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The rescue or the demise of Lake Neusiedl
Danube water discharge into Lake Neusiedl – effects on physical and chemical properties

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Kurzfassung

Der Neusiedler See, ein einzigartiger Steppensee in Europa, ist besonders empfindlich gegenüber Umweltveränderungen. In den letzten Jahren haben der Klimawandel und der Rückgang der Niederschläge zu einem drastischen Rückgang des Wasserspiegels geführt, was in weiterer Folge dramatische Auswirkungen auf das Ökosystem und umliegende Gebiete befürchten lässt. In der vorliegenden Studie werden die Auswirkungen der Dotation des Sees mit Donauwasser untersucht, um festzustellen, ob diese Maßnahme als Rettung oder als mögliche Zerstörung des Ökosystems anzusehen ist. Ziel der Forschung ist es, zu analysieren, wie sich verschiedene physikalisch-chemische Eigenschaften des Neusiedler Sees durch die Zugabe von Donauwasser verändern und welche langfristigen Folgen diese Veränderungen haben könnten. Zur Beantwortung dieser Forschungsfrage wurden zwei Experimente durchgeführt: in Versuch 1 wurden verschiedene Mischungsverhältnisse von See- und Donauwasser über einen Zeitraum von zwei Wochen analysiert, während in Versuch 2 zusätzlich Verdunstungsversuche durchgeführt wurden, um die Stabilität der Wasserparameter zu testen. Die Ergebnisse zeigen, dass die Zugabe von Donauwasser zu signifikanten Veränderungen bei mehreren Parametern führt, darunter Alkalinität, Kalzium-, Nitrat- und Chloridgehalt sowie die Trübe, was auf eine mögliche Veränderung des ökologischen Gleichgewichts hinweist. Diese Veränderungen sind entscheidende Faktoren, die bei der Entscheidung über Maßnahmen zum langfristigen Schutz des Sees berücksichtigt werden müssen. In Anbetracht der kurzen Dauer der Studie sollten insbesondere die Parameter, die signifikante Veränderungen aufwiesen, über einen längeren Zeitraum erneut untersucht werden.

Abstract

Lake Neusiedl, a unique steppe lake in Europe, is particularly sensitive to environmental changes because of its endorheic basin. In recent years, climate change has led to a drastic decline in water levels, raising ecological concerns. We investigated the potential impact of the lake's refilling with Danube water to assess whether this measure should be considered a salvation or a potential destruction of the ecosystem. The aim of the research was to analyze how various physical-chemical properties of Lake Neusiedl change with the addition of Danube water and what long-term consequences these changes could have. Two experiments were carried out to address this research question: in experiment 1, different mixing ratios of lake Neusiedl and Danube water were analyzed over a period of two weeks, while in experiment 2 additional evaporation/refilling experiments were conducted to test the stability of the water properties over time. The results show that the addition of Danube water causes significant changes in several properties, including alkalinity, calcium, nitrate, chloride content, as much as turbidity, indicating a potential change in ecological balance. These changes are crucial factors that need to be considered when deciding on dotation to protect the lake in the long term. Considering the short duration of the study, the parameters that showed significant changes should be reexamined over a longer period.

keywords: ecological balance, dotation, long-term effects, evaporation, hydrochemistry

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1. Introduction

Lake Neusiedl is a unique ecosystem which, as a steppe lake with a shallow depth and high evaporation rates, is particularly susceptible to climate fluctuations and changes in water levels. Due to climate-related dry periods and increasing evaporation rates, the water level of the lake has continuously decreased in recent decades, which poses ecological and economic challenges. Recharging the lake with water from the nearby Danube is currently being discussed as a potential solution to stabilize the water level in the long term and to prevent the lake from drying out (Maracek & Seiler, 2023; Wolfram et al., 2023).

The aim of this work is to investigate the possible effects of refilling Lake Neusiedl with Danube water from an ecological and hydrological perspective. By analyzing current data and evaluating existing studies, a comprehensive understanding of the opportunities and risks of this measure is to be developed before looking at the data from our study in more detail. The following section provides background information and focuses on fundamental topics, such as pro- and cons of a Danube water discharge into Lake Neusiedl.

1.1. Current state of research

There exist already some studies that deal with the water discharge into Lake Neusiedl, as concerns about the drying up of the steppe lake have been present for several years. Wolfram et al. (2020) published a report that dealt with the chemical and ecological effects of Lake Neusiedl's water when it is fed with water from the Moson-Danube. The planned water inflow of around one $cm^3\ s^{-1}$ could raise the lake water level by around ten cm. The report focused on the following four areas: Basic chemistry including water quality regarding nutrients, water quality regarding trace substances and loading processes. The final assessment indicated that the lake hydrology is heavily dependent on climatic conditions; climate change will affect the water balance of the lake. The fundamental aim of the dotation is to avoid extremely low water levels, emphasizes Wolfram et al. (2020). The final assessments of the hydrochemistry indicated that the investigations of recent years have identified two major problems. On the one hand, discharges via the Hanság main channel have a negative impact on salinity and, on the other hand, a direct link between basic chemistry and the decomposition of organic material is expected. Wolfram et al. (2020) highlight that the soda character of the lake, i.e. the elevated pH-value and the high sodium and hydrogencarbonate concentration, must be maintained to protect the lake on a long term. The expert opinion confirms that surface water discharge into the lake does not entail an increased risk of water abstraction via the Hanság main channel and that the changes in the pH-value are also expected to be negligible. Regarding the basic chemistry of the lake, Wolfram et al. (2020) therefore considers discharge as a possible solution to keep the lake in the long term.

According to Wolfram et al. (2020) the addition of calcium-rich water, for example from the Moson-Danube, would increase the precipitation of calcite in Lake Neusiedl. This process leads to the formation of calcareous sludge, which contributes to the silting up of the lake. The input of calcium via doping measures could therefore increase sediment formation in the lake and accelerate the sedimentation process. The formation of lime sludge from calcium precipitation is already promoted by the natural calcium input from the Wulka. Additional fertilization would therefore further increase this effect, albeit to a moderate extent compared to the existing calcium input via the Wulka.

Krachler et al. (2005) studied hydrochemical aspects of charging Lake Neusiedl with Danube bank filtrate. Mixing experiments were carried out with Lake Neusiedl water and rainwater, as well as with Lake Neusiedl water and Danube bank filtrate (mixing ratios were always 1:1). Measurements were taken weekly until the end of the study after 147 days. PH-value did not change in the Lake Neusiedl water/rainwater mixing tests and remained at 8.8 - as did the control with only lake water. PH-value however dropped to 7.9 in the Lake Neusiedl water/Danube bank filtrate mixing tests. Krachler et al. (2005) therefore assumed that mixing Danube bank filtrate with Lake Neusiedl water cannot be seen as pure dilution, but that the strong change in pH can only be explained by a chemical reaction. Krachler et al. (2005) also described shifts in alkalinity, confirming that the alkalinity of Lake Neusiedl water is almost twice as high as that of the Danube bank filtrate. The concentration of carbonate and hydrogen carbonate is correspondingly high. In addition, the Ca^{2+} concentration in the Danube bank filtrate is more than four times the calcium concentration of the Lake Neusiedl water with a total mineralization of less than one third. Based on these findings, Krachler et al. (2005) identified two potential side effects of dotation, namely the formation of calcareous sludge on the one hand and a massive drop in the pH-value on the other.

Wolfram et al. (2019) studied nutrient dynamics of Lake Neusiedl with special emphasis on the long-term development. The suspended solids, which were calculated based on ash mass and loss on ignition, were also relevant. The study was focusing on changes caused by the Wulka water, as the Wulka is the most important inflow is also the main input pathway for external nutrients alongside atmospheric inputs and wastewater treatment plants.

The focus of the current study lies on the potential change of pH, ion composition and light climate in the water column after mixing with Danube surface water. In contrast to Krachler et al. (2005), our study not only examined the sudden change of pH value with a 1:1 mixing ratio, but we also considered different mixing ratios with a lower proportion of Danube water and, above all, a temporal component. To simulate this temporal component periodical changes of the water level due to evaporation and precipitation, the mixed water samples were partly evaporated and refilled with Danube water in the laboratory then measured, as explained in more detail later.

1.2. Danube River

This summary illustrates the main hydrological and geographical characteristics of the Danube that could be of significance for the potential endowment of Lake Neusiedl with Danube water. With a length of 2850 km, the Danube is the second largest river in Europe and is the only major river to flow from west to east. As can be seen in figure 1, it has its source in Germany and crosses ten countries on its way to the Black Sea, including Austria, where it runs for 350 km. The Danube is divided into three sections: the Upper Danube, which flows through mountainous terrain, the Middle Danube, which runs through the Pannonian Plain, and the Lower Danube, which flows along the edge of the Carpathian Mountains. Its riverbed branches out into numerous tributaries and forms islands, especially in the Danube delta area.

figure 1: Location of Danube River

From a hydrometeorological point of view, the Danube basin lies in a temperate climate zone with cold winters and hot summers.

With an average flow rate of around 1733 $m^3 s^{-1}$, it is one of the most water-rich rivers in Europe and has a slightly alkaline pH balance of around 7.8 to 8.4. The electrical conductivity is between 250 and 650 $\mu S\ cm^{-1}$, which indicates a moderate content of dissolved minerals, including calcium, magnesium and sulphate, which are absorbed in the

Carpathian foothills and the calcareous soils of the catchment area (Danube Commission, n.d.).

The typical ion concentrations of Danube River include higher amounts of **calcium** (2.76 meq L^{-1}) and **magnesium** (1.04 meq L^{-1}) and lower amounts of **sodium** (0.50 meq L^{-1}) and **potassium** (0.06 meq $L^{-1)}$. **Sulphate** (0.55 meq $L^{-1)}$ and **chloride** (0.48 meq L^{-1}).
The ion concentration of Danube River vary due to inflows and agricultural discharges. The values represent the mean values from the period from January 2023 to September 2024 (Bundesministerium für Land- und Forstwirtschaft, Regionen und Wasserwirtschaft, 2024).

The Danube is also subject to seasonal temperature differences with values ranging from near 0 °C in winter to around 25 °C in summer. The water current promotes mixing and have a positive influence on oxygen distribution, which around 8 mg L^{-1} in the upper reaches and decreases slightly towards the lower reaches. These characteristics have an impact on biodiversity and water quality along the entire stretch of the river (ICPDR, 2021). Precipitation varies greatly, from 500-600 mm per year in the lowlands to 2500 mm in the Alps. The water quality in the floodplains of the Austrian section of the Danube corresponds to class II, which indicates good water quality (Danube Commission, n.d.).

The Austrian section of the Danube has a mountain river-like character due to the gradient of 40 cm km^{-1} and a flow velocity of 1-3 m s^{-1}. Flooding occurs mainly due to snowmelt in late spring to summer and rainfall throughout the year. The Danube floodplains are an important migration corridor for flora and fauna. Originally, the Danube had a complex, branched riverbed in this section, but this was regulated in the 19th century. Renaturation efforts, such as the connection of oxbow lakes and the restoration of banks, are underway to restore the natural dynamics (ICPDR, 2021).

1.3. Lake Neusiedl

Lake Neusiedl is a unique waterbody, not least because it is one of the largest steppe lakes in Europe. In principle, the lake is characterized by three different categories that influence the ecological conditions: hydrometeorology (evaporation, precipitation, and wind), morphology (size, water depth, reed belt) and physical-chemical water properties (salinity, pH-value, nutrients, turbidity, temperature) (Wolfram et al., 2023). To understand the lake water properties and to be able to assess the lake area and consequently answer the research question, it is necessary to look at all those factors. However, the focus of this study and thus also the theoretical part is undoubtedly on the physical-chemical properties of the lake water. Nevertheless, it is essential to briefly summarize the other factors to gain a general understanding of the lake properties and to examine the lake's history, since its often part of discussions about the dotation of the lake.

With a total area of around 320 km², Lake Neusiedl is the largest steppe lake in Austria. The open water surface of the lake covers around 140 km², while the surrounding reed belt, the largest continuous reed bed in Central Europe, covers around 180 km². With an average depth of around 1.1 m and a maximum depth of 1.8 m, Lake Neusiedl is one of the very shallow lakes, which characterizes its hydrological and ecological dynamics. The catchment area of the lake covers around 1120 km², with the Wulka serving as the main tributary. Due to the high evaporation rate, the lake has a fluctuating salinity of around 0.3% to 0.5 %, which makes it more saline as a terminal lake during dry periods and influences its sensitive water chemistry (Dokulil et al., 2001; Biological Station Lake Neusiedl, n.d.). Lake Neusiedl is located in the Pannonian climate region and is surrounded by a specific catchment area with special climatic and geographical characteristics. The catchment area extends over parts of Austria and Hungary (Dokulil et al., 2001).

Climate

The Pannonian climate is characterized by high summer and low winter air temperatures. The summer months often reach more than 30 °C, while winters are relatively cold, with average lows of around -2 to -4 °C. The annual precipitation is relatively low, averaging around 600 mm, which places the lake and its catchment area in a rather dry climate zone. The highest precipitation usually falls in spring and autumn, while summer is often characterized by dry periods (Herzig, 1976).

Vegetation and soil

The catchment area of Lake Neusiedl is characterized by salt-loving plant species, especially in the surrounding salt pans. The soils are strongly influenced by the geological development, and evaporation, which leads to the formation of salt-rich layers. The very specific conditions promote vegetation that is adapted to drought and salt and therefore creates unique ecological niches in the region (Wolfram et al., 2020).

Influences on water quality

Due to the continental climate and shallow depth, Lake Neusiedl is susceptible to high evaporation losses and the associated concentration effects of dissolved ions, particularly sodium and hydrogen carbonate. In addition to the Wulka, the catchment area also contributes agricultural wastewater and nutrients discharge into the lake, which deteriorates its water quality. The high alkalinity and buffering capacity of the lake are crucial for maintaining a stable pH-value, but the climatic conditions often lead to high nutrient concentrations and eutrophication tendencies (Dokulil & Teubner, 2001).

Lake Neusiedls sourrounding

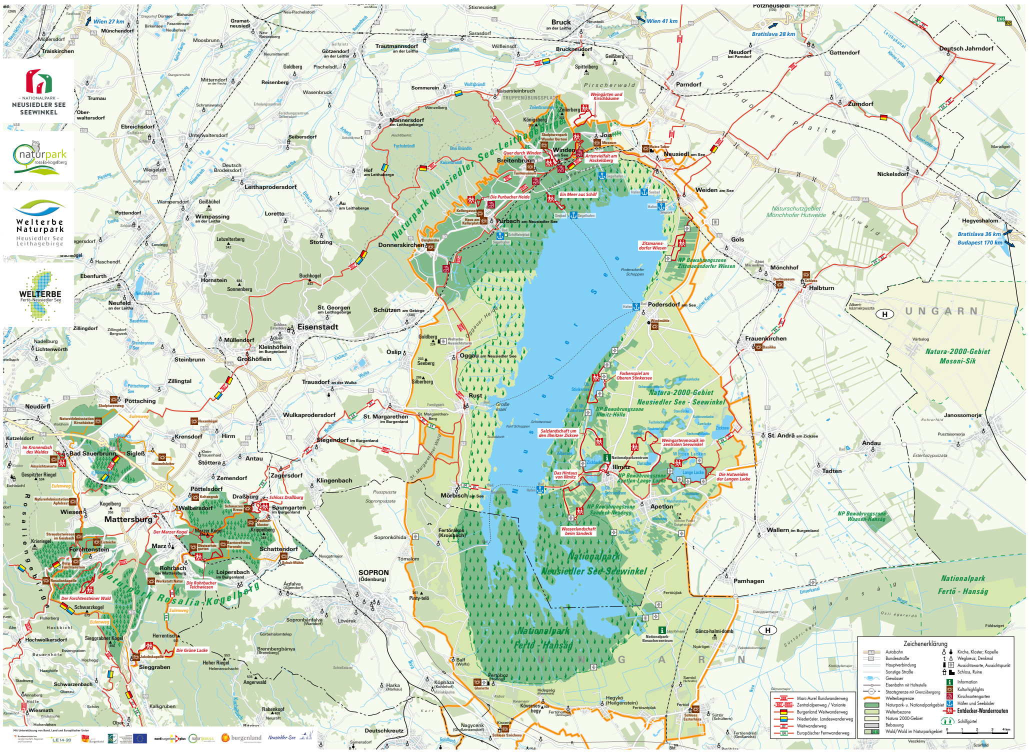

figure 2: Lake Neusiedls sourroundings (Welterbe Naturpark, n.d.)

The Leitha Mountains in the West are around 35 km long and separate the Vienna Basin from the Little Hungarian Plain of Kisalföld. They serve as a weather divide and climate regulator. The Leitha Mountains are separated from the lower reaches of the Wulka and continue in the Ruster Höhenzug mountain range, which stretches for around 21 km. The Parndorfer Platte, which lies about 35 meters above the lake level, borders the lake to the North with an altitude of about 150 m - 190 m. To the South, the terrace gravels of the Ivka, a river that also flows into the “Einserkanal” (Hanság Canal), form the counterpart to the Parndorfer plateau. In the past, villages such as Fertöboz were located on the lake before the reed belt reached its current extent. Today, they are part of the Hungarian Plain (Krizsanits & Machtinger, 2023).

To describe the lake, it is also necessary to mention the salt pans and the Hanság in the East, which belong to the greater Lake Neusiedl area like the Leitha Mountains belong to the Alps. The Hanság is a fen on a gravel bed and used to be called a "floating lawn". In former times, it was connected to the lake at high-water events, but this has changed when, in 1895, drainage channels were built and the Hanság Canal was created to lower the water level of the lake and drain the agricultural land. The Hanság, which was

originally characterized by moisture and moorland, now stands for its dryness and salt marshes since human intervention, starting in the 18th century but especially since building the Hanság Canal in 1895. As a result, Lake Neusiedl is seen as a water body with high anthropogenic impact. The salt marshes and their number have changed considerably. While around 140 salt ponds in the 19th century were listed, there are fewer than 30 still existing, most of them endangered. The reduction can be attributed to several reasons, such as drainage measures and regulation, changes in the groundwater balance (also due to abstraction for agricultural purposes) and especially climate change. Since the 19th century, extensive drainage projects have been implemented, such as the construction of the Hanság Canal and other drainage canals, to make the land suitable for agriculture and prevent flooding. These measures led to the draining of many smaller salt ponds and a reduction in the water level in the existing ones.
Also, intensive agricultural use and water abstraction have further lowered the groundwater table in the Lake Neusiedl area, which has led to the drying up of wetlands and salt ponds. The reduced groundwater supply impairs the natural recharge of the ponds. As mentioned before, also climate change can be seen as one of the main factors for the change in the number of salt ponds.
Climate change has increased the frequency and duration of dry periods in the region. Rising temperatures and the reduction of precipitation, especially in summer, have led to the few remaining ponds drying out more, as was observed in the summer of 2022 when all salt ponds dried out completely. These factors have severely altered the hydrology and ecological dynamics of the salt ponds, jeopardizing the long-term existence of these unique biotopes (Krizsanits & Machtinger, 2023).

The morphology of the lake is also a key factor, which is characterized by several aspects. One characteristic is the very shallow depth. Depending on the water level, Lake Neusiedl has an average depth of 1.1 m to a maximum depth of 1.8 m and is therefore extremely shallow. The open lake is heavily exposed to winds and waves. Frequent mixing of the entire water body combined with the soft sediment turns the lake into a highly turbid system. The open water is subject to alternating erosion and sedimentation, resulting in a thick sediment layer. Fine sediment particles are mainly deposited in wind-protected areas, which is limited mainly to the western shoreline, bays and the reed belt. This also results in the typical high turbidity of Lake Neusiedl (Wolfram et al., 2023).

Although the change in lake depth and volume is determined by various components, the water balance is mainly influenced by meteorological factors such as evaporation and precipitation.

Hydrometeorology

To consider the meteorological and hydrological conditions, it is mandatory to consider the catchment area. The catchment area of Lake Neusiedl is very small. The lake has a basin of 320 km^2. Its actual catchment area is only just 1116 km^2 (it has decreased dramatically in the last centuries due to human impact – see below). The ratio between Lake Neusiedl and catchment area has a strong effect on the lake water. The catchment area can be divided into different types: the eastern area can be defined as lowlands, while on the other hand the northern and north-eastern parts form a hilly landscape and the eastern foothills of the Leitha Mountains form a mountainous landscape. Except for the Wulka River, no significant surface tributaries discharge into the lake in these days. This largest inflow with around 30 million m^3 per year contributes to only around 22% of the total water balance of Lake Neusiedl (Wolfram et al., 2014).

Much more important in the context of the water balance is the precipitation, which fluctuates greatly from year to year. Evaporation is at least as variable, which means that the lake can dry out completely after several hydrologically unfavorable years, which was the case around 150 years ago (Wolfram et al., 2020). In this period between 1865 and 1871, the conditions were however different to the current ones, since in those years there was no regulation of the water balance as there is today. Canal systems and sluices had not yet been built in this period and people therefore had no way of stabilizing the water level and were entirely at the mercy of natural fluctuations. The climatic conditions were also different; there were several dry periods of the lake compared to today.

According to Maracek & Sailer (2023), historical comparisons are therefore only of limited use regarding climate change. One difference that Maracek & Sailer (2023) also emphasize is the change in salinity, which is higher today than in the past. This is partly due to the lower water level but also caused by changed hydrological conditions. The lake basin turned from a flow-through system with in- and outflow to an +- endorheic system (there exists a lock construction, which is closed since years). Nowadays, the lake is a closed basin, which must not be neglected in the discussion about water level management.

Endorheic lakes, also called terminal lakes, are commonly found in steppe regions where the lake hydrology is mainly dependent on evaporation and precipitation; surface inflows and outflows only play a secondary role. Lake Neusiedl can be seen not only as an endorheic lake, but also as an amplifier lake with the water level mainly controlled by the local climate (figure 3).

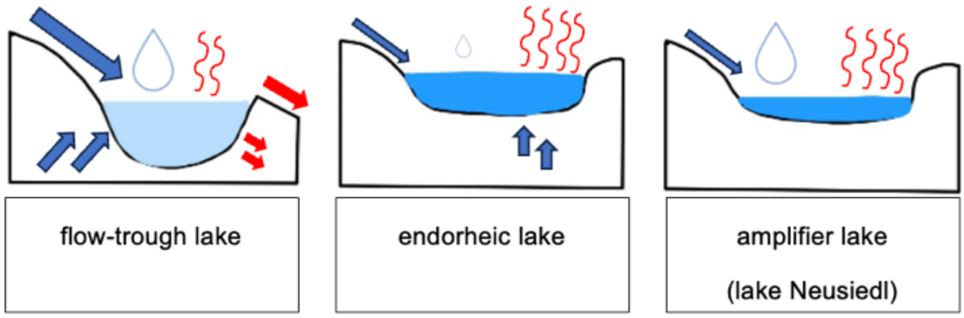

figure 3: Different types of lakes, edited after Schagerl & Renaut, 2016

A comparison of the water balance of Lake Neusiedl between 1996 and 2003 (figures 4 and 5) clearly reveals the changing hydrology between years. In 1996, water was drained from the lake via the weir "Einserkanal", the evaporation was measured with 509 mm, and the precipitation with 728 mm (Wolfram et al., 2020).

