A Master's Thesis submitted for the degree of
"Master of Science"

supervised by
Dr. Matthias Zessner-Spitzenberg

Lisa Maria Schranz

1007171

Vienna, 04.06.2016

Affidavit

I, **LISA MARIA SCHRANZ**, hereby declare

1. that I am the sole author of the present Master's Thesis, "THE PROTECTION OF LAKES IN THE FACE OF CLIMATE CHANGE. CHALLENGES REGARDING THE PRESERVATION OF THE "GOOD WATER STATUS" - EXPLAINED ON THE EXAMPLES OF LAKE CONSTANCE AND LAKE NEUSIEDL", 74 pages, bound, and that I have not used any source or tool other than those referenced or any other illicit aid or tool, and

2. that I have not prior to this date submitted this Master's Thesis as an examination paper in any form in Austria or abroad.

Vienna, 04.06.2016

_____

Signature

ABSTRACT

The focus of this master thesis is put on the effects of climate change on standing water bodies in Austria, based on literature research as well as a comparative study. Explained on the examples of Lake Constance and Lake Neusiedl it intends to show that lakes react differently to the challenges posed by global warming: For the whole of Austria, the temperature increase is expected be faster than on the global average. So far, the mean temperatures in the federal republic have risen for +1,8°C since the 1880s and this trend is very likely to continue in the future. As a result, there will be an increase in evaporation. Precipitation patterns are characterized by regional differences with large insecurities about the future trend. Overall, rainfall levels have slightly increased since the 1970s, with the only exception being Austria's south-east.

These changes have an impact on the hydrology of standing water bodies: There is a close connection between the average air and water temperate. The comparison showed that the Neusiedlersee's water balance is mostly dependent on the annual difference between evaporation and precipitation. Because there is little water input from inflows, a complete dry-out scenario is possible and might threaten its survival, which is also endangered by the extension of the reed belt. Lake Constance is strongly influenced by the temperature regime. It is vertically divided into layers with exchange only possibly during spring and autumn/ winter, when the whole water body assumes the same temperature allowing wind to mix it through. Mild winters with warmer-than-average temperatures result in longer periods of thermal stability. This has an impact on the oxygen content in the lake's Hypolimnion, potentially resulting in anoxia. Furthermore, it may cause the mobilisation of nutrients stored in the lake's bed.

Taking account of the characteristics of standing water bodies is essential for the achievement and preservation of the "good ecological and chemical water status" as set forth by the Water Framework Directive: By comparing Lake Constance and the Neusiedlersee it becomes apparent that their potential degradation needs to be addressed by management plans which consider the long-term effects of measures.

Table of Contents

1. Introduction

Non-saline freshwater, occurring in lentic inland water bodies such as lakes, ground water reserves, sea as well as land ice and running waters, is a vital component of the Earth's surface, as it is fundamental for the sustenance of life: Humans, animals and plants depend on the regular supply of water in order to survive. Lake Constance, for example, supplies over 4 million people with drinking water. Furthermore, it forms an essential part of the agricultural production process (e.g. aquaculture) and has a socio-economic function. – Both Lake Constance and the Neusiedlersee are important for tourism in their respective regions (e.g. nature tourism, water activities). In addition, water has a geomorphologic impact on the landscape, provides a habitat for various species and moderates the (local) climate due to its heat storage capacity (see Chapter 3.1). While almost three quarters of the Earth's surface are covered by water, the actual amount of freshwater is relatively low: In fact, only 2,5 % is non-saline water and as such suitable for human consumption. Less than 1 % thereof residues in easily-accessible surface water bodies, with more than half (52 %) being contained in lakes (Withgott and Laposata, 2014). In the face of climate change and global warming, the access to freshwater sources is becoming increasingly valuable and the protection of lakes as the majority thereof is an important step to achieve supply security for water. Due to its location in the temperate climate zone, Austria has a rather high annual precipitation rate that ranges between 500 mm in the east (e.g. Burgenland) to over 1.500 mm in the western regions, such as Vorarlberg. Moderate temperatures coupled with regular water supply via precipitation (e.g. rain, snow) and glacial melting have added to its status as one of the most water-rich countries within the EU (European Union): Overall, the water reserves in Austria amount to approximately 122 km^3, with about 18 km^3 contained in standing water bodies (BMLFUW, 2014a: 37). In sum, the federal republic comprises over 25.000 lakes with an extension of more than 250 m^2 (BMLFUW, 2011a). Yet, climate change has changed the environmental conditions, both in Austria and worldwide (see Chapter 3.2): Recent studies show that changes in the temperature regime, regional shifts in precipitation patterns as well as the increase in weather extremes have indeed put a strain on existing water bodies, such as Lake Constance and the Neusiedlersee (e.g. Dokulil, 2009; IGKB, 2004). In the past years, the endeavors to study the vulnerability of lakes to the change in global climate have increased significantly (e.g. Livingstone and Padisák, 2007) – especially with regard to the drinking and bathing water quality of standing water bodies as well as the species community therein (see Chapter 4).

Taking account of the particular characteristics of standing water bodies is essential for their maintenance as well as the achievement of a good water quality: Even though lakes are formed by different processes (e.g. tectonic phenomena), these standing water bodies share a similar composition. Due to the influence of solar radiation, most of them are vertically divided into strata with certain characteristic properties – provided their water depth is large enough to withstand the wind's mixing power. In contrast to Lake Constance, the Neusiedlersee is completely mixed through throughout the day (holomictic), preventing the formation of a strong vertical division. Furthermore, lentic waters are distinguished according to their mass balance. Increasing mean temperatures have an impact on the gas absorption of water bodies possibly leading to the depletion of oxygen in the lake's lower strata and the loss of species due to anoxia, eutrophication or changed temperature regimes.

Because standing water bodies as opposed to running waters are particularly vulnerable to exterior environmental influences, the effects of climate change will potentially threaten the *"good status of surface water (...) throughout the Community"* as outlined in Article 25 of the WFD (Water Framework Directive) resulting in economic losses and ecologic deficiencies. In fact, there are several legal provisions aimed at the protection of Europe's and Austria's water resources (see Chapter 3.3). For the protection of Austria's standing water bodies, legal provisions on the international level and the national level are relevant. On the international level the WFD, the Ramsar Convention as well as the Fauna-Flora-Habitats Directive and the Birds Directive are important. Providing a habitat for more than 300 bird species, most of the Neusiedlersee and its surroundings are being protected as an "Important Bird Area". On the regional level the Nature Conservation Acts of Vorarlberg and Burgenland are important. In fact, nature conservancy in Austria is rather complicated: According to Article 15 of the Austrian Federal Constitution the legislation and execution of nature conservation lies in the responsibility of the federal provinces. As a result, the legal sphere of Austria is shaped by 9 Acts for the Protection of Nature, with the Austrian Water Rights Act providing an important legal basis.

Facing these threats and their potential impacts on the quality and security of standing water bodies, this master thesis aims to **investigate the effects of global warming and climate change on lakes in Austria – particularly with regard to Lake Constance and Lake Neusiedl**. By contrasting the specific conditions, characteristics and utilizations of these two lakes, it becomes apparent that their potential degradation needs to be addressed by management plans which consider the specific features of the respective water body (see Chapter 5).

Perhaps the international community as well as the Austrian government can utilize that information to define cost-efficient and sustainable plans of action in order to secure the supply of non-saline fresh water for the future generations. The thesis is based on literature research from online and analogous sources as well as a comparative study between Lake Constance and the Neusiedlersee with figures attached to illustrate the theoretical body of information.

2. Research Methods

The thesis is based on the assembly and evaluation of scientific data both from online as well as analogous sources (literature research). Conclusions are drawn from the information provided by statistical and environmental agencies (e.g. Intergovernmental Panel on Climate Change), the Austrian ministry as well as legal documents (e.g. Water Framework Directive): In a two-step process consisting of a research-phase and the final interpretation- and contextualization-phase it aims to **investigate the effects of global warming and climate change on standing water bodies in Austria – particularly with regard to Lake Constance and the Neusiedlersee.** In Chapter 5 I will discuss some measures aimed to protect lentic inland water bodies from the adverse effects of climate change. By contrasting the specific features and utilizations of Lake Constance and Lake Neusiedl (comparative study) I want to show how differently lakes react to the challenges imposed by climate change. As a result of this, the thesis intends to stress the importance of type-specific responses to global warming that consider the long-term effects of measures. In some cases figures as well as tables are attached to illustrate more clearly the theoretical body of information.

The research focused on the characteristics (e.g. vertical stratification) and relevance (e.g. functions) of freshwater bodies in order to stress their vulnerability to external changes in the environment (e.g. rising temperatures). The effects of climate change will potentially threaten the attainment and conservation of the "good ecological and chemical water status", which has to be achieved according to the WFD (Water Framework Directive). For this reason, a focus was also put on the climate change scenarios for Europe and Austria, stressing the change in average temperatures as well as the precipitation patterns in Vorarlberg (Lake Constance) and Burgenland (Neusiedlersee). Furthermore, the research looked deeper into the legal acts dealing with the protection of standing water bodies, both on the international and the national level: Apart from the WFD, also the Ramsar Convention, the Fauna-Flora-Habitats-Directive and the Birds Directive have an impact on the conservation of lentic waters. By describing the objectives as well as the systematic approach outlined in the WFD, it becomes apparent that (standing) water bodies have to fulfil both hydro-morphological as well as physical-chemical conditions to achieve the "good water status". The description of the national legal sphere underlines that nature conservancy lies within the responsibility of the nine federal provinces of Austria (Article 15 of the Austrian Federal Constitution) and can therefore vary with regard to the protective measures, the protected objects as well as the protection intensity.

The research showed that they share a common leitmotif, which is the general obligation to protect and maintain functioning ecosystems, such as wetlands, as the life basis for humans, animals and plant species. Furthermore, the location, conditions (e.g. climate), hydro-morphological (e.g. water depth) as well as physical-chemical characteristics (e.g. mass balance) as well as the main utilizations of Lake Constance (e.g. drinking water supply) and Lake Neusiedl (e.g. nature tourism) were researched.

The selection of the water bodies was based on their noticeable differences with regard to the water balance (water input), their climatic and geographical location (Alpine foothills vs. lowlands), hydro-morphology (e.g. depth) as well as the mass balance (oligotrophic vs. eutrophic). The theoretical input from literature was put into the context of the lakes in order to investigate the specific effects that climate change has on them.

"*Comparative research or analysis is a broad term that includes both quantitative and qualitative comparison. (...) The underlying goal of comparative analysis is to search for similarity and variance*" (Mills et al., 2006: 621). A common methodology applied in social sciences to identify and analyze parallels in different study units (e.g. societies), it has been used in this context to study the effects of climate change on two noticeably different water bodies as well as their different and shared reactions to changes in the exterior environment (e.g. temperature). By contrasting and comparing the specific characteristics of the two lakes, it is possible to draw wider conclusions from the impact of global warming on standing water bodies, which allows insights into possible protection and remediation measures.

3. Scientific Background Material

3.1. Significance and Characteristics of Standing Water Bodies

Amongst the most significant characteristics of the Earth is the abundance of water in its three phases: liquid, frozen and gaseous. These physical states of water are repeatedly changed throughout the hydrological cycle, a "*never-ending global process of water circulation from clouds to land, to the ocean, and back to the clouds*" (NASA, 2010). In fact, the water resources are interlinked: When water evaporates from the surface of the Earth (e.g. lakes) due to increasing temperatures, the steam rises up into the atmosphere, where it cools and condenses to form clouds. Once the water particles become too heavy, they fall back to the surface in the form of precipitation (e.g. rain). The precipitate then accumulates in lakes, rivers, infiltrates the soil and feeds the stock of groundwater or freezes and becomes part of the planet's ice bodies (cryosphere). Furthermore, "*[t]his cycling of water is intimately linked with energy exchanges (...) that determine the Earth's climate*" (NASA, 2010). This prevalence of water has coined the term Blue Planet. However, over 97 % of the total amount of the Earth's water body (hydrosphere) is saline ocean water and as such "*too salty to drink or to use to water crops*" (Withgott and Laposata, 2014: 262). Only 2,5 % of the hydrosphere is non-saline fresh water, with the majority of it being stored in the cryosphere (79 %). Almost 20 % is contained in underground aquifers. Less than 1 % residues in surface water bodies. Of the latter, more than half (52 %) is contained in lakes, while the rest is divided amongst soil moisture in subsurface porous spaces (38 %), atmospheric water vapour (8 %) as well as rivers and organisms (1 %). In sum less than "*1 part in 10.000 of the Earth's water is easily accessible for human use*" (Withgott and Laposata, 2014: 262). The average distribution of the Earth's water resources is illustrated in Figure 1:
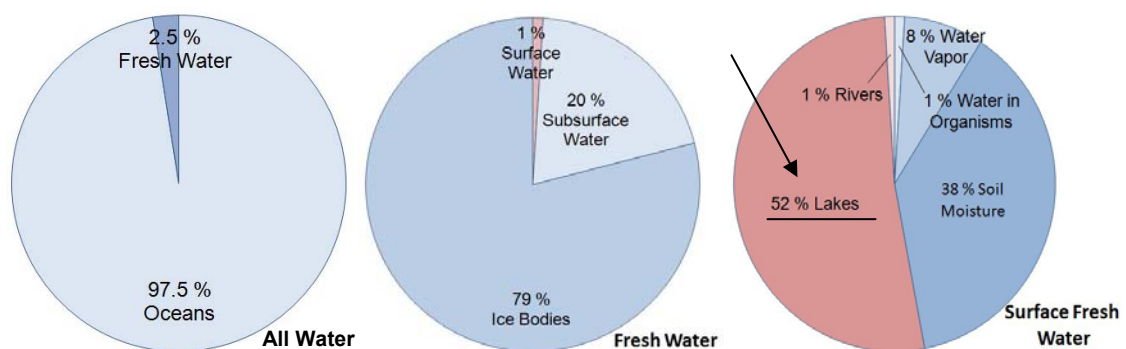

Figure 1. Distribution of the Earth's Water Resources.

With the water supply getting progressively under pressure (e.g. as a result of global warming), the access to freshwater is becoming increasingly valuable. As the world population is predicted to grow, this may result in water shortages:

According to the Intergovernmental Panel on Climate Change (IPCC) over 2 billion people might be afflicted by severe water stress issues in 2030 (IPCC 2014a). Therefore, the protection of easily-accessible surface freshwater sources and particularly lakes, which form the majority thereof (52 %), is an important step to achieve supply security for water: Globally, the area of wetlands amounts to approximately 570 million ha, of which 2 % are lakes (EC, 2007). The total amount of water reserves in Austria is 122 km^3. About 18 km^3 is contained in standing water bodies, while the majority (>60 km^3) is found in soil pores underground. In sum 1 % of the federal republic is covered by water (BMLFUW, 2014a: 37), with about 25.000 lakes extending over an area >250 m^2 (BMLFUW, 2011a).

While stagnant water bodies share certain similarities (e.g. thermal stratification, ecological zoning), they are by no means equal. In fact, anthropogenic pressures (e.g. agriculture), climatic conditions (e.g. temperature) and local circumstances (e.g. shadowing by trees) can greatly alter their chemical and physical state. Therefore, classification schemes for lakes (e.g. according to the amount of primary production) can only be made in general, while a more accurate description requires the observance of the local geological, ecological, climatic and biological background. Even though standing water bodies are formed by different processes (e.g. by tectonic phenomena such as subsidence, erosion, as leftovers from moraines and landslides or by anthropogenic processes), they generally share a similar composition: Due to the influence of solar radiation and thus temperature, they tend to be vertically divided into strata. Primary production mostly takes place in the light-flooded trophogenic layer, which comprises the upper part of the water body (limnetic zone). In this layer the production processes due to photosynthesis exceed degradation and respiration. Because the attenuation of the incident radiation increases exponentially with a lake's depth (Beer-Lambert Law), the lower parts of a water body receive less sunlight. The unexposed part below the trophogenic zone (tropholytic layer) is dominated by heterotrophic organisms, bacteria and detritivores, with degradation being prevailing over production. In the compensation zone between both layers, the net gain from primary production is zero, indicating that production and reduction processes are more or less balanced. Only 1 % of the solar radiation reaches this area (Schwörbel and Brendelberger, 2013). Figure 2 demonstrates the lake's vertical zoning, which has an impact on the chemical and ecological composition of a lake's water body:
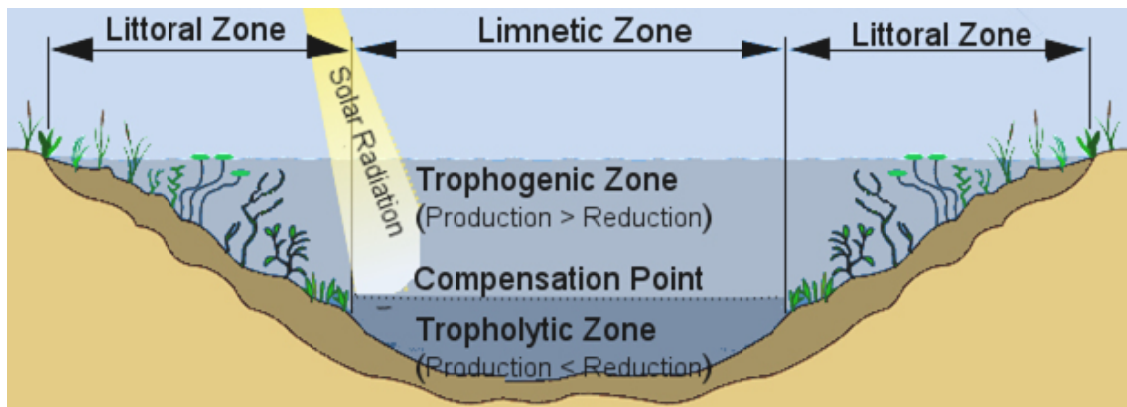
Figure 2. Vertical Zonation (Source – modified after: Collin Community College, 2015).

Another characterizing feature of lakes is their thermal stratification, which varies according to the exterior climate (summer-winter months) and is driven by the local wind circulation as well as the diverging densities of differently heated water layers: Water reaches its largest density at 4°C (density anomaly of water). The difference between the layers of a lake's water body becomes especially pronounced during the summer months: Long-waved red radiation resulting from solar insulation is absorbed in the upper parts of the water, causing the formation of a well-ventilated, warm layer at the top (Epilimnion), while the colder and therefore heavier water accumulates below (Hypolimnion). These layers are separated by the Metalimnion (thermocline region) that isolates the Hypolimnion and prevents mixing and exchange (summer stagnation). Complete mixing is possible in spring and autumn/ winter: During the autumnal months colder exterior temperatures cool down the water within the Epilimnion.

Eventually, the whole water body assumes the same temperature (density) allowing the wind to mix it through. Similar processes can be observed during spring, when warmer temperatures cause the upper regions of the lake to warm, leading to convergence and exchange processes. In the winter months deep lakes stratify again – however inversely to the summer (winter stagnation): Because of the density anomaly, 4°C-warm water sinks to the bottom of the lake, while the cooler, less dense water accumulates in the upper parts. Ice further prevents mixing. In some cases (e.g. very deep lakes or lakes situated in especially wind-protected areas) standing water bodies can be meromictic, which describes a situation of incomplete mixing (Schwörbel and Brendelberger, 2013). In sum, the stratification influences various exchange processes, including the oxygen transfer into deeper strata and the nutrient exchange. As such it impacts a lake's water quality. Figure 3 illustrates the seasonal mixing patterns:
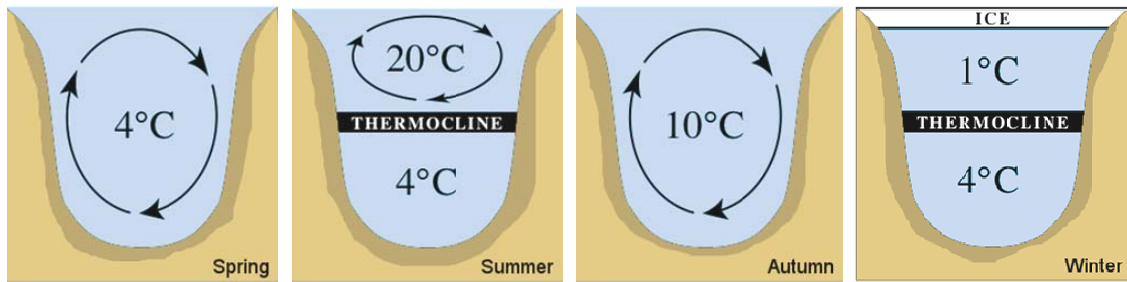
Figure 3. Stratification Scheme and Mixing Patterns (Source – modified after: Wikipedia, 2006).

Lentic waters can also be distinguished according to their mass balance and the amount of (primary) production. The term "oligotrophic" describes water bodies for which "*nutrients are in poor supply, and secondary production is depressed*" (Mann, 2016). This generally results in clear water as well as high oxygen content. Over time or due to sudden events (e.g. leak of a waste water treatment plant), they may, however, "*give way to the high-nutrient, low-oxygen conditions of eutrophic water bodies*" (Withgott and Laposata, 2014: 265) that are usually characterized by murky water (e.g. because of algae growth). Due to the elevated nutrient concentration, these waters tend to be highly productive until the oxygen content becomes too low to sustain life. Anaerobic (oxygen-poor) or anoxic conditions – especially near the lake's bed – result in the large-scale loss of fauna and flora species within the respective lake. Standing water bodies with intermediate nutrient, oxygen content and plant growth are designated as mesotrophic lakes (Mann, 2016). Changes in the chemical and physical condition of standing water bodies not only affect the composition and quality of the aquatic life (e.g. lakes provide a habitat for fauna and flora), but may also result in economic losses and supply shortfalls:

Freshwater, as for example contained in lakes, has a socio-economic function (e.g. summer tourism), forms an essential part of the industrial and agricultural production processes (e.g. aquaculture, irrigation for agricultural fields) and is used to generate energy (e.g. storage power plant Kaprun). It is fundamental for the sustenance of life as humans and animals depend on the supply of fresh drinking water (e.g. Lake Constance). In addition, water has a geomorphologic impact on the landscape and moderates the (local) climate due to its heat storage capacity (BMLFUW, 2014a: 37).

