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Impacts of Climate Change on the Ecological Status of Lake Neusiedl

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

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Vienna, 8 June 2015

Affidavit

I, **CHRISTOPHER SIMON**, hereby declare

1. that I am the sole author of the present Master's Thesis, "IMPACTS OF CLIMATE CHANGE ON THE ECOLOGICAL STATUS OF LAKE NEUSIEDL", 64 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.

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Abstract

As an endorheic steppe lake with a relatively small catchment area and an annual evaporation rate that usually exceeds annual precipitation, Lake Neusiedl's water budget is highly dependent on evaporation and precipitation patterns. Considering the continuous increase of global GHG emissions and the correlating increase of global mean temperatures, a temperature rise in Austria is very likely in the following decades. This increase of atmospheric temperatures will have a positive effect on the evaporation rates of surface waters including Lake Neusiedl and, thus, a negative effect on their water budget. Due to the lake's special ecological characteristics, an increase of evaporation with merely slight changes in precipitation patterns could easily cause a net water loss, result in a more frequent occurrence of extreme water levels and even lead to desiccation in the long run. The lower water level of Lake Neusiedl and concomitant ecological changes will have a detrimental impact on the region's economy, most notably regarding tourism, as touristic activities are highly dependent on a sufficient water level of the lake. Lower water levels of Lake Neusiedl will attract fewer visitors, unless appropriate actions to mitigate the effects of increased evaporation are implemented.

Therefore, this thesis outlines the ecological impacts of increased atmospheric temperatures on Lake Neusiedl, their effect on the touristic activity in the region and provides mitigation strategies. Furthermore, the potential evaporation rate of Lake Neusiedl at various mean temperature levels is calculated in 3 future climate scenarios until 2050. The results are indicating that the annual water budget will most probably turn negative.

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1. Introduction

Ecosystems, hydrological systems as well as our human culture and economy are adapted to the climate in which they have developed. Given the increasing change in climate, the question arises whether the adaptive capacity of society and ecosystems can keep up with climate change and what can be done to attain a balance between climate, ecosystems and our society. Due to the inertia of the climate system, accumulated greenhouse gases will still influence the global climate far in the future and force us to develop new strategies to minimize the risks of climate change. In the coming decades we will therefore be faced with numerous new, still unpredictable challenges (KIKS, 2012).

In order to tackle current threats posed to surface water bodies within Europe due to problems such as pollution, the over-exploitation of natural resources, damage to aquatic ecosystems and climate change, the European Union has adopted the Water Framework Directive (WFD), which establishes a common approach for addressing these problems. To meet the objectives set by the WFD, Member States are required to introduce measures necessary to ensure that all their surface waters reach a “good ecological and chemical status” by 2015. During the evolution of this policy, it had become evident that climate change would have an enormous impact on the development of the WFD, an issue covered in the recent European Commission White Paper on the Adaptation to Climate Change (Glen 2010).

Climate change poses an imminent threat to stagnant water bodies within Europe. Its effects will be further complicated by changes in water availability and demand. Especially shallow lakes (<10 m) such as Lake Neusiedl will be heavily affected by climate variations, as they feature a low buffering capacity for changing climate conditions. The precise response of lakes to changing climatic conditions is, therefore, highly dependent on the characteristics of the lake. Human activities such as water withdrawals, overexploitation, the introduction of alien species, shipping or tourism have direct and indirect impacts on the future state of lakes. This can affect climate change or be affected by it. Such interactions make it difficult to accurately estimate the causal consequences of climate change for lakes (Gattenlöhner 2003, cited in KIKS, 2012).

Lake Neusiedl, the largest lake in Austria, is especially sensitive to climate change because of its extreme shallowness and a small catchment area. As an endorheic water body, evaporation accounts for most of its water loss (90%). 79% of water input is attributed to precipitation. This evaporation : precipitation ratio alone highlights Lake Neusiedl's sensitivity to temperature increases. As temperatures are likely to increase over the next decades, evaporation rates will rise along with it. Also, precipitation patterns will change, leading to a distortion of the lake's water budget. Water level and volume of Lake Neusiedl are very sensitive to precipitation shifts with after effects of individual years lasting up to 2 years. Precipitation during summer is more significant for lake water amount than during any other season. Historical records reveal that large variations of the lake area have occurred naturally (0% to >150% of present). Contemporary touristic uses of the lake, however, require a largely constant water level. This requirement further increases the regional economic vulnerability (Soja et al., 2012).

This thesis will elaborate on the specific ramifications of increased mean temperatures for the region both from an ecological as well as from an economic standpoint, the hypothesis being that climate change and the concomitant temperature increase implicate higher evaporation rates at Lake Neusiedl that result in lower mean water levels and an increase in the occurrence of extreme water levels. This change in water levels will impact the ecological status of the lake bring about negative effects for the regional economy, especially regarding tourism.

The outline of the thesis follows the following structure: First, a general explanation of global climate change, trends and recent efforts to mitigate the effects of climate change on a global scale will be given. After that, climate predictions for Austria will be elaborated. Secondly, ecological characteristics of Lake Neusiedl and its limnological peculiarities are shed further light upon, in order to demonstrate what parameters and elements of the lake might be affected by a change in climate patterns. Subsequently, the specific vulnerabilities of Lake Neusiedl, especially regarding water quantity, quality and the reed belt are explained and a list of strategies to tackle potential negative developments related to these vulnerabilities is provided. Furthermore, economic repercussions for the region and impacts of lower water levels on tourism are outlined. In order to provide back up for the alleged assertions, current and potential future evaporation rates will be estimated via the Kalmar approach, a calculation method based on the Dalton approach, but adjusted to the specific requirements of Lake Neusiedl.

Therefore, 3 different future scenarios will be estimated, an increase in temperatures of 0.8°C, 1.4°C and 2°C until 2050.

2. Global Climate Change

A common definition describes climate change as a long-term change in the earth's climate, mainly due to an increase in the atmospheric temperature. It is a natural process that has been taking place since the planet's existence. As the most recent example for a long-term negative change in climate patterns, the Little Ice Age lasted approximately from the 14th century until the mid-1800s causing independent regional climate changes rather than a globally synchronous increased glaciation, whereas the ice ages of the Pleistocene were marked by a clear global expression associated with considerable growth of continental ice sheets and a substantial drop in global temperatures of 2–3°C below current levels (Mann, 2012). Current climate change figures have been brought about mainly by human activity through the excessive emission of greenhouse gases (GHGs), a process that has started with the industrialization in the mid-18th century. Since 1880, the global mean temperature has increased by 1°C, in Austria the temperature increase amounted to 2°C. While less than half of this increase is attributed to the contribution of natural climate variability to global warming, the comparably small rise in global average temperature since 1998 is likely attributed to natural climate variability (APCC, 2014). Annual anthropogenic GHG emissions have risen by 10 $GtCO_2eq$ between 2000 and 2010, of which 47% directly stem from energy supply, 30% form industry, 11% from transport and 3% from buildings sectors. Accounting for indirect emissions increases the contributions of the buildings and industry sectors (IPCC, 2014).

Without the introduction of extensive measures to reduce pollution, a dramatic increase in global average temperature of 3–5°C until the year 2100 *compared to current conditions* is to be expected (APCC, 2014). Estimations by Intergovernmental Panel on Climate Change (2014), have resulted in baseline scenarios, those without additional mitigation, with global mean surface temperature increases of „merely" 3.7–4.8°C until 2100 *compared to pre-industrial levels* (before 1750). However, when including climate uncertainty the range changes to 2.5–7.8°C. In this regard, self-reinforcing processes, such as the ice-albedo feedback or additional release of GHGs due to the thawing of permafrost in the Arctic regions will be of major importance. The persistence of climate change and its effects show significant regional differences. The Mediterranean region will experience a distinctive decline in precipitation and, consequently, water availability. Following the worst-case emission scenario, an associated rise of the sea level by the order 0.5–1 m compared to the current level would pose a great threat to the densely populated coastal regions (APCC, 2014).

Due to the severity of unbridled anthropogenic climate change for humanity, internationally binding agreements on emission reductions have been put in place. Furthermore, numerous states as well as cities, local authorities, businesses and intergovernmental organizations such as the United Nations with its Sustainable Development Goals, the European Union or the G-20 have set objectives that reach beyond aforementioned arrangements. Both the UNFCCC Copenhagen Accord and in the EU Resolution targeted a global temperature increase of maximum 2°C compared to pre-industrial in order to limit dangerous climate change ramifications. Unfortunately, this goal seems impossible to reach, considering the insufficient measures so far taken by the international community on a voluntary basis for emission reduction commitments. In the long-run, an almost complete avoidance of GHG emissions would be necessary in order to keep a temperature increase under the 2°C threshold, which requires a change in energy supply and industrial processes, land use and lifestyles as well as ceasing deforestation. The possibility of success would increase drastically if these changes could be induced until 2020 and GHG emissions could drop to a level 30%-70% below those of the year 2010 (APCC, 2014). Due to the fact that industrialized, developed countries are responsible for the major part of historical pollution, and because of which they are more economically powerful and influential than developing countries today, they are required to contribute an overproportional effort to emission reduction, as elaborated in Article 4 of the UNFCCC (1992) under the notion of “common and differentiated responsibilities”. In its “*Roadmap for moving to a competitive low CO_2 economy in 2050*” the EU aims for GHG emission reductions of 80%-95% compared to 1990 levels (ECF, 2010). Global CO2 emissions from fossil fuel combustion and industrial processes contributed about 78% of the total GHG emission increase from 1970 to 2010, with a similar percentage contribution for the period 2000–2010 (IPCC, 2014).

Globally, economic and population growth remain to be the most important drivers of CO_2 emission increases from fossil fuel combustion. While the contribution of population growth between 2000 and 2010 remained similar to the previous three decades, that of economic growth has risen steeply. Between 2000 and 2010, both of these sources caused pollution that outpaced emission reductions from improvements in energy intensity. Furthermore, a surge in the use of coal relative to other energy sources has reversed the long-standing trend of gradual decarbonization of the world's energy supply (IPCC, 2014). The International Energy Agency (IEA, 2012) predicts an "*infrastructure lock-in*" already in 2017 due to the expansion of coal-fired power plants and long-lasting investment cycles. Energy supplying and consuming infrastructure would already contribute the total amount of allowed CO_2 emissions. Thus, there would be no more leeway for additional power plants, factories or other infrastructure, provided that these are not CO_2 free. However, in the Global Energy Assessment (GEA, 2012) it was shown through a number of development scenarios that a stabilization of the global mean temperature increase at 2°C was indeed possible. Additionally, normative goals, such as improvement of energy-supply security and avoidance of pollutants are considered achievable.

2.1. Climate Change in Austria

Despite of the fact that under the EU 2050 Roadmap no emission reduction obligations were stipulated for individual EU Member States, Austria can expect a similar reduction commitment of 80%-95%. In 2014, the Austrian Panel on Climate Change released its Austrian Assessment Report (AAR14) that described past, present and potential future climate developments in Austria, their impacts on Austria's environment and economy and possible prevention and mitigation actions. According to the AAR14 global temperatures increased by 0.85°C on average since 1880, while Austria has experienced a major increase of 2°C of which 0.5°C and 1°C are attributed to the post-1980 period. The expected temperature increase of the 21st century will amount to approximately 1.4°C compared to current temperature and is not greatly affected by the various emission scenarios due to the inertia in the climate system as well as the persistence of GHGs in the atmosphere. Since the temperature development thereafter is strongly dependent on anthropogenic GHGs emissions in the years to come, it can be countered via mitigation actions in the short-term. Precipitation figures of the last 150 years show significant regional differences. Opposed to an increase in annual precipitation of about 10-15 % in western Austria, a decrease in a similar order of magnitude was observable in the southeast. As the 21st century advances we can expect a surge of precipitation rates in the winter months and a drop in the summer months, while the annual average stays constant. This is because Austria lies in the larger transition area between two regions with opposing trends (increase in North Europe/decrease in the Mediterranean). In the past temperature extremes have shifted significantly towards a drop of the annual amount of cold nights and an increase in hot days. This is a trend that is very likely to continue and intensify throughout the 21st century along with an increase of heat wave frequency. Hot days will not only be hotter than nowadays, they will also be much more common. Extreme precipitation patterns are not uniformly detectable yet, but extreme precipitation events are considered to become more likely from autumn to spring. While Austria has experienced exceptional storm events in the recent past, a long-term surge in storm activity is not identifiable. Storm frequency is likely to remain constant in the future (APCC, 2014).

It is evident, that the West of Austria will be the region most affected by climate change under elaborated baseline scenarios, due to increasing sun duration, decreasing duration of snow-cover, receding glaciers and so forth. Also economically, West Austria is likely to suffer the most under climate change impacts. This paper, however, will avoid the focus on mountainous regions in order to emphasize impacts on East Austria, especially Burgenland and, more specifically, the area around Lake Neusiedl. The economic impact of climate change in Austria is already considerable, has been steadily increasing throughout the past three decades and is likely to continue to rise in the long run. Considering the relevance of economical ramifications due to climate change, the last part of this thesis will investigate consequences in probably the most important economical factor of Lake Neusiedl, namely tourism.

Besides the obvious intensity and frequency of extreme weather events, mainly socio-economic and demographic factors, such as age structure of the population in urban areas, the value of exposed assets, infrastructure development as well as overall land use, will determine the future costs of climate change. Since climate change particularly affects the weather dependent sectors and areas such as agriculture and forestry, tourism, hydrology, energy, health and transport and related sectors Austria’s vulnerability to climate change is substantial. In 2012 Austria adopted a national adaption strategy plan to cope with the impacts of climate change (BMLFUW, 2012). It categorizes its adaption options into three main groups: *grey* (technical, e.g. constructions preventing floods), *green* (sustain natural functions of ecosystems and improve resilience to serve as climate change buffers) and *soft/smart* measures (raise awareness, improve knowledge, create economic incentives, enable institutional framework conditions for adaption). The effectiveness of this strategy will be estimated mainly by how successful individual sectors or policy areas will be able to develop and implement appropriate adaptation strategies. Criteria for their evaluation, such as regular surveys of the effectiveness of these measures, as other nations have already established, do not yet exist in Austria (APCC, 2012).

Austria has made commitments under the Kyoto Protocol. With a total of approximately 81 million tons of CO_2- equivalents (CO_2 eq.) or 9.7 tons CO_2 eq. per capita, the emissions for the commitment period 2008 to 2012 were 18.8 % higher than the reduction target of 68.8 million tons CO2- eq. per year. Emission values for Austria are almost 50% higher when also including consumption-related CO2-emissions abroad, particularly referring to imports from South Asia and from East Asia, specifically China, and from Russia. Even though Austria has committed itself to a reduction of 13% until 2012 compared to 1990 levels national GHG emissions have risen. Current efforts of Austria to achieve emission reductions focus on improving energy efficiency and promoting renewable energy sources. The energy strategy of 2010 targeted a reduction in energy consumption to the level of 2005 until 2020 (1100 PJ). Furthermore, Austria's Environment Energy Law (Ökostromgesetz) determined an additional 10.5 TWh (37.8 PJ) per annum until 2020 to be generated from renewable sources. In order to reach these objectives, they have to be backed by effective, tangible measures to make them achievable. Particularly the transport sector lacks such measures. Moreover, Austria has set only short-term reduction targets until 2020, while other nations such as the UK and Germany target a reduction of 80% and 85% until 2050, respectfully. Tee APCC (2014) reveals, that measures taken so far to meet Austria's expected contribution to achieve the global 2 °C target are insufficient. Additionally, institutional, economic, social and knowledge barriers slow mitigation and adaptation progress. Various scenario simulations showed, that emission reductions of up to 90% are achievable in Austria by 2050 through additional implementation measures and that the target set by the EU reached by halving energy consumption in Austria by 2050 (APCC, 2014).

3. Lake Neusiedl

Lake Neusiedl and its surroundings are ecologically, economically and socio-culturally relevant for the population and visitors. The area has important functions such as:

- Ecological, macro- and micro-climatic functions such as habitat functions for plants and animals
- Hydrological functions for the region (water budget)
- Important regional economic functions and uses that are dependent on the functionality of the lake, such as tourism, agriculture and viniculture, fishing, reed usage, infrastructure
- Socio-cultural functions in particular landscape aesthetics, rural management customs and traditions
- Social functions for the population (health, recreation)

The area is characterized by a mostly agrarian landscape. The slopes of the Leitha Mountains (Leithagebirge) are predominately occupied by vineyards (approximately 16,500 hectares cultivated land) while the flat areas feature arable land. Between the reed belt of Lake Neusiedl and the described agricultural and wine-growing region there is a diverse landscape of meadows and pastures. The region offers a variety of cultural activities in places like Mörbisch or in St. Margarethen. Since the 1970s tourism has continuously gained in importance. Today the tourism sector mainly benefits from the lake through events and facilities for sailing, surfing, kite surfing, beach volleyball, inline skating, horse riding and cycling. The old cultural landscape around Lake Neusiedl presents itself as a wine- and recreational area for the metropolitan area of Vienna. Due to the specific climate and soil conditions one of Europe’s most unique flora and fauna could develop at Lake Neusiedl with more than 300 species of birds. For many plant and animal species this transition zone between land and lake serves as a habitat.

