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Water supply into Lake Neusiedler See to prevent shrinkage: effects on chemical and physical properties

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German Abstract:

Der Klimawandel führt zu steigenden Temperaturen und Trockenperioden in vielen Regionen der Welt. Dadurch sind sensible Ökosysteme, wie flache Seen, dramatischen Veränderungen ausgesetzt, welche auch signifikante Auswirkungen auf deren Artengemeinschaften haben. In jüngster Vergangenheit hatte auch der Neusiedler See alarmierend niedrige Wasserstände. Wir untersuchten Wasser vom Neusiedler See verdünnt mit Regenwasser. Dazu führten wir ein Verdünnungsexperiment mit Regenwasser durch und analysierten potentielle Veränderungen von chemischen und physikalischen Eigenschaften. Das erste Experiment konzentrierte sich auf Zeiteffekte in Verdünnungsserien. Die Ergebnisse legen nahe, dass Parameter wie Alkalinität, der pH-Wert, Partikelstreuung und Trübe statistisch signifikanten Interaktionseffekten von Zeit x Verdünnung unterliegen. In einem zweiten Experiment untersuchten wir diese Effekte mit wiederholter Eindampfung von Wasserproben, gefolgt von einer Verdünnung mit Regenwasser (um schwankende Wasserstände über mehrere Jahre zu imitieren). Wir fanden keine signifikanten Effekte von Trübe und Streuung, aber Zeit x Verdünnung Interaktionseffekte bei der Leitfähigkeit und dem pH-Wert.

Abstract: Climate change is leading to rising temperatures and drought events in many regions of the world. As a result, sensible ecosystems such as shallow lakes may undergo dramatic changes, resulting in significant impacts on their communities. Lake Neusiedler See faced alarming low water levels in the recent past. We studied water originating from this lake diluted with rainwater. We conducted a dilution experiment with rainwater and studied potential changes of chemical and physical properties. The first experiment focused on time effects in dilution series. The results suggest that parameters such as alkalinity, pH-value, particle scattering and turbidity are subject to a statistically significant interaction effect of time x dilution. A second experiment examined these effects with repeated concentrating of water samples followed by dilution with rainwater (mimicking varying water levels over some years; evaporation experiment). We did not find significant effects on turbidity and scattering, but time x dilution interaction effects on specific conductivity and pH-value.

Keywords: climate change, increasing dryness, extreme weather conditions, dilution, time effects

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1. Introduction

1.1 Specific characteristics of Lake Neusiedler See region

Lake Neusiedler See is the largest steppe lake in Europe, and with covering more than 300km² also the largest lake of Austria. It is located near the far eastern reaches of the Alps at the border to Hungary; a small part belongs to Hungary. The western shore is bounded by the Wulka basin and the Ödenburger, Rosalien and Leitha mountains. Towards the north, the lake is contiguous to the Parndorfer Hills, in the south and east by the Seewinkel, Hanság and Ikvavalleys and the lake basin of the Little Hungarian Plain (Herzig, 2014; Magyar et al., 2021; Wolfram et al., 2019). The lake was formed by a tectonic valley about 13.000 years ago (Herzig, 2014). Some features make Lake Neusiedler See a very special habitat. Besides a reed belt covering around 50% of the lake area, no summer stratification is developed due to the low depth and the windy area (Herzig, 2014; Sailer & Maracek, 2019). The water temperature correlates with the air temperature with only a small time lag and shows little variability due to the low storage capacity of the lake. The average ice cover was 56 days in the past, but due to climate change, winters exist without ice cover (Herzig, 2014). Due to wind and low water depth, the clay sediments at the bottom of the open lake are constantly resuspended resulting in high turbidity (Herzig, 20114).

The lake area is part of the larger Lake Neusiedler See habitat. The nearby Hanság is a very special natural habitat; it is a fen on a gravelly bottom, often called a floating lawn. At increased water levels, the Hanság is still connected to the lake, at low levels, it is somehow separated (Krizsanits & Machtinger, 2023). Most of the Hanság area was drained to create an agricultural land that is a steppe or steppe lake nowadays. This process took several steps to complete. First, some canals were dug to cultivate the land. Then, in the second half of the 19th century, the Einser Canal was built. Its main purpose was to prevent surrounding areas from floodings. In summary, before the anthropogenic interventions took place, Hanság was a moor characterized by its high humidity. In contrast, the north of Lake Neusiedler See is now known for its salt meadows and aridity (Krizsanits & Machtinger, 2023).

The area around Lake Neusiedler See is part of the Natura 2000 network of protected areas. Some parts are integral nature reserves. There is a strict biological reserve of 5500 ha and a nature reserve of 4000 ha. The United Nations Educational,

Scientific and Cultural Organisation (UNESCO) has declared the landscape around Lake Neusiedler See a world cultural heritage site (Sailer & Maracek, 2019). This highlights the priority of preserving the lake and preventing it from drying up.

Furthermore, if Lake Neusiedler See were to shrink dramatically, a very special and important habitat for animals and plants would disappear.

In summary, Lake Neusiedler See is a crucial and unique habitat that has been utilized for economic, recreational, and cultural purposes throughout history. Although the specific methods and goals for protection have evolved over time, there is an urgent need for the preservation and maintenance of this area (Krizsanits & Machtinger, 2023). Fishing and hunting were valuable sources of food. In general, local knowledge was an important skill because of the danger of getting lost in the dense reeds. Typical fish of this region were catfish, carp, pike and zander (Krizsanits & Machtinger, 2023). An important point of reference for fishermen was the water level. At the end of the 19th century, the level dramatically declined. Consequently, lots of fish died, and people collected them to feed their animals, such as pigs. Nowadays, the fish population is endangered due to increasing water temperatures combined with low water levels. Today, not only scientists but also laymen notice the dead bodies of fish on the surface (Krizsanits & Machtinger, 2023). Compared to fishing as a source of income, hunting was a leisure activity for the aristocracy. Today there are stricter regulations regarding hunting, because of the implementation of the national park, which is prohibited in the nature reserve. Lastly, hunting also depends on the water level of Lake Neusiedler See (Krizsanits & Machtinger, 2023).

Another important resource of Lake Neusiedler See is reed. Until the 19th century, only small areas were covered by reed. Nowadays, it extends for miles between the land and the lake. In the past, this plant was a fundamental source of income for people living in the area around Lake Neusiedler See. Reed was used as a construction material, for insulation, and for animals. Especially during winter, when other sources of income were scarce, it provided an opportunity to earn money. However, it required a lot of manual work. The best season for cutting the reed was in winter, making working conditions difficult due to the weather. The young plants were used as litter in stables for animals. Additionally, reed served as a food for animals when hay was scarce. In winter, it was used as a covering for houses and as insulation for walls and ceilings. But reed can only be harvested in winter when the

ground is frozen, otherwise the harvesters would sink in the mud. And with climate change, such periods are becoming increasingly rare. The significance of reed has changed in modern times (Kriszanits & Machtinger, 2023). Its importance as a source of income has declined, while economic factors have become more important. Today, questions regarding the conservation of the countryside and the maintenance of the characteristic landscape are at the forefront. Reed plays a crucial role as a filter and buffer for Lake Neusiedler See. Scientists have been researching solutions for utilizing reed for about 20 years. For example, biological insulation boards have been developed, and reed has been used as a fuel in heating stations. Currently, reed is being considered as a regional resource for biogas production (Kriszanits & Machtinger, 2023). Another potential resource in the region is the mud found on the lake's ground. While in other regions it is often used for medical purposes, a profitable use of the mud from Lake Neusiedler See has not been fully realized, despite its significant quantity of about 55 million cubic meters (Kriszanits & Machtinger, 2023).

In general, steppe lakes are subject to large fluctuations in water level. However, the main factors influencing the hydrological balance of a lake are precipitation and evaporation. Therefore, potential climate changes will also affect Lake Neusiedler See. For example, a decrease of five percent in precipitation will lead to a critically low water level (Sailer & Maracek, 2019).

Hydrological balance: inflow

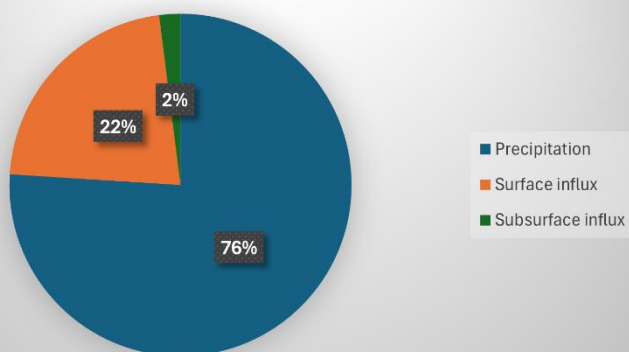


Figure 1. Mean values of inflows contributing to the hydrological balance of Lake Neusiedler See from 1965 to 2018. Original source: Herzig, 2014; Sailer & Maracek, 2019

Hydrological balance: outflow

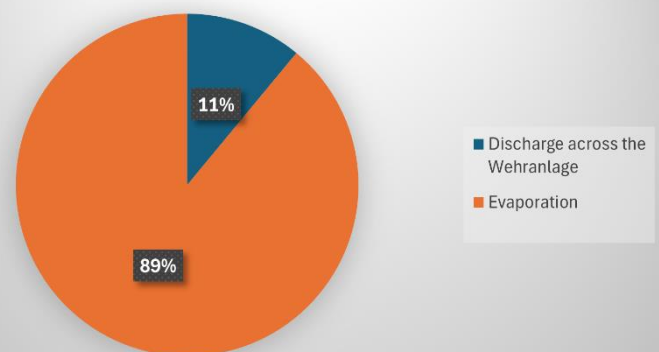


Figure 2. Mean values of outflows contributing to the hydrological balance of Lake Neusiedler See from 1965 to 2018. Original source: Herzig, 2014; Sailer & Maracek, 2019

When measuring the hydrological balance of a lake, at least five factors must be taken into account. On the one hand, rainfall and surface- and groundwater-inflow have a positive effect on the hydrological balance, and on the other hand, evaporation and leakage have a negative effect. Rainfall is the most important component of the lake's water supply, accounting for 76-78% of the hydrological balance (Eitzinger et al., 2009; Herzig, 2014). The rest comes from inflows (Fig. 1). The largest surface inflow is the Wulka river, which has its source in the Rosalien Mountains. Groundwater inflows mainly originate from the Seewinkel, Hungary, Wulka valley and Leitha mountains regions and account for less than 2% of the hydrological balance (Eitzinger et al., 2009). Otherwise, evaporation is the largest negative factor, accounting for 89-90% of the water loss (Eitzinger et al., 2009; Herzig, 2014). In addition, there is a potential outflow over the construction Wehranlage (Fig. 2), but this construction is closed since years due to the permanently low water level. In a hot year, evaporation dominates, and water levels are low. In a rainy year, the opposite is the case (Sailer & Maracek, 2019). Current data on the water cycle, such as precipitation, air temperature and evaporation, around Lake Neusiedler See can be found on the website of the Wasserportal Burgenland (Sailer & Maracek, 2019).