3.2. Projected Effects of Climate Change in Europe & Austria

"*Human influence on the climate system is clear, and recent anthropogenic emissions of greenhouse gases are the highest in history*" (IPCC, 2014a: 2). While the IPCC's Fifth Assessment Report stresses that the climatic changes show regionally varying characteristics, there are also certain trends with regard to global warming: Overall, the global mean near-surface temperatures averaged over land and ocean area have experienced an increase of +0,8°C since 1880 compared to pre-industrial levels. Most of the warming trend has occurred in the second half of the 20th century (on the average +0,15-0,20°C per decade). While a global 1°C-increase might sound little, it is actually quite "*significant because it takes a vast amount of heat to warm all the oceans, atmosphere, and land by that much*" (Earth Observatory, n.d.a). And this trend is very likely to continue: The estimated rise in mean temperatures for the lowest and highest RCP (representative concentration pathway) ranges between 1,0°C and 3,7°C over the next 100 years. However, the rise in global temperatures might be even higher: "*The uncertainty ranges for the lowest and highest RCP are 0,3-1,7°C and 2,6-4,8°C, respectively*" (EEA, 2015a). RCPs "*provide time-dependent projections of atmospheric greenhouse gas (GHG) concentrations. (...) They are representative in that they are one of several different scenarios that have similar radiative forcing and emissions characteristics*" (IPCC, 2007: 4f). Figure 4 depicts the temperature trend since industrialization: The graph illustrates that despite of varying on a year-to-year basis the "*temperature is rising. By the beginning of the 21st century, Earth's temperature was roughly 0,5 degree Celsius above the long-term (1951-1980) average*" (Earth Observatory, n.d.b). Furthermore, it shows that the largest temperature increase has occurred in recent times (since the 1970s).
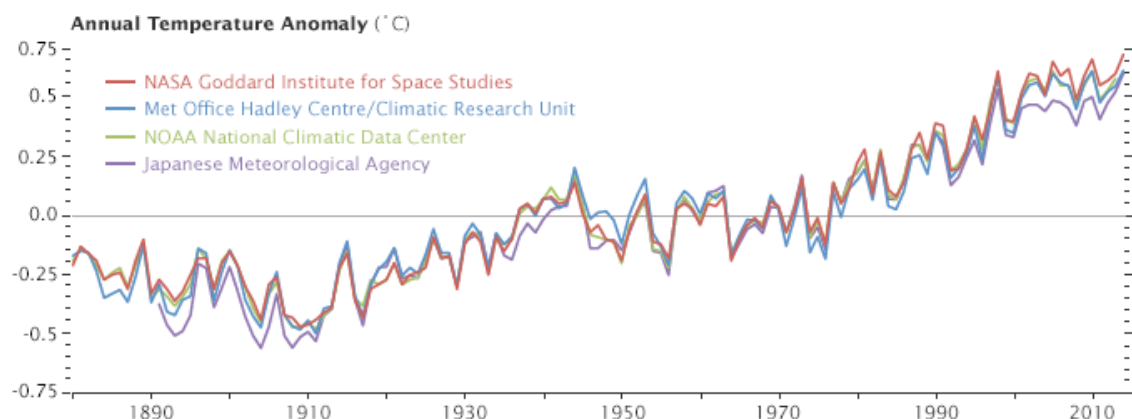

Figure 4. Development of the Global Mean Temperatures (Source: Earth Observatory, n.d.a).

In general, the European countries have observed "*changes in average and extreme temperature and precipitation, warmer oceans, rising sea level and shrinking snow and ice cover*" (EEA, 2015b).

According to the EC (European Commission) and the IPCC, the likelihood of heat waves will increase, both with regard to their frequency and intensity (RCP8.5): In sum, the "*number of hot days (...) have increased by 2% on average per decade since 1960*" (EEA, 2015a). Between 2005 and 2014 mean temperatures in Europe have been almost 1,5°C warmer than pre-industrial temperatures and this trend is likely to continue in the future (EEA, 2015a). A slight rise in temperatures has already been observed, especially in the northern latitudes (2002-2011: about 1,3°C ± 0,11°C compared to 1850-1899): "*Since the 1980s, warming has been strongest over Scandinavia, especially in winter*" (IPCC, 2014b: 1276). By contrast, in the central and southern parts of Europe (e.g. the Mediterranean) increasing mean temperatures have been particularly pronounced during the summer, leading to an elevated risk of desertification, droughts and bush fires (IPCC, 2014b). "*Annual average land temperature over Europe is projected to continue increasing by more than global average temperature over the rest of this century, by around 2.4 °C and 4.1 °C under RCP4.5 and RCP8.5*" (EEA, 2015a). Furthermore, the projected temperature increase leads to an increased likelihood of locally intense rain and storm events, resulting in higher risks of flooding across Europe (IPCC, 2014b). Coastal areas are particularly vulnerable to floods, due to rising sea levels (2081-2011: +0,29- 1 m compared to 1986-2005; IPCC, 2014b). Precipitation shows a slightly increasing trend in the north and north-west of Europe (+70 mm per decade since 1950), while the southern parts will experience a decline in annual rainfall (IPCC, 2014b). Together with increasing mean temperatures, this will result in increased rates of glacial retreat. Given that almost "*40 % of Europe's water comes from the Alps*" (EC, 2015), this in conjunction with reduced precipitation and higher mean temperatures might result in severe water shortages: Already "*changes have been observed in river flows, with reductions in southern and eastern Europe*" (EC, 2015). The maps in Figure 5 show the projected effects on temperature levels and precipitation patterns across Europe:

Projected changes in annual mean temperature (left) and annual precipitation (right)
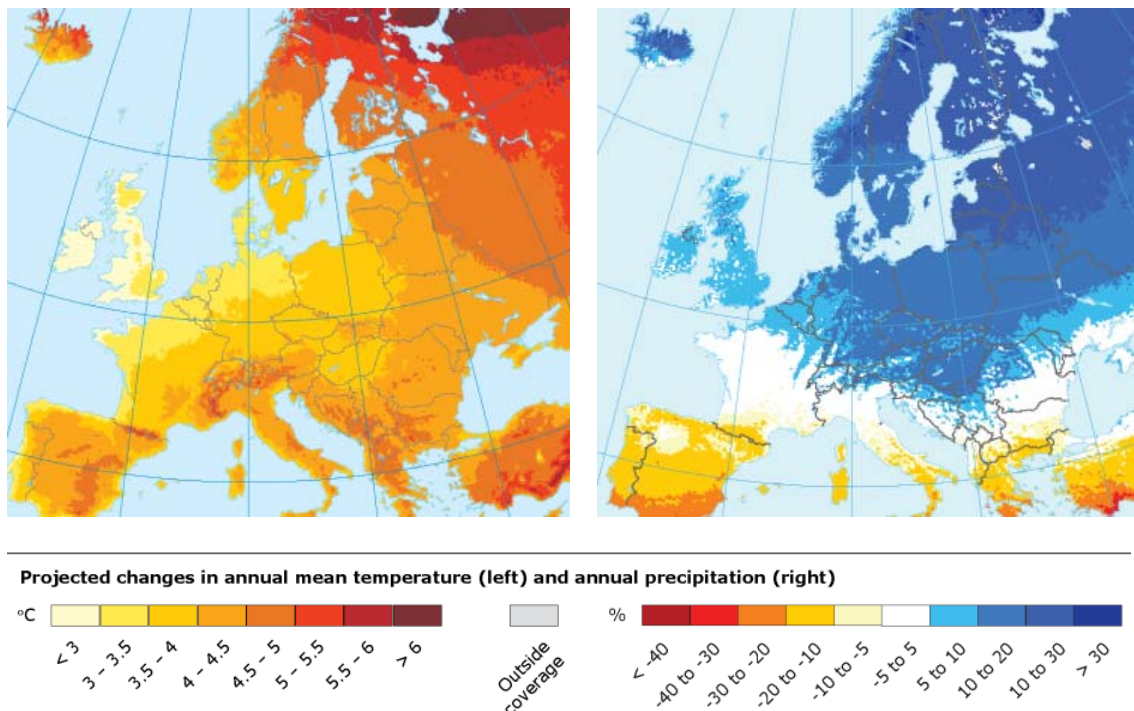
Figure 5. Changes in Annual Mean Temperatures and Precipitation Patterns for 2071-2100 Compared to 1971-2000 based on RCP8.5 (Source: EEA, 2015c).

According to the 2014 Austrian Assessment Report by the APCC (Austrian Panel on Climate Change) the temperature increase might be faster in Austria than on the global average: So far, the mean temperatures in Austria have risen for +1,8°C since the 1880s (compared to +0,8°C on the global mean). This trend is very likely to continue in the future (on the average: +2,0-2,5°C until 2050): While the winter months (December-February) might see a temperature increase of 1,3-2,0°C until 2050, the summer months June to August will see an especially pronounced increase of possibly more than 2,0-2,5°C (+3,0°C in the western regions).

During spring and autumn temperatures might increase for +2°C to +3°C (Formayer et al., 2009). In the region of the Neusiedlersee average annual temperatures might rise for +1,9°C until 2020 and +2,5°C until 2040. Mean temperatures have already increased for +0,7°C between 1991 and 2004 (Eitzinger et al., 2009). On the average, the yearly temperature in Austria will rise for about 1°C between 2021 and 2050 compared to 1976-2007 with more warming being expected for the summer months than for the winter time (BMLFUW, 2011b). The sum of days that have a temperature >30°C is projected to quadruple in the eastern parts of Austria until 2050, while days >25°C will double (Formayer et al., 2005). The projected temperature change is illustrated in Figure 6, showing that the west will be particularly warmed:
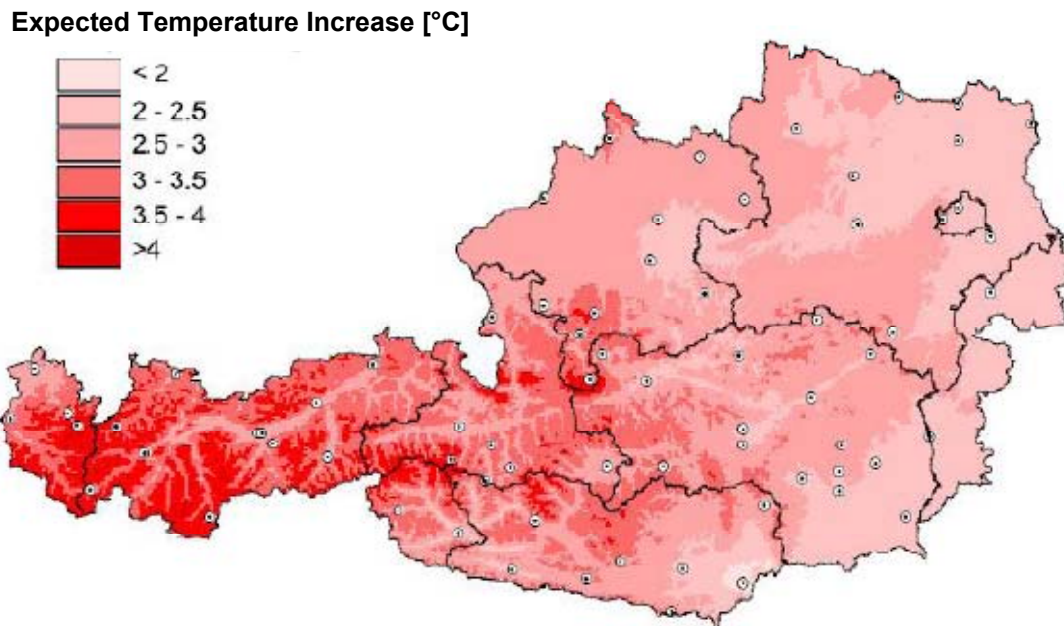
Expected Temperature Increase [°C]

Figure 6. Projected Temperature Change in Austria during 2019-2048 Compared to 1961-1990 (Source: Formayer et al., 2005: 8).

In Austria, the observed and projected rainfall patterns are characterized by regional differences. Overall, however, the precipitation levels have slightly increased since the 1970s, with the only exception being Austria's south-east: While the northern and western parts of the country (e.g. Lake Bodensee) experienced slightly increasing precipitation rates (+10-15 %), the southern and eastern regions showed a decreasing trend in rainfall (e.g. Lake Neusiedl) of about the same size (IIASA, 2014). For the whole of Burgenland an increase in precipitation of +35 % during the winter is possible until 2050. At the same time, however, the annual rainfall during the summer and autumn period will be reduced by -25 % in the same time scale (Formayer et al., 2009). In Vorarlberg a similar trend is perceptible, yet there might be a positive or at least neutral trend in rainfall. While the precipitation rates during the winter months increased in the north of the Alpine divide (Alpenhauptkamm), the southern parts experienced significant declines in winter precipitation. This trend is likely to continue (BMLFUW, 2011b). Overall, however, no assumptions can be made, because "*Austria lies in the (...) transition region between two zones with opposing trends*" (IIASA, 2014: 49), which causes significant insecurities with regard to the (regional) climate models: While Northern-Europe will very likely experience an increase in rainfall, it will decline in the Mediterranean area where droughts will become more common.

These increases in mean temperatures will very likely result in higher evaporation levels between 2021 and 2050 compared to 1967-2007 with high insecurities about the size of the increase.

Because the precipitation levels for most of Austria have slightly increased but the discharge from the surface water bodies has remained more or less constant in parallel, there is a strong indication for increased amounts of evaporation. Decreasing trends for the discharge have been observed in Vorarlberg as well as the south and increasing trends in the east of Austria. Except for the far-east most of the decrease occurred during the summer months. Because of the slightly increasing winter precipitation, the discharge during the winter months is projected to increase for +20 % in most of Austria, except for the south. It is very likely that the discharge during spring will decrease in the eastern lowlands (-10-20 %), while the Alpine area will be especially affected by decreases during the summer months (BMLFUW, 2011b).

Furthermore, Austria will be especially affected by glacial retreat. The average loss per glacier amounts to about -90 m per year (2015): "*All observed glaciers in Austria have clearly shown a reduction in surface area and in volume in the period since 1980*" (IIASA, 2014: 50). Furthermore, the mean snow coverage at mid-latitudes (1.000 m above sea level) has been significantly reduced. While increased (summer) temperatures will at first lead to larger water inputs due to enhanced glacial melting in the summer time (until 2050), this will be drastically reduced once the glaciers are gone (Dokulil, 2009): While small and medium-sized glaciers might be completely gone until the end of the 21st century, the bigger ones (e.g. Pasterze) might survive until the 22nd century, albeit in a dramatically reduced state. By 2100 the glacial area in the Alps might be scaled-down to 13-20 % of its former size (ZAMG, n.d.).

Yet, because of the complexity and interconnectedness of the climate system it is difficult to predict the future development of temperature, precipitation and weather trends. Climate models are only a simplification. Furthermore, the changes in the exterior environment will be regionally different, making predictions even more difficult.

3.3. Legal Provisions Aimed at the Protection of Standing Water Bodies
3.3.1. International Law

Since 1995 the federal republic of Austria is part of a supranational organisation, the EU (European Union), to which the 28 member states (2015) have ceded some of their sovereignty. Therefore, the EU can adopt legal acts that have the same force as domestic rules of law in the respective member states (Borchardt, 2010, 29ff): Decisions, regulations and directives are binding legal acts of the EU's institutions.

While regulations are directly applicable within the EU members, directives are only "*binding, as to the result to be achieved, (...) but shall leave the national authorities the choice of form and methods*" (Article 288 Treaty on the Functioning of the EU). Amongst the main objectives is the "*protection and improvement of the quality of the environment*" (Article 3 (3) Treaty on the EU). Furthermore, Austria is a member of the UN (United Nations), which also supports activities for the improvement of the environment (e.g. United Nations Environment Programme) as well as other associations. In sum, the protection of environmental resources has grown in importance: Since the 1950s Austria has signed several agreements to achieve this end. The accession to conventions dealing with the protection of nature is decided by the federal republic, albeit with the consent of the federal provinces (see Chapter 3.3.2). Amongst the most important international acts for the protection of standing water bodies are the WFD (Water Framework Directive), the Ramsar Convention as well as the Fauna-Flora-Habitats-Directive and the Birds Directive.

3.3.1.1. EU Water Framework Directive (WFD)

The WFD is a regionally confined intergovernmental treaty between the EU members: The "Directive 2000/60/EC of the European Parliament and of the Council Establishing a Framework for the Community Action in the Field of Water Policy" was adopted and entered into force in 2000. According to Article 1 WFD, inland surface waters (both standing and running water bodies), transitional and coastal waters as well as the groundwater fall within the scope of the legislation. Its main aim is to "*ensure that good status of surface water and groundwater is achieved throughout the Community and that deterioration in the status of water is prevented*" (Preamble (25) WFD).

The deadline for achieving the "good ecological and chemical status" of surface water bodies within the EU is set for 2015. In contrast, groundwater sources have to achieve the "good chemical and quantitative status", whilst heavily modified and artificial water bodies have to reach the "good chemical status" as well as the "good ecological potential" (Article 4 WFD).

This shall be achieved through the "combined approach", which includes the definition of emission limit values as well as of environmental quality standards and the establishment of measures to control the "*discharges and emissions into surface waters*" (Article 2 (36) WFD). Furthermore, the WFD aims to strengthen public participation (Preamble (14) WFD) and to streamline the states' national legislative acts. Moreover, member states shall strive to promote a "*sustainable use based on a long-term protection of available water resources*" (Article 1 (b) WFD) and take the necessary measures to prevent floods as well as droughts. Its operational structure is based on River Basin Management Plans: In fact, water management according to the WFD is based on smaller units that take account of the natural hydrological, geographical and ecological conditions of the respective water body.

The Convention recognizes the diverse "*conditions and needs in the Community which require different specific solutions. This diversity should be taken into account in the planning and execution of measures (...) in the framework of the river basin*" (Preamble (13) WFD). The river basin as defined by Article 2 (13) of the WFD comprises the "*area of land from which all surface run-off flows through a sequence of streams, rivers and, possibly, lakes into the sea at a single river mouth*". Catchment areas or river basins cover the entire river, starting from its source and ending at its outlet into the sea, including the groundwater sources and standing water bodies. The division into river basins takes into consideration the natural background of water systems and complies with the fact that running water bodies rarely end at the national state boundaries. The contracting parties are obliged to identify these areas and to formulate "River Basin Management Plans" that have to be updated on the basis of 6 years: These shall contain information on the status of the area concerned, threats and anthropogenic pressures within the respective river basin, the objectives set for the region as well as the appropriate measures to achieve these goals. The ecological and chemical objectives therein shall ensure the attainment of the good water status, the prevention of its deterioration and the development of sustainable water utilisations in the respective area (Annex VII WFD). In Austria, these objectives are further described within two ordinances (see Chapter 3.3.2.2). The River Basin Management Plan in Austria entered into force in 2010 (2009-2015): With the Danube, the Rhine and the Elbe, there are 3 river basin districts in the federal republic that are stretching across the borders to Germany, Slovakia and the Czech Republic. The Neusiedlersee is part of the Danube area that covers about 80.593 km^2 in Austria (10,1 % of the total river basin). Lake Constance is part of the Rhine area, which stretches across a region of more than 2.366 km^2 in the federal republic (only about 1,3 % of the total river basin).

The "good status", which is the Convention's main objective, includes both the "good chemical status" and the "good ecological status" for a surface water body (Article 2 (18) WFD). In case of the latter, the WFD differentiates between five water quality classes that distinguish between high, good, moderate, poor and bad water quality. The "high" status is associated with (almost) pristine natural conditions of a specific water body and low or at least very little anthropogenic pressures. It is "*the best status achievable – the benchmark*" (EPA 2016), against which the observed water conditions are compared to. However, Annex V WFD recognizes that there are certain conditions as well as species communities type-specific to each water body. Slight deviations from the "high" water quality are defined as "good" status: "*The values of the biological quality elements for the surface water body type show low levels of distortion resulting from human activity, but deviate only slightly from those normally associated with the surface water body type under undisturbed conditions*" (Annex V 1.2 WFD). A moderate divergence is classified as a "moderate" water class. Water qualities below this status are further defined as poor or bad. As such, the "*[e]cological status' is an expression of the quality of the structure and functioning of aquatic ecosystems (...) classified in accordance with Annex V*" (Article 2 (21) WFD). In accordance with this, Annex V WFD sets forth a detailed description of the classification scheme: According to Paragraph 1.1.2 of the Annex, biological elements (e.g. condition of the fish community) are especially important for determining a lake's quality. Furthermore, it defines a number of hydro-morphological (e.g. residence time of water) and chemical as well as physical elements (e.g. oxygen content) that support the biological criteria.

In order to achieve a "high ecological status", the WFD requires that both the biological as well as the hydro-morphological elements are close to the natural conditions, whereas in the case of "*lower classes (...) hydromorphological quality is not explicitly required*" (EA, 2010). Article 2 (17) WFD clearly underlines that the water status "*is determined by the poorer of its ecological status and its chemical status*". The biological, hydro-morphological and physical-chemical elements indicative for a surface water body's overall quality assessment are listed in Table 1 below:

Table 1. Quality Criteria for the Assessment of the Water Status.

Biological Elements	Hydro-Morphological Elements	Physical-Chemical Elements
	Supporting the Biological Elements	
Composition, Abundance and Biomass of Phytoplankton	Hydrological Regime Quantity, Dynamics of Flow Residence Time Connection to Groundwater	General Thermal Conditions Oxygenation Conditions Salinity Acidification Status Nutrient Conditions
Composition and Abundance of Other Aquatic Flora Composition and Abundance of Benthic Invertebrate Fauna Composition, Abundance and Age Structure of Fish Fauna	Morphological Conditions Lake Depth Variation Quantity, Structure and Substrate of Lake Bed Structure of Lake Shore	Specific Pollutants Pollution by all Priority Substances Identified as Being Discharged into the Body of Water Pollution by all Other Substances Identified as Being Discharged in Significant Quantities into the Body of Water

Most of the lakes exceeding a size of 50 ha in Austria, have either a high (34 %) or a good ecological water status (21 %). Only 5 % were classified as having a moderate water status (BMLFUW, 2014b).

3.3.1.2. Convention on Wetlands ("Ramsar Convention")

Unlike the WFD, the "Convention on Wetlands of International Importance especially as Waterfowl Habitat" is an international treaty, signed in the Iranian town of Ramsar in 1971. Its aim is to achieve the "*conservation, management and wise use of wetlands and their flora and fauna*" (Article 6 (2) (d) Ramsar). Overall, the Convention is based on a "Three-Pillar-Structure" that shall ensure the maintenance of designated water bodies: By accepting the terms of the treaty, member states are mandated to promote their wetlands' wise use, assemble a list of suitable wetland-habitats and "*cooperate internationally on transboundary wetlands, shared wetland systems and (…) species*" (RCS, 2014a). Over the years the Convention's original emphasis on the protection of wetlands particularly as feeding and living habitat for bird-species has been broadened to include "*all aspects of wetland conservation and wise use*" (RCS, 2013: 6).