3.1. History of the Lake

With a total area of 315 km^2 (depending on current water level), out of which approximately 20% lie in Hungarian territory, the Neusiedler See is the largest steppe lake in Europe. It is a very shallow, well-mixed, alkaline lake, situated at the western edge of the Lesser Hungarian Plains. The lake emerged from a tectonic delve that occurred during the Late Glacial Maximum (13.000-10.000 years ago). Post-glacial water levels occasionally exceeded the current level by 5 m, resulting in the flooding of the southern part of the Seewinkel and Hanság. Besides these periods of very high water levels, the lake has faced aridification at many times of its existence. The last time the lake was completely dried up was between 1865 and 1868. Five years later, however, water levels of 2-3 m were measured. Until the beginning of the 20th century the lake lacked an outlet. This changed with the construction of the Hanság-channel (Einser-Kanal) in 1911 connecting it indirectly to the Danube. Initially, this measure was to drain the lake and use the land for agricultural purposes. Today, however, it solely serves the objective of water-level regulation (Herzig, 2014).

After the Second World War, the Iron Curtain separated Austria and Hungary and both regions experienced different development processes over almost half a century. Since the opening of the border an economic convergence has occurred. Meanwhile, both nations are part of the European Union and the Schengen Agreement has become effective, enabling a free passage over the Austrian-Hungarian border. A great benefit of both nations joining the EU is a common legal framework on environmental protection and water management, which makes cooperation much easier in this regard. Naturally, the long separation period has left its marks in the region around Lake Neusiedl. The limited economical development due to the former political landscape, however, shaped the environmental development in a unique way that has enabled it to become refuge to a large number of plants and animals. Because of its high grade of biodiversity hosting numerous rare plant and animal species Austria and Hungary have established many protective environmental regulations for the region. Starting out as a partial nature reserve and protected landscape since in 1962, the Austrian part was declared a biosphere reserve in 1977. The Hungarian part followed 2 years later. After the Hungarians had established a nature reserve in 1977, Austria followed example in 1980 and created the „*Natur- und Landschaftsschutzgebiet Neusiedler See und Umgebung*". Finally, in 1993 a transboundary national park Neusiedler See-Seewinkel was established and in 2001 the region was declared a UNESCO world heritage site with a size of 74.716 ha (Wolfram et al., 2013).

3.2. Ecological Characterization

The lake covers a total area of 315 km^2 and has a maximum depth of 1.8 m, with a catchment/lake area ratio of about 3:1, which, compared to other Central European lakes of similar size, is quite small. The mean depth of 1.2 m entails a low water volume. The north and east sides of Lake Neusiedl consist of Danubian and glacial Danubian gravels. While the west side is formed by limestone ("*Leithakalk*"), the south-east area is covered by the Hanság, ("*fen*" in Hungarian), a former bog and marsh land which has been partly transformed into wet meadows after partial desiccation (EU Lakes, 2013a).

Figure 1: Catchment area of Lake Neusiedl (Herzig, 2014)

3.2.1. Climate

The climate of the region Burgenland is continental and characterized by annual average precipitation of 574 mm, which is lower than the annual potential evaporation (630 mm), resulting in a net water loss in dry years. However, annual precipitation values of less than 400 mm or exceeding 900mm are not rare. The summer months are hot and dry and the winter months fall below 0 °C for short periods (EU Lakes, 2013a). The area around the lake is the warmest region in all of Austria. An annual average of 61 days feature temperatures of over 25°C while temperatures of less than 0°C can occur during October an May. In winter the lake is usually completely frozen over. As a consequence, the lake's water temperature ranges from 0°C in winter under the ice cover and can go up to 28°C in summer, partly even to 31°C at water depths of 10cm. Within a couple of days the water temperature can drop or rise by more than 10°C.

3.2.2. Water Budget

As Figure 2 shows, the water budget of Lake Neusiedl relies mainly on precipitation that contributes 76% (ca. 184.3 Mio. m³/y) to the water input. The River Wulka provides a small portion of about 22% to the water gains (47,2 Mio. m³ y-1) while the inflow of other sources like groundwater or wastewater treatment plants are negligible (Eitzinger & Kubu, 2005, cited in EU Lakes, 2013a). As the lake has only one artificial outflow (Einser-Kanal) regulated by an Austro-Hungarian lake management contractor, there may be some years where no water at all is drained through the channel. Consequently, it is assumed that about 11% of the lake water losses are attributed to the channel and 89 % to the natural evaporation from the lake surface (EU Lakes, 2013a). As already mentioned, annual potential evaporation exceeds annual average precipitation by about 13%. These 13%, however, are compensated by inflows of the River Wulka so that, overall, water loss is usually compensated by the various inputs on an annual average. Seasonal water level fluctuations in Lake Neusiedl follow a relatively regular pattern with an amplitude of 0.4m (Figure 3). These fluctuations are caused by a seasonal interplay of evaporation and inflow (Dinka et al., 2004 cited in Wantzen et al., 2008). According to other sources (Herzig, 2014; Eitzinger et al., 2009) these water level fluctuations often exceed 50 cm.

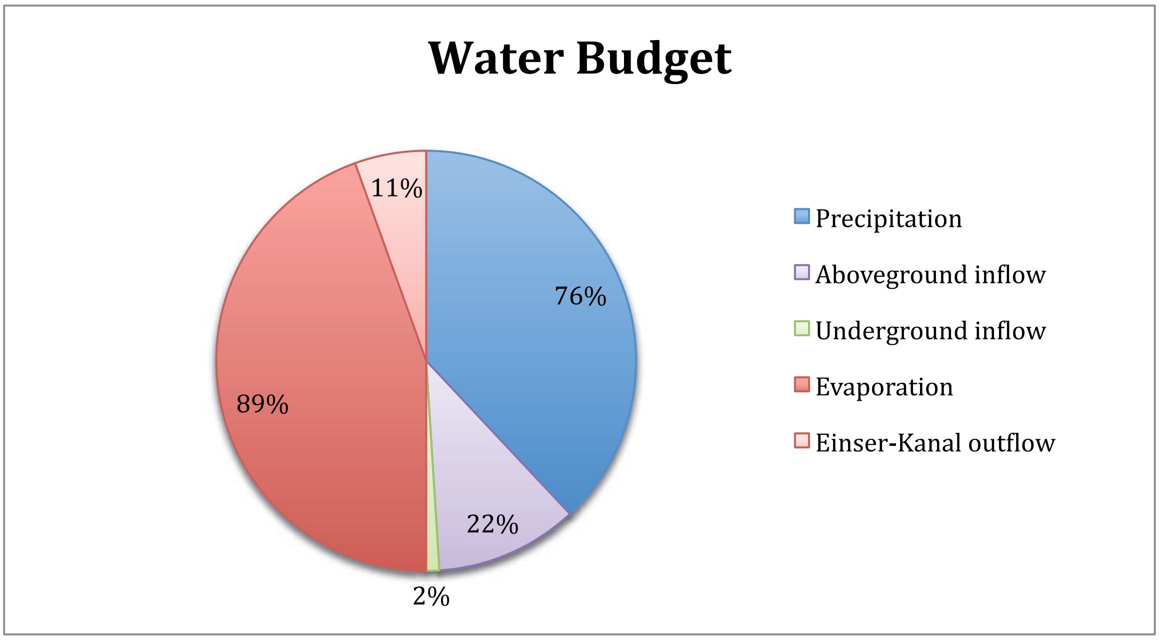

Figure 2: Water Budget between 1965-2012 (Wolfram et al., 2013)

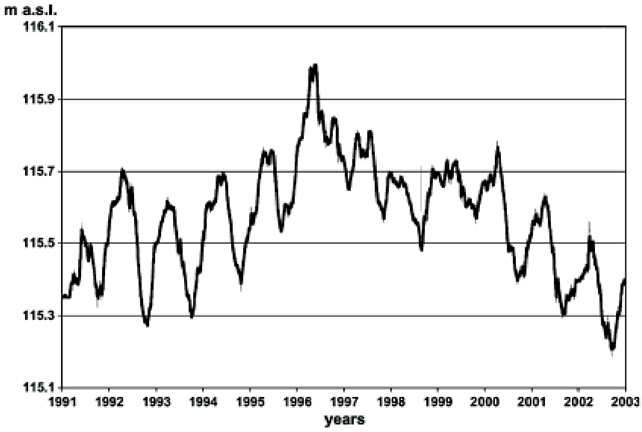

Figure 3: Hydrograph of Lake Neusiedl 1991-2003 (Dinka et al., 2004 in Wantzen et al., 2008)

Since the water volume varies considerably over the years and the seasons, it is evident that the lake area changes along with it. Historically, the area of Lake Neusiedl varied from 0 at the end of the 19th to nearly 500 km² in the 18th century. Since 1965, the management contract for the Einser-Kanal is aiming to keep the water level at a minimum of 115,5 m a.s.l., which is one of the main reasons for the current surface area of about 315 km^2. High precipitation values, however, are still able to cause small-scaled floods of the wetlands near the lake, as happened in 1997. Before the water level regulation, high water levels occured in 1941 with 116,1 m a.s.l., in the 18th and first half of the 19th century (EU Lakes, 2013a). Due to its shallowness and the rather windy conditions Lake Neusiedl's water is well mixed so that the horizontal variability results more important than the vertical thermal stratification (Dokulil & Padisák, 1994, cited in EU Lakes, 2013a).

Interestingly, when taking a look at the lake volume at different points of time one realizes that it shows a decreasing trend even though the water level has stayed constant (Figure 4). This development is attributed to the successive deposition of mud in the basin as well as to the increasing expansion of reed at the lake. The mud volume in the Austrian part of the lake has almost doubled in the period 1963-1988 (75 mio. m^3 to 150.17 mio. m^3) (Csaplovics , 1997, cited in Eitzinger et al., 2009). The advancing expansion of reed does not only affect the water volume but, moreover, the evaporation rate of the lake (transpiration), as further elaborated in the next chapter.

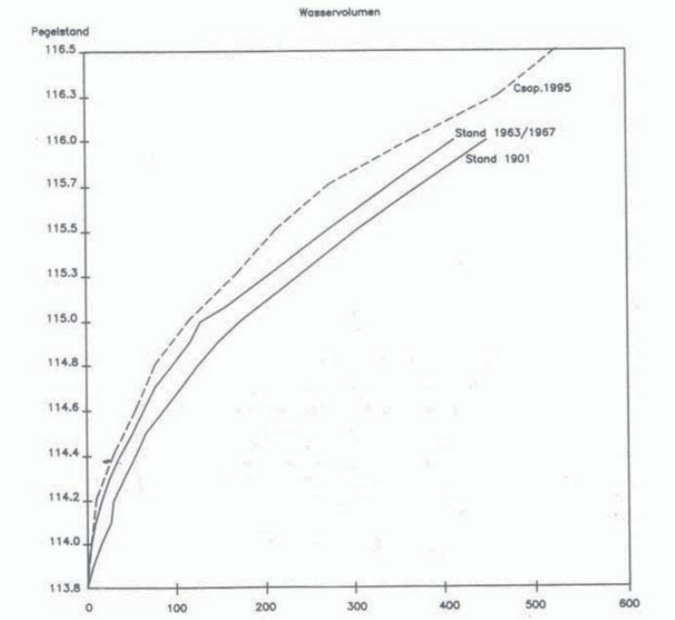

Figure 4: Area and content diagram of the Lake Neusiedl basin, water level in m a.s.l. and volume [$10^6 m^3$] after Csaplovics (1997, in Eitzinger et al., 2009).

3.2.3. The Reed Belt

Over the centuries the reed belt of Lake Neusiedl has been subject to major changes. While little is known from earlier times, its development is well documented for at least the past 200 years. It turns out that the reed has grown strongly in the last century; a circumstance which in the meantime led to the fear that the whole lake could disappear in the reeds (Kopf, 1967, cited in Nemeth et al., 2014). We know now that these concerns were ungrounded, considering the fact that in the past twenty years no significant reed expansion could be observed. On the contrary, within the reed a loss of reed is observable leading to areas open water (Csaplovics and Schmidt, 2011; EU Lakes, 2013b). According to the latest figures on the basis of aerial photography on the Hungarian (2007) and Austrian side (2008), the reed belt covers an area of approximately 181 km^2, including the transition area landwards, of which about 64 km^2 is located on the Hungarian and 117 km^2 on the Austrian side. Significant is the high ratio of reed beds with very little (35% of reed beds in Austria, reed fraction <70%) to no reed stock and, therefore, a greater proportion of open water surfaces (15% in Austria) (Wolfram et al., 2013). The area of the actual reed belt without transition zone on the Austrian side is 104.9 km2, whereby this area includes 12-19% open water surface, depending on the applied resolution and method of analysis (Csaplovics and Schmidt, 2011, cited in Nemeth et al., 2014). In general it is obvious that the older, sparse reed populations are in the inner reed belt and along the lake- and landside borders rather vital, dense, young reed. Besides areas with young, vital reed, marsh or swampland as well as sedge are found as expected along the border between the reed belt and the backcountry. According to Csaplovics and Schmidt (2011) more than 10km^2 of the reed belt consists of *„considerably sparse, old reed“* to *„very old reed; dying reed“* with more than 50% open water surface. The decrease in reed area at Lake Neusiedl compared to other European countries is of minor magnitude. So far only hypotheses exist as to why the reed belt area has not expanded after 1979 and why the area of brownwater has increased (EU Lakes, 2013d).

The water level fluctuations of the lake have a decisive influence on the extent and the structure of the reed belt. Although these are largely determined by climatic factors, the establishment of the Einser-Kanal also made human intervention into the system’s ecology possible. In 1965 the water level was raised causing reed expansion on the landside while the offshore boundary of the reed belt remained rather constant or moved just slightly. This was the last time the reed belt experienced a major expansion (Csaplovics and Schmidt, 2011). In general, declining water levels cause the reed to expand on the side of the shore to former open water surfaces (Wolfram et al., 2013; EU Lakes, 2013b).

As already mentioned, the reed belt has a significant impact on the overall evaporation rate of lake Neusiedl due to transpiration. Herbst and Kappen (1999) investigated the ratio of transpiration versus evaporation in a reed belt as influenced by weather conditions. According to their findings the high water consumption in reed belts requires large amounts of energy which are gained by cooling of the air. Therefore, reed stands strongly affect not only the hydrology but also the microclimate of lakeshore areas. While in the literature there is still some confusion about the magnitude of these effects, as evident from the attempts to find certain values for the ratio of transpiration versus evaporation, their long-term study revealed that this ratio varies significantly depending on weather conditions, because reed transpiration responds more sensitively than evaporation to meteorological variables. However, it is evident that independent from the meteorological characteristics of a certain year the annual water consumption of the investigated reed belt always exceeds the evaporation from the open lake surface and even the evapotranspiration of the adjacent alder zones common to lake Bornhöved in northern Germany, which was their main study site. Consequently, water flows from the lake and trees to the reed bank during most parts of the growing season demonstrating the significance of reed belts for lateral and vertical fluxes of water and soluble nutrients or pollutants in the transition zones between lakes and wetlands (Herbst and Kappen, 1999).

To put it into the context of Lake Neusiedl, the reed belt is responsible for a major part of annual water losses, considering the fact that it represents more than 55% of the lakes total area. It is, therefore, safe to conclude that the major part of the total annual evaporation figures of Lake Neusiedl is attributed to the reed belt.