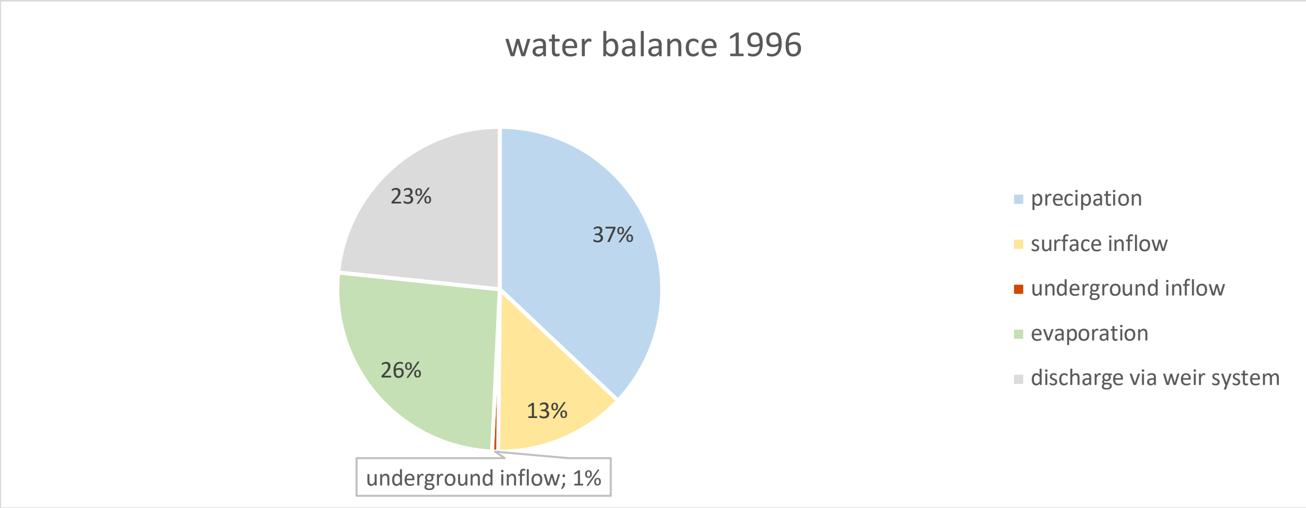

figure 4: Water balance of Lake Neusiedl of the significant year 1996, edited after Wolfram et al., 2014

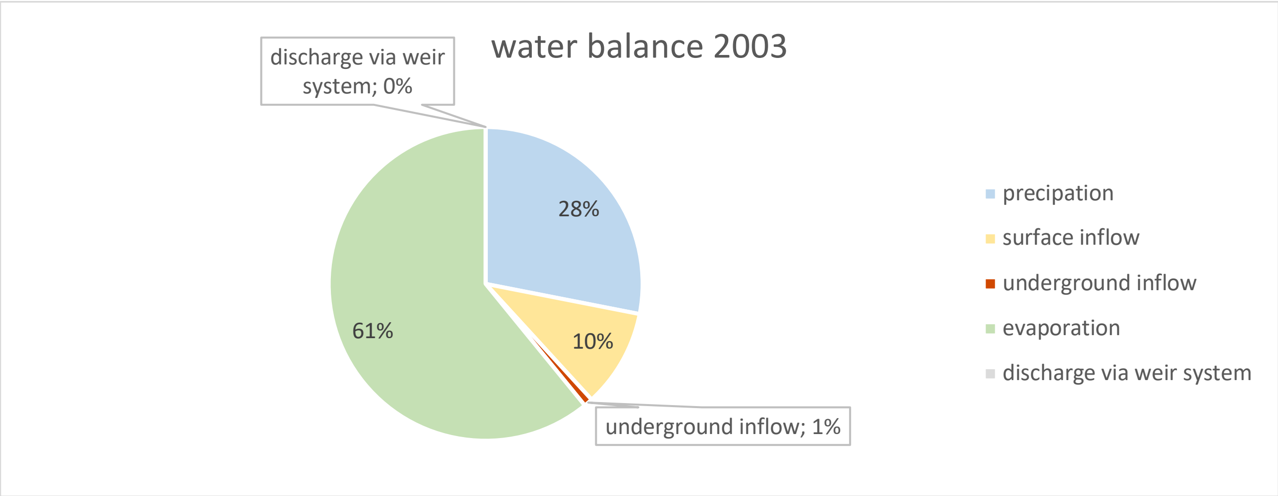

figure 5: Water balance of Lake Neusiedl of the significant year 2003, edited after Wolfram et al., 2014

In 2003, the lock construction was closed, evaporation rose to 800 mm and precipitation dropped to 369 mm. The conclusion is that Lake Neusiedl developed from a lake with high precipitation to a lake receiving low precipitation (Wolfram et al., 2020).

The shift of the lake is still ongoing; precipitation and water temperature continue to change significantly, primarily due to climate change. The change in temperature can be seen in figures 6 and 7, which shows the temperature of the indicated year and the percentage of the deviation regarding the reference period from 1961 to 1990. The low precipitation and high temperatures result in an accelerated drying out of Lake Neusiedl.

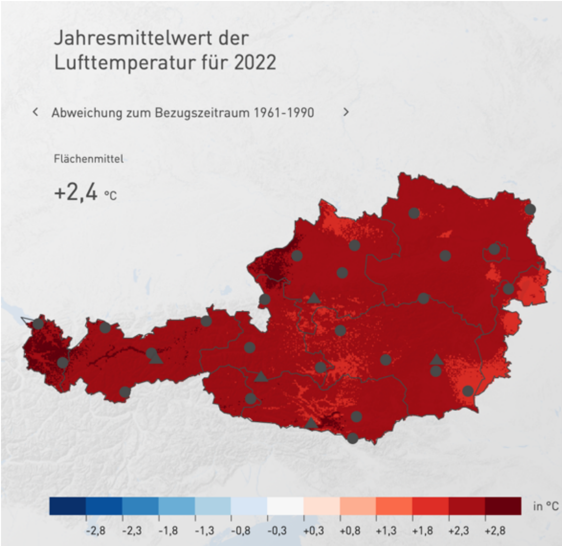

figure 6: Annual average of temperature 2022 (Geosphere, n.d.)

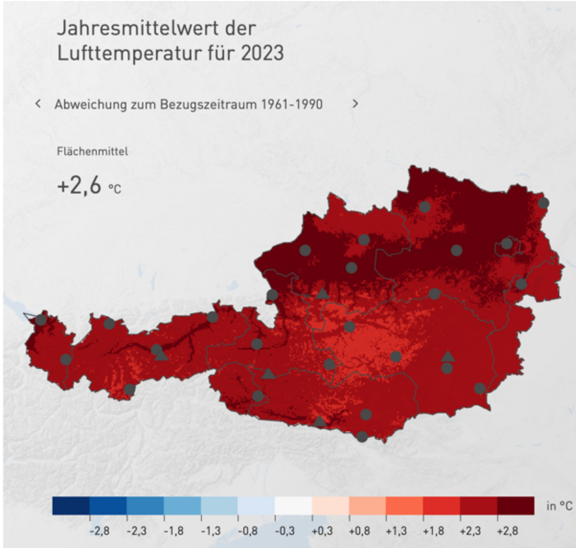

figure 7: Annual average of temperature 2023 (Geosphere, n.d.)

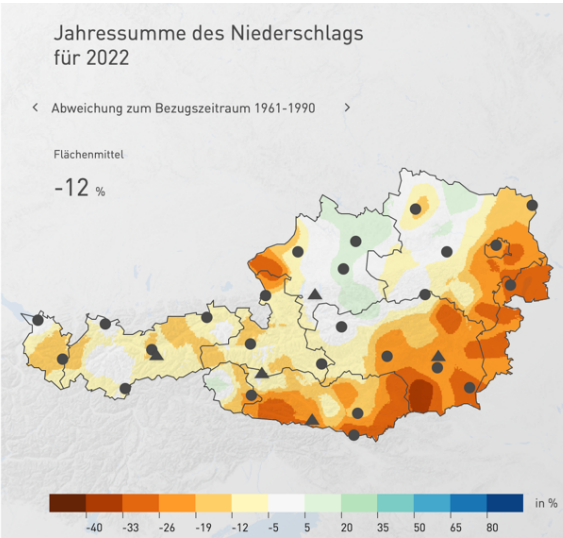

figure 8: Annual total precipitation 2022 (Geosphere, n.d.)

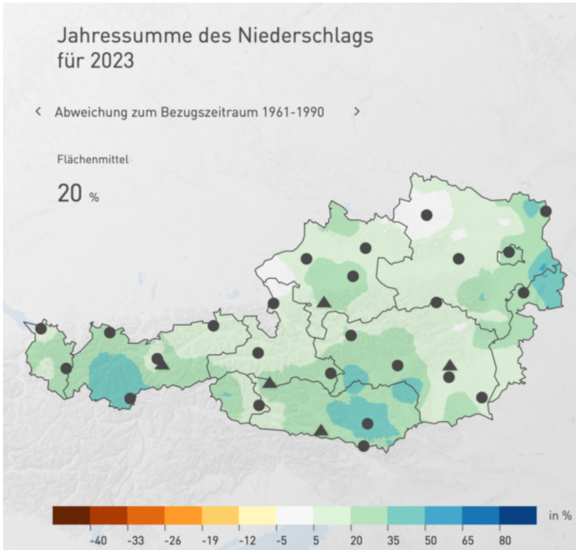

figure 9: Annual total precipitation 2023 (Geosphere, n.d.)

Annual precipitation highly fluctuates (figures 8 and 9), however, a general decline is clearly recognizable over the last decades (figure 10).

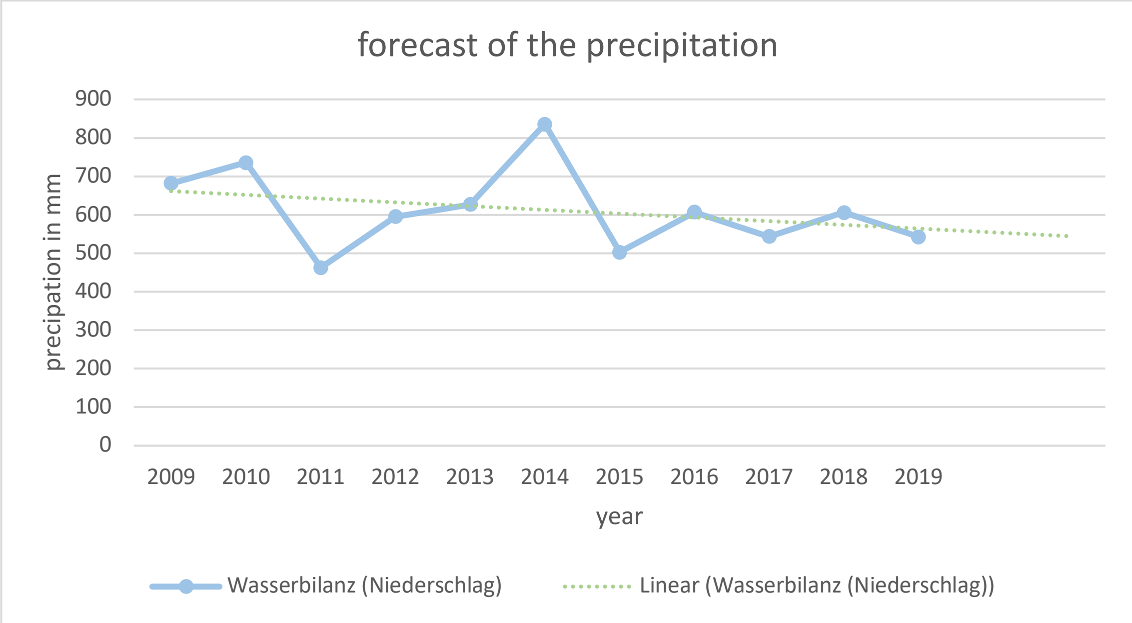

figure 10: Forecast of the precipitation, edited after Geosphere Austria, n.d.

Wolfram et al. (2023) discuss shifts of the sodium content of Lake Neusiedl and emphasize that it changes permanently. The lake has the tendency to develop in the direction of a true salt lake, but this is often interrupted by discharges into the "Einserkanal" (Hanság Canal) at elevated water levels, which then dilute the previous salt content. Repeated anthropogenic interventions are taking place since centuries. The Hanság Canal is by far the largest hydraulic engineering infrastructure in the Lake Neusiedl area. It is an approximately 30 km long canal with a slight east-west gradient and connects the lake basin with the Raab-Danube system via a weir system (Maracek & Sailer, 2023).

Physical-chemical properties of the lake

The water temperature of Lake Neusiedl fluctuates greatly as can be also seen in table 1. The daily temperature variation in Lake Neusiedl can be up to 4°C to 5 °C due to the shallow depth and the large water surface. This effect is characteristic of shallow lakes due to heating via direct sunlight and strong nocturnal cooling (Dokulil & Teubner, 2001).

In wind-protected areas such as the reed beds, Lake Neusiedl can reach maximum temperatures of up to 35 °C. Compared to other lakes, the average water temperature is warm. It is possible that the humic substances additionally increase the absorption of light (Wolfram et al., 2023).

Dokulil et al. (2001) mention the polymictic mixing regime of the lake. Due to its shallow depth and high surface-to-volume ratio, the lake's water is regularly mixed by the wind, which allows the water body to circulate. As a result, the water column remains homogeneous almost all year round and no permanent thermal stratification occurs. The polymictic regime ensures a constant oxygen supply throughout the water body and favors the distribution of nutrients.

An overview of the physical-chemical aspects of the lake water is found in table 1. Selected parameters show that the lake is rich in dissolved minerals, which explains the high conductivity and alkalinity. This reflects the specific hydrological and geochemical conditions that characterize Lake Neusiedl.

table 1: Chemical-physical parameter of Lake Neusiedl (1998-2009) (Wolfram et al., 2014)

Chemisch-physikalische Parameter des Neusiedler Sees (1998-2009)

Parameter	Einheit	offener See Österreich	
		MW	Bandbreite
Elektrische Leitfähigkeit	µS cm^{-1}	2 249	1 300–3 200
pH-Wert	–	8,7	8,0–9,1
Sauerstoff	mg O_2 L^{-1}	10,3	5,8–17,2
Wassertemperatur	°C	14,7	0,2–28,7
Calcium	mg Ca L^{-1}	31	3–119
Magnesium	mg Mg L^{-1}	144	17–199
Natrium	mg Na L^{-1}	363	207–684
Kalium	mg K L^{-1}	39	15–67
Carbonat	mg CO_3 L^{-1}	39	3–97
Hydrogencarbonat	mg HCO_3 L^{-1}	610	346–1 139
Chlorid	mg Cl L^{-1}	253	141–406
Sulfat	mg SO_4-S L^{-1}	163	90–270

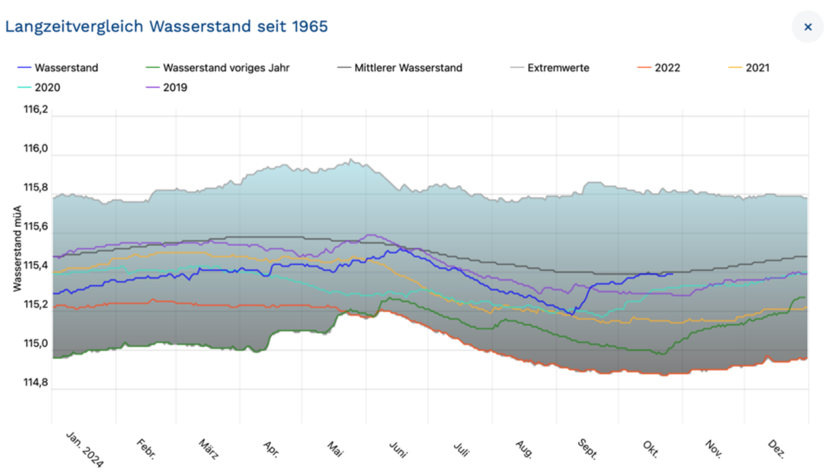

figure 11: water level of Lake Neusiedl since 1965 (Wasserportal Bugenland, 2024)

Figure 11 shows the long-term comparison of the water level of Lake Neusiedl since 1965 and thus provides a comprehensive representation of the annual and seasonal fluctuations over several decades. The curves illustrate the developments and changes in the water level in different years and provide indications of climatic and hydrological trends as well as potential effects of anthropogenic interventions.

There are some points, that need to be considered when discussing the dotation of Lake Neusiedl (see also figure 11):

-Long-term decrease in water level: A long-term comparison shows a gradual decrease in the average water level, particularly in recent years. While the water level tended to be higher in the 1970s and 1980s, a significant decline has been observed since the 2000s. This decline can be attributed to a combination of climatic changes, such as rising temperatures and longer dry periods, as well as changes in precipitation patterns. Wolfram et al. (2020) indicate that climate change is leading to an increase in evaporation rates, which is particularly serious for a shallow body of water such as Lake Neusiedl.

-Seasonal fluctuations and evaporation effects: Fluctuations of the water level over the year show that the lake loses water particularly in the summer months due to evaporation. Evaporation is one of the main components in the water balance of Lake Neusiedl and can quickly lead to a water deficit due to the shallow depth and large surface area of the lake (Blaschke, 2023). The extremely low lake levles recorded in recent summers make it clear that the lake loses significantly more water in summer than can be replenished by precipitation or inflows.

-Water level deviations and climatic extremes: The boundaries of the grey area in figure 11 shows the highest and lowest water levels since detailed records are available (year 1965). Extreme low water levels, such as in 2022, occur nowadays more frequently, which illustrates the lake's increasing susceptibility to dry periods. According to Maracek & Sailer (2023), this is a further indication of the influence of climate change on the hydrological conditions in the region. The increasing trend towards more extreme low levels shows that the lake reaches the limits of its capacity in hydrologically unfavorable years, which can have a negative impact on the ecosystem and water quality.

-Comparison with previous years and the average water level: The grey line in the diagram marks the average water level over the entire period and provides a reference value for comparisons. The water levels in recent years are increasingly below this average value, which indicates a long-term shift in the water balance towards lower water levels. The years 2019, 2020 and 2021 are each below the average water level and reinforce the impression that Lake Neusiedl is permanently carrying less water. According to studies by Krachler et al. (2005), this could not only affect water availability, but also lead to a change in water chemistry and increased sediment deposition.

-Effects on the ecosystem and the risk of salinization: A permanently low water level can severely disrupt the ecological balance of the lake. A reduction in the water volume leads to an increased concentration of ions, which can contribute to the salinization of the water in the long term. Wolfram et al. (2020) assume that this can strongly influence the plant growth and aquatic organisms. A low water level could result in fewer nutrients and less oxygen being available in the water, which could destabilize the entire ecosystem.

-Discussion of water dotation as a possible solution: The actual trends of the water level highly support the argument for water allocation as a measure to stabilize the water level. A targeted supply of Danube water could partially compensate for the loss of water through evaporation in the summer months. However, this is a controversial issue. While proponents argue that a controlled dotation is mandatory to maintain the ecological and economic balance of the lake (Maracek & Sailer, 2023), critics such as the WWF (2023) warn of the ecological risks. Damming could alter the delicate balance of ion concentrations in the lake and increase the risk of salinization or sedimentation. The diagram shows that the water level in the summer months is often below the average values, which suggests that an allocation makes sense as a possible solution to avoid extreme low levels.

-Long-term forecasts and management strategies: Data of the actual lake status imply that Lake Neusiedl is increasingly affected by the climate change and that a long-term solution is required to ensure its continued existence. In addition to the dotation, alternative strategies such as optimizing water retention in the Seewinkel, closing the Hanság Canal in dry years and building retention basins could also offer a solution

(Blaschke, 2023). These measures could help to reduce water loss without affecting the natural chemistry of the lake.

Development of the lake area

Lake Neusiedl has undergone significant changes since its formation approximately 13000 years ago. From its geological formation to changes in the water level, human influence, protective measures and renaturation, several aspects need to be considered, before pros and cons of dotations should be discussed. First, Lake Neusiedl, as we know it today, has been strongly influenced in the past including considerable changes of the lake area and the catchment area. This is relevant to highlight when talking about the consequences of an endowment. It was only at the end of the last ice age (approximately 13000 years ago) that various tectonic activities led to the partial subsidence of the Pannonian deep-sea plain and the development of Lake Neusiedl. The original level was the Parndorfer plate.

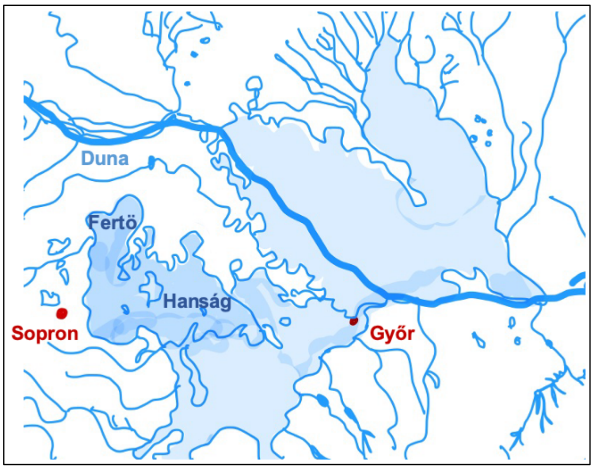

figure 12: Water landscape around the lake 1830, edited after Archiv des MBFSZ (n.d.)

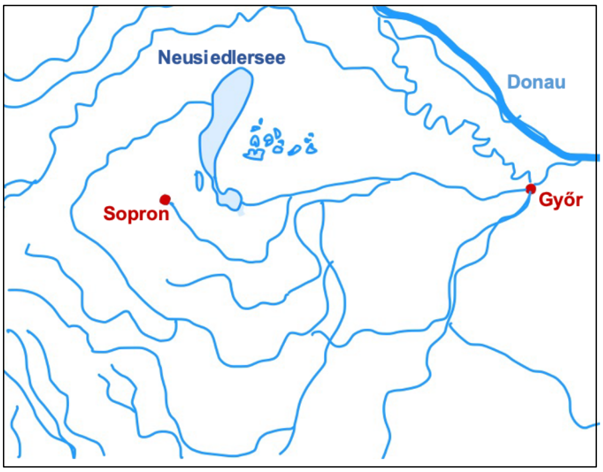

figure 13: Lake surroundings now, edited after Archiv des MBFSZ (n.d.)

Figures 12 and 13 clearly show a dramatic decline of water bodies and swampy areas in the last two centuries, and demonstrate that Lake Neusiedl received significant changes, many of them caused by anthropogenic impact. Where once there was a large lake area, today there are no longer any free, open water areas next to Lake Neusiedl, only rivers that point to the former water landscape (Häusler et al., 2021).

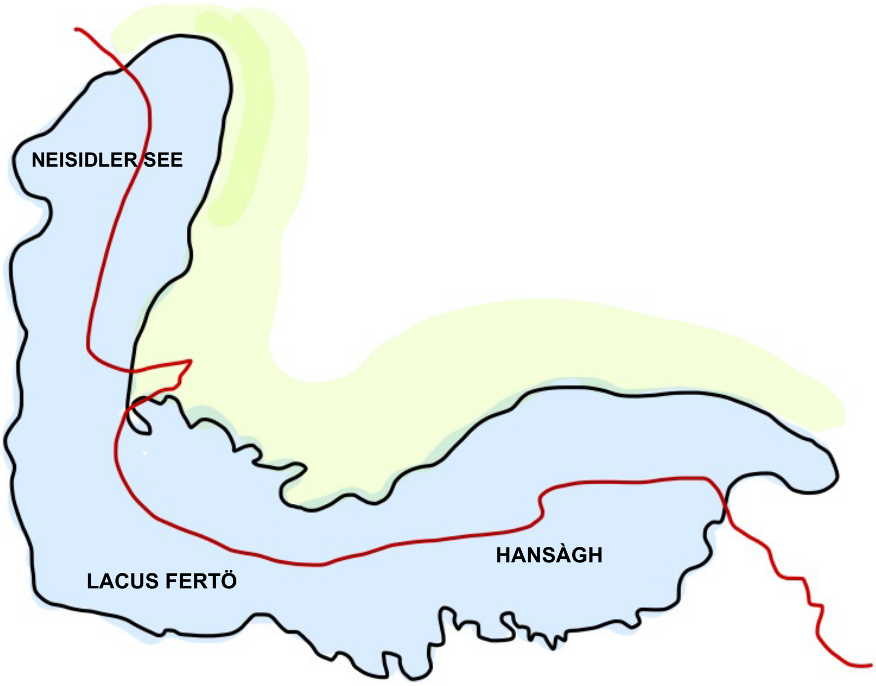

figure 14: Lake Neusiedl before separating through the Hanság, edited after Häusler et al. (2021)

The size of Lake Neusiedl has also changed drastically since then. Around 1780, a dam road was built between Pamhagen and Fertöd, separating Lake Neusiedl from the Hanság. Before the lake looked like shown in figure 14. Old maps indicate that south-east tributaries Rabnitz and Ikva were discharging into the Hanság, which was still considered as part of the lake at that time. There was also a natural outflow in the direction of the Danube River. Nevertheless, it can be assumed that the lake already had the character of a steppe lake at that time and had features of today's lake basin.
A closer look at the history of the lake's formation reveals that it is around 12000 to 15000 years old, although there is no stratigraphic evidence of this. The Wulka is said to have been depositing sediments into the lake for around 9000 years (Häusler, 2007).

The origin of Lake Neusiedl was formerly explained by two theories: (1) the lake is a remnant of an arm of the Danube being connected to the river underground, and (2) the lake dates to a time when the Burgenland was "still by the sea". Both theories can be ruled out today (Krizsanits & Machtinger, 2023), because modern methods, boreholes and laser scans gained new insights. In the 20th century, the lake was no longer considered as an isolated water body, but as a landscape. It is nowadays recognized that the lake is embedded in the greater area between the Leitha Mountains, Rosalia Mountains, Wiener Neustädter Pforte, Ruster Hügelland, Wulka Plain, Parndorfer Platte, Seewinkel and Heideboden, between various landscape elements that are seen as peripheral zones of large landscapes. The lake is located between the Eastern Alps, the Carpathians and the Pannonian Basin and thus in a tension-filled transition zone that has been undergoing tectonic changes since the Miocene. These changes, therefore, have been taking place for 23 million years, and they have also led to the collision of the Eurasian plate and the Adriatic plate. These tectonic forces have not only resulted in numerous mineral springs but also many earthquakes and movements. According to current findings, this is one of the reasons for the formation of Lake Neusiedl (Krizsanits & Machtinger, 2023).