Wetlands falling within the scope of the convention include "*areas of marsh, fen, peatland or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt*" (Article 1 (1) Ramsar). In order to achieve the protection of internationally important wetlands, each member is obliged to "*designate suitable wetlands within its territory in a List of Wetlands of International Importance*" (Article 2 (1) Ramsar). They are selected according to their botanical, ecological, hydrological and zoological significance (Article 2 (2) Ramsar). To guarantee their conservation, the wetlands included in the list have to be monitored and potential threats have to be communicated to the other contractors (Article 3 (2) Ramsar). The protection of wetlands is further strengthened by the states' obligation to "*promote the conservation (…) by establishing nature reserves on wetlands*" (Article 4 (1) Ramsar).

Austria has joined the Convention in 1983: Both Lake Constance and the Neusiedlersee are mentioned as Ramsar-areas. In fact, the region Neusiedlersee-Seewinkel (>44.000 ha) is the biggest and most extensive Ramsar-area in Austria. About 2.000 ha of the Rheindelta-Bodensee are protected under the Ramsar Convention (BMLFUW, 2016b). In Austria, however, the designation as Ramsar-wetland does not automatically assign a legal protection status to the respective area. It is, in fact, only a "quality seal". In order to achieve the protection and conservation objectives set by the Convention, the respective wetland areas have to be protected under the national law: Since 1993, the whole Ramsar-area Neusiedlersee-Seewinkel is protected as a national park. Furthermore, some regions of the lake are protected as a nature reserve (Naturschutzgebiet) as well as a protected landscape (Landschaftsschutzgebiet). In 1977, the Austrian part of the lake was recognized as a UNESCO-Biosphere reserve (BMLFUW, 2016c). Because of its rich species community the area has been nominated under Natura-2000 (see Chapter 3.3.1.3). The Rheindelta-Bodensee is protected as a nature reserve and under Natura 2000.

3.3.1.3. Fauna-Flora Habitats Directive & Birds Directive (Natura 2000)

The EU has adopted the Fauna-Flora-Habitats Directive (92/43/EWG), "*which provides a framework for the conservation of natural habitats of wild flora and fauna*" (EC, 2007: 8). It contains six annexes listing habitats as well as species subject to varying protection intensities. Since its adoption in 1992 the EU member states have proposed areas, which in sum cover about 12,8 % of the EU's territory, as SCIs (Sites of Community Importance). Most of the SCIs concern peat lands and other waterlogged habitats, such as naturally eutrophic lakes with a *Magnopotamion* or *Hydrocharition* vegetation (EC, 2007: 8).

The EU Birds Directive was adopted in 1979 and is the result of the 1972 UN Conference on Human Environment in Stockholm. Its aim is to guarantee the survival of wild bird species, of which many are dependent on water environments (e.g. *Gallinago gallinago*). Thereby it "*explicitly recognises the need for the protection of wetlands as a vital habitat*" (EC, 2007: 8). The contractors are required to identify and protect wetlands of international importance for the survival and well-being of birds as SPAs (Special Protection Areas). Under these directives an EU-wide network of protected areas (Natura 2000) has been created that "*is the centrepiece of EU nature and biodiversity policy. The aim (…) is to assure the long-term survival of Europe's most valuable and threatened species and habitats*" (EC, 2007: 7).

In Austria 218 Natura-2000 areas have been identified, which cover an area of about 15 % (UBA, 2015). The Neusiedlersee provides a habitat for more than 300 bird species as well as numerous amphibians and fishes. Many of them fall under the Annexes of the Directives, such as the trench (*Tinca tinca*) or the moor frog (*Rana arvalis*), which both are protected under FFH-Annex II. Furthermore, it is an important nesting place for the great bittern (*Botaurus stellaris*) or the common pochard (*Aythya nyroca*), which are protected under Annex I of the Birds Directive. The area of the Rheindelta-Bodensee is also an important bird area: Together with the Neusiedlersee it provides a breeding ground and nesting site for waterfowls, of which many are mentioned under Annex I of the Birds Directive (e.g. common kingfisher, *Alcedo atthis*). Furthermore, both lakes are internationally relevant wintering grounds.

3.3.2. National Law
3.3.2.1. Nature Conservation Acts

According to Article 15 of the Austrian Federal Constitution legislation and execution of nature conservation lies in the responsibility of the nine provinces (Burgenland, Vienna in the east, Lower and Upper Austria, Carinthia, Styria, Salzburg, Tyrol and Vorarlberg in the west). As a result, the legal sphere of Austria is shaped by nine Acts for the Protection of Nature: What they share is the obligation to protect and maintain functioning ecosystems as the life basis for humans, animals and plants. In alignment with this super-ordinate leitmotif there are objectives to protect the abundance, recreational value and beauty of nature and landscapes. Furthermore, the federal state laws contain provisions for certain species, areas and define the terms and criteria for potentially destructive projects.

In Burgenland wetlands (e.g. lakes) are protected under §7 of the Nature Conservation Act ("Burgenländisches Naturschutz- und Landschaftspflegegesetz"): It underlines that the national authorities are obliged to adopt management plans in order to ensure the conservation of waterlogged environments. Furthermore, it prohibits measures that are potentially destructive for the naturally occurring fauna, flora and their habitats. §13 of Burgenland's Nature Conservation Act concerns the protection of Lake Neusiedl. It underlines the protection of the water body as well as its surrounding reed belt as part of a UNESCO biosphere reserve and bans the degradation of its environment. The protection of the species community and their biotopes is further underlined by the definition of terms for the utilization of vessels on the lake. The act also recognizes the importance of wetlands as habitat for migrating birds and other waterfowls (§16 (a)-(c)). In accordance with §§44 and 45 of Burgenland's Nature Conservation Act, LGBl. 28/1993 ("Gesetz über den Nationalpark Neusiedlersee-Seewinkel") regulates the protection of the lake and its surrounding area as a national park (International Union for Conservation of Nature – IUCN Category II): §1a (2) of this ordinance underlines the obligation to protect the representative landscape-types for this ecological biotope as well as the species community and its habitats. §5 (1) divides the area of the national park in the most stringently protected nature zone (Naturzone) which is partly closed for visitors and the less strictly protected preservation zone (Bewahrungszone). LGBl. 22/1980 ("Natur- und Landschaftsschutzverordnung Neusiedlersee") regulates the conservation of the lake as a nature reserve and a preserved landscape: According to §2 of this act any intended destruction, intrusion or alteration of the landscape that might potentially cause a degradation of the nature including the lake is prohibited. §2a especially underlines the prohibition to disrupt or alter the natural condition of the Neusiedlersee's water body, waterlogged habitats (e.g. bogs) or its reed belt.

Furthermore, §2c-d protects the fauna and flora species of the lake and its surrounding region. Recognizing the importance of the Neusiedlersee as a nesting site and breeding ground (Natura 2000) §2e highlights the prohibition to disturb birds during the hatching time, allowing the authorities to designate areas as breeding ground. In Vorarlberg, wetlands are protected under §24 of the Nature Conservation Act ("Gesetz über Naturschutz und Landschaftsentwicklung"): According to this Article any measures that threaten the goals of nature conservation for a lake and a stripe of 50 m (Bodensee: 500 m) of its littoral zone are subject to permit. In accordance with its Nature Conservation Act, LGBl. 57/1992 regulates the protection of the Rheindelta as a nature reserve. §3 prohibits measures that are not approved by the government.

3.3.2.2. Austrian Water Rights Act 1959

The Austrian Water Rights Act (WRA), as enacted in 1959, lays down the legal foundation for water-related questions, such as the utilization of water (bodies), their conservation as well as the protection from possible adverse effects, including flooding (BMLFUW, 2016a). §30 (1) of the ordinance defines the obligation to prevent the deterioration of lakes, rivers and groundwater within the federal republic to protect and improve human health, the environment as well as the natural habitat of the fauna and flora, evade damages to the landscape and ensure the sustainable utilization of water. Amongst its main objectives is to protect the Austrian water bodies with regard to their hydro-morphological, physical-chemical and biological characteristics (§30 (3) WRA). §30a of the ordinance defines several environmental as well as ecological objectives for the quality of lakes and other types of surface waters: Strengthening the main aims of the WFD, §30a (1) WRA contains the general obligation to avoid any degradation of the current status of surface water bodies and to achieve their "good ecological" and "good chemical status" (Annex C) by no later than the 22nd of December in 2015. In alignment with §30 and the following provisions, §59e of the Act describes the general obligation to monitor the water quality of lakes and rivers.

Pursuant to §30a WRA two ordinances describe the target states set to determine the "good ecological and chemical water status" as demanded by the WFD for surface water bodies: The Quality Objective Ordinance – Ecological Status of Surface Waters ("Qualitätszielverordnung Ökologie Oberflächengewässer"; QOE) and the Quality Objective Ordinance – Chemical Status of Surface Waters ("Qualitätszielverordnung Chemie Oberflächengewässer"; QOC). Section 4 of the QOE "*lays down values for types of surface waters as regards the biological, hydromorphological and general conditions for the physico-chemical quality components*". For lakes the biological quality elements concern the fish species, phytoplankton and makrophytes.

The hydro-morphological quality criteria apply to the hydrological regime and morphology. Physico-chemical quality elements (general conditions) comprise the secchi depth, acidification, thermal and oxygenation conditions, the salt content of the respective water body as well as the nutrient conditions/ mass balance (Section 4 Paragraphs 2-4 QOE – see Table 2).

The conditions for reaching the "good ecological status" are described in Section 4 Paragraph 7, with the details laid down in Chapter 3 of the ordinance. The worst value is decisive for the final classification of the lake: Overall, the "good ecological water status" is achieved "*if the 1. a) biological and b) general physico-chemical quality elements (...) with regard to a good status are complied with and 2. If the values set forth in (...) the Quality Objective Ordinance – Chemical Condition of Surface Waters with regard to a good status are complied with*" (Section 4 Paragraph 7 QOE). The conditions laid down in Chapter 3 QOE for the quality criteria are described in Table 2. Detailed descriptions as well as reference values for the individual quality criteria and bioregions defined in the Ordinance are laid down in the Annexes to the QOE.

The benchmarks for achieving the "good chemical status" as well as the chemical component of the "good ecological status" are described in the QOC, which defines a number of environmental quality standards (Umweltqualitätsnormen). Its four Annexes contain a list of synthetic and non-synthetic pollutants or toxins, setting limit values and maximum concentrations for achieving the good water quality (e.g. for Aldrin, Dieldrin).

Table 2. Objectives for the Assessment of a Lake's Water Quality Class.

Biological Quality Elements Article 1	Hydro-Morphological Quality Elements Article 2	Physico-Chemical Quality Elements Article 3
Phytoplankton §15 (1) "*The assessment (...) shall be based on the modules of "Brettum Index" and "Total Biovolume". Both modules describe the nutrient load as well as the trophy of the water body concerned*". **Makrophytes §16 (1)** "*For the assessment (...) shall be used: vegetation density, tree line, zonation, trophic index and taxonomic composition*". **Fish Fauna §17 (1)** "*For the assessment (...) the Fish Index shall be used (...): 1. Evidence quality of the dominant fish species, 2. Length frequency distribution of the dominant fish species,* *3. Relative reproduction rate of type-specific species,* *4. Absence of type-specific species and* *5. Exceedance/ undercutting of original biomass* *and is calculated as the deviation of the status of each module from the respective reference value*".	**Hydrological Regime** **Morphology §19 (1)** "*A hydromorphological status is rated as good if (...)* *1. The characteristics of the surface water body generally correspond to the natural water-body type.* *2. The amount and dynamics of current, water level and residence time and the resulting connection with the ground water exhibit only marginal anthropogenic disturbance.* *3. The lake's depth variation and the substrate's amount and structure have changed only marginally.* *4. Depth-wise, the shore construction replaces less than half of the uppermost zone of aquatic plants. The impact of deeper-reaching shore constructions does not go beyond a local level.*"	**Temperature** **Oxygenation** **Salinity** **Nutrient Content** **Acidity §20 (1)** "*water temperature in the hypolimnion,* *salinity (expressed by chloride concentration, electrical conductivity and alkalinity),* *pH value,* *total phosphorus concentration,* *chlorophyll-a concentration,* *Secchi depth and* *oxygen saturation in the hypolimnion*".

3.4 The Selected Examples: Lake Neusiedl & Lake Constance
3.4.1   Neusiedlersee

This water body is situated at an elevation of about 115 m above sea level and covers an area of 320 km^2, of which the majority is located within Austria (240 km^2). About 80 km^2 are situated in Hungary. The lake is surrounded by extensive reed fields that extend over an area of more than 180 km^2 of the lake's water surface and are in constant exchange with the free water zone (Wolfram and Herzig, 2013). It comprises about 34 km in length and 12 km in width, with an average water depth of 1,0 to 1,8 m. Its catchment area covers approximately 1.120 km^2 and is dominated by agricultural utilization – especially vineyards (47 %) and forestry (20 %, BAW, 2008 in: ABL, 2012). In sum the lake's drainage basin is influenced by three types of landscape: In the north-west, its surrounding is dominated by the terminating mountain region of the "Leithagebirge", while the western, northern and north-eastern areas are characterized by rolling hills. In the lake's north-east and eastern parts the features of the lowlands ("Seewinkel", "Parndorfer Plain") are becoming predominant (ÖUG, 2014).

The lake was formed by tectonic processes around 20 million years ago, which created the Pannonian Lowlands that were flooded by the primeval ocean Tethys. Once the water retreated about 13 million years ago, a water body was formed, based on the saline remnants of the ocean. The lake's basin was further influenced by subsidence following the end of the last ice age 13.000 years ago (BAW, 2008 in: ABL, 2012).

For the protection of the lake and its water quality several legal acts on the national and international level are important (see Chapters 3.3.1 and 3.3.2): In 1993 the area of the Neusiedlersee and its surrounding wetlands were designated as national park. About 44.000 ha of the area are recognized as wetlands of international importance under the Ramsar Convention with the majority being protected as a nature reserve as well as a protected landscape. Furthermore, the area Neusiedlersee-Seewinkel has been nominated under the Natura-2000 network. So far, about 70 % of the lake's shoreline is considered to be undisturbed (e.g. no infrastructure, reed belt).

Figure 7 shows the location of the lake in the border area of Austria and Hungary:
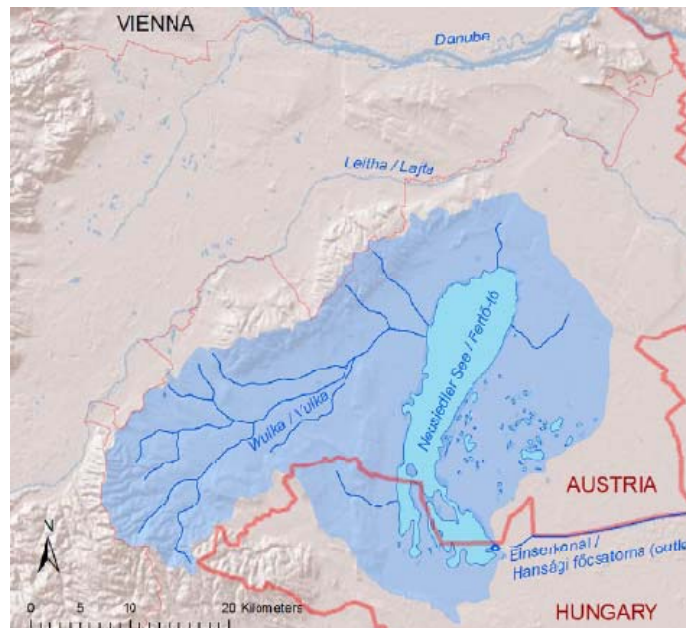
Figure 7. Location of Lake Neusiedl (Source: Soja et al., 2013: 116).

The climatic conditions are dominated by the Pannonian Climate, which is characterized by little amounts of precipitation (annual average precipitation: <600 mm) and large temperature differences between the summer and winter months (annual average temperature: >10°C): Summers are generally hot and dry, resulting in almost semi-arid conditions and high average evaporation during the summertime. The region is all-year-round windy, with the prevailing wind direction from the north-west (NP Neusiedlersee, n.d.a). Because of the constant wind influence and the low water table, no vertical stratification of the water body is possible: Instead it is completely mixed through throughout the day (holomictic). This total turnover of the water mass can occur several times throughout the day (polymictic) in case of strong wind (ABL, 2012). This reduces the lake's visibility depth to only a few centimetres. The high turbidity reduces the light conditions for the aquatic plants and phytoplankton (ÖUG, 2014).

The lake's hydrological balance is determined by the difference between water input and output, with the output determined mainly by evaporation:

$$\Delta V_L = (V_P + V_{AI} + V_{SI}) - (V_{EV} + V_O)$$

ΔV_L ... Change in the lake's water volume
V_P ... Water input from precipitation
V_{AI} ... Water input from aboveground inflow
V_{SI} ... Water input from subsurface inflow
V_{EV} ... Water loss from evaporation
V_O ... Water loss from (artificial) outlet

Overall, the Neusiedlersee has little inputs from above- and subsurface inflows (24 % of the lake's hydrological balance, as measured between 1965 and 2012). The largest tributaries are Wulka, Golser Kanal and Rákos patak.

Therefore, the lake's hydrological balance is dominated by precipitation (76 %) and evaporation (89 %), with the difference between them being decisive for the lake's water table. In 1909 the construction of the Einser-/ Hansag-Kanal created an artificial outlet (11 %), which today functions as a protective measure against floods (ÖUG, 2014: 9). Table 3 demonstrates the components of the lake's hydrological balance.

Table 3. Hydrological Balance of the Neusiedlersee 1965-2012.

Components of the Neusiedlersee's Hydrological Balance (1965-2012)	Average Value [mm/ year]	Percentage [%]
Evaporation	660	89
Artificial Outlet through Canal	85	11
Precipitation	574	76

Inflow (Rivers etc.)
  Aboveground Inflow (e.g. River Wulka)
  Subsurface Inflow
	180	24
		22
		2

The lake's mass balance is characterized by mesotrophic-eutrophic conditions and a high concentration of salts (ABL, 2012): Dominant ions are soda and carbonate ($NaHCO_3$, Na_2CO_3), which designates Lake Neusiedl as a "Soda-Lake".

The lake is classified as having a "good" water status (BMLFUW, 2014b): It is a "Lake of the Pannonian Plain" and belongs to the pike-perch lakes, according to Annex A QOE. Amongst the most decisive parameters is its salinity: The electrical conductivity reaches >2.200 µS/ cm (class boundary high-good in Annex L2 QOE: 1.449 µS/ cm), Chloride concentrations reaches 253 mg/ litre (class boundary high-good: 110 mg/ litre). Its pH-value slightly fluctuates around 9 (class boundary high-good in Annex L3 QOE: 8,0-9,5; ÖUG, 2014: 43). The total phosphorous content fluctuates around 60 mg/ m^3 (class boundary good/ moderate in Annex L4 QOE: 92 mg/ m^3).

Because the Neusiedlersee is heavily influenced by the exterior climatic conditions (see Table 3) it has experienced significant fluctuations of the average water table. In the past there have been episodes of the lake's dry-out (e.g. 1318, 1811, 1865) though the records about the actual water level are varying (e.g. "complete dry-out", "15-20 cm of water"). In parallel, the area has, however, also been affected by flooding as well as uncommonly high water tables: This was the case in 1786, when the Neusiedlersee extended over an area of more than 500 km^2. Between 1872 and 1880 the lake had a water depth of approximately 2-3 m.

A succession of dry years with less than the annual precipitation (1850-1870) coupled with more than 35 % precipitation deficit in 1865 resulted in the complete dry-out of the lake in 1865 (Eitzinger et al., 2009). Such remarkable fluctuations have become less pronounced since the 1960s: The construction and regulation of the weir Meksziópuszta in 1965 has resulted in higher average water tables. A comparison of 1930-1965 (about 115,11 m above the sea level) and 1965-2016 (about 115,50 m above the sea level) shows that is has been raised by more than 30 cm (ÖUG, 2014: 14). In times of high water levels the lake's water flows through the Einser-Kanal (maximal water discharge 15 $m^3/$ s) to the weir (flood protection): The ordinance regulating the operation of the lock has been renewed in 2011. While the weir influences the average water table of the lake, studies show that it is not able to prevent the potential drying out of the Neusiedlersee (ÖUG, 2014). Furthermore, the lake's water table is influenced by the discharge from the river Wulka, which has slightly decreased (-1,2 ± 0.6 x 10^6 $m^3/$ decade compared to an annual inflow of about 8,2 x 10^6 m^3) between 1961 and 2010 (Soja et al., 2013). Figure 8 shows the development of the lake's water table. The grey area signifies the range of variations between the minima and maxima of the daily water table (1930-2015), while the black line shows the average values in this period.
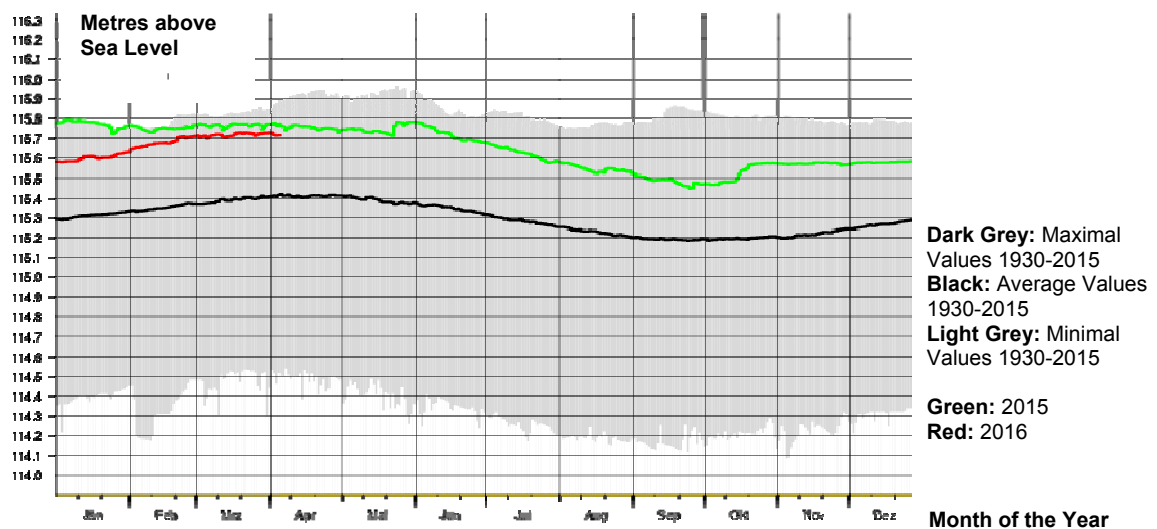
Figure 8. Comparison of the Lake's Water Table Development (Source: HDB, 2016).