3.3. Limnology

3.3.1. Salt Content

Reasons for the elevated salt content of Lake Neusiedl are the semi-arid climate, the hydrological peculiarities, salty, tertiary marine sediments and the connection to groundwater over tectonic cracks (Wolfram, 2006, cited in Herzig, 2014). Current salt content amounts to 1-2 g l^{-1} with a conductivity of 1.300- 3.200 µS cm^{-1} at 25 °C. The water has an alkaline character with a pH value of over 8. In times of low water levels at the beginning of the 20th century a salt content of up to 16 g l^{-1} could be measured. The concentration is based on the cations sodium (Na) and magnesium (Mg) as well as the anions hydrogen carbonate (HCO_3^-), sulfate (SO_4^{2-}) and chloride (Cl^-) (Berger & Neuhuber 1979, cited in Herzig, 2014). The dominant salt is sodium bicarbonate ($NaHCO^3$), thus the lake is often referred to as „*Sodasee*“. The water exchange between open water and the reed belt further affects the salt content. Wind-induced seiche-movements are the main cause for seasonal fluctuations of the salt content through deposition and the re-dissolving of salts in those parts of the reed belt that fall dry regularly. The usage of the Hanság-channel is accompanied by severe losses of salts (Wolfram and Herzig, 2013).

3.3.2. Nutrients

In addition to the natural fluctuations and changes in salinity, turbidity and light transmittance a significant increase in nutrient levels and, in turn, of phytoplankton occurred from the late 1960s on leading to eutrophication. This was triggered by a rising amount of waste water discharge as a result of increased tourism combined with inadequate sanitation and waste water disposal as well as strongly intensified fertilizer application in agriculture due to the expansion of viniculture at the end of the 1960s

(Löffler 1979, Löffler and Newrkla 1985, cited in Herzig 2014). More specifically, influences include loads in surface flows (Wulka, Gols channel Kroisbach, Teufelsgraben, Angersbach), receiving water from sewage treatment plants, diffuse inputs (erosion by wind and rain from agricultural land), boat operations, swimmers, water birds, fish and the dissolution of nutrients from the reed area. Certain measures of professional fishermen targeting specific species such as the grass carp and the eel resulted in unbalanced fish stocks which further affected the lake negatively (Herzig and Dokulil 2001, cited in Herzig 2014).

From 1970 on, annual mean total phosphorus concentration in the open lake rose steadily and reached its highest value so far in 1979 with 162 µg l^{-1}. Along with it, dissolved reactive phosphorus and dissolved inorganic nitrogen (mainly ammonium) reached peak values in the mid-1970s as well. Simultaneous to the rising P-concentrations, phytoplankton biomass increased considerably to 14 µg l^{-1} on average peaking in 1978. Compared to other lakes with good light transmittance, these values are not high considering the limitation of available light for algae growth in the open water. In the wind-protected embayments and docks, however, severe algae blooms were witnessed (Herzig 1990, cited in Herzig 2014).

From the mid-1980s onwards, the total- phosphorus values decreased continuously and ranged around 50 µg l^{-1}. Peak values near areas of reed rarely exceeded 200 µg l^{-1}. The main reason for the sharp decline in concentrations was successful sanitation in the catchment area. The external inflow into the lake dropped from around 80 tons of P/year (1982/1983, calculation only for the Austrian part of the lake) to about 30 tons P/year (1992-2000, calculation for the entire lake) from. Between 2001 and 2005 the annual load of phosphorus merely reached 12 tons (entire lake). The external nitrogen load decreased by 885 tons (1982/1983, Austrian part of the lake) to 559 tons (1992- 2000, entire lake) and finally reached 250 tons between 2001 and 2005 (entire lake) (Wolfram and Herzig, 2013, cited in Herzig 2014).
Between 1993 and 2007, the feeding rivers contributed the highest proportion of the total external nutrient freight (51-80%), of which the Wulka was the main source with 35-73%. 16-44% of the external quantities stem from atmospheric deposition. The proportions stemming from waste water treatment plants that discharge their effluents into the lake (1-8%) and from groundwater (1-2%) that enters the lake, is negligible (Zessner et al., 2012, cited in Wolfram et al., 2013). Among the loads in Wulka

catchment, erosion from surrounding agricultural areas represent a high proportion in wet years, whereas in dry years loads of the treatment plants of Eisenstadt, Wulkaprodersdorf and "*Lake Neusiedl West*" prevail (Wolfram et al., 2007, Gabriel et al., 2011, Kovasc et al., 2012, Zessner et al., 2004, cited in Wolfram et al., 2013).

Apart from the external loads, phosphorus concentrations in the lake depend heavily on internal processes. This became evident in the dry years of 2003 and 2004 as the P-concentrations in the open lake increased significantly to achieve annual averages of more than 60 $\mu g\ L^{-1}$ with peaks of several 100 $\mu g\ L^{-1}$. Normally, particulate phosphorus is distributed over the lake with a significant proportion accumulating in the reed belt area. On an annual average the loss of phosphorous by sedimentation exceeds internal loads in the open lake stemming from the reed belt, provided that the reed belt is flooded and water exchange between open lake and reed belt is possible. At low water levels, however, when the reed belt is mostly dry, this water exchange is greatly reduced. As a consequence, both phosphorus export into the reeds and net sedimentation decline, while the importance of internal loading increases (Wolfram et al., 2013).

The mechanisms of "*internal loading*" of dissolved phosphorus in Lake Neusiedl were studied in the 1980s by Metz (1984, cited in Wolfram et al., 2013). Ágoston-Szabó and Dinka (2006) showed that sediments in degraded reed areas feature four times more organic material as well as many times higher total nitrogen and total phosphorus levels than sediments in non-degraded sites. The re-dissolution of dissolved phosphorus from the sediment is most pronounced at high temperatures and sulfate reduction. These conditions occur mainly at low water levels and lead to increased transport of dissolved phosphorus from the reed areas into the inner lake as the water level rises again (Gunatilaka 1984, cited in Wolfram et al., 2013). Wolfram and Herzig (2013) recently presented a phosphorus budget for the lake over 20 years and showed that the phosphorus increase in 2003/2004 was due to a shift of sedimentation towards internal loading and not due to increased resuspension at a low water level. Their findings revealed that discharges from the lake over the Einser-Kanal have a major impact on the chemistry of the lake leading to a reduction of dissolved salts and a sweetening of Lake Neusiedl, which is contrary to its nature as endorheic salty lake. In this regard, dry years help the lake to renew its concentrations and compensates for the previous losses. Furthermore, the reed belt is of great importance for the chemistry and the water quality of Lake Neusiedl, since its key role is to serve as a depot for phosphorous-sedimentation. At low water levels, therefore, the reed cannot fulfill its function as a nutrient sink, which explains the increase in phosphorus (and consequently chlorophyll-a) concentrations in the open water during the years of low precipitation 2003 and 2004, when the reed belt was temporarily completely dry. Thus, the increases in nutrient concentrations in the early 2000s are not attributed to external inputs, but to internal processes. Anthropogenic nutrient inputs have declined continuously over the past three decades (Wolfram and Herzig, 2013).

3.3.3. Aquatic Biocenosis

Phytoplankton

Phytoplankton is highly influenced by the almost constant mixing of the lake and the resulting high content of suspended particles leading to low penetration of light. Light limitation prevents the development of those algal masses, which would be expected considering the lake’s nutrient content. Nevertheless, eutrophication has induced pronounced qualitative and quantitative changes in the plant plankton societies (Herzig, 2014). While in the beginning of the 1970s plankton diatoms dominated phytoplankton supply, green algae, and even more so, blue-green algae (cyanobacteria) appeared in increasing numbers after 1987 (Wolfram et al., 2013). By the end of the 1990s blue-green algae blooms still occurred in local bays. After all, between 1995 and 1997 cyanobacteria accounted for 38% (24-61%) in spring and for 36% (23-55%) of the total phytoplankton biomass in fall, respectively (Herzig and Dokulil 2001, cited in Herzig, 2014).

Today green algae, diatoms and cyanobacteria represent the most common phytoplankton of the open lake. Pico-plankton (<2 micrometers) is abundant, which is a distinctive characteristic of Lake Neusiedl. Compared to other mesotrophic shallow lakes, the abundance (>10 million cells per liter) and the proportion of pico-plankton in the total phytoplankton biomass (up to 80%) of the open lake is very high (Somogyi et al . 2010, cited in Herzig 2014) . But even large diatoms, that mostly inhabit the lake bottom and are whirled up by the wind and waves, are essential components of phytoplankton (Herzig, 2014).

Zooplankton

In the last 50 years Arctodiaptomus spinosus (Copepoda) and Diaphanosoma mongolianum (Cladocera, Ctenopoda) were the most common crustaceans in the plankton of lake Neusiedl. Some representatives of the zooplankton have adapted optimally to the salty conditions of soda lakes, which is why they serve as potential indicators for changes in the water chemistry (Wolfram et al., 2013). In the zooplankton qualitative changes are observable, especially regarding rotifers. Due to eutrophication the number of common species has decreased from the original twelve (1968) to just three to five today. The crustaceans dominate zooplankton biomass in the open lake. The highest values fall within the period 1970-1987 (time of eutrophication). After that, biomass values dropped to much lower levels and were at 50 mg dry-mass.m^{-3} between 2008 and 2012 (Herzig 2014).

Benthic Invertebrates in the Open Lake

Since there are significant differences between the open lake (exposed to the wind), and wind-protected areas such as bays we differentiate between benthic communities inhabiting the respective areas (Herzig, 2014). For most groups a pronounced horizontal distribution could be observed in terms of species composition, abundance and biomass, determined by wind exposure and the resulting differences in the sediment size distribution. While the substrate of the open lake is tough, compact, partly sandy and features merely a fine sediment layer, the sediment of wind-protected areas in close proximity to the reed belt presents itself as a powerful soft mud layer of several decimeters in thickness (Wolfram, 1996).

At the beginning of the 1990s Wolfram (1996) investigated the sediment-inhabiting chironomids, which represent the predominant group of benthic invertebrates in Lake Neusiedl. Their mean abundance varied between 17,000 ind m^{-2} in the open lake and 49,000 ind m^{-2} in sheltered bays. Their biomass accounted for 0.05 to 1.23g dw m^{-2} on a yearly average. Annual secondary production was estimated at 0.55 to 6.64g dw m^{-2} yr^{-2}. Compared to other stagnant waters these are considered rather low values (Wolfram, 1996).

Most identified invertebrates in the open lake are typically representatives of mesotrophic to eutrophic standing waters. Generally, however, this part of the lake is poor in species, both in zoobenthos and zooplankton. A significantly higher diversity among invertebrates is found in areas of submerged macrophytes and the reed belt (Wolfram et al., 2013).

Benthic Invertebrates in the reed belt

Compared to the species community of the open lake, that of the reed belt features a much larger variety. To date, more than 300 invertebrate taxa have been identified. Their greatest variety is found in areas with dense and diverse aquatic vegetation, which highlights the relationship between structural and biotic diversity. The number of species within each major group varies considerably (Wolfram et al., 2013). Of particular importance are taxa that are considered as an indicator of the slight increase in salinity of the lake, as the freshwater hydroid (*coelenterates*) or the chironomid *Polypedilum nubifer* (Wolfram et al., 2013).

Conclusions about the ecological status of the littoral zone of the lake and its importance for the entire ecosystem are not possible here. It can be assumed that biodiversity as well as abundance and biomass vary from habitat to habitat, hard evidence, however, does not exist. Some species probably require reed puddles or the channels of the reed belt as a habitat. Others mostly inhabit reed areas that are adequately supplied with oxygen by the open lake (Wolfram et al., 2013).

Fish

Currently, 22 species of fish, 5 of which are non-native species inhabit Lake Neusiedl. Species composition remained relatively constant for decades. Carp fishes are predominating. The origin of the various species can be attributed to their immigration during floods from the rivers Danube, Raab, and Rabnitz and Ikva, which had been connected directly to Lake Neusiedl during high water level periods before regulatory measures were introduced. Complete drying out (1865-1868) or the freezing of the lake in winter 1928/29 resulted in a marked decline in stocks, which however, hardly altered the species composition (Herzig et al. 1994, cited in Herzig 2014). Only in the second half of the 20th century it came to significant changes in the fish fauna through restocking measures fishermen. Most notably, eel was introduced and restocked intensively resulting to higher predation pressure on small fish. As a result many types of smaller fish disappeared in the lake. The stocking with grass carp led to the disappearance of submerged aquatic plants, which meant the loss of valuable spawning habitat and protection for fish (Herzig & Dokulil 2001, cited in Herzig 2014). The highest biomass of fish can be found in well-structured areas near the reed borders (several 100 kg/ha), while biomass in the open lake is measured at 5-20 kg/ha (Herzig & Dokulil 2001, cited in Herzig 2014).

4. Vulnerabilities

Currently Lake Neusiedl is threatened by many natural and anthropogenic stresses. "*Because of the various climatic effects (continental, sub-Mediterranean, alpine) it is a meeting point not only of geographical but also global and faunal borders*" (Welterbe, 2015). As the UNESCO World Heritage website (2015) states, this landscape, with its villages, cultural and natural treasures, is of extraordinary universal value.

4.1. Water Quantity

The low water depth of Lake Neusiedl is a primary risk factor due to its catchment area being located in a semi-arid climate region. As a shallow endorheic lake, its ecological status is highly affected by changes in water level. The average annual mean temperature (10.1°C) and a sunshine duration of 1900 hours per year show that there is a substantial evaporation potential, aggravated by relatively windy conditions and low air humidity compared to average Central European conditions (EU Lakes, 2013c).

Since Lake Neusiedl is an endorheic lake, without any major outflows, except for the Einser-Kanal, it is save to assume that more than 90% of total annual water loss is attributed to evaporation. In dry years, when the use of the Einser-Kanal is redundant, however, total water loss attributed to evaporation might approach the 100%. The rate of annual evaporation usually exceeds total precipitation by about 10%. As the main feeder except for precipitation, the River Wulka compensates for this net loss by a total water inflow share of approximately 20%. Other inflows stem from groundwater sources and waste water treatment plants and are considered negligible. Considering these factors, it becomes evident that a climate shift towards higher temperatures would aggravate evaporation and alter the water budget of Lake Neusiedl in a way that total annual water inflow cannot compensate for total annual water losses any longer, leading to a drop of the total water volume und, thus, of water depth. Let alone the change of temperature (+0.7°C) in the period 1991-2004 compared to 1961-1990 induced a rise in evaporation of 9.6% (EU Lakes, 2013d). To what extent the water level might drop or rise at various climate scenarios will be elaborated in the course of this thesis. The direct impacts of falling water levels include reed belt drying, the growth of trees at the landside, acceleration of reed growth at the lakeside and shrinking of the open water surface, a threat to biodiversity, especially bird and fish populations, and a drop in water quality. Fishery suffers from lower water levels as the reed belt is drying up, since this area is an important habitat for spawning and young fish. Freshly growing reed on the lakeside could possibly compensate for lost habitats to the landside of the lake. The local gastronomy depends highly on the prospering of fishery. On the contrary, a lower water level is beneficial to fish-eating wading birds, as many of the young fish crowd the reed belt, since they cannot reach the open water zone and are forced to swim near the surface because of reduced oxygen concentrations. Eventually, however, a series of dry years as in the last century reduces fish, which in turn brings about a decline of wading bird populations (EU Lakes, 2013d).

Another major regional drawback of a possible long-lasting water level decline concerns tourism, which will also be discussed in the chapters to come. Indirect effects of a decreased water level through the comprise the impacts of the resulting increased water temperature which have negative repercussions for the self-purification capacity of the lake and foster cyanobacterial blooms, longer growing periods, increased productivity, higher nutrient concentrations, depleting oxygen concentrations, reduced ice cover (thinner ice cover or a reduced duration of ice cover in winter would not only cause accidents of skaters but also affect reed harvesting) and growth of pathogenic germs. Freshwater ecosystems, above all ecosystems, will have the highest proportion of species threatened by the impacts of climate change.

4.1.1. Economic Damages Resulting From Lower Water Levels

Between 2000 and 2003 the low water level of Lake Neusiedl caused both quantifiable and non-quantifiable (or difficult to quantify) economic damages. According to Kutics (2004, cited in EU Lakes, 2013f) the economic impacts of low water level and the lack of outflow from the lake are the following. It is to be noted that these estimations were based on Lake Balaton. However, due to both lakes' similarity in terms of ecological factors (shallow, endorheic, reed belt, chemical composition etc.), climate and popularity, comparisons of economic damages are feasible. The impact on tourism is treated in detail in another chapter.

- Commercial shipping: 1.0 to 2.0 million Euro/year
- Commercial fishing: 0.5 to 0.7 million Euro/year
- Dredging of harbors and bathing areas: 1.3- 1.6 million Euro/year
- Clean-up of Cladophora biomass from shallow waters: 0.1 to 0.2 million Euro/year Reduction of entrance fee revenues of beaches: 0.5 million Euro/year
- Halt of shipping in Einser-Kanal: not available

- Ecological damages: not available

The total quantifiable damages amounted to 3.4 to 5.0 million Euro/year.

