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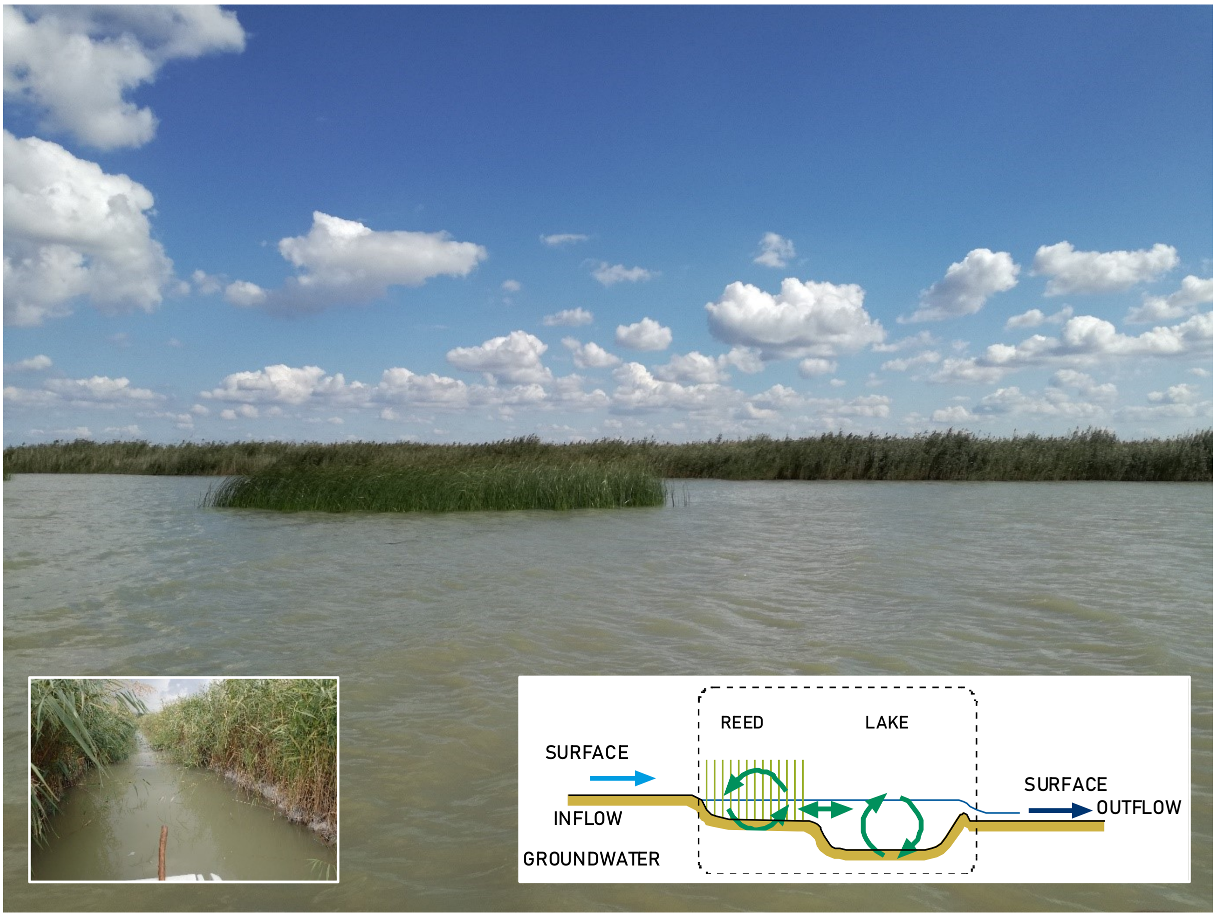
ÖKOLÓGIAI KUTATÓKÖZPONT

REBEN

Interreg Austria-Hungary
European Union – European Regional Development Fund
REBEN

Reed Belt Neusiedler See/Fertő (Interreg AT-HU 2014-20)

Water management plan



Land Burgenland

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ÉSZAK-DUNÁNTÚLI VÍZÜGYI IGAZGATÓSÁG GYŐR

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ABSTRACT

The project REBEN comprised a large number of investigations and analyses on exchange processes between the open lake and the reed belt of Lake Neusiedl (work package 1). The work extended over a period of more than two years on both the Austrian and Hungarian side and could answer important questions raised in the Strategy Study Lake Neusiedl and improved our understanding of the ecological interrelationships. The expert teams of both countries presented their results in several technical reports and a national synthesis. On the basis of this work a joint bilaterally agreed synthesis was prepared.

According to the project description, the aim of the investigations was to create a data and knowledge base for the preparation of the water management plan presented in this document (work package T2). It is divided into six main chapters:

- Reduction of pollution from the catchment area
- Passage of tributaries through the reed belt
- Sediment management
- Reed management
- Monitoring
- Responsibilities

For the topics 1 to 4 the key findings of the project REBEN are briefly reviewed and the status quo described. Based on this, measures are proposed how to improve the current situation, to support a sustainable future development and to achieve the goals defined in the Strategy Study Lake Neusiedl.

Topic 5 presents an overview of the current monitoring programmes at Lake Neusiedl in the fields of hydro-morphology, reed, physico-chemical parameters and biological classification. We highlight the complex requirements and the legal backgrounds of the different monitoring programmes and, based on our findings in REBEN as well as on data analysis from other studies, propose several adaptations and amendments of the current monitoring network and the set of parameters analysed.

The final topic deals with the responsibilities for the 34 measures defined and gives an overview of the relevance and the share of competences among the two countries within and beyond the AHWC for the measures.

1 INTRODUCTION

1.1 Background and objectives

Lake Neusiedl is the most western and largest steppe lakes of the Palearctic and one of the most important natural landscapes in Central Europe and due to its favourable geographical location in the vicinity of large cities (Vienna, Bratislava, Győr, Szombathely) is undisputedly also of great economic importance. The coexistence of high-quality natural area and diverse uses within a cultural landscape is what makes the region especially attractive, but it also makes a careful coordination of different interests indispensable (Wolfram *et al.* 2014b).

In several sectoral studies within the project REBEN, bilaterally coordinated basic investigations were carried out on Austrian and Hungarian territory. They dealt with hydrology (Blaschke 2020; Krámer *et al*. 2019), reed structure (Csaplovics *et al*. 2020; Király 2019), hydrochemistry (Fertő 2019 Consortium 2019a; Hainz *et al*. 2020; Reif *et al*. 2020; Wolfram *et al*. 2020c) and biology (Fertő 2019 Consortium 2019b; c; Krisa *et al*. 2020). The studies provided answers to open and unsolved questions and deepened our under-standing of the ecosystem interrelationships at Lake Neusiedl. The results of these studies allow a better assessment of future developments, but also show possibilities to take appropriate measures to prevent unfavourable developments.

The results of the sectoral studies were first compiled into synthesis reports at the national level (Fertő 2019 Consortium (Hungary) 2020; Wolfram *et al.* 2020a). From these two documents, experts from both countries, in cooperation with the two clients from the Province of Burgenland and the North Transdanubian Directorate for Water Management, developed a bilaterally agreed synthesis (Wolfram *et al*. 2020b). In the report it was shown in different scenarios to what extent changing hydro-morphological conditions contribute to the achievement of the most important water management objectives. These framework conditions took into account the natural variability (water level fluctuations) and ongoing interventions in the structure of the reed belt in the form of regular restoration of reed channels.

While the scenarios in the synthesis report have already partially considered human intervention, there are further possible measures to influence the processes in Lake Neusiedl in order to protect or achieve the water management goals as defined in the Strategy Study Lake Neusiedl.

These measures are the subject of the present Water Management Plan. It was prepared on the basis of the expert reports mentioned above, but also considers the general measures formulated in the Strategy Study Lake Neusiedl. Though we basically focus on water management issues, we also discussed and, where feasible, implemented ideas, proposals and demands from a nature conservation perspective as described in Nemeth *et al.* (2014).

The Programmes of Measures (PoM) for the implementation of the National Water Management Plans of Austria (BMLFUW 2015; BMLRT 2020a) and Hungary (National Water Strategy[1]) were consulted to take into account water management on a national level. However, hardly any specific measures are related to Lake Neusiedl in these documents.

In spatial terms, the measures in the present report are not limited to Lake Neusiedl itself, but also extend to the catchment area. However, the Seewinkel and Hanság region (which were partly considered in the Strategy Study) are not part of the Management Plan.

The Hungarian sectoral reports are available in Hungarian and English, the Austrian reports in German with an English extended summary. The Austrian national synthesis was additionally translated into English as a whole. For the bilateral synthesis, as for the present management plan, English was chosen as the working language to facilitate the joint work on the documents. Both documents are available also in the two national languages.

[1] https://www.vizugy.hu/index.php?module=vizstrat&programelemid=144

2 REDUCTION OF POLLUTION FROM THE CATCHMENT AREA

2.1 Key findings in REBEN

Based on key findings from the REBEN-project two major management needs can be derived in relation to the reduction of pollution from the catchment area:

- In order to slow down siltation in the reed belt at the estuary of river Wulka, the input of particulate matter via Wulka needs be reduced. This would as well reduce the input of phosphorus and particle-bound micro-pollutants. Efforts are required to reduce this type of pollution from the catchment.
- The lake in general is extremely sensitive against pollution with micro-pollutants as they may concentrate in the open water, be stored in the reed sediments, and eventually mobilized later or be metabolized with unknown endpoints (metabolites). Specifically, for several regulated micro-pollutants (PFOS, benzo(a)pyrene, fluoranthene, lead) the risk of not achieving the good chemical status in the Wulka or the lake has been identified. Additional efforts of pollution reduction from the catchment are required.

The catchment of Lake Neusiedl / Fertő has not been directly addressed by investigations within the project REBEN. Anyway, findings of this project shown above address the necessity to rise the focus beyond the lake itself and include the catchment into management consideration. While reduction of nutrient discharges has been very successful during the last decades, sediment loads from the catchment are still a matter of concern for the reed belt. In addition, micro-pollutants stemming from the catchment have been recently recognized as highly relevant concern for the lake water quality status (Zessner *et al.* 2019b). Therefore, water management of the lake must not focus on the lake itself but also address the catchment and potential measures there. To handle this issue former investigations have been used to summarize the main sources and pathways of emissions in the catchment of the lake.

The Wulka is the largest tributary into Lake Neusiedl / Fertő and – in addition to the atmospheric input and discharges from wastewater treatment plants into the lake – it is also the most important input path for external nutrients into the lake. This is mainly due to the intensive agricultural use of the catchment area, from which significant amounts of nutrients are washed away into the Wulka (Wolfram *et al.* 2019; Wolfram & Herzig 2013). While the load of suspended solids in the Wulka is almost exclusively due to agricultural erosion, phosphorus is still emitted in a long-term average of almost 70% *via* this input path and thus in particulate form into the Wulka. In the case of nitrogen, the majority of the input is in dissolved form and comes via groundwater and agricultural drainage systems. Agricultural erosion or particulate transport is relatively insignificant in this case. After widespread implementation of extensive phosphorus and nitrogen removal during wastewater treatment, which highly contributed to the reduction of nutrient inputs into the lake, wastewater disposal supplies about 20–25% of the emissions into the Wulka for both parameters today.

Trace substances and pollutants are emitted into the Wulka and the lake via diffuse and point sources as well. Figure 1 shows as an example an estimation of the distribution of the input pathways for the parameters PFOS, PFOA, benzo(a)pyrene and fluoranthene for the Wulka itself but also for the whole catchment area of Lake Neusiedl / Fertő including deposition on the lake surface. While the perflourtensides PFOS and PFOA are mainly discharged into the Wulka via wastewater management facilities, PAH benzo(a)pyrene and fluoranthene are mainly emitted via erosion (Zessner *et al.* 2019b). Atmospheric deposition is also likely to play a major role in the lake itself, although the quantitative data are highly uncertain due to the small number of samples.