1.2 Current set of problems and previous studies

Given the increasingly low water level of Lake Neusiedler See, a possible solution could be to discharge an external water source, for example from the Danube or Raab river into the lake (Sailer & Maracek, 2019). Supplying Lake Neusiedler See with water from the Raab river is only possible in winter, as its water is taken for agriculture during the growing season. Lake Neusiedler See has an elevated salinity due to its semi-arid climate, hydrological peculiarities, connection to groundwater and tertiary marine sediments. Today, the lake has a salinity of 1-2 g/l⁻¹ (Herzig, 2014). Therefore, the chemical properties of Lake Neusiedler See differ from those of other Austrian lakes. The salinity is mainly composed of the cations sodium and magnesium and the anions sulfate, chloride and hydrocarbonate (Herzig, 2014; Wolfram et al., 2021). For this reason, Lake Neusiedler See is often referred to as a soda lake (Herzig, 2014). Taking into account discharge, precipitation and diversions,

salinity can be reduced, especially when discharges are as large as diversions. If low salinity water is discharged into the lake, each diversion will reduce the salinity and change the chemistry of the water (Sailer & Maracek, 2019).

Another, more gentle solution is to discharge Danube water. This could also be done during August or September when the lake water level is low. However, the water level of the Danube river can also be critically low during this period. A critically low water level of the Danube is a consequence of the lack of precipitation. As a result, the river has been temporarily closed for shipping in some years (Stadt Wien, 2018). In addition, a study predicts that during the summer months, from June to August, higher temperatures will lead to more evaporation and less precipitation. This in turn, leads to a reduction in mean runoff, especially in mountain regions such as the Alps (Stagl & Hattermann, 2015). Moreover, the Danube is located at a comparable altitude compared to Lake Neusiedler See, so it would not be possible to discharge without pumps. Therefore, the cost of construction and maintenance needs to be considered. Nevertheless, mixing water from Lake Neusiedler See with water from the Danube would not significantly affect the nutrient content (Sailer & Maracek, 2019). However, changes in sediments are very likely due to the high magnesium and calcium content of the Danube (Sailer & Maracek, 2019). Moreover, a human caused discharge is always an intervention in a natural ecosystem. In summary, discharging only makes sense when the hydrological balance of the lake is negative and to prevent it from drying up. In this case, the public interest in maintaining the lake outweighs the anthropogenic intervention in the ecosystem. If the hydrological balance remains positive, the discharge should be neglected or stopped for conservation reasons (Sailer & Maracek, 2019).

In the past decades, the border between Austria and Hungary divided the Lake Neusiedler See region into two different parts. During this period, there was no relationship between the two countries and each part of the lake had its own development process. Nowadays, the border is open and there is a gradual adaptation of the development on both sides (Wolfram et al., 2014). Although the region is growing together more and more, the political and economic conditions of the past have an enormous impact on nature. Due to the need for action in order to protect the flora and fauna of the Lake Neusiedler See region a committee of experts from both sides of the lake was established in 2009 (Wolfram et al., 2014). This

committee conducted a comprehensive inventory of limnology, water policy, land use planning, and nature conservation. In addition, recommendations were made for concrete steps concerning the prospective development (Wolfram et al., 2014).

Previous studies have mainly focused on the discharge of water from Lake Neusiedler See with other surface waters or groundwater. For example, Wolfram et al. (2021) discussed the possibility of adding Danube water to Lake Neusiedler See. Parameters such as salinity, pH-value, nutrients or trace elements were taken into account. In other experiments, the mixing of rainwater with water from Lake Neusiedler See was compared to the mixing of Danube water with water from Lake Neusiedler See. Variables such as the pH-value, ion content, alkalinity and specific conductivity of the samples were then compared (Krachler, 2005). Another study examined the pH-value, the ion content, specific conductivity, water temperature, oxygen content, turbidity, visibility depth, salinity and duration of ice cover of water from Lake Neusiedler See (Wolfram et al., 2014). The chemistry of Lake Neusiedler See has been well studied since the 1920s. Since 1960 there has been a regular monitoring of the lake in Austria and Hungary (Wolfram et al., 2014). Since then, data collection has improved in terms of spatial resolution and sampling frequency. Although the chemistry of Lake Neusiedler See is well documented, there are knowledge gaps regarding the impact of wind and waves, as well as the light climate and turbidity (Wolfram et al., 2014). Therefore, this study also focuses on light properties such as turbidity and particle scattering.

Climate change is a very important and current threat to Lake Neusiedler See, as the lake may dry up without anthropogenic interventions. Global warming is accelerating this process. In the coming decades the air temperature will increase and the drought in Eastern Austria will increase (Eitzinger et al., 2009; Wolfram, 2021). It is not possible to predict when Lake Neusiedler See has a critically low water level or in the worst case scenario it is completely dried out due to a few years in a row of low precipitation (Wolfram et al., 2014). But an already low water level is a deficiency for Lake Neusiedler See as a recreation area. Moreover, there will be an economic loss for gastronomy, water sports, fishery and accommodation (Wolfram et al., 2014). An enhanced dryness with two to three years of low precipitation is very problematic (Krachler, 2005). A study suggests that a constant sequence of extremely dry years, such as 2003, with about 60% less precipitation than the average between 1961 and

1990, would largely dry up Lake Neusiedler See within four to six years (Wolfram et al., 2014).

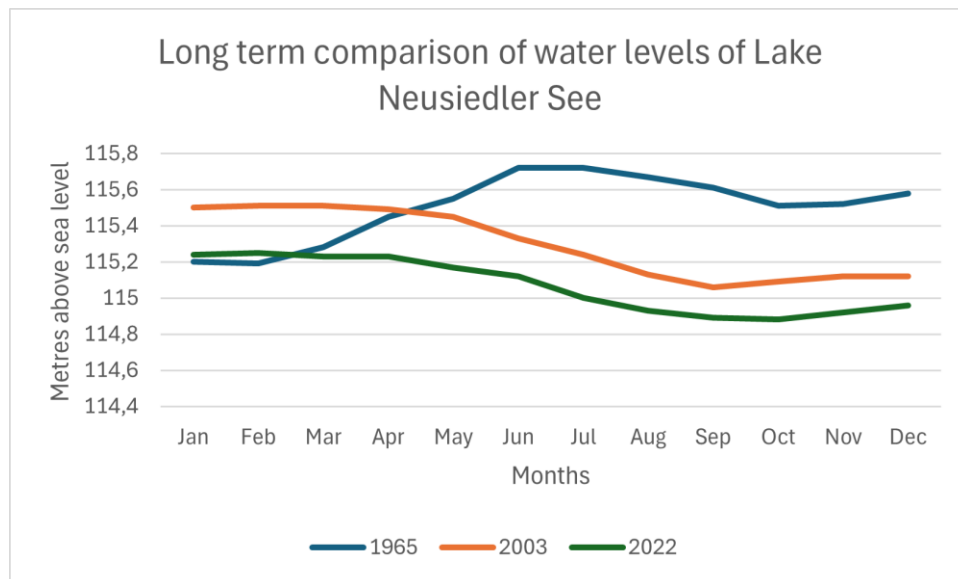


Figure 3. Average water level of Lake Neusiedler See in three different years. Original source: Wasserportal Burgenland

Even in the recent past, e.g. in 2022, Lake Neusiedler See has reached a dramatically low water level (Fig. 3). Decreased water levels lead to a decoupling of the reed belt from the open lake. This in turn leads to fish kills, because they cannot retreat from the warm open lake (Krachler et al., 2005; Krizsanits & Machtinger, 2023). It is now conceivable that Lake Neusiedler See could dry up if global warming and climate change are not drastically slowed down. Therefore, the current study focuses on mixing experiments with rainwater compared to pure water from Lake Neusiedler See.

1.3 Research questions and hypotheses

The main interest was to study the development of chemical and physical properties at laboratory conditions from water originating from Lake Neusiedler See as a reference and compare the pattern with dilutions series with rainwater over three weeks. Specifically, we were interested in possible changes in specific conductivity, ion content, pH-value, total alkalinity, turbidity and scattering. We also considered

potential changes of dry mass and ash mass, which might occur due to e.g. mineral precipitation. Besides the obvious decrease in specific conductivity and total alkalinity due to the lower amount of dissolved salts in rainwater compared to water from Lake Neusiedler See, we expected the pH-value to remain relatively stable, as it was already shown by Krachler et al. (2005). Lake Neusiedler See is a steppe lake with a high turbidity. Particle scattering and turbidity are related. Therefore, if the samples from Lake Neusiedler See are mixed with rainwater, which is much clearer, a decrease in turbidity and particle scattering is expected over time. Because rainwater contains less organic matter than water from Lake Neusiedler See, we also assumed a decrease of dry and ash mass over time.

In a second experiment, we mimicked evaporation during summer of about 10% of the volume and refilling during winter with rainwater over three years and analyzed parameters mentioned in the previous experiment. We hypothesized a slight decrease in specific conductivity, particle scattering, turbidity, dry and ash mass. A change in alkalinity was also expected and the pH-value was expected to remain relatively stable for the reasons given above from the dilution experiment.

The following hypotheses were formulated for the dilution and evaporation experiment:

- The specific conductivity, total alkalinity and major ions of the mixed samples decrease over time compared to the water from Lake Neusiedler See. Lake Neusiedler See is a slightly saline steppe lake. It typically has a higher specific conductivity than flowing waters in Austria, e.g. the Wulka river. In addition, the groundwater in the Seewinkel also has a higher concentration of dissolved salts (Wolfram et al., 2021). The most dominant cations offshore of Lake Neusiedler See are, in descending order sodium, magnesium, potassium and calcium, the most dominant anions are hydrogen carbonate, chloride, sulfate and carbonate (Wolfram et al., 2014). Therefore, Lake Neusiedler See is characterized as a soda lake. The salinity as well as other characteristics of Lake Neusiedler See are also influenced by the exchange of water between the open body of water and the reed belt. This exchange is in turn driven by wind induced movements (Wolfram et al., 2014). If those potential water sources are excluded, a slight decrease in specific conductivity and ions over time is expected if samples are refilled with pure rainwater.