Potential damages that are difficult to quantify are (Kutics, 2004, cited in EU Lakes, 2013f):

- Decrease of the number of tourists (guest nights)
- Yacht owners chose harbors at other lakes or the Adriatic due to the low level
- Overall decrease of tourism related incomes (total such income is estimated at 1,300 million Euro/year)
- Value reduction of homes and second houses due to the loss of popularity of the lake region (total value of the houses is estimated at 8.6 billion Euro)

4.2. Water Quality

4.2.1. Nutrients' Impact on Water Quality

The low water depth poses a threat to the lake's ecological status due to its significance regarding eutrophication. Eutrophication is the excessive fertilization of a water body leading to the abundant growth of aquatic plants such as algae or macrophytes. The surge of nutrients in a water body can occur naturally in the normal evolution of a lake, however, the process is accelerated by human activities (Whitehead, 1982). Decreased water levels cause the water to warm up faster, which in turn, intensifies eutrophication and causes nutrient levels to rise. Higher water temperatures have complex and unpredictable effects on biocoenoses and hence nutrient cycles in the lake leading to depleting oxygen concentrations in the water. Higher water temperatures enable a longer growing season and subsequently higher primary production. Furthermore, biodegradation of organic matter is enhanced and in turn can further diminish oxygen levels which has severe impact on the self-purification capacity of the lake, as elaborated in the next paragraph. The decreased oxygen solubility can bring about problems for fish and other organisms. Higher water temperatures further facilitate survival of pathogens in water. Reed plants can endure anoxic conditions but the phytotoxic substances produced under these circumstances are detrimental for reed plant growth (EU Lakes, 2013e).

Self-purification processes in lakes and reservoirs are controlled by the hydraulic behavior of the water mass and by a number of other vital factors. According to Whitehead (1982) these factors include the following:

- dissolved oxygen supply
- pH
- water column stability and stratification
- residence time in the littoral region
- particulate suspension
- dissolved solids, including organic matter
- temperature profiles
- atmospheric loadings
- nutrient and productivity controls
- depth and concentration gradients
- aquatic ecocommunity

Future climate change scenarios involving an increase in atmospheric temperatures coupled with a continuing inadequate global mitigation effort will influence all of above-mentioned factors at Lake Neusiedl. The main sources of nitrogen and phosphorus inducing eutrophication, according to Whitehead (1982) are:

1. Community wastewater (excreta and detergents)
2. Drainage from agricultural land, forests and wasteland
3. Input from animal excrement
4. Erosion products
5. Precipitation; wet and dry
6. Storm water drains
7. Internal recycling within the waterbody.

Nutrients reach a lake mainly by drainage from its catchment and direct rainfall. Focusing on the two nutrients important for eutrophication, nitrogen (N) and phosphorus (P), it is essential to differentiate natural sources from eutrophication that is induced by human activity beyond natural levels, also known as cultural eutrophication. Natural sources of nitrogen and phosphorus stem from background nutrient cycles and biogeochemical processes, with a major input attributed to nutrients in the soil and the atmosphere. Nitrogen and phosphorous deposition via rainfall involves natural particulate matter such as pollen, dust, and soil particles as well as chemical products from economic activities. Hereby, sources might be located far away from the receiving watershed. Since most human activities rather emit nitrogen products into long-range atmospheric circulation patterns, atmospheric deposition of nitrogen is usually higher than that of phosphorous. Another source of gaseous oxides of nitrogen is the combustion of fossil fuels in industrial and energy production and in transportation (UNEP, 2015).

The United Nations Environmental Program (2015) lists power plants, sewage treatment plants and industrial plants as point sources of cultural eutrophication, while agriculture and sewage are listed as non-point sources. Of the point sources, power plants (emitting nitrogen products into the atmosphere, which are carried down by rainfall and other processes) and waste water treatment plants (treatment process releases oxides of N and P in effluents, which drain into water bodies) are of concern to Lake Neusiedl as insufficient regional and global pollution mitigation measures might cause a rise in atmospheric deposition. Coupled with a decreasing water volume of the lake and the continuous discharge of treated wastewater by 19 surrounding communities, concentrations are likely to rise. In 2010 the amount of wastewater discharged into Lake Neusiedl exceeded 22.106 m^3 (EU Lakes, 2013c). The EU Lakes (2013c) project further pointed out the still ongoing increase in nitrogen concentrations related to agriculture within the lake catchment to pose a significant threat for the lake's ecological status.

The consequences of eutrophication can be distinguished as chemical and biological. Briefly, the chemical consequences of eutrophication (Whitehead, 1982) are:

- PH shifts to alkaline as CO2 is utilized
- A change in oxygen resources due to excessive production in the trophogenic layer and complete utilization in the tropholytic layer resulting in deoxygenation
- Reducing conditions which support
  - incomplete mineralization of organic substances
  - reduction of nitrate to nitrite and ammonia
  - conversion of sulphates to hydrogen sulphite
  - emission of iron and manganese from the sediments to the free water
  - formation of iron sulphide
  - emission of phosphate from the sediment to the free water

These reducing conditions are also referred to as 'internal loading' and are an important factor in the continued eutrophication of water bodies following reduction in the external sources of nutrients (Whitehead, 1982).

Obvious are biological effects of eutrophication, which include the excessive growth of algae and aquatic plants. The impacts of eutrophication on zooplankton generally manifest themselves in a rise in the numbers of herbivorous species as a result of the richer and more varied food supply. The size of the algae is of vital importance because small algae have a positive impact on the development of small herbivorous members of the zooplankton. Solely larger grazers are capable of feeding on the large algae. Eutrophication also has an impact on the fish fauna. Higher nutrient input induces algae growth and increased Zooplankton supply. Since these are an important food source for small fish, eutrophication generally results in an increase in fish production. However, reductions in the oxygen concentration at night can cause fish mortalities in extreme cases (Whitehead, 1982).

Water quality has improved significantly by wastewater treatment and by diminishing the input of agricultural area nutrients into the lake by various management measures. This has been verified by the reduced nitrogen and phosphorous concentrations in the lake. However, a correlation between the low water levels along with higher water temperatures in the early 2000s and rising total phosphorous concentrations has been proven. These scenarios are likely to recur more frequently in the future and therefore the inner dynamics of the lake and reed belt will be of vital significance. Water quality of Lake Neusiedl is dependent on input of nutrients via the atmosphere and tributaries. Wastewater treatment plants around the lake are state of the art, however, the capacity of the basins can be exceeded in case of floods. Diffuse input of nutrients from agricultural areas may also cause problems after heavy rainfall if detention basins are unable to hold water back sufficiently. If lake resilience under climate change conditions is to be attained, the load of nutrients entering the lake must be held as low as possible (EU Lakes, 2013d).

4.2.2. Water Temperature's Impact on Water Quality

Lake water quality is strongly dependent on lake water temperature. The following correlations exist between water temperature and concurrent measured water quality parameters (EU Lakes, 2013d; calculated exemplarily for the year 2011): Ptot=+0.26, O_2 r=-0.86, Chl-a r=+0.22 (all significant at $p<0.05$); Ntot r=+0.12 (not significant at $p<0.05$). Obviously, higher water temperatures, lower oxygen saturation in water (r=-0.22 with Ptot) and lower lakewater levels accelerate the resuspension of phosphorous from sediments. According to climate change predictions these conditions will inevitably become more probable in the course of the 21st century. A pronounced risk of high algal biomass in extremely hot and dry years exists. The high inorganic turbidity has a negative influence on phytoplankton development in Lake Neusiedl. During the bathing season (June-August) the proportion of cyanobacteria has exceeded 0.9 $mm^3\ l^{-1}$ corresponding to a total biovolume of less than 30%. Consequently, the danger of mass development of cyanobacteria is negligible. For winter photyplankton it was revealed that the proportion of cyanobacteria has increased after the year 2000 to a maximum of 80%. Hence, the contribution of cyanobacteria, being less than 5% in the 1980s and early 1990s, reached a mean share of 46% between the winters 1997/1998 and 2006/2007. Moreover, total winter phytoplankton fresh biomass also significantly increased from 0.1 mg l-1 in the late 1960s to about 2 mg l-1 between 2000 and 2005. Due to their dependence on such a great variety of variables, it is not possible to reliably predict the effects of climate change on algal communities. A surge in the proportion of cyanobacteria was found occasionally after hot temperature periods. This effect, however, cannot be generalized (EU Lakes, 2013d).

Increasing water temperatures have complex and unpredictable impacts on biocoenoses and, in turn, nutrient cycles in the lake. In general, oxygen concentrations in the water are decreasing, primary production is accelerated and a longer growing season is initiated. Biodegradation of organic matter is intensified and subsequently further diminishes oxygen supply, inhibiting the lake’s self-purification capacity. If hot periods in summer occur more often, periods of anoxic conditions especially in the reed belt will be extended. Reduced oxygen solubility further leads to problems for fish and other oxygen-dependent organisms. Furthermore, increased water temperatures favor the survival of pathogens in water (EU Lakes, 2013d).

4.2.3. Agriculture and Soil Erosion

The significant drop in diffuse inputs of phosphorus and inorganic soluble nitrogen is an indicator for the reduction of erosion and surface run-off in the catchment area. This can be attributed to variation in land use type, vegetative cover, precipitation and land management practice. With the introduction of the soil protection tax in 1986 fertilizer use dropped rapidly (Figure 5). Various land management measures protecting soil and diminishing inputs are promoted by programs such as ÖPUL, an Austrian program that supports agriculture to reach environmental compatibility, reduces input intensity and protects natural habitats. In the province Burgenland nearly 39,000 ha were managed under this program in the year 2008, corresponding to 573 farms of which 140 were organic farms. Within the catchment area, organic farming and integrated production has experienced an increase since the 1990s. The area of vineyards, which is especially sensitive to erosion, has been reduced after a peak in the 1980s and 1990s in the catchment area (Figure 6) (EU Lakes, 2013f).

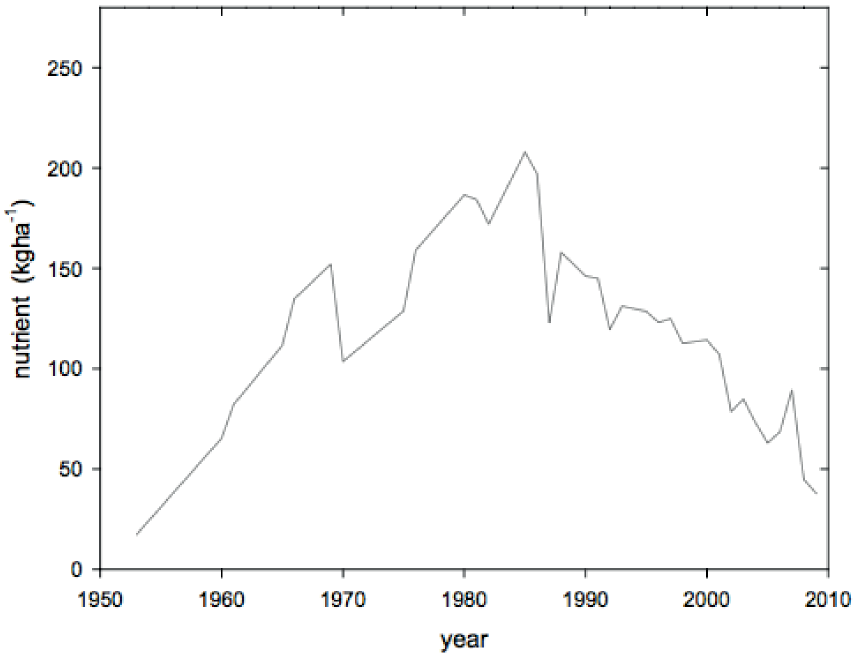

Figure 5: Fertilizer use (NPK on a nutrient basis) in the Austrian province of Burgenland after 1950 (EU Lakes, 2013f)

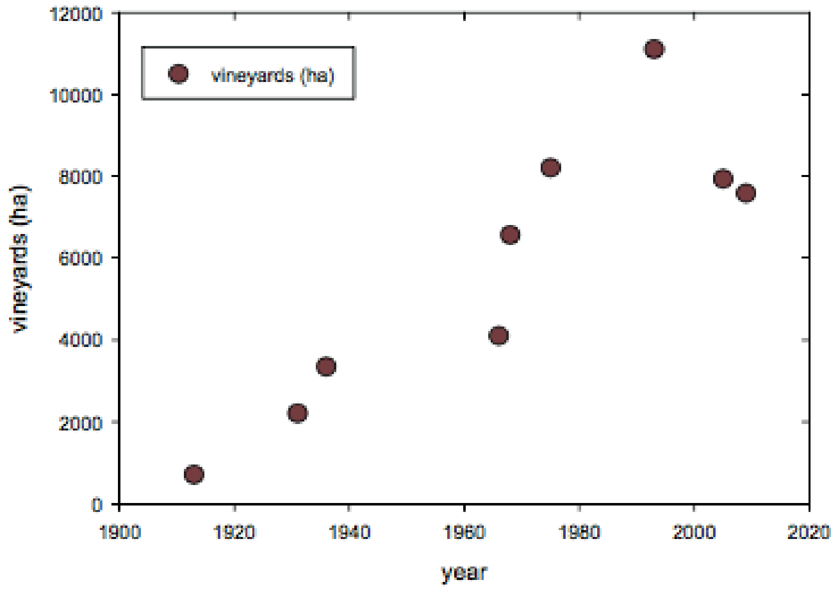

Figure 6: Development of area cultivated for vine production (in ha) in the district Neusiedl/See (EU Lakes, 2013g)

The Lake Neusiedl region is seriously threatened by drought when increased temperatures and low precipitation coincide. Agriculture around Lake Neusiedl is partly dependent on irrigation due to the soils' low water-holding capacity. Many farmers have obtained insurance against such losses. Under the climate change conditions this situations are likely to worsen, when the number of dry days in summer will rise and the duration of dry periods will increase by 40-50% as compared to the period 1971-2000 (as according to IPCC scenario A1B). Measures to fight aggravating problems of drought periods in agriculture include an increase in water-use efficiency and water availability, and a reduction of water demand. Nevertheless, erosion hazard can increase considering more heavy precipitation events. The accumulation of sediments in the lake basin is one of the main threats to the ecological status of Lake Neusiedl. This is why it is imperative to maintain and/or expand the vegetated shore area as a buffer zone as well as filter strips between water bodies and agricultural land. Further steps to fight erosion problems could be the stabilization of soil structure covering soil during the whole year, contour farming (plowing/planting across a slope following its elevation contour lines), terracing of slopes, reduced tillage, conservation tillage (at least 30% of crop residue remain on the soil surface during the critical soil erosion period in order to slow water movement) and avoidance of overgrazing (EU Lakes, 2013d).

Studies have shown an increase in mean precipitation per wet day even in areas, which are becoming drier (IPCC, 2007, cited in EU Lakes 2013f). This development implies a higher risk of soil erosion and nutrient input. Extreme events are significant for the non point inputs of nutrients into the lake, which can be highlighted via data of the flood year 1996, when the discharge of river Wulka was twice the amount of an average year of the period 1992 to 2005, but the phosphorus freights quintupled and the nitrogen freights tripled. Overflowing sewage treatment plants influenced these high nutrient inputs as well (EU Lakes 2013f).

Milder winters will have more precipitation in the form of rain rather than snow, which is why winter run-off will be earlier and higher. Therefore, a shift in winter precipitation from non-erosive snow to erosive rainfall due to higher winter temperatures is to be expected. More extreme rainfall events and higher net precipitation are likely to induce increased nutrient loading, especially with phosphorus, due to increased leaching from the soil. As a result of increased soil erosion a rise in sediment generation is likely (Dokulil et al., 2010, cited in EU Lakes 2013f).

4.2.4. Impacts of Eutrophication on Aquatic Biocenosis

During the early phase of eutrophication, algal biomass increased steadily along with zooplankton biomass. Between 1968 and 1973 a highly positive relationship between phytoplankton and zooplankton could be observed (bottom-up control). Since the biomass of planktivorous fish was not very high (about 5 kg ha-1 on average) the resulting predation pressure on zooplankton was low. Ten years later, however, an improved food supply for planktivorous fish led to a surge in fish biomass and, in turn, to a significant decrease in zooplankton biomass. The consistent increase in biomass of planktivorous fish continuously intensified predation pressure on zooplankton (top-down control). Studies revealed that during summer time (May-August) 8-27% of zooplankton supply is eliminated per day on average. These elimination rates are attributed almost entirely to planktivorous fish (Herzig 1994, cited in Herzig 2014). In the years 1975-1987 the relationship between phytoplankton and zooplankton biomass show merely a weak correlation. During this time top-down control seems to overlay with the bottom-up control, which becomes even more evident during the years 1988-1998. Through their induced predation pressure planktivorous fish reduced zooplankton to such an extent that eventually the grazing of herbivorous plankton could not affect algae development negatively any longer (Carpenter et al. 1985, cited in Herzig 2014). This trend continued from 2005 to 2012. Since food supply for zooplankton has not changed significantly during all these years, the small current zooplankton biomass is likely to be attributed to predation by planktivorous fish and invertebrates (Herzig, 2014).