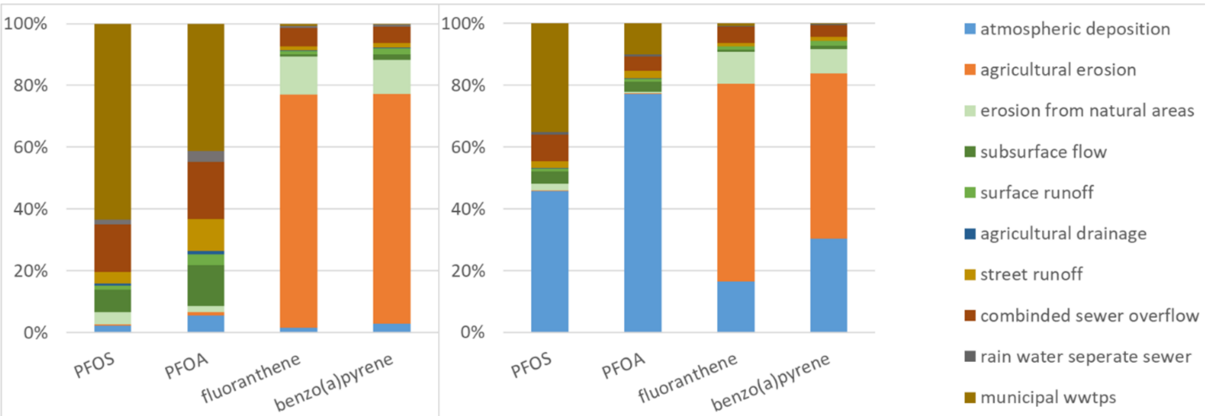

Figure 1. Emission pathways into river Wulka (left) and Lake Neusiedl (right). From: Zessner *et al.* (2019b).

2.2 Measures

Lake Neusiedl / Fertő or the river Wulka are not specifically mentioned in the 1st or 2nd River Basin Management Plan (RBMP) nor in any document in preparation of the 3rd RBMP in Austria. General measures, however, are related to the topic pollution from diffuse sources (agriculture → Wulka basin) and climate change (→ water level issues). Only in respect to measures for improving the chemical status of the water bodies, the river Wulka can been found in a table addressing benzo(a)pyrene pollution and the need for evaluation of the potential to reduce pollution by means of measures on point and diffuse sources of pollution. From more detailed considerations in frame of the project REBEN it can be seen that reduction of solid matter input from the catchment into the reed belt and reduction of micro-pollutant emissions into the Wulka and the lake from the catchment are highly relevant management topics. Specific management concepts are not ready by now. In future, more focus on the development and implementation of specific concepts for pollution control of suspended mater and trace pollutants in the catchment are needed.

Efforts to reduce suspended matter input into the water bodies of the lake catchment start with **abatement of agricultural erosion**. Common approaches for instance are greening and mulch seed, which are promoted by the Austrian funding programs for environmentally friendly agriculture (ÖPUL[2]). Further on, crop choices at steeper slopes could significantly impact agricultural erosion and should be addressed in agricultural management plans. Erosion abatement has the advantage that it contributes to soil protection by avoiding losses of fertile agricultural soils in addition to water protection. Additionally, the release of particulate matter into rivers from arable land can be reduced by measures as greening of preferential flow path or buffer stripes that hinder mobilized soil to enter the water courses.

On the one hand, recent studies from Upper Austria indicate that the ÖPUL funding program has not been highly successful in respect to erosion control, as long-term development of particulate phosphorus and suspended matter in rivers have tended to increase since 2000, because reductions by erosion abatement measures were counteracted by changes of the farmers' crop choices towards crops, which facilitate soil erosion, such as maize (Zessner *et al.* 2016). On the other hand, investigations in Upper Austria showed that for water protection the focus of pollution control on only little shares of arable land would be efficient to reduce the suspended solid inputs by up to 50% if the measures are located target-oriented in the catchment (Kovacs *et al.* 2012; Strenge *et al.* in prep.; Zessner *et al.* 2019a). For the Lake Neusiedl / Fertő catchment similar investigations would be needed to evaluate the success of former erosion abatement measures and sharpen the focus on the effectiveness of these measures in the future.

In case particulate matter has entered the river system it can be retained by **riverine sediment retention basins** to some extent. At the Wulka a sediment retention basin exists close to the inflow into the lake near the mouth of river Eisbach. In the last years, the functionality of the sedimentation basin was not 100%. New experiences and considerations resulted in a revision of the concept in order to fulfil the actual purpose as a sediment retention basin. The constructional measures have already been partly implemented. The current effect on retention of solids is unknown, and other functionalities (*e.g.*, as a wetland and habitat for water-bound birds) have been recognized

[2] https://www.bmlrt.gv.at/land/laendl_entwicklung/oepul/oepul2015.html

as more attractive. Nevertheless, in context of an overall suspended matter management in the catchment for protection of the functionality of the reed belt, the benefit of this or other riverine sediment retention basins in the catchment needs to be evaluated, as the sediments can potentially be better managed in such a basin than when they have reached the reed belt. Overall, a sediment management plan for the catchment with specific focus on the Wulka area should be developed including targeted erosion abatement and sediment trapping in buffer stripes as well as sediment retention basins.

A successful sediment management in the catchment already is the first step for a successful strategy for reduction of pollution with trace substances (**micro-pollutants**). This is due to the fact that a significant share of this type of pollution is related to erosive inputs. Anyway, other sources and pathways play an important role as well and efficient management depends on a clear understanding of how pollutants enter the water courses (Zessner 2008). The driving forces for pollution routes are physical-chemical properties and application patterns of trace pollutants. While some stem from air pollution and enter the water bodies indirectly via accumulation in soils and erosion or directly via atmospheric deposition, others are mainly used in urban areas and enter water bodies via municipal wastewater systems or are used as veterinary pharmaceuticals. They may also be applied as pesticides in agriculture and enter water bodies via surface or subsurface runoff.

Measures to reduce trace substance pollution may address source control (ÖWAV 2020), which exceeds the competences of water management in the context of a regional catchment. Anyway, a specific strategy for micro-pollutant management beyond that is required for the Lake Neusiedl / Fertő catchment, as the lake is specifically vulnerable but not everything can be handled by source control on a national/international level. A micro-pollutant strategy for the lake in addition to sediment management should

- include the identification of sources and pathways of emissions for selected indicator substances,
- improve investigations on the environmental behaviour of these substances and
- be based on the evaluation of costs and effectiveness of measures to reduce pollution.

For municipal wastewater management for instance, different forms of advanced waste-water treatment or addressing emissions from combined sewer overflows or rainwater sewers could be favourable depending on the substance considered. Even if for the future advances in municipal wastewater treatment will probably be become necessary in the lake catchment, it still needs to be investigated how they could be implemented most cost effectively.

Summary of proposed measures

2-1 Develop and implement specific concepts for pollution control of suspended matter and trace pollutants in the catchment

2-2 Reduce suspended matter input into the water bodies of the lake catchment by abatement of agricultural erosion (*e.g.*, greening and mulch seed, reconsider crop choices, greening of preferential flow path, buffer stripes)

2-3 Evaluate the functionality of the existing sediment retention basin and, depending on the outcome of the evaluation, consider further sediment retention basins in the catchment of the river Wulka

2-4 Reduce trace substance pollution by identifying and controlling sources and pathways of emissions for selected indicator substances, improving investigations on the environmental behaviour of these substances, and evaluating costs and effectiveness of measures to reduce pollution

3 PASSAGE OF TRIBUTARIES THROUGH THE REED BELT

3.1 Key findings of REBEN

3.1.1 Processes and loads

The flow of the tributaries and the changes of the chemical composition of the water were studied in detail at the river Wulka (Hainz *et al.* 2020; Wolfram *et al.* 2020a; Wolfram *et al.* 2020c). The reed belt in this area has a width of several kilometres and acts as a huge filter. Suspended solids entering the reed belt are deposited to a large extent even during strong flood events. On average, 3 890 t of suspended solids are deposited every year. In the period 1992–2009 the annual load of suspended solids varied between 740 and 24 230 t depending on the frequency and the size of flood events. Only a very small part (estimated as approx. 3% on average) is transported into the open lake.

The mean annual phosphorus load from the Wulka catchment into the lake is 14 t (range 4–40 t). A large amount is deposited in the reed belt as particulate phosphorus but the release of dissolved phosphorus from the sediment leads to a significant nutrient export from the reed belt (approx. 80% of the total incoming load). Like for the suspended solids, there is a strong variation between dry and wet years.

Nitrogen is almost totally reduced through denitrification, if the Wulka flows diffusely through the reed belt. Since currently a significant part of the Wulka flows through a channel to the open lake, about 1/3 of the total nitrogen load from the catchment area reaches the open lake.

As regards total loads and changes of the chemical composition of the water, much less is known about other tributaries of Lake Neusiedl such as Golser Kanal and small brooks coming from the Leitha mountains or the Parndorfer Platte. The Rákos patak (Kroißbach) is well investigated in terms of water quality, loads and changes on the catchment. No specific investigations were planned in the framework of the project REBEN, but the long-term data series, observations, and monitoring results of the controlled diffuse flow across the wetland near the mouth of the Rákos patak should be used as one of the technical solutions or proposals for water quality management of the tributaries. The contribution of the small tributaries to the water balance of the lake is negligible, but at least the Golser Kanal and the Rákos patak have a contribution to the total nutrient load. Both do not flow directly into the lake but through a wetland (Rákos patak) or through the reed belt (Golser Kanal).

3.1.2 Assessment

The assessment of different scenarios in the synthesis report (Wolfram *et al.* 2020b) made clear that uncontrolled diffuse flow of the river Wulka through the reed belt causes less impact on the ecosystem locally but has an impact on the open lake due to released nutrients. Water management goals such as the *protection of the uniqueness of the reed belt*, the *preservation of natural physico-chemical dynamics* and the support of *largely undisturbed biological processes* can be more easily met without ongoing disturbance by annual dredging.

The diffuse flow supports the filter function (= sink) of the reed belt, hence preventing direct transport of suspended sediment to the open lake. In other words, the silting-up of Lake Neusiedl as a whole is mitigated or delayed at the expense of a part of the reed belt near the mouth of the river Wulka.

Finally, letting the Wulka find its own way through the reed belt without providing a preferred pathway through channels is much less expensive than regular dredging and channel engineering.

On the other hand, dredging would have the undeniable advantage, if it would also involve effective (although in the long run very costly) removal of sediment and pollutants from the lake basin. Protection of upstream infrastructure from backwater flooding is an additional argument to enable quick passage of the river to the open lake.

3.2 Measures

The proposed measures aim at the type of flow through the reed belt (diffuse *versus* linear), and the time of retention of the incoming water in the reed belt. They concern sedimentation / precipitation in the red belt *versus* transport through the reed belt as well as remobilisation and (secondary) transport to the open lake.

The tracer experiment, which was carried out in parallel to the project REBEN, revealed that at *high discharges* the Wulka does not flow through narrow channels but mainly *diffusely* through the reed belt making it a huge filter for suspended solids and associated pollutants. This retention and filter function should be maintained.

The dredging of a new channel in winter 2019 did not significantly alter the chemical composition of the Wulka water at site WU1 close to the open lake (see monitoring sites in Wolfram *et al.* (2020c)), thus questioning the impact and meaningfulness of this measure in low-discharge situations. In addition, the chemical analyses showed positive impacts of diffuse flow on denitrification due to enhanced retention time.

After weighing the positive and negative impacts of different flow modes through the reed belt (see chapter 4 in Wolfram *et al.* (2020b)), we see more arguments in favour of diffuse flow than against. Slight negative effects in other fields, or the non-realization of positive effects, can be accepted. This includes the lack of connectivity between Wulka and lake for some fish species. The positive effect of dredging and removing sediment from the system *on a large scale* may be theoretical anyway, since this method will most probably turn out to be too costly. A key open question concerns impacts on flood protection upstream. Therefore, the risk of a tailback caused by an increase of the water level in the area of the Wulka estuary should be evaluated.