- The pH-value of the mixed samples does not change over time compared to the water from Lake Neusiedler See. Typically, rainwater is very low in ions, not buffered and slightly acidic with an pH-value of around 6,2 (Krachler et al., 2005). Water from Lake Neusiedler See has a pH-value of 8,8 (Krachler et al., 2005), has a high load of salts and is well buffered. Diluting this well-buffered water with almost distilled water will therefore not change the pH-value.
- Turbidity and scattering of the mixed samples decrease over time compared to the water from Lake Neusiedler See. Another distinct characteristic of Lake Neusiedler See is its high turbidity and whitish/greyish color caused by back-scattering of sunlight. The particle load is caused the shallowness of the lake, fine sediments combined with wind exposure. On very stormy days the Secchi-depth can drop to only a few centimeters. The consequence of that is a worsening of the light supply for phytoplankton and submerged plants (Wolfram et al., 2014). Wolfram et al. (2014) showed a negative correlation between transparency and particles in the water – the more particles in the water the lower the Secchi depth. The calcite crystals of Lake Neusiedler See are constantly reformed by wind and waves (Wolfram et al, 2021). In a laboratory environment, such factors are excluded, same for contact with the sediment including repeated resuspension. Therefore, a decrease in turbidity is expected over time.
- Dry and ash mass will slightly increase during the experiment due to salt precipitation and biomass development.

1.4 Site description

Austria is located in the nemoral zonobiome. Typically, there is a distinct cold period in winter and there is usually a warm summer period of at least four months. On the northern hemisphere, the peak of rainfall occurs during summer (Breckle, S. W. & Rafiqpoor, M. D., 2019). The region around Lake Neusiedler See is the warmest in Austria. On about 61 days of the year the temperature is above 25°C. Frost occurs in winter, especially between October and May. Annual rainfall varies greatly, ranging between 400 mm and 900 mm (Herzig, 2014). Lake Neusiedler See is very shallow and polymictic, with an average depth of 1.2 meters and an average annual water

temperature of 14.7 degrees (Herzig, 2014). The lake area can be divided into two distinct parts - the open water and the reed belt, but there is a strong interdependence in terms of physical, chemical and biological parameters (Herzig, 2014). The environment is windy, with predominant north-western winds, in winter and late autumn also south-east. The hydrological balance of a lake is highly determined by local weather conditions and highly depends on evaporation and precipitation. Moving from the macroclimate to the microclimate situation, in winter the temperature around Lake Neusiedler See drops below 0°C. The coldest month of the year is usually January, with an average air temperature of -1°C. If there is a prolonged period of frost, the lake freezes. The summers have also been as extreme as the winters in this region. The warmest month is usually July with an average air temperature of 20°C (Krizsanits & Machtinger, 2023). During very hot summers, air temperatures can reach 40°C. In 2013, for example, the temperature in Neusiedl was 40.3°C, which was a (negative) record (Krizsanits & Machtinger, 2023). For the hydrological cycle of Lake Neusiedler See it is mainly the winter precipitation that is important, because in summer the sun evaporates the water on the surface (Krizsanits & Machtinger, 2023).

A critical aspect in maintaining ecological balance is winter precipitation. The consequences of the loss of precipitation can be seen, for example, in the year 2022 (or even earlier in 2003). During hot summers the water level drops from day to day, sometimes almost 1cm per day. Erratically, also prolonged wet periods can occur in in summer. In 2014, for example, which was a very rainy summer and a wet autumn, the lake reached an above average level of 116 meters (Krizsanits & Machtinger, 2023). Wind and related seiches play also a role. But if it is very windy, the water level can shift from one bank to the other. For example, if there is a strong wind from the northeast, the water level in the south can rise by up to 50 cm (Krizsanits & Machtinger, 2023).

Although also in the past unusual extreme weather conditions occurred from time to time, the 21st century is marked by anthropogenic climate change with much more frequent extreme weather conditions. Longer drought periods combined with rising temperatures and strong winds and their consequences for Lake Neusiedler See are of main concern not only of scientists, but also of inhabitants. If the average annual temperature increases by 1 °C, Lake Neusiedler See could dry up completely in

about 50 years (Krizsanits & Machtinger, 2023). This underlines the importance of studies such as the current one to maintain at least the present conditions. Moreover, scientific studies can only calculate a model, the weather itself remains unpredictable. There is no doubt that the temperature will rise. Therefore, precipitation will be the determining factor for the future of Lake Neusiedler See, but this factor cannot be controlled (Krizsanits & Machtinger, 2023).

2. Material and methods

2.1 Experimental set up

For the dilution experiment, water samples were taken by boat on 20 August 2023 at Neusiedl. For the evaporation experiment, water samples were taken on 27 August 2023. Rainwater for both setups was collected during two to three rainy days in mid-July in Pötsching, Burgenland. The exact coordinates for each location are listed in the appendix. In both experiments, the water samples were stored in cleaned plastic bottles in a dark place for about half a day. They were then brought to the laboratory in the Biology Building of the University of Vienna and further processed.

The mixing experiments were divided into two sub-sets. The dilution experiment involved mixing water from Lake Neusiedler See with rainwater to measure possible changes of various chemical and physical parameters over time. The evaporation experiment studied repeated concentrating and dilution series, followed by physico-chemical analysis of the water. In both cases, pure water from Lake Neusiedler See was used as a control. Each experiment consisted of a baseline measurement and following data collection. Each weekly measurement simulated one year at Lake Neusiedler See. For example, data collection after one week in the shaker represents the second year in Lake Neusiedler See.

In the dilution experiment, following dilutions were prepared, each in triplicates:

- 100% (pure) water from Lake Neusiedler See as a control
- 90% water from Lake Neusiedler See mixed with 10% rainwater
- 75% water from Lake Neusiedler See mixed with 25% rainwater

- 50% water from Lake Neusiedler See mixed with 50% rainwater

The evaporation experiment started with pure water from Lake Neusiedler See, of which 10 % was evaporated. Then the 10% were replenished with pure water from Lake Neusiedler See and the physical and chemical parameters of interest were studied. After one week the evaporation of 10% of the sample was then repeated and the 10% was refilled with pure water from Lake Neusiedler See. Each trial had four replicates and this cycle was done in order to mimic three years at Lake Neusiedler See in the laboratory.

At the beginning of each experiment, 400 ml of respective samples were prepared. 200ml was used as a baseline measurement, with 50ml taken for chemical analysis and another 50ml for measuring scattering, turbidity, pH-value, alkalinity and specific conductivity. The remaining 100ml was filtered for dry and ash mass determination. Also we measured scattering and turbidity of the filtered water to detect possible changes in the clay range.

The remaining 200ml were exposed in Schott-bottles at room temperature in the dark on a shaker for prospective measurements. From then on, measurements for scattering, turbidity, pH-value, alkalinity and specific conductivity were taken weekly. At the end of each experiment, the whole analysis including ion composition and ash and dry mass were conducted again. In total, there were three replicates for the dilution experiment and four replicates for the evaporation experiment.

Data analysis, including descriptive and inferential statistics, was performed using JASP, version 0.18.3. Each chemical and physical parameter was examined separately (in both sub-experiments). In addition, only the change in chemical composition over time and for different dilutions is described, as inferential analysis is not meaningful in this case. A linear mixed model was fitted for all other parameters. Additionally, data analysis was performed for dilution and time separately and for the interaction of dilution and time. The main focus of the statistics was on the interaction of dilution and time.

The following laboratory equipment was used in order to measure the chemical and physical properties of interest: Specific conductivity was measured with the WTW Cond 3310, pH-value was measured with the WTW inoLab pH Level 1. Total

alkalinity was measured with titration and indicator (Merck 108048 test kit). Cations (OENORM DIN EN ISO 14911) and anions (DIN EN ISO 10304-1) were analyzed by ion chromatography (IC) using a Metrohm 761 Compact IC (Cation column: Metrohm Metrosep C2; Anion column: Metrohm Metrosep A Supp 5) of filtrated samples (0.45 µm filters, Whatman Puradisc, UK). For the chemical composition an ion balance was calculated. This was done by calculating the sum of positive cations and the sum of negative anions in terms of their valence, and then subtracting the anions from the cations. Particle scattering was measured with the spectrofluorometer SHIMADZU RF-5301 PC, both excitation and emission at a wavelength of 860 nanometers. Turbidity was measured with the Hach DR 3900 at a wavelength of 860 nanometers. A turbidity standard was used to calibrate the relative units into NTUs. Therefore a cuvette was taken and only touched at the uppermost part and filled to 2/3 of its capacity with MilliQ-water that was used for cultivation. For dry and ash mass, a defined volume was filtered on pre-dried and pre-weighted glass microfiber filters (Type C, pore size 1.2 µm). The filters were first dried at 90°C for dry mass determination, followed by combusting in a muffle furnace (Labin) at 450°C for 2 h for ash mass measurements. For the evaporation experiment, a Rotavapor Buchi B-491 was used (temperature: 38°C, pressure: 31mbar).

3. Results

3.1 Dilution experiment

The pH-value remained quite stable over time with only marginal, insignificant increases of about 0.1 units for the control, 90% and 75% NS water, and a tendency to decrease in the 50% approach. For the pH-value, the interaction between time x dilution was statistically significant.

Also Specific conductivity remained constant over time ($p = 0.78$), with no significant interaction effects of dilution x time.

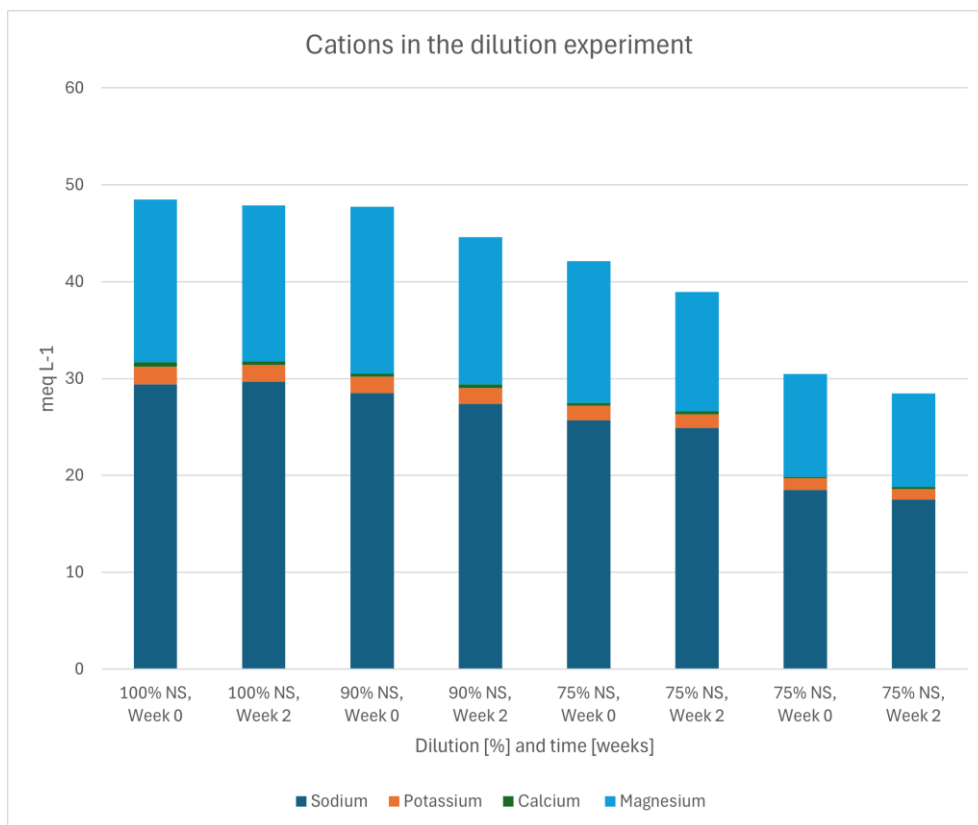


Figure 4. Major cations contributing to the ion balance in all conditions at the baseline measurement and 2 weeks later.