Thus, we can conclude that the short-term effect of eutrophication on the aquatic biocenosis is an increased algal biomass, that accelerates the expansion of zooplankton biomass. As zooplankton supply surges, planktivorous fish are offered an increased food supply resulting in an increase of fish biomass in the long-term

4.3. The Reed Belt

A steady increase of reed area since the 18th century until 1979, especially in the first half of the 20th century, can be observed. The comparison of data from 1979 with the most recent investigations of 2008 reveals that the earlier long-lasting increase in reed belt area halted, stabilizing the Austrian section of the reed belt at $103km^2$. Considering only the reed belt as such, the area has decreased from 1979 (99 km2) to 2008 (89 km^2). These reductions are mainly attributed to the marked surge of open water areas within the reed belt (brownwater) from 2.4 km^2 to 12.5 km^2 in the same timeframe. However, compared to the dieback in other European countries the decrease in the reed area at Lake Neusiedl is considered very slight. So far, only hypotheses exist as to why the reed belt area has not continued to expand after 1979 and why the area of brownwater has increased (EU Lakes, 2013d; Wolfram et al., 2013).

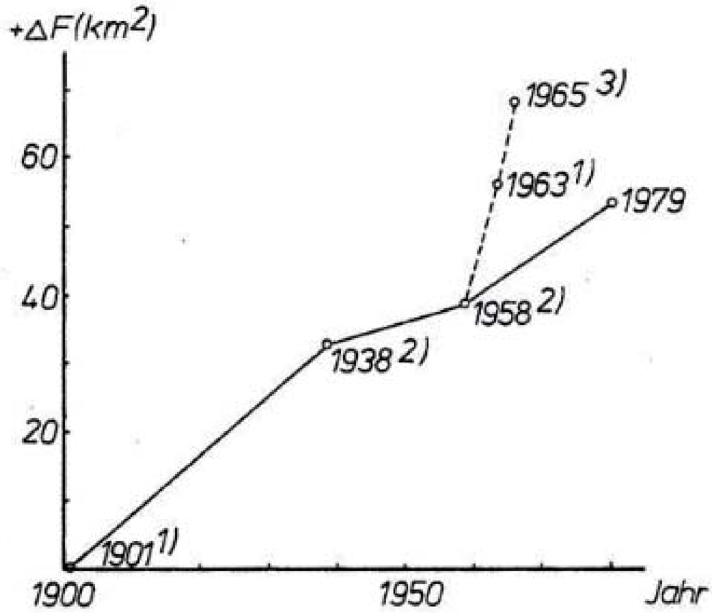

Figure 7: Increase in area of the Austrian part of the reed belt at Lake Neusiedl from 1901-1979 after Csaplovics 1982, Kopf 1967, Riedmüller 1965 and Weisser 1970 (EU Lakes, 2013g)

In general, water levels of 80 cm are considered optimal for reed growth. However, also levels of up to 1.70 m should not inhibit growth at the lakeside. After the regulation of the water level in 1965 the reed belt area stabilized, due to of higher mean water levels throughout the year (+40 cm compared to mean water levels before regulation). This explanation is valid mainly for reed growth at the lakeside and to a lesser extent for that inside the reed belt (EU Lakes, 2013f).

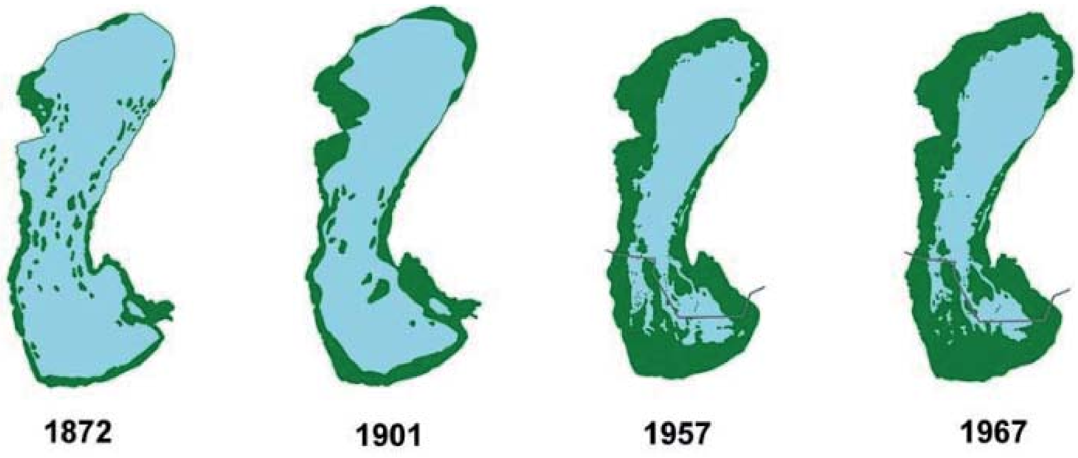

*Figure 8: Development of the reed belt (*EU Lakes, 2013g)

Floods can disrupt reed structures so that they may never recur at all or to an extent that recovery can take multiple years. Therefore, an increase in the occurrence of extreme weather events is of major concern to Lake Neusiedl. Eutrophication results in a reduced mechanical stability of the reed stalks and a lesser reed quality for construction purposes due to lower storage pools in the rhizomes (Lang 2008, cited in EU Lakes, 2013f). This, in turn, leads to a drop in reed demand for export and in a subsequent abolition of reed harvest and concomitant ageing of the remaining reed belt (EU Lakes, 2013d). Sedimentation of inorganic and organic particles lowers the water level in the reed belt. Since the regulation of the lake, the accumulation of mud in the reed belt has increased because before the regulation these substances were washed to the surrounding meadows (EU Lakes, 2013f). Silted areas can be a cause of reed belt die-back and result in accelerated reed mace growth (Lang 2008, cited in EU Lakes, 2013f).

Together with the harvesting of reed and the negative influence of higher mean water levels after the regulation by sluices in the 1960s, hot summers can also be a cause of brownwater. Anoxic conditions occurring when water temperatures are high and organic substances are decomposing triggers the production of phytotoxic substances, which can negatively influence the reed belt as they are inhibitory to the growth of or poisonous to plants. Low water levels and lake desiccation (drying up of the lake) obviously leads to the deterioration of the pure reed belts. Moreover, harvesting machines, which damage the rhizomes can cause great and long-lasting damages to the reed belt (Figure 9). Conversely, increased aging of the reed belt due to the abandonment of reed use can induce deterioration as well (EU Lakes, 2013d). The optimal temperature for the growth of reed plants is 30-35°C (FAO, 2015). Consequently, high temperatures alone are not detrimental for reed plants, although big differences between biotypes are observable (Haslam, 1975, cited in EU Lakes, 2013f).

Figure 9: Damages caused by reed harvesting (Wolfram et al., 2013)

5. Strategies

The goal of preventive measures to combat climate change (mitigation, climate protection) is to reduce in advance the positive shift in the global radiation balance in order to diminish the potential effects of global warming. Adjustment (adaptation) to climate change includes measures to help tolerate the already incurred or expected effects of global warming. Not always is a sharp distinction between adaptation and preventive measures possible, some measures act at both levels. The following suggestions and measures to prevent negative effects of climate change on Lake Neusiedl and its surroundings have been elaborated by the Austrian Institute of Technology within the framework of the EU Lakes (2013g) program supplemented by Wolfram et al. (2013), the former laying out 67 measures for 22 different potential impacts on Lake Neusiedl and the latter 179 targets and measures regarding lake management. The most important and suggestions are summarized and listed here. It is to be noted that at a certain increase of temperatures any preventive measures can merely postpone or at best milden the negative impacts on Lake Neusiedl, even more so if concomitant with a decrease in precipitation.

5.1. Increase of Temperature and Decrease of Precipitation

5.1.1. Impact: Lower water level

- **Water retention by optimizing sluice management**

  Until 1964, no special provisions existed regarding sluice management of the Einser-Kanal. Since then the water level has been managed according to an Austro-Hungarian agreement, which led to a decrease in the magnitude of water fluctuations (from 1.6m to 0.9m) and an increase in the average water level by about 40cm. In 2011, more flexible sluice arrangements have been agreed upon improving, among others, precautionary actions for dry years and a low flow rate in spring to induce a relaxation of the water situation in the region and reduced pumping costs. The new sluice management, however, will not be able to prevent extreme water levels or the desiccation of the lake bed in times of supra-regional, long lasting droughts.

- **Reduction of sediment input into the lake through the reduction of erosion**

  See chapter 4.2.3. Agriculture and Soil Erosion

- **Increasing the volume of the lake by sediment removal**

  The removal of sediments benefits boating, fishing and swimming and, thus, has a positive impact on tourism. Another objective of this measure is the reduction of the internal re-dissolution of nutrients (particularly phosphorus) from the sediment and the reduction of effects of toxic substances. Additionally, disturbing aquatic plants are either removed or their growth inhibited. The problems that can arise from this measure, such as sediment suspension, the release of nutrients and toxic substances, the impact on benthic organisms and mollusks, are usually of short duration compared to the expected long-term positive effects (Peterson, 1981, cited in EU Lakes, 2013g).

  Various methods of sediment removal are possible, such as mechanical dredging or hydraulic dredging. As an environmentally friendly technology, the vacuuming-method allows for the extraction of the sediment without stirring it up. For this method, however, large volumes have to be moved (the removed sediment contains up to 90% water) and the method is relatively expensive. Other problems are arising from the transportation and the disposal of the wet sediment.

- **Endowment with water from other catchment areas**

  See chapter 5.3. Endowment with water from other catchment areas

- **Promotion of touristic activities that do not depend on the lake**

5.1.2. Impact: Degradation of water quality through higher temperatures

- **Reduction of external inputs through the creation of vegetated filter strips and buffer zones between the water bodies (lakes and streams) and agricultural land to reduce nutrients and pollution from agriculture**
- **Reducing the internal input of nutrients from the sediment through lake restoration**

  Lake sediments store an enormous amount of phosphate that inhibits the reduction in P-concentrations, even in case of a decline in the external phosphate load. Furthermore, higher water temperatures and lower water levels can promote the release of phosphate from the sediment into the water. Lake restoration measures include physical (sediment removal), chemical (oxidation of hypolimnion, adding nitrate or aluminum) and biological (removal of non-predatory fish, stocking of predatory fish, transplantation) methods.

5.1.3. Impact: Problems for fisheries though more frequent heat periods and temporary drying up of the reed belt

- **Guaranteeing the connection of the reed belt with the open water area also at low water levels by the reactivation of old channels into the reed belt**

  For fish, this connection is important. However, it can cause problems for the water quality of the lake in hot summers, when an exchange between the hypoxic water with high concentrations of phosphorus from the reeds and the open lake takes place.

- **Conservation of fish stocks by restocking measures**
- **Development of management plans for sustainable fisheries through the monitoring of fish species and quantities, alien and/or invasive species, the health status and quality of fish (pollutants, parasites)**

  In 2006 the BAW-IGF Scharfling has conducted a study whose results have not yet been published. In addition, publishing statistics on the catches by professional fisherman would be important.

5.1.4. Impact: Reed dying under adverse climatic conditions

- **Maintaining a heterogeneous age structure of the reed belt through improved and coordinated reed management**

In certain areas landside of the reed belt, reed must be replaced by meadows and pastures. Moreover, the preservation of stocks with high variability of age structure is necessary to ensure a favorable ecological diversity of habitats within the reed belt.

- **Reducing outdated stocks by increasing reed harvest**

Traditionally these as natural building material used by some regional firms for roofing, mats, insulation materials, etc. scattered . Most products are exported to Germany and the Netherlands. The trend towards environmentally friendly building materials could promote the sale in Austria. Apart from reeds could be used as renewable energy sources. Currently about 10-15% of the reed belt is professionally harvested (Mücke et al., 2010, cited in EU Lakes, 2013g).

5.1.5. Impact: Low water volume of inflows

The river Wulka is the most important tributary of Lake Neusiedl. In the long-term average about 20 % of the water input of Lake Neusiedl derives from surface inflow, 80 % of which come from the Wulka. Many of the small tributaries of the Wulka are at risk of intermittent drying out (Figure 10).

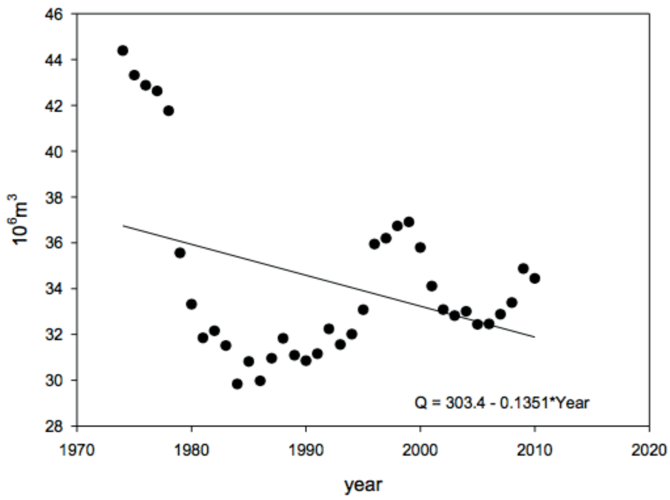

Figure 10: Annual outflow of Wulka in Schützen (Q in 10^6 m^3) smoothed by a 14 year filter (Q:R2= 0.138; p = 0.0236) (EU Lakes 2013g)

Due to large fluctuations during the year, the runoff of the Wulka shows no unambiguous trend for the period 1961 to 2008. However, after an assessment of the overall results, a decreasing trend of the water volume could be identified. Research shows the strong dependence of the Wulka on total annual precipitation.

- **Maintaining the groundwater input into the tributaries by adjusting land use and land management as well as restricting the use of groundwater for irrigation purposes during dry periods or at low groundwater levels**

  Water saving measures include rainwater collection, adjusting sowing dates on temperature and precipitation patterns, water reuse, improving the efficiency of irrigation, adapting irrigation plans and the modernization of irrigation infrastructure.

- **Measures against the loads in rivers with low water flow by increasing the efficiency of sewage systems**

5.1.6. Impact: Groundwater depletion

With only 2% of total inflows groundwater is of minor importance for the water balance of the lake. However, groundwater has great importance for the region around the lake, especially for rivers, irrigation purposes and private wells, as east of the lake soil is rather sandy with a very low water holding capacity. Because 40-100% of newly formed groundwater in the Seewinkel is removed through channels and pumping stations, the groundwater level may fall so low in dry periods that irrigation measures must be ceased. In Figure 11, the decreasing trend of groundwater since the second half of last century is shown. Predicted climate change scenarios (higher mean temperatures and increased evapotranspiration) indicate a severe negative impact on groundwater levels. An increase in heavy rain events will result in lower infiltration rates, regardless of the development of the total precipitation figures. Reduced groundwater regeneration and lower groundwater levels could result in water-use conflicts between agriculture and the drinking water supply in Burgenland.

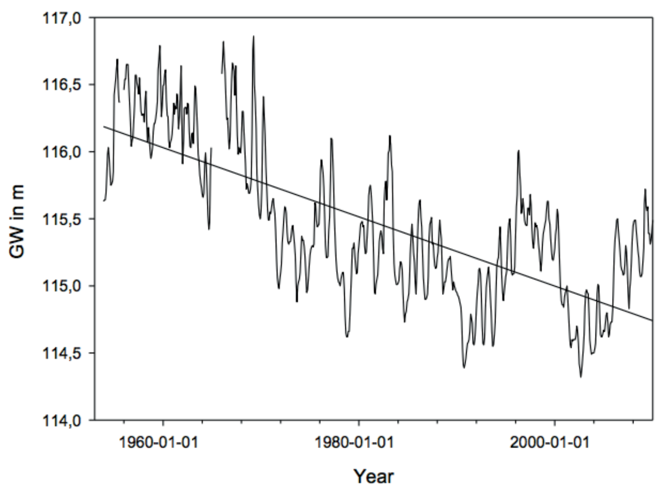

Figure 11: Monthly average of groundwater for Wallern (in m a.s.l.) 1953-2009 (EU Lakes, 2013g)

- **Groundwater recharge by reducing soil sealing**
- **Increase the capacity of water retention basins**
- **Measures to prevent the accumulation of pollutants in groundwater at low recharge rates by reducing the use of fertilizers and pesticides**

5.1.7. Impact: Higher risk of invasive alien species through climate change

For Austria an assessment of the effects of continuous warming in terms of nonnative animal species (Nebiota) exists (Kromp-Kolb and Gerersdorfer, 2003, cited in EU Lakes, 2013g):

- Non-native species will occur
- Rare non-native species will occur more frequently
- New non-native species will arrive in Austria and spread

Most of alien animal species arriving in Austria will come from warmer neighboring countries.