To support the hydraulic system of the Wulka estuary, we suggest improving the connectivity between the large area of diffuse flow (area between channels B, C and D in Figure 2) and the main channels (B, C and D) by opening the longitudinal dams along the channels at several places. This will probably lead to a slight increase of the nutrient and organic load export from this area to the open lake. However, while the mineralization of organic material is strongly reduced in the (predominantly anoxic) area in the reed belt, the opportunity to degrade the organic material is much higher in the turbulent, oxygen-rich open lake. A steady low-level diffusion from the reed belt will unburden the Wulka estuary from an increasing accumulation of non-degraded organic matter, while the open lake is expected to cope with the slightly enhanced internal nutrient load.

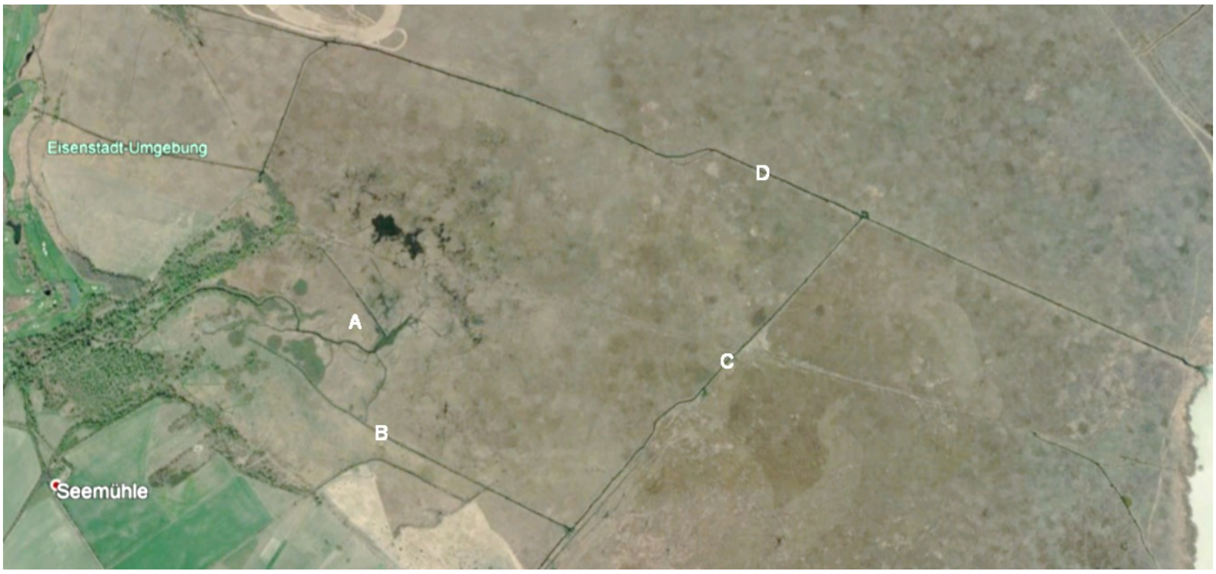

Figure 2. Channels at the mouth of the river Wulka into Lake Neusiedl. Most recent channel dredging occurred between A and B. Channel B – C is the preferred pathway of the river at low discharge. At high discharge, a significant part of the river flows also through channel D.

If future dredging activities will be necessary at a small scale, the sediment should not be deposited by forming a continuous channel embankment. There should rather be regular openings between the channel and the area behind the dams. This concerns also to the river section between Seemühle and point A in Figure 2, where the river should be allowed developing an open network ("delta") within the alluvial forest rather than flowing between banks. In case local dredging activities are required along the channels B and D, the sediment should be deposited at the "outer" side of the channels (south at channel B, north at channel D) to reduce further damming of the inner field of reed stands.

Openings should not follow a regular pattern (*e.g.,* every 50 meters). We rather suggest first to check the situation behind the dams and plan openings preferably where an effective connectivity between pools and channels can be established. Since this will not be visible from aerial or satellite images alone, our knowledge on the elevation level of the sediment should be improved by a geodetic survey of the morphology in this area to allow developing a digital elevation model. It can serve as reference for future mapping of the area to document the long-term changes of sediment accumulation at the mouth of the Wulka river.

Summary of proposed measures

3-1 Promote predominantly diffuse flow of the river Wulka through the reed belt by restricting channel restoration to the river section between Seemühle and point A in Figure 2.

3-2 Open existing dams along channels B, C and D in Figure 2 at several points, predominantly where open water areas or other channels behind the dams are present.

3-3 In case of dredging (at small scale) between Seemühle and point A in Figure 2, avoid a continuous embankment but leave openings to the surrounding alluvial forest and reed stands.

3-4 In case of dredging (at small scale) downstream of point A in Figure 2, deposit the sediment along the southern ("right") side of channel B and along the northern ("left") side of channel D. Like in measure 3-3 leave openings to the area behind.

3-5 Improve our knowledge on the sediment elevation at the Wulka estuary by carrying out a geodetic survey and developing a digital elevation model for this area.

3-6 In case of Rákos patak the controlled diffuse flow through in lake-wetland (pre-sedimentation and distribution on reed area) is considered as an applicable solution for nutrient retention.

4 SEDIMENT MANAGEMENT

Sediment management can be understood in different ways. To avoid misunderstandings, we would like to state that we do not understand this term to mean measures for the use of sediment or with the aim of *influencing* processes within the lake, such as reed management. Rather, it is a general term for interventions in the sediment, partly resulting from anthropogenic uses (*e.g.*, restoration on channels). As they can have a relevant indirect impact on water management, they must be considered in this management plan.

4.1 Key findings of REBEN

Natural sedimentation is caused by

i. predominantly mineral sediments entering the lake from the catchment area (mainly Wulka river and dry deposition)
ii. sediment production within the lake through calcite (and other mineral) precipitation, and
iii. organic sediments produced within the lake

The natural sedimentation processes can be influenced by

iv. restoration of reed channels,
v. dredging for sediment removal in marinas (port facilities) and bathing bays, and
vi. reed management

ad i. The mean import of sediment from the catchment area of the river Wulka was estimated to amount 3 890 t dry mass per year (= ca. 10 000 m³ wet sediment per year). A comparable amount comes from dry deposition (3 000 t/a), while other tributaries (Golser Kanal, Rákos patak) transport approx. one eighth of the Wulka load to Lake Neusiedl. The measurements from REBEN showed that the majority of the Wulka sediment loads is (not artificially, but naturally and thus uncontrolled) deposited in the reed belt before the river reaches the open lake. Only about 3% of external sediment load from surface waters was estimated to contribute to the sediment load entering the open lake area.

ad ii. Mass balances for the whole lake over more than 20 years revealed that thousands of tons of sediment are formed each year through calcite precipitation. An annual net amount of 10 000 t dry mass of this autochthonous sediment is transported through the reed channels to the reed belt (= ca. 26 000 m³ wet sediment per year). It can be assumed that without channels (and if they were not restored regularly) this amount of sediment would largely be deposited in the open lake, hence increasing the sedimentation rate outside the reed belt.

ad iii. The organic sediment production is a great unknown in the sediment balance. A comparison of lake basin elevation revealed that between the 1960s and the end of the 1980s / beginning of the 1990s, the total amount of sediment in the lake increased by about 75 million m³ (3 million m³ per year) (Csaplovics *et al.* 1997), which is way more than the loads calculated from external inputs and autigenic (mineral) sediment production. It must be assumed that the by far largest share of this sedimentation relates to organic production and a strongly reduced decomposition in the material produced.

ad iv. Since the late 1990s the channels have been regularly restored by the water management authority in Austria as part of ongoing maintenance measures. Usually, the dredged sediments are deposited along the channels in the form of dams, which do not allow water exchange between the reed channel and any adjacent water surfaces (though in 2019 and 2020, the lateral dams included already openings). In Austria, since the winter season 2004/2005 more than 230 km of reed channels have been restored, which illustrates the amount of sediment which has been removed from the system, even if it still remains within the lake basin. In Hungary, the network of channels was restored in 2014/2015 in an EU funded project. In contrast to the procedure in Austria until 2018 (and in Hungary in the years before), regular openings of the dams were made to allow a water exchange between channels and surrounding water pools.

Calculations were carried out to quantify the water, sediment, and nutrient transport through the reed channels. In different methodical approaches (measurements, modelling) it could be clearly shown that water level and wind influence as well as the size, shape and number of reed channels are of great importance to create and maintain paths for water and material exchange between the reed belt and the open lake. Over the last years between 2.9–40.3 km (average 16.6 km) of reed channels in Austria have been restored per year. The amount of removed (and laterally deposited) sediment is estimated at 450 – 9 070 t/a (average 3 140 t dry mass, only Austria). On the Hungarian side 76 km reed channels have been restored in the EU co-funded project (KEOP-7.3.1.2/09-2009-0020).

Before the 1990s, channel restoration works on the Hungarian side were carried out by the water directorate, reed management company and border watching. Intensive motorboat use into the reed channels also moderated the sedimentation processes.

In the Fertőrákos bay the reed island was removed in the framework of the EU co-funded project 2014–2015.

ad v. In contrast to the restoration of channels, sediment dredging on Lake Neusiedl effectively removes sediment from the lake basin. Mud dredging takes place on the lake in the form of suction dredging. The sediment is pumped out of the lake into sedimentation basins, from where the dried sediment is either landfilled or can be applied to agricultural land. An estimate of the cubature of the sediments dredged since 2005 results in a volume of almost 300,000 m^3, on average 20,000 m^3 per year (6 800 t/a).

On the Hungarian side the dredging activity is restricted to sediment translocations, sediment stabilization, or filling-up within the lake basin for recreational purposes.

It is not necessary to emphasize that the process of sedimentation is of utmost importance for a shallow lake in view of the manifold human uses, but also for the lake as an ecosystem. The question may arise as to why the lake, after thousands of years, has not long since fallen victim to sedimentation. In answering this question, we must differentiate between external (mainly mineral) inputs, internal formation by calcite and organic sediment production.

As for the first point, there is no doubt that the sediment load of the tributaries has significantly grown during the 20th century with increasing erosion in the catchment area. It is thus a rather young sediment input.

The autochthonous production of mineral sediment resulting from salt precipitation *in situ* in the lake has a longer "tradition", since calcium-rich water entered the lake all times and thus contributed to an increasing sediment deposit in the lake. We know from the salt pans in the Seewinkel area that minerals, which are formed at high salt concentrations and deposited on the lake bottom in dry phases, can be blown out and discharged by the wind in large quantities. A similar process can be assumed for the lake in former times, and indeed reports from the last dry phase of the lake in the 1860s indicate that the people in the surrounding village complained about eye irritation as a result of the salts, dust and sand carried by the wind. We can thus hypothesize that regular dry phases help and support the lake to get rid of accumulated minerals and salts.

In addition, we have to calculate precipitation / sedimentation of salts on water plants and on the dried lake bottom at low water level as well as resolving processes at high water level. Losses of salts shall be calculated in the (rare) case of controlled and regulated outflow via the Hanság Channel. Also the inlet of the Hanság Channel and its modification must be taken into consideration (flow of water from the reed belt instead direct from Madárvárta bay).

The processes behind the organic production and the limited decomposition are complex and only partly understood. They were also beyond the scope of the project REBEN. Therefore, we have to build on the findings of other studies. There is no doubt that the special chemical composition of the water of Lake Neusiedl is of great importance for the decomposition of organic material. The higher the soda content and pH, the more effective the mineralization of organic matter (Krachler *et al.* 2009). As long as the lake had high salt concentrations (at least in regular intervals and for longer periods), the organic material produced by algae, macrophytes and helophytes such as reed could be mineralized and did only in certain phases and reversibly contribute to accumulation of organic matter.

This process experienced a break with the construction of the Hanság Channel and water regulation measures, which led to significant outflows of salt-rich lake water and subsequently to severe losses of salts. The mean salt content over the last 25 years is approx. 2 g L^{-1} (range of annual means 1997–2019: 1.92–2,85 g L^{-1}) while Berger & Neuhuber (1979) reported about concentrations of up to 16 g L^{-1} in previous years. The higher frequency of phases with low salt content is assumed to be one of the factors which let the reed belt grow significantly during the 20th century. Lowered salt content and pH in the lake, but also low oxygen concentrations in the reed belt as result of diminished exchange with the open lake, finally the intensified productivity during the eutrophication in the 1960s to 1980s are considered the driving forces behind the accumulation of organic material in the littoral of the lake.