Age information of this magnitude results primarily from the ion balance of the calcium in the lake mud which, according to Schroll (1995), is approximately 10000 years old and therefore makes the age of the lake younger than 20000 years. Based on 14-C dating of deposits in the Hanság, five stages in the development of Lake Neusiedl can be summarized (Häusler 2007):

1. **highstands of unknown age**
   Although Kollmann (1960) documented the remains of lake deposits near Großhöflein/Eisenstadt, there is a lack of age-related investigations. Therefore, the data for the formation of the Palaeo-Lake-Neusiedl are based on findings of shell crabs, which were found near Jois, but according to Kollmann (1960) are not intended for an adequate age classification. However, the joint occurrence of cold- and warm-loving shell crabs was later used for age classification and the findings showed that Lake Neusiedl in its present size must be significantly older than 10000 years (Sauerzopf, 1959).
2. **low level from 3600 BC - 1700 BC**
   A low point, such as Lake Neusiedl has also recorded in recent years, was previously documented at the northern edge of the lake in 3600 BC. This was documented by linear pottery. In addition, at the southern edge around 2000 BC and some grave finds dating from 1700 BC, which were found in today's Oggau area, proved the age. The oldest 14-C dating comes from the moor development in Hanság around 2000 BC (Häusler, 2007).

3. **lake high from 600 BC to Anno Domini (AD)**
   Sauerzopf (1959) describes the Hallstatt residential pits in the Zicksee area from this period as evidence of the earliest settlement of the Seewinkel at a height of about 120 m above the Adriatic Sea, thus indicating a former lake highstand in the former Raab/Rabnitz estuary area. Since the 14-C dating records a continuous bog development from 2000 BC to the beginning of the present era, there are no proven lake deposits in the Hanság from this period. The lake clays of Hanság therefore appear to be younger and the finds from the La Téne period, around 400 BC to Anno Domini, also suggest a peak in the water level. Salt lakes could only be formed after the lake receded (Häusler, 2007).
4. **low level of the lake around 400 AD and formation of the lake dam**
   There is evidence from the late Roman period from the vicinity of Oggau and north of Podersdorf, which proves a low point. Around this time, a moor in Hanság dates to 400 AD. After this period, a dam was formed on the eastern shore at higher water level. The sediment was pressed against the shore in the form of a wall due to winter ice impacts and storms and a lake dam was formed (Häusler, 2007).
5. **last contiguous Hanság - Lake Neusiedl around 1560**
   Since the drying out of Lake Neusiedl in 1740, the subsequent fluctuations of the lake level have been very well documented. Before that, the Lazius map of 1561 still shows a clear mouth of the Raab into a coherent lake, which also still included the water surface of the Hanság. As a result of the drainage of the Rabnitz to the Danube and works since 1568, the level of the Lake Neusiedl sank and the Hanság fell dry (Häusler, 2007).

Even if no exact age classification of the oldest deposits of Lake Neusiedl can be made to date, it is still possible to reconstruct to some extent how Lake Neusiedl was formed with the help of the available facts (Häusler, 2007).

What is certain is that no humans lived in the region when the lake was formed. This only happened in the Mesolithic and Neolithic periods. At that time, a warm, dry climate prevailed, which today is referred to as the Atlantic climate. It was only when the lake receded completely in the 19th century that Count Béla Széchenyi found the remains of a settlement between Fertöboz (Holling) and Hidegség (Kleinandrä) in 1874. Even though no pile-dwelling settlement has been found on Lake Neusiedl to date, Széchenyi's findings and documentation are of great importance, as they suggest that the lake had probably dried up for a long period of time before this. Shards and stone tools, as well as jewelry, teeth and charcoal were found 200 m to 500 m from the original shore. Remains of human settlement were also found in Rust. The lake probably reached its present size towards the end of the Stone Age and many settlements were built (Krizsanits & Machtinger, 2023).

When talking about the historical components of Lake Neusiedl, it must be clearly emphasized that the biostability, i.e. the chemical, chemical-physical and biological characteristics of Lake Neusiedl, began to alter at the beginning of the 20th century. The construction of the Hanság Canal and the increased discharge of nutrient-rich wastewater until the 1970s, because of settlement development in northern Burgenland, are seen as decisive factors for this. As a result of these developments and the artificial discharge, thousands of tons of specific salts were lost whenever there was a risk of flooding (Zechmeister, 2023). Zechmeister (2023) explains that "sweetening" of the lake and the introduced nutrients promoted the expansion of the reed belt as it is today. If the actual area of the reed belt is compared with that of the 19th century, it becomes evident that it significantly increased in size. In former times, the reed belt showed many gaps and did not cover the entire area. The lack of essential salts increasingly sealed off the reed belt and thus changed the chemical processes in the lake area, which influenced the decomposition of organic materials. Peat formation and sediment deposition is increased. As a result, the loading processes were also intensified and subsequently less dynamics are recognizable in the lake, which in turn leads to lower water levels. The global warming that has been measurable since the end of the 1990s has also led to higher evaporation rates and changes in precipitation periods. This cycle means that even small increases in temperature due to global warming led to a significant change in the extent of the water surface, and it can therefore be summarized that anthropogenic factors have significantly contributed to the general conditions of the lake since the 20th century. Lake measurements from 1963 and 1988 show that the extent of sedimentation has increased; the volume of silt sediment in the Austrian lake basin (including the reed belt) roughly doubled between the two dates.

The water level regulation is of central interest, as the water level is one of the decisive factors of dotation or opening the lock. In 1964 there was a cross-border agreement between Hungary and Austria on a higher regulation level and technical changes to the lock. From 1965 on, the water fluctuations were half a meter higher than before, so comparisons with the water levels before 1965 can be considered meaningless (Maracek & Sailer, 2023).

Changes in the lake level also affect its chemistry, which is the focus of the work. Sodium concentration has changed repeatedly over the years, even recently during the first decade of the new millennium. There is evidence of a slow but steady increase in sodium, which is then interrupted by regular discharges into the Hanság Canal (Maracek & Sailer, 2023). Maracek & Sailer (2023) emphasize that also nutrient contents showed strong fluctuations in the last century, which can be explained by eutrophication in the 1970s and 1980s, followed by construction of sewage treatment plants. Particularly unexpected and striking was the increase in phosphorus concentration at the beginning of the 2000s at low water levels. This phenomenon is also currently observed and likely to increase over the next few years unless the lake can show a significantly higher water level so that the interaction between the open lake and the reed belt can function again.

Since 1868, Lake Neusiedl's cultural history has been shaped by significant geopolitical changes, including the Nationalities Act and the division between Austria and Hungary. Tourism on the Austrian side began in the 1920s, while Hungary's side remained less developed. In the 1960s, conservation efforts increased, leading to the lake's designation as a UNESCO Biosphere Reserve in 1977 and as a World Heritage Site in 2001, underscoring the importance of responsible protection (Krizsanits & Machtinger, 2023).

1.4. Adding Danube water as a solution?

The lake and the surrounding area are unique in many aspects and therefore particularly worthy of protection. The initial idea in the 1920s was to artificially dry out the lake. This consideration has however completely turned into the opposite, namely, to preserve the lake at all costs. One major problem is that the interests of the stakeholders around the lake are manifold: nature conservation, recreation, fishing, economic issues versus individual interests, tourism demands and the interests of local people. The ideal solution would be to consider all concerns, which is how the province of Burgenland is formulating its goal, taking many factors into account. The aim is to preserve the uniqueness of the region in its actual state, protect the organisms and their habitats and at the same time preserve Lake Neusiedl as a landscape element (Krizsanits & Machtinger, 2023).

The groundwater situation of the Seewinkel area is also exceptional. The natural water balance in the area is determined by the warm air temperatures during the summer season combined with low annual precipitation of less than 600 mm. The clear influence of the Pannonian climate leads to a high average air temperature, whereby evaporation leads to a negative water balance, especially in the summer months. The result is a typical annual variation of the groundwater level, which leads to high levels in spring and, in comparison, low levels in late summer. In addition, there are no large natural rivers in the area, so the groundwater cannot be naturally renewed by infiltration. This means that groundwater is not recharged by watercourses, as is usually the case, but solely through the infiltration of rainwater - which poses a problem due to the low rainfall combined with agricultural use for irrigation. The Seewinkel is therefore a very sensitive area. In addition, Lake Neusiedl has a low flow velocity or longer water retention times, as it only has a low groundwater gradient, which is also a special feature (Blaschke, 2023). Blaschke (2023) states that it is not possible to predict how climate change will affect the Seewinkel and what it will mean for the lake to have to tolerate this additional component.

Of course, there are also other components that are always under discussion regarding endowment of Lake Neusiedl. In addition to the already sensitive water management situation, there are numerous other uses of the Seewinkel that place demands on the groundwater body, such as agriculture with irrigation wells, nature conservation, which is primarily intended to protect the salt pans and the national park, and of course tourism, as well as the preservation of bathing facilities and flood protection for settlements. The issue of Lake Neusiedl drying out was repeatedly highlighted in the media, especially during dry periods, but the fact is that this alternation between absolute highs and lows makes balanced water management difficult (Blaschke, 2023).

What does all this mean for a possible endowment? The fact is that Lake Neusiedl and the lake area pursue different areas of interest which are interconnected. No matter which one is pursued more, it will inevitably have a smaller or larger impact on other issues. This means that when intervening in the system, which must be regarded as highly sensitive, the potential impact must also be considered on a large scale

(Blaschke 2023). According to Blaschke (2023), there are various measures that are effective during high groundwater conditions and others that are effective at low groundwater. Some measures have already led to interventions in the past, such as the construction of weirs. Measures are often cited that could be effective locally but do not take the overall concept into account. The reasons for this are inadequate data, conflicts of interest, and/or a lack of funding.

The supply of external water is one approach to solving the problem of low water levels in Lake Neusiedl and low groundwater in its vicinity. Not only the current problems need to be solved, also an additional increase of hot and dry periods are expected, which gives rise to the fear that Lake Neusiedl can hardly be preserved in its current state without the supply of external water, which on the other side shows that it will not be possible to meet the different interests (Blaschke, 2023). In this context, Maracek & Sailer (2023) emphasize that the goal of endowing Lake Neusiedl is by no means to fill it up, but rather to preserve the lake as a landscape element and the associated habitat. In addition, the aim is not to continue to exceed the fluctuation range but to fall below it and to bring balance to the lake area. According to Maracek & Sailer (2023), "filling up" the lake would not be desirable, especially regarding the salt concentration, but it is necessary to react to global warming timely. Blaschke (2023) emphasizes that there are no fundamental "red flags" that make it appear unfeasible to supply Lake Neusiedl with Danube water in terms of water quality, but strict hydrological and hydro-chemical specifications are required to avoid possible negative effects or at least keep them to a minimum. However, he criticizes the fact that only existing data was used, and no additional analyses were carried out.

By carefully managing the endowment of Danube water, it should be possible to support the sustainability and the health of Lake Neusiedl, ensuring its ecological, economic, and social benefits for future generations. There are, however, some necessary steps for an implementation, such as feasibility studies or pilot projects, the current study amongst them.

According to Maracek & Sailer (2023), the current status regarding the dotation of Lake Neusiedl is characterized by extensive discussions and planning. Dotating the lake, i.e. the possible supply of water from the Danube, is being considered as a measure to stabilize the water level to address the lake's long-term ecological and economic challenges. Due to climate change and increasingly frequent periods of drought, the water level of the lake is falling, resulting in ecological risks and economic losses, particularly in tourism and agriculture. However, the project is controversial and requires close cooperation between Austria and Hungary, as Lake Neusiedl is a transboundary body of water. In addition, the dotation plans are subject to strict ecological and regulatory requirements, as an influx of Danube water could affect the water quality and natural salinity of the lake. Further studies and tests are still required to fully assess the feasibility and potential impact of the dotation (Maracek & Sailer, 2023). Since the original plan to obtain the water from Hungary will not be implemented, the current status of the water supply to Lake Neusiedl provides for the possibility of supplying water from Lower Austria in order to keep the water level stable in view of the climate-related fluctuations. The Burgenland government is examining various options and is working on compliance with legal and ecological framework conditions to secure the lake in the long term. Further scientific studies and close cooperation with Lower Austria are required for implementation (BVZ, 2024; BVZ, 2023).

The social discourse surrounding the topic and, above all, the ecological consequences, also play a role that must not be neglected. Not least for this reason, other solutions within Austria and across borders are also being weighed up and variants of endowment are being sought. Landgesell & Lang (2023) emphasize that the high costs associated with the endowment of Lake Neusiedl call for certainty about the future. At the same time, the authors mention that the "advantage" of global warming in this respect is that the problems that were already present are now becoming visible to everyone and solutions should finally be found. It is important to clarify that the aim of the endowment is not to fill the lake, but rather to compensate for climate-related deficits and to maintain salinity through controlled supply and not allow the lake to dry out. Lake Neusiedl should be preserved as a landscape element (Krizsanits & Machtinger, 2023).

Wolfram et al. (2014) cites a lake height of 115 m above sea level as the value that at least should be maintained if the lake is to be seen as a landscape element, but there is no ideal value for a perfect water level. According to Krizsanits & Machtinger (2023), the difficulty lies in compensating for the deficits of the annual water level. While the precipitation in 2023 brought relief, but certainly not an all-clear signal.

However, there are opinions against the endowment of Lake Neusiedl. The environmental protection organization WWF (2023), for example, believes that doping Lake Neusiedl with Danube water would be the most serious intervention in 100 years. WWF states that doping would be ecologically extremely risky and that better water retention would be the better solution for Lake Neusiedl (WWF, 2023). In a discussion with Mag. Dr. Georg Wolfram in the podcast of the Green Parliamentary Club Burgenland, Dr. Kohler from WWF also emphasizes once again that doping is bad because the lake needs strong water level fluctuations and occasional drying out. It also needs a certain salt content to survive in the long term. He believes that the lake is only 13000 years old because it has these characteristics and that interfering with it would not help it but would have the opposite effect.

According to Kohler (2023), an artificial water supply promotes the silting up of the lake for two reasons: (1) permanent water coverage of the lake is not natural, as the lake dries up once or twice a hundred years, which is normal. However, it fills itself up again with water, other than many other water bodies that dry out completely but are not able to revive themselves. (2) during periods of drying out, the organic part of the sludge that collects in the lake can decompose in the air and the inorganic part can then be blown out by the wind. It is therefore very relevant that the lake dries out completely every once in a time.
Dr. Kohler believes that the addition of water would change the chemistry and the turbidity necessary for life would be lost. Turbidity however has an inhibiting effect on siltation and must therefore be maintained. In addition, the salt balance would be severely disturbed. He goes on to explain that the supply line automatically promotes the discharge via the Hanság Canal and that a lot of salt is lost as a result. However, the salt is vital. In addition, the reed belt will dissolve because the reeds cannot rejuvenate due to the permanent water cover. The permanent addition of more than 10 cm will make the lake richer in nutrients and clearer, resulting in more algae blooms. He therefore considers doping again to be unnecessary. He emphasized that the low levels, but also the high levels, would become more extreme due to climate change and that the aim should be to manage the water better. He therefore advocates better water retention. Finally, he emphasizes that doping the lake would be the worst attack on the ecological integrity of the lake since the Hanság Canal went into operation in 1910. According to Kohler, saving the lake means preventing doping (Petrik, 2023).

As an alternative to external water supply, retention measures are often raised, which means that lake floods should be retained and not discharged via the Hanság-Canal. Afterwards, this water can be used to refill the lake at low levels. Kohler punctuates that these options would not be researched to the same extent, but that this should happen (Petrik, 2023).

Maracek & Sailer (2023) summarize that in former times water had to be drained in order not to endanger the lake facilities and buildings in the shore area. At the same time, the question arises as to how and where such buffer basins should be created, as former floodplains were cut off centuries ago. Constructing buffer basins is not a realistic option. They would mean enormous costs, while at the same time these basins would have to be sealed so that the water does not seep away. Moreover, large areas of the Seewinkel are flooded at high water. In addition, recirculation would also only be possible with pumps. Contrarily, Dr. Kohler argues that high costs of the buffer basins are not an argument against better retention measures, since also the dotation is expensive. He even says that the money which is planned to be spent on the dotation should better be spent for a better retention system of the water (Petrik, 2023).

On the other hand, there are compelling arguments for the endowment of Lake Neusiedl, apart from those that were already mentioned before. The most convincing one for an endowment is certainly that Lake Neusiedl already receives river water from tributaries. They are small except the river Wulka, discharging approx. 32 million m^3 of river water into Lake Neusiedl every year (Baranyi et al., 1994). Water from Wulka differs water from Lake Neusiedl as well as Danube water does, as it will be explained more precisely in the following chapter.

Mag. Dr. Georg Wolfram, who has been focusing on Lake Neusiedl for many years, also make clear statements in the podcast of the Burgenland State Parliament Club. He is in favor of endowment and explains first and foremost that Kohler's contra opinion is very superficial. Mag. Dr. Wolfram says that it is of course not possible to say a clear yes or no, but that there are conditions that must be adhered to allow an endowment to take place and at the same time protect the lake. He emphasizes that there are indeed risks and problems, but that these are calculable and that several times that it is important to differentiate between how much water supply the lake needs and how much it can tolerate. From an aquatic ecology perspective, he agrees with Kohler, saying that the lake does not need an inflow. It dries out and is still able to replenish itself; he emphasizes that this is part of its characteristics as a steppe lake. It can withstand variability in various aspects, including its chemistry - there were phases when the lake was significantly more saline, just as there were phases when it moved towards freshwater conditions. He further explains that the effect of an inflow would not be so drastic, as the lake has also received water from comparable systems in the past, such as the strong floods that caused water to enter the lake from the Danube and the Raab-Rabnitz system. The lake was repeatedly filled with water due to flood levels, which led to substantial changes, but the lake has always recovered. However, the changes that took place were far greater than the extent that is now being discussed regarding the dotation. He emphasizes that the supply of external water must always deal with the question of quantity and frequency. In certain framework conditions and to a certain extent, it can of course lead to dramatic pictures, but that is not the framework in which doping should take place. He finally emphasizes that if an inflow is considered at very only low water levels and this takes place on a manageable scale. He does not see the problem of the lake tipping over and losing its properties. However, he also emphasizes that there are still issues that need to be clarified, such as the pollutants that would be carried by the Danube. A “second” Wulka would be the image Wolfram uses to illustrate the entry (Petrik, 2023).

Expected changes in the water of Lake Neusiedl

Regarding published papers and previous studies, some changes can be expected for Lake Neusiedl after Danube water is introduced. Wolfram et al. (2023) discuss that the Danube and Lake Neusiedl differ significantly in terms of their calcium and sodium content, two of the dominant cations. It is therefore assumed that an inflow from the Danube would seriously change the water of Lake Neusiedl in at least these two elements. However, the calcium-rich tributary Wulka already discharges into the lake and thus influences hydrochemistry of the lake since centuries. Ongoing monitoring in the vicinity of Illmitz and the fact that the composition of the Wulka has characteristics closer to those of the Danube than to those of Lake Neusiedl itself make this assumption uncertain and requires further investigation. This means that the has chemical and biological characteristics that are also typical for Danube Wulka water rather than the specific characteristics of Lake Neusiedl, as can be seen in figure 15.

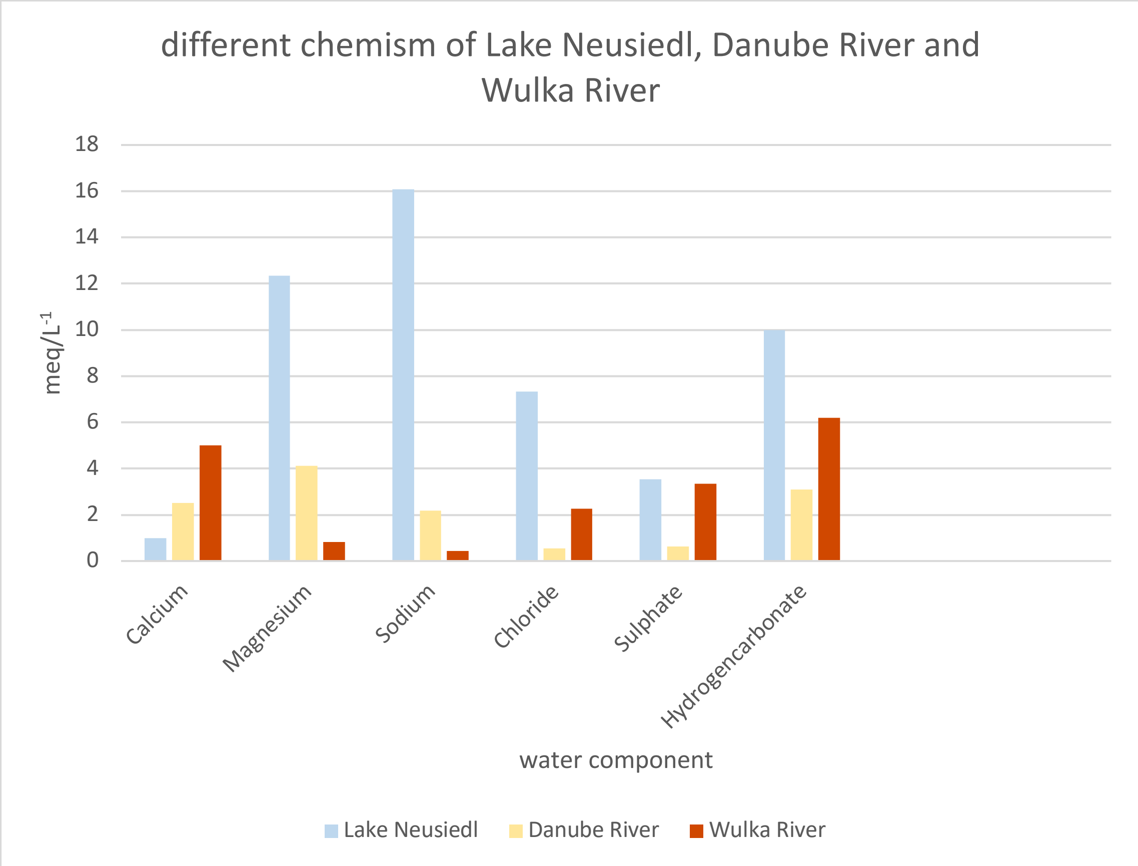

figure 15: Different chemistry of Lake Neusiedl, Wulka River and Danube River, edited after Wolfram et al., 2023

The concentrations of the individual ion components show clear differences between Lake Neusiedl, the Danube and the Wulka. **Calcium** shows the highest concentrations in the Danube, followed by the Wulka. Lake Neusiedl shows only a very low calcium concentration, which indicates that the Danube and the Wulka have a significantly higher calcium supply, which is typical for flowing waters. The **magnesium concentration**, on the other hand, is highest in Lake Neusiedl, while the Danube and Wulka have significantly lower values. This reflects the special chemical conditions of Lake Neusiedl, which is characterized by high magnesium levels. **Sodium** is present in particularly high concentrations in Lake Neusiedl, which is typical of saline or alkaline waters. In comparison, the Danube and the Wulka have significantly lower sodium concentrations. The **chloride concentration** is also highest in Lake Neusiedl, while the Danube and Wulka have significantly lower values. The high chloride content contributes to the unique chemical signature of Lake Neusiedl. **Sulphate** shows the highest concentrations in the Wulka, followed by the Danube, while Lake Neusiedl has comparatively low sulphate values. This indicates that the inflow of the Wulka may influence the sulphate balance in the lake. The **hydrogen carbonate content** is particularly high in Lake

Neusiedl and significantly exceeds the values of the Danube and the Wulka. These high hydrogen carbonate values are typical of alkaline lakes with a high buffering capacity and indicate the strong buffering effect of the lake, which compensates for fluctuations in the pH value.
Overall, these differences reflect the specific chemical properties of the water bodies. Lake Neusiedl shows typical characteristics of an alkaline lake with high concentrations of magnesium, sodium, chloride and hydrogen carbonate, while the Danube and Wulka have higher levels of calcium and sulphate, which are characteristic of running waters. These differences could have a significant impact on the chemical balance and ecological dynamics of Lake Neusiedl, particularly due to the influence of the Wulka tributary (Wolfram et al., 2023).

Figure 15 therefore shows that the chemical composition of Lake Neusiedl differs significantly from that of the Danube and the Wulka. In particular, the high concentrations of sodium, chloride and hydrogen carbonate in Lake Neusiedl emphasize its alkaline and saline nature. In comparison, the Danube and Wulka have higher levels of calcium and sulphate, indicating that their chemical composition is more typical of running waters. These differences in water chemistry underline the importance of careful monitoring of the tributaries, as the Wulka shows characteristics closer to those of the Danube than to those of Lake Neusiedl and could therefore potentially affect the chemical balance of the lake.