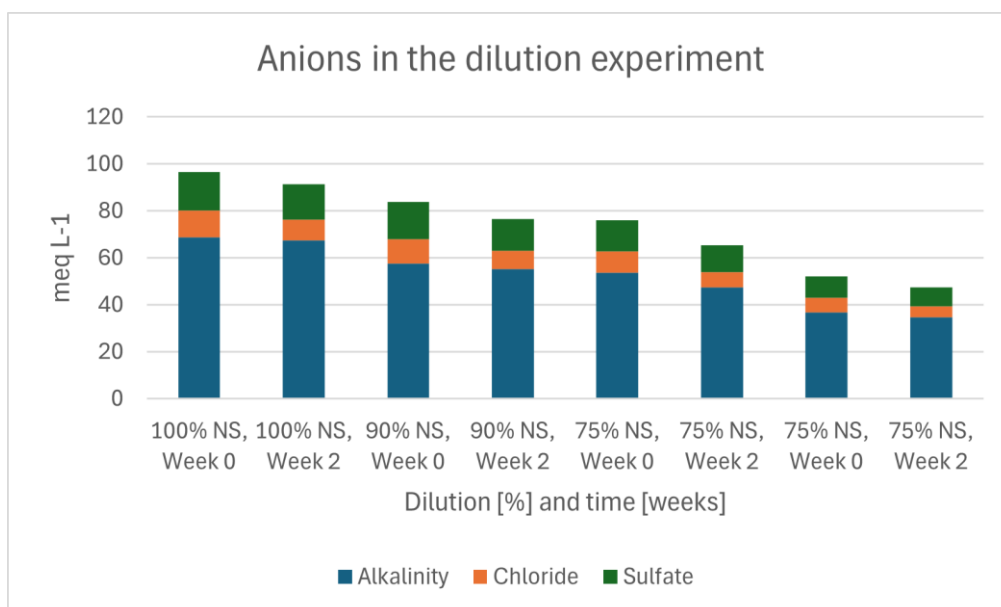


Figure 5. Major anions contributing to the ion balance in all conditions at the baseline measurement and 2 weeks later.

Major cations in the chemical composition were sodium, potassium, calcium and magnesium (Fig. 4). Major anions were chloride, nitrate, sulfate and alkalinity (Fig. 5). As can be seen in figure 4 all cations show marginal decreased values with time in each condition. Also the anions slightly decreased with time in all four conditions. Alkalinity shows significantly decreased values with time in all four conditions.

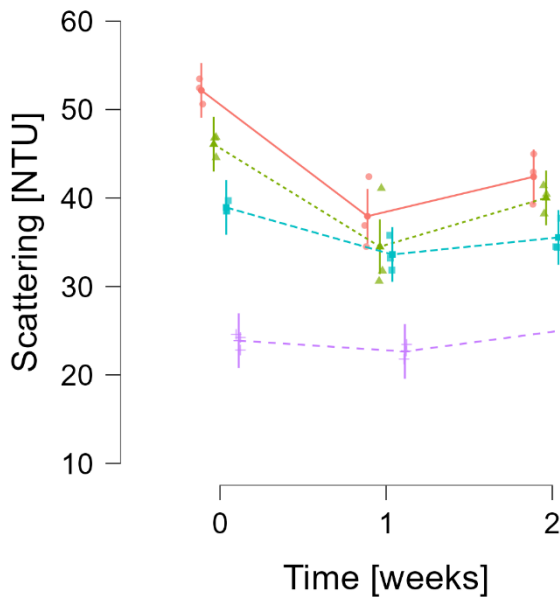


Figure 6. Variation with time of the particle scattering of the unfiltered samples in the 4 conditions. 100 % NS = red; 90 % NS = green; 75% NS = blue; 50% NS = purple

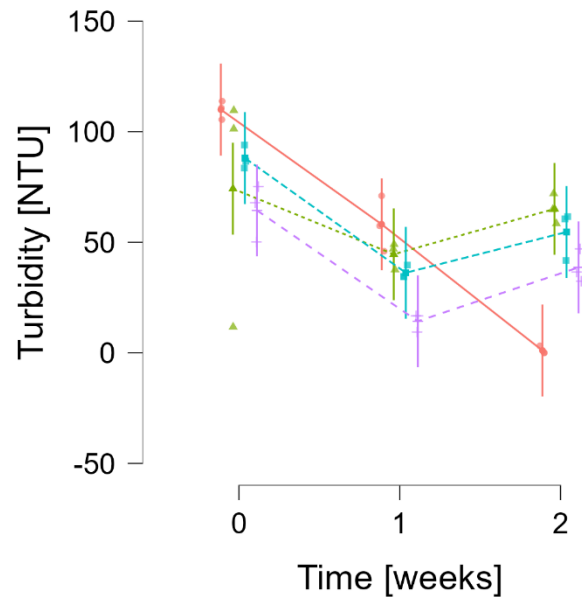


Figure 7. Variation with time of the turbidity of the unfiltered samples in the 4 conditions. 100 % NS = red; 90 % NS = green; 75% NS = blue; 50% NS = purple

Particle scattering and turbidity was measured with both filtered and unfiltered samples. During the first week, scattering of the unfiltered samples significantly decreased in each dilution series (Fig. 6), followed by stable to slight increase in the second period of the experiment. Scattering of filtered water showed no significant changes over time. Turbidity of unfiltered samples shows a decrease in the first period of the experiment with dilution having no significant effect (Fig. 7). Comparable to scattering, turbidity then slightly increased except in the control. Turbidity of filtered water kept stable over time, independently of the dilution.

Dry mass decreased with time in each treatment, with dilution having a significant effect. Most of the dry mass is inorganic, as the ash weight is about 83% of the dry weight for the control, for the 90% NS water and for the 75% NS water, and for the 50% NS approach it is 84%. Ash weight shows a tendency to decrease with time, with dilution also having a significant effect.

3.2 Evaporation experiment

The pH-value shows a tendency to increase over time of about 0.1 units for the control. During the first week, the pH-value of the mixed samples increased, followed by a stable to slight decrease in the second week, and an increase in the third week of the experiment. For the pH-value, the interaction between time x dilution was statistically significant.

Specific conductivity remained constant during the first week of the experiment for the mixed samples, followed by a decrease in the second and third week. The control tended to a stable to slight decrease over time. For specific conductivity the time x dilution effect was statistically significant.

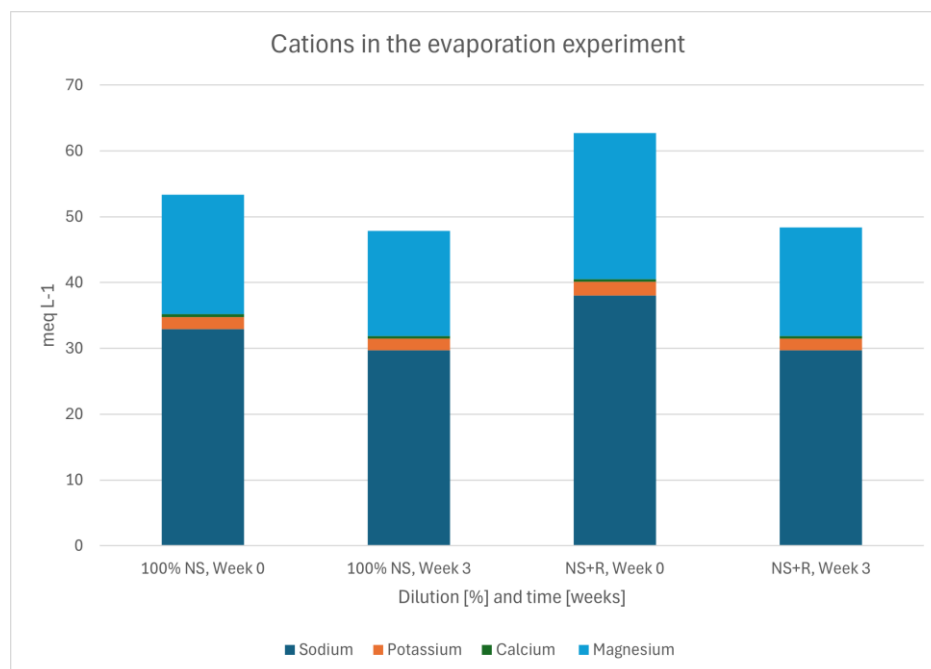


Figure 8. Major cations contributing to the ion balance in the both conditions at the baseline measurement and 3 weeks later.

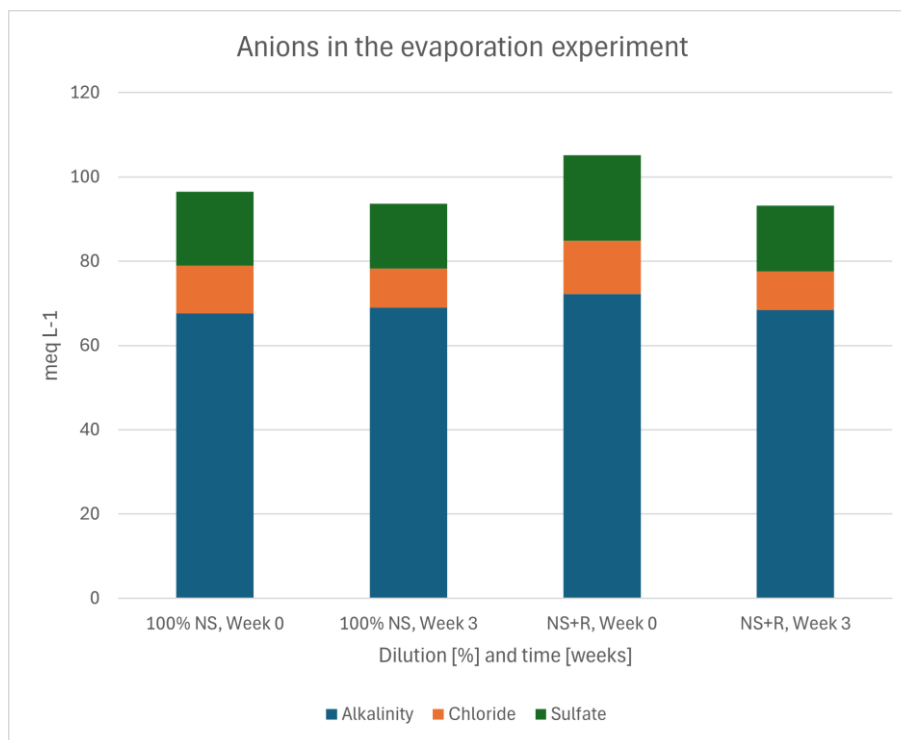


Figure 9. Major anions contributing to the ion balance in both conditions at the baseline measurement and 3 weeks later.