Concluding we have to take into account not only the natural sedimentation processes (i-iii) and direct anthropogenic interventions on the sediment budget by dredging and sediment removal (iv-v), but also indirect influences on sediment formation and distribution by discharges via the Hanság Channel as well as transport processes between the open lake and the belt through channels. These indirect influences have great impact on the reed growth (see next chapter) and the silting-up of the lake but also on the balance of nutrients and pollutants, since their transport is strongly linked to sediment transport mechanisms. This makes clear that the topic of sedimentation is not an issue of hydro-morphology but also has a strong implication for water quality.

4.2 Measures

The assessment of various scenarios in the synthesis report (Wolfram *et al.* 2020b) have shown that there is no scenario which allows meeting all water management objectives as defined in the Strategy Study Lake Neusiedl (Wolfram *et al.* 2014b). In several cases we saw a conflict of interests, which makes it necessary to weigh different goals against each other based on ecosystem services. Should we focus on the prevention of sedimentation of the open lake or rather prevent sedimentation in the reed belt? Do positive impacts from an intensified water and material exchange between open lake and reed belt weigh more than negative effects from mobilizing pollutants which are otherwise safely deposited in the sediment within the reed belt? Finally, can we leave the lake as it is without any interventions and measures in order to support natural processes and natural dynamics?

There is obviously a need to prioritize objectives and, in consequence, of measures. In the end, apart from water management goals, also the intensity, costs, and possible side-effects of the measures must be considered.

In the following, we propose a tiered view of measures related to sediment management:

A. Prevention of external inputs
B. Influence (or control) of internal processes
C. Direct intervention by removal of sediments

Prevention or minimizing of external inputs start in the catchment area. The measures concerning this goal were discussed already in chapter 2.

Influencing internal processes includes measures, which help to keep autochthonous mineral sediment formation and organic sediment production low, and measures to improve the exchange of water between the open lake and the reed belt.

Measures to keep autochthonous sediment production low aim at

- preventing significant inputs of calcium-rich water from tributaries or other sources,
- strengthening the mineralization of organic material by keeping the soda content and pH high or even increasing it. This can be achieved by avoiding outflows of salt-rich water from the lake as much as possible

Measures to improve the water exchange between the open lake and the reed belt aim at

- extending the existing network of reed channels, with the goal
    - to supply the reed belt with oxygen-rich water from the open lake, which improves the redox conditions at the sediment-water boundary and also supports degradation of organic matter,
    - to export nutrients from the open lake to the reed belt, hence improving water quality in the open lake,
    - to export dissolved organic matter from the brown water areas within the reed belt to the open lake, where little-degradable organic compounds can be more effectively broken-up and mineralized (steady oxygen supply, high surface for biofilm, high UV radiation in an unsheltered area), and thus removed from the system.

An increased export of water from the reed belt to the open lake can of course also lead to unwanted counter-effects such as the export of persistent pollutants. Stirring up the sediment in the reed belt during restoration measures cannot be avoided, but there may be ways to modify the techniques to keep negative impacts immediately after the dredging at a minimum. Ideas in this direction (as also suggested below) should be discussed in co-operation with experienced drivers of the dredging machine. An option could be to start in the inner reed belt and complete the connection to open lake after a recovery phase of several days to allow sediment (and attached pollutants) to settle again.

- enabling a high water-level. Since the water balance of Lake Neusiedl is driven mainly by precipitation and evaporation, there are little opportunities to have influence on it; in fact, only two: raising the threshold water level from which water is discharged via the Hanság Channel, and additional external water supply. External water supply to the lake was in discussion at all times after long dry periods and low water levels. One of the first usable solution dates back to the year 1929, and the last comprehensive investigation was carried out for the Burgenland Government by Zessner *et al.* (2012) ("Neusiedlersee – ökodynamische Rehabilitation"). Recently, an external water supply has again become the subject of discussions in the dry year 2020. It must be noted that it contradicts the above-mentioned goal of minimizing external nutrient and calcium input to keep calcite sediment formation low, but also opposes requirements from a nature conservation perspective (high variability of water levels). Options of external water input can be justified only if the water balance becomes increasingly negative as a result of global warming.

Sediment removal is a costly measure with local effect. However, as the calculation in REBEN report No. 7 (Wolfram *et al.* 2020a) have shown, they are not negligible compared to external inputs from the catchment area and to the autochthonous mineral sediment formation. They rather can have a significant effect on the whole-lake sediment budget.

Measures that remove sediment from the entire system are preferable to those where the sediment remains in the lake basin and is deposited only locally, though excluded from further sediment transport processes. While currently sediment removal by suction dredging is restricted to marinas and small bathing areas, the possibility of including other, larger areas should be considered. Since the spatial extension of such a measure would break new ground, the effects should be well examined by the preservation of evidence, for example concerning the resilience of a dredged area with regard to the re-colonization by benthic invertebrates and thus their restoration as feeding ground for fish.

If sediment removal measures are not only spatially but also temporally extended, consideration should be given to not only carrying them out on an occasional basis, but also, for example, allowing repeated removal through permanently installed pipes. This option should be evaluated separately.

As regards sediment dredging in channels, possible practices are:

- removing the material entirely from the lake basin (like the sediment dredged from marinas and bathing areas)
- depositing the sediment along the channels (current practice)
- depositing the sediment along the channels but with openings, preferably not following a regular pattern but rather at places where an effective connectivity between pools and channels can be achieved
- depositing the sediment not along the channels (linear deposits), but at selected deposit areas, where it has to be transported

While we have a clear preference for the first point, key aspects to be considered are technical restrictions, costs and space availability, the latter related both to deposit areas within the reed belt as well as outside the lake basin.

Finally, questions arise regarding the number of channels, their location and size. The calculations on the REBEN synthesis report have shown that channels can serve as effective pathways of matter transport if they are connected to large water areas in the inner reed belt (which are not many, mainly in the areas of Mörbisch and Illmitz). Channels will have limited effect if they only go through dense reed stands such as those in the outer, a few 100 m broad reed fringe along the western shore of the lake.

Modelling calculations in the Hungarian part of the reed belt have shown that strong wind effects can also lead to circulation currents depending on the design of the channel network. Due to the low flow velocities, stirring-up of soft sediments does not occur, but the currents result in significant inflows of turbid lake water and outflows of brown water through channels in different parts of the reed belt (Fertő 2019 Consortium (Hungary) 2020; Krámer *et al.* 2019). In Austria, comparable circulation flows occur only locally (*e.g.*, at the channel to the Biological Station Illmitz or at the bay immediately north of the Illmitz Resort). We propose to promote this type of channel network to increase the water exchange.

Regarding the design of the channels, linear ones will more effectively enable water flow than tortuous channels with narrow sections. The breadth of the channels should be at least 5 m to reduce the need to restore them at short intervals. The orientation of the channels according to cardinal points is not taken into account, since the room for alternatives is limited in this respect anyway.

To conclude, we propose to focus in a first step on existing (old) channels rather than creating new ones in order to limit these artificial interventions in the ecosystem. On the basis of an improved digital elevation model for the reed belt – which is an open task though – and the models tested and used in the project REBEN both by Hungarian and Austrian hydrologists, a concrete design of a channel network, its effects on currents through the reed belt and options for optimizing them can be established. We recommend establishing a core group of experts and representatives of land-owners, the Land Burgenland, municipalities, and stakeholders on a regular (annual) basis to discuss and agree, which and when channels shall be restored.

Summary of proposed measures

4-1 Evaluate the regulation order of the weir at Mexikópuszta and Hanság Channel at Mosonszentjános (→ high water level and reduced losses of salts); investigate the inlet configuration of the Hanság Channel

4-2 Evaluate options, advantages, and disadvantages of an external water supply → high water level, but increased calcite formation resulting from inputs of calcium-rich water

4-3 Strengthen and extend the existing network of channels in the Austrian part of the reed belt (outside the conservation zone of the national park)

4-3-1 Establish a core group of experts and representatives of stakeholders on a regular basis to discuss and agree, which and when channels shall be restored. Channel maintenance must be in accordance with the legal requirements of water management and nature conservation.

4-3-2 In a first step, focus on existing (old) channels rather than creating new ones in order to limit interventions in the ecosystem

4-3-3 In a second step, support channel circulation currents through the reed belt near Illmitz to study the import and export processes

4-3-4 On the long run, develop a concrete design of a channel network for the reed belt based on an improved digital elevation model and hydraulic modelling

4-3-5 Evaluate options and costs to permanently remove dredged sediment from the channels (this is currently rejected by nature conservation authorities)

4-3-6 Evaluate options to form deposit areas within the reed belt rather creating than longitudinal dams along the reed

4-3-7 In case the sediment is deposited along the channels (as currently during channel restoration in Austria), include openings to connect pools and channels in the surrounding

4-3-8 Evaluate options to minimize the export of sediment and pollutants from the reed belt to the open lake during and immediately after dredging (*e.g.*, recovery phase before final opening to the open lake)

4-3-9 If new channels are planned, avoid tortuous lines but rather make them straight and broad enough (at least 5 m) to allow effective water transport

4-4 Evaluate costs of sediment removal from marinas and bays on a permanent basis (permanently installed pipes), accompanied by preservation of evidence

4-5 Establish a GIS-based documentation system on all interventions in the sediment of the lake, including channel restoration, dredged areas, sediment deposits and estimations of the sediment cubature in marinas and bays

4-6 Perform a homogeneous cross-border full-coverage 3D-survey of extent and spatial distribution of sediment layers and produce digital surface models for spatio-temporal volumetric assessment of vectors of change in a ten-years interval

5 REED MANAGEMENT

5.1 Key findings REBEN

Status quo and development of the reed belt during the 20th century

The reed belt of Lake Neusiedl / Fertő covers about 181 km² including the lake-land transition zone, with about 64 km² on Hungarian and about 117 km² on Austrian territory (Csaplovics 2019). It thus represents the second largest closed reed area in Europe and is considered a zone with a particularly high sensitivity for the landscape (Wolfram *et al.* 2014b). The eminent importance of the reed belt for the ecology of the lake is well known and does not need to be explained in detail. There is also agreement today that the ecological protective function of the reed belt must be ensured by appropriate forms of care and management (Landesentwicklungsprogramm Burgenland 2011, LGBl. Nr. 71/2011).

It should not be forgotten that the reed belt of Lake Neusiedl / Fertő is actually relatively young. Although there are sufficient reports on swamp and reed areas in earlier centuries (Csaplovics 2019), it only experienced a noticeable increase after the last drying up in the 1860s. The main period of expansion of the reed beds began after 1900 after the construction of the Hanság Channel as an artificial outflow of the lake.

In times of low water levels in the first half of the 20th century, the expansion of the reed belt raised concerns that the lake could become overgrown with reed beds. With the commissioning of the weir system on the Hanság Channel near Meksikópuszta in 1965, the average water level of the lake was raised by several decimetres, which slowed down or even stopped the expansion of the reed beds lakeward (and at the same time increased its expansion on former lake meadows on the landside edge of the lake basin). Recent mapping demonstrated a stabilization of the lateral extension of the reed belt (Csaplovics *et al.* 2020; Király 2019).

Of course, the term "stabilization" does by far not mean that the reed belt is not subject to further changes. Csaplovics (2019) points out the progressive degradation of the reed structure: Between 1979 and 2008 the proportion of brown water areas in the reed belt in the Austrian part increased from 2.42 km² (Csaplovics 1982) to 12.54 km² (Csaplovics & Schmidt 2011b). The reasons for this are unclear and could be related to insufficient nutrient or oxygen availability (redox ratios) in the reed belt. However, many other causes for a decline in reed populations are discussed in the literature and cannot be excluded for Lake Neusiedl / Fertő, for instance hydro-morphological impacts (Binz-Reist 1989), allelopathic substances (Armstrong & Armstrong 2001), feeding by herbivorous animals (Ritterbusch-

Nauwerck 1995) or heavy metal pollution (Lastrucci *et al.* 2016) (for a general discussion on this topic see Ostendorp (1989)).