This could indicate that the Wulka may be introducing additional or different substances into the lake that could influence the water quality and ecological conditions. As the composition of the Wulka is so different from that of Lake Neusiedl, the assumption that the Wulka does not cause any significant changes to the lake is called into question. Further studies are needed to better understand the influence of the Wulka on the chemical and ecological dynamics of Lake Neusiedl (Wolfram et al., 2023).

The area of Lake Neusiedl where water from the Wulka enters the lake differs only slightly from the southern part in Hungary. Wolfram et al. (2023) emphasizes that not every inflow would mean the end of the lake, but that it depends on the amount of water supplied and that siltation is to be expected if the water supply is too high. From the difference in hydrogen carbonate concentration, as well as chloride and sulphate, is also clearly visible, why dotation need to be done with care. Since the difference between water of Lake Neusiedl and both the Danube and the Wulka River is most pronounced in the sodium content, the greatest change is to be expected here.

Comparison to Wulka River

If you compare the water in Lake Neusiedl with that of the Wulka, the difference in calcium content is particularly noticeable. Whereas calcium is available as cation in the Wulka, calcium is precipitated calcite crystals in the lake water, which are responsible for the whitish-grey appearance of the open lake. Sunlight is reflected and absorbed by high particle load, which causes light limitation in deeper parts of the water column. Due to specific chemical conditions prevailing in the lake, dissolved calcium content is very low, and mainly replaced by sodium. Calcite crystals and other siliceous mineral particles contribute to the lake´s milky and cloudy appearance. The high turbidity is a result of calcium-rich inflows, soft sediments and wind exposure. The turbidity is then stabilized by the lake's special pH-value, which is indirectly responsible for the decomposition of organic material (Wolfram et al., 2023). Turbidity is particularly important for the lake and is a unique feature, also responsible for its “self-cleaning function”: microparticles create a surface for bacteria and microorganisms that form a biofilm, which in turn breaks down the biomass. The good water quality of the lake is therefore closely linked to its turbidity (Wolfram et al., 2023).

Lake Neusiedl has a conductivity of around 2000 µS cm^{-1} and a salinity of about 2, which indicates slightly saline conditions. In some places, Lake Neusiedl even reaches a conductivity of up to 6000 µS cm^{-1}. A salinity of 2 is just one twentieth of seawater but at the same time twice the concentration of the threshold value for fresh water. Lake Neusiedl counts therefore as a subsaline water body (Schagerl & Renaut, 2016).

The prevalent cation in the lake is sodium. Together with hydrogen carbonate, sodium forms soda $Na_2(CO_3)$ and sodium bicarbonate $Na(HCO_3)$. The high concentration of sodium carbonate in Lake Neusiedl results from fissures of the mineral water springs typical of the entire region, which reach far into the tertiary marine sediment area. This low, but constant influx of salt in combination with the very high evaporation makes Lake Neusiedl a slightly saline soda lake (Wolfram et al., 2023).

Based on the ion balance of Lake Neusiedl and the surrounding waters, the difference between Lake Neusiedl and Danube River is obvious (figure 16). The lake has a unique ion composition and differs especially regarding its cations. Regarding the anions, the differences are not as great, but still recognizable. Taking a closer look at Danube River regarding its anions, its clearly visible that it differs from Lake Neusiedl, while the other water bodies are closer to the ion composition of the lake.

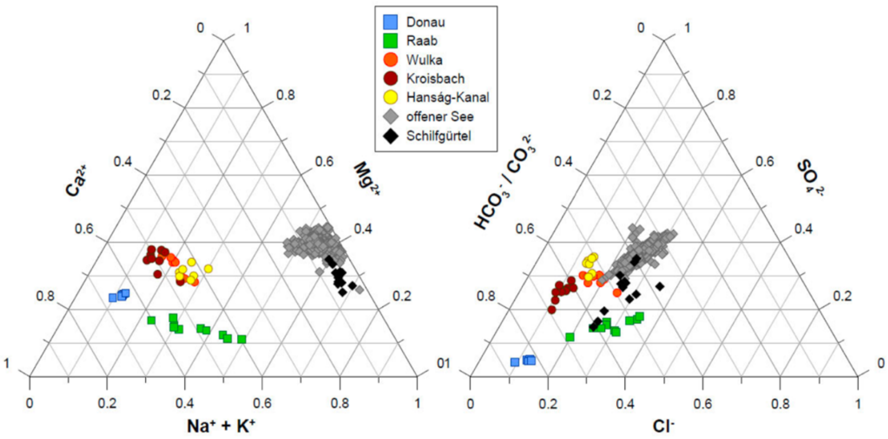

figure 16: Ion balance of different water bodies (Wolfram et al., 2014)

The pH-value of the lake is around 8.5 – 9.0, which is above average when compared to other Austrian lakes (figure 17). Total alkalinity of Lake Neusiedl is between 4 and 6 meq L^{-1} and attributed to the geological composition of the catchment area and the high proportion of dissolved bicarbonates and carbonates in the water (Herzig, 2014). Tolotti et al. (2021) mentioned that alkalinity is an important indicator of the lake water quality, also because high bicarbonate and carbonate concentrations increase the buffer capacity.

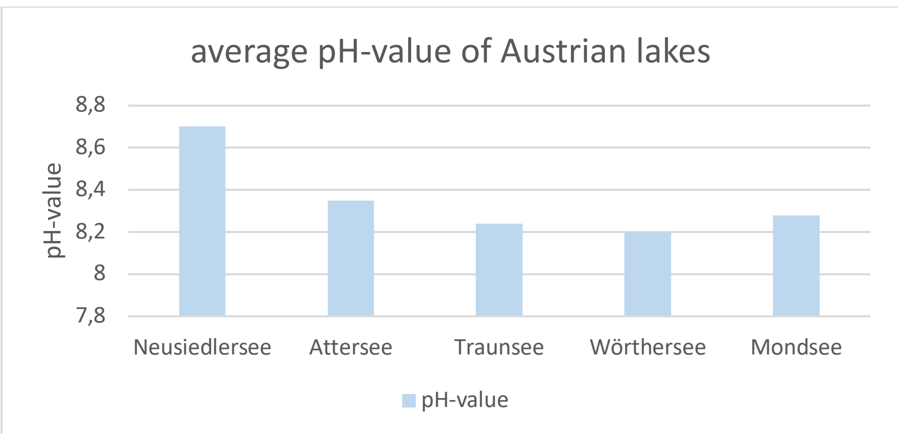

figure 17: Average pH value of Austrian lakes, based on KIS, 2024

1.5. Study aims

This study is dealing with possible effects of feeding Lake Neusiedl with water of the river Danube. Specifically, we were studying selected physical-chemical properties including, conductivity, pH-value, alkalinity, scattering (filtered and unfiltered), turbidity (filtered and unfiltered), dry and ash mass, dominant ions, and nutrients. The research question addressed potential changes of chemical or physical properties in the individual dilutions change over time. Lake Neusiedl water was taken as a reference, the mixed samples were compared regarding this reference to get insight, whether the mixtures react in the same way. We assumed that the properties in which the water of the Danube and Lake Neusiedl differ greatly will also show different characteristics in the various mixing ratios. A second experiment mimicked periodical water level changes over the year (evaporation/refilling experiment). Particular attention was paid to pH-values, sodium content, and chloride and the sulphate in this experiment to find out how the parameters change over time. Moreover, optical properties, i.e. scattering and absorption were in focus, because high turbidity represents a unique feature of the lake. If these parameters show unexpected large shifts, this would be an argument against the doping of Lake Neusiedl with Danube water.

2. Materials and Methods

Sampling

The water samples were taken at two different locations. Danube water was sampled in Haslau (coordinates: 48°07'19.8"N 16°42'56.4"E), lake water was sampled from the open lake (northern shore; coordinates: 47°55'29.7"N 16°50'00.8"E). For the dilution experiment, samples were taken on 20th august 2023, while the samples for the evaporation experiment were taken on the 27th august 2023. Samples were taken in several canisters and transported to the laboratory of the university's biology center to start the experiments. The water samples were constantly stored on a shaker and always mixed well before experiments so that the sediments they contained did not settle.

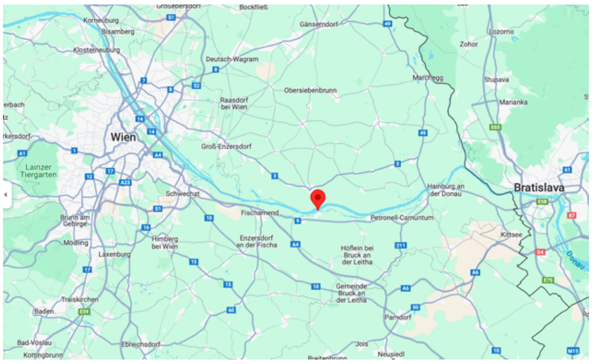

figure 18: sampling location Danube River (Google, o.D. - b)

figure 19: sampling location Danube River (Google, o.D. – b)

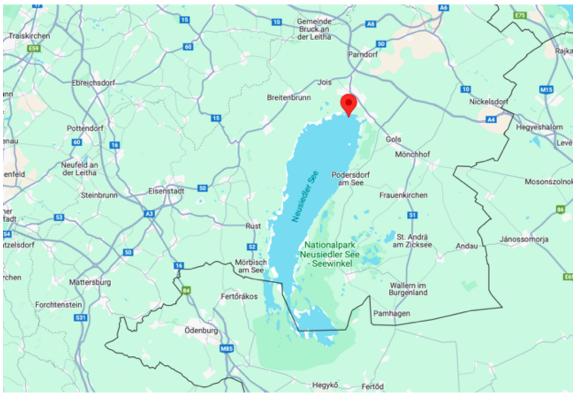

figure 20: sampling location Lake Neusiedl (Google, o.D. - c)

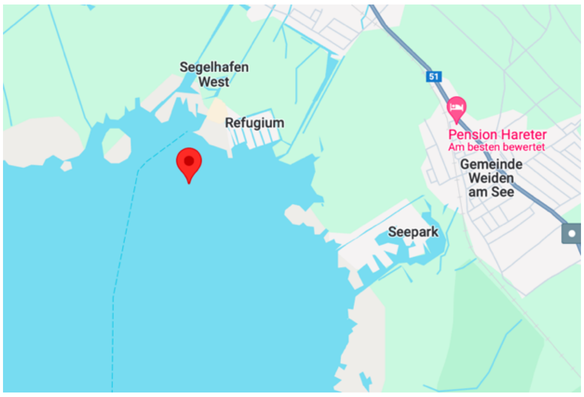

figure 21: sampling location Lake Neusiedl (Google, o.D. - d)

Laboratory experiments

Various mixing ratios of the two types of water were prepared for the tests with pure lake water (N100) always taken as a control. Mixing ratios of the treatments of experiment 1 were: 90% Lake Neusiedl water and 10% Danube water (N90D10), 75% Lake Neusiedl water and 25% Danube water (N75D25) and 50% Lake Neusiedl water and 50% Danube water (N50D50). Mixing ratios of experiment 2 are: 100% Lake Neusiedl water (N) and Lake Neusiedl water evaporated to 90% and filled up with 10% Danube water (ND). Between the experiments, the water was constantly agitated on a shaker and kept at room temperature at a 16:8 hours day night cycle.

2.1. Experiment 1 (V1)

Experiment 1 focused on the different mixing ratios with measurements of unfiltered water taken weekly (t0, t1 and t2). Dry and ash mass were determined and filtered samples were measured at times t0 and t2, same for ions and nutrients (figure 22). Three replicates taken for each dilution.

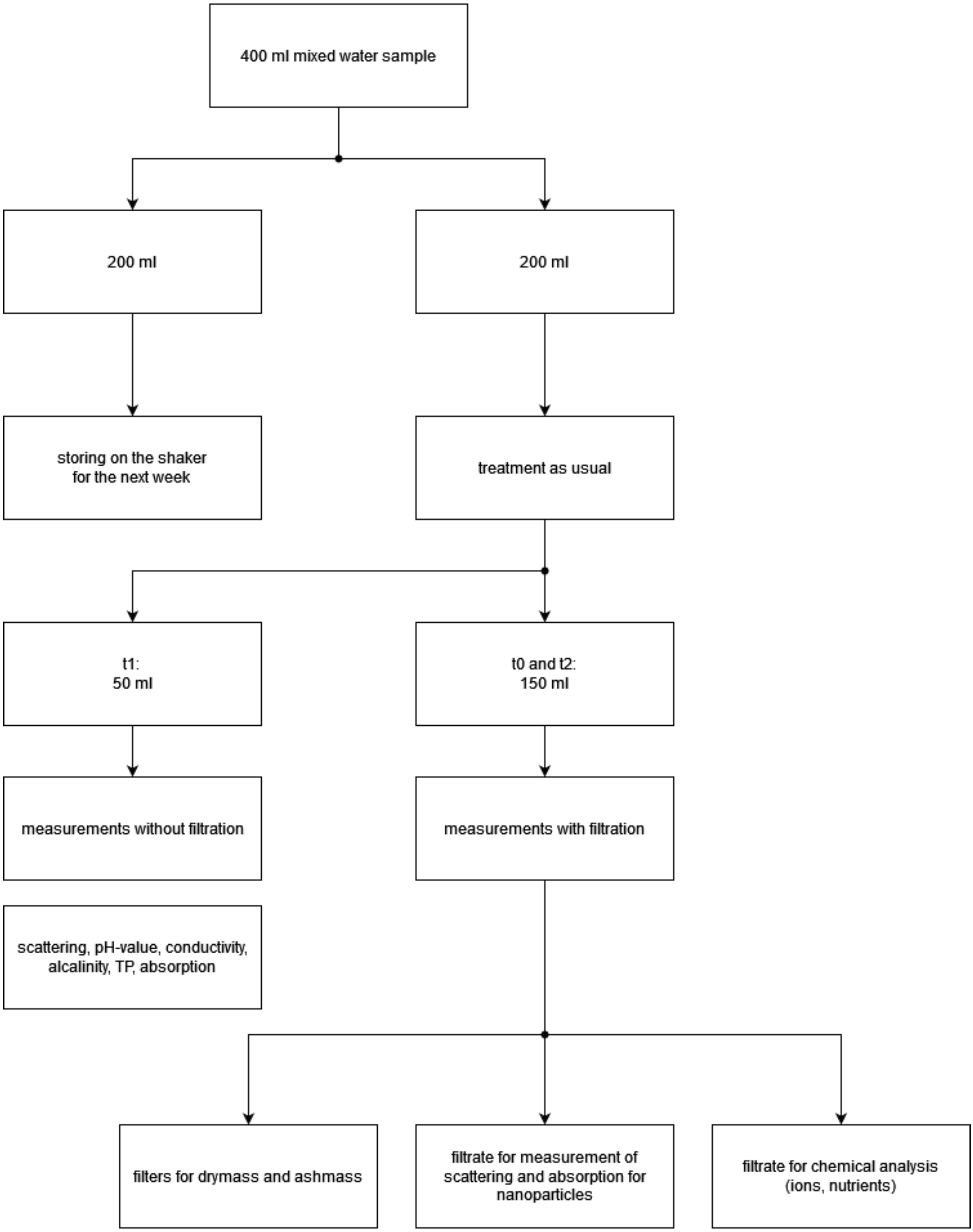

figure 22: Flow chart of the design of experiment 1

2.2. Experiment 2 (V2)

In experiment 2, we did repeated evaporation and dilution; it considered a temporal component of changes in the lake level. The experiment mimicked a refilling of around 10% Danube water after a heat period with evaporation of about 10% lake water volume over a period of three years. The results of experiment 2 are therefore intended to show how the water in Lake Neusiedl would change if the lake had to be dosed repeatedly with Danube water. The samples of pure Lake Neusiedl water (N) and Lake Neusiedl water mixed with Danube water (ND) had a total of four measurement times (t0, t1, t2, t3) and four replicates each.

The Lake Neusiedl samples mixed with Danube water (ND) were reduced to 90% of the initial volume after the first measurements on day 1 (t0) and topped up with 10% Danube water. This procedure was repeated at 7-day intervals, resulting in three weeks of measurements t1, t2, t3. By evaporating to 90% water and topping up again with Danube water, it is possible to imitate how a mixture of Lake Neusiedl and Danube water develops over time.

The following properties were measured every week t0, t1, t2, t3: conductivity, alkalinity, pH value, TP, scattering and turbidity. In addition, scattering and absorption for nanoparticles from filtered water, dry and ash mass and ions and nutrients were analyzed at the beginning t0 and the end t3 of the experiment. In experiment V2, 4 x 400 ml of Lake Neusiedl as a control and 4 x 400 mixture were prepared (evaporation treatment) and processed as shown in figure 23.

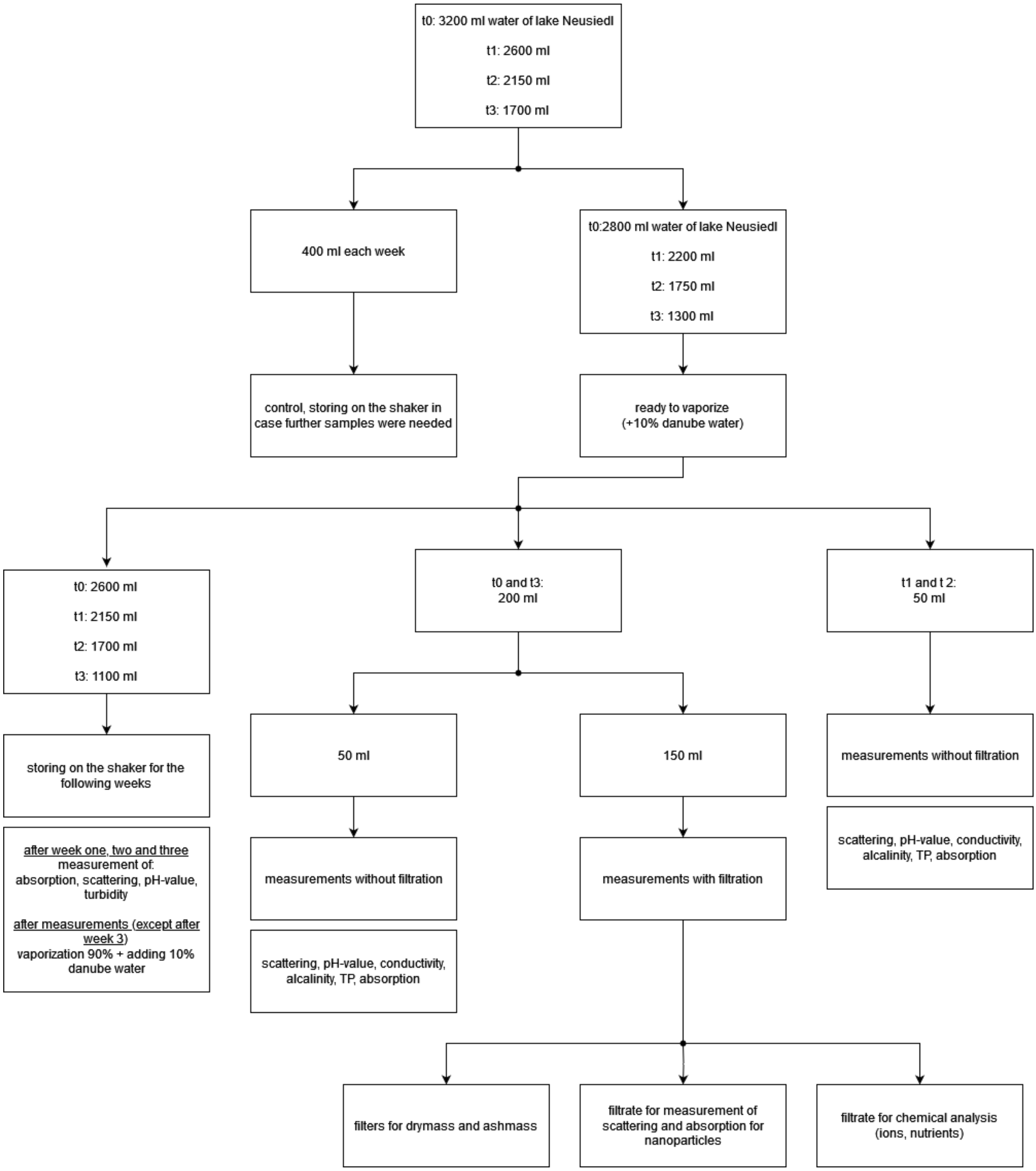

figure 23: Flow chart of the design of experiment 2

2.3. Methods applied

The **conductivity** was measured using a WTW ProfiLine Cond 3110 conductivity meter. The measurement times were t0, t1 and t2 for V1 and t0, t1, t2 and t3 for V2. The **pH-value** was determined using an INOLAB pH Level 1 pH meter. Here too, the measurements in V1 were carried out at the times t0, t1 and t2, in V2 they were carried out at t0, t1, t2 and t3. To determine the **scattering**, a Shimadzu RF- RF-5301PC Spectrofluorophotometer was used in combination with VWR disposable cuvettes (polystyrene, 4-sided clear, 2.5 ml), with both excitation and emission wavelength set to 860 nm. Measurements were taken in V1 at t0, t1 and t2 and in V2 at t0, t1, t2 and t3. The **turbidity** was determined by spectrophotometry and a HACH DR3900 spectrophotometer using the same disposable cuvettes and a wavelength of 860 nm. The measurements were taken immediately after scattering measurements.

The **alkalinity** was determined by titration of the unfiltrated sample using an indicator solution (Supelco MQuant 108048) and a titration pipette. The measurements were carried out in V1 at t0 and t2 and in V2 at t0 and t3. The **chemical analysis** included the measurement of various ions including major nutrients (sodium, potassium, calcium, magnesium, chloride, nitrate, sulphate, phosphate, nitrite, ammonium) via ion chromatography of the filtered samples. 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). Silicate (Si-SiO4; filtrated water) and total phosphorus (Pt; unfiltrated water, persulphate digestion) were analysed spectrophotometrically. Chemical analyses were carried out in V1 at the time points t0 and t2 and in V2 at t0 and t3.
A Mettler MT5 precision balance, a Heraeus UT6120 drying oven (90 °C), a Labin L3/R muffle furnace (450 °C) and glass microfiber filters (VWRI516-0868, 24 mm) were used to analyze the **dry and ash mass**. The dry mass was calculated as the difference between mass of the dried filter + material W2 and initial filter mass W1, the ash mass as the difference between mass after combusting W3 and the dry mass. These measurements were carried out in V1 at t0 and t2 and in V2 at t0 and t3.
The **evaporation experiments** were carried out with a Buchi R3 rotary evaporator at 38

°C and 31 mbar. The evaporation measurements were carried out in test series V2 at the times t1, t2 and t3.

2.4. Statistics

The mean changes over time were tested with repeated measures mixed models (dependent variable = parameter of interest; independent variables = mixture and time points of measurements, correlation structure = compound symmetry matrix) and the average change from the first measure time (=t1) over all timepoints (average of change from t1 to t2 and t1 to t3) were tested for statistical significance (i.e. parameter test of the mixture variable -> did any of the mixtures have a different average change over time). All tests with *p*-s <0.05 were considered statistically significant. For parameters which were measured just at the beginning and the end of the experiments, *t*-tests or ANOVA of the change variables (parameter value at end minus value at the beginning) were applied. Visual checks for skewed distributions and outliers were performed to see if results were heavily influenced by those. SPSS v29 was used for statistical analysis.

3. Results

Development of mixtures need to be compared with controls N100. It is obvious that properties change if lake water is mixed with Danube water, regardless of the ratio. What is relevant, is whether temporal changes of the mixtures are comparable to reference samples. For a graphical comparison, we connected mean values of measuring times with straight lines and focused on slopes of individual line for interpreting results (parallel development of control and mixtures versus different slopes).

The raw data of the experiments are provided in the appendix.

3.1. Dilution experiment (experiment 1, V1)

The results of the first experiment are now explained in more detail. The table shows which parameters are significant and which are not (i.e. testing if mixture has significant contribution to the model). The exact explanation of individual properties can be found in the following subchapters.