- **Raise public awareness of invasive species by increasing informative campaigns**

  The communication of the problem needs to reach policy-makers, administrative authorities and the general public.

- **Observe international, national and local migration developments**

  It is advisable to form a cooperative network on an international level in order to better coordinate actions and priorities. It would be particularly important to improve the transfer of national data and information on neighboring countries (Internet data bases). Continuous monitoring and updating of the data to spread non-native species in Austria would be required, as well as the installation of an early warning and control system for problematic species.

- **Preventing the spread of invasive alien species**

  According to the UN Convention on Biological Diversity (1992) this requires an analysis of the shortcomings in terms of preventive measures, such as import regulations, border controls or phytosanitary measures. Furthermore, measures to avoid inadvertent importation of plants, animals and reproductive goods are advisable. An action plan for alien species, which are classified as problematic, need to be established and as well as early containment, control and eradication of problematic alien species guaranteed.

5.2. Increase In Extreme Weather Events (Higher Risk of Increased Precipitation Quantities And Storms)

5.2.1. Impact: High lake water levels due to increased rainfall and storms

As climate change will possibly be accompanied by a shift in rainfall patterns to increased spring precipitation and more intense rain events, not only increased drought but also flooding should be expected. Figure 12 shows a flood event for the catchment area of Lake Neusiedl that occurs about every 30 years. Significant flood risk exists for the Wulka (45.6 km without any protection from a 30-year event) and for Lake Neusiedl in Illmitz, Podersdorf, Neusiedl, Mörbisch, Rust and Weiden (all together about 6 km without any protection from a 30-year event) (BMLFUW, 2011, cited in EU Lakes, 2013g).

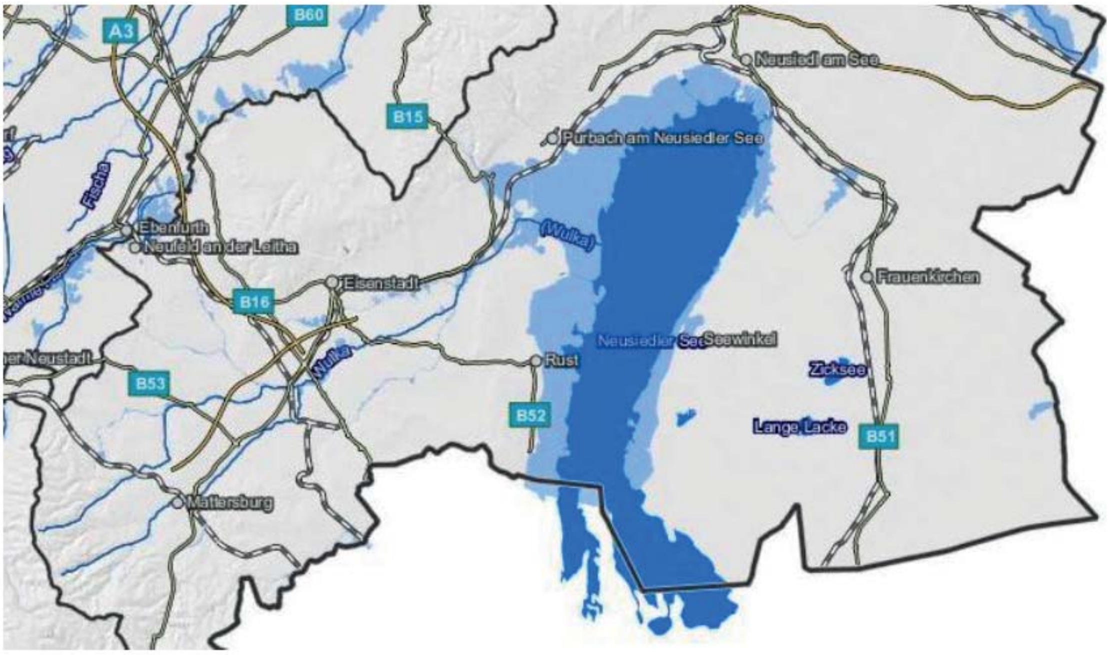

Figure 12: Areas endangered by 30-year flood events (EU Lakes 2013g)

- **Drainage by sluice control and increasing the capacity of drainage channels**

  The maximum capacity of the sluices in the Einser-Kanal is 15 m^3s^{-1}, which corresponds to a total of 1.3 million m^3 per day. This means that the floodgates need to be opened during flooding for 25 days in order to reduce the water level by 10 cm. Due to the very low tendency of the channel critical water levels occur at flow rates of about $5m^3s^{-1}$, resulting in a backlog in the tributaries on both sides. Then, the barriers at the junctions have to be closed and water has to be pumped out.

- **Water retention by increasing the storage capacity or new construction of flood or storm water retention basin**

  Retention basins are used to prevent flooding and erosion through storm-water drains and to guarantee water quality in the adjacent river or lake. Distinguishable are storage tanks that store water temporarily after a storm, but eventually drain it into downstream water bodies with regulated speed, as well as infiltration basins, which direct rainwater through permeable soils into the groundwater. Although many basins in northern Burgenland already exist to reduce the risk of flooding (Figure 13), these measures are not sufficient. According to EU Lakes (2013g) for the protection from 100-year floods (>116.0 m a.s.l.) the following investments in technical measures within the catchment area would be required (data from 2009):

- Lake Neusiedl: € 4.8 million (Gols, Parndorfer Bach, Purbach, Donnerskirchen)
- Wulka and other tributaries: € 47.3 million

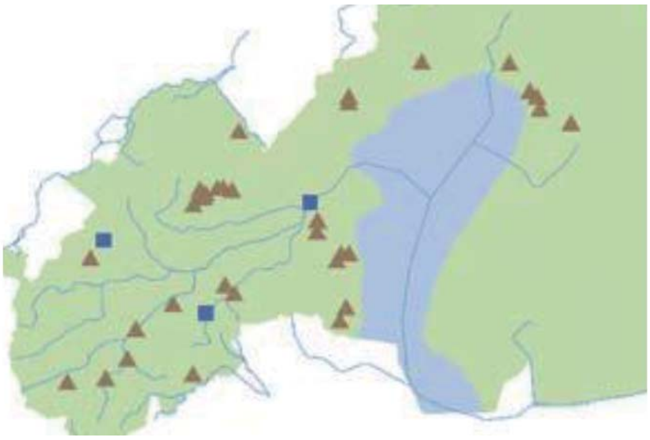

Figure 13: Retention basins in the catchment area (brown triangles: capacity<100,000 m^3, blue squares: capacity 100,000-500,000 m^3 (EU Lakes 2013g)

- **Increasing the lake volume by sediment removal and reed management**
- **Protection of population and settlements through flood forecasting and warning systems**

5.2.2. Impact: Higher risk of damage to the bank of the lake by climate change

- **Improving the bank's structural stability through spatial and land use planning (no reclassifications and construction activities in sensitive areas)**

  The existing reed belt protects the bank against wave impacts during heavy rain or wind. Therefore, no (or merely strictly limited) reclassifications or construction activities are allowed in these highly sensitive territories. The areas of salt marshes south of Podersdorf are also part of the national park. These territories must be preserved and maintained accordingly.

- **Improving the bank's structural stability through conservation and protection measures**

  Bank protection facilities often have negative effects on the ecological status of the bank sections. Thus. They should only be installed, when they are necessary to prevent erosion problems. Shallow water areas near the shore represent habitats for a wide variety of organisms and are essential for the life cycles of many fish and wildlife species. Hard obstructions, such as vertical walls or stone fortifications, have significant effects on fisheries, wildlife and the entire water quality of the lake. Under the current climate conditions no additional measures in this regard are required, nor will they be required under estimated 2100 climate scenarios, since the shoreline of Lake Neusiedl is well protected by the reeds and baths, moorings and ports are already protected by sufficient structural measures.

5.2.3. Impact: Changed interactions of agriculture and marine environment due to higher risk of extreme events and storms

Figure 14 shows the risk of erosion by water in the catchment area of Lake Neusiedl. Nearly half of the territory is arable land, which makes the risk of erosion west of the lake considerable, unless precautions are taken.

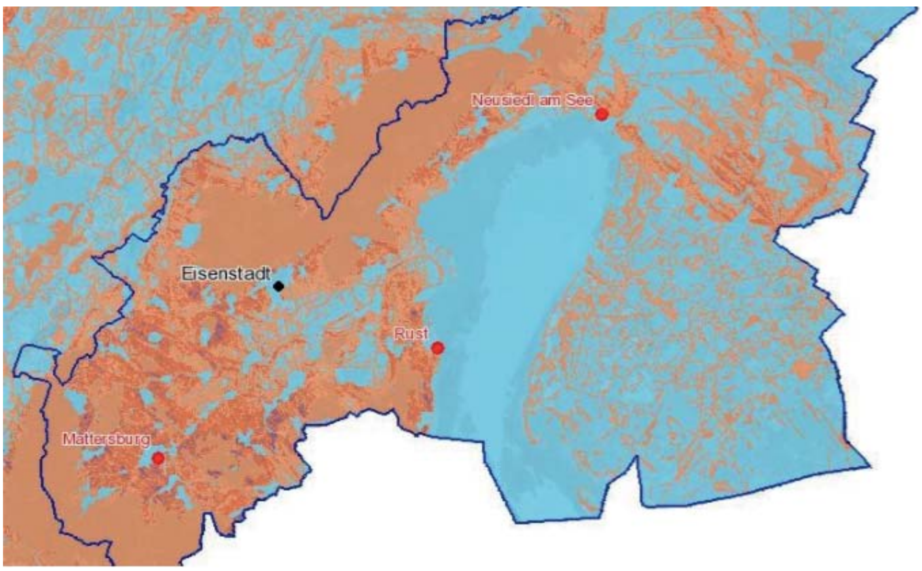

Figure 14: Risk of erosion in northern Burgenland (violet: very high, purple: high, orange: medium, light orange: low, blue: no erosion) (EU Lakes, 2013g)

- **Maintaining or expanding the vegetated littoral zones as buffer and filter strips between water bodies and farmlands**

  According to this measure, an area along a body of water is used as grassland or bush strip, or is exempt from agricultural use, without fertilization and protective measures for plants and without any terrain change. This measure is very effective as nutrient and sediment inputs are reduced by up to 90%. Even drainage ditches should be considered. Unfortunately, this measure has not been well received by farmers because of the conditions of participation.

- **Reduction of erosion by year-round soil cover**

  Mulching in vineyards and orchards, green manure, soil covering or intercropping have numerous environmental benefits, such as reduction of nitrate in groundwater, protection from water and wind erosion, various positive effects on soil health, increased proportion of organic matter etc.

- **Reduction of erosion by stabilizing the soil structure**

  The floor structure may be improved by

  - Increasing the proportion of organic matter in the soil, for example, by incorporation of pastures in crop rotations, by intercropping, organic soil improvements, etc.
  - Reduction in the use of heavy machinery in soil preparation and cultivation in order to avoid soil compaction and aggregate destruction
  - Avoiding soil disturbance during periods of severe drought or moisture when soil may be prone to cracks or capping
  - Ensuring sufficient land cover to protect the soil from irrigation-water impact
  - Admixture of gypsum in order to exchange the sodium ions with calcium and thereby reduce sodium enrichment

- **Reduction of erosion through contour farming and terracing of slopes**
- **Reduction of erosion by preventing overgrazing**

  Overgrazing occurs when plants are exposed to intensive grazing pressure over a longer period, or without adequate recovery periods. This can be caused by inadequate agricultural management, or by excessive wild animal population. Overgrazing reduces the usefulness, productivity and biodiversity of a region and is a major cause of desertification and erosion. Overgrazing is also seen as a cause for the spread of invasive species of non-native plants and seeds.

- **Reduction of erosion through reduced tillage and conservation tillage methods**

5.3. Endowment with Water from other Catchment Areas

The endowment of the lake with external water can pose a general threat to water quality (Leth, 2004, Wolfram et al., 2013). Very little is known about potential influences of loads that directly advect from the catchment area, for example, originating from agriculture, traffic areas, boats or ships (oil, antifouling) (Wolfram et al., 2013). According to Leth et al. (2004) the following points should be considered in order not to endanger the flora and fauna of Lake Neusiedl through endowment: a steady flow of extraneous water into the lake should be avoided in any case, since this would destroy the ecological balance of the steppe lake. This is why only an incremental endowment is imaginable. Furthermore, it is important to minimize changes in the concentrations of important constituents. These considerations lead to two potential possibilities for endowment.

- The cheaper option is infiltration through the Raab-Rabnitz system. Due to the small amounts of water carried by the river, endowment would be only possible in the winter months. Hence the necessity of building a storage basin. Due to the lack of biological and chemical water data no conclusion on the qualitative impact of this variant on the ecosystem can be made.
- The second option is a partial diversion of the River Danube. The slightly higher costs are compensated by the possibility of a yearly endowment. Moreover, also the values of concentrations of key constituents after endowment are less than the maximum of the last years (Leth, 2004).

Since our knowledge about micro pollutants in the lake is very low (Zessner et al., 2012, cited in Wolfram et al, 2013), it is necessary to establish a monitoring system that covers aspects of potential accumulation (both in the water and the sediment) and takes into account the specific toxicity of pollutants. The toxicity of organic pollutants should be examined in terms of a potential water endowment of the lake.

From the perspective of nature conservation, plans involving the artificial upkeep of permanent high water levels as well as the endowment with artificial groundwater and/or surface water from adjacent rivers are strictly rejected, as they would limit even further the already restricted dynamics in the water balance and therefore have an adverse impact on biodiversity. However, the reason why such plans are permanently considered is strictly economical as low water levels might be devastating for tourism. The boating and sailing community is highly approving of plans to pump water from the

Danube-bank filtrate near Hainburg from the shore area to be transported via a pipeline into the Parndorfer Bach, which flows into Lake Neusiedl (orf.at, 2006).

In order to understand and evaluate the options of an endowment with extraneous water can the following criteria must be considered in all scenarios (Wolfram et al., 2013):

- Current regulation on the operation of outflows (Mekszikópuszta facility) according to the "*Wehrbetriebsordnung*"
- New data on volume-water level ratio ("*Seeinhaltslinie*"), available from the GENESE-project in 2014
- Boundary water level values, at which endowment should be initiated; in consultation with other stakeholders and depending on the seasonally changing needs
- Availability of water from other catchments
- Expected amount of inflowing and outflowing water

It must also be borne in mind that introduced external water can be used not only for the lake, but also for the Seewinkel area, generating financial synergies in a multi-functional project. This could alleviate the problems for the agricultural sector in dry summers, but at the same time creates new nature-conservation related issues. According to Wolfram et al. (2013), the effects of a future endowment will be assessed as follows:

Short- and long-term positive effects can be expected for recreational activities such as bathing and water sports, for shipping (prevention of water levels below 115.1 m a.s.l.) and fishing.

A higher water level improves the water exchange between the open lake and the reeds and can result in the accelerated growth of reed. At high water levels the reed belt can fulfill its function as a nutrient sink as well as a habitat for aquatic communities much better. A larger water volume results in a reduced volume-specific load of treated wastewater into the lake.

Short-term negative effects are possible due to local improvements of light penetration in the lake, which could promote local eutrophication incidents. This could also have local effects on water quality. Pollutant inputs from other catchments cannot be excluded, even if the effects on the chemical status of the lake are unclear.

Long-term negative effects are to be expected as a result of chemical changes. They can interfere with the mineralization processes of organic matter and, thus, contribute to increased sedimentation rates in the reed belt and ultimately to accelerated siltation of the lake. In this case, indirect negative effects would be expected on the water exchange and water quality. Changes in the chemical composition can have a direct impact on aquatic organisms and, hence, bring about a change of biotic communities, which are specially adapted to the physico-chemical particularities of the lake. In extreme cases, this could lead to a deterioration of the ecological status. This could also occur as a result of the abovementioned accelerated silting up of the reed belt. Not least, birdlife is affected by reduced hydrological dynamics and a potentially accelerated silting-up of the reed belt (Wolfram et al., 2013). A detailed description of the result of the endowment at different water levels is provided by Wolfram et al. (2004).