As can be seen in figure 8 and 9, the cations and the anions tend to decrease with time. Alkalinity shows a slight increase with time for the mixed samples, and a tendency to decrease with time in the control, with no significant effects.

In the evaporation experiment the variation of particle scattering and turbidity was also examined with both filtered and unfiltered samples. Scattering of unfiltered water results in a decrease over time for the mixed samples, with no significant interaction effects of dilution x time ($p = 0.23$). The control slightly increases during the first and second week, followed by a stable to slight decrease in the third period of the experiment. Scattering of filtered samples tends to increase over time for the control and for the mixed samples, with no significant interaction effects of dilution x time.

The turbidity of unfiltered samples shows a decrease in the first week of the experiment, followed by an increase in the second week, and then turbidity tends to decrease in the third period of the experiment, with dilution having no significant effect. The turbidity of filtered samples shows a slight increase over time, with no significant interaction effects of dilution x time ($p = 0.57$).

Dry weight remained constant over time for the mixed samples, and shows a tendency to increase over time for the control. Ash weight shows a tendency to decrease over time for each condition. As the ash weight is about 84% of the dry weight for the mixed samples and 83% for the control, most of the dry weight is inorganic.

4. Discussion

The results of both experiments suggest that the effect of dilution x time is statistically significant for the pH-value. Previous studies have found that mixing water from Lake Neusiedler See with rainwater in a 1:1 ratio, the pH-value remains relatively stable (Krachler et al., 2005; Wolfram et al., 2021). However, these studies did not monitor the pH-value over prolonged periods as we have done. The pH-value of Lake Neusiedler See varies depending on the mixing ratio of lake water and an external water source, e.g. from the Danube river. Wolfram et al. (2021) found that a percentage of 16-27 % of Danube water results in a slight decrease in pH-value of about 0.1 units. The same amount of increased influx from the Wulka river would decrease the pH-value by the same amount. In conclusion, a decline in the pH-value is only locally relevant, but has no effect on the pH-value of the open water body (Wolfram et al., 2021). However, the reason for the interaction effect could be because a measurable pH-value decline might take years (Wolfram et al., 2021).

In the evaporation experiment, the interaction of dilution x time was statistically significant for conductivity. As a steppe lake, Lake Neusiedler See differs from other surface waters, such as the Danube or the Wulka river, by its high content of dissolved salts, which is about 2.5 times higher than the specific conductivity of the Wulka river (Wolfram et al., 2021). The conductivity is even higher in the area of the reed beds and in the nearby salt pans (Seewinkel area). Usually, groundwater has a lower specific conductivity than water from Lake Neusiedler See, but in the Seewinkel the groundwater has a higher concentration of dissolved salts (Wolfram et al., 2021). Most of the groundwater originates from rainwater runoff. Boros et al. (2014) found comparable results of an increased conductivity of the soda pans in the Carpathian Basin. The specific conductivity also depends on the season. Usually, it is the lowest during snowmelt and the highest in summer before drying out (Boros et al., 2014).

Wolfram et al. (2021) also reported an increase in conductivity at the groundwater monitoring site in the area of the Martentaulacke just before drying out, because of the extreme accumulation of the dissolved salts. Besides, Wolfram et al. (2014) found that the specific conductivity has decreased over the past decades, from 1994 to 2010. However, the dilution x time effect could be, due to the accumulation of particles in the water.

The major ion composition of the lake was formed by the cations sodium, magnesium, calcium and potassium, while anions were sulfate, chloride, alkalinity and nitrate. Wolfram et al. (2014) reported a comparable pattern for the major ion composition in the open water body of Lake Neusiedler See. In the study by Wolfram et al. (2014), the largest percentage of the cations is formed by sodium and the largest percentage of the anions is formed by hydrogen carbonate (alkalinity). Our study shows exactly the same composition, which is logical, as the lake volume will not be exchanged over decades (it is a terminal lake). The conspicuously high amount of sodium ions is explained by break lines of deep marine waters, where there is an influx of sodium-hydrocarbonate from groundwater (Wolfram et al., 2021). Comparable to the specific conductivity, the alkalinity of the water in Lake Neusiedler See exceeds the alkalinity of running waters (Wolfram et al., 2021). For instance, the Wulka river has a medium alkalinity and the Danube River bank filtrate has a low alkalinity with half as much as water from Lake Neusiedler See (Krachler et al., 2005; Wolfram et al., 2021). This in turn explains the high amount of carbonate and hydrogen carbonate ions in water from Lake Neusiedler See (Krachler et al., 2005). Additionally, also the groundwater in the Seewinkel has an increased alkalinity, compared to groundwater in other regions of Austria (Wolfram et al., 2021). Due to their saline characteristics, the soda pans have an even higher alkalinity than the water from the open water of Lake Neusiedler See. It is therefore not surprising that in dry years, especially just before drying out, the soda pans had an extremely high alkalinity (Wolfram et al., 2021). Furthermore, Boros et al. (2014) found a similarly high concentration of sodium and alkalinity for the soda pans in the Carpathian Basin. There, the basic alkaline type (Na-HCO_3) is the most frequent type of soda waters, in addition to 11 other subtypes (Boros et al., 2014).

Another distinct characteristic of Lake Neusiedler See is its high turbidity (Wolfram et al., 2014). This turbidity is caused by gust of wind of the upper fine grained sediment

layers, in combination with an alkaline pH-value. This slows particles sinking and stabilizes turbidity (Krachler et al., 2005). There is also a positive correlation between turbidity and Secchi depth readings (Wolfram et al., 2014). The light turbidity of the water of Lake Neusiedler See consist mainly of particles of silicate and carbonate minerals (Krachler et al., 2005). In addition, the turbidity plays an important role for the water purification of Lake Neusiedler See. Microorganisms attach to particles and form a biofilm, resulting in a very effective self-purification (Krachler et al., 2005).

The high turbidity of Lake Neusiedler See also affects phytoplankton. Light limitation prevents algal blooms that would be expected due to the high amount of nutrients. In other words, light limitation is more the key variable for limited phytoplankton growth, and not nutrient limitation (Wolfram et al., 2014). For consideration of additional water supply to the lake, the light climate is therefore of special importance. Wolfram et al. (2014) moreover suggested that further studies should focus on the relation between turbidity and light extinction (absorption and scattering). In the current study, we did not find significant changes of turbidity and particle scattering over time, however feeding the lake with rainwater will not be a realistic solution. In the dilution experiment, scattering and turbidity of filtered water kept stable over time, independently of the dilution. In the evaporation experiment, particle scattering and turbidity tended to increase over time, with no significant dilution x time effect. As the results suggest, there is no significant change in scattering and turbidity in the clay range.

In the dilution experiment, dry mass decreased over time in each condition. In the evaporation experiment it remained constant over time for the mixed samples and it showed an insignificant tendency to increase over time in the control. In both experiments the ash mass showed a tendency to decrease over time in each condition. It is interesting to note that the ash mass was over 80% of the dry mass in both experiments. In the 1970s, concentrations of dissolved phosphor and dissolved inorganic nitrogen in Lake Neusiedler See peaked due to increased tourism and economic development, as well as increased use of fertilizer in the intensive agriculture. This time was also the peak of the eutrophication period of Lake Neusiedler See. Recently, investigations have been conducted on organic and inorganic pollutants (Wolfram et al., 2014). In addition, the light conditions in the open water as well as in the reed belt are highly depended on inorganic turbidity and

dissolved organic matter. Furthermore, wherever soda pans and saline soils are connected to a drainage system, this leads to a loss of salts and consequently to a damage to a habitat (Wolfram et al., 2014). As mentioned above the inorganic turbidity plays an important role in the self-purification of Lake Neusiedler See (Krachler et al., 2005). Inorganic turbidity has mainly been studied in soda pans. Boros et al. (2014) suggested to distinguish two types of soda pans. The “turbid-white” ones, characterized by a high amount of inorganic particles, causing high turbidity and the “non-turbid-colored” ones, characterized by a high amount of humic substances. (Boros et al., 2014).

Freshwater habitats are threatened globally by salinization, and climate change has accelerated this trend (Kelly et al., 2023). Salinization refers to an increase in the concentration of major ions in waterbodies (Kelly et al., 2023). Criteria need to be defined to protect ecosystem health. Many countries have not taken this step and there are also differences between criteria (Kelly et al., 2023). The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Policy (2019) formulated a regulation on the ecological status of surface waters, in which Lake Neusiedler See is also listed as a special type. In the chapter on physico-chemical quality criteria, some recommendations for the pH-value, specific conductivity, alkalinity, etc. are listed. It is mentioned that the pH-value of Lake Neusiedler See should be between 8.0 and 9.5 for a very good to good status (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2019). In contrast, the pH-value of the Danube should be between 7.5 and 9.0 for a very good to good status (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2019).

The salinity can be determined by considering the conductivity, the alkalinity and the chloride-concentration (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2019; Kelly et al., 2023). The recommendation for the specific conductivity of Lake Neusiedler See is $1449 \mu\text{m cm}^{-1}$ for a very good to good status, and $1010 \mu\text{m cm}^{-1}$ for a good to moderate status (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2019). Kelly et al. (2023) reported a comparable value with $1010 \mu\text{m cm}^{-1}$ as the minimum. The critical value for a very good to good alkalinity status of Lake Neusiedler See is 6.85 mmol L^{-1} , and 4.88 mmol L^{-1} for a good to moderate quality (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2019). The minimum chloride

concentration should be 60 mg L⁻¹ (Kelly et al., 2023). The Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Policy (2019) reports a similar value for a good to moderate status of the ecosystem of Lake Neusiedler See, and a value of 110 mg L⁻¹ of the chloride concentration for a very good to good status. In summary, the Austrian Federal Ministry of Agriculture, Forestry, Environment and Water Policy (2019) and Kelly et al. (2023) report comparable thresholds. However, there are also some questionable points in the paper of Kelly et al. (2023).