In this analysis, the variable mixture was examined rather than the slope. The aim was to determine whether one of the mixtures shows a significantly different average change over time. Due to the small sample size and the limited test power, no differentiated individual tests could be carried out. Instead, a joint test was carried out across all concentrations. If the results were significant, this would indicate that at least one of the concentrations showed a deviating average change.

table 2 p-s of V1

property	***p*-s**
alkalinity	0.166
unfiltered scattering	0.507
filtered scattering	0.346
unfiltered turbidity	**0.027***
filtered turbidity	0.994
sodium	0.499
potassium	0.155
calcium	**0.002***
magnesium	0.639
chloride	0.062
nitrate	**0.003***
sulphate	0.357

P-PO4	0.339
P-t	0.054
N-NO2	0.101
N-NH4	0.071
Si-SiO4	0.286
conductivity	0.764
pH-value	0.540

**highly significant

*significant

3.1.1. Major cations and major anions of experiment 1

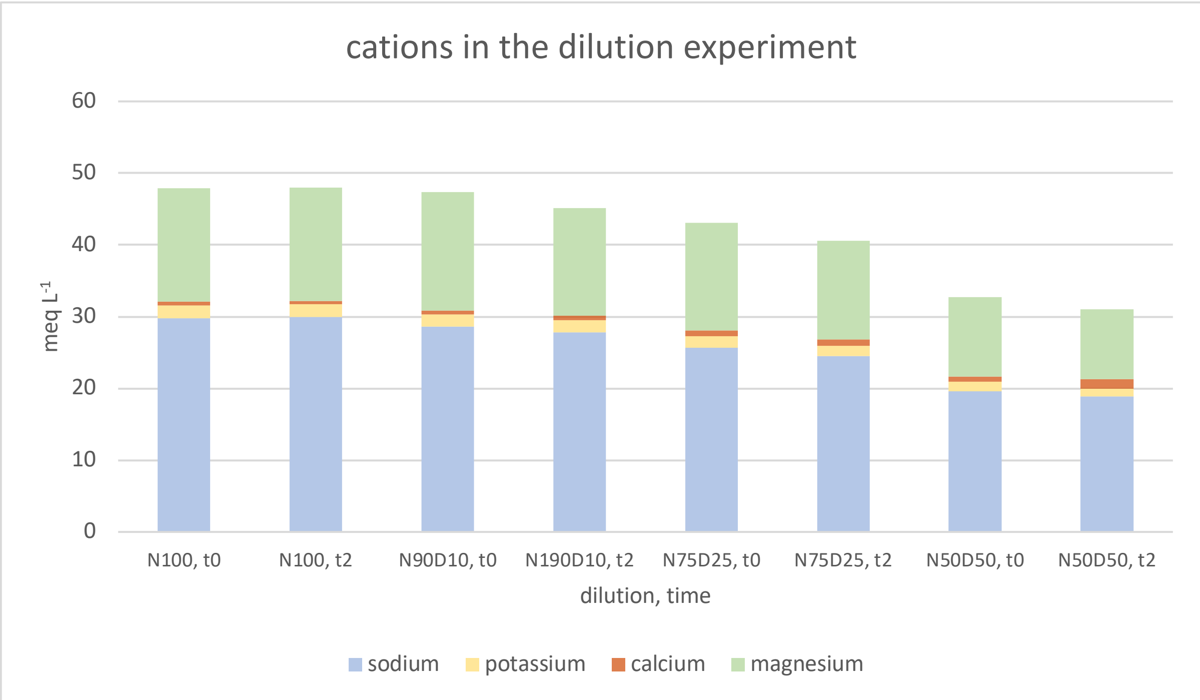

figure 24: major cations at the baseline measurement and at time point t2

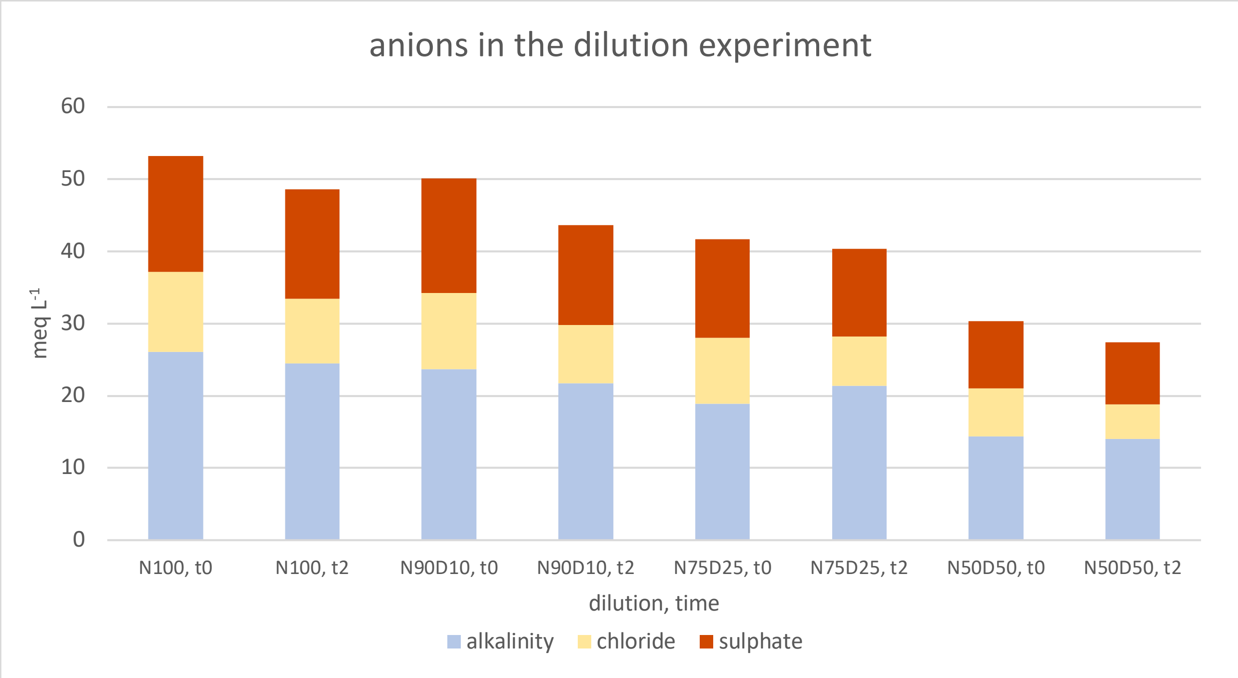

figure 25: major anions at the baseline measurement and at timepoint t2

Figure 24 shows the concentrations of the four **major cations** - sodium, potassium, calcium and magnesium over different dilution levels and time points in the context of experiment 1. The figure illustrates the influence of dilution and time on the cation concentrations, with sodium and magnesium being most affected by the increased dilution. The cation concentrations vary according to the dilution level, with sodium (shown in blue) consistently having the highest concentration, followed by magnesium (green), calcium (orange) and potassium (yellow), which is present in the lowest concentrations. Over time, as indicated by the changes between t0 and t2 for each dilution level, there is a general trend of decreasing total cation concentrations. This effect is particularly evident in more diluted samples (e.g. N50D50) compared to the undiluted samples (N100), where the concentrations remain relatively stable between t0 and t2.

The analysis of the **anion concentrations** (figure 25) in the dilution experiment shows clear changes as a function of dilution and time. In the undiluted samples (N100), the concentrations of the anions - alkalinity, chloride and sulphate - remain largely constant between the measurement times t0 and t2. However, in the diluted samples, particularly N50D50, there is a significant decrease in the total concentration over time. Alkalinity shows the highest concentrations in all samples, followed by chloride and sulphate. In the more diluted samples, alkalinity decreases significantly between time points t0 and t2, indicating a decrease in buffer capacity in the system. Chloride also shows a sensitive response to dilution, while sulphate remains more stable but also decreases slightly.

Some of the measured properties show statistically significant changes, indicating that they were clearly influenced by the dilution and the time course. To better understand the underlying processes, these significant parameters are presented and discussed in detail below.
By observing these significant parameters in detail, conclusions can be drawn about the chemical and biological dynamics of the system. In particular, the interaction of dilution time provides valuable insights into the change in water quality and the possible influence of biological processes in the investigated environment.

Calcium

The results of the calcium concentrations show clear trends (Figure 26). The reference samples remain constant over time with an average value of around 0.5 meq L^{-1}, while the N75D25 sample series shows stable but slightly higher values between 0.8 and 0.9 meq L^{-1}. A clear increase from t0 to t2 can be seen in the N90D10 series, and the N50D50 series shows a particularly conspicuous behavior: it increases from below 0.8 meq L^{-1} to over 1.3 meq L^{-1}, with a clear scattering of values visible at the beginning (t0), which no longer occurs at t2.

The scattering of the calcium values in the first measurement is pronounced in almost all samples, except for the N100 samples, and disappears in the second measurement. These fluctuations as well as the different courses of the calcium concentrations between the sample series require further investigations to clarify the causes at different dilutions.

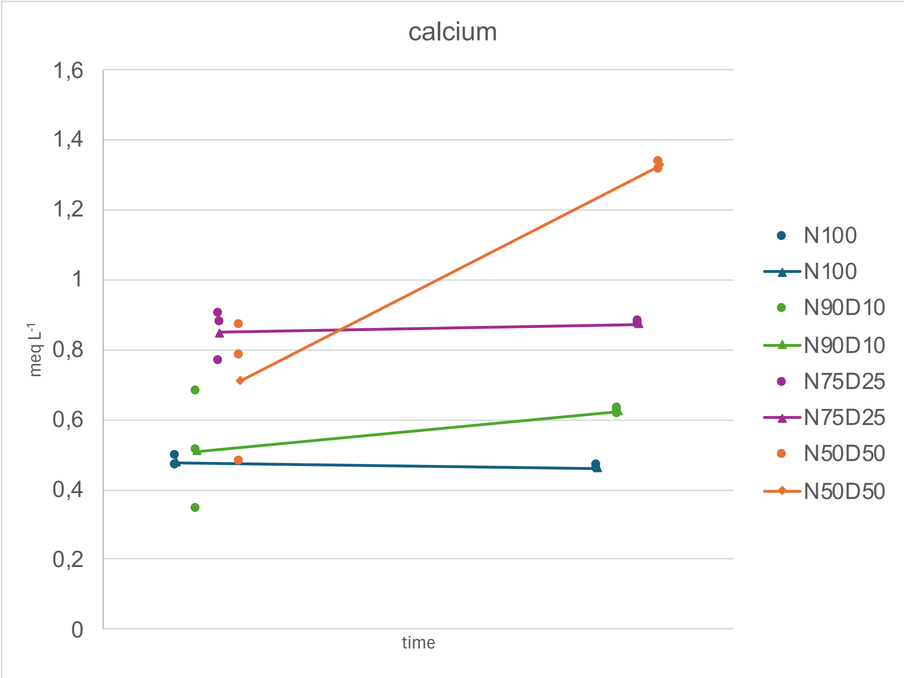

figure 26: V1, calcium

Looking at the average changes in the calcium values (Figure 27), the sample series N100 remains almost stable with a minimal decrease of -0.02 meq L^{-1}. N90D10 shows a moderate increase of 0.11 meq L^{-1}, while N75D25 shows a very small change of 0.02 meq L^{-1}. The N50D50 series shows the largest average change of 0.62 meq L^{-1}, indicating a significant shift in chemical composition at higher dilution levels (*p* = 0.002).

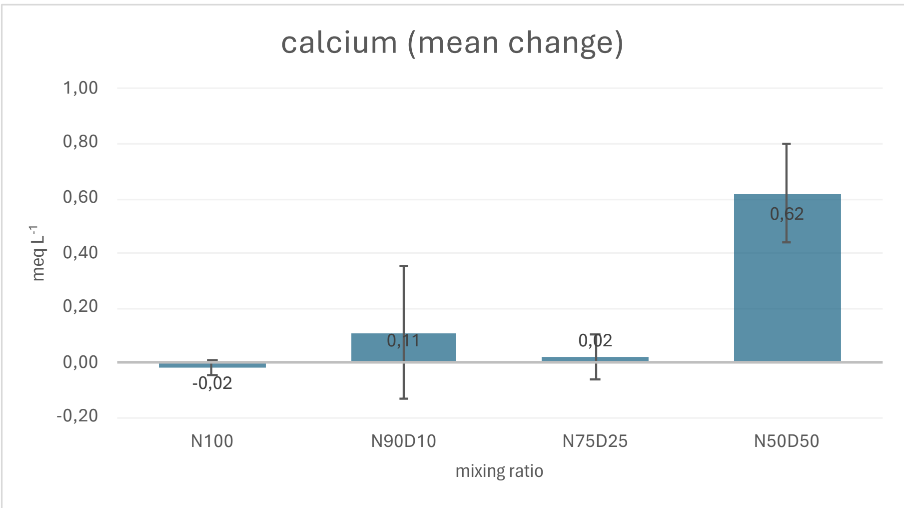

figure 27: V1, calcium mean change

Nitrate

Figure 28 shows the development of nitrate concentrations over time in the different dilution levels. N100 shows a minimal change in the nitrate concentration. In the N90D10 and N75D25 series, a moderate increase in nitrate concentration can be observed over the measurement period, whereby the increase in N75D25 is slightly more pronounced than in N90D10. This slight increase could be due to a gradual release or accumulation of nitrate in these dilution levels.

In contrast, the N50D50 dilution series shows a significant increase in nitrate concentration, ranging from around 1.20 mg L^{-1} to over 1.59 mg L^{-1}. In summary, the nitrate concentration increases significantly with increasing degree of dilution, with the N50D50 dilution series showing the strongest increase. The *p*- is 0.003 and therefore statistically significant.

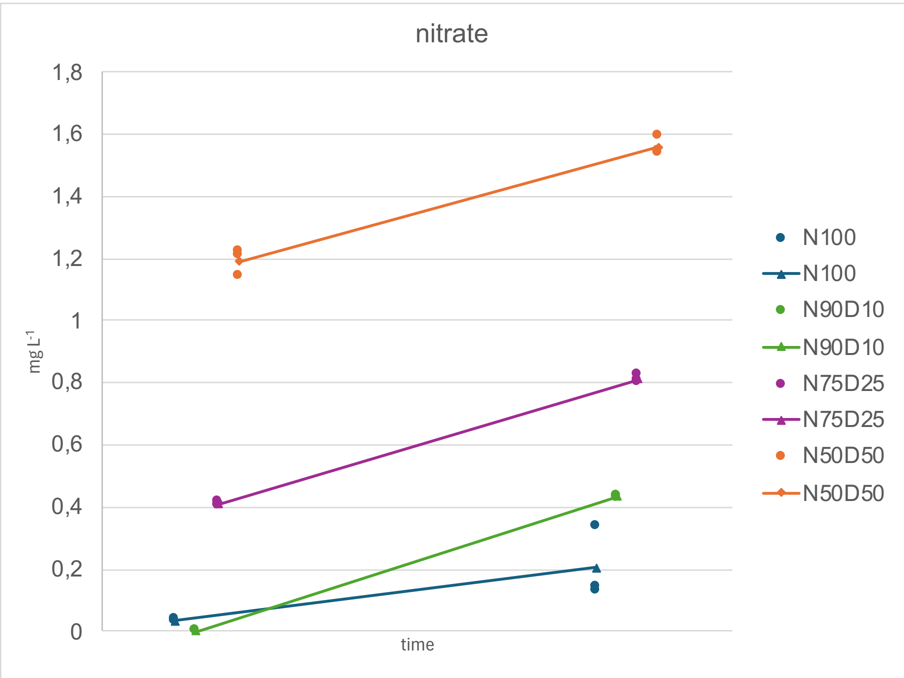

figure 28: V1, nitrate

3.1.2. Scattering and turbidity

Scattering did not show any significant change in experiment 1 (unfiltered scattering *p*=0.507; filtered scattering *p*=0.346) during experiment 1.

The same pattern was observed for the filtered turbidity. The unfiltered samples however revealed different results, as shown in figure 29. The data is represented as the mean of the values.

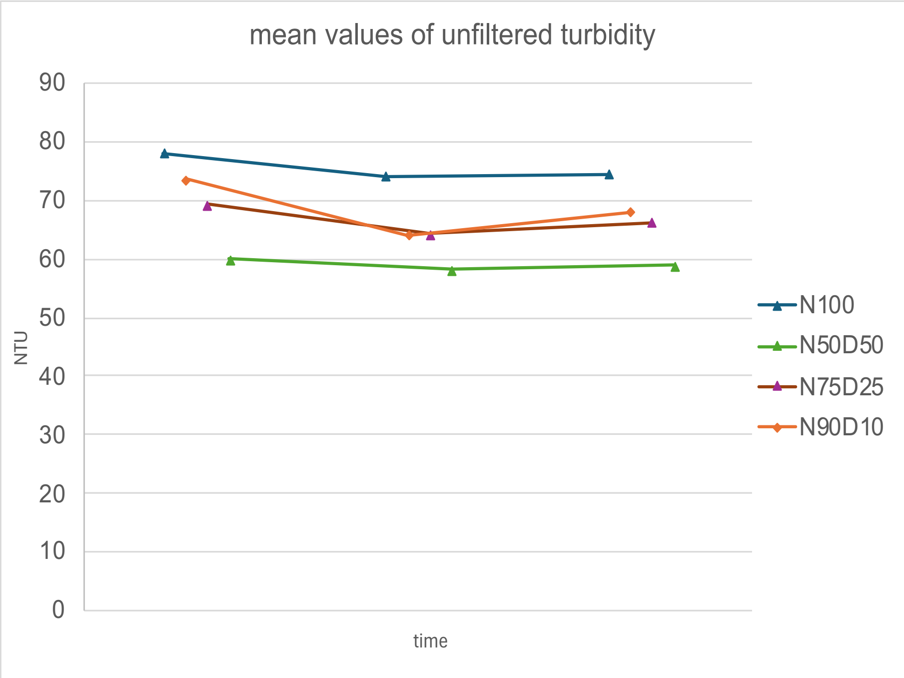

figure 29: unfiltered turbidity, V1

The results show that the mixing ratio N100 has a turbidity value of around 80 NTU at the start of the experiment. As can be observed in figure 29, this value decreases only slightly over the time points t1 to t2, which indicates a relatively stable turbidity compared to the other mixing ratios. The small changes in turbidity values at N100 indicate that pure Lake Neusiedl water only causes a minimal reduction in the particle concentration in the water, over time.

In contrast, the N50D50 mixture shows the lowest turbidity from the beginning, with a starting value of about 60 NTU. This value decreases slightly over the measurement times t1 to t3 and remains relatively constant at a lower level than in the other groups. This indicates that the mixture of water from Lake Neusiedl and Danube water in equal proportions (50:50) can effectively contribute to the reduction of turbidity, possibly through efficient precipitation or binding of the particles.

The N75D25 treatment starts at a turbidity value of about 75 NTU and initially shows a slight decrease from t0 to t1. However, the turbidity value then increases again slightly at t2. A similar pattern is seen for the N90D10 treatment, which starts at around 72

NTU, decreases slightly from t0 to t1 and then increases again at t2. These results suggest that the N75D25 and N90D10 mixtures are less stable in reducing turbidity and may have less effective particle removal mechanisms. In summary, the N50D50 blend showed the highest reduction in turbidity compared to the other variants. The results suggest that a balanced mixture of the two substances water from Lake Neusiedl and Danube water reduces turbidity the most. The *p*-value is 0.027 and is therefore statistically significant, which means that the changes of the four mixtures did non behave equally, as can be observed in figure 29.

3.1.3. Dry and ash mass

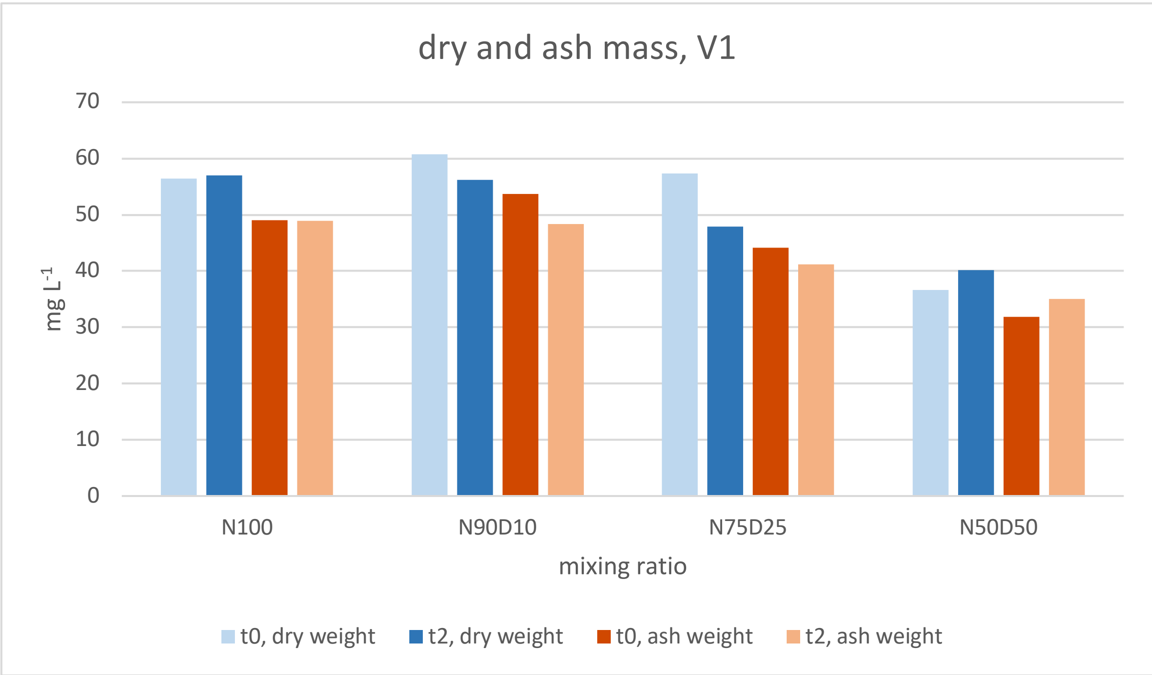

figure 30: dry and ash mass, V1

Figure 30 shows the values for dry and ash mass in the different mixing ratios (N100, N90D10, N75D25 and N50D50) at the times t0 and t2 in mg L^{-1}.

Both ash and the dry mass show a similar behavior. While the ash mass is slightly below the dry mass in all mixing ratios, but also decreases with increasing Danube water content. The difference between the times t0 and t2 is minimal, which indicates that the composition of the dissolved and suspended solids remains largely stable over the course of the experiment, as can be observed in figure 30. In order to test whether there is a statistically significant difference between t0 and t2, new studies with several samples and thus several measurements must be carried out in any case. With the samples measured in this study, we only tested whether differences occur within the mixing ratios, not whether the drop within a sample is significant. However, some changes can be observed looking at the figure.

Nevertheless, the small fluctuations in the ash mass could be due to slight changes in the mineral components.

The results also show that the dry mass decreases as the proportion of Lake Neusiedl water decreases. The mixing ratio N100 (pure Lake Neusiedl water) has the highest dry mass, followed by N90D10 and N75D25, while the mixing ratio N50D50 has the lowest dry mass. This decrease indicates that the proportion of Danube water in the mixture reduces the dry mass, which is possibly due to a lower content of dissolved and suspended substances in the Danube water compared to the Lake Neusiedl water.

In summary, it can be said that the decrease in dry and ash mass with increasing Danube water content indicates a different chemical and physical composition of the Danube water compared to Lake Neusiedl water. These results suggest that the water of Lake Neusiedl has a higher concentration of dissolved substances and organic and inorganic particles. The low temporal variation in the values also indicates that the system remains stable during the experiment and only shows slight changes in the composition of the solids.

3.1.4. Conductivity and pH-value

Conductivity

Regardless of the mixing ratio, conductivity remains constant over time. The reference samples N100 with pure water from Lake Neusiedl have a higher conductivity than the mixtures, but none of the samples shows a shift in the values. The *p*- is 0.764 and therefore statistically not significant.

pH-value

Figure 31 shows the pH development over time in the various dilution series (N100, N90D10, N75D25, N50D50). In the undiluted reference series N100 and in the slightly diluted series N90D10, the pH values remain stable, with slight fluctuations in the range from 8.86 to 8.90. The dilution series N75D25 shows a moderate increase in the pH values, which rise to a maximum value of 8.92, possibly due to changes in the chemical composition caused by the dilution effect. The N50D50 dilution series, on the other hand, shows a marked reduction and stability of the pH value, which remains constant in the range of 8.76 to 8.80. These results indicate that a higher degree of dilution leads to a reduction and stabilization of the pH value, possibly due to a reduction in buffer capacity or due to altered ion ratios. Overall, it appears that the pH tends to decrease with increasing dilution and a more stable but lower pH level is achieved at a high degree of dilution (N50D50). The *p*- is 0.540 and therefore even statistically not significant.