6. Impact of Low Water Levels on Tourism

After the Second World War the Lake Neusiedl region had no possibility to distinguish itself as a cohesive tourist destination as a result of the 40 year long separation by the Iron Curtain. In the late 1990s, however, the region experienced a significant upward trend. In the Austrian part of the region 1.25 million overnight stays were registered in 1996, compared to 1.39 million in 2010 (Memmer, 2012). Especially the national park is of great touristic importance. Based on existing statistics a magnitude of one million overnight stays in the national park region can be assumed (on the Austrian side, including camping), while the bed capacity amounts to 10,000. Since the experience of nature is best in the springtime and autumn, the national park increases the bed occupancy rate of accommodation facilities. Occupancy rates in Illmitz, for example, are significantly higher (>25%) than in the heavily advertised "*event*"-locations Podersdorf or Mörbisch. With the National Park Information Centre open year-round and the special events that are held there additional target groups can be brought into the region (Wolfram et al., 2013).

Tourism is an important economic factor in the region around Lake Neusiedl. In the future, however, many touristic activities may be constrained by low lake water levels, specifically regarding summer tourism (beach tourism) and water sports (sailing, surfing, etc.). Schönerklee et al. (2007, cited in BIO intelligence service, 2012) identifies four characteristic water levels for Lake Neusiedl:

- 115.50 m a.s.l.: average lake water level during the time period 1965-2005
- 115.20 m a.s.l.: feasible starting level of artificially supplying water to the lake

- 115.00 m a.s.l.: level which is slightly below the minimum lake water level of the driest year 2003 (115.06 m a.s.l.)
- 114.70 m a.s.l.: extreme event

Extremely shallow water is generally expected in the littoral zones and especially in bathing areas. Swimming will be possible only in greater distance to the shore. Water levels below 115.0 m a.s.l. are most likely to occur in the bathing areas of the northern lakeshores (Neusiedl, Weiden, Breitenbrunn). A minimum water level of 1.2-1.3m is required for sailing with respect to the currently used boats at the lake (taking into account local wind conditions, waves and mud transportation). In water depths below 1 m sailing is merely possible for a small number of boat types. The current types of passenger ships/ferryboats can easily be operated in water levels of 115.2 m a.s.l.. With water levels at 115.0 m a.s.l. the usual capacity of most ferries need to be reduced. For water levels at 114.5 m no boating at all is possible any longer (EU Lakes, 2013g).

At the Austrian part of Lake Neusiedl there are 14 sailing and windsurfing schools and 22 boat rentals. A large number of sailors are members of associations and yacht clubs. The Landessegelverband Burgenland, as the governing body of yacht clubs in Burgenland, currently comprises 16 clubs and 4 clubs, in which more than 3, 000 sailors are included (LSV Burgenland, 2013). There are no official statistics on the number of sailboats on Lake Neusiedl, as sailing vessels with a length up to 10 m and a power of less than 4,4 kW do not have to be registered. Wolfram et al. (2013) estimated a number of at least 6000 berths in the municipality of ports and harbors of private clubs or operators (Figure 15). To be added are an unknown number of dry berths. Many ports also feature infrastructure for windsurfers.

Segelhäfen und Segelclubs	Anzahl der Liegeplätze (gerundet)
Neusiedl am See	580
Breitenbrunn	750
Illmitz	200
Mörbisch	430
Podersdorf	700
Rust	1 400
Oggau	250
Purbach	100
Jois	200
Weiden	970

Figure 15: Number of berths for sailboats (Wolfram et al., 2013)

In total, there are 7 bathing facilities on the shores of Lake Neusiedl (Mörbisch, Rust, Breitenbrunn, Weiden/See, Neusiedl/See, Podersdorf, Illmitz) and a swimming area in Jois, for which no admission is required. Additional swimming possibilities are provided in St. Andrä (Zicksee) and two bathing lakes in Andau and Apetlon. These are supplemented by outdoor pools in Oggau, Frauenkirchen, Gols, Purbach, Schattendorf, Donnerskirchen and the St. Martins Therme in Frauenkirchen (Wolfram et al., 2013).

According to Schönerklee et al. (2006, cited in Wolfram et al., 2013) the annual number of bathers amount to about 420,000. Wolfram et al.'s (2013) survey came to an estimate of about 600 000 bathers (Figure 16). The number of visitors strongly depends on the weather situation. Interestingly, in the past could an especially large number of bathers could be observed in sunny years with low water. However, bathing is still affected by low water levels, since bathing areas become so shallow that swimming is only possible at a greater distance from the shore. This applies especially to the bathing areas at the northern shore. Furthermore, statistics of St. Andrä show, that low water levels over multiple years cause a significant drop in the number of visitors (about 3,500 guests per seasonal month in 2006, compared to 3,500 people as a whole in the entire season of 2011). Therefore, operators of the baths prefer higher water levels (possibly more than 115.5 m a.s.l.).

Seebäder	Anzahl der Badegäste (gerundet)
Neusiedl am See	~ 65 000
Breitenbrunn	~ 20 000
Illmitz	~ 15 000
Mörbisch	~ 145 000
Weiden	~ 45 500
Podersdorf	~ 235 000
Rust	~ 70 000
St. Andrä	~ 3 500

Figure 16: Number of bathers (Wolfram et al., 2013)

An economic analysis of the lake area clearly indicates that the local gross value added and employment situation is related to the good state of the lake. Low lake water level scenarios would mainly impact tourism (hotel business, restaurants, water sports etc.), retail sales and agriculture (Figure 17). For the 115.0 m a.s.l. scenario, Schönerklee et al. (2007, cited in BIO intelligence service, 2012) estimated a drop of the gross value added of approximately 13 Mio € and a decline in employment of 476 full-time equivalents for the region. This corresponds to a decrease of 0.5% for the total economic situation of the region. The economic impacts are even more evident for the 114.70 m a.s.l. scenario, with a loss of 41 Mio € for the total gross value added of the region and 1,271 full-time equivalents (BIO intelligence service, 2012).

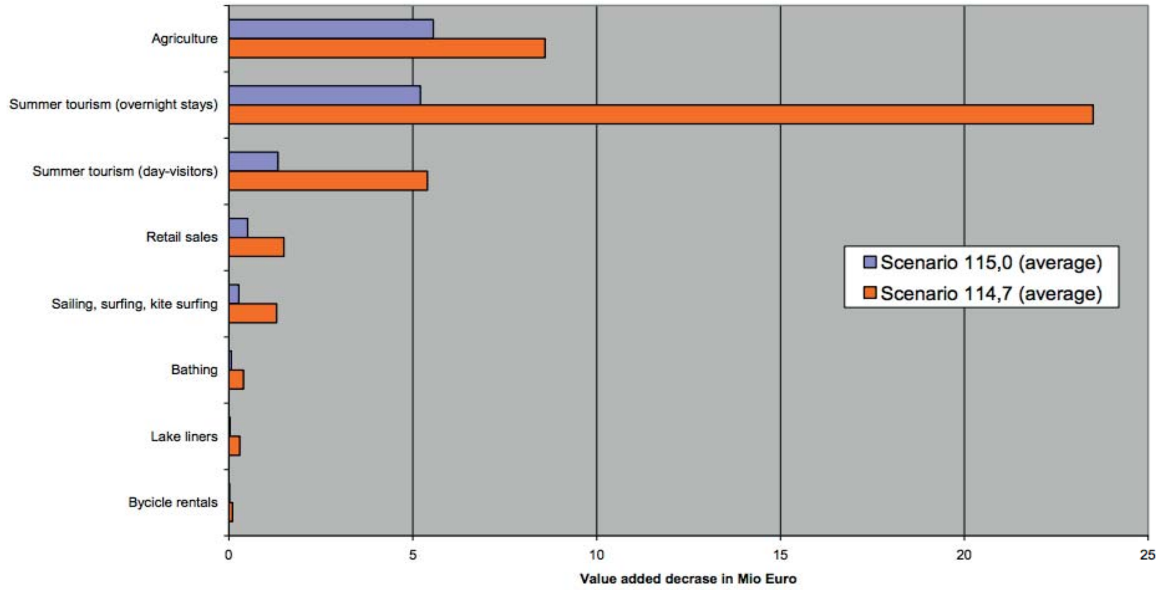

Figure 17: quantifying the economic impacts for both scenarios by sector (BIO intelligence service, 2012)

In contrast to this, a survey conducted in 2006 by the method of "*Discrete Choice Experiments*" (DCE) revealed that tourists are rather insensitive towards the water level (Pröbstl et al., 2007). While weekend guests regarded sports activities and infrastructure (swimming in lakes and swimming pool) primarily as important, especially the landscape attributes of the water level and the offer of the experience of nature, as well as cultural, culinary and wine events and activities represent the most important criteria for tourists. Hereby, the impact of lower water levels is strongly dependent on the landscape type at the lakeshore (reed zone, open shore, gravel beach). Nature enthusiasts showed much stronger reactions to the presented pictures of hypothetical changes of water levels (Figure 18). Adaptation strategies could diversify the offers for tourists, which are less threatened by decreasing water levels, and result in the temporal extension of such offers in spring and autumn. In any way, a package of measures that includes agriculture and water management in addition to tourism would be required (Pröbstl et al., 2007; Schönerklee et al., 2007, cited in APCC, 2014).

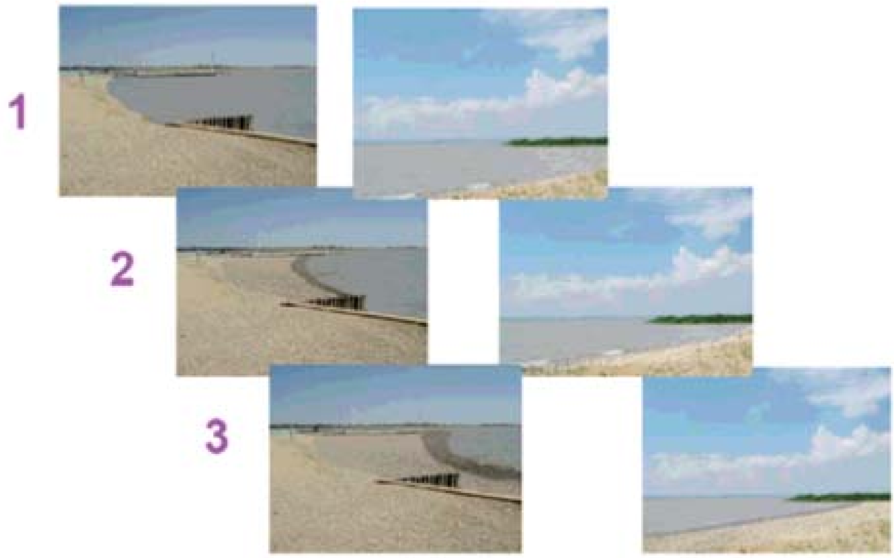

Figure 18: Waterlevel at 115.5 m, 115.2 m, 115.0 m a.s.l. (Pröbstl et al., 2007)

According to the survey conducted by Pröbstl (2007) tourists do not favor sporting activities, of which the "*leading-three*" (biking, hiking, swimming) are the most important. Other water sports such as sailing and surfing are for most only of average importance. More important than sports are recreational activities at the lake, which inevitably depend on nature and the landscape. Both vacationers and weekend guests consider the region as "*relaxing*" and "*natural*". About 43% of the weekend guests and slightly more than half of vacationers feel disturbed by low water levels. This difference in perception may be due to the fact that vacationers visit the region rather in summertime. Questioned on their visual perception of low water levels and associated feelings vacationers and weekenders came to similar results - each two-thirds stated that they have never felt visually impaired by low water levels, 25% said they have barely felt disturbed. Also with regard to their swimming behavior both weekenders and vacationers are similar. According to their statements, 57% go into the lake to swim, 38% go rarely into the lake and only 4% avoid going into the lake. Nevertheless, more than half the guests regard the muddy bottom of the lake as not pleasant, a quarter of respondents is undecided or ambivalent and 20% regard the mud as pleasant. Most notably, about 90% of respondents expressed a strong interest for the nature and landscape of the region by stating they would inform themselves about the place they spend their vacation at. Over two-thirds indicated that knowledge about the holiday region and its landscape influenced ones perception of the landscape (Pröbstl, 2007).

The results of the survey (Pröbstl, 2007) conclude:

- A restricted possibility to swim in the lake is not critical for most tourists, as long as an appealing picture of the lake prevails. Pools or spas could therefore compensate limited bathing possibilities. In contrast, day and weekend guests find the possibility to compensate the bathing in the lake by pools or spas to be limited. Significant losses are also expected in the area of sailing. A limitation of sailing traffic for certain boat classes is not compensable.
- Unlike originally expected, a potential for adaption possibilities is merely given for vacationers due to their high interest in cultural, nature- and wine-related activities. Future expansion or maintenance in these fields is advisable.
- In addition to the lake and the characteristic offerings of the region (culture, nature, wine) the more sport-related activities (horse riding, golf) are of little influence. They address only minor parts of visitors.
- To increase the acceptance of water fluctuations through the provision of more information about the steppe lake is a consideration that has not been confirmed to be effective so far.

Due to the complexity of the problem a number of measures will be necessary in order to successfully position the Lake Neusiedl region as a primary tourism and economic region in the future. EU Lakes (2013g) brought forward the following suggestions:

- **Developing alternatives to beach tourism by extending the tourist season and creating artificial bathing lakes**
- **Developing alternatives to beach tourism through touristic long-term development plans with alternatives to water-related recreation**
- **Developing alternatives to beach tourism in the national park with information points, bird watching, vegetation exploring**
- **Developing alternatives to beach tourism through cultural tourism (music events, architecture, exhibitions)**
- **Developing alternatives to beach tourism through wellness tourism or special sports such as horse riding or golf tourism**

7. Calculating evapotranspiration of Lake Neusiedl

The following calculations of evapotranspiration were done via the Dalton-method, modified according to Kalmar (1982, cited in Eitzinger et al., 2009). "*This modified method considers parameterizations of the classical Dalton-formula specific for Lake Neusiedl according to the long-term records of the hydrological station Fertörákos*" (Eitzinger et al., 2009, cited in Soja et al., 2012). Contrary to the regular Dalton approach, this method has the advantage of considering the transpiration of the reed, which is, as already discussed, always higher as evaporation above the open lake.

7.1. Aerodynamic or Dalton Approach

The Dalton approach applies the following formula:

$$E_W = f(v) \times (e_s(T_{WO}) - e)$$

where:

E_w = evaporation above the water surface in mm/d

f (v) = function of the wind speed

e_s (T_{WO}) = saturation vapor pressure at the water surface temperature in hPa

e = vapor pressure of the air in hPa

The wind function for the daily mean wind speed in m/s, measured at 2 m above the water surface is

$$fv = a + b \times v^c$$

The coefficients a, b and c approved for Lake Neusiedl are 0.13, 0.11 and 1.00 respectively (Neuwirth, 1974, cited in Eitzinger et al., 2009)

7.2. Kalmar Approach

At the hydrological station Fertörakos along with the Institute Vituki in Györ, an empirical formula could be developed based on many years of measurements, following the principle of the Dalton's approach of determining evaporation rates, however, separately considering reed transpiration at the lake (Kalmar approach). The total evaporation of the lake is derived from the sum of the evaporation of the open water surface and the evapotranspiration of the reeds:

$$P_{See} = 0{,}51 \times P_{Wasser} + 0{,}49 \times P_{Schilf}$$

where:

P_{See} = Evapotranspiration of the entire lake area in mm/d

P_{Wasser} = Evapotranspiration of the open lake in mm/d

P_{Schilf} = Evapotranspiration of the reed in mm/d

The evaporation of the open lake P_{Wasser} is determined by:

$$P_{Wasser} = (E_0 - e) \times (0{,}294 + 0{,}056 \times u)$$

where:

$E_0 = e_s(T)$ = saturation vapor pressure of the lake surface temperature in hPa

e = vapor pressure of the air in hPa

u = mean wind speed in m/s

The evaporation of the reed area P_{Schilf} is determined by:

$$P_{Schilf} = k \times P_{Wasser}$$

How the constant k varies between the months of April to October is seen in Table 1:

Table 1: Variations of constant k between the months

Month	Constant k
April	1.02
May	1.11
June	1.20
July	1.26
August	1.21
September	1.13
October	1.11

The estimation of the saturation vapor pressure $e_S(T)$ ($=E_0$) in hPa from the air temperature in °C over water is calculated according to the Magnus formula with coefficients according to Sunday (1994, cited in Eitzinger et al., 2009) for the temperature range -45 ... +60°C:

$$e_s(T) = 6{,}11 \times \exp\left(\frac{17{,}62 \times T}{243{,}12 + T}\right)$$

At negative temperatures, the saturation vapor pressure over ice follows a slightly different formula. However, for reasons of simplicity, this formula will not be taken into consideration. The vapor pressure *e* in hPa is calculated from the relative humidity *U* in %:

$$e = e_s(T) \times \frac{U}{100}$$

7.3. Method

The numbers for the various parameters are taken from Lotteraner (2001), who estimated the maximum wind speed *u* at Lake Neusiedl at 4 kn, which corresponds to approximately 2 m/s. The mean relative humidity *U* at the surrounding area of Lake Neusiedl is about 75-77%. The average temperature *T* at the lake is around 10°C. In order to achieve realistic results the relative humidity *U* was set to 70% and the average temperature *T* to 11°C. Additionally, a mean value of 1.148… for constant *k* was used. Using these numbers with the formulas above, a current evaporation rate of 633 mm/a can be estimated, which corresponds to the results of other studies (Wolfram et al., 2013; Kubu & Kramer, 2014, cited in Herzig 2014).