In addition to changes in reed areas and shifts of different reed classes, an increase in the elevation of the sediment within the reed belt has also been observed, though it is more difficult to document and occurs relatively unnoticed compared to the area expansion or the degradation of reed beds.

Objectives – and a weak knowledge base for measures

A main goal of water management is the protection of the reed belt of Lake Neusiedl / Fertő as a habitat and the preservation of its function for the entire lake. At the same time, however, excessive growth of the reed belt at the expense of the open lake area should be avoided – which though is currently not a problem, as mentioned above. Therefore, the focus of water management measures should rather be on sedimentation "in the vertical", *i.e.*, the accumulation or decomposition of the annually occurring organic material.

In order to clarify how these goals are to be achieved, it must first be determined which biomass is actually present in the reed belt, produced annually and accumulated at the lake bottom. Unfortunately and surprisingly, however, our knowledge about production and dying in the reed belt and even more about degradation and accumulation is incomplete.

Burian *et al.* (1986) give a range of annual production of 9–12 t/ha for uncut and 10–22 t/ha for cut reed areas. As a rough guideline the average annual production can be set at 10 t/ha (1 kg/m²). This is in the range (0.8–6 kg/m² per year) given by Whittaker & Likens (1975, *cit.* in Ostendorp (1993)) for swamps, marshes and reeds, and very much like a more recent estimate of Dietrich & Gamauf (1998) (12–18 t/ha per year).

Simple extrapolation to the whole reed belt (ca. 180 km²) would result in an annual production of 180 000 t (dry mass), of which only a small part is harvested annually (about 10 000 t in Austria, ca. 14 000 t/a in Hungary in the 1970s and 1980s). According to an earlier estimate by Löffler (1974), this corresponds to about ¼ of the total biomass, of which a significant proportion is accounted for by underground production; the authors assumed a ratio of the biomass underground : aboveground of 1 : 1. Burian *et al.* (1986) state a ratio of 2 : 1 to 3 : 1 at the peak of the vegetation period. A recent comparative evaluation by Pyšek *et al.* (2019) shows – with a pronounced allometric ratio – in most cases a significantly higher biomass underground than above ground (Figure 3).

The figures given here refer to dry mass. According to Burian *et al.* (1986), the dry matter amounts to 10–20% of the fresh weight in leaves, 30–50% in shoots and about 80% in the stalk, but seasonally decreases from an average of 70–75% in spring to 45–50%. In other

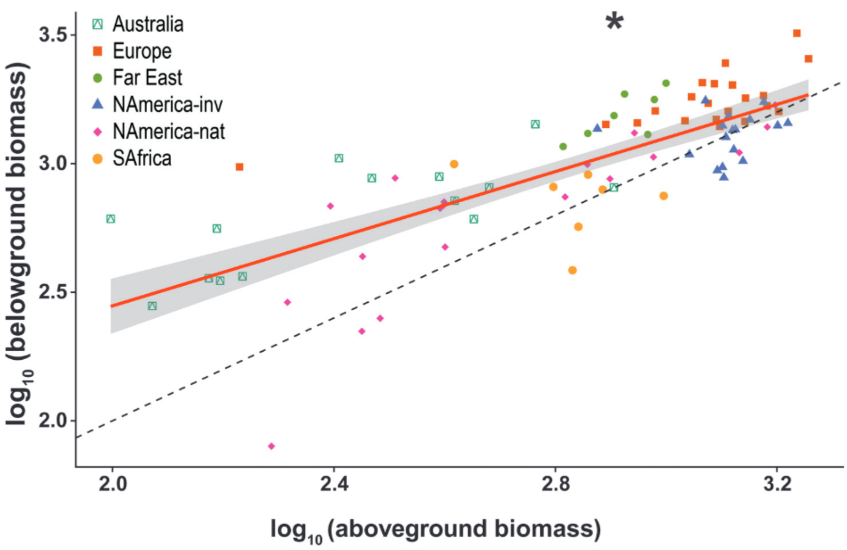

Figure 3. Allometric relationships between biomass of different organ parts. Dashed lines represent isometric line (slope = 1), solid red lines represent significant relationships between variables. From: Pyšek *et al.* (2019).

studies, the carbon content is reported to be between 40% and 45% (Obolewski *et al.* 2007; Pyšek *et al.* 2019), the ash content with 3–13% (Baran *et al.* 2002; Gelosia *et al.* 2015; Rodewald-Rudescu 1974).

Should reeds be removed? If so, how and how much?

In view of the ongoing vertical increase of the sediment elevation in the reed belt resulting from incomplete decay of organic matter, a regular reduction of the reed beds seems reasonable from a water management point of view. This goal is in line with the concerns of nature conservation (aiming at the reduction of reed which is several years old), but also of reed cutters who prefer young and intact reed.

The only two quantitatively relevant methods to reduce the reed biomass are harvesting by reed cutting and burning. As investigations of the 1980s demonstrated, cutting (harvesting) is only sustainable as winter cutting, whereas green cutting is seen as disadvantageous for the nutrient balance (Gunatilaka 1986). Since burning should also be avoided in spring and summer for ecological reasons, biomass reduction in both cases is limited to the winter period.

The annual amount of reed removed by **harvesting** and the areas affected are fairly well known (see Report 2 of the Austrian experts). Experiences are also available on the (often negative) effects of the reed harvest. The mechanical damage of heavy harvesting machines can cause long-lasting effects, but also the ‘flattening’, *i.e.*, the rolling down of old reed in order to favour the emergence of young reed in the following year, is to be rejected from a water management point of view. These two effects, quasi collateral

Figure 4. Aerial photograph of a shelf fire on the northern shore of Lake Neusiedl in January 1984. Photo from the Burgenland Provincial Archive (No. 15741 LM 2009), taken from the master thesis of Führer (2010).

damage of the reed cut, are probably more disadvantageous in the long run than the advantage of biomass extraction resulting from the annual harvest.

The effects of **fire** are much more difficult to estimate. Concerns exist particularly with regard to possible ecological effects on the fauna in the reed belt, but also increased air emissions are seen as disadvantageous. (One should also not ignore the negative public perception of fire in general. It is seen as destructive and thus also disadvantageous for an ecosystem.)

In principle, fire management is a very efficient and cost-effective way to reduce biomass. As with harvesting, fire management concerns only the above-ground reed, at least at first glimpse, and is also (and especially) applicable to old reed, which is unattractive for reed cutters. It cannot be excluded, however, that a fire at low water level in a largely dry area has the potential to also burn the accumulated reed litter near the ground and remove from the system by mineralization. It could thus be an interesting approach to reduce the amount of non-degraded organic material.

At present, the share of the annual accumulation to the total stock and annual production cannot be estimated with certainty, but there can be no doubt that not all organic production will be degraded in the long term. According to Ostendorp (1993) the degradation rate by microorganisms and detritivores under unfavourable conditions (high production, oxygen deficiency in the litter layer, nutrient deficiency, pH-values far below 7) is lower than the annual production, which leads to the formation of 'reed peat' rich in humic substances. In the reed belt of Lake Neusiedl / Fertő this is reflected by the high concentrations of dissolved organic nitrogen and carbon (DON, DOC) as demonstrated at isolated sites of the reed belt near Illmitz (Report No. 3 of the Austrian experts).

In Report No. 2 of the Austrian experts the share of non-mineralized reed was estimated at 1–5%, which is in the range of the estimated value for the reed beds at Lake Constance (4%)

(Ostendorp 1988). Of course, fire will not have any influence on this accumulated organic matter during inundation of the burn area nor if the organic matter is already covered by mineral sediment, but a partial mineralization of near-surface organic matter on the dry or only moist sediment surface seems possible.

Apart from cutting and fire management, there is a third approach to influence not only the areal extension of the reed belt but also the decomposition processes in the reed belt: water level management. It may influence these processes and, in consequence, the accumulation of non-degraded organic matter in different ways:

It was hypothesized that the drying up of the reed belt at low water level promotes the decomposition of organic material due to the availability of atmospheric oxygen. This should be observed at least temporarily in the often dry falling land-ward areas of the reed belt. However, we do not know whether this is actually the case. An opposite effect, namely an invasion of other plants and an increase of the plant mass is probable, too.

Gunatilaka (1986) assumed that the decomposition of organic material is promoted when the water level, after high values (and anaerobic conditions) in spring/summer, drops towards autumn, allowing better aeration of the upper litter layer.

A better oxygen supply can also be achieved by increased water exchange between the reed belt and the open lake, at least in those areas that are reached by the inflowing lake water (see REBEN Synthesis Report, Wolfram *et al.* (2020b), and chapter 4 of this report).

Increased degradation of organic material a) in areas that have fallen dry, b) in shallow water and c) by increased exchange with the open lake – at present we cannot reject any of these three hypotheses with certainty. Probably a combination of different processes is needed to promote degradation and thus slow down the accumulation or organic matter.

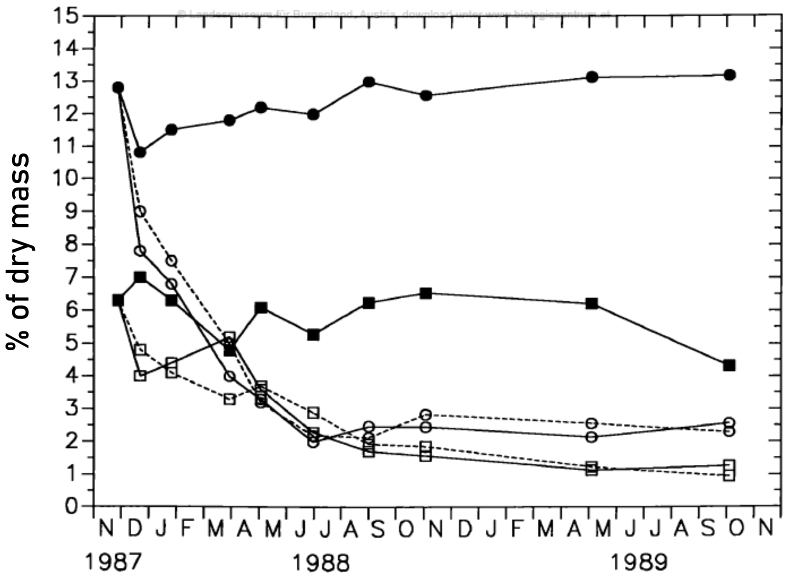

Figure 5. Ash content of leaf and stalk litter of reed in long-term tests in November 1987 (Hietz 1989). Circles = leaves, squares = stalks, filled symbols = above water, open symbols = below water, dashed line = reed parts enclosed in a fine mesh bag, solid line = enclosed in coarse mesh bag.

In our opinion, the arguments for the third hypothesis currently predominate, *i.e.*, for an intensified exchange and thus a high water level. This is also supported by earlier degradation tests carried out by Hietz (1989) who proved a more effective degradation of organic matter under water than above. A better evidence, however, is needed to clarify this important question.

5.2 Measures

Concluding the discussion on advantages and disadvantages in the section above, we support a sustainable use of reed for harvesting, but without the negative side-effects of heavy machines on the rhizome structure and without the practice of 'flattening' old reed. The permits, annual harvesting plans and the current documentation of reed cutting (as carried out by ornithologists and recorded in GIS for the Austrian part of the lake, see Korner *et al.* (2014)) should become a task of water management authorities in co-operation with nature conservation stakeholders and reed cutter companies. The harvesting itself is not included in the measures below, since is not in the competence of the water management authorities. However, since the reed cutting business is under strong economic pressure due to an increased supply of cheap reed on the international market, financial or other kind of support of reed harvesting as a valuable water management measure should be considered.