Firstly, the original source of the thresholds in the respective table is missing. Secondly, it is misleading to cite Lake Neusiedler See as a positive example of successful implementation. Thresholds for Lake Neusiedler See were defined several years ago in order to protect the lake from sweetening due to a dilution by opening a water gate (Bundesministerium für Land- und Forstwirtschaft, Umwelt und Wasserwirtschaft, 2019). The artificially constructed water gate is the main surface outlet of Lake Neusiedler See, but it has been permanently closed for years. In addition, precipitation is the main water source of water for Lake Neusiedler See, accounting for more than 90%. This raises the question of how the lake can be protected from desalinization if the precipitation in Lake Neusiedler See has become too low in recent years due to climate change. In contrary, there is a lot of discussion going on of how to protect the lake from drying out. Lower water levels can cause a number of problems, including fish kills, the dispersal of reeds, and ultimately a breakdown of tourism in a region where it is the main source of income. So not only minimum values need to be defined in terms of ions, but also in terms of water level, otherwise there could be the impression that e.g., higher conductivity always means very good condition. Defining critical levels for such saline, highly variable systems as Lake Neusiedler See remains a challenge.

From 1865 to 1871, Lake Neusiedler See dried up, which was the last time until today. This event was caused also by anthropogenic impact, and it is well documented by many researches and reports. The process of drying up started in 1854 and continued step by step. After eight years, the water had receded about 40 steps from the shore. The ground was very dry and hard. There were also conflicts over the plants that grew on the dry land (Krizsanits & Machtinger, 2023). Nowadays, scientists are sure that the reasons were the decrease of precipitation, very hot

summers, a lack of snow in winter and anthropogenic interventions, such as the construction of drainage channels (Krizsanits & Machtinger, 2023).

The area around Lake Neusiedler See is one of the driest, warmest and sunniest in Austria. With an average annual temperature of 10.1°C and a very high sunshine duration of more than 1900 hours per year in Neusiedl am See, it is considered a semiarid region (Eitzinger et al., 2009). Since the end of the 19th century, there has been an increase in temperature, especially since 1970. For precipitation, there is not such trend, but a change between dry and humid years (Eitzinger et al., 2009). Since 1970, there has been a precipitation deficit in the last decades, with a few humid years in between (Eitzinger et al., 2009).

During the late Miocene the Paratethys Sea was tectonically trapped and separated from the global ocean. This was the time, when the largest megalake was formed in Eurasia (Palcu et al., 2021). There were also regressive phases during this time, when the megalake lost most of its surface area. The remaining water was then divided into a central salt lake and peripheral basins of low salinity or freshwater lakes that periodically refilled. During these regressive periods, the megalake lost up to 70% of its surface area and a third of its volume (Palcu, et al., 2021). This means that in the past, about 11-7.5 million years ago, there were also four hydrological crises, that affected the hydrology, the climate and the vegetation of the surrounding regions (Palcu et al., 2021). However, the underlying mechanisms are poorly understood. The above mentioned regressive phases were associated with changes in vegetation, fauna exchanges and aridification in large parts of Europe (Palcu et al., 2021). After the Ice Age, the water level of Lake Neusiedler See was about five meters. However, there were also times when Lake Neusiedler See was almost dry, for example between 1865 and 1868 (Herzig, 2014). In conclusion, drought and desiccation of lakes is not a new phenomenon, but what is new is that a large proportion of these events are now man made. Comparing the water levels of Lake Neusiedler See and Lake Balaton, there are some similarities. Lake Balaton also shows a large fluctuation of water levels over the last 1000 years. Moreover, there has also been a significant decline in water levels since 1999, which is another parallel to Lake Neusiedler See (Eitzinger et al., 2009). Since hundreds of years, but especially since the 20th century, anthropogenic impacts have accelerated the process of aggradation of Lake Neusiedler See, mainly due to the construction of

drainage systems, e.g. the Einser Canal, which lead to the export of large amounts of salts (Wolfram et al., 2021). The reed is a filter and a sink for particles, which also accelerates the aggradation. In addition, the exchange between the reed bed and the open body of water is restricted. In part, this leads to a lack of inorganic turbidity and the above mentioned self-purification via the biofilm formed on the particles is disturbed (Wolfram et al., 2021). Our knowledge of the reduction of organic matter in the reed belt is insufficient. It is possible that the process of aggradation can only be slowed down by the accumulation of organic matter in the reed bed (Wolfram et al., 2021).

For a broader perspective on nature conservation at Lake Neusiedler See, one can consider the Sustainable Development Goals. Austria is a member of the United Nations. These are global goals to be implemented by 2030 (Umweltbundesamt, 2023). There are 17 goals in total, three of which are very important for the current situation at Lake Neusiedler See. These are: clean water and sanitation (Goal 6), climate action (Goal 13) and life on land (Goal 15). Ecosystems with water, such as rivers or lakes, need to be protected (Goldenitsch, 2022). Therefore, sustainable use, reduction of pollution and protection of the habitat also apply to Lake Neusiedler See. Goal 13 on climate action includes concrete steps to combat climate change. Lake Neusiedler See is definitely affected by climate change, and the consequences affect the entire habitat. Species and habitats that are endangered should be protected and ecosystems that have been destroyed by humans should be restored (Goldenitsch, 2022). Lake Neusiedler See is therefore an important terrestrial habitat for Goal 15. On the one hand, it is important for nature and species for the protection of biodiversity, and on the other hand, it is a recreational area for humans (Goldenitsch, 2022). In addition, one can argue for the protection of the ecosystem around Lake Neusiedler See because of its aesthetic value, which is worth preserving.

4.1. Conclusion

Austria is still a country with sufficient water resources. However, groundwater is very unevenly distributed. Due to climate change, dry periods are becoming more frequent, leading to regional and local water scarcity. Other consequences of climate

change include changes in precipitation, increased evaporation of surface water and rising temperatures (Lindinger et al., 2021). In summary, climate change is leading to higher temperatures and less rainfall in eastern Austria, and is increasing the likelihood of extreme weather events such as storms. This pilot study provides first insights into possible chemical and physical changes in the water characteristics of Lake Neusiedler See supplied with rain water. The first experiment shows that parameters such as conductivity, alkalinity, unfiltered scattering, unfiltered turbidity, dry and ash mass differ significantly in the different conditions, which refer to different percentages of mixing of water from Lake Neusiedl with rainwater. In addition, pH-value, unfiltered scattering and unfiltered turbidity underline the significant effect of time and dilution. In the second experiment, the statistically significant interaction effects of time and dilution on conductivity and pH-value were investigated.

The laboratory experiments highlight the changes in pH-value over time in the mixed samples compared to the control group. There is a significant interaction between time x dilution in both experiments. This hypothesis can be fully accepted in both cases. In addition, the working hypothesis concerning conductivity can be accepted in the second experiment with Rotavapor and in the first experiment there is a significant difference between the different dilutions (but not for time). The first experiment shows a number of other significant changes over time between the mixed rainwater samples and the pure samples. The hypotheses concerning unfiltered scattering and unfiltered turbidity, which predict a significant change over time between the different groups, can be accepted. The working hypotheses for dry weight and ash weight in the first experiment cannot be fully accepted, although they show a significant difference between the different dilutions, the effect is not significant over time. Furthermore, for alkalinity, a significant difference was found between the different dilutions and over time, only the interaction of time x dilution is not significant.

Finally, laboratory experiments indicate that the physical and chemical properties of Lake Neusiedler See will change significantly in the coming decades, especially if extreme weather conditions increase the likelihood of heavy rainfall within a short period of time. The Austrian-Hungarian Lake-Commission formulated three overarching objectives for the conservation of the ecosystem of Lake Neusiedler See. These goals relate to the preservation of Lake Neusiedler See as a landscape

component, the maintenance of the ratio between the open water body and the reed beds, and finally, the maintenance of the bathing quality (Wolfram et al., 2014). The planned measures can be divided into three broad groups: On the one hand, there are habitat protection goals, which mainly concern the protection of nature and the ecological status, but also the improvement of facilities, such as a sewage treatment plant, and the promotion of sustainable development in agriculture (Wolfram et al., 2014). On the other hand, there are objectives to implement monitoring programs to document developments and to improve knowledge. Furthermore, there are administrative objectives related to the development of cross-border cooperations (Wolfram et al., 2014).

The fact that Lake Neusiedler See has survived for thousands of years with an average water depth of 1.5-2 meters is due to its high pH-value and high turbidity (Krachler et al., 2005). High pH-levels favor the decomposition of plant debris, but the microorganisms needed to do this do not float but require the particles as a substrate. The high pH-value of Lake Neusiedler See is a legacy of the former Paratethys. The lake is facing anthropogenic impacts since hundreds of years, which is however largely neglected in ongoing discussions to keep its “natural” status. Lake Neusiedler See had no outflow in former times. Waters flowing into the lake, e.g. from the Wulka river, remained in the lake basin. The original catchment area was 5x larger than the current one; some tributaries and swamps were cut off already long time ago to prevent the local population from floods. In the beginning of the 20th century, an artificial drainage channel was constructed. With this construction, the Einser Canal, Lake Neusiedler See is losing saline water (Krachler et al., 2005). Today, it is important to note that the discharge of large amounts of water from Lake Neusiedler See represents a massive anthropogenic intervention in the ecosystem, which has led to the reduction of the water body and the increased the reed belt (Krachler et al., 2005).

A high discharge of the Danube bank filtrate into Lake Neusiedler See together with water removal via the Einser Canal would turn the terminal lake into a flow-through system with several negative effects. These include a massive decrease in the pH-value, the formation of calcareous mud, the risk of invasion by non-native species and xenobiotic substances, and finally an accumulation of organic matter (Krachler et al., 2005; Wolfram et al., 2021). Local effects are also expected, particularly in the

inflow area. These include a worsening in bathing quality and the spread of reeds (Krachler et al., 2005; Wolfram et al., 2021). The reason for the worsening in bathing quality is that a decrease in the pH-value and a reduction in the salinity would lead to an accumulation of undesirable microbes such as *Escherichia coli* (Krachler et al., 2005). Such a high discharge is however not envisaged. Additional water supply should rather be performed to keep the lake in its current state. Just “leave the system as it is”, which is sometimes argued by conservationists, will probably result in dramatic changes. For keeping the system as it is, additional measures definitely need to be taken.

4.2 Limitations of the study

Probably a weakness of the study was that there were only three replicates for each dilution at one point in time. Further studies could include more replicates, which would help to draw conclusions more precisely, including conclusive statistics.

4.3. Implications for further research

Formerly, Lake Neusiedler See was thought to be fed mainly by underground springs. This assumption however completely changed due to new insights. Nowadays, it is assumed that water supply is highly dependent on precipitation. This is why the water level rises in wet years and falls in dry years. Such systems are therefore also called amplifier-lakes, because they amplify climate changes in very short periods of time. Discussions about a possible water support are relevant as soon as the ecological environment of the lake is endangered (Krizsanits & Machtinger, 2023).

Since decades, political debates discuss ideas to keep the lake. Depending on the water level, the discussions come and go. In the last years, especially from 2022 onwards, the media again became interested in the preservation of Lake Neusiedler See because of a dramatic drop of the lake level, leading also to a decrease of tourism. The government, which is responsible for public waters, therefore established the Task Force Neusiedler See in 2019. Amongst other things the task

force measured the amount of silt in the Ruster Bay. The main goal is to develop a concept for the keeping landscape around the lake and the lake itself. In order to preserve Lake Neusiedler See in the long term, sensible management will be mandatory - it is not enough to leave the “natural environment” to its own devices.