Studies show that the development of the lake's average water table is also connected to the development of the reed belt, which surrounds the Neusiedlersee: The records prove that the reed fields extended towards the land area (riparian zone) in times of high water levels (e.g. 1785), while they developed towards the lake's centre (previously free water zone) in times of low water tables. The almost complete dry-out of the lake (e.g. 1865-1870) resulted in almost no reed fields, threatening the survival of reed-dependant (fish) species (e.g. Pike, *Esox lucius*).

Because reed (*Phragmites communis*) is highly competitive it can develop under unfavourable conditions, yet it prefers fine-grained sediments (sludge), nutrient-rich conditions as well as low water tables. Decreasing water levels during the 1950s and 60s stimulated the significant growth of reed, almost resulting in the overgrowing of the lake. Since then the rise in the average water table caused by the weir has also regulated the reed population, preventing the loss of the free water zone. At the same time, however, it has resulted in the landside development of the reed fields (ÖUG, 2014). The change in reed coverage has a potential impact on the evaporation levels with high insecurities about the direction and size of the development (Eitzinger et al., 2009). The development of the lake's reed belt is depicted in Figure 9: Today over half of the lake's surface is covered by reed.
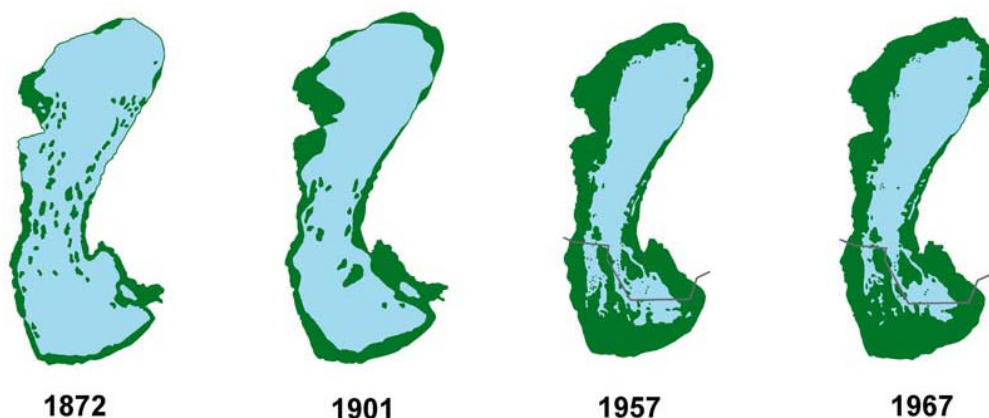
Figure 9. Development of Lake Neusiedl's Reed Belt (Source: NP Neusiedlersee, n.d.b).

In fact, the Neusiedlersee's bed consists of two layers, namely the solid ground beneath a varying coverage of mud: The lake's bed is covered by hard mud (Hartschlamm) as well as soft sludge (Weichschlamm). The latter is unevenly distributed over the lake's bottom, generally reaching 10 cm depth in the centre and increasing in thickness towards the reed belts (>40 cm). Yet, in some parts of the lake, it seems to be missing completely (e.g. in Rust). The hard mud has an undulated surface with wavelengths ranging between 25 to 30 m (Löffler, 1969). Time series analysis shows that in parallel to the development of the lake's water table, the Neusiedlersee's average water volume has slightly decreased. As research shows, this is caused by the spread of the reed belt, as well as the growing deposition of mud: Between 1963 (75 Mio. m^3 mud) and 1988 (150,17 Mio. m^3 mud) the mud layer in the Austrian part of the lake has more than doubled (Eitzinger et al., 2009).

Landsat images of the Neusiedlersee show that its water temperature is slightly higher within the reed belt than in the free water zone. Generally, however, the water temperature has increased in parallel to the increasing trend in air temperatures.

Figure 10 demonstrates this rising trend in the average annual water temperature between 1975 (about 10,5°C) and 2003 (almost 13°C).
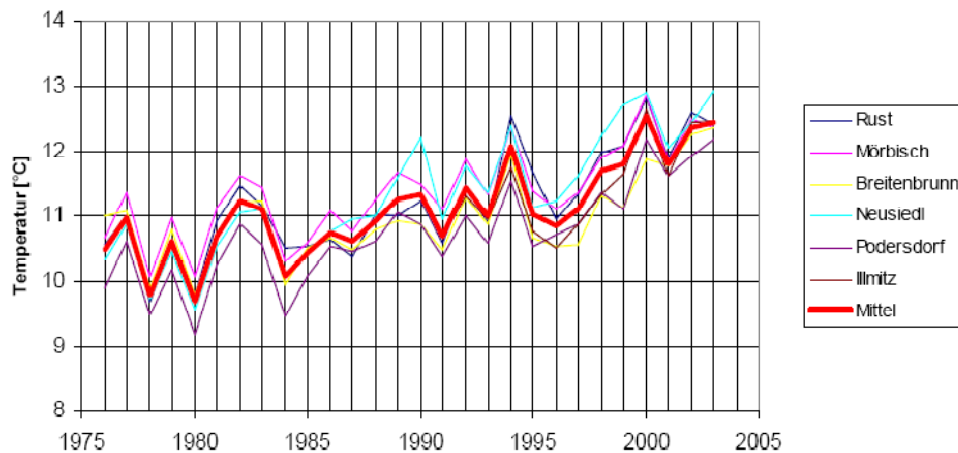

Figure 10. Trend in Annual Average Water Temperatures (Source: Eitzinger et al., 2009: 45).

Because the lake is quite shallow (little water storage capacity), significant variations in the average water temperatures throughout the year are quite common: Maximum water temperatures are reached between June and August (>25°C) and minimum values (<4°C) in the months of December to February (Eitzinger et al., 2009). During the summer months temperature maxima of up to 31°C (in 10 cm water depth) have been measured (ÖUG, 2014). The analysis of data measured at Breitenbrunn, Illmitz (1999-2003), Neusiedl, Mörbisch, Rust and Podersdorf shows that the maximum surface water temperatures measured for each month have slightly increased over the years. Amongst the most important parameters influencing the water content of the lake is the evaporation (see Table 3), which has increased in parallel with the rising trend in the average water and air temperature. Between 1991 and 2004 it has risen by about 10 % (Eitzinger et al., 2009). Figure 11 shows the monthly average water temperatures as measured between 1976 and 2003.
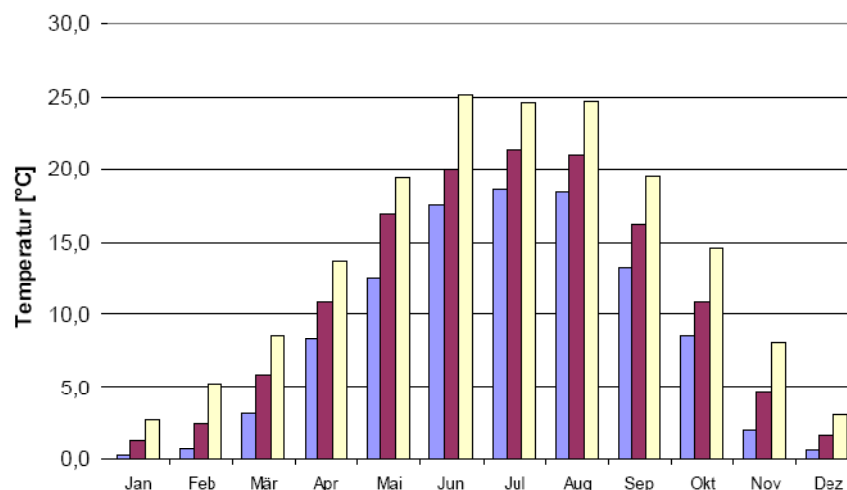
Figure 11. Average Water Temperatures (Purple) including the Maximum (Yellow) and Minimum Values Measured (Blue) between 1976-2003 (Source: Eitzinger et al., 2009: 44).

The combination of little discharge from the lake, the semi-arid climatic conditions as well as the tertiary remains of saline, maritime sediments result in high salt contents: Today, the lake's salinity fluctuates around a value of about 2,8 ‰ though it has been higher in the past: During periods of low water levels it has been particularly high. In the 1930s values of more than 3,3 ‰ were measured and in 1902/03 the lake's salt content ranged between 5 and 16 ‰ (ÖUG, 2014: 43). The outlet of lake water from the Einser-Kanal slightly reduces the Neusiedlersee's salinity, while the outer parts of the reed belt that dry out during summer lead to new salt inputs into the lake once they are flooded again in winter/ early spring. The close connection between the water table and the Chloride-concentration of the lake is depicted in Figure 12. It shows significant variations, being higher in times of low water levels (e.g. 1992-1994 and 2001-2008). Since the creation of the Einser-Kanal, the salt content has decreased because of the water outlet (e.g. 1995-2000) from the lake (Wolfram and Herzig, 2013).
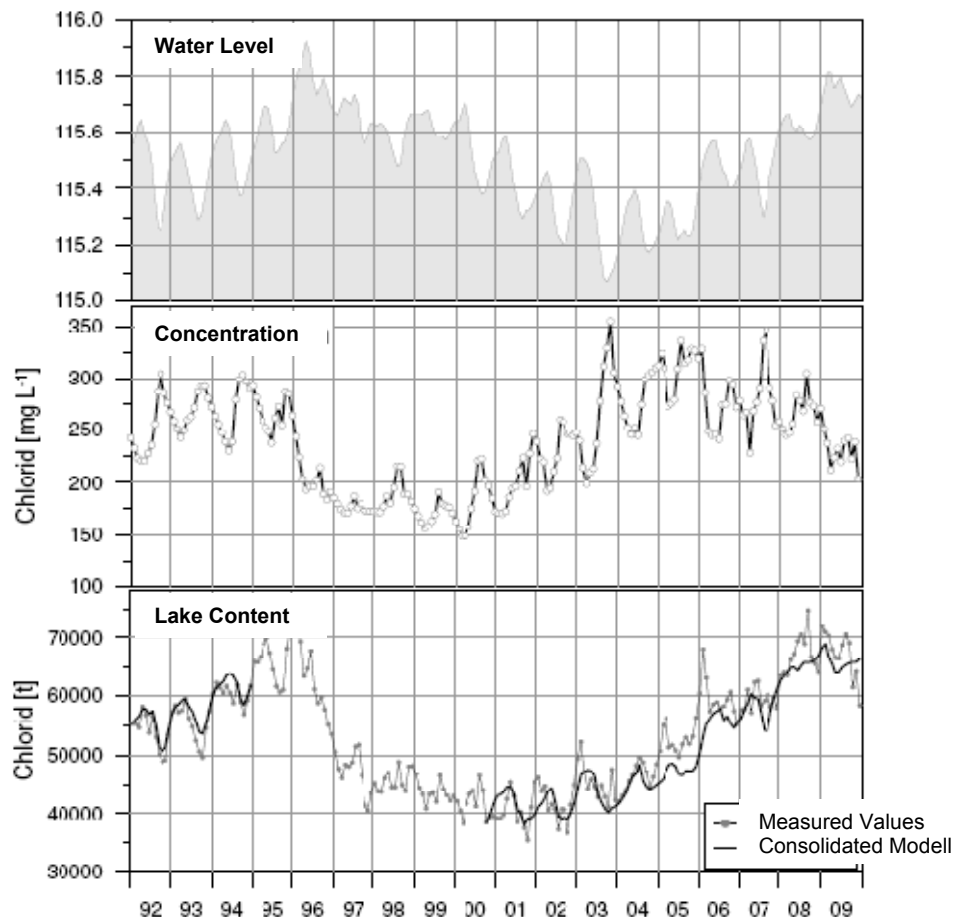
Figure 12. Variations in the Lake's Water Table are Closely Connected to the Chloride Concentration (Source: Wolfram and Herzig, 2013: 9).

What has been noticed is that the lake's phosphorous concentration is higher during periods of strong winds, which add particulate phosphorous through swirling up the lake's bed and bringing in phosphorous from the shallow water areas.

Apart from such short-term fluctuations it is dependent on input from the surrounding area, the exchange with the reed belt and the mobilization of phosphor from the sediments ("internal loading"): Because of tourism and agriculture, the lake was severely affected by eutrophication during the 1970s/80s (maximal value: 160 µg phosphorous/ litre, starting from 40 µg phosphorous/ litre), threatening its mass balance. However, the high degree of turbidity, which significantly reduced the conditions of illumination in the lake, prevented an algae bloom as well as a significant rise in biomass. Since then, remediation measures have proven successful: Today, the total phosphorous contained in the lake fluctuates around 60 µg/ litre. It is, however, heavily influenced by the water level and the resulting exchange with the reed: The concentration of particulate phosphorous is especially high during dry periods, when the exchange with the riparian/ shallow water area is reduced by the declining water surface, which reaches less into the reed fields. As a result less particulate phosphorous accumulates in the reed belts (ÖUG, 2014: 47). In 2003/04 the phosphor concentration measured in the free water zone reached values of <100 µg/ litre: The mobilization of phosphor from the lake's bed sediments is especially high during high temperatures and sulphate reduction, which occurs during the dry-period. Once the water table increases again, the phosphorous from the reed belt is released into the free water zone, increasing the phosphor content (ÖUG, 2014).

The "*Neusiedlersee (...) exhibits scarcely any vertical oxygen gradient. On the other hand, very distinct horizontal variations in oxygen content occur, due to the presence of the two sub-biotopes, the open lake and the reed belt*" (Neuhuber and Hammer, 1979: 121). A weak vertical gradient may develop only in case of a sustained period of calm weather (Neuhuber and Hammer, 1979). Because the Neusiedlersee is shallow as well as completely mixed through throughout the day, it is generally well oxygenated – especially within its free water zone (about 8-15 mg oxygen/ litre; ÖUG, 2014). According to Neuhuber and Hammer (1979) it reaches the saturation point in the open lake during summer and autumn (>88 %), sometimes even surpassing it due to assimilation processes by phytoplankton (mostly during April to June). Because of degradation processes coupled with reduced water exchange, the dissolved oxygen (DO) content measured in the reed belt is significantly lower (about 4 mg oxygen/ litre) than in the free water zone (0-70 %). During summer nights it can reach values <2 mg/ litre, resulting in poor oxygen conditions or even an oxygen deficit (ÖUG, 2014: 50).

The Neusiedlersee is an important tourist destination, both during the summer time as well as in the winter (e.g. ice skating) period. Because of the north-west winds, it is amongst the most important surfing as well as sailing spots in Austria.

Furthermore, the lake is crossed by ships, which provide round tours as well as connections between the bordering villages. The lake is also used to catch fish, however, in a smaller scale than at Lake Constance. It is managed by an association of professional fishermen ("Fischereiverband Neusiedlersee").

3.4.2   Lake Constance

Extending over an area of about 536 km^2, Lake Constance (German: Bodensee) is situated in the borderland of three states: About 11 % are located in Austria (Vorarlberg), 57 % in Germany (Bavaria and Baden-Württemberg) and 32 % in Switzerland (Thurgau, St. Gallen and Schaffhausen, Ebner, n.d.). The lake consists of two parts, which are connected by a river ("See-Rhein"). With an area of 473 km^2, the Upper Lake (including the "Überlinger Lake") is by far larger and deeper than the "Lower Bodensee" (63 km^2). In total, the longitudinal length of Lake Constance amounts to approximately 63 km, while its maximal width is about 14 km. The average water depth of the "Obersee" amounts to 40 m, with the deepest part of the lake reaching more than 250 m downwards. With an average depth of 13 m (maximal depth: 101 m), the "Untersee" is considerably less deep (IGKB, 2004). These water depths promote the vertical stratification of the lake's water body (about 50 km^3) that follow the seasonal mixing patterns and are at least mixed through once a year (holomictic):

The average water temperature during the winter months is about 4°C in the Epilimnion and <4°C in the Hypolimnion, but with the start of spring (March) the upper parts are warming up faster than the lake's lower area resulting in the development of a 20 m-thick Epilimnion. It is separated from the Hypolimnion by the Metalimnion, with an average temperature difference of <16°C during July. With decreasing external temperature, the lake's water temperature becomes about equal during late autumn, allowing the mixing through of the lake's water layers by the wind (IGKB, 2004). Within the water area, there are several islands, of which the three largest are inhabited on an all-year-round basis (Lindau, Mainau, Reichenau): Together they account to approximately 5 km^2 (Ebner, n.d.). The lake is situated at an elevation of about 395 m above sea level (IGKB, 2004). The lake's drainage basin comprises an area of more than 11.500 km^2 and is dominated by agriculture (especially viniculture and fruit cultivation) and urbanized areas (IGKB, 2013a) that are situated within the molasse region of the Alpine foreland: In the south, wooded hills pass into the Appenzeller Alps and further east into the Vorarlberger Alps; in the lake's eastern parts are the rolling hills of the Bregenz Forest and the adjacent Allgäuer Alps. In the south-east of Lake Constance plane landscapes and bays are characteristic (Ebner, n.d.). Figure 13 demonstrates the geographical location of the lake and its main inflows:
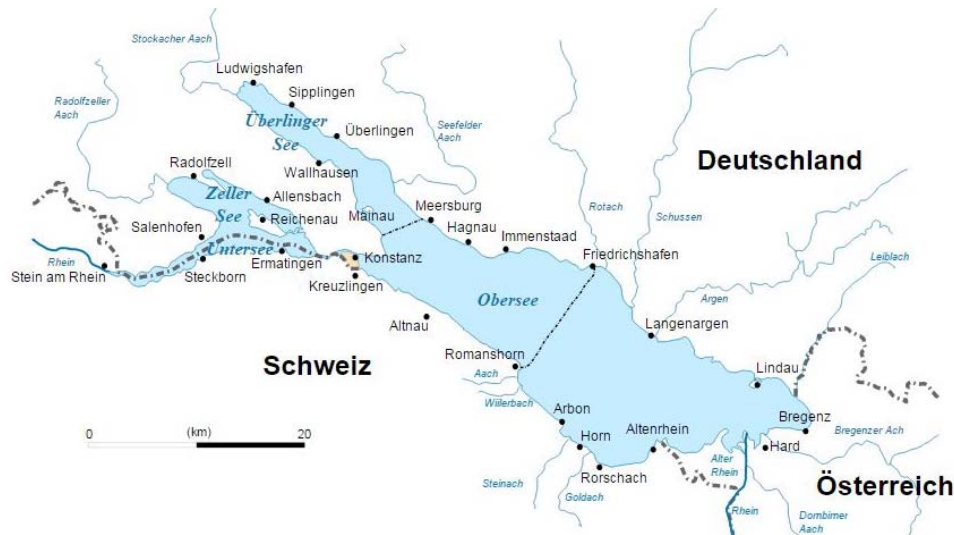
Figure 13. Location of Lake Constance (Source: Sieber, n.d.).

The lake's basin was formed by glacial erosion during the ice age and used to be much larger than it is today: About 14.000 years ago it was almost double the size ("Rheintalsee"). However, large sediment inputs from rivers gradually decreased both its size and depth. These processes of sedimentation and deposition of Alpine gravel are still prevalent today (IGKB, 2013b): Between 1911 and 1979 the Rhine ("Alpenrhein") deposited over 3 million m^3 of solid matter into the lake (IGKB, 2004).

The size and depth of its water body have a moderating impact on the region's climate, which is characterized by mild temperatures (yearly average: 8-9°C) and little thermal differences between summer and winter. While its western part is influenced by the Atlantic, the eastern regions of the lake are impacted by a more continental influence (IGKB, 2004). Foehn winds from the mountains (warm katabatic winds) are rather common and can create sudden squalls resulting in high waves: Overall, however, the lake is mostly influenced by western winds (Schröder, n.d.). In sum, Lake Constance is fed by 14 main tributaries (inflows in the Upper Lake: Rhein as the main inflow that covers almost 62 % of the rivers' total water outlet into Lake Bodensee, as well as Dornbirnerach, Bregenzerach, Leiblach, Argen, Schussen, Rotach, Seefelder Aach, Stockacher Aach, Salmsacher Aach, Steinach, Goldach and Alter Rhein; inflows in the Lower Lake: Radolfzeller Aach, Seerhein as the connection from the Upper Lake) as well as several smaller inflows, which result in an annual average water flow of 370 m^3 per second (IGKB, 2013a).

The lake's hydrological balance is dominated by the water input from these rivers, which is especially large during June/ July as it is largely influenced by melting water from the surrounding glaciers, ice and snow.

Water inputs from the average annual precipitation on the upper lake's surface (about 0,45 km^3 per year) and losses resulting from evaporation (0,29 km^3 per year) as well as the withdrawal of freshwater for drinking water production (about 0,17 km^3 per year) have little impact on the Bodensee's total water balance (IGKB, 2004: 10). Table 4 below enlists the components of the upper lake's (473 km^2) hydrological balance.

Table 4. Hydrological Balance of Lake Constance.

Components of the Upper Lake's Hydrological Balance	Average Value [mm / year]	Percentage [%]
Evaporation	600	9,15
Water Withdrawal	359	5,48
Outflow See-Rhein (Upper and Lower Lake)	2.321	35,40
Precipitation	951	14,51
Inflow (Rivers etc.)	2.325	35,46

Even though considered to be an oligotrophic Alpine lake, the water body's ecological status was threatened by eutrophication during the 1970s: Due to large inputs of phosphorus (e.g. stemming from the nearby agricultural utilization, wastewater from the surrounding cities) the lake's mass balance was seriously disturbed.