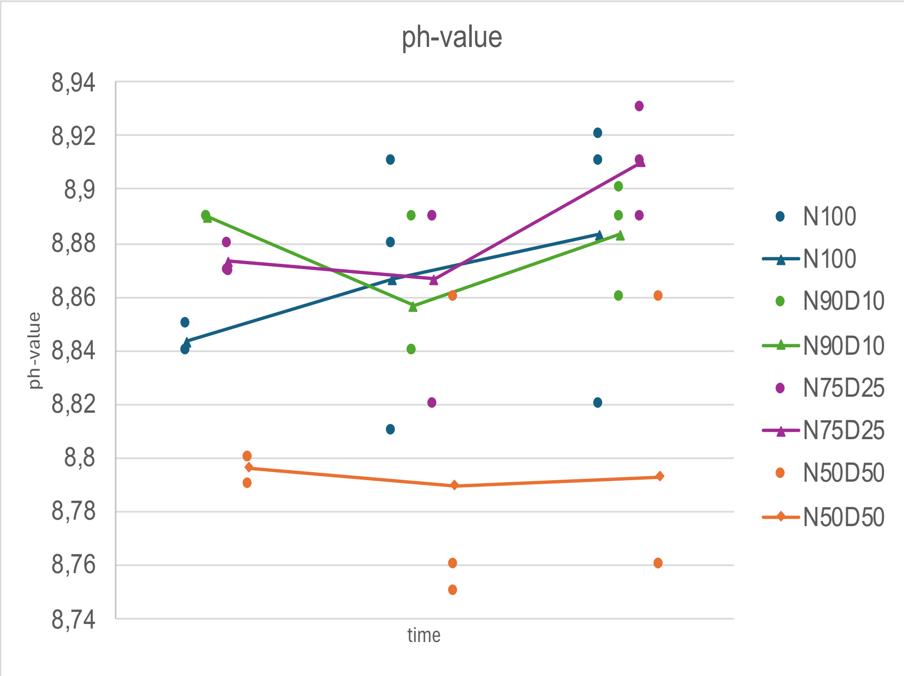

figure 31: V1, pH-value

3.2. Evaporation experiment (experiment 2, V2)

A table providing an overview of the statistical evaluation is also provided for experiment 2. The *p*-values are from testing the null hypothesis of both mixtures behaving the same (i.e., same changes over time). In other words, if any of the mixtures showed a different change behavior over time then the *p*-value was small. Some parameters showed significant differences are discussed in detail in the following section.

table 3 p-s of V2

property	*p*-
alkalinity	**0.045***
unfiltered scattering	0.841
filtered scattering	0.365

unfiltered turbidity	0.727
filtered turbidity	0.554
sodium	0.119
potassium	**0.036***
calcium	**<0.001****
magnesium	0.086
chloride	**0.021***
nitrate	n.a.
sulphate	0.083
P-PO4	0.110
P-t	0.103
N-NO2	0.058
N-NH4	0.413
Si-SiO4	0.467
conductivity	0.109
pH-value	0.083

**highly significant

*significant

3.2.1. Major cations and major anions of experiment 2

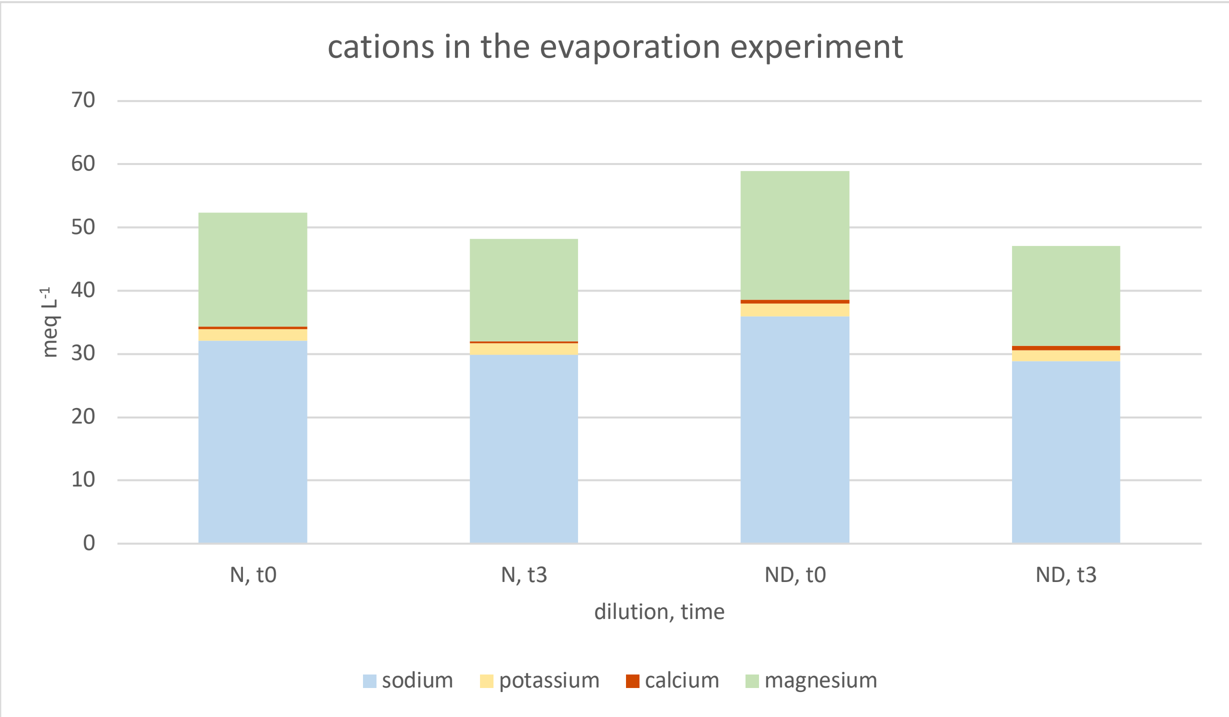

figure 32: major cations at the baseline measurement and at timepoint t3

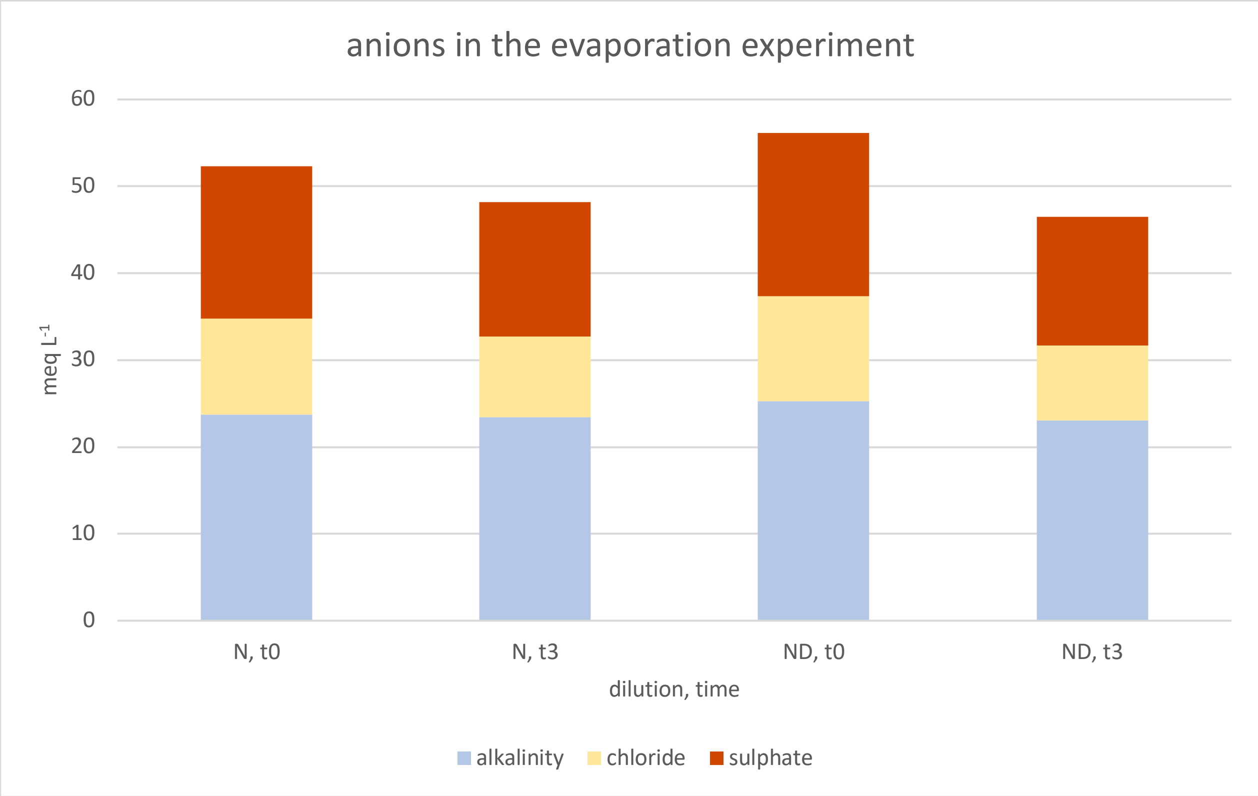

figure 33: major anions at the baseline measurement and at timepoint t3

In the samples of the N series, the cation distribution remains relatively constant between t0 and t3 (Fig. 33). Sodium (shown in blue) has the highest concentration, followed by magnesium (green), while potassium (yellow) and calcium (orange) make up only small proportions. There is only a slight decrease in the cation concentrations between the two time points, which indicates a stable composition despite evaporation.
The ND samples show a somewhat more pronounced decrease in cation values from t0 to t3. However, the distribution of cations remains similar, with sodium as the dominant ion, followed by magnesium. Here too, the concentrations of potassium and calcium remain relatively low.
In the sample series N, it can be observed that the anion distribution remains relatively stable between t0 and t3, but there is a slight decrease in the total concentration. Alkalinity (shown in blue) is the dominant anion, followed by sulphate (orange) and chloride (yellow). The slight decrease in the anion concentration could be due to an evaporation effect, which slightly influences the concentration of all ions without significantly changing the ratio of the anions to each other.
The sample series ND shows a similar pattern, but with a clearer decrease in the anion concentration from t0 to t3. The order of the anions also remains constant here:

alkalinity is the highest, followed by sulphate and chloride. The greater decrease in the ND samples compared to the N series indicates that this sample series is more sensitive to the evaporation process and is possibly less stable.

Alkalinity

Figure 34 shows the temporal development of alkalinity in the sample series N and ND. Sample series N and sample series ND both show a drop in alkalinity over the course of the experiment. Sample series N shows a slight decrease in alkalinity from approximately 14 meq L^{-1} to approximately 13 meq L^{-1}, which indicates a slight reduction in buffer capacity. In the ND sample series, the decrease is more pronounced, with a drop from around 14.5 meq L^{-1} to around 12 meq L^{-1}. This greater reduction in the ND series could indicate a higher sensitivity to evaporation losses.
The results show that evaporation causes a moderate decrease in alkalinity in both sample series, with the ND sample series showing a greater variation. Despite the reduction, however, the alkalinity remains at a comparatively stable level, which indicates that the chemical stability of the system and the buffer capacity are largely maintained.

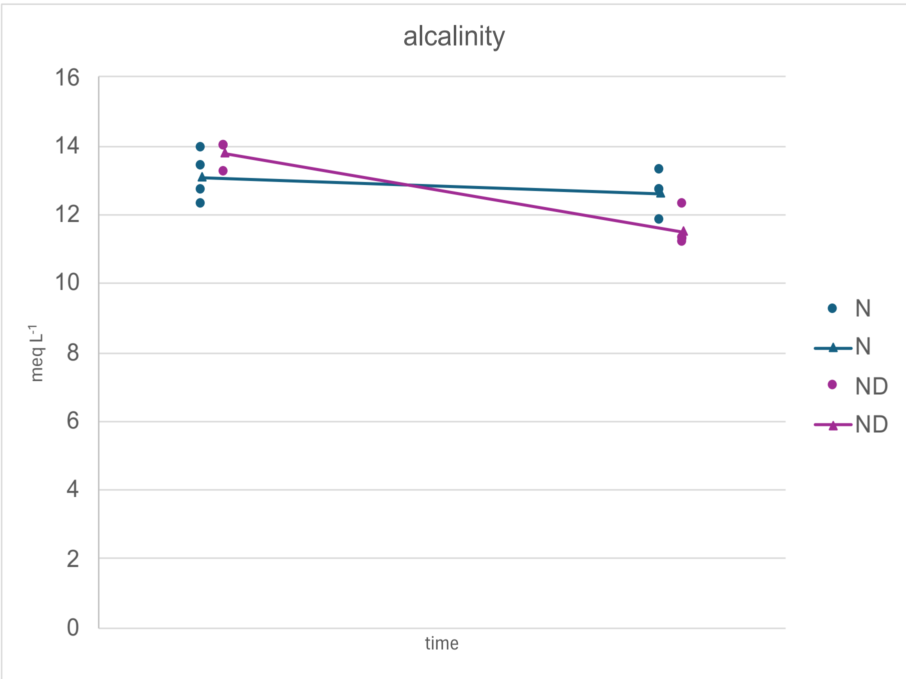

figure 34: V2, alkalinity

The *p*- is 0.045 and therefore statistically significant.

Potassium

Potassium concentrations show remarkable results in experiment 2, as can be seen in figure 35. While the reference samples show constant values throughout the period and only a minimal decrease, the potassium concentrations of ND samples decrease significantly more (p=**0.036)**. Therefore, compared to the control sample (N) the ND sample did show a significant stronger decrease from t0 to t2. The high scattering of potassium values in the ND samples at the initial measurement is particularly conspicuous, with a range of more than 0.5 meq L^{-1}.

These results indicate that mixing negatively influences the stability of the potassium concentration and leads to an increased loss. The pronounced scattering at the beginning could indicate an ongoing precipitation, which stabilize over time.

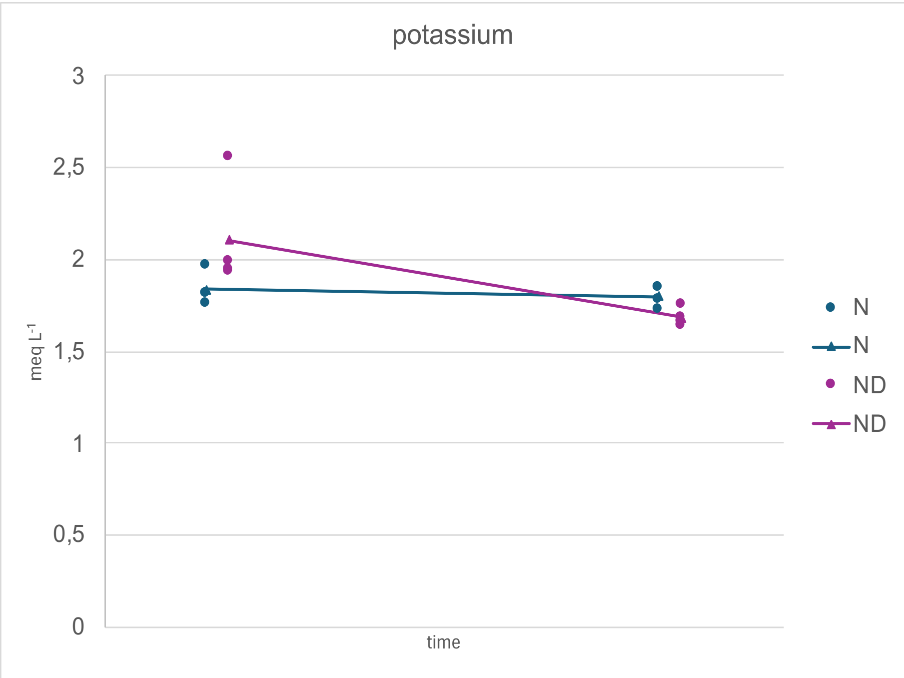

figure 35: V2, potassium

An average change of -0.037 meq L^{-1} in the pure Lake Neusiedl samples was examined. In the Lake Neusiedl-Danube water samples on the other hand, there is an average change of -0.413 meq L^{-1}.

Calcium

The calcium concentrations in experiment 2 (figure 36) show particularly interesting trends. While the calcium values in N samples are initially just over 0.4 meq L^{-1} and only decrease slightly over the course of the experiment, ND samples show the opposite pattern. The initial mean value here is already over 0.6 meq L^{-1} and increases continuously over time until it reaches a mean value of just under 0.7 meq L^{-1} in the last measurements.

These results indicate that the addition of Danube water significantly increases the calcium concentration in the system and leads to further enrichment over time. The different dynamics between the two sample series indicate that mixing of lake water with Danube water influences the availability and stability of calcium ions and possibly leads to an increased release or reduced binding of calcium.

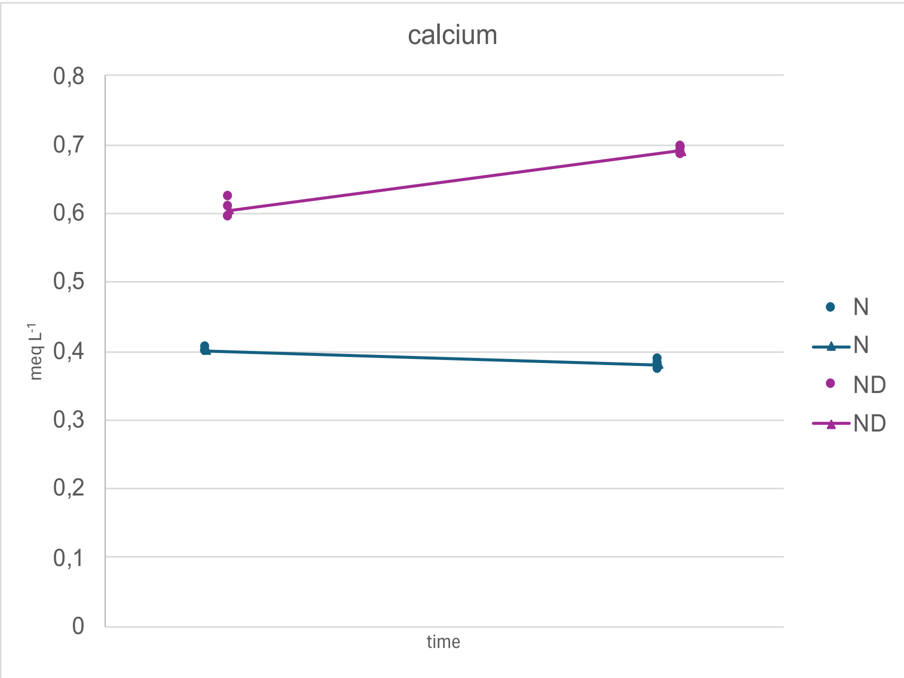

figure 36: V2, calcium

Figure 37 shows the mean change in calcium concentrations in the sample series N and ND over the course of the experiment.
Sample series N shows a negative mean change of -0.02 meq L^{-1}, which indicates a slight decrease in calcium concentration over time. In contrast, the ND sample series shows a significant increase in calcium concentration with a mean change of 0.09 meq L^{-1}. This positive change in the ND samples indicates that the mixing ratio in the Lake Neusiedl-Danube water leads to an enrichment of calcium. The significant difference between the two sample series suggests that the addition of Danube water increases calcium availability in the system and leads to a stable accumulation, while the Lake

Neusiedl water alone shows a slight decrease in calcium concentration. These results support the hypothesis that the mixing ratio in the ND system has a decisive influence on the chemical stability and dynamics of the calcium concentration during the experiment. The *p*- is smaller than 0.001 and therefore statistically highly significant.

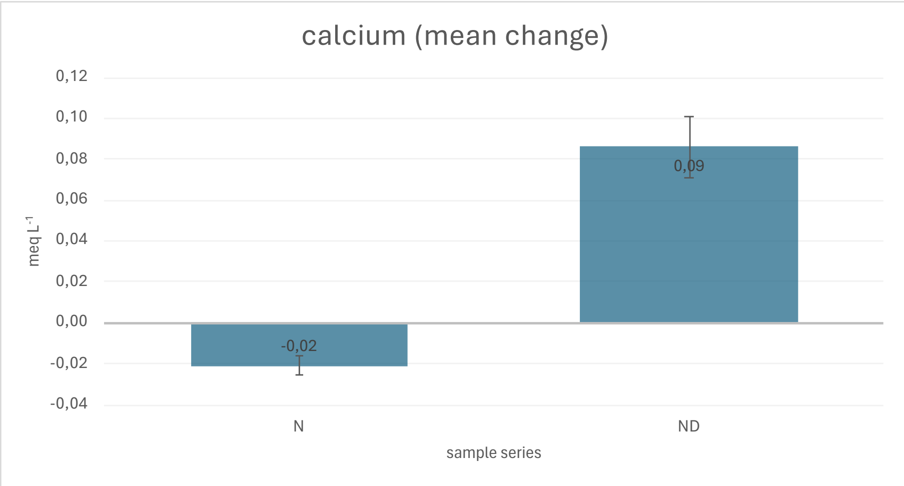

figure 37: V2, calcium mean change

Chloride

Both of the N and ND samples have decreased in chloride values over time, as can be seen in figure 38. It can also be seen that the pure Lake Neusiedl samples have decreased less and although there was a lower initial value, the chloride value at the end is higher than that of the mixed, evaporated samples. The *p*- is 0.021 and therefore statistically significant.

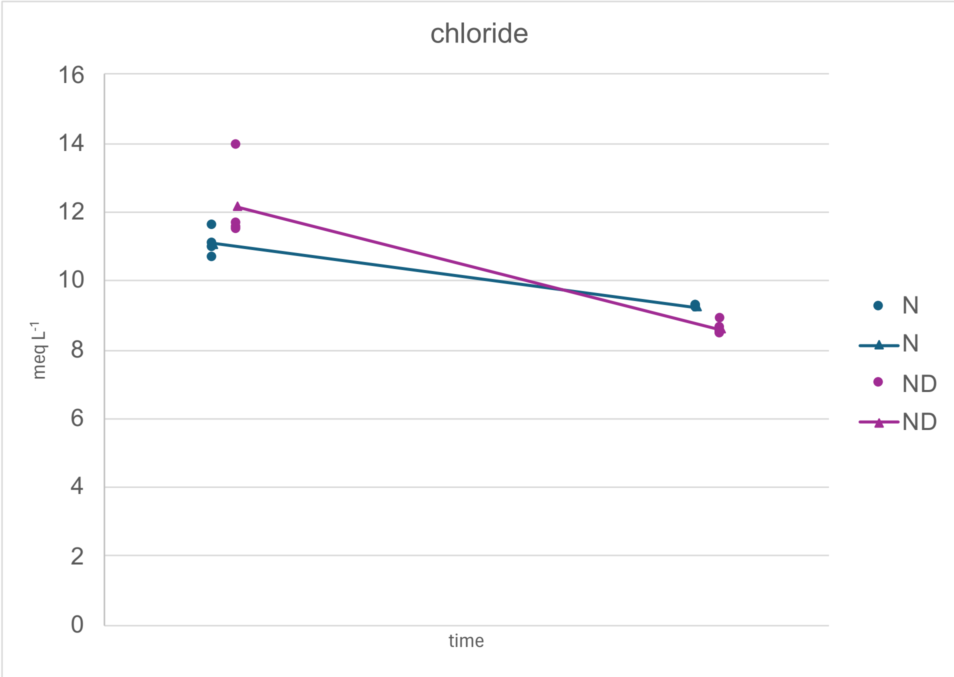

figure 38: V2, chloride

3.2.2. Scattering and turbidity

In experiment 2 unfiltered scattering (*p*= 0.841), filtered scattering (*p= 0.365)*, unfiltered turbidity (*p*=0.727) and filtered turbidity (*p*=0.554) did not show any statistically significant change over time.

3.2.3. Dry and ash mass

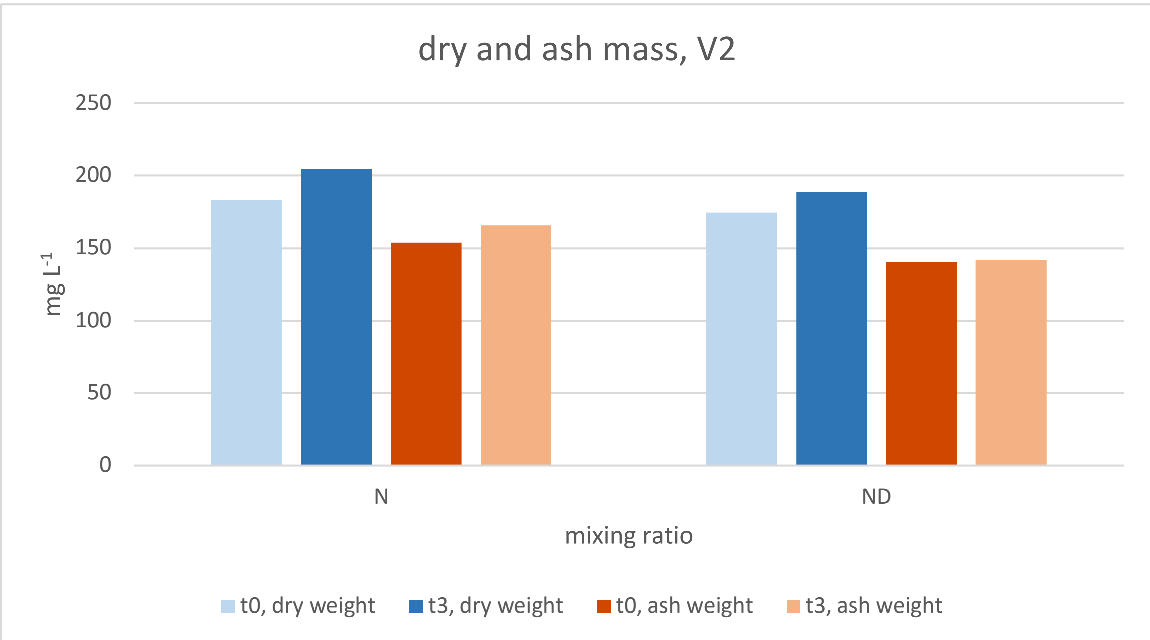

figure 39: dry and ash mass, V2

Figure 39 shows the dry mass and ash mass for the sample series N and ND at the times t0 and t3 in the course of experiment 2. In the sample series N, the dry mass remains relatively constant over time and shows only a slight increase from t0 to t3. Similar values can also be observed for the ash mass, which also remains stable, but is slightly below the dry mass. The difference between dry and ash mass indicates that part of the mass consists of organic components, which show hardly any fluctuations over the course of the experiment.