When the water evaporates from Lake Neusiedler See, salt is left over. The salinity will therefore increase as the water level falls. A feared consequence is that the salinity will be threatened. A possible solution could be to carefully fill the lake. However, the lake should not be completely filled, but rather the deficits caused by the climate should be balanced out. Researchers believe that inflow and outflow (e.g. through the Einser canal) are not contradictory, but help to maintain the ecological system of the lake (Krizsanits & Machtinger, 2023).

Lake Neusiedler See was already threatened before there was widespread public interest. One strategy that has been discussed in this context is an inflow from the Danube into Lake Neusiedler See. At first sight, this may seem simple, but it raises many questions. Lake Neusiedler See is often compared to a large bathtub. This is only true for its shape. There is no tap that you can turn on and let the water flow in. A better analogy is a screw in a big machine - if you turn a screw in a machine, the whole system changes. Some essential questions that need to be answered before realizing additional water supply from surface waters like the Danube are following: where and when will the water from the Danube be divert, because the river also has to cope with low water levels at certain periods. (How) will the water from the Danube affect the salinity of Lake Neusiedler See? Will the chemistry of the lake water be significantly influenced by water entering from other systems. Another big question is whether invasive species will reach Lake Neusiedler See through this route (Krizsanits & Machtinger, 2023). As vectors such as water birds are very common, we however do not think that the problem of invasive species will only start with artificial water supply. These and many other questions need to be answered by careful scientific research before an influx should be realized.

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Donau, Gutachten im Auftrag des Amts der Burgenländischen Landesregierung –
Abt. 5 – Baudirektion.

Appendix

Date and location where the water samples were taken

For the dilution experiment, water samples were taken by boat on 20 August 2023 at Neusiedl (GPS coordinates: 47.92491°N, 16.83356°E). For the evaporation experiment, water samples were taken on 27 August 2023 (GPS coordinates: 47.92842°N, 16.83500°E). Rainwater for both setups was collected during two to three rainy days in mid-July in Pötsching, Burgenland. The coordinates are 47.80670°N, 16.35504°E.

In both experiments, the water samples were stored in cleaned plastic bottles in a dark place for about half a day. They were then brought to the laboratory in the Biology Building of the University of Vienna and further processed.

Basic information of hydro-chemical parameters for non-limnologists

Electric conductivity

The electrical conductivity of a substance defines its ability to transport electrical charge. A distinction is made between first order charge carriers, which transport electrons, and second order charge carriers, which transport ions (Spektrum, 1998). Both sub-experiments focused on ionic conductivity.

In general, electrical conductivity depends on temperature. For electrons it decreases with increasing temperature and for ions it increases with increasing temperature. Electrical conductivity is defined as the reciprocal of electrical resistance (Spektrum, 1998).

Pure water has no conductivity because it contains no ions. By adding substances that form ions, water becomes an electrical conductor. After the experiments, an ionic balance of the chemical values was calculated. This involved calculating the sum of positive cations and negative anions. The next step was to subtract the anions from the cations. The expected value should be close to zero and correlate with the measured electrical conductivity. This step was also done to check for possible errors.

First of all, I would like to clarify the abbreviations used. "N" stands for water from Lake Neusiedl, "R" for rainwater. To increase reliability, each sample was measured three times and a mean value was calculated. The abbreviation "MW" stands for mean value (of the three different samples). The different numbers indicate the percentage of the mixing process. For example, N90R10MW stands for a sample consisting of 90% water from Lake Neusiedl and 10% rainwater (MW is, as already mentioned, based on the mean of three replicates).

Summe Kationen und Anionen (*Wertigkeit)			
	Kationen +	Anionen -	Kat-An
N100MW	48,6323226	50,80029	-2,167969
N90R10MW	47,7094924	45,4852	2,224297
N75R25MW	42,2260564	40,43006	1,795993
N50R50MW	30,5971973	27,59079	3,006409

Table 1: Ionic balance for the first sub-experiment at timepoint 0

Summe Kationen und Anionen (*Wertigkeit)			
	Kationen +	Anionen -	Kat-An
N100MW	47,97252	46,46691	1,505613
N90R10MW	44,63929	40,08329	4,555996
N75R25MW	39,01754	33,87968	5,137862
N50R50MW	28,45223	24,39486	4,057365

Table 2: Ionic balance for the first sub-experiment at timepoint 2

As can be seen in Table 1, the ion balance for the first sub-experiment at time zero was slightly negative for the pure water from Lake Neusiedl. As the proportion of rainwater in the samples increases, the ion balance becomes more positive.

Table 2 shows the ion balance of the first sub-experiment two weeks later at time point two. The data became more positive. However, the pure samples from Lake Neusiedl remained more negative than the mixed samples with rainwater.

Summe Kationen und Anionen (*Wertigkeit)			
	Kationen +	Anionen -	Kat-An
NMW	53,36754	51,37673	1,990808
NRMW	62,96903	57,20578	5,763249

Table 3: Ionic balance for the second sub-experiment at timepoint 0

Summe Kationen und Anionen (*Wertigkeit)			
	Kationen +	Anionen -	Kat-An
NMW	47,95682	47,61659	0,340232
NRMW	48,36588	47,82404	0,541843

Table 4: Ionic balance for the second sub-experiment at timepoint 3

In the second sub-trial at timepoint zero, the mixed samples showed slightly more positive values than the pure ones.

Table 4 shows the ionic balance in the second sub-experiment at time point three. In both cases, the values are approaching zero, both for the pure water and for the mixed samples with rainwater.

In conclusion, the ionic balance for the pure water of Lake Neusiedl is in all cases lower than the balance for the mixed samples with rainwater. Furthermore, the values become more positive over time in the first sub-experiment. For the second sub-experiment, which contained the evaporated samples, the ion balance becomes lower over time and tends towards zero.

pH-value

The pH-value is a measure of the concentration of hydrogen ions in water or aqueous solutions. It is an important quantity in biology, medicine and chemistry because life processes, especially the activity of enzymes, depend on the pH-value. The electrical conductivity of pure water is very low, but it is present. This is why water is dissociated with ions (Kremer & Bannwarth, 2018).

The pH-value of a solution can be neutral, acidic or alkaline. A molecule that can release a positive hydrogen ion is called an acid. Conversely, a molecule that can absorb a positive hydrogen ion is called an alkaline solution. The pH-scale goes from one to 14. A value of seven is called neutral. The more hydrogen ions a solution can absorb, the stronger the acid and the lower the pH-value. For an alkaline solution, the opposite is true and the pH-value is higher than seven (Hauk, 2012).

There are several techniques for measuring pH-value. The most common are indicators and digital measurement devices. Indicators are dyes that change color depending on the pH-value. Another possibility is to test with the taste. However, this is too inaccurate and too dangerous in the laboratory (Hauk, 2012). In these experiments, a digital device was used.

The pH-value of pure rainwater is typically 6.2 and that of Lake Neusiedl is 8.8. Previous studies have shown that when the two water samples are mixed in a 1:1 ratio (at 21 °C), the pH-value of Lake Neusiedl remains at 8.8 (Krachler et al., 2005).

Alkalinity

Another word for alkalinity is acid capacity. It describes the ability of a strong acid to neutralize a given volume, say 100ml, of a water sample to a pH of 4.3. In natural

waters, alkalinity is mainly due to the presence of elements such as calcium, magnesium, potassium and sodium. In general, surface water and groundwater have a lower acid capacity than wastewater from industry or households (Pohling, 2015).

To determine the alkalinity of a solution, there is a quantitative method in chemistry called titration. The instrumental method combines a pH meter with a glass electrode. The turning point at a pH-value of 8.3 describes the acid capacity caused by hydroxide and carbonate, and the turning point at a pH of 4.3 describes the acid capacity caused by hydrogen carbonate (Pohling, 2015).

A common device for measuring alkalinity is a drop count method. This laboratory device is based on titration against the indicators mentioned above (Pohling, 2015). In both sub-experiments, an indicator was used where the color change signaled the value of alkalinity in German degrees of hardness. Later, for the calculation of the ion balance, the values were converted into moles.

Scattering

Particle scattering in the water samples was measured using nephelometry. This is an optical method used in chemistry. It quantifies the amount of solids in suspensions or aerosols. It is measured by the intensity of scattered light produced by suspended particles. The intensity of the scattered light can be measured in two ways. Either by measuring the intensity of the scattered radiation directly, or by calculating the attenuation of the transmitted light, which is an indirect method. The first method is usually carried out at right angles to the primary light source (Spektrum, Lexikon der Chemie, 1998).

The technical equipment used to measure particle scattering in water is called nephelometry. It can be supplemented with a photometer (Spektrum, Lexikon der Chemie, 1998). In this sub-experiment, a nephelometric measurement of the particle scattering of the water samples was carried out. A SHIMADZU RF-5301PC spectrofluorometer was used. The exact wavelength was 860 nanometers. The values were then converted to NTU, a national unit of turbidity.

The exact procedure starts with taking a cuvette that is transparent on all sides (otherwise the measurement cannot be made). You should also only touch the top of the cell to avoid leaving fingerprints on the glass. The cuvette was then filled to two thirds with MilliQ-water and a zero measurement was taken. The cuvette was then carefully cleaned, e.g. with laboratory wipes. The main samples were then analyzed.

Turbidity

Turbidity can be measured using a photometer. This is an instrument used to determine the intensity of light emitted by a light source in a given direction. Technical devices use photoelectric, thermoelectric or photochemical detectors (Spektrum, Lexikon der Physik, 1998).

Light absorption cannot be measured directly. Therefore, a special principle exists to quantify turbidity. This involves studying the attenuation of light as it passes through the solution. The intensity of the incident light and the intensity of the transmitted (non-absorbed) light are measured. The next step is to calculate the transmittance from the quotient. If there are no absorbing particles in the solution of interest, the quotient is one. This is the case with pure water, for example. As the number of absorbing molecules in a solution increases, the light transmittance decreases. The degree of transmission and the concentration of molecules are exponentially related (Spektrum, Lexikon der Biologie, 1999).

In this sub-trial, turbidimetry was performed using the DR3900 photometer. At the beginning, a zero measurement was made with MilliQ-water. To do this, the cuvettes were filled to two-thirds capacity and touched only at the top to avoid fingerprints. After this step, the cuvette was cleaned with laboratory wipes and the measurement of the main samples started. This was also done at a wavelength of 860 nanometers. The values were then converted to NTU, the national unit of turbidity.