The amount of 80 µg P/ liter promoted extensive algae growth and significantly reduced the amounts of oxygen in the lake's lower strata (see Figure 16). The highest amount of phosphorous was reached in 1979, when the concentration reached its maximum value of >87 µg P per litre. Since then the construction of sewerages as well as sewage treatment plants has more or less restored the natural conditions (IGKB, 2004). According to the latest studies, Lake Constance has now a "good" water status (BMLFUW, 2014b). It is classified as a "Special Type Lake" that belongs to the common bleak-lakes, according to the QOE. With <10 mg P/ m^3 it falls within the upper limit (10 mg P/ m^3) of an oligotrophic lake and lies within the class boundaries good/ moderate (Annex L4 QOE). An important parameter is the water temperature of the Hypolimnion (limit high-good according to Annex L1: 4-6°C), which currently measures <4°C. With a Chlorophyll-a-Concentration of about 3 µg/ liter, the lake remains within the "good" limit (limit good-moderate according to Annex L5 QOE: 3,8 µg/ liter).

Orthophosphate (PO$_4$-P) is an important plant nutrient, whose availability has a limiting influence on plant growth and primary production. Its abundance is influenced by the mixing processes and shows significant variations:

Within the Epilimnion the PO_4-P concentration increases during winter, when the seasonal mixing transports nutrient from the lower layers to the lake's top. During the phases of thermal stability algae and other phytoplankton consume PO_4-P, reducing its abundance. In the Hypolimnion, however, the PO_4-P concentration is largest during stable periods and decreases during times of (complete) mixing (IGKB, 2015).

Time series analysis of the past years (1960-2005) show that the average water temperature of Lake Constance has increased (about +0,03°C per year) in parallel to the air temperature (approximately +0,05°C per year) reflecting the projected trend in global warming. The same trend can be observed for the lake's two main tributaries Rhine ("Alpen-Rhine") and Bregenzer Aache, whose water temperature has significantly increased since the 1980s. Since the last complete ice covering of the lake in 1962/63 (-1,7°C on the average), the average winter temperatures have wavered between +1°C and over +4°C. Since the 1970s the numbers of warmer-than average winters has increased significantly. Overall, the increase in water temperatures (1961-2006: +0,5°C) has been less dramatic than the average rise in air temperatures (1961-2006: +1,8°C). Figure 14 illustrates this temperature increase of the lake's water body:
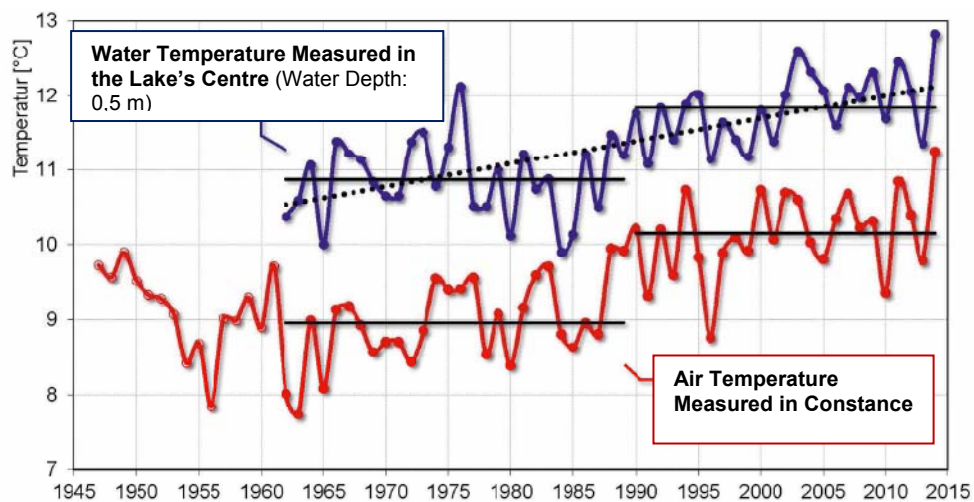
Figure 14. Development of the Average Annual Water Temperatures (Blue) and the Average Annual Air Temperatures (Source: IGKB, 2015: 14).

This already has an impact on the vertical stratification of the lake's water body and the mixing of the lake's strata with regard to gaseous exchange (oxygen, CO_2) and nutrient transport: Especially mild winters (average temperature +3°C) and little frost during January and February interfere with the seasonal mixing behaviour of the lake because of the warmer and, therefore less dense, upper layer (KLIWA, 2007): If the water body does not assume the same temperature then thermal stability will impede the mixing process spurred on by the winds.

In case of several mild winters (and reduced seasonal mixing) the water in the lake's lower zone cannot get exchanged with new water resulting in reduced water quality of the Hypolimnion (Hollan, 2000). This happened, for example, in the years 1988 to 1990. The studies also underline that over the past 40 years the stratification process of Lake Constance has begun to start earlier resulting in longer periods with thermal stability. Figure 15 shows that vertical mixing during winter has decreased. The intensity of the mixing is an estimation based on the wintery reduction of the vertical difference in the phosphorous concentration between the water layers, expressed as a dimensionless parameter.

Green: Complete Mixing
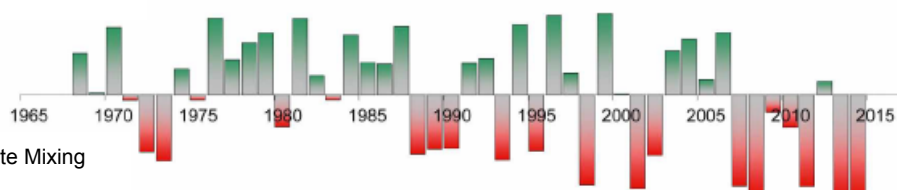
Red: Incomplete Mixing

Figure 15. Vertical Mixing of the Lake's Water Body (Source: IGKB, 2015: 15).

Figure 16 depicts the impact of reduced seasonal mixing on the oxygen content near the lake's bed. In order to estimate the quality of the lake's mixing, a mixing value Z was defined. According to KLIWA 2007 this parameter is based on the analysis of substance concentrations (e.g. orthophosphate) that show a yearly vertical gradient, which is reduced by the lake's mixing during the autumn/ winter season:

$$Z = 1 - \frac{\text{(Minimum Standard Deviation of the Measurement Profile in Spring)}}{\text{(Maximal Standard Deviation of the Measurement Profile in Autumn/ Early-Winter)}}$$

Mixing values Z >0,8 represent conditions of complete mixing, while Z values of <0,8 demonstrate years of oxygen depletion due to incomplete seasonal mixing. The oxygen content in the Metalimnion decreases between spring and early summer (June), reaching its minimum value (e.g. because of biological degradation) in September. Because of the water's low nutrient content (<8 µg Phosphorus/ liter) as a result of the remediation measures, the oxygen consumption in Lake Constance's bottom zone is nowadays low. This has been noticeably different during the high-nutrient conditions of the early 1970s and 1988/90, when eutrophication, which caused increased biological activity/ productivity (algae bloom), coupled with incomplete seasonal mixing (see Figure 15) resulted in poor oxygen conditions in the Hypolimnion. Since the 1990s, the re-oligotrophication of this Alpine lake has resulted in minimum oxygen contents of at least ≥ 7 mg/ liter near the lake bed – even in years of incomplete mixing (KLIWA, 2007: 25f). The development of the annual oxygen content (measured in a depth of 253 m) is demonstrated by the blue curve in Figure 16.

It underlines the importance of low-nutrient (oligotrophic) conditions, which cushion the impact of incomplete mixing and prevent a significant drop of oxygen concentrations in the lake's Hypolimnion.
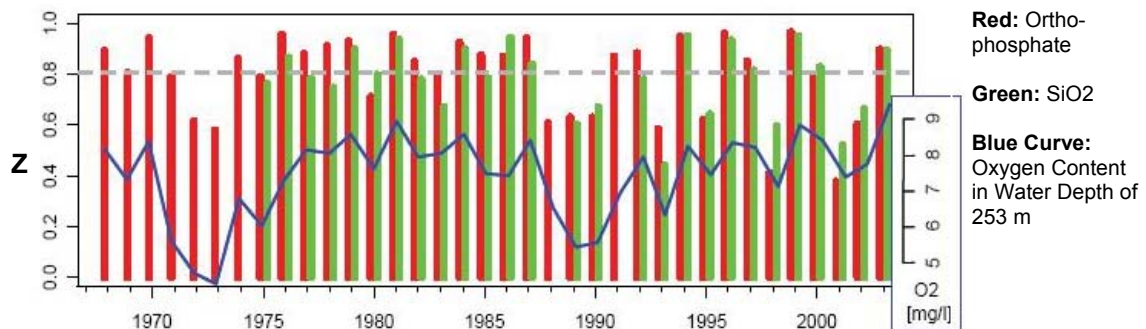

Figure 16. Measured Oxygen Content Near the Lake's Bed (Source: KLIWA, 2007: 26).

According to the KLIWA study, the impact of winds on the circulation pattern of Lake Constance is minor: Contrary to the Neusiedlersee's water, the large water body of Lake Constance (about 50 km^3) is big enough to resist the wind's mixing power. In fact, the impact of strong winter winds (wind velocity: >6 m/s in the hour) on the lake's mixing depends on the water temperature and is significantly impeded by conditions of thermal stability (Hollan, 2000). Longer lasting strong storm events can, however, promote vertical mixing.

While both the years 1994 and 1989 were characterized by mild winter temperatures (about 3,7°C), vertical mixing could be observed during spring 1994 but not in the early months of 1989 (January-March). What distinguished the winter of 1993/94 from 1988/89 were the strong winter storms (>6 m/s) during November to March that were almost 5 times more frequent in 1994 than in the previous years. Especially during the months January to mid-February storm events that lasted several days were quite common. Yet there are examples of years (e.g. 2001/02) that were characterized by especially strong, sustained storm events but little exchange because of the profound thermal stability (KLIWA, 2007). Furthermore, the KLIWA report suggests that the average water line of Lake Constance has decreased during the summer months as a result of higher evaporation and less precipitation (July-September). As such it follows the increase in average air and water temperatures that has characterized the region since the 1960s. At the same time the water level has increased between November and January – possibly because of river regulations within the hinterland that cause the faster discharge of melting water. Figure 17 illustrates the lake's water level development within the time periods.
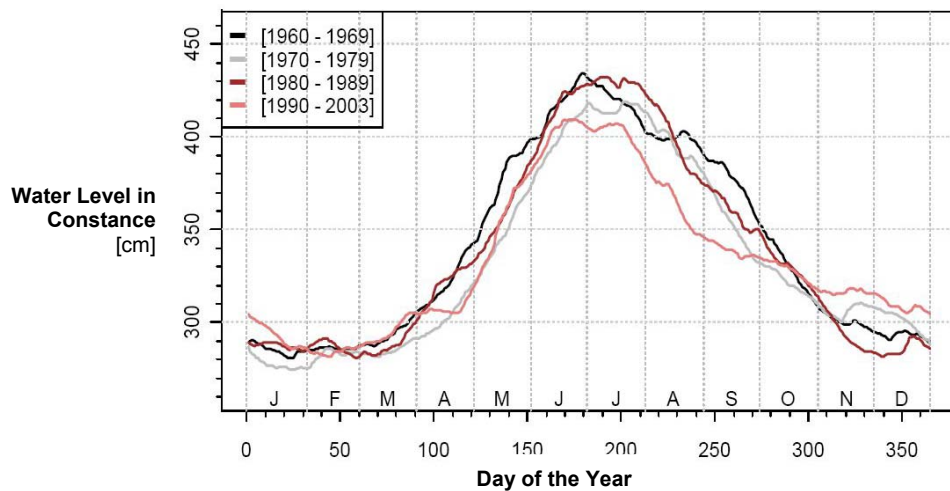
Figure 17. Comparison of the Lake's Water Level Development (Source: KLIWA, 2007: 40).

Independent of climate change, the most pressing issue in the Bodensee area are the anthropogenic interventions in the lake's riparian and shallow water zone. Today, more than half of the littoral zone is either built on (e.g. about 180 harbors) or otherwise utilized, thereby reducing its ecological potential (IGKB, 2004). Figure 18 illustrates the different conditions of the lake's riparian area.

Figure 18. Water Area, Embankments and Reed Belt (Source: IGKB, 2004: 21).

The harbors are important for touristic as well as aquatic sport purposes (e.g. sailing) and transportation: There is an extensive shipping traffic in the form of round trips, car ferries, linking the three countries Austria, Germany and Switzerland but also between the riparian zone and the islands.

Furthermore, the lake functions as an important supply of drinking water for the adjacent German cities ("Administration Unit Bodensee-Water Supply") and supplies over 4 million people with freshwater. Lake Constance also forms an essential part of the agricultural production process and is important for fishery: Each of the three bordering countries has its own fishing territory, which reaches from the waterfront towards the middle of the lake into a water depth of 25 m (German: "Halde"). However, in Vorarlberg most of this territory falls within the area of the nature reserve "Rheindelta-Bodensee" (see Chapter 3.3.2.1). Following the "Halde" is the borderless "High Sea"-area where all countries are allowed to catch fish albeit under the control of an international committee ("Internationale Konferenz der Bevollmächtigten für die Bodenseefischerei"). Currently, there are 34 fish species of which about 29 are native to the region. A few have been newly introduced (e.g. Rainbow trout, *Oncorhynchus mykiss*) to enhance the catch. However, in recent years, there have been losses in the average fish catch, which are mostly due to strict nature protection laws and the remediation measures. In fact, the fishing sector clearly benefited from the lake's eutrophication. The highest amounts of fish were caught between the 1960s and 80s (e.g. 1977: 2.000 tonnes of fish, 1986: 1.800 tonnes). The protection of the cormorant has increased its population to more than 2.000 individuals that annually catch more than 180 tonnes of fish, preferring expensive gourmet species such as the pike and the whitefish (Land Vorarlberg, n.d.).

Table 5. Comparison and Overview of the Neusiedlersee and Lake Constance.

Neusiedlersee	Lake Constance
Geography & Climate	**Geography & Climate**
Location:	Location:
Austria-Hungary Burgenland (Pannonian Lowlands) 115 m above sea level	Austria-Germany-Switzerland Vorarlberg (Alpine Foothills) 395 m above sea level
Pannonian Climate:	Moderate Climate:
Annual Average Precipitation <600 mm Annual Average Temperature >10°C Large Thermal Summer/ Winter Differences	Annual Average Precipitation >1.500 mm Annual Average Temperature 8-9°C Mild Thermal Summer/ Winter Differences
Water Body:	Water Body:
Size: 320 km^2 (180 km^2 covered by reed) Catchment Area: 1.120 km^2 Length: 34 km & Width: 12 km Water Depth: 1,0-1,8 m	Size: 536 km^2 (Upper Lake & Lower Lake) Catchment Area: 11.500 km^2 Length: 63 km & Width: 14 km Water Depth: <250 m
Hydrological Regime	**Hydrological Regime**
Mass Balance:	Mass Balance:
Meso-/ Eutrophic Conditions Soda Lake (Salt Content: ≥ 2,8‰)	Oligotrophic Conditions
Phosphorous Content	Phosphorous Content
Today: 60 µg/ litre; 1970/80s: 160 µg/ litre	Today: <8 µg/ litre; 1970/80s: > 80 µg/ litre
No Vertical Stratification	Vertical Stratification into Layers
Water Temperature:	Water Temperature:
Significant Variations due to Shallowness December-February <4°C, June-August >25°C	Winter: Epilimnion 4°C; Hypolimnion <4°C Summer: <16°C Temperature Difference
Holomictic and Polymictic	Holomictic
Hydrological Balance:	Hydrological Balance:
Rainfall (76 %) and Evaporation (89 %)	14 Main Tributaries (35,46 %)
Main Utilizations	**Main Utilizations**
	Drinking Water Supply
Fishery	Fishery
Habitat for Fauna and Flora	Habitat for Fauna and Flora
Tourism (e.g. Water Sports, Nature)	Tourism (e.g. Water Sports)
Transportation	Transportation

4. Effects of Climate Change: Threats to the "Good Status"
4.1. General Impact of Global Warming on Standing Water Bodies

Because standing water bodies are directly influenced by the external environmental conditions, they are particularly vulnerable to the effects of climate change (see Chapter 3.1): Overall, their water quality and hydrological balance is influenced by the amount and frequency of precipitation, the wind (speed) as well as the seasonal temperature profile. Studies show that shallow lakes (<10 m water depth), such as the Neusiedlersee, tend to be more severely affected by climate change than deep lakes (>10 m) like Lake Constance, whose larger water body can better cushion the effects of the warming. Furthermore, lakes that show a holomictic behavior tend to be less influenced by climate change: Being mixed through at least once a year allows the transport of nutrients and oxygen into upper or lower strata respectively (Mikula, 2012).

First of all, an increase in air temperature results in increased water temperatures (e.g. Dokulil et al., 2006; Livingstone and Padisák, 2003), which has also been characteristic for the thermal development of Lake Constance and the Neusiedlersee (see Chapter 3.4). This has an impact on the solubility of gases (e.g. oxygen). The solubility of gaseous substances in liquids (e.g. water) decreases with increasing temperature and decreasing pressure (Henry Law): For this reason colder water bodies generally contain more oxygen than warmer lakes. At 0°C and 760 torr a lake that is 100 % oxygenated contains about 14,5 mg O_2 per liter, which decreases with increasing temperature (e.g. about 9 mg O_2 per liter at 20°C). The value for the "dissolved oxygen" (DO-value) in a water body serves as an indicator for its water quality and is important for the sustenance of the aquatic life. An oxygen content below 4 mg O_2 per liter is considered to be lethal for fish species (Jungwirth et al., 2003). Water is oxygenated by way of photosynthesis (formula: $CO_2 + H_2O +$ Solar Energy $\rightarrow C_6H_{12}O_6 + O_2$) and the diffusion of oxygen from the atmosphere. Overall, the oxygen content of standing water bodies can be reduced as a result of increased water temperatures, but also of over-fertilization (eutrophication) as well as the surfeit of species. The amount of DO needed by an organism is type-specific: It "*depends upon its species, its physical state, water temperature, pollutants present*" (Lenntech, 2016).

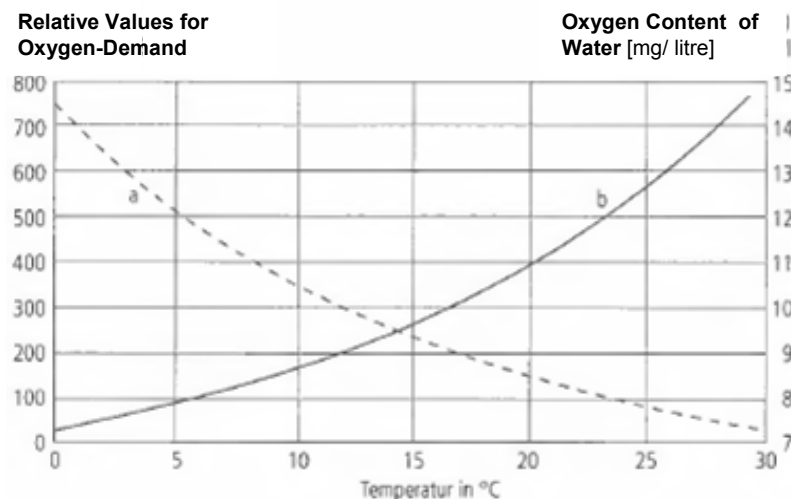**Relative Values for Oxygen-Demand** — **Oxygen Content of Water [mg/ litre]**

Figure 19. Temperature-Dependant Oxygen Content in Water (Curve a) and Temperature-Dependant Oxygen Demand of Species (Curve b; Jungwirth at al., 2003: 41).

As the curves in Figure 19 show, there is a positive correlation between the oxygen demand of poikilothermic organisms and the water temperature. Because of increased metabolic processes, the required amount of oxygen increases with rising water temperatures (Van't-Hoff-Law): In general, the oxygen demand of cold-blooded animals, such as fishes, doubles or even triples with a temperature increase of +10°C (Jungwirth et al., 2003). Respiration, degradation and diffusion into the surrounding air decrease the water's oxygen content.

Increased (surface) temperatures encourage evaporation, which has an impact on the hydrological balance of lakes. Reductions in the amount of precipitation (particularly during summer time) further decrease the input of water (Böhm et al., n.d.).

Furthermore, lakes typically show a vertical oxygen gradient. Oxygen production takes place in the upper, trophogenic layer (Epilimnion), where degradation processes equal the generation of oxygen by plants. The water body below (tropholytic layer, Hypolimnion) is characterized by reduction processes and depends on the oxygen input from the upper parts during the mixing period (see Chapter 3.1). For this reason, changes in the vertical stratification of standing water bodies can cause oxygen-poor or even anoxic conditions in the lake's lower zone: According to recent studies (e.g. Dokulil, 2009; Peeters et al., 2002) the temperature increase will be particularly pronounced in the lake's upper water body (Epi- and Metalimnion). This, however, results in a steeper temperature gradient and promotes thermal stability, which reduces the seasonal mixing processes. The higher temperatures during spring further elongate the water's stagnation time and shorten the period that mixing occurs (Mikula, 2012). This might have an impact on the lake's mass balance, as the seasonal mixing processes transport nutrients from the water's bottom layer to the top.

In some cases, warmer water temperatures might also result in the mobilization of nutrients that are stored in the lake's bed. Furthermore, increased erosion (as a result of heavy precipitation events), as well as the increased water input from glacial melting (see Chapter 3.2) might potentially result in an enhanced discharge of nutrients from the hinterland into the lake (Mikula, 2012). Changes in the nutrient content, the average water temperature as well as in the dissolved gases (particularly in the lake's lower water body) have an impact on the lake's water quality but also the composition of the species community, especially on those that are water-dependant: fish, phytoplankton. According to Gerten and Adrian (2000) the earlier beginning of spring already results in the acceleration of their onset of growth (e.g. *Daphnia*). Furthermore, higher temperatures in summer promote the biomass production of plants that prefer or tolerate higher temperatures, while it reduces the survival odds for cold adapted species. As a result of climate change and global warming, plants show a migrating behavior from warmer European regions into previously colder ones (e.g. Water fern, *Hydropterides*). The increase in temperature also benefits the survival of non-native neophytes (e.g. *Crassula helmsii*) in Austrian water bodies (Janauer, n.d.).