Subsequently, the value for temperature *T* was increased according to the estimations of the APCC (2014), which predicted an approximate temperature increase of 1.4°C in Austria until 2050 (average scenario). Since these predictions go along with high uncertainties, a best-case scenario (+0.8°C) and a worst-case scenario (2°C) have been included into the calculations. Moreover, for each scenario, the constant *k* was set to the minimum and maximum value - 1.02 and 1.26 - respectively, in order to provide for interval values to further decrease uncertainty.

To summarize the parameters and variables:

u = 2.1 m/s

U = 70%

k = 1.02 – 1.26

T_{best} = 11.8 °C

$T_{average}$ = 12.4°C

T_{worst} = 13°C

7.4. Results

7.4.1. Average Scenario

Using the above-mentioned parameters the average scenario reveals an evaporation rate of 654 - 730 mm/a. That would mean an increase of the evaporation rate by at least 3.3% and 15.3% at the maximum. Consequently, when considering an annual inflow of 754 mm and an outflow of 85 mm/a via the Einser-Kanal (Wolfram et al., 2013), an annual water loss of 61 mm/a at worst could be the result. It needs to be highlighted though, that the annual inflow via the river Wulka is likely to decrease along with a slight drop in overall precipitation, which would result in an even lower water budget, further accelerating a potential desiccation process.

7.4.2. Best-Case Scenario

The increase of the average temperature of 0.8°C would result in an evaporation rate between 629 and 702 mm/a, corresponding to an increase between 0 and 11%. A possible consequence of this scenario could be a negative water budget of -33 mm/a at worst at unchanged inflow and outflow rates. It is to be highlighted that increasing temperatures are unlikely to result in an unchanged evaporation rate. However, at best the water budget may still remain positive in this scenario, if the increase in evaporation will not cause the total water loss per annum to surpass total water gains per annum.

7.4.3. Worst-Case Scenario

This scenario of a 2°C increase of the average temperature brings about an evaporation rate between 680 and 759 mm/a, corresponding to an evaporation increase of 7.4 - 20% at unchanged inflow and outflow rates. The ramifications of this temperature increase could possibly lead to an annual water loss of up to 90 mm at worst, not considering eventual drops in inflow rates.

7.4.4. Interpretation of the Results

A global temperature development other than a mean temperature increase is unlikely, even with increased global mitigation efforts. Thus, a mean temperature increase of a certain magnitude until 2050 is to be expected also in Austria. This magnitude will most probably lie somewhere between the lowest and highest temperature figures used for the calculation of evaporation rates in the three scenarios, namely 0.8°C and 2°C. Since evaporation highly depends on atmospheric and water temperature, an increase of the evaporation rate of Lake Neusiedl is inevitable. Merely, an unlikely event of increased precipitation to compensate for the additional water loss inflicted by the accelerated evaporation rate would be able to keep the water budget from dropping. As a matter of fact, a slight decrease in mean precipitation patterns is to be expected for Austria.

Considering the current water level of 115.5 m a.s.l., a negative water budget of 33 mm/a - 90 mm/a would have huge impacts on the ecological status of the lake and bring about devastating economic ramifications for the region as a whole. From an ecological point of view the impacts of higher mean temperatures are negligible, as nature always adapts to environmental changes. The detriment of one organism can be the benefit of multiple others. Landscapes change and so do the various forms of life dependent on it. The inevitable consequences of such ecological changes, however, negatively affect the region from an economic standpoint, especially, but not limited to, tourism. As most of the tourism industry in the north of Burgenland has evolved from the unique opportunities Lake Neusiedl offers, the region will suffer economically from a drop of the mean water level. While a consecutive negative water budget of 33 mm/a leads to a complete permanent desiccation of the lake within 36 years, a water loss of 61 mm/a would bring about such a condition within less than 20 years already, considering the lake's mean water depth of 1.2 m. The devastating worst-case scenario would cause a temporary drying out of the lake already within 13 years. It is to be highlighted, however, that seasonal desiccation and temporary extreme water levels will occur on a much more frequent basis. Considering the anticipated drop of precipitation during the hot season, as opposed to an increase in winter precipitation, we can expect that in the mid-21st century the water level of Lake Neusiedl in summer will be too low for major touristic activities. Events of complete seasonal desiccation cannot be ruled out, their occurrence depending on the extent of the drop of summer precipitation. At such significant levels of water loss, anthropogenic efforts to prevent desiccation are unsustainable and, to put it bluntly, useless. At lower levels of water loss per annum such efforts will merely postpone the increasing and elongated occurrence of periods of extreme water levels and at best provide the region with more time to adapt its tourism industry to non-lake related activities, as outlined in the strategy section of this thesis. Should the region fail to implement these strategies, the economic ramifications of the lower water levels at Lake Neusiedl will be detrimental, as the subjective damage to the appearance of the lake, a potential change in the region's biodiversity as well as the inability to bathe, boat or surf will result in significantly decreased numbers of visitors.

Of course, the future mean temperature development depends on many factors, including future global climate mitigation efforts. As the past decades have shown, the establishment of effective international agreements to reduce pollution takes a very long time. Furthermore, the rise of emerging markets such as the BRIC states will most likely result in an amount of increased GHG emissions not compensable by the rest of the world. Hence, a continuous surge in GHG emissions is to be expected in the following years. This unfortunate circumstance implies that scenarios such as the worst-case scenario described in this thesis cannot be ruled out. As the progression of global mitigation efforts cannot be relied upon, regional steps must be taken to adapt to or compensate for a potential future economic damage to the region around Lake Neusiedl.

7.5. Comparison with other Studies

The BOKU study (Eitzinger et al., 2009) concluded that 4-6 consecutive "*2003*"-years (extremely dry, drop of precipitation by 40%) would result in the drying up of the lake. This study also attempted the calculation of various potential water scenarios, however, considered significantly higher future temperature increases, namely, an increase until 2030 of 1.9°C and an increase of 2.5°C until 2050. These figures were predicted by the IPCC (2014) and merely represent global average temperature increases which is not representative for Austria, or single countries in general, since there are major regional differences in temperature development. Austria lies in the larger transition area between two regions with opposing trends. While an increase is expected in North Europe, a temperature drop in the Mediterranean is to be expected. As a result, the APCC (2014) concludes an average increase in Austria of 1.4°C depending on future mitigation efforts. Consequently, this thesis focused on the APCC’s figures and worked with a 0.8°C increase in the case of very intense and successful future mitigation efforts as well as a 2°C increase for the opposite.

Nevertheless, the BOKU results reveal important information on the impacts of such temperature increases. 2030 scenarios demonstrate a higher water-level sensitivity because of higher temperatures and, hence, a higher evaporation potential. Already the period between 1991-2004 brought about a rise in temperature of 0,7°C and a decrease of mean annual precipitation of 6% (about 40mm) compared to 1961-90. Evaporation rose by about 10%. Under these circumstances the lake water level drops lower than the critical level of 115,2 m a. s. l. every 12th year, which would entail usage constraints. Until 2030 - assuming unchanged precipitation patterns (= as in the period 1961-90) -

this critical level would occur every 6th year, assuming a precipitation reduction of 5% already every 4th year, respectively. Under current climatic conditions (1991-2004) the drying up of the lake is unlikely. However, the 2030 scenario with normal precipitation reveals an occurrence probability of 166 years. Assuming a drop in precipitation of -5% desiccation statistically will occur every 71st year (Eitzinger 2009, cited in EU Lakes, 2013f).

The following table (Table 2) demonstrates the lake water levels and their probability of occurrence on the basis of climate scenarios according to Eitzinger et al. (2009, in EU Lakes, 2013f).

Table 2: Lake water levels and their probability of occurrence on the basis of climate scenarios

Scenario	Change in temperature and precipitation from normal period (1961-90)	Water level 115.00 m a.s.l.		Water level 114.70 m a.s.l.	
		Probability of occurrence	Mean duration	Probability of occurrence	Mean duration
Current state (period 1991-2004)	T: + 0.7°C P: ± 0 %	71.4 years	78 days	> 500 years	-
Climate scenario 2020 (period 2010-2030)	T: + 1.9°C P: - 5%	6.9 years	213 days	22.7 years	191 days
Climate scenario 2040 (period 2030-2050)	T: + 2.5°C P: - 5%	3.5 years	190 days	12.5 years	196 days

The following figure shows the lake area at water levels of 115.50 m, 115.00 m, and 114.70 m a.s.l. according to Schönerklee (2006, taken from EU Lakes, 2013f). At the current mean level of 115.50 m almost the entire reed belt is flooded, whereas at 114.70 m the reed belt is nearly dried up.

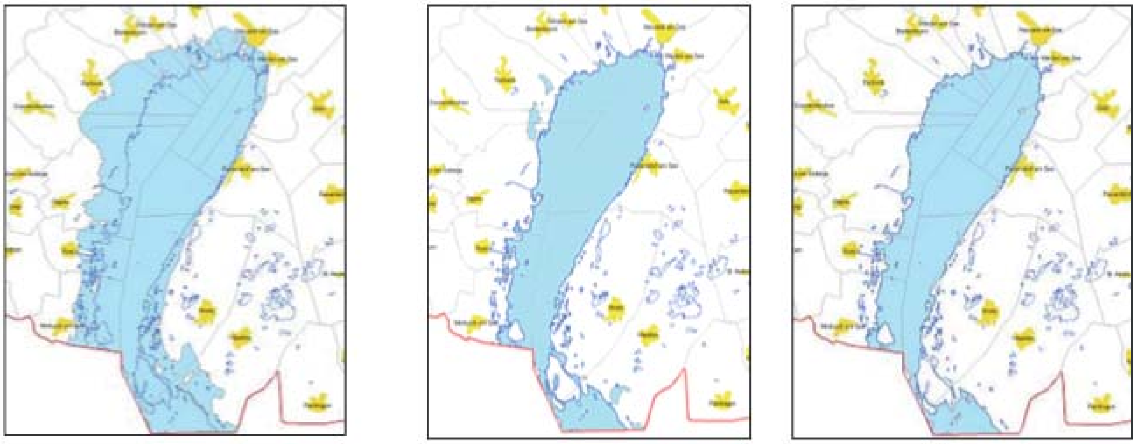

Figure 19: Lake area at three scenarios of water level (from left to right: 115.50 m a.s.l., 115.00 m a.s.l., and 114.70 m a.s.l.) (Schönerklee, 2006, taken from EU Lakes, 2013g)

The next figure water depth categories at the three selected water level scenarios are displayed in the next figure. At water levels of 115.00 and 114.70 m a.s.l. vast parts of the lake are either or 1 m less than 1 m deep. The northern lake basin will be so shallow, that only in a distance of some hundreds of meters water depth is rising. The middle of the lake reaches a maximum depth of 1.3 to 1.5 m (EU Lakes, 2013f).

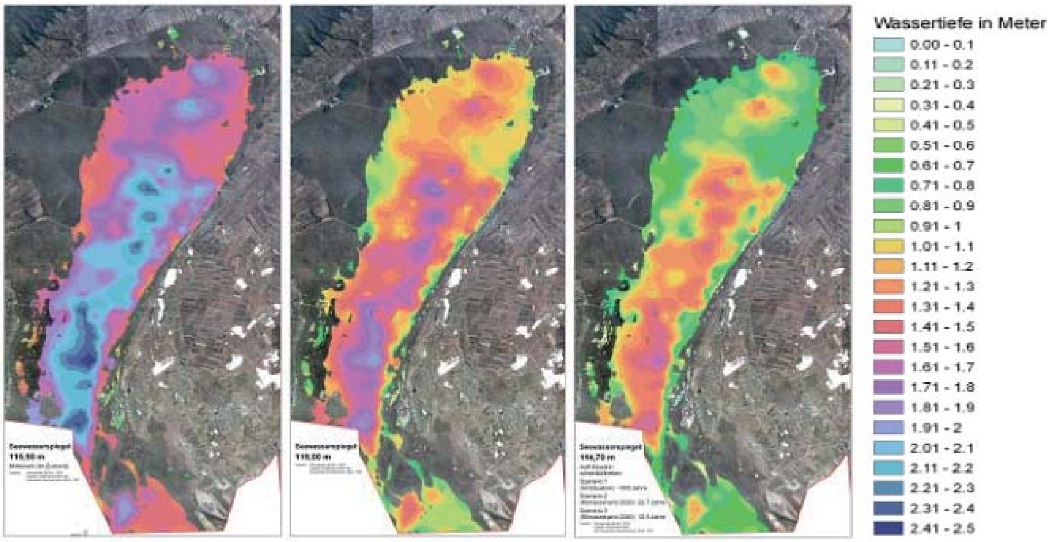

Figure 20: Lake water depth in categories at 115.5 m a.s.l., 115.0 m a.s.l., and 114.7 m a.s.l. for Lake Neusiedl (Schönerklee 2006, taken from EU Lakes 2013g)

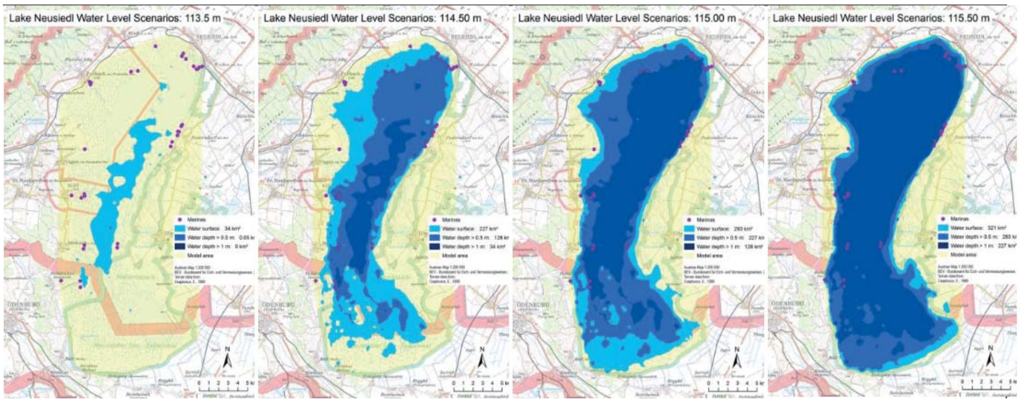

Figure 21: Water surface area and depth of Lake Neusiedl from >0 to 0.5 m (light blue), 0.5 to 1.0 m (mid blue) and >1.0 m (dark blue) at water level scenarios of 113.5, 114.5, 115.0, and 115.5 m a.s.l. (EU Lakes, 2013g)

8. Conclusion

As the mean global temperature is likely to increase in the 21st century, the evaporation rate of Lake Neusiedl will be positively affected. Depending on the extent of the temperature increase in the region this increase in evaporation will most probably result in a negative water budget for the steppe lake. As a major consequence, mean water levels will constantly decrease to a point detrimental to the economic activity of the region. Especially the summer period will be accompanied by extremely low water levels. Most affected by lower water levels will be tourism, which is the pulse of the region’s economy. As water levels drop, the lake region will lose its appeal to tourists and the number of visitors will decrease. Unless appropriate strategies to counter this development or adapt to it are implemented, the region will be faced with a severe economic struggle. For that reason, this thesis elaborated on the various factors affected by increased mean temperatures, provided mitigation strategies and calculated the potential evaporation rate resulting from increased mean temperatures in three different scenarios.

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