We also support the idea of fire management as a measure to reduce biomass in the reed belt of Lake Neusiedl / Fertő. It is clear that pursuing this option requires consideration of risks for negative impacts on the terrestrial fauna of the reed belt (birds, mammals, invertebrates), especially by careful planning and by restricting the possible time of such a measure. The risk of possible damage to infrastructure by a fire out of control must also be kept as low as possible, *e.g.,* by establishing firebreaks. However, we should not ignore several unanswered questions regarding the short-term effects of reed fire on the matter balances, which cannot be solved by analyses of the chemical constituents in the reed alone. Finally, legal questions must also be clarified. Führer (2010) emphasizes concerns of the reed harvesting companies in case they were in charge of the fire management, among others the effort required to submit an official permit, the costs, and the liability. Therefore, the measures related to fire management are considered as general recommendations and as a basis for more detailed considerations and discussion.

Finally, we think that a high water level and a regular exchange of water between the open lake and the reed belt (resulting from regular wind setup/setdown and the accompanying *seiche* movements of the lake) is favourable for the oxygen supply in the reed belt and thus improves the decomposition of organic matter and slows down accumulation processes.

In addition to these three direct and indirect interventions in the reed belt, we recommend including any other works within the reed belt (*e.g.* channel maintenance – see chapter 3 & 4; local reed cutting initiated by hunters – see addendum below in this chapter) as well as zones of uses within the reed belt (*e.g.* tourist tours) in a Geodatabase which could become available to all stakeholders involved or even to the public (*e.g.* as web GIS tool) to increase awareness and knowledge of uses and interests of each other.

Summary of proposed measures

Reed harvest

5-1 Collate information on permits and annual harvesting plans, and document in GIS the reed areas cut each year

5-2 In co-operation with nature conservation and reed cutting companies: support a transformation process of the current reed cutting practice towards sustainable use without the current negative impacts

5-3 Consider direct or indirect support of sustainable reed harvesting to maintain and preserve a practice of long tradition with the potential to effectively reduce biomass from the reed belt and slow down the tendency to enhanced accumulation of organic material

Fire management

5-4 Support removal of old reed stands by fire management in winter in defined areas outside the national park
- Prepare legal basis for permits (frequency, area, control)
- Consider broad channels or stripes of cut reed as fire-breaks against endangered infrastructure
- Accompany fire management by investigations on matter balance and nutrient export and biological monitoring

Water level management

5-5 Support high water levels by evaluating options for raised threshold levels for the outflow through the weir at Fertőújlak

5-6 Support exchange between the open lake and reed belt … see measures 4-3ff in chapter 4.2 of this report

5-7 Close knowledge gaps on the accumulation of organic matter in the reed belt and on reed decomposition on varying environmental conditions

General issues

5-8 Establish a Geodatabase including the homogeneous spatio-temporal cross-border assessment of structure and density of reed stands (reed classification) in a ten years interval as well as the documentation of all direct and indirect interventions in the reed belt (harvest, fire management, channel maintenance, zones of additional uses) in order to prepare a database available to all stakeholders involved and/or to the public as such (*e.g.,* as web-based GIS tool) with the aim to increase public awareness

Addendum: Examples of reed channel restoration in Austria

The following maps, taken from Google Earth, shall illustrate channel restorations in the past (example 1 & 2) and give an idea of options of channel restoration in the future (example 3).

Figure 6 shows an area near Oggau, where channels were dredged but also newly created in a virtually random and unplanned way in (winter) 2005/06, 2006/07, 2009/10, 2011/12, 2014/15 and 2015/16 (*cf* Figure 27 in Csaplovics *et al.* (2020)). They do not comply with the recommendations given above, probably enabling only a restricted water exchange. The large "pools" shown in the right picture were created between 2003 and 2011 and may serve as duck "traps" for hunters.

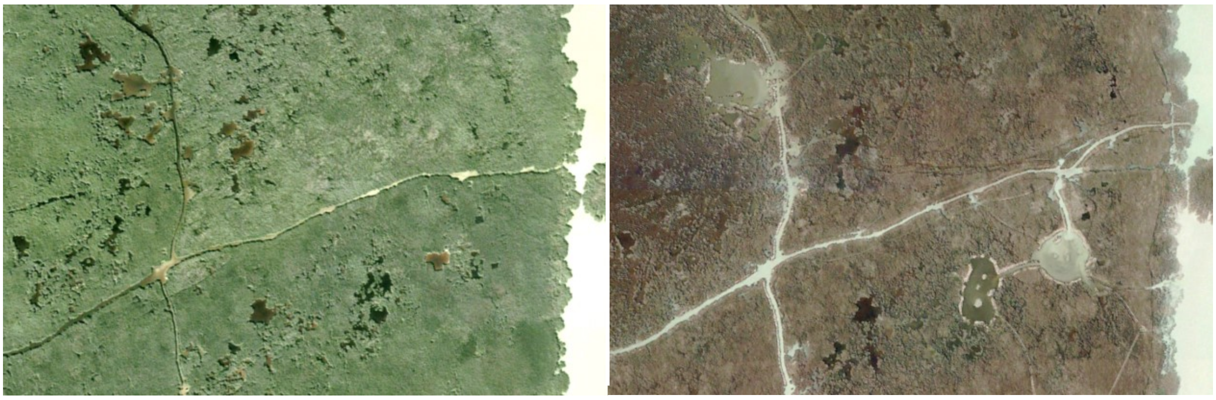

Figure 6. Details of Google Earth satellite images of the reed belt near Oggau. Left: at least until 2003, right: at least since 2011.

Figure 7 shows another reed belt area on the Western shore of Lake Neusiedl close to the Resort of Breitenbrunn. According to the GIS data on channel restoration provided by the Land Burgenland (*cf* Figure 27 in Csaplovics *et al.* (2020)), channel dredging occurred mainly in winter 2010/11, 2013/14 and 2015/16. The small, slightly meandering channels from 2010/11, visible in the picture from 2012 (bottom left in Figure 7) may not be more than traces of the channel dredging machine. They did not have a long "life" and became quickly overgrown. While most channels lead to the inner part of the reed belt, one runs parallel to the outer reed fringe (white arrow) and is of little use in terms of water exchange. Changing traces of reed cutting and channel dredging machines in the upper right field of the four images do also not comply with the idea of promoting effective water exchange.

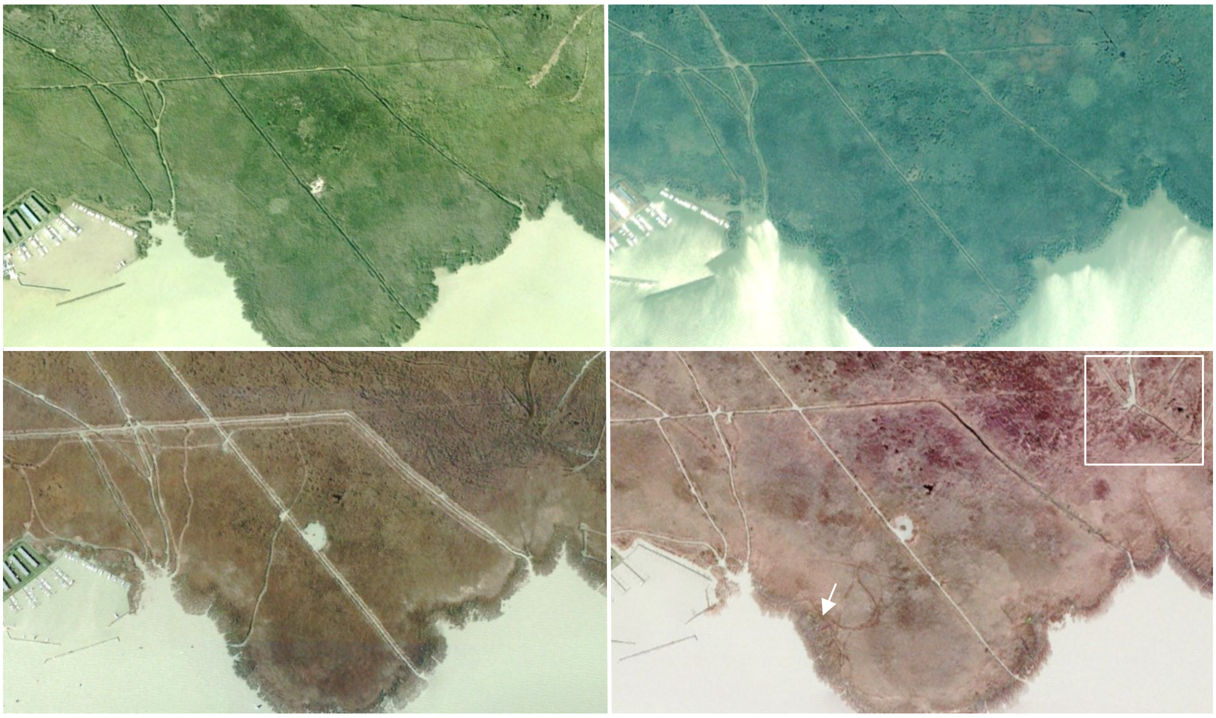

Figure 7. Details of Google Earth satellite images of the reed belt near Breitenbrunn Resort. Top left: Dec 2000, top right: 26 Jun 2003, bottom left: 28 Apr 2012, bottom right: 29 Apr 2018. Arrow and square explained in the text.

The third example shows an area near Illmitz (Figure 8). The channel from the open lake to the Ruster Poschn is strongly silted-up and overgrown. Restoring this channel could provide an effective pathway to the inner part of the reed belt in this area. Whether it also allows establishing circulation currents towards south should be evaluated by hydraulic modelling.

Figure 8. Reed channel from the open lake to the so-called Ruster Poschn near Illmitz.

6 MONITORING

6.1 Current monitoring programmes

Currently, there are different monitoring programmes and monitoring requirements defined:

- National Monitoring programme according to the Water Framework Directive in Austria
- National Monitoring programme according to the Water Framework Directive in Hungary
- The Austrian-Hungarian Water Commission (AHWC) Monitoring Programme
- Local operational monitoring in Hungary (Hydro-meteorological Station)
- Local operational monitoring in Austria (Biologische Station Illmitz)

In Austria, the roots of the monitoring network according to the WFD lie in the hydrographical monitoring network as defined in the Austrian Water Law (WRG 1959 and decrees to the Water Law).

In this chapter the programmes are split according to the main topics, namely lake basin & sediment, hydrology, general physico-chemical parameters, micro-pollutants, and biology. Where appropriate, the requirements of the different programmes mentioned above are discussed consecutively in each sub-chapter. A joint description is finally presented in chapter 6.2.

6.1.1 Lake basin & sediment

The GeNeSee project aimed at a comprehensive topographic survey of the lake basin. While the open lake could be surveyed in great detail via ultra-sounding, soil physical measurements in the reed belt fell short of expectations which had been expressed in the Strategy Study (Csaplovics *et al.* 2014b; Csaplovics *et al.* 2020). Apart from scattered measurements, there are no current data available on sediment elevation and thickness in the reed belt, especially concerning the height of the so-called lake wall. To calculate the lake volume from the water level, the old key curve of Csaplovics *et al.* (1997) must be used. As a consequence, changes which have occurred during the last 25 years cannot be covered by that formula. Thus, fundamental data on the recent topography of the lake basin and its sediment layers are missing. Consequently, there is also no regular monitoring established in order to provide the estimation of long-term changes.

6.1.2 Hydrology

6.1.2.1 Resolution of the Austrian-Hungarian Water Commission

In a resolution of the Austrian-Hungarian Water Commission a common monitoring programme for hydro-morphology was agreed (Table 1).

Public information services:

- Austria: https://wasser.bgld.gv.at (water level)
- Hungary: www.ferto-neusiedlersee.hu (Fertőrákos actual data: wind direction, wind velocity (10 min. average, air temperature, water temperature. water temperature 50 cm above bottom, water level)

6.1.2.2 Detailed description

A general overview of the hydrological monitoring in Austria is given in Sailer & Maracek (2019). The **water level** of lake Neusiedl is measured at 7 stations in 15 minutes intervals. The data are available to the public from https://wasser.bgld.gv.at/hydrographie/der-neusiedler-see (Hydrographischer Dienst Burgenland 2020). On the Hungarian side current daily water level data (measured at 7 a.m.) can be downloaded from the website of the National General Directorate for Water Management (2020), while older data are available from Országos Vízjelző Szolgálat [National Water Service] (2020) (Table 2).