Similar to the aquatic plants the projected temperature increase benefits thermophilic fish species (e.g. Bass, *Lepomis gibbosus*), while it significantly disturbs cryophilic organisms (e.g. Graylings, *Thymallus thymallus*), whose competitiveness with regard to foraging, disease control and rivalry is noticeably reduced (Mikula, 2012):

While lethal temperatures below or above the individual, type-specific temperature limits result in the specie's death, sub-optimal water temperatures may very likely cause physiological impairments (e.g. growth disturbance) as well as reduced resistance against parasites and pathogens. Because different fish species and their different developmental stages have different ranges of tolerance with regard to temperature changes it is difficult to predict the effects of climate change on the fish fauna. Typically, for example, fish spawn is rather sensitive to changed environmental conditions, while the fish adult tolerates temperature increases, hydrological changes or changed oxygen/ nutrient contents more easily (Schmutz, n.d.).

4.2. Impact of Global Warming on the Neusiedlersee and Lake Constance
4.2.1. Most Important Effects on the Neusiedlersee

Because the Neusiedlersee's hydrological balance is heavily dependent on the average annual precipitation and evaporation levels, a change in one or both of these parameters is significantly affecting its water volume: In the past the increase in evaporation coupled with a decrease in rainfall has repeatedly caused the near or complete drying out of the lake (see Chapter 3.4.1). That the Neusiedlersee might dry out again is amongst the most threatening scenarios: "*Although water-level fluctuations are characteristic for a steppe lake, in the context of climate change this is the key vulnerability of Lake Neusiedl*" (EULakes Model, 2013a). According to a study by Eitzinger et al. (2009: 52ff) a period of 4 to 6 years with significantly reduced rainfall levels (e.g. 2003: -60 % less annual precipitation) would cause the (almost) complete dry out. Within less than 10 years the lake's water table would drop from currently >115,50 metres above the sea level to maximal 114 metres above the sea level. The scenario for a dry period of about 5 years is depicted in Figure 20, showing the steep decline in water volume. The scenarios are based on the calculation of 500 annual time series from regionalised climate data (1961-1990), using a weather generator.
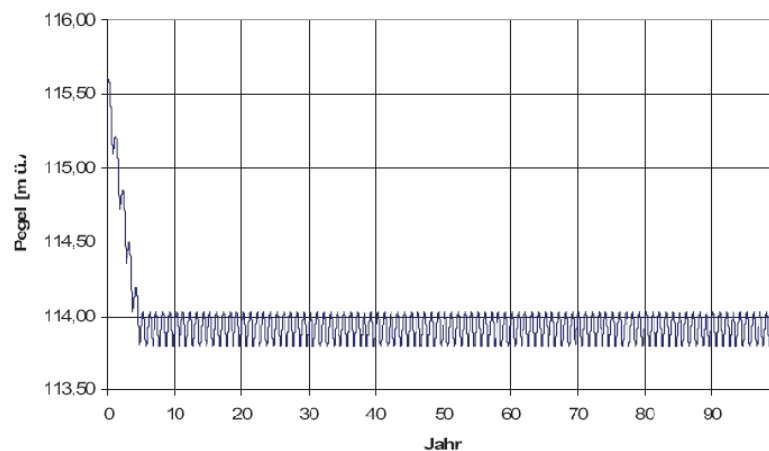
Figure 20. Effect on the Water Table in Case of Dry Years (Source: Eitzinger et al., 2009: 63).

A decline in the water table (to about 114,50 metres above the sea level) would also be caused by a succession of wet and dry years. Yet the larger water input of the wet years would slightly cushion the negative trend, resulting in a less pronounced decrease taking place over a period of approximately 10 years (see Figure 21).
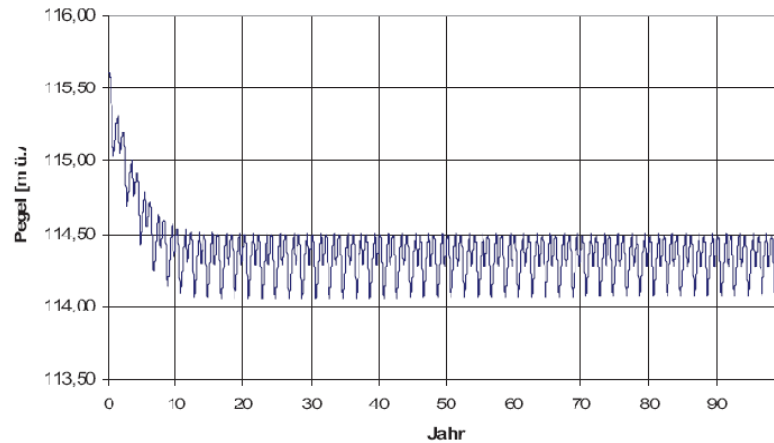
Figure 21. Effect of Dry and Wet Years on the Water Table (Source: Eitzinger et al., 2009: 63).

By contrast, a sequence of 4-6 wet years (e.g. as of 2004) would cause a high water table (about 115,70 metres above the sea level). In fact, the lake's water level could potentially reach about 116 metres above the sea level, which already happened in the past. However, the introduction of the Einser-Kanal would prevent flooding and reduce the possible amounts of water in the lake's basin. The scenario for a succession of wet years with larger-than-average amounts of precipitation, are depicted in Figure 22.
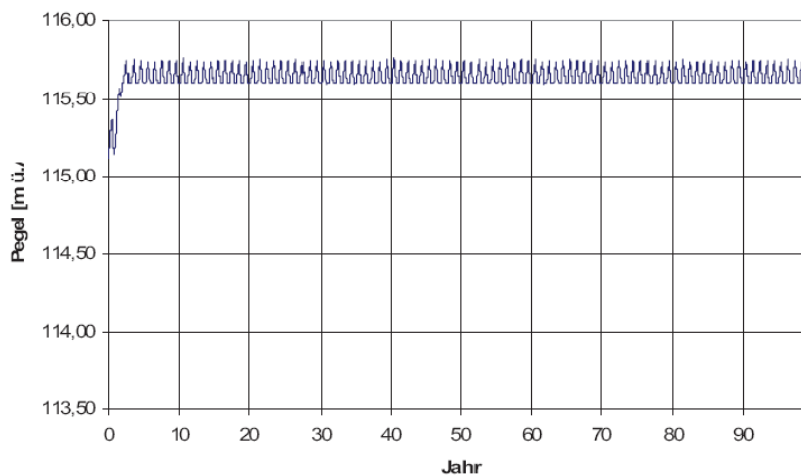
Figure 22. Effect on the Water Table in Case of Wet Years (Source: Eitzinger et al., 2009: 64).

Because of this high dependency from the exterior environmental conditions, even slight changes in the precipitation between 5 % and 10 % would result in large variations of the lake's water table: In case of -5 % in the amount of rainfall, for example, the average water table of 115,20 metres above the sea level would be undershot each 3,6 years (2010-2030) and each 1,8 years within the period 2030-2050. In fact, it would increase the likelihood of the lake's complete dry out (<114,50 metres above the sea) to each 71 years within 2010-2030 and each 25 years within 2030-2050 (Eitzinger et al., 2009: 73). About 22 % of the lake's water input stems from surface inflows (see Table 3): A decrease in precipitation would also have an effect on the water discharge from the river Wulka further decreasing the lake's water volume.

Even in case of a constant precipitation rate, the increase in evaporation levels (e.g. 1991-2004: +10 %) caused by the rising average water temperature of the lake (2010-2030: about +1,9°C and 2030-2050: +2,5°C) will potentially cause a decline of the lake's water table. Because of the lake's shallowness coupled with the strong mixing power of the winds, there is a "*close relationship between air and water temperatures. The rise in temperature of the water is therefore uniquely high for Lake Neusiedl compared to other Austrian lakes*" (EULakes Model, 2013a). According to the projections of Eitzinger et al. (2009), the evaporation might increase for +18,3 % in the period 2010-2030 and more than 20 % between 2030-2050, leading to significantly lowered water tables: With an average annual evaporation level of +10 % and a decrease in the annual precipitation amount of about -6 % (compared to 1961-1990) the water table of 115,30 metres above the sea level was undershot in 18 % of the years in the period 1991-2004 (every 5-6 years). If, in the future years, evaporation increases to +18 %, then this index value of 115,30 metres will be undershot in 33 % of the years (every 3 years). A future increase in evaporation levels of +23 % (as predicted for the period 2030-2050) might result in water tables sub 115,30 metres every 2 years (46 % of the period). Under the current assumptions a water table of 114,50 metres above the sea level is undershot in 0,6 % of the time between 2010-2030 and 1,2 % within 2030-2050 (Eitzinger et al., 2009: 65f).

Apart from the variations in precipitation and evaporation levels, the lake's water level might be negatively influenced by the accumulation of mud, though there are large insecurities about its future development and distribution (Eitzinger et al., 2009). In fact, the mud layer is largely influenced by the average wind speeds as well as the direction, from which they blow. According to Weisser (1977) the development of mud is caused by strong winds that create waves, eroding the lake's bed and creating floating mud particles, which in turn cause Lake Neusiedl's turbidity. Together with the lake's water masses these suspended particles are dislocated by the winds: Strong north-west winds shift the water towards the lake's steep eastern shoreline, where it is partly diverted towards the south. Once these water masses pass the reed belt, they are "filtered" and the suspended mud is deposited within the reed fields. For this reason, the development of the mud layer is particularly characteristic for the lake's riparian areas: Especially the accumulation of soft sludge in the harbour areas might become an increasing problem in the future.

The accumulation of sludge together with the potential decrease of the water level have an impact on the development of the reed belt, whose population expands and retracts in close connection to the variation of water and mud.

In fact, it benefits from the accumulation of mud as it grows best in fine-grained sediments and prefers shallow water areas. Moreover, the reed belt is positively influenced by the inflow of nutrient-rich waters from the surrounding agricultural fields. Therefore, the projected decrease of the water table might lead to overgrowing: Extrapolating the average growth tendency of reed, Weisser (1977) predicted that the Austrian part of Lake Neusiedl might be completely covered by reed in 2120. If, however, the lake completely dries out because of a sustained period of low precipitation rates, the reed belt would be significantly reduced and possibly destroyed. If the water level drops, then parts of the reed belt may become inaccessible for reed-dependent species. As a result the fishes are not able to reach their preferred spawning habitats. In fact, the populations of perch, tench and pike decreased during dryer periods (EULakes Model, 2013b). Figure 23 shows the connection between the lake's water table (horizontal axis) and the population of fish species <5 cm (vertical axis x 10^6):
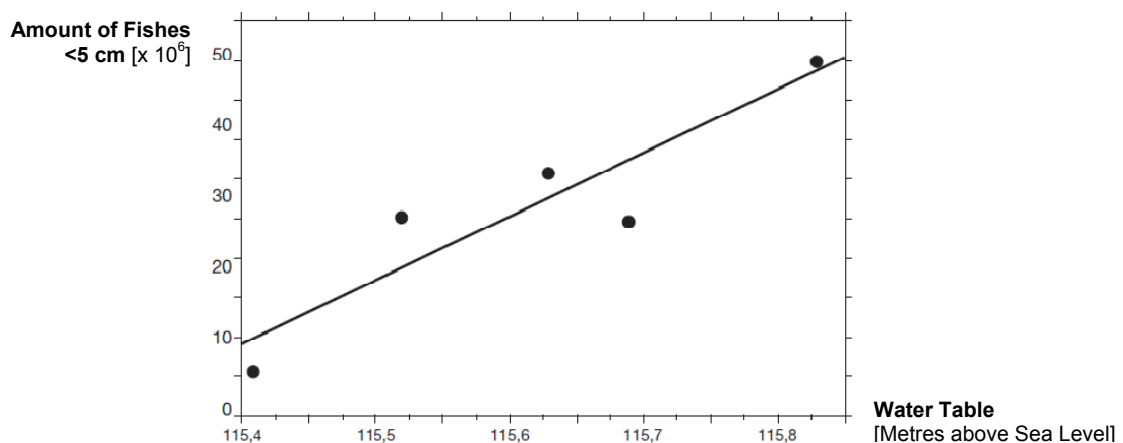
Figure 23. Connection between the Lake's Water Table and the Amount of Fish Species <5 cm (Source: EULakes Model, 2013b: 33).

They will also suffer from the decrease in the available oxygen – especially within the reed fields: The increase in water temperatures will lead to a decrease of the lake's oxygen content, which is however, less pronounced than for other Austrian lakes. Because Lake Neusiedl is repeatedly mixed through throughout the day (holo- and polymictic) the free water zone will be less affected than the reed belt, which will experience more frequent events of poor oxygen content (hypoxia). While the warmer water temperatures cause a longer growth and production period as well as an increase in primary production (see Chapter 4.1), the lake's turbidity (light as a limiting factor) will potentially cushion the induced plant growth.

Furthermore, Lake Neusiedl's increased water temperatures might benefit waterborne pathogens, such as *Vibrio cholerae* or *Escherichia coli* (EULakes Model, 2013b).

According to Soja et al. (2013: 123), "*even minor changes may be accompanied by further deterioration of the current meso-eutrophic state*" inducing the growth of algae and phytoplankton. This is caused by the specific (hydro-) morphology of the lake (Soja et al., 2013), which is characterized by shallowness (<1,8 m) and a relatively large water surface (320 km^2), which results in a relatively low water volume (360 x 10^6 m^3) compared to the whole catchment area (1.120 km^2). For this reason, even minor inputs of nutrients from the surrounding agricultural fields as well as touristic utilizations can have a significant impact on the lake's mass balance (e.g. eutrophication in 1970s/ 80s). Furthermore, the phosphorous content of the lake is largely influenced by the water table and the average water temperatures, which are projected to increase: The concentration of particulate phosphor is especially high during dry periods. Moreover, the mobilization of phosphor from the bed sediments is high during high temperatures.

Overall, the most important threats on the lake's water quality, resulting from climate change, are as follows:

1. Significant change in the lake's water table, possibly resulting in the complete dry-out of Lake Neusiedl within a period of 4-6 years, due to changes in the annual average precipitation or evaporation levels.
2. Accumulation of mud as well as soft sludge in harbour areas partly as a result of changes in average wind speeds and directions.
3. Significant changes in the extension of the lake's reed belt in close connection with the development of the lake's water line and mud layer. A drop in the water line might cause an increase of the reed area, possibly resulting in the complete overgrowing of the lake. In a complete dry-out scenario the reed belt would disappear causing the loss of habitats.
4. Reduction in the amount of (reed dependent) fish species <5 cm because of the decreasing water line, which prohibits access to the preferred spawning grounds in shallow water areas and the reed belt (e.g. perch, tench, pike).
5. Increase in the average water temperature resulting in decreases in the available oxygen content (especially within the reed belt), increases in waterborne pathogens and the mobilisation of phosphorous stored in the lake's bed sediments.

4.2.2. Most Important Effects on Lake Constance

Contrary to Lake Neusiedl, the water volume of Lake Constance is largely dependent on the water discharge from its 14 main tributaries, the Rhine being of foremost importance (see Chapter 3.4.2). Because these are largely fed by precipitation and melting water from the glacial and snow coverage during winter, their water load is biggest during June/ July. So far, an analysis of the Swiss and South-German rivers has shown that their annual discharge has slightly increased – particularly during the past 30 years – because of higher water inputs during winter and spring. This has been observed, for example, for the Rhine, which accounts for about 60 % of the lake's water input. This agrees with the projected increasing trend in winter precipitation for the region (see Chapter 3.2). The future increase in evaporation coupled with higher average temperatures will, however, reduce the average annual discharge by 2050 by about -10 % in Switzerland (AWEL, 2007). Overall, more pronounced variations in the water table between summer and winter are expected with a slightly decreasing trend during the summer months (as compared to 1860-2011) and slightly increased amounts during spring and winter (BWV, 2013). Overall, however, the water volume will not experience drastic changes within the next 100 years, and the supply with drinking water is covered. Figure 24 demonstrates the development of the water line.
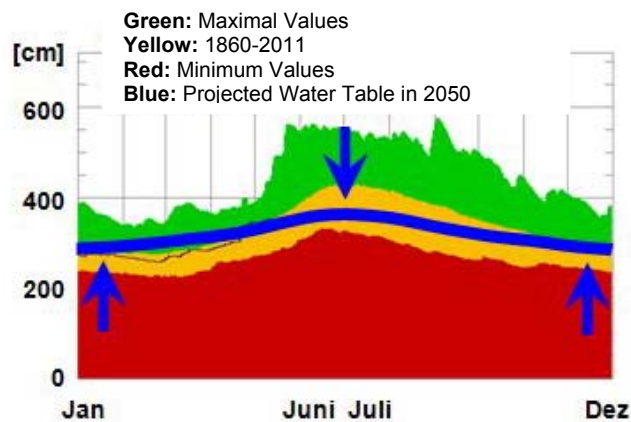
Figure 24. Development of Lake Constance's Water Table in 2050 (Source: BWV 2013: 15).

Yet, the expected increase in extreme weather events (e.g. heavy precipitation, heat waves) will lead to more frequent short timed fluctuations in the water table both during summer (e.g. floods in June 2013) and winter (AWEL, 2007).

Research agrees that there is a close connection between the average annual air temperatures and the temperature regime of a water body. As the past shows, the water temperature of Lake Constance has already shown an increase (1960-2005: about +0,03°C per year). In the face of climate change, the changed temperature regime and its effect on the vertical stratification of the lake is amongst the most pressing issues:

According to projections of the IGKB (2015: 52), the lake's water temperature is projected to increase further in the future. In the period 2010-2085 this rise in average water temperatures will be especially pronounced for the Epilimnion (+1,6-2,4°C), while the other water layers will warm up for about +1,5°C. This is caused by Lake Constance's large water volume that cushions the vertical temperature exchange. Figure 25 demonstrates the potential increase in water temperatures within different depths of Lake Constance. The increasing trend is obvious for all water layers and will be especially pronounced in the second half of this century.
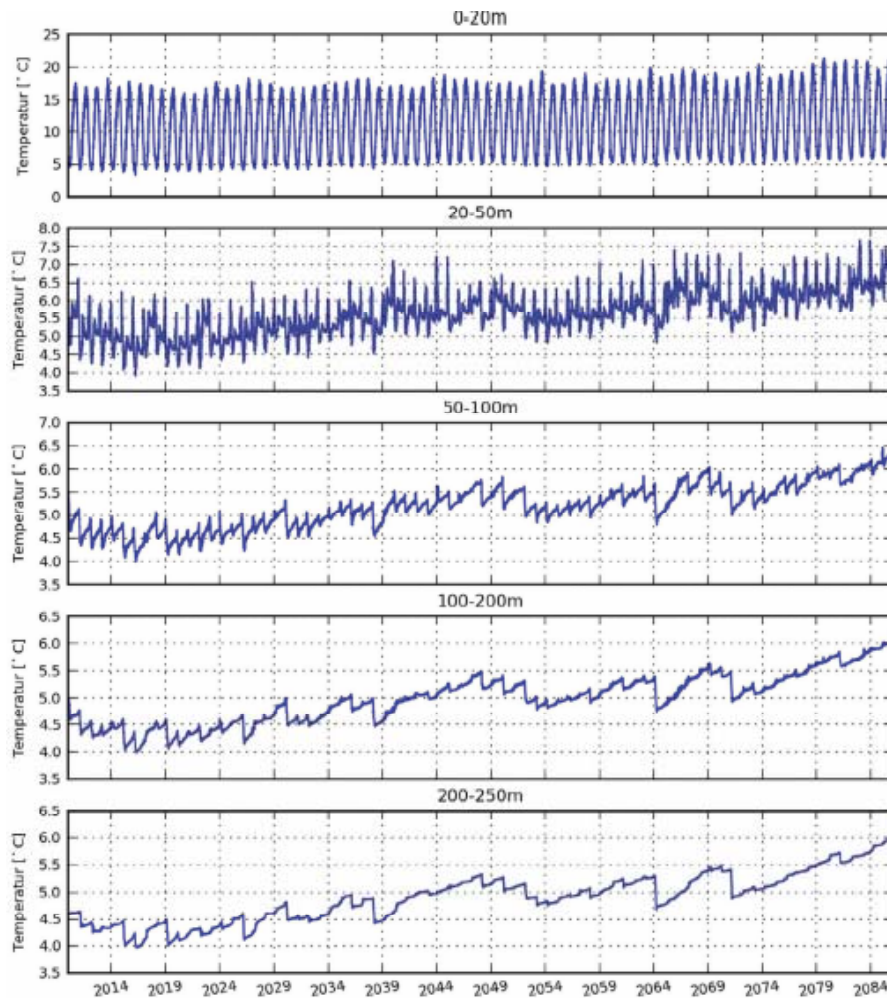
Figure 25. Projected Temperature Rise in Different Water Depths of the Lake (IGKB, 2015: 52).

Figure 26 demonstrates the expected temperature increase in the Epilimnion within the time period 2010 and 2080.
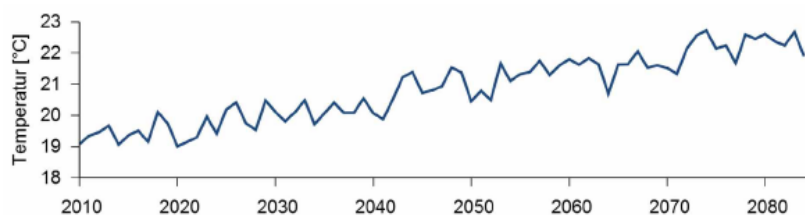
Figure 26. Projected Temperature Rise in the Epilimnion of Lake Constance (IGKB, 2015: 54).