Chemical composition

Before looking at the chemical composition of samples, it is important to understand what ions are from a theoretical point of view. It is therefore important to understand the structure of atoms. Atoms are the smallest particles that cannot be divided. They are made up of elementary particles. In every atom there is a region where the positive charge is concentrated. This is called the nucleus. Around this area in the atomic shell are negative particles. The most important elementary particles are protons, which carry positive charge (in the atomic nucleus), electrons, which carry negative charge (in the atomic shell), and neutrons, which are neutral (in the atomic nucleus). Most substances do not exist in pure form, but as compounds (simple to complex). Compounds are formed when atoms bond together. There are four different types of bonds: ionic bonds, atomic bonds, metallic bonds and van der Waals bonds. Ionic bonds occur when there is a large difference in electronegativity between the bonding partners. Ionic bonds are mainly found between metals and non-metals. An example of an ionic bond is sodium chloride, which consists of the positive sodium ion and the negative chloride ion (Schönherr, 2022).

Particles that have one or more electrons less than protons are called ions. They carry an electrical charge called an ionic charge. Monoatomic ions are made up of a single atom. Polyatomic ions, called molecular ions, consist of several atoms, where the total number of electrons can be higher or lower than the total number of protons. Therefore, positively charged ions are called cations and negatively charged ions are called anions. The terms are derived from the field of electrochemistry. In this discipline, a positively charged electrode is called an anode. Negatively charged particles move towards the anode in an electric field and are therefore called anions. Cations, on the other hand, move towards the negatively charged cathode because they are positively charged (Schmidt & Dietrich, 2022).

The chemical composition was determined at the beginning and end of both experiments. Approximately 20ml of each sample was analyzed by the lab technician for the relative content of different ions. The units used were milligrams and micrograms per liter. The main ions were sodium, potassium, calcium, magnesium, chloride and sulphate. The relative contribution of the other substances was very small. Therefore, they are not mentioned here.

Dry weight

Dry mass, oven dry mass and dry substance are terms used synonymously. It describes the mass, typically in grams, of an organic substance after removal of water using a standardized method (Spektrum, Lexikon der Geowissenschaften, 2000). In this sub-experiment, the organic substance was the plant biomass.

Dehydration is usually carried out at a temperature of 60°C or 105°C. In ecology, dry weight is measured to compare different organic substances with different amounts of water (Spektrum, Lexikon der Geowissenschaften, 2000).

In this sub-trial, empty filters were weighed using a special accuracy weighing machine. The water samples were then filtered, using 100 milliliters in the first sub-experiment and 20 milliliters in the second sub-experiment. After this step, the filters were left in an oven at 100 degrees for a few hours. The samples were then collected and weighed again to determine the dry weight.

Ash weight

Ash determination is a method used to determine the quantity of inorganic substances after combustion of the organic fraction. It is typically carried out on animals or plants. The ash of plants usually contains potassium, sodium, calcium and nitrogen, whereas the ash of animals contains calcium phosphate, also known as bone ash. The weight of ash is given as a percentage of the dry weight (Spektrum, Lexikon der Biologie, 1999).

In both laboratory experiments, ash weight was measured at the beginning and at the end of the experiments. Both measurements were made on filtered and unfiltered samples. The oven used to burn the organic matter had a temperature of 450 degrees Celsius. The filters were left there for a few hours. After removing the samples from the oven, the weight was determined using a special precision balance. The percentage of dry weight and the loss due to combustion were then calculated.

Chemical composition:

Raw data in the dilution experiment:

T0: 21.08.2023	mg/l Natrium	mg/l Kalium	mg/l Calcium	mg/l Magnesium	mg/l Chlorid	mg/l Nitrat	mg/l Sulfat	P-PO4 µg/l	P-t µg/l	N-NO2 µg/l	N-NH4 µg/l	Si-SiO4 mg/l
N100R1	684,0	68,6	8,1	211,9	411,5	0,0	837,9	8	66	1,0	38	2,3
N100R2	652,6	68,6	11,1	186,6	393,1	0,0	742,4	7	67	1,9	61	2,4
N100R3	694,3	70,8	9,8	211,6	400,9	0,0	798,6	5	67	1,0	31	2,3
MW	677,0	69,3	9,6	203,3	401,9	0,0	793,0	6,8	66,6	1,3	43,3	2,3
N90R10R1	663,7	65,3	7,1	213,0	372,8	0,0	784,1	7	59	4,7	94	2,2
N90R10R2	638,3	63,1	7,8	203,5	369,4	n.a.	744,5	8	79	3,9	102	2,2
N90R10R3	662,5	68,1	6,5	203,0	372,3	0,0	755,1	5	63	2,3	74	2,1
MW	654,9	65,5	7,1	206,5	371,5		761,2	6,3	67,0	3,6	89,8	2,2
N75R25R1	593,0	59,8	6,9	173,6	320,2	n.a.	651,2	5	62	4,4	132	1,8
N75R25R2	574,8	57,4	5,3	167,2	311,1	n.a.	622,6	4	53	4,3	136	1,8
N75R25R3	605,5	60,9	6,6	188,3	326,6	n.a.	672,5	3	54	4,5	132	1,8
MW	591,1	59,3	6,3	176,4	319,3		648,8	3,9	56,2	4,4	133,3	1,8
N50R50R1	397,9	44,5	4,7	108,6	213,1	n.a.	387,6	3	37	8,7	237	1,3
N50R50R2	464,7	49,3	3,1	154,2	236,3	0,2	491,2	2	37	8,5	231	1,2
N50R50R3	416,4	45,0	2,6	122,5	218,4	0,2	423,1	2	36	8,1	232	1,2
MW	426,4	46,3	3,4	128,5	222,6		433,9	2,5	36,5	8,4	233,4	1,2

T2: 03.09.2023	mg/l Natrium	mg/l Kalium	mg/l Calcium	mg/l Magnesium	mg/l Chlorid	mg/l Nitrat	mg/l Sulfat	P-PO4 µg/l	P-t µg/l	N-NO2 µg/l	N-NH4 µg/l	Si-SiO4 mg/l
N100R1	686,5	68,2	10,1	201,4	313,6	0,3	734,7	2	53	0,5	49	2,4
N100R2	692,2	68,3	9,5	199,5	316,4	0,2	728,5	78	53	0,6	41	2,4
N100R3	668,1	67,1	9,2	178,6	317,3	0,1	708,0	4	53	1,2	40	2,5
MW	682,3	67,8	9,6	193,1	315,8	0,2	723,7	28,2	52,9	0,8	43,5	2,4
N90R10R1	613,7	65,4	8,3	187,9	279,6	0,3	668,9	3	51	0,8	43	2,2
N90R10R2	639,0	65,7	8,3	180,0	280,9	0,4	656,1	4	55	0,6	42	2,4
N90R10R3	639,1	62,7	8,3	177,7	282,4	0,5	658,3	5	50	0,3	51	2,2
MW	630,6	64,6	8,3	181,9	281,0	0,4	661,1	4,0	51,8	0,6	45,5	2,3
N75R25R1	559,2	56,5	7,2	159,5	241,7	0,6	576,7	7	46	0,4	45	1,9
N75R25R2	595,9	57,3	6,9	144,2	234,8	0,7	535,3	18	57	0,6	28	2,0
N75R25R3	563,0	53,8	6,9	140,6	234,0	0,0	532,6	9	48	3,2	249	1,9
MW	572,7	55,9	7,0	148,1	236,9	0,4	548,2	11,2	50,1	1,4	107,6	1,9
N50R50R1	408,4	41,3	4,7	104,8	165,3	1,2	372,9	1	31	0,8	24	1,3
N50R50R2	440,9	44,1	4,5	130,8	171,7	1,3	426,9	5	33	0,2	14	1,3
N50R50R3	358,9	39,1	4,4	111,9	158,2	0,8	374,8	4	32	0,2	113	1,3
MW	402,7	41,5	4,5	115,9	165,1	1,1	391,5	3,4	32,1	0,4	50,3	1,3

Raw data in the evaporation experiment:

T0: 28.08.2023	mg/l Natrium	mg/l Kalium	mg/l Calcium	mg/l Magnesium	mg/l Chlorid	mg/l Nitrat	mg/l Sulfat	P-PO4 µg/l	P-t µg/l	N-NO2 µg/l	N-NH4 µg/l	Si-SiO4 mg/l
NR1	750,3	72,4	8,5	215,2	399,7	n.a.	841,6	6	146	3,0	94	2,8
NR2	837,8	78,9	8,3	242,5	418,3	n.a.	903,0	12	167	3,2	127	2,8
NR3	741,7	71,1	8,3	209,3	392,8	n.a.	830,0	10	154	3,0	99	2,8
NR4	698,5	70,1	8,1	205,1	380,9	n.a.	806,1	8	163	3,0	120	2,8
MW	757,1	73,1	8,3	218,0	397,9		845,2	8,9	157,6	3,1	109,8	2,8
NRR1	741,8	75,0	9,4	225,1	412,4	n.a.	862,5	8	150	3,3	135	3,0
NRR2	769,4	76,4	9,0	224,8	417,5	n.a.	883,8	11	147	3,7	117	3,0
NRR3	959,2	91,2	9,2	304,5	480,3	n.a.	1085,1	17	181	3,6	120	3,0
NRR4	1029,3	92,7	8,9	317,5	485,0	n.a.	1103,1	13	159	3,4	122	3,0
MW	874,9	83,8	9,1	268,0	448,8		983,7	12,2	159,0	3,5	123,4	3,0

T3: 11.09.23	mg/l Natrium	mg/l Kalium	mg/l Calcium	mg/l Magnesium	mg/l Chlorid	mg/l Nitrat	mg/l Sulfat	P-PO4 µg/l	P-t µg/l	N-NO2 µg/l	N-NH4 µg/l	Si-SiO4 mg/l
NR1	711,5	74,2	7,6	193,7	330,8	n.a.	745,9	2,45	135	1,4	128	1,80
NR2	684,3	72,1	7,6	189,3	321,3	n.a.	728,0	1,86	135	1,2	60	1,73
NR3	672,2	69,1	7,6	186,4	325,9	n.a.	736,0	1,57	128	1,2	67	1,71
NR4	663,7	70,3	7,6	201,4	326,0	n.a.	751,4	1,86	133	1,0	57	1,57
MW	682,9	71,4	7,6	192,7	326,0		740,3	1,94	132,9	1,2	78,1	1,70
NRR1	687,3	70,7	8,7	205,7	330,6	0,2	773,1	1,57	121	4,0	128	2,09
NRR2	687,8	68,0	8,2	213,0	329,8	0,3	789,7	4,51	142	60,7	49	3,15
NRR3	669,1	66,7	8,0	183,1	318,2	0,5	719,0	6,27	135	16,2	38	3,08
NRR4	679,4	68,2	8,2	194,9	327,1	0,5	742,5	1,86	131	4,6	55	2,99
MW	680,9	68,4	8,3	199,2	326,5	0,4	756,1	3,55	132,3	21,4	67,6	2,83