The dense network of existing surface water gauges, most of them operating in Austria, is an important element of recording wind-induced motion of the water surface. This allows the long-term, continuous estimation of bulk wind momentum input to the lake with the help of modelling (as performed in the Hungarian REBEN study), which is essential to estimate the temporal statistics of waves, currents, and gravitational excitation of water exchange between the lake and the reed belt.

The **surface inflow** of the river Wulka and the Golser Kanal is measured at Schützen/ Gebirge (HZB-No. 210096) and at Gols (HZB-No. 210369), respectively, in 15 minutes intervals. The data can be freely downloaded from the website of *Hydrographischer Dienst Burgenland* (2020). The water level of Rákos-patak is measured at Fertőrákos (Station ID: 000027) in 1-hour intervals and the discharge data are calculated quarterly. These data are not published on the Web.

The **outflow via Hanság channel** is regulated at the weir in Mekszikópuszta (ÉDU-KÖVIZIG 2011; Kubu 2010). Data on water level and discharge in the channel is shown on the *Wasserportal Burgenland* (Hydrographischer Dienst Burgenland 2020). Daily water level data are also available from the website of the National General Directorate for Water Management (2020).

Table 1. Hydro-morphological parameters and frequency agreed by the Austrian-Hungarian Water Commission.

Parameter	Investigation period	Frequency/year Hungary	Frequency/year Austria
Hydro-morphological quality elements			
Water level	Yearly	continually, min. daily	continually, min. daily
Water budget	Yearly	1x	1x
Morphology	Every 6 years	1x	1x

Table 2. Hydrological monitoring stations and frequency in Austria and Hungary.

Balance elements	No of stations		Frequency		Available to the public	
	AT	HU	AT	HU	AT	HU
Water level	7	1	15 min	daily (7 a.m.)	B, C	C, D
Surface inflow	2	1	15 min	hourly	+	D
Surface outflow	–	1	–	hourly	+	C, D
Groundwater inflow	–	–	–	–	–	–
Groundwater outflow	–	–	–	–	–	–
Precipitation lake + basin	4 + 7 *)	3	15 min	daily (7 a.m.)	C, D	D
	2 + 17 **)	n.a.	n.a.	–	B	–
Evaporation	1	1	–	daily (7 a.m.)	–	D

A … free download of all raw data, B … free download of daily mean values or daily sums of all data, but most recent data 2 years old, C … free download of raw data from the current month, D … raw data are provided on request

*) Wasserportal Burgenland (Hydrographischer Dienst Burgenland 2020), only remotely transmitted data

**) eHyd (2020), including analogue stations

According to the *Wasserportal Burgenland*, **precipitation** is measured at 4 stations directly at the lake (Neusiedl, Rust, Illmitz, Apetlon) and additional 7 stations within the Wulka and lake basin. The eHyd website provides data from 19 stations within the Wulka and lake basin (eHyd 2020). On the Hungarian side, precipitation is measured at Fertőrákos (000336), Fertőújlak (000337) and Fertőboz (110215) with daily sampling rate. The data are not published.

No regular monitoring is carried out on **groundwater** inflow and outflow. Based on age calculations using isotope analyses (Rank 1986; Reitinger 1991), it is considered as negligible.

Evaporation is measured regularly at the Biological Station Illmitz (Sailer & Maracek 2019). The data are used to evaluate the water balance, which is calculated as 'remaining' balance element. During the last years, the data match well, and deviations can be explained by seasonal variation in reed growth (K. Maracek, pers. comm.). The calculations on the evaporation are harmonized annually among the representatives of the Austrian-Hungarian Water Commission. On the Hungarian side evaporation is measured at Fertőrákos (000336) in daily intervals and data calculated from monthly meteorological parameters are also available. Neither the Austrian nor the Hungarian evaporation data are published on any website.

6.1.3 General physico-chemical parameters

6.1.3.1 Monitoring programme according to the resolution of the Austrian-Hungarian Water Commission

In a resolution of the Austrian-Hungarian Water Commission (AHWC) a common monitoring programme for physico-chemical parameters was agreed. This monitoring is carried out at 4 sites in Austria and at 1 site in Hungary (Table 3). In both countries, these sites are part of the national surveillance monitoring programme *sensu* EU Water Framework Directive (WFD) and included in the national River Basin Management Plans (RBMP). The analytical results (Table 4) are exchanged yearly in the frame of an expert meeting. Every three years the experts prepare a common report.

Table 3. Monitoring sites agreed by the Austrian-Hungarian Water Commission.

Country	Name of the sampling site	Coordinates
Austria	Weiden (island lake middle), site 24 in Figure 9	47° 41.03 / 16° 45.58
	Donnerskirchen, site 27	47° 45.24 / 16° 43.43
	Illmitz – Mörbisch (line, lake middle), site 5	47° 51.19 / 16° 45.87
	South state border (lake middle), site 4	47° 53.97 / 16° 48.18
Hungary	Fertőrákosi öböl (bay)	47° 43.26 / 16° 41.53

Table 4. Parameters agreed by the Austrian-Hungarian Water Commission.

Parameter	Investigation period	Frequency/year Hungary	Frequency/year Austria
Physico-chemical quality elements			
Secchi depth	Yearly	12x	4x
Water temperature	Yearly	12x	4x
Dissolved oxygen, O_2 saturation	Yearly	12x	4x
pH, alkalinity	Yearly	12x	4x
Electric conductivity	Yearly	12x	4x
Ca, Mg, Na, K, Cl, SO4	Yearly	12x	4x
PO_4-P, Total P, NO_3-N	Yearly	12x	4x
NH_4-N, NO_2-N	Yearly	12x	4x
Chlorophyll-a	Yearly	12x	4x

6.1.3.2 National and local operational monitoring in Austria

The results of the monitoring as agreed by the AHWC can be freely downloaded from the H2O database of the Federal Ministry of Agriculture, Region and Tourism (BMLRT 2020b). Sampling frequency of the data in the H2O database varies over the years: 4 dates in 2010, 2018 and 2019, 8 dates in 2011, 2013–2017, and 12 dates in 2012. The parameters comply with those agreed by the AHWC and listed in (Table 4), except for ortho-phosphate. This parameter was analysed until 2004 along with total dissolved phosphorus (DP), while currently only DP is included in the regular monitoring and reported to the H2O database. Additional parameters in the national monitoring are dissolved and total organic carbon (DOC, TOC).

The local operational monitoring of the Biological Station Illmitz includes additional data:

- Monitoring stations: Until 2014 38 stations in the open lake and near the reed belt, some stations also in channels and large pools within the reed belt (*e.g.*, Ruster Poschn, Hoadasepplposchnlucka) were sampled. In 2015 the programme was reduced to 17 monitoring stations: 4 in the open lake, 12 near the reed belt and in bays (mainly near bathing areas) and 1 within the reed belt (Figure 9)
- Sampling frequency was weekly bi-weekly at about 10 stations and monthly to bi-monthly at the remaining stations until 2014. Since 2015, sampling is carried out at monthly intervals between (March) April and October (November) (Table 5)
- Parameters: In former years also silicate (until 2012 from 3 monitoring stations), dissolved nitrogen (until 2003), total nitrogen (in 2011 and 2012 from selected stations) were analysed. Besides, as mentioned above, until 2004 both dissolved phosphorus and orthophosphate-P were measured.

6.1.3.3 National monitoring in Hungary

In Hungary, the Environmental Measurement Centre of the Department of Environment and Nature Protection of the Győr-Moson-Sopron County Government Office performs chemical water sampling in the Fertőrákos Bay in accordance with the WFD. If weather conditions allow, 12 water samples are taken per year. Parameters and frequencies are defined in the RBMP of water quality monitoring.

The general physico-chemical parameters included in the Hungarian monitoring comply with those agreed by the AHWC as listed in Table 4, but include additionally: odour, BOD_5, COD(ap), COD(Cr), total suspended matter, total dissolved matter, total dry matter, Kjeldahl-nitrogen, organic nitrogen, total nitrogen. Besides, general weather conditions and air temperature °C are noted.

Table 5. Monitoring stations (*cf* Figure 9) and general physico-chemical parameters in the annual monitoring of Lake Neusiedl as performed by the Biological Station Illmitz. The figures give the number of sampling dates in 2019. The colours in the column heads indicate the location of monitoring stations in the open lake (blue), near the reed belt and in bays (green) and within the reed belt (brown).

Parameter	Monitoring stations in Austria																
	1	2	4	5	6	8	13	18	21	23	24	25	26	27	29	35	36*)
Water temperature	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Electric conductivity	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
pH	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Dissolved oxygen	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Oxygen saturation	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Secchi depth	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
DOC	–	–	8	8	–	–	–	–	–	–	8	–	–	8	–	–	–
TOC	–	–	8	8	–	–	–	–	–	–	8	–	–	8	–	–	–
Total hardness	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Calcium	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Magnesium	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Sodium	8	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Potassium	8	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Hydrogen carbonate	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Carbonate	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Chloride	8	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Sulphate	8	7	7	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Nitrate-N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Nitrite-N	–	–	8	8	–	–	–	–	–	–	8	–	–	8	–	–	–
Ammonium-N	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3
Total phosphorus	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	3
Dissolved phosphorus	–	–	8	8	–	–	–	–	–	–	8	–	–	8	–	–	–
Chlorophyll-a	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	8	3

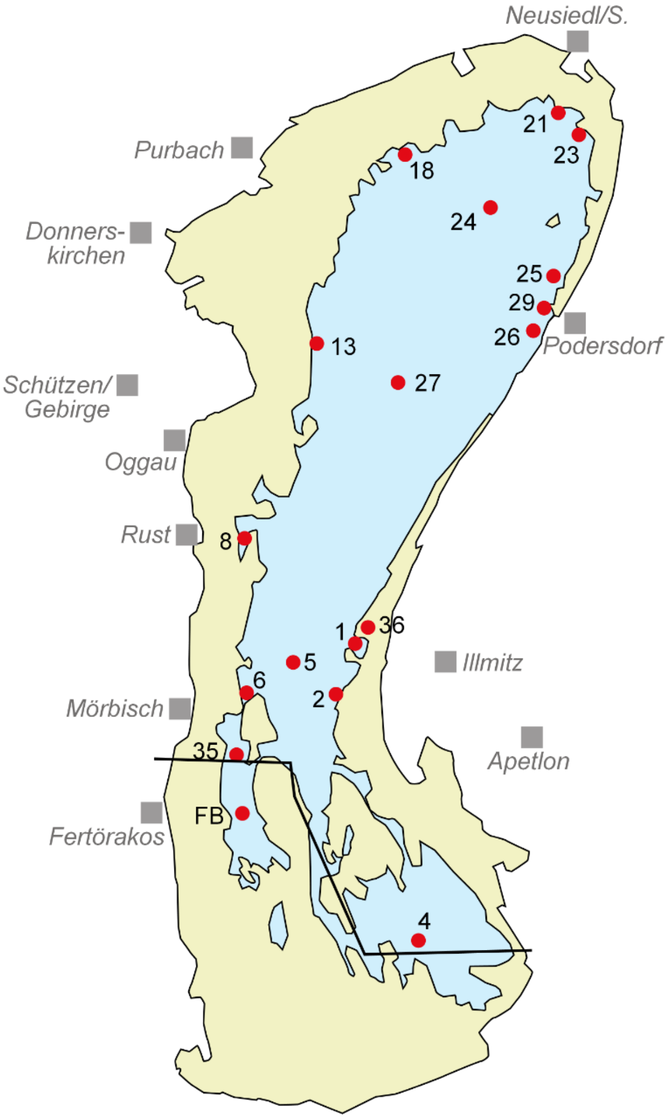

Figure 9. Monitoring stations at Lake Neusiedl. The official sampling sites agreed by the HAWC and listed in the RBMP are 24, 27, 5, 4 and FB (Fertőrákos bay).