In sum, the differently strong temperature increase of the water layers has a significant impact on the lake's vertical mixing and promotes thermal stability throughout its water body. Due to the projected increasing trend in winter temperatures the water volume of Lake Constance will be subject to less cooling, which decreases the events and time periods of complete mixing (IGKB, 2015). Overall, the time periods of stability will increase, while the periods during which mixing occurs will decrease as is already perceptible in the lake's stratification. Figure 27 depicts the frequency of complete mixing for different scenarios (based on temperature and precipitation). What they share is a generally decreasing trend until 2085 (e.g. 2010-2025: 7-8 times of complete mixing on the average; 2070-2085: only about 5-6 times of mixing averagely).
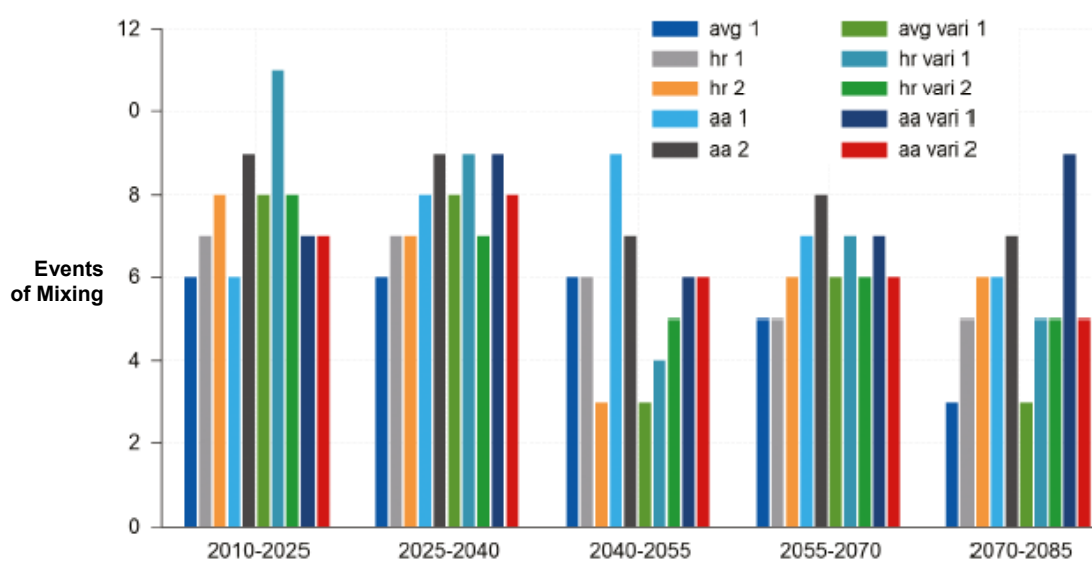
Figure 27. Effect of Climate Change on the Vertical Mixing of Lake Constance (IGKB, 2015: 54).

As the lake's oxygen content in the Hypolimnion is closely connected to the mixing behaviour of the water volume, the change in exchange has a significant impact on the amount of oxygen available for the aquatic species. In sum, the oxygen content in the lower layers is being reduced due to the increased time periods of thermal stability and the more frequent events of incomplete mixing.

Due to the mixing, the differences in the oxygen concentration are less significant during winter/ spring and become more pronounced during late summer/ autumn. According to the projections of the IGKB (2015: 71) the oxygen content following complete mixing within the Hypolimnion will decrease to about 9-10 mg oxygen/ litre by 2075/85 (compared to 2005/15: 11 mg O_2/litre). In case of sustained periods of incomplete mixing, the oxygen concentration within the lake's lowest water layer (about 250 m water depth) will decrease to values ≤ 4 mg/ litre which is critical for the survival of the aquatic species. The potential decrease in oxygen within the Hypolimnion is depicted in Figure 28.
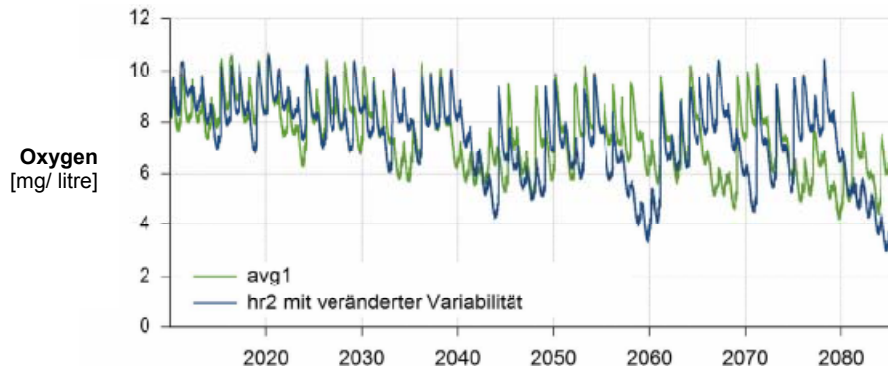
Figure 28. Impact of Incomplete Mixing on the Oxygen Concentration of the Hypolimnion (Source: IGKB, 2015: 72).

However, even in case of complete mixing the increase in average water temperature reduces the possible level of oxygen saturation within the lake's water volume (see Chapter 4.1): Figure 29 shows that the available oxygen in the lowest water zone is decreasing because of the increase in average water temperatures (2050: >4,8°C) expected within the lake's lower water zone (2010-2015: about 4,4°C). Critical values of ≤ 4 mg oxygen/ litre will be reached more frequently in the future (e.g. 2025; 2030) and are devastating for the survival of fish species.
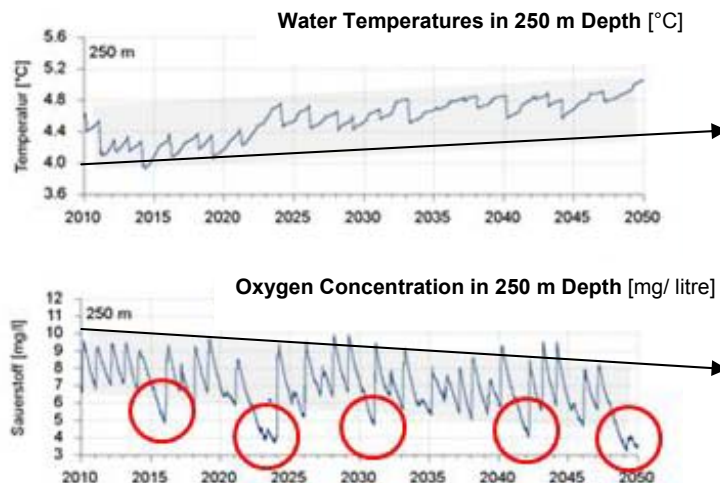
Figure 29. Connection between Increase in Water Temperatures and Decrease in the Oxygen Content in the Hypolimnion of Lake Constance (Source: BWV, 2013: 19).

Similar to the situation at Lake Neusiedl, the bed sediments of Lake Constance contain significant reserves of phosphorous (P). The mobilization of this (plant) nutrient due to higher temperatures would have a measurable effect on the available oxygen of the water body: Due to an increased primary productivity (photosynthesis) the oxygen concentration within the Epilminion will increase. By contrast, degradation and respiration processes will lead to significant oxygen consumption within the Hypolimnion. If the P-content of the lake increases to about 10 µg phosphorous/ litre then the oxygen values within the Hypolimnion will be reduced by about 1,5 mg/ litre as compared to the values shown in Figure 28.

During the eutrophication of Lake Constance in the 1970s the oxygen values measured in a water depth of 200-250 metres were approximately 3 mg/ litre lower (IGKB, 2015: 73). This underlines the threat of anoxic conditions within the Hypolimnion, which might result from a combination of a climate induced temperature increase, thermal stagnation within the water layers and the mobilization of phosphorous from the bed sediments. The concentration and availability of the plant nutrient orthophosphate (PO_4-P) is also significantly influenced by the lake's water temperature: Climate induced changes in the lake's mixing behaviour have an impact on its abundance within the strata. In case of reduced mixing the orthophosphate available within the Epilminion will decrease, while its concentration within the Hypolimnion (where it is significantly less convenient for makrophytes, phytoplankton and algae) will increase (IGKB, 2015). Figure 30 shows the variations in available orthophosphate for the Epi- and Hypolimnion. The seesaw-like structure of the two curves represents the seasonal pattern due to mixing.
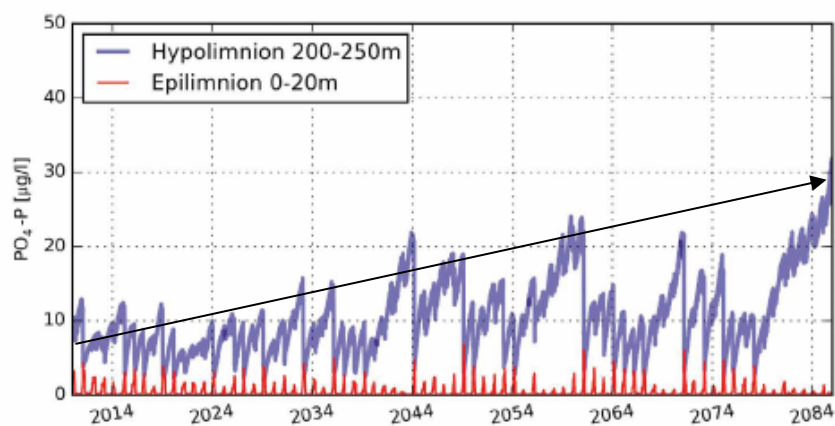
Figure 30. Climate-Induced Variations in the Available PO_4-P Content (Source: IGKB, 2015: 75).

According to the IGKB (2015) the PO_4-P concentration (blue curve) in the Hypolimnion will increase over the next 60-70 years (2014: about 10 mg PO_4-P/ litre compared to 2084: <30 mg PO_4-P/ litre). The PO_4-P available in the Epilimnion (red curve) might slightly decrease within the same time span. Especially at the end of the 21st century, the number of years with low PO_4-P concentrations in the Epilimnion, are expected to increase in frequency. The curves intersect in times of complete mixing, which are projected to decrease as well.

Yet, climate-driven changes in the mixing, as well as changes in the available oxygen and nutrient content, have an impact on the phytoplankton (as measured in the form of the Chlorophyll-a-Concentration). Its growth commences in the Epilimnion with the lake's thermal stability and depends significantly on the previous input of nutrients (e.g. phosphate) from the lower layers.

As a result, it is strongest in the time following complete mixing. Due to the decreasing trend with regard to complete mixing and the resulting variations in the available PO_4-P within the Epilimnion (see Figure 30), the amount of phytoplankton might be negatively affected (IGKB, 2015). Figure 31 demonstrates that the future is likely to bring more frequent years of reduced phytoplankton growth (e.g. 2070s), possibly negatively impacting the fish catch as well.
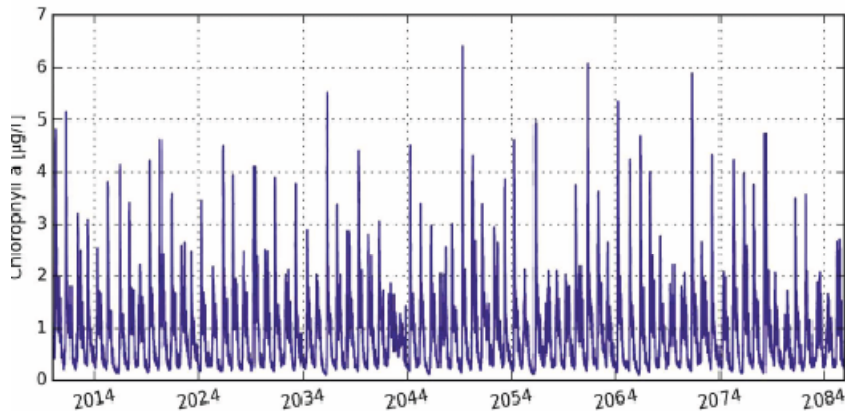

Figure 31. Future Phytoplankton Abundance in Lake Constance (Source: IGKB, 2015: 78).

In sum, the climatic effects on Lake Constance can be summarized as follows:

1. More frequent short-term fluctuations in the lake's water line due to increased likelihood of extreme weather events. Overall, the average water table will decrease during the summer time and slightly increase during spring and winter.

2. Warmer water temperatures will cause longer time periods of thermal stability, prohibiting the exchange of nutrients and oxygen between the water layers. Overall, there is a decreasing trend for complete mixing of the lake's water body.

3. Reduction in the available oxygen content, particularly in the lower water zone (Hypolimnion), due to incomplete mixing and higher average water temperatures.

4. Mobilization of phosphorous stored in the lake's bed sediments because of increased water temperatures, stimulating plant growth and primary productivity.

5. Changes in the available PO_4-P concentration with an expected increase in the Hypolimnion and a possible (slight) decrease in the Epilimnion, which negatively affects the growth of biomass (phytoplankton).

5. Measures to Prevent a Deterioration of the Water Quality
5.1. Lake Neusiedl

Because the Neusiedlersee is very shallow it reacts strongly to variations in the temperature regime as well as in the water input. "*Due to its remarkable shallowness and the relatively large water surface compared to the size of its catchment, the lake is deemed to be sensitive to climatic variations*" (Soja et al., 2013: 115). Amongst the most pressing issues, is its potential drying-out, which might occur in a relatively short span of years: According to past experiences, a period of 4-6 drier-than average years is enough to reduce the water discharge to a critical level, which is not sufficient to sustain the lake's survival (see Chapter 4.2.1). In fact, (significant) variations in the lake's water level have happened naturally during the past decades and are somewhat even characteristic for a shallow steppe lake, such as Lake Neusiedl (EULakes Model, 2013b). However, as the lake provides an important source of income for the surrounding region (e.g. tourism, fishery) the complete dry out would generate significant economic losses. It would also have devastating effects on the reed area and the species community dependent on it (e.g. pike, waterfowls). For this reason, the conservation and stabilization of a minimum water table should be amongst the foremost aims of management measures. It is also important for the management of the reed belt, preventing the overgrowth of the free water zone. Already, more than half of the lake's water surface is covered by reed (see Chapter 3.4.1).

An option to check the lake's water table is provided by the Einser-Kanal, which was introduced in 1895. Through the optimization and flexibilization of the lock's management in 2011, variations in the lake's water table could be further reduced (1965: already from 1,6 m to 0,9 m) and a more stable water level secured (approximately 115,50 metres above the sea level). Overall, the Kanal slightly raised the lake's water table (since 1965: about +30-40 cm), which had a positive impact on the reed belt, slightly cushioning its growth. Yet, the Einser-Kanal will not be able to prevent a complete dry out. Moreover, it has a negative impact on the lake's naturally high salinity: In recent years the water outlet through the Einser-Kanal has presented a threat to the salt content of the lake, generating losses (e.g. in 2000: only about 150 mg Chloride/ litre as compared to the lake's average Chloride concentration of about 250 mg Chloride/ litre; ÖUG, 2014: 44). According to Krachler et al. (2005: 112), the lake's salt content today is only about 1/8 (1-2 g total salt content/ litre) of the salt content it had before the introduction of the Kanal (1903: 16 g total salt content/ litre).

In order to prevent the lake's complete drying out the Ministry of Burgenland has thought about the discharge of river water into the lake ("ökodynamische Rehabilitierung des Neusiedlersees"), possibly through the inlet of bank filtrate from river Danube into Lake Neusiedl via the Parndorfer Bach: Because the lake's water table reacts relatively fast to changes in precipitation and evaporation, this artificial water input would have to be matched by an increase in water outlet from the Einser-Kanal, in order to prevent flooding. Yet, this input of freshwater from other catchment areas or water bodies, such as the river Danube, poses an incalculable risk for the lake's hydrology. The unique species community of Lake Neusiedl is very dependent on the naturally high salt content (≥ 2,8 ‰): The artificial increase in the lake's water volume coupled with the outlet of water from the Einser-Kanal can only come at the expense of salinity, threatening the lake's chemical composition. Furthermore, it might lead to the development of organic sapropel and lime mud (Krachler et al., 2005).

According to the EULakes Model (2013b) measures aimed at preventing the complete dry-out scenario, could also include an increase in the lake's water volume through the removal of lake sediments. In the shallow harbour area, soft sludge will increasingly have to be removed in order to guarantee accessibility for ships. While the excavation of bed sediments could possibly reduce the mobilization of phosphorous and thus benefit the lake's water quality, it could also have an adverse impact through the release of toxic substances/ nutrients contained in the lake's bed and should thus be carefully monitored. Furthermore, negative effects on ground-dwelling benthic organisms and molluscs are to be expected. The lake's salt content may be reduced.

A further problem caused by a drop in the lake's water line is the inaccessibility of the shallow water and reed area, which function as an important spawning and breeding ground for various species. In case of low water tables, their accessibility could be secured through the (re-) construction of old waterways into the reed fields. Thereby, reed-dependant fish species would be able to reach their preferred spawning habitats. Yet, this would also promote the inflow of phosphorous-rich and oxygen-deficient water from the riparian zone into the free water area with possible adverse effects on the water quality of the lake (EULakes Model, 2013b).

The increased mobilization of phosphorous is another challenge posed by global warming: Measures to reduce the pollution with phorphor should focus on decreasing external sources of phosphorous from the surrounding agricultural fields (e.g. through vegetated buffer zones between the water body and fields) and internal phorphor-storages. In fact, the lake's bed sediments contain phosphorous, which is why the excavation of bed sediments (physical measure) might reduce the phosphor-load.

Other measures include biological (e.g. reduction of non-predatory fish) as well as chemical activities (e.g. input of aluminium to increase the binding potential for P). Yet, all of these measures have (long-term) effects on the lake's complex composition and should as such be subject to research. Currently, the excavation method proves to be the most effective but also the most expensive measure (EULakes Model, 2013b).

5.2. Lake Constance

Contrary to Lake Neusiedl, the water quality of Lake Constance is mostly threatened by the expected temperature increase, which has significant effects on the lake's water body: As research has shown there is a close connection between the average air temperatures and water temperatures. Due to its large water volume, Lake Constance shows a vertical stratification into layers, with oxygen and nutrient exchange being limited to the time periods of mixing. This is possible during spring and autumn/ winter, when the whole of Lake Constance's water body assumes the same mean temperature and density, enabling wind to mix it through. Yet, climate change causes more sustained periods of incomplete mixing as well as longer time spans of thermal stability (see Chapter 4.2.2), which significantly reduces the oxygen content of the Hypolimnion. As the past experience has shown the oxygen consumption in this water layer is particularly high during times of high nutrient loads. Coupled with the increased mobilization of phosphorous due to warming water temperatures, this might lead to anoxic conditions in the lake's lower water layer. Therefore, protection measures should mostly address the reduction of phosphorous in the lake's bed sediments as well as from external sources. This not being the case in the 1970s, large inputs of phosphorous from the surrounding agricultural fields as well as from the discharge of urban wastewater into the lake, seriously threatened the lake's naturally low nutrient conditions (oligotrophic), resulting in eutrophication (see Chapter 3.4.2).

In case of the latter, vegetated buffer zones between the lake's water body and the agricultural fields as well as the urban areas could somewhat cushion the discharge of nutrients into the lake (EULakes Model, 2013b). This would also benefit the riparian area of Lake Constance: Irrespective of climate change, the lake and its shallow water area is threatened by the increased amount of littoral infrastructure activities (see Figure 18). Already, over half of the riparian and shallow water zone is either built on or otherwise utilized (e.g. harbors). These provide, however, important nesting and spawning grounds for the waterfowls. For this reason, the preservation of yet undisturbed littoral areas as well as the reed zones should be of future concern. Controlling and limiting the amount of nutrients that enter the lake's water body is amongst the most powerful protection measures. The past has shown that remediation measures, including the construction of state-of-the-art sewage plants had a significant impact on the lake's water quality, restoring the oligotrophic nutrient conditions characteristic for an Alpine lake.

Because of the lake's significant water depth (up to 250 m) the physical removal of bed sediments is not feasible. For this reason, chemical as well as biological restoration methods seem to be more appropriate measures aimed at the removal of phosphorous: Chemical methods include the oxygenation of the Hypolimnion in order to increase the binding potential for phosphate. Other options include the input of nitrate into the Hypolimnion or the input of aluminium into the lake's water (EU Lakes Model, 2013b). Yet, all of these methods tend to be rather expensive and impact the natural composition and mass balance of (sensitive) standing water bodies. Because of the Lake Constance's considerable water volume their effectiveness remains questionable. Biological management measures focus on the fauna and flora: Possible approaches include the decrease of non-predatory fishes (e.g. bream) through the increase of predators, such as the pike as well as the plantation and conservation of underwater plants (EU Lakes Model, 2013b).

6. Conclusion

The comparative study has shown that regardless of size and water depth, standing freshwater bodies fulfil a number of socio-economic and ecological functions: Both of the observed lakes are an important tourist destination (especially water sports and nature tourism), provide a source of income in the fishery sector, are used for transportation and function as a habitat for species (e.g. waterfowls, fishes). Because of their significant ecological importance (e.g. as spawning and nesting grounds for waterfowls), both Lake Constance and the Neusiedlersee are – among others – mentioned as Ramsar-areas. In fact, the region Neusiedlersee-Seewinkel (>44.000 ha) is the most extensive Ramsar-area within the federal republic of Austria and provides a habitat for over 300 bird species. Since 1993 the area is also protected as a national park, which is one of the highest nature protection categories in Austria. Because of its rich species community both areas have been nominated under the Natura-2000 network with the aim "*to assure the long-term survival of Europe's most valuable and threatened species and habitats*" (EC, 2007: 7). Overall, freshwater sources of good water quality are important for the survival of humans, animals and plants: Lake Constance, for example, provides a vital source of drinking water for the surrounding German cities, supplying over 4 million people with freshwater. Yet, the global amount of accessible freshwater is relatively low. In fact, less than 3 % of the world's water resources are non-saline water and only about 1 % thereof residues in easily-accessible surface water bodies. Given that over half of this surface freshwater is contained in lakes, their conservation and importance is of utmost importance. This is also true for the federal republic of Austria, where the standing water sources amount to approximately 18 km^3 (BMLFUW, 2014a: 37). In sum, Austria comprises about 25.000 lakes that have an average extension of more than 250 m^2 (BMLFUW, 2011a). With a water size of 536 km^2 in case of Lake Constance and about 320 km^2 in case of Lake Neusiedl, the selected examples are amongst the biggest water bodies in the federal republic, but are stretching over the national boundaries.

What unites them further is that their survival is highly dependent on the exterior environmental conditions. For this reason they are rather vulnerable to the effects of climate change and global warming: The hydrological balance of Lake Constance and the Neusiedlersee is largely influenced by the yearly precipitation rates, the mean evaporation levels as well as the average annual temperature profile. Especially the water table of Lake Neusiedl is highly dependent on the annual balance between evaporation (89 % of the hydrological balance) and precipitation (76 %).