The results for sample series ND show a similar pattern. The dry mass remains relatively constant between t0 and t3, and the ash mass remains slightly below the dry mass. Compared to sample series N, the values for ND are slightly lower, which could indicate a lower content of suspended and dissolved solids in the ND mixing ratio.

In summary, both sample series (N and ND) show stable values for dry and ash mass over the period of the experiment. This indicates that the chemical and physical composition of the samples remains essentially constant and shows no significant changes in terms of dissolved and suspended components. The slightly lower values in the sample series ND could indicate a different composition or dilution effects.

3.2.4. Conductivity and pH-value

Conductivity

Figure 40 shows the course of conductivity for the sample series N and ND over the study period. In sample series N, the conductivity remains relatively stable and only shows a slight drop from around 3.95 mS cm^{-1} at the beginning of the experiment to around 3.90 mS cm^{-1} at the end of the study period. This indicates a largely constant ion concentration in the water of Lake Neusiedl without significant fluctuations.
The sample series ND, on the other hand, shows a conspicuous change. At the beginning of the experiment, the conductivity is stable at around 3.80 mS cm^{-1} but shows a sharp increase to over 3.90 mS cm^{-1} at the end of the study period. This increase could indicate an increased release of ions or a change in the chemical composition of the Lake Neusiedl-Danube water mixture caused by the dilution effect or a reaction between the two water systems.

In summary, the conductivity in the Lake Neusiedl samples remains stable over time, while an increase can be observed in the Lake Neusiedl-Danube samples. This indicates that the mixing ratio in the ND system increases ion availability over the course of the experiment and influences conductivity. These results suggest that the Danube water plays a significant role in modifying the chemical properties of the Lake Neusiedl water. Still, the *p*- is 0.109 and therefore statistically not significant.

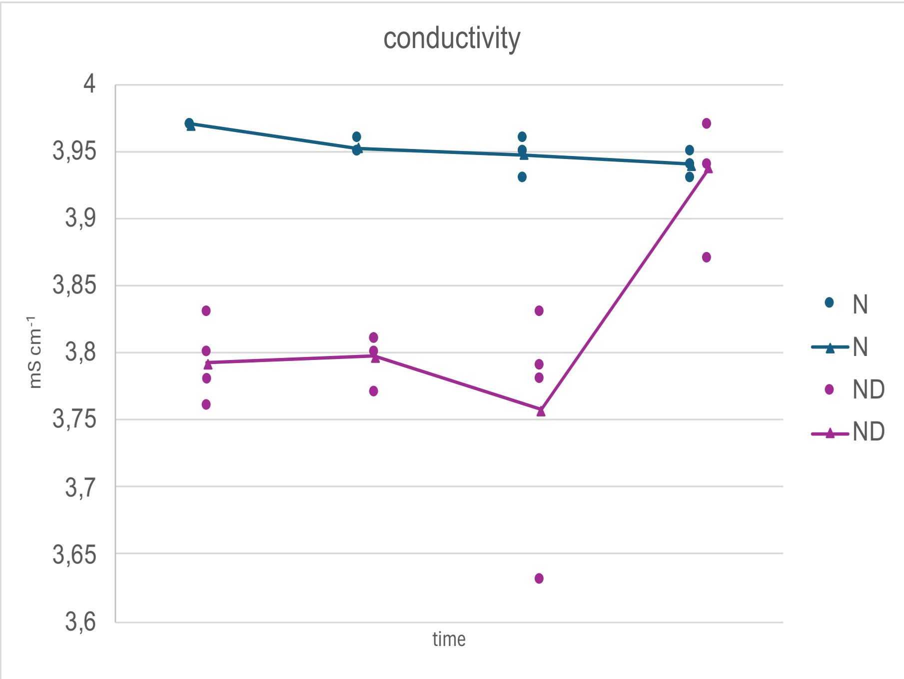

figure 40: V2, conductivity

pH-value

Regarding the results of the pH value of experiment 2 (figure 41) an increase between t2 and t3, regardless of whether it was the pure Lake Neusiedl samples or the mixed and evaporated Lake Neusiedl-Danube samples is shown. However, looking at the y-axis, it is noticeable that the change shows a pH value of initially just over 8.90 and finally only just over 9.00 for the pure Lake Neusiedl water samples and just under 8.95 initially and finally under 9.10 for the mixed samples, which does not represent a major change.

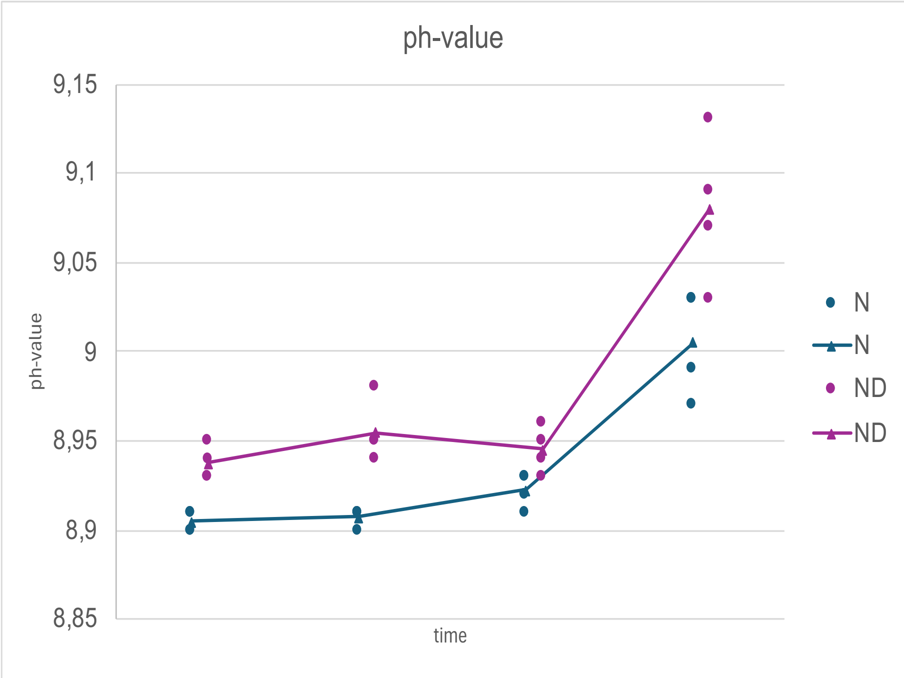

figure 41: V2, pH-value

Looking at the mean change (figure 42), the increase between the first and the last measurement time is 0.10 for the pure Lake Neusiedl samples and 0.14 for the mixed sample, which is at the same time the biggest mean change. The p- is 0.083 and therefore statistically not significant.

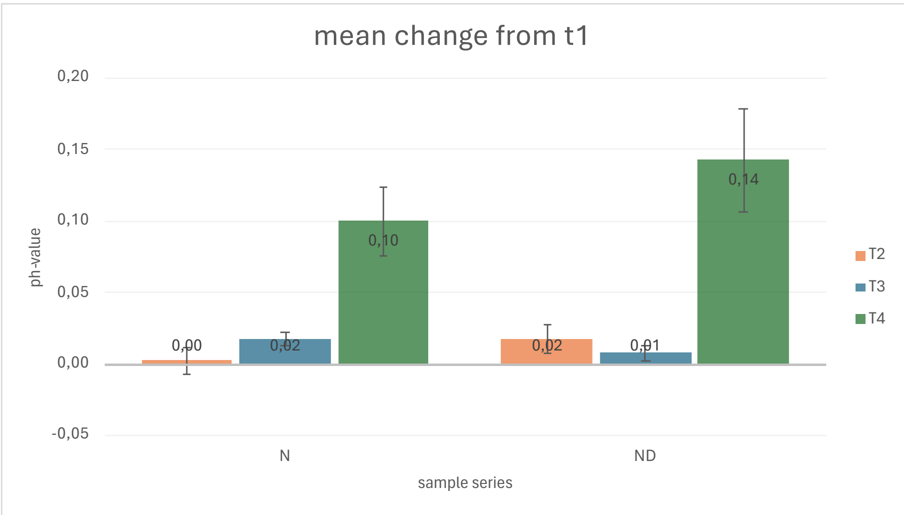

figure 42: V2, pH-value mean change

Ion balances of V2 in comparison to Wolfram et al. (2014)

To finally compare the results of experiment 2 regarding the ion balance, figure 43 shows the results of experiment together with the edited graph of Wolfram et al. (2014) by highlighting the areas of the open lake and the reed beds in gray and the areas of the Danube River in blue. The created ion balance of experiment 2 was superimposed to have a direct comparison and to recognize whether the main ion composition is also subject to a strong change or not. As can be seen in the graph, both the green crosses (reference series of pure Lake Neusiedl water) and the red crosses (evaporated water samples) are in the area that Wolfram et al. (2014) also determined as Lake Neusiedl water main ion composition.

While the results of the experiment for the cations do not come close to the ionic composition of the Danube water and are obviously only in the range of the ionic composition of Lake Neusiedl water, the picture for the cations is somewhat different. The area where the lower red cross is located is still marked in gray and therefore belongs to Lake Neusiedls ion composition, but if you look at the original graph, you can see that this ion composition is mainly found in the reed area. Further studies are needed to see if the ion composition moves even further the one from Lake Neusiedl.

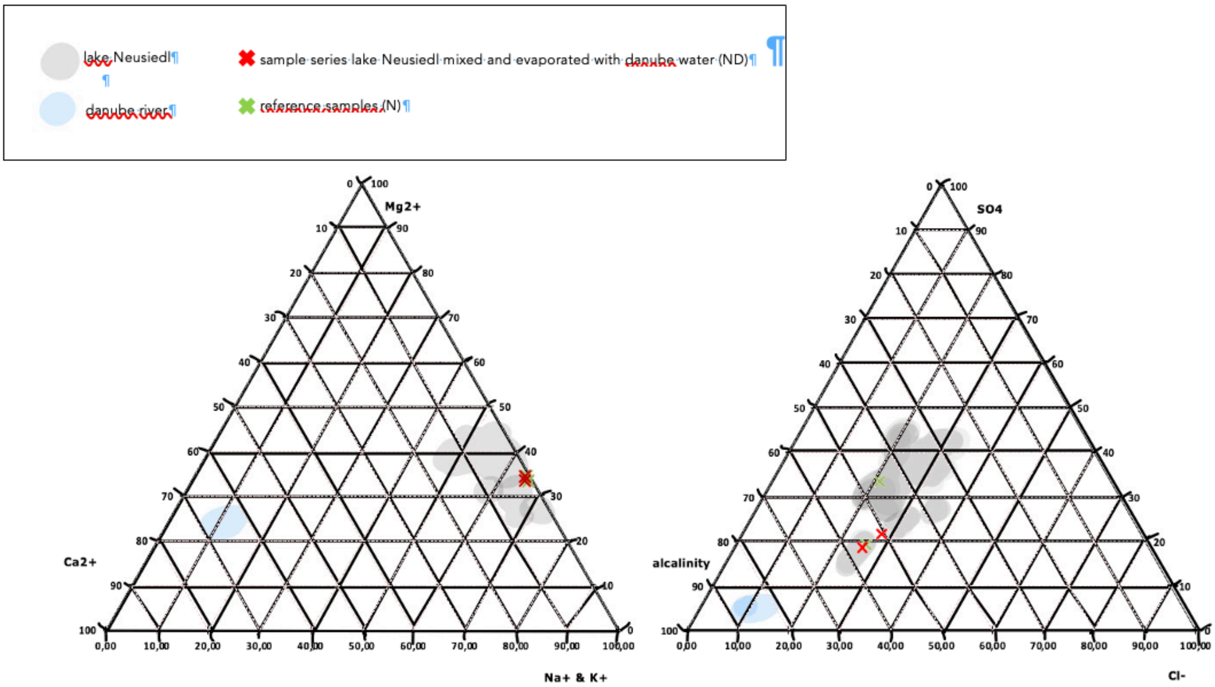

figure 43: Ion balance of V2 in comparison to Wolfram et al. (2014)

4. Discussion

Lake Neusiedl, as we experience it today, should not be considered as natural ecosystem which developed without significant human impact. Lake Neusiedl has changed considerably since centuries due to human intervention. One example is the reduction of the original catchment area to one fifth. The argument against an endowment because Lake Neusiedl should be left in its natural, original state is therefore meaningless. Lake Neusiedl as we face it today does no longer correspond to its original state. Therefore, other arguments should be examined rather than **keeping the natural state of the lake.** We prefer and oppose the formulation that the lake should be **kept in its present state**.

For assessment of a dotation, it is mandatory to consider various aspects and not only a few parameters. This makes defining a solution quite complex. Not only immediate changes need to be considered, but also developments over longer periods of time. **pH value** of the lake may serve as an example here: Krachler et al. (2005) stated that the pH-value drops by 0.9 after Danube bank filtrate is mixed with Lake Neusiedl water. However, Krachler et al. (2005) only prepared a 1:1 mixing ratio and also did not measure over days. The current study, however, did not confirm this result. Samples of pure Lake Neusiedl water have an average pH value of 8.84, while the 1:1 mixture with Danube water have an average pH value of 8.79. According to our findings (which is also only a snapshot), pH shifts were only marginal. In experiment 2, the results indicated the opposite, i.e. an increase of pH over time. The mixed and subsequently evaporated samples of Lake Neusiedl-Danube samples initially had a pH value of 8.94; after three weeks, a pH value of 9.08 was measured. Particularly in experiment 2, which is intended to imitate the time component, the pH-value did not drop. Potential reasons for the discrepancies could on the one hand be the different experimental conditions, like the mixing ratio or on the other hand the temporal component. Our study includes the temporal component, which can be seen as crucial, since it shows that over time chemical dynamics in the mixtures may lead to different results than results which are observed right after mixing experiments. Moreover, also biological interactions become important, as the lake (and also our laboratory conditions) is not a sterile system.

In their study, Wolfram et al. (2020) highlight that the **soda character** must be maintained to protect Lake Neusiedl in the long term. The soda character is especially characterized by the high pH-value and the high sodium hydrogen carbonate concentration. This soda character provides a strong buffering capacity, so that the water can resist despite the addition of Danube water. In our study, the buffering capacity might have mitigated the expected pH decrease, especially over a longer time frame. Our study provides valuable insights that challenge previous findings by demonstrating the complexity of chemical interactions between Lake Neusiedl and Danube water. The results underscore the importance of considering both immediate and long-term effects of environmental management strategies. While our findings suggest that careful adding of smaller volumes of Danube water might not drastically alter the lake's pH value, further comprehensive studies are necessary to confirm these results under various conditions and over extended periods.

The **sodium values** observed in the experiments reveal important insights into the impact of Danube water to Lake Neusiedl water. Pure lake water showed slightly increasing sodium values over time, however this change is not statistically significant. Environmental conditions maintain or slightly increase its sodium concentration due to impacts like evaporation, which concentrate ions, including sodium, in the remaining water. Mixed samples on the other hand showed a decrease in sodium values, ranging from minus 0.79 meq L^{-1} to minus 1.12 meq L^{-1} across different mixing ratios due to dilution. The degree of decrease depends on the mixing ratio; the more Danube water is added, the lower the sodium concentration becomes. For answering whether an endowment would change the sodium value of the Lake dramatically, results of experiment 2 become important, since it includes repeated evaporation and dilution mimicking annual variations. The sample series of pure Lake Neusiedl water show again a slight decrease in sodium value of around 2.26 meq L^{-1}. Over time, without the influence of Danube water, there might still be processes that cause a reduction in sodium, such as precipitation where sodium ions form salts that settle. The mixed and evaporated samples showed a much more pronounced decrease of 6.96 meq L^{-1}. Evaporation concentrate ions, which induce shifts in chemical equilibria leading to sodium salt precipitation. In view of these results, it cannot be guaranteed that the sodium value of Lake Neusiedl will remain as high if it is fed with Danube water.

Ion balances of experiment 2 however change only within a small range expected for Lake Neusiedl.

However, ion concentrations will also not be stable without Danube water supply. In case of high-water levels due to heavy rains, ion dilution is also present, and with opening the lock to prevent the region from floodings, salts will be washed out of the basin. More comprehensive studies on repeated evaporation and dilution are required in any case. Anyways, further studies regarding the chemistry especially over a longer period are needed.

Krachler (2005) mentioned the difference in **alkalinity** between Lake Neusiedl and the Danube and expected a strong change in the mixed samples. Indeed, in experiment 2 the alkalinity shift was significant, reacting different than the reference. The results of experiment 2 clearly show that the alkalinity decreases over time both in the reference samples (N100) and in the evaporated mixed samples from Lake Neusiedl and Danube water, whereby the decrease in the mixed samples is significantly steeper.

From a biological perspective, this leads to the conclusion that doping Lake Neusiedl with Danube water will have a visible effect on the buffering capacity of the lake. The decrease in alkalinity in the mixed samples indicates that the characteristic carbonate buffer system of Lake Neusiedl - which is crucial for self-purification and stabilization of the water column - is weakened by the additional calcium in the Danube water. Such a loss of alkalinity could lead to a drop in the pH value, which would have a direct impact on biological processes in the lake.

On the one hand, a lower pH value has a negative effect on the microbial decomposition of organic substances, which promotes the accumulation of organic material in the sediment. On the other hand, a reduction in alkalinity impairs the stability of the characteristic inorganic turbidity, which acts as a substrate for the growth of biofilm-associated microorganisms. These microorganisms play a central role in the degradation of organic residues. Doping with Danube water could therefore affect not only the physico-chemical balance, but also the biological integrity and self-purification capacity of Lake Neusiedl in the long term.

Krachler (2005) warned that discharging Danube water into the lake is not just a dilution, but that **chemical reactions** will take place, which need to be examined carefully. Our results showed pronounces shifts in some parameters such as potassium, calcium or chloride. Since **potassium** values had pronounced changes, they are discussed more in detail. In experiment 1, the reference showed stable potassium level, with just a minimal decrease between t0 and t2. This suggests that the potassium concentration in Lake Neusiedl, does not vary widely over time. N90D10 had a comparable pattern with just a light decrease of potassium over time, so even with a minor addition of Danube water, the potassium level will remain constant. The other mixed sample series N75D25 and N50D50 however indicated a greater decrease of potassium with mean changes of minus 0.14 meq L^{-1} (N75D25) and minus 0.12 meq L^{-1} (N50D50), although not significant (p = 0.155). In experiment 2, potassium of the control remained constant, the mixed and evaporated samples (ND) however showed a significant decrease of minus 0.42 meq L^{-1} (p = 0.036). This pattern obtained in experiment 2 pointed out that factors such as evaporation and time significantly enhance the leaching or removal of potassium from the water. This shows again the high need to also include long-term experiments to provide reliable results and to forecast possible changes in the lake.

Especially the findings of the **calcium** content during the mixing experiments were highly interesting. Experiment 1 already indicated pronounced shifts. The reference samples N100 remained relatively constant with an average of 0.47 meq L^{-1}. The mixed samples N75D25 and N910D10 were comparable. The mixed samples N50D50 however showed a significant increase of calcium from initially below 0.71 meq L^{-1} to more than 1.33 meq L^{-1}. Experiment 2 shows that the calcium concentration of lake water was around 0.4 meq L^{-1}; it decreased slightly over time, with a mean change of minus -0.02 meq L^{-1}. This leads to the conclusion that Lake Neusiedl without any external inputs (like in the case of this experiment Danube water will be), the calcium value might decrease slowly. This decrease is due to natural processes such as precipitation of calcium due to the increased salinity. Mixing Danube water with lake water started with 0,61 meq L^{-1} and further increased over time, reaching a mean value of around 0.69 meq $L^{-1.}$ The mean change observed is plus 0.08 meq L^{-1}. This increase indicates that the addition of Danube water introduces a higher calcium concentration into the lake, but on the other side decreases the overall salinity. The shift in the calcium amounts show the impact of external water sources on the lake chemistry. Rising calcium levels will have various ecological implications. Both experiments reinforce the impact of mixing Danube water on the chemical composition of Lake Neusiedl, highlighting the need for careful management of such interventions to maintain the lake's ecological balance. Further research is essential to explore these dynamics over longer periods and under varying environmental conditions to ensure the sustainable management of Lake Neusiedl.

The results of the **chloride** concentrations in experiment 2 show that both the pure Lake Neusiedl samples and the mixed samples of Lake Neusiedl and Danube water exhibit a decrease in chloride values over time. However, the pure Lake Neusiedl samples show a smaller decrease compared to the mixed samples. Although the initial chloride values were lower in the N samples, the final concentrations of these samples were higher than in the ND samples. This significant reduction in chloride levels in the composite samples suggests that the evaporation process in combination with the addition of Danube bank filtrate accelerates the loss of chloride in the water, possibly through chemical precipitation reactions or different evaporation rates. From a biological point of view, this suggests that the introduction of Danube water could change the ion distribution and salinity of Lake Neusiedl in the long term, which could potentially have far-reaching effects on the ecological balance of the lake. A change in salinity could affect the living conditions for certain organisms in the lake and thus impair the biodiversity and self-purification capacity of Lake Neusiedl.

It is often argued that **turbidity** will be lowered due to feeding. Therefore, also **absorption** and **scattering** including also **ash mass** must not be neglected in the discussion. What does reduced turbidity mean in a shallow lake? What consequences might follow?

In a shallow lake such as Lake Neusiedl, a reduction in turbidity has significant ecological consequences. Turbidity is caused by suspended matter, which scatters and absorbs light in the water and thus influences light conditions, photosynthesis and material cycles. A reduction in turbidity can have several effects, such as increased light penetration and increased plant growth, displacement of nutrient cycles and microorganisms, habitat modification for aquatic organisms as much as lime precipitation and pH changes (Carpenter & Cottingham, 1997; Herzig & Dokulil, 2001; Eiler et al.; 2003; Scheffer, 2004; Wetzel, 2001). Scheffer (2004) and Wetzel (2001) argued that increased light penetration into deeper water layers promotes growth of submerged macrophytes. In shallow lakes, this increased light availability can lead to the development of denser plant populations and an increase in algae production, which has a significant impact on biogeochemical nutrient cycles. The increased primary production increases the biomass, which generates a high oxygen demand after death and decomposition. This increased oxygen consumption in the sediment can lead to anoxic conditions in the near-bottom layers, which has far-reaching consequences for the benthic community and the chemical processes in these layers.

In addition, particles provide an important adhesion surface for bacteria and other microorganisms that play a role in the degradation of organic matter. A reduction in turbidity could slow down the decomposition processes and lead to the accumulation of organic material. This can impair the self-cleaning capacity of the lake, as microorganisms work less efficiently without sufficient substrate surfaces. (Eiler et al., 2003). Carpenter & Cottingham (1997) examined that turbidity provides protection for zooplankton and smaller fish from predators. A reduction in turbidity could affect the habitat of less cover-rich organisms and negatively impact their populations. Also lime precipitation and pH changes can be caused by reduced turbidity mean in a shallow lake. In lakes with high alkaline levels, turbidity helps to stabilize the pH and maintain chemical balances. A reduction in turbidity can cause the pH value to drop and reduce the buffering capacity of the lake, which in turn can affect water quality and the ecological balance (Dokulil & Teubner, 2001).

The results from dry and ash mass measurements lead to the following interpretation:

The comparison of the two experiments illustrates the different influences of dilution and evaporation on the chemical composition of the samples. In the dilution experiment V1, the addition of Danube water leads to a reduction in the dry and ash mass, which reflects the dilution of the ionic and solid components in the water of Lake Neusiedl. This decrease indicates that the Danube water has a lower concentration of dissolved and suspended solids than the Lake Neusiedl water, which is confirmed by previous studies on the water quality of the Danube (Bundesministerium für Land- und Forstwirtschaft, Regionen und Wasserwirtschaft, 2024). In contrast, the evaporation experiment V2 shows an increase in dry and ash mass, as evaporation leads to a concentration of dissolved substances in the water. This is characteristic of terminal lakes such as Lake Neusiedl, where evaporation strongly influences the ion concentration and leads to the long-term accumulation of specific ions and solids (Dokulil, 2009).