6.1.3.4 Local operational monitoring in Hungary (Fertőrákos Hydro-meteorological Station)

The North-Transdanubian Water Directorate operates a local water quality monitoring system at Lake Neusiedl, which includes 16 sampling sites. This monitoring programme focuses on channels in the reed belt and bays (Figure 10, list of sites see Annex Table 13).

The implementation of the programme depends on the weather conditions. During the navigable period, sampling lasts from April to November, at some sites a maximum of 8 sampling dates per year is possible. During the winter (non-navigable period, December to March) the following sampling sites are accessible: Virágosmajori főcsatorna 2, Nádas állomás and Fertőrákos Bay. At these sites 12 samples/year are taken.

Table 6. Monitoring stations and general physico-chemical parameters in the local operational monitoring of Lake Neusiedl in Hungary. The figures give the number of sampling dates.

Parameters	Monitoring stations in Hungary														
	Bozi- főcsat. 1.	Bozi-főcsat. 2.	Bozi-főcsat. 3.	Bozi-főcsat. 4.	Bozi-főcsat. 5.	Körcsat. 1.	Körcsat. 2.	Körcsat. 3.	Körcsat. 4.	B0	Madárvárta (HFCS)	Herlakni-tó	Fertőrákosi-öböl	Virágosmajori-főcsat. 2.	Nádas állomás
No. in Figure 10	1	6	7	8	9	5	4	3	2	14	11	13	12	16	15
Water temperature	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Conductivity	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
pH	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Dissolved oxygen	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Secchi depth	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Chlorophyll-a	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
COD(ap)	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
COD(Cr)	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Calcium	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Magnesium	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Sodium	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Potassium	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Hydrogencarbonate	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Carbonate	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Chloride	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Sulphate	5	5	5	5	5	5	5	5	4	6	5	5	10	10	10
NO_2-N	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
NO3-N	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
NH4-N	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Kjeldahl-N	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
Total phosphorus	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12
PO_4-P	5	5	5	5	5	5	5	5	4	6	5	5	12	12	12

Sampling (both in the navigable and in the non-navigable period) takes place once a month, on the first Monday (or Tuesday) of the month. The samples are analysed by the laboratory of the Fertő tavi Hydrometeorological Station. Neither the sampling nor the laboratory tests are accredited. The used analytical methods correspond to the Hungarian standards. The investigated parameters are listed in Table 6. In addition, on-the-spot investigations include color, odor, water temperature °C, air temperature °C, water depth cm, transparency (Secchi depth) cm, and weather conditions. From 2020 these parameters have been supplemented with on-site measurements of pH, conductivity, dissolved oxygen, and redox potential.

In support of the efforts to improve or protect the water quality of Lake Neusiedl by reducing its external nutrient load and the degradation of reedbeds, two biological wetlands have been established in 2004 on the Rákos-patak. The Fertőrákos Hydro-meteorological Station additionally performs chemical water analyses for the controlled wetland of Rákos patak situated into reed.

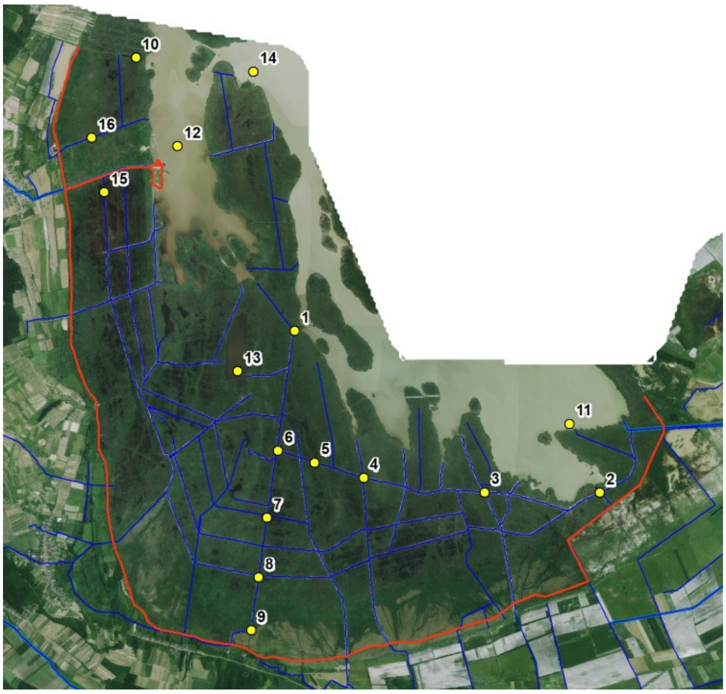

Figure 10. Local operational monitoring stations at Lake Neusiedl in Hungary in the annual monitoring of the North-Transdanubian Water Directorate (numbers see Table 6, coordinates see Table 13 in the Annex; site 10 Meggyesi szél is not part of the regular monitoring since 2018).

6.1.4 Micro-pollutants

6.1.4.1 Common Austrian-Hungarian Lake Neusiedl monitoring

Based on the Austrian-Hungarian Water Commission (HAWC) resolution, for the period 2016–2021 a common monitoring programme was agreed for pollutants at the sampling sites listed in Table 3. The parameters comply with those listed in Directives 2013/39/EC (European Commission 2013). In Hungary, in addition the parameters phenol index, ANA (anionic detergent content), Oil-UV (UV oil index) are analysed.

6.1.4.2 National monitoring in Austria

In Austria, the micro-pollutants according to the Austrian regulation on Environmental Quality Standards of Chemical Parameters in Surface Waters (QZV Chemie Oberflächengewässer, BGBl. II Nr. 96/2006), which includes priority substances from Directive 2013/39/EC, are monitored in river Wulka in the water phase. PAH have been monitored in

2013, other parameters in 2018. No monitoring of this substances in Lake Neusiedl / Fertő exists according to the national Austrian monitoring programme. In the river Wulka and Lake Neusiedl / Fertő regulated substances in biota have been monitored within a national program in 2013 (Clara *et al.* 2015). Investigations of trace pollutants in the lake have been performed in the frame of targeted projects (Wolfram *et al.* 2020c; Zessner *et al.* 2019b).

6.1.4.3 National monitoring in Hungary

Like for the general physico-chemical pollutants, the Environmental Measurement Centre of the Department of Environment and Nature Protection of the Győr-Moson-Sopron County Government Office performs chemical water sampling in the Fertőrákos Bay in accordance with the WFD. The parameters included in this monitoring are listed in the Annex (chapter 9.2).

Every three years the Environmental Measurement Centre performs sediment analyses for heavy metals and PAH from the same sampling site according to the requirements of the WFD.

6.1.4.4 Local operational monitoring in Hungary (Fertőrákos Hydro-meteorological Station)

Our knowledge about the specific pollutants of the Lake Neusiedl water and sediments are fairly insufficient (Wolfram *et al.* 2014b). In 1987, sediments from 12 sites in the Hungarian part of the lake were investigated for heavy metals. The heavy metal concentration in the sediment was very low, close to the geological background concentrations (Horváth & Pannonhalmi 1989). Very similar values were published in 1991 by the Hungarian Academic of Science (Dinka 1991).

After the reconstruction programme of the channels in the Southern part of the lake in November 2014, heavy metals and pesticides were investigated at 6 sampling locations (Figure 11). Among the heavy metals, concentrations were under the background concentration level except for mercury (ubiquitous). In the North-Eastern sampling locations, the mercury concentration was above background values but far below the pollution level. Pesticide concentrations were close to the measurable level, but at 4 sampling locations DDT derivates were detected (Pannonhalmi 2014).

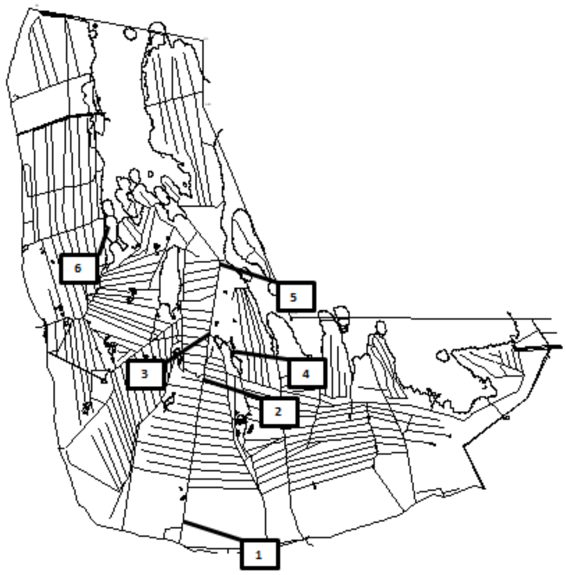

Figure 11. Local operational monitoring sediment sampling sites in the Hungarian part of Lake Neusiedl for micro-pollutants (2014).

6.1.5 Biology

6.1.5.1 Common Austrian-Hungarian Lake Neusiedl monitoring

Based on the Austrian-Hungarian Water Commission (HAWC) resolution, the following common monitoring programme was agreed for biological quality elements in Lake Neusiedl in the period 2016–2021 (Table 7).

Table 7. Monitoring of biological quality elements agreed by the Austrian-Hungarian Water Commission.

Parameter	Investigation period	Frequency/year Hungary	Frequency/year Austria
Biological quality elements			
Phytoplankton	Yearly	4x	4x
Phytobenthos	AT: – / HU: yearly	2x	–
Macrophytes	AT: every 6 years / HU: every 3 years	1x	1x
Fish	every 6 years	1x	1x

6.1.5.2 National monitoring in Austria

Currently, annual monitoring is carried out for phytoplankton and zooplankton (the latter though not included in the WFD), though with much lower effort than during the scientific monitoring of the 1970s to 1990s. Macrophytes and fish were sampled once during the last years following the requirements of the WFD (Gassner & Achleitner 2008; Pall *et al.* 2013). In addition fish-ecological studies have been carried out with varying programmes almost annually since the 1990s as part of the research of the Austrian national park (Fürnweger *et al.* 2019; Herzig *et al.* 1994; Wolfram *et al.* 2001).

The current zooplankton monitoring is restricted to four to six sampling sites in the open lake and carried out by the Biological station Illmitz in cooperation with the Dpt. 5 *Baudirektion*, section 'Water pollution control' (Großschartner 2020) (Table 8).

Phytoplankton monitoring is part of the official WFD monitoring on the ecological status and includes the 4 main sites in the open lake at 4 sampling dates (Krisa 2020) (Table 3, Table 8). For the classification of phytoplankton according to the assessment method of Wolfram *et al.* (2011), total biovolume and chlorophyll-a data are used.

6.1.5.3 National monitoring in Hungary

In Hungary, the Environmental Measurement Centre of the Department of Environment and Nature Protection of the Győr-Moson-Sopron County Government Office performs biological sampling in the Fertőrákos Bay in accordance with the Water Framework Directive. Biological tests are performed annually: macrozoobenthos (1× per year), phytoplankton (4×), phytobenthos (2×), macrophytes (1×).

6.1.6 Reed

Since the beginning of the 1980s, there has been close cooperation between experts on the Austrian and Hungarian sides involved in detailed reed mapping (Csaplovics & Schmidt 2011a; Márkus & Király 2011). Unfortunately, until today it has not been possible to coordinate the inventory of the reed belt based on airborne aerial photography to allow creating a homogeneous, cross-border aerial survey of the whole area (Csaplovics *et al.* 2014a). For the reed belt there are no common regular monitoring motoring programme and classification of the aquatic flora.

Table 8. Number of sampling dates in the monitoring programme for phytoplankton and zooplankton at Lake Neusiedl from 2015 and 2019.

<table>
<tr><th>Monitoring site</th><th colspan="5">Phytoplankton</th><th colspan="6">Zooplankton</th></tr>
<tr><th></th><th>2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th><th colspan="2">2015</th><th>2016</th><th>2017</th><th>2018</th><th>2019</th></tr>
<tr><td>Weiden (P24)</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td colspan="2" rowspan="2">9</td><td rowspan="2">8</td><td rowspan="2">8</td><td rowspan="