Yet, these parameters are very likely to change, with a possible increase in evaporation levels due to warmer temperatures and a decreasing trend in rainfall. Overall, however, the effects of global warming and climate change show significant regional differences and are different for Burgenland and Vorarlberg. Studies (e.g. IGKB, 2004) show that changes in the seasonal temperature regime, regional shifts in precipitation patterns as well as the increase in weather extremes have put a strain on standing water bodies – not only in Austria but worldwide. Both in case of Lake Constance and the Neusiedlersee changes have occurred, which have influenced the lakes' water body and their physico-chemical composition (e.g. with regard to the oxygen content). However, even though standing water bodies share similarities with regard to composition and hydrology, they react differently to climate change, which is also underlined by the example of the selected lakes:

While Lake Neusiedl is mostly threatened by the decreasing trend in precipitation and the increase in evaporation levels, Lake Constance is mostly vulnerable to the warming water temperatures. For the Neusiedlersee a significant decrease in the water table is possible that may result in the complete dry-out of the lake within a relatively short time span of 4-6 drier-than-average years. Its water volume may further be reduced by the accumulation of mud as well as soft sludge – particularly in the harbour areas. Furthermore, the decrease in water levels coupled with the increasing mud layer may result in a significant spread of the reed belt, which already covers more than half of the lake's water surface (180 km^2), possibly resulting in the complete overgrowth of the lake's free water zone. Yet, another scenario sees the complete disappearance of reed as a result of the lake's complete drying out. This would, however, result in the loss of habitats. Furthermore, the decreasing water line might cause a reduction in the amount of fish species <5 cm (e.g. tench, pike), by prohibiting the access to their preferred spawning grounds in shallow water areas and the reed belt. Because the solubility of oxygen is influenced by the water temperatures, an increase in the average water temperature might result in decreases in the available oxygen content – particularly in the reed area. It could also lead to increases in waterborne pathogens and cause the mobilisation of phosphorous stored in the lake's bed sediments further stimulating biological productivity (primary production) and oxygen consumption.

The water table of Lake Constance will be significantly less subject to a decrease. While it may slightly decrease during the summer time, it will also slightly increase during the period of winter/ spring due to the increased input of melting water. On the other hand, the increased likelihood of extreme weather events (e.g. thunderstorms) might result in more frequent short-term fluctuations in the lake's water line.

More threatening is, however, the increase in average water temperatures, which will cause longer time periods of thermal stability, prohibiting the exchange of nutrients and oxygen between the lake's vertical water layers. Overall, there is a decreasing trend for complete mixing of the lake's water volume, which will result in reductions in the available oxygen, particularly in the lower water zone (Hypolimnion). Similar to Lake Neusiedl, the increase in water temperatures might result in the mobilization of phosphorous stored in the lake's bed sediments, stimulating plant growth and primary production. The past shows that high phosphor-concentrations coupled with high mean water temperatures have a serious effect on the availability of oxygen in the lake's water, significantly increasing the oxygen consumption in the Hypolimnion. Furthermore, the expected temperature increase will lead to changes in the available PO_4-P concentration in the lake's water body with an expected increase in the Hypolimnion and a possible (slight) decrease in the Epilimnion. This would, however, negatively affect the growth of biomass (phytoplankton), which is important for the production of oxygen via photosynthesis and functions as nutrition for fish species.

The results of the comparative study show clearly that the lakes' responses to climate change and global warming differ from each other, which in turn calls for type-specific responses and mitigation measures to ensure their conservation. Taking account of the particular characteristics of standing water bodies is essential for their maintenance as well as the achievement of the "good ecological and chemical water quality" as set as an objective in Article 25 WFD. In case of Lake Neusiedl, protection measures should focus on securing the lake's water table in order to prevent a complete dry out scenario.

Furthermore, the extension of the reed belt needs to be controlled and its vitality ensured. Because of the lake's sensitivity with regard to its naturally high salt content, a dotation with freshwater from other catchment areas (e.g. River Danube) coupled with higher water outlets via the Einser-Kanal is not advisable as it might result in significant losses of Chloride, negatively affecting the rich species community.

For both cases, it might be an advisable approach to decrease the phosphorous content that is currently stored in the lakes' bed sediments. While Lake Neusiedl might benefit from the physical removal of bed sediments through excavation, a combination of biological and chemical methods might be more feasible for Lake Constance. Yet, all of these protection measures have to be tested for their long-term impact on the lakes' water quality and hydrology. Especially the input of artificial substances (e.g. aluminium, nitrate) needs to be researched with regard to immediate impact, possible side-effects and the overall effectiveness.

In that regard the development of Lake Neusiedl's salinity in the face of climate change and decreasing mean water table should be subject of future research. The unique fauna and flora of the lake depends heavily on the naturally high salinity and would suffer significantly in case of a reduction. Furthermore, the accumulation and development of the mud layer should be researched. In case of Lake Constance, the oxygen concentration within the Hypolimnion is of utmost importance. It develops in close connection with the phosphorous content and has an impact on the lake's water quality and the aquatic life. For this reason, it should be closely monitored.

Bibliography

ABL (2012): Neusiedlersee – Ökodynamische Rehabilitation. Betrachtungen zur Wasserqualität der Raab. Amt der Burgenländischen Landesregierung. Kontaktperson: Dr. Matthias Zessner, TU Vienna.

AWEL (2007): Auswirkungen des Klimawandels und mögliche Anpassungsstrategien. Erste Standortbestimmung. Amt für Abfall, Wasser Energie und Luft. Zu beziehen: AWEL, Abteilung Energie, Zürich und Internationale Bodenseekonferenz, Konstanz.

BAW (2008): Atlas der natürlichen Seen Österreichs mit einer Fläche ≥ 50 ha. Bundesamt für Wasserwirtschaft. Schriftenreihe des Bundesamtes für Wasserwirtschaft, Band 29.

BMLFUW (2016a): Wasserrechtsgesetz 1959 (WRG 1959). Bundesministerium für Land-, und Forst-, Umwelt- und Wasserwirtschaft https://www.bmlfuw.gv.at/wasser/wasser-oesterreich/wasserrecht_national/wasserrechtsgesetz/WRG1959.html - accessed: January 4, 2016.

BMLFUW (2016b): Ramsar-Gebiete. Bundesministerium für Land-, und Forst-, Umwelt- und Wasserwirtschaft. http://www.umweltbundesamt.at/umweltsituation/naturschutz/sg/ramsar_gebiete/ - accessed: April 14, 2016.

BMLFUW (2016c): Neusiedlersee-Seewinkel. Bundesministerium für Land-, und Forst-, Umwelt- und Wasserwirtschaft. https://www.bmlfuw.gv.at/umwelt/natur-artenschutz/feuchtgebiete/ramsar/neusiedlersee.html - accessed: April 14, 2016.

BMLFUW (2014a): Daten, Zahlen & Fakten 2015. Bundesministerium für Land-, und Forst-, Umwelt- und Wasserwirtschaft. http://www.wasseraktiv.at/resources/files/2015/7/13/7354/21-mlo-daten-und-zahlen-de-2015-rz-neu-www.pdf - accessed: June 1, 2016.

BMLFUW (2014b): Ökologischer Zustand der Oberflächengewässer in Österreich. Bundesministerium für Land-, und Forst-, Umwelt- und Wasserwirtschaft. https://www.bmlfuw.gv.at/wasser/wasser-oesterreich/zahlen/Zustand.html - accessed: December 26, 2015.

BMLFUW (2011a): Flüsse und Seen. Bundesministerium für Land-, und Forst-, Umwelt- und Wasserwirtschaft. https://www.bmlfuw.gv.at/wasser/wasser-oesterreich/zahlen/fluesse_seen_zahlen.html - accessed: June 1, 2016.

BMLFUW (2011b): Anpassungsstragien an den Klimawandel für Österreichs Wasserwirtschaft. Studie der Zentralanstalt für Meteorologie und Geodynamik und der Technischen Universität Wien. Bundesministerium für Land-, und Forst-, Umwelt- und Wasserwirtschaft.

Böhm R., Godina R., Nachtnebel H. P., Pirker O. (n.d.): Mögliche Klimafolgen für die Wasserwirtschaft in Österreich. In: ÖWAV. (n.d.): Auswirkungen des Klimawandels auf die Österreichische Wasserwirtschaft. Österreichischer Wasser- und Abfallwirtschaftsverband, 7-26.

Borchardt K. D. (2010): The ABC of European Union Law.
http://europa.eu/documentation/legislation/pdf/oa8107147_en.pdf - accessed:
December 31, 2015.

BWV (2013): Auswirkungen/ Folgen des Klimawandels auf die Trinkwasserversorgung
aus dem Bodensee. Bodensee Wasserversorgung. Folien aus dem Workshop
"Interreg IV Projekt ,Klimawandel am Bodensee'" (18.04.2013).

Collin Community College (2015): Aquatic Ecosystems.
http://iws.collin.edu/biopage/faculty/mcculloch/2406/Notes/Aquatic%20Ecosystems/
Lentic/images/Lake%20Zones.jpg – accessed: January 22, 2016.

Dokulil M. T. (2009): Abschätzung der Klimabedingten Temperaturänderung bis zum
Jahr 2050 während der Badesaison.
http://www.bundesforste.at/uploads/publikationen/Klimastudie_Seen_2009_Dokulil.p
df - accessed: February 7, 2016.

Dokulil M. T., Jagsch A., George D., Anneville O., Jankowski T., Wahl B., Lenhart B.,
Blenckner B., Teubner T. and K. (2006): Twenty Years of Spatially Coherent Deep-
Water Warming in Lakes across Europe related to the North Atlantic Oscillation.
Limnology and Oceanography, Volume 51, Issue 6, 2787-2793.

EA (2010): About the Water Framework Directive. Environment Agency.
http://evidence.environment-agency.gov.uk/FCERM/en/SC060065/About.aspx -
accessed: January 31, 2016.

Earth Observatory (n.d.a): World of Change.
http://earthobservatory.nasa.gov/Features/WorldOfChange/decadaltemp.php -
accessed: May 2, 2016.

Earth Observatory (n.d.b): Global Warming.
http://earthobservatory.nasa.gov/Features/GlobalWarming/page2.php - accessed:
February 2, 2016.

Ebner M. (n.d.): Bodensee. http://austria-
forum.org/af/Wissenssammlungen/Bibliothek/Eine_Auswahl_aus_den_sch%C3%B6
nsten_Seen_%C3%96sterreichs/Vorarlberg/Bodensee - accessed: February 13,
2016.

EC (2015): How Will We Be Affected? European Commission.
http://ec.europa.eu/clima/policies/adaptation/how/index_en.htm - accessed:
November 28, 2015.

EC (2007): LIFE and Europe's Wetlands. Restoring a Vital Ecosystem. European
Commission.
http://ec.europa.eu/environment/life/publications/lifepublications/lifefocus/documents
/wetlands.pdf - accessed: December 31, 2015.

EEA (2015a): Global and European Temperatures. European Environment Agency.
http://www.eea.europa.eu/data-and-maps/indicators/global-and-european-
temperature-1/assessment - accessed: November 28, 2015.

EEA (2015b): Climate Change Impacts and Adaptation. European Environment
Agency. http://www.eea.europa.eu/soer-2015/europe/climate-change-impacts-and-
adaptation - accessed: November 28, 2015.

EEA (2015c): Projected Changes in Annual Mean Temperature (Left) and Annual Precipitation (Right). European Environment Agency. http://www.eea.europa.eu/data-and-maps/figures/projected-change-in-annual-mean - accessed: January 26, 2016.

Eitzinger J., Kubu G., Formayer H., Haas P., Gerersdorfer T., Kromp-Kolb H. (2009): Auswirkungen einer Klimaänderung auf den Wasserhaushalt des Neusiedler Sees. BOKU-Met Report 1.

EPA (2016): Classification. Environmental Protection Agency. http://www.epa.ie/water/watmg/wfd/classification/ - accessed: June 1, 2016.

EULakes Model (2013a): Impacts on Climate Change Scenarios. http://eulakes-model.eu/outputs/impacts-of-climate-change-scenarios.html - accessed: April 26, 2016.

EULakes Model (2013b): Leitlinie für Nachhaltiges Seenmanagement im Klimawandel – Neusiedler See. http://biologische-station.bgld.gv.at/wp-content/uploads/2014/07/WP623Guideline_Lake_Neusiedl.pdf - accessed: April 27, 2016.

Formayer H., Clementschitsch L., Hofstätter M., Kromp-Kolb H. (2009): Vor Sicht! Klimawandel in Österreich Regional Betrachtet. BOKU-Met Report 16. https://meteo.boku.ac.at/report/boku-met_report_16_online.pdf - accessed: January 26, 2016.

Formayer H., Haas P., Matulla C., Frank A., Seibert P. (2005): Untersuchung Regionaler Klimaänderungsszenarien hinsichtlich Hitze- und Trockenperioden in Österreich. StartClim2004, Teil B. https://austroclimweb.boku.ac.at/startclim/bericht2004/StCl04B.pdf - accessed: February 8, 2016.

Gerten D. and Adrian R. (2000): Climate Driven Changes in Spring Plankton Dynamics and the Sensitivity of Shallow Polymictic Lakes to the North Atlantic Oscillation. Limnology and Oceanography, Volume 45, Issue 5, 1058-1066.

HDB (2016): Langzeitvergleich Wasserstand. Hydrographischer Dienst Burgenland. http://wasser.bgld.gv.at/hydrographie/seestationen/mittler-wasserstand-neusiedler-see.html - accessed: April 20, 2016.

Hollan E. (2000): Mögliche Auswirkungen einer Klimaveränderung auf größere Binnenseen. In: Mikula K. (2012): Literaturstudie. Auswirkungen des Klimawandels auf den Wasserhaushalt Stehender Gewässer. Kärntner Institut für Seenforschung, Klagenfurt.

IGKB (2015): KlimBo – Klimawandel am Bodensee. Ein Interreg IV-Forschungsprojekt von 2011-2015, Bericht Nummer 60. Internationale Gewässerschutzkommission für den Bodensee. http://www.igkb.org/fileadmin/user_upload/dokumente/klimbo/KlimBo_Blauer_Bericht_60_s.pdf - accessed: April 28, 2016.

IGKB (2013a): Bodensee-Daten. Internationale Gewässerschutzkommission für den Bodensee. http://www.igkb.org/der-bodensee/seedaten/ - accessed: December 28, 2015.

IGKB (2013b): Entstehung des Bodensees. Internationale Gewässerschutzkommission für den Bodensee. http://www.igkb.org/der-bodensee/entstehung-des-bodensees/ - accessed: December 28, 2015.

IGKB (2004): Der Bodensee. Zustand – Fakten – Perspektiven. Internationale Gewässerschutzkommission für den Bodensee. http://www.unterwasserservice.de/igkb/IGKB%20Bilanz.pdf - accessed on: 29.12. 2015.

IIASA (2014): Austrian Climate Change Assessment Report 2014. Summary for Policymakers. International Institute for Applied Systems Analysis. http://www.iiasa.ac.at/web/home/about/news/APCC-SPM.pdf - accessed: November 29, 2015.

IPCC (2014a): Climate Change 2014. Synthesis Report. Summary for Policymakers. Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar5/syr/AR5_SYR_FINAL_SPM.pdf - accessed: November 28, 2015.

IPCC (2014b): Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B. Regional Aspects. Europe. Intergovernmental Panel on Climate Change. http://www.ipcc.ch/pdf/assessment-report/ar5/wg2/WGIIAR5-Chap23_FINAL.pdf - accessed: November 28, 2015.

IPCC (2007): Towards New Scenarios for Analysis of Emissions, Climate Change, Impacts, and Response Strategies. Technical Summary. Intergovernmental Panel on Climate Change. https://www.ipcc.ch/pdf/supporting-material/expert-meeting-ts-scenarios.pdf - accessed: March 22, 2016.

Janauer G. A. (n.d.): Klimawandel und aquatische Makrophyten. In: ÖWAV. (n.d.): Auswirkungen des Klimawandels auf die Österreichische Wasserwirtschaft. Österreichischer Wasser- und Abfallwirtschaftsverband, 165-176.

Jungwirth M., Haidvogl G., Moog O., Muhar S., Schmutz S. (2003): Angewandte Fischökologie. Facultas, Vienna.

KLIWA (2007): Zum Einfluss des Klimas auf den Bodensee. Klimaveränderung und Wasserwirtschaft, Heft 11. http://www.kliwa.de/download/KLIWAHeft11.pdf - accessed: February 14, 2016.

Krachler R. and R., Geiger J. (2005): Wasserchemische Aspekte einer Dotierung des Neusiedlersees mit Donau-Uferfiltrat. Burgenländische Heimatblätter Nummer 67, 105-116. http://www.zobodat.at/pdf/Burgenlaendische-Heimatblaetter_67_0105-0116.pdf - accessed: May 28, 2016.

Land Vorarlberg (n.d.): Landwirtschaft – Fischerei. Bodenseefischerei. https://www.vorarlberg.at/vorarlberg/landwirtschaft_forst/landwirtschaft/fischerei/weitereinformationen/bodenseefischerei.htm - accessed: April 18, 2016.

Lenntech (2016): Why Oxygen Dissolved in Waters is Important. http://www.lenntech.com/why_the_oxygen_dissolved_is_important.htm - accessed: February 5, 2016.

Livingstone D. and Padisák J. (2007): Large-Scale Coherence in the Response of Lake Surface-Water Temperatures to Synoptic-Scale Climate Forcing During Summer. Limnology and Oceanography, Volume 52, Issue 2, 896-902.

Löffler H. (1969): Beitrag zur Kenntnis der Neusiedler See-Sedimente. Abhandlung des Natrongewässer-Symposiums Tihany – Szeged – Szarvas (29.9-4.10.1969), Nummer 16, Akademie der Wissenschaften, Wien. http://www.zobodat.at/pdf/SBAWW_179_5-10_0313-0318.pdf - accessed: April 23, 2016.

Mann K. H. (2016): Inland Water Ecosystem. Biota of Inland Waters. Encyclopaedia Britannica Online. http://www.britannica.com/science/inland-water-ecosystem/Biota-of-inland-waters#ref588698 - accessed: June 1, 2016.

Mikula K. (2012): Literaturstudie. Auswirkungen des Klimawandels auf den Wasserhaushalt Stehender Gewässer. Kärntner Institut für Seenforschung, Klagenfurt.

Mills M., Van de Bunt G., Bruijn J. (2006): Comparative Research. Persistent Problems and Promising Solutions. International Sociology, Volume 21, Issue 5, 619-631. http://www.rug.nl/research/portal/files/2861632/65-MillsM-Comparative-2006.pdf - accessed: March 22, 2016.

NASA (2010): Water Cycle. National Aeronautics and Space Administration. http://science.nasa.gov/earth-science/oceanography/ocean-earth-system/ocean-water-cycle/ - accessed: June 1, 2016.

Neuhuber F. and Hammer L. (1979): Oxygen Conditions. In: Löffler H. (ed): Neusiedlersee: The Limnology of a Shallow Lake in Central Europe, Monographiae Biologicae, Volume 37. Springer, Netherlands, 121-130.

NP Neusiedlersee (n.d.a): Klima. Nationalpark Neusiedlersee. http://www.nationalpark-neusiedlersee-seewinkel.at/klima.html - accessed: December 27, 2015.

NP Neusiedlersee (n.d.b): Lake Neusiedl and its Reed Belt. Nationalpark Neusiedlersee. http://www.nationalpark-neusiedlersee-seewinkel.at/lake-neusiedl-and-its-reed-belt.html - accessed: April 25, 2016.

ÖUG (2014): Strategiestudie Neusiedler See – Phase 1. Österreichisch-Ungarische Gewässerkommission.

Peeters F., Livingstone D., Goudsmit G., Kipfer R., Forster R. (2002): Modeling 50 years of Historical Temperature Profiles in a Large Central European Lake. Limnology and Oceanography, Volume 47, Issue 1, 186-197.

RCS (2014a): The Ramsar Convention and its Mission. Ramsar Convention Secretariat. http://www.ramsar.org/about/the-ramsar-convention-and-its-mission - accessed: December 30, 2015.

RCS (2014b): The Wise Use of Wetlands. Ramsar Convention Secretariat. http://www.ramsar.org/about/the-wise-use-of-wetlands - accessed: December 30, 2015.

RCS (2013): The Ramsar Convention Manual, 6th ed, Ramsar Convention Secretariat, Gland, Switzerland. http://www.ramsar.org/sites/default/files/documents/library/manual6-2013-e.pdf - accessed: December 12, 2015.

Schmutz S. (n.d.): Auswirkungen von Klimaänderungen auf die Fischfauna. In: ÖWAV. (n.d.): Auswirkungen des Klimawandels auf die Österreichische Wasserwirtschaft. Österreichischer Wasser- und Abfallwirtschaftsverband, 177-187.

Schröder H. (n.d.): Internationaler Gewässerschutz für den Bodensee. https://www.globalnature.org/bausteine.net/f/7001/InternationalerGewsserschutzfrdenBodensee_Schroeder.pdf?fd=2 – accessed: February 13, 2016.

Schwörbel. J. and Brendelberger H. (2013): Einführung in die Limnologie. 10th ed. Springer Spektrum, Heidelberg.

Sieber A. (n.d.): Der Bodensee. http://schifferpatent.org/bodensee - accessed: February 2, 2016.

Soja G. and A., Züger J., Knoflacher M. and Kinner P. (2013): Climate Impacts on Water Balance of a Shallow Steppe Lake in Eastern Austria (Lake Neusiedl). Journal of Hydrology, Volume 480, 114-128. http://www.eulakes.eu/upload/eulakes/gestionedocumentale/Artikel%20Soja%20J.Hydrol%202013_784_2607.pdf – accessed: April 26, 2016.

UBA (2015): Natura-2000-Gebiete. Umweltbundesamt. http://www.umweltbundesamt.at/umweltsituation/naturschutz/sg/n2000/ - accessed: December 31, 2015.

Weisser P. (1977): Die Verschilfungsdynamik (*Phragmites communis* Trin.) des Neusiedlersees. Wissenschaftliche Arbeiten Burgenland, Band 58, 101-114. http://www.zobodat.at/pdf/Wiss-Arbeiten-Burgenland_058_0101-0114.pdf - accessed: April 25, 2016.

Wikipedia (2006): Typical Mixing Patterns for a Dimictic Lake. https://en.wikipedia.org/wiki/Meromictic_lake#/media/File:LSE_Stratification.png – accessed: January 22, 2016.

Withgott, J. H. and Laposata, M. (2014): Essential Environment. The Science Behind the Stories. 4th ed. Pearson Education Limited, Essex.

Wolfram G. and Herzig A. (2013): Nährstoffbilanz Neusiedlersee. Wiener Mitteilungen, Band 228, 317-338, http://www.dws-hydro-oekologie.at/download/pub/wolfram_herzig_2013.pdf - accessed: April 26, 2016.

ZAMG (n.d.): Zukunft. Zentralanstalt für Meteorologie und Geodynamik. https://www.zamg.ac.at/cms/de/klima/informationsportal-klimawandel/standpunkt/klimafolgen/gebirgsgletscher/zukunft - accessed: February 8, 2016.

List of Tables

List of Figures