The different influence of the addition of Danube water in the two experiments emphasizes that the effectiveness of dosing in Lake Neusiedl depends strongly on the evaporation conditions. The results show that dosing with Danube water can reduce the concentrations of dissolved substances in the short term; however, this effect is compensated for or even reversed at high evaporation rates, as the natural evaporation effects increase the concentration of the substances again. These observations are consistent with studies on the water balance in arid and semi-arid regions, in which evaporation is described as the dominant factor in water chemistry (Wetzel, 2001).

It can be deduced from both experiments that although dosing with Danube water can potentially help to reduce the concentrations of dissolved substances in Lake Neusiedl, this measure only has a limited effect in the case of strong evaporation effects. The natural evaporation effects of Lake Neusiedl lead to a reaccumulation of ions, which limits the effectiveness of dosing. It is therefore essential to include both dilution effects and evaporation processes in the planning for an effective long-term fertilization strategy. Ideally, dosing should take place during phases of low evaporation or in conjunction with measures to reduce evaporation in order to keep the water quality of Lake Neusiedl stable and minimize undesirable chemical changes (Herzig & Dokulil, 2001; Maracek & Sailer, 2023).

Another factor that is relevant to the protection of Lake Neusiedl in its present state is the currently **valid guidelines** for bodies of water (RIS2019). For example, threshold values are defined for some properties that were also dealt with during the study, such as calcium, electrical conductivity, and physical parameters. The limits are intended to protect water bodies and enable action to be taken if the values are exceeded. Of course, such thresholds are undoubtedly important for lake monitoring, however unique systems need special attention. Special types of lakes such as Lake Neusiedl as a terminal lake will experience significant shifts in the concentrations of substances depending on the water level. Moreover, it would be useful to include morphometric measures such as water depth to protect such lakes, not only minimum values of specific ions. Particularly the definition of a minimum water depth is largely disregarded. This is problematic from a biological point of view, as the water depth has a direct influence on the ecological processes and biodiversity. This lake is a shallow steppe lake with an already shallow average depth, which makes it susceptible to significant hydrological fluctuations. A further decrease in water depth due to evaporation or anthropogenic water abstraction could lead to several negative ecological consequences, including deterioration of water quality, oxygen depletion and alteration of habitats for flora and fauna. It requires therefore also the introduction of minimum water depth in the legal regulations, since it would help to maintain the balance of the ecosystem by ensuring that hydrological conditions remain stable, thus protecting habitats and biodiversity. When focusing just on the chemical limits, especially in case of Lake Neusiedl, does not pursue the goal of protecting the lake and it´s area. It is therefore necessary to extend the guidelines with hydromorphological parameters such as minimum water depth, and therefore not have a one-sided focus anymore. Arvola et al. (2009) studied the effects of climate change on steppe lakes and stated that decreasing water levels can have direct and indirect effects on the water body. The studies emphasize the need for management strategies that also consider minimum water levels to protect biodiversity.

The aim of endowment is protection of the lake and the lake region in its current state, not to replenish the lake to always maximum water levels. Studies such as that of Tolotti et al. (2021) confirm the need for lake management adapted to climate change. They emphasize that the lake is very sensitive and that its hydrological fluctuations pose a major threat to the lake. This could lead to critical ecological transitions of the lake in the near future if these become even more severe due to climate change.

Regarding the experiments conducted, some recommendations for future studies should be raised. Experiment 1 (V1) lasted for only two weeks and is therefore not very comprehensive. The experiment may be repeated with focusing on selected parameters, which turned out to be sensitive, but over a longer period. It would also make sense to split the mixing ratios, especially in the range of the planned dotation. Both the 50N50D and the 75N25D mixing were very useful to search for larger changes but could be omitted in future experiments.

A longer period is also helpful for experiment 2 (V2) to identify actual changes in the parameters and to establish whether chemical compounds are involved and, above all, to what extent the changes take place. Also, sediment addition to the bottles would be interesting to provide a more realistic environment. Investigation on particle loadings and their possible change in size and chemical composition over time would be essential to provide reliable results for turbidity development. Lastly, biological parameters such as bacteria and algae development over time would be interesting to include in future experiments.

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raw data V1

Leitfähigkeit				
Probe	Repl.	T0	T1	T2
N100	R1	3,80	3,81	3,80
	R2	3,81	3,80	3,80
	R3	3,81	3,81	3,80
N90/D10	R1	3,48	3,48	3,49
	R2	3,50	3,48	3,48
	R3	3,49	3,49	3,49
N75/D25	R1	2,99	2,99	2,99
	R2	3,00	3,00	3,00
	R3	3,00	3,00	2,99
N50/D50	R1	2,17	2,17	2,18
	R2	2,16	2,16	2,16
	R3	2,16	2,16	2,16
pH-Wert				
Probe	Repl.	T0	T1	T2
N100	R1	8,84	8,81	8,82
	R2	8,84	8,91	8,92
	R3	8,85	8,88	8,91
N90/D10	R1	8,89	8,84	8,90
	R2	8,89	8,89	8,89
	R3	8,89	8,84	8,86
N75/D25	R1	8,87	8,89	8,91
	R2	8,87	8,82	8,89
	R3	8,88	8,89	8,93
N50/D50	R1	8,80	8,75	8,76
	R2	8,79	8,86	8,86
	R3	8,80	8,76	8,76
Alkalinität				
Probe	Repl.	T0	T1	T2
N100	R1	13,5		11,9
	R2	12,6		12,1
	R3	13,0		12,8
N90/D10	R1	13,5		10,9
	R2	10,9		10,7
	R3	11,2		11,1
N75/D25	R1	8,9		10,6
	R2	9,2		10,3

	R3	10,3	11,2
N50/D50	R1	7,2	7,0
	R2	7,2	7,1
	R3	7,2	6,9

Streuung unfiltriert				
Probe	Repl.	T0	T1	T2
N100	R1	0,106	0,069	0,005
	R2	0,106	0,066	-0,003
	R3	0,108	0,063	0,011
N90/D10	R1	0,100	0,046	0,061
	R2	0,114	0,044	0,045
	R3	0,094	0,045	0,067
N75/D25	R1	0,088	0,038	0,049
	R2	0,090	0,026	0,052
	R3	0,079	0,033	0,055
N50/D50	R1	0,064	0,031	0,043
	R2	0,074	0,021	0,029
	R3	0,073	0,017	0,044
Trübe unfiltriert				
Probe	Repl.	T0	T1	T2
N100	R1	1299074,890	1334128,688	1242094,744
		1255422,973	1327944,489	1173376,921
		1290355,079	1326424,169	1231733,901
		1351446,617	1348017,406	1321173,410
	R2	1433174,882	1100479,773	1236789,630
		1394991,016	1101932,883	1230770,581
		1452175,386	1101846,052	1239255,691
		1452358,243	1097660,384	1240342,618
	R3	1354195,328	1248804,147	1246105,599
		1343875,793	1126012,186	1276673,991
		1338448,883	1242816,936	1256068,208
		1380261,308	1377583,319	1205574,598
N90/D10	R1	1251099,865	989219,179	1084016,050
		1225020,668	977769,472	1149653,756
		1253704,473	990456,721	1110181,121
		1274574,453	999431,344	992213,274
	R2	1270948,169	785573,782	722595,891
		1263645,927	798380,383	707729,700
		1262953,701	797284,452	703913,387
		1286244,878	761056,512	756144,587

	R3	1108122,871	901400,504	1274604,078
		1073390,179	893669,597	1320388,861
		1119527,524	910312,660	1252430,729
		1131450,910	900219,256	1250992,645
N75/D25	R1	1179238,311	920588,720	973733,802
		1140757,856	871886,352	956621,822
		1193539,735	932826,445	954625,844
		1203417,343	957053,362	1009953,741
	R2	1029419,199	800905,353	921693,305
		1014158,626	855381,704	932671,533
		1044651,211	785256,102	913944,590
		1029447,760	762078,252	918463,793
	R3	988405,037	989625,671	1001574,830
		986272,714	953853,489	992558,877
		981879, 673	1016075,690	1015954,253
		990537,360	998947,833	996211,360
N50/D50	R1	723115,880	724690,555	714830,654
		755670,652	689374,389	721279,009
		713201,816	685118,873	710948,600
		700475,173	799578,404	712264,354
	R2	733731,685	547673,895	687922,705
		715908,090	563456,149	697933,305
		734612,388	533076,222	696529,698
		750674,578	546489,314	669305,111
	R3	814985,739	812912,464	759779,725
		808471,175	837968,963	775126,427
		809839,348	811758,263	753757,931
		826646,694	789010,165	750454,817

Streuung filtriert

Probe	Repl.	T0	T1	T2
N100	R1	0,010		0,045
	R2	0,028		0,017
	R3	0,003		0,138
	R4	0,017		0,035
	R5	0,014		0,009
	R6	0,053		-0,001
N90/R10	R1	0,024		0,016
	R2	0,026		0,028
	R3	0,004		0,029
N75/R25	R1	0,002		-0,005
	R2	-0,003		0,001
	R3	0,002		-0,009
N50/R50	R1	0,011		-0,007

	R2	0,006		1,285
	R3	0,003		-0,009
N90/D10	R1	-0,001		-0,018
	R2	0,031		0,002
	R3	0,002		-0,005
N75/D25	R1	0,002		-0,004
	R2	0,000		-0,016
	R3	0,009		-0,019
N50/D50	R1	0,003		-0,014
	R2	0,024		-0,006
	R3	0,001		-0,005
Trübe filtriert				
Probe	Repl.	T0	T1	T2
N100	R1	12168,517		147902,219
		13458,167		139468,410
		13274,928		154064,471
		9772,456		150173,776
	R2	17660,176		26752,130
		22734,195		35198,068
		16857,250		23343,060
		13389,082		21715,262
	R3	379830,017		30740,707
		381398,360		34489,692
		383903,771		25556,035
		374187,919		32176,394
N90/D10	R1	12185,407		12440,729
		11509,504		10797,157
		11965,192		11459,615
		13081,526		15065,414
	R2	8583,198		11477,826
		10560,959		10367,244
		9844,303		11543,349
		5344,333		12522,885
	R3	9991,861		11995,280
		8476,054		10483,558
		9510,388		12935,831
		11989,142		12566,450
N75/D25	R1	11026,648		8763,436
		12783,937		6727,663
		10950,378		6822,256
		9345,630		12740,389
	R2	14080,210		7271,665
		13948,311		7029,741

		12557,797	8059,905
		15734,521	6725,348
	R3	95037,305	24123,405
		95285,280	26439,178
		98192,320	23117,447
		91634,314	22813,590
N50/D50	R1	146769,631	172610,892
		137634,715	173363,581
		149093,441	178591,771
		153580,736	165877,323
	R2	249076,208	7604,025
		248423,135	5223,509
		263951,455	7917,525
		234854,034	9671,042
	R3	22324,025	9876,846
		23058,014	8902,347
		22823,686	7973,762
		21090,374	12754,429
N90/D10	R1	12185,407	12440,729
		11509,504	10797,157
		11965,192	11459,615
		13081,526	15065,414
	R2	8583,198	11477,826
		10560,959	10367,244
		9844,303	11543,349
		5344,333	12522,885
	R3	9991,861	11995,280
		8476,054	10483,558
		9510,388	12935,831
		11989,142	12566,450
N75/D25	R1	11026,648	8763,436
		12783,937	6727,663
		10950,378	6822,256
		9345,630	12740,389
	R2	14080,210	7271,665
		13948,311	7029,741
		12557,797	8059,905
		15734,521	6725,348
	R3	95037,305	24123,405
		95285,280	26439,178
		98192,320	23117,447
		91634,314	22813,590
N50/D50	R1	146769,631	172610,892

	137634,715	173363,581
	149093,441	178591,771
	153580,736	165877,323
R2	249076,208	7604,025
	248423,135	5223,509
	263951,455	7917,525
	234854,034	9671,042
R3	22324,025	9876,846
	23058,014	8902,347
	22823,686	7973,762
	21090,374	12754,429

TROCKEN- UND ASCHEGEWICHT, T0, 100 ml

Filternr.	Probe	Filter leer	Ofen 1	Ofen 2	Trockengewicht	TG (mg/l)	Aschegewicht	AG (mg/l)	Glühverlust (mg/l)
4	N100, R1	25,906	32,424	31,611	6,518	65,18	5,705	57,05	8,130
5	N100, R2	26,586	32,905	32,170	6,319	63,19	5,584	55,84	7,350
6	N100, R3	26,476	30,577	29,898	4,101	41,01	3,422	34,22	6,790
16	N90/D10, R1	26,421	32,576	31,843	6,155	61,55	5,422	54,22	7,330
17	N90/D10, R2	26,272	31,981	31,322	5,709	57,09	5,050	50,5	6,590
18	N90/D10, R3	26,753	33,111	32,390	6,358	63,58	5,637	56,37	7,210
19	N75/D25, R1	26,893	33,688	31,612	6,795	67,95	4,719	47,19	20,760
20	N75/D25, R2	27,111	32,772	31,763	5,661	56,61	4,652	46,52	10,090
21	N75/D25, R3	26,736	31,475	30,616	4,739	47,39	3,880	38,8	8,590
22	N50/D50, R1	26,888	30,847	30,191	3,959	39,59	3,303	33,03	6,560
23	N50/D50, R2	25,862	28,308	28,004	2,446	24,46	2,142	21,42	3,040
24	N50/D50, R3	25,630	30,214	29,742	4,584	45,84	4,112	41,12	4,720

TROCKEN- UND ASCHEGEWICHT, T2- 100 ml

Filternr.	Probe	Filter leer	Ofen 1	Ofen 2	Trockengewicht	TG (mg/l)	Aschegewicht	AG (mg/l)	Glühverlust (mg/l)
4	N100, R1	25,131	30,488	29,767	5,357	53,57	4,636	46,36	7,210
5	N100, R2	25,308	31,505	30,643	6,197	61,97	5,335	53,35	8,620
6	N100, R3	25,246	30,799	29,959	5,553	55,53	4,713	47,13	8,400
16	N90/D10, R1	25,214	30,829	29,992	5,615	56,15	4,778	47,78	8,370
17	N90/D10, R2	25,130	30,280	29,549	5,150	51,50	4,419	44,19	7,310
18	N90/D10, R3	25,275	31,357	30,590	6,082	60,82	5,315	53,15	7,670
19	N75/D25, R1	25,225	30,388	29,561	5,163	51,63	4,336	43,36	8,270
20	N75/D25, R2	25,312	30,129	29,501	4,817	48,17	4,189	41,89	6,280
21	N75/D25, R3	25,322	29,698	29,142	4,376	43,76	3,820	38,2	5,560
22	N50/D50, R1	24,895	28,735	28,145	3,840	38,40	3,250	32,5	5,900
23	N50/D50, R2	25,163	28,928	28,476	3,765	37,65	3,313	33,13	4,520
24	N50/D50, R3	24,916	29,371	28,878	4,455	44,55	3,962	39,62	4,930

Chemische Analysen, T2

	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	P-PO4	P-t	N-NO2	N-NH4	Si-SiO4
	Natrium	**Kalium**	**Calcium**	**Magnesium**	**Chlorid**	**Nitrat**	**Sulfat**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**mg/l**
N50D50R1	458,7	48,4	17,4	137,1	243,1	1,1	469,0	3	52	3,3	26	2,1
N50D50R2	491,8	50,6	15,7	142,8	241,0	1,2	471,4	5	52	5,1	29	2,1
N50D50R3	404,4	48,4	9,6	124,8	225,9	1,2	426,8	3	61	3,4	28	2,0
N75D25R1	579,3	60,3	17,7	184,5	323,3	0,4	645,5	3	59	2,2	39	2,2
N75D25R2	609,6	60,3	18,0	177,1	323,3	0,4	648,4	4	59	2,1	24	2,1
N75D25R3	581,4	63,6	15,4	183,4	327,9	0,4	665,8	5	62	2,5	35	2,2
N90D10R1	673,1	65,9	6,9	216,6	384,6	n.a.	792,0	4	64	1,5	40	2,2
N90D10R2	650,3	63,6	13,6	199,6	377,8	n.a.	768,2	4	79	1,3	28	2,2
N90D10R3	651,8	68,3	10,2	185,2	358,0	n.a.	718,3	4	67	1,3	28	2,2
N100R1	679,9	69,4	9,3	181,5	390,4	0,0	745,1	5	68	0,9	37	2,3
N100R2	685,0	71,3	9,9	188,8	398,3	0,0	763,1	5	67	0,9	33	2,3
N100R3	689,5	69,0	9,4	207,8	397,1	0,0	801,1	8	71	3,0	55	2,4

raw data V2

Leitfähigkeit

Probe	Repl.	T0	T1	T2	T3
ND	R1	3,83	3,77	3,63	3,69
	R2	3,80	3,81	3,79	3,67
	R3	3,78	3,81	3,78	3,65
	R4	3,76	3,80	3,83	3,71
N	R1	3,97	3,95	3,93	3,94
	R2	3,97	3,95	3,95	3,95
	R3	3,97	3,95	3,95	3,93
	R4	3,97	3,96	3,96	3,94

pH-Wert

Probe	Repl.	T0	T1	T2	T3
ND	R1	8,93	8,94	8,93	9,03
	R2	8,93	8,95	8,94	9,07
	R3	8,94	8,95	8,95	9,13
	R4	8,95	8,98	8,96	9,09
N	R1	8,90	8,91	8,91	8,99
	R2	8,90	8,91	8,92	8,97
	R3	8,91	8,90	8,93	9,03
	R4	8,91	8,91	8,93	9,03

Alkalinität

Probe	Repl.	T0	T1	T2	T3
ND	R1	14,00			11,3
	R2	14,00			11,3
	R3	14,00			11,2
	R4	13,20			12,3
N	R1	13,40			11,8
	R2	12,30			12,7
	R3	13,90			12,7
	R4	12,70			13,3

Streuung unfiltriert

Probe	Repl.	T0	T1	T2	T3
ND	R1	0,306	0,268	0,291	0,254
	R2	0,289	0,278	0,296	0,295
	R3	0,305	0,271	0,298	0,291
	R4	0,312	0,280	0,317	0,314
N	R1	0,306	0,284	0,308	0,296
	R2	0,311	0,290	0,291	0,327
	R3	0,304	0,279	0,301	0,312
	R4	0,307	0,261	0,299	0,276

Trübe unfiltriert

Probe	Repl.	T0	T1	T2	T3
ND	R1	4790551,899	4605633,742	4574066,360	4445668,610
		4778498,988	4597195,070	4594302,555	4442352,323
		4762958,171	4593948,589	4555015,843	4420471,264
		4830198,537	4625757,566	4572880,683	4474182,242
	R2	4580863,509	4836760,454	5144045,650	5307799,535
		4605430,794	4815216,506	5145086,778	5276345,035
		4588389,833	4831351,865	5172060,767	5285673,305
		4548769,901	4863712,990	5114989,405	5361380,265
	R3	4819871,022	4667793,095	4897773,630	4938628,420
		4753454,705	4668278,501	4889872,804	4942901,387
		4838661,045	4654829,304	4885807,551	4957126,961
		4867497,316	4680271,481	4917640,535	4915856,912
	R4	4903960,639	4797138,333	5242928,508	5362923,144
		4924401,654	4789169,063	5281920,216	5289872,891
		4912296,815	4783974,488	5241511,253	5388695,451
		4875183,447	4818271,447	5205354,054	5410201,09
N	R1	4792203,913	5007243,279	4955596,510	4773073,204
		4798193,422	5014880,716	4962189,755	4758213,589
		4809349,243	4985749,728	4945278,019	4768123,12
		4769069,074	5021099,393	4959321,757	4792882,902
	R2	4878855,914	5020208,943	4961691,750	5328085,947
		4858158,319	5052401,682	4920380,839	5340525,863
		4886494,032	4999660,665	4988731,628	5312842,41
		4891915,390	5008564,482	4975962,783	5330889,569
	R3	4737952,196	4948432,731	4911372,995	5052578,240
		4728687,262	4984342,034	4930294,967	5128782,353
		4723380,317	4914868,563	4931466,684	5047377,707
		4761789,009	4946087,597	4872357,333	4981574,659
	R4	4687788,205	4971139,541	4829907,055	4787286,349
		4696482,945	4934679,964	4808280,703	4798072,369
		4678505,734	4995752,220	4824265,383	4754831,753
		4688375,936	4982986,439	4857175,079	4808954,925

Streuung filtriert

Probe	Repl.	T0	T1,T2	T3
ND	R1	0.032		-0,018
	R2	0,002		0,091
	R3	-0,002		-0,01
	R4	-0,005		0,064
N	R1	0,074		0,044
	R2	0,000		-0,011
	R3	-0,013		0,014

	R4	0,103		0,08
Trübe filtriert				
Probe	Repl.	T0	T1, T2	T3
ND	R1	33233,585		34631,471
		29884,488		35879,988
		32555,508		35023,26
		37260,758		32991,164
	R2	28738,599		31167,299
		28182,095		31396,068
		30337,457		31857,976
		27696,245		30247,854
	R3	28748,325		35311,096
		26817,989		33704,872
		28383,057		35465,81
		31043,929		36762,606
	R4	33396,804		245732,467
		32976,538		236671,56
		32350,933		233099,572
		34862,941		267426,268
N	R1	36662,317		24909,418
		36538,595		23309,68
		38244,310		26597,504
		35204,046		24821,069
	R2	31989,446		31229,529
		31677,521		30282,636
		33591,907		29172,177
		30698,911		34233,774
	R3	35673,702		23720,347
		36395,690		24594,006
		34880,854		21060,013
		35744,561		25507,023
	R4	36705,688		762364,647
		37309,873		738986,786
		39673,915		776881,575
		33133,277		771225,580

TROCKEN- UND ASCHEGEWICHT, T0, 20ml									
Filternr.	Probe	Filter leer	Ofen 1	Ofen 2	Trockengewicht	TG (mg/l)	Aschegewicht	AG (mg/l)	Glühverlust (mg/l)
5	ND, 1	26,390	29,915	29,214	3,525	176,25	2,824	141,2	35,050
6	ND, 2	26,344	29,724	29,073	3,380	169	2,729	136,45	32,550
7	ND, 3	26,412	29,849	29,168	3,437	171,85	2,756	137,8	34,050
8	ND, 4	26,815	30,436	29,749	3,621	181,05	2,934	146,7	34,350
13	N, 5	26,840	30,425	29,799	3,585	179,25	2,959	147,95	31,300
14	N, 6	26,559	30,340	29,755	3,781	189,05	3,196	159,8	29,250
15	N, 7	26,289	29,925	29,35	3,636	181,8	3,061	153,05	28,750
16	N, 8	26,543	30,207	29,639	3,664	183,2	3,096	154,8	28,400

TROCKEN- UND ASCHEGEWICHT, T3, 20ml									
Filternr.	Probe	Filter leer	Ofen 1	Ofen 2	Trockengewicht	TG (mg/l)	Aschegewicht	AG (mg/l)	Glühverlust (mg/l)
5	ND, 1	27,848	31,956	30,949	4,108	205,4	3,101	155,05	50,350
6	ND, 2	27,751	31,622	30,704	3,871	193,55	2,953	147,65	45,900
7	ND, 3	28,287	32,197	31,206	3,910	195,5	2,919	145,95	49,550
8	ND, 4	26,638	29,844	29,026	3,206	160,3	2,388	119,4	40,900
13	N, 5	26,874	30,959	30,135	4,085	204,25	3,261	163,05	41,200
14	N, 6	25,331	29,402	28,681	4,071	203,55	3,350	167,5	36,050
15	N, 7	25,151	29,171	28,322	4,020	201	3,171	158,55	42,450
16	N, 8	25,267	29,475	28,745	4,208	210,4	3,478	173,9	36,500

Chemische Analyse, V2

	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	mg/l	P-PO4	P-t	N-NO2	N-NH4	Si-SiO4
	Natrium	**Kalium**	**Calcium**	**Magnesium**	**Chlorid**	**Nitrat**	**Sulfat**	**µg/l**	**µg/l**	**µg/l**	**µg/l**	**mg/l**
NDR1	990,8	99,8	11,9	310,7	494,3	0,2	1038,5	14	138	3,1	105	2,9
NDR2	756,9	75,3	12,5	221,8	413,3	n.a.	859,7	23	154	3,1	142	2,9
NDR3	749,2	75,7	11,9	222,6	408,7	0,0	842,4	16	145	3,0	105	2,8
NDR4	805,5	77,3	12,2	233,8	406,6	0,0	864,2	10	153	3,2	100	2,8
NR1	711,8	70,8	8,0	202,2	377,0	n.a.	795,7	7	149	3,0	113	2,9
NR2	837,7	76,7	8,1	261,5	411,1	n.a.	948,5	8	149	2,9	102	2,9
NR3	717,9	70,6	8,0	212,9	392,0	n.a.	836,5	10	146	2,9	96	2,9
NR4	685,1	68,4	8,0	197,9	388,8	n.a.	793,9	12	153	3,0	91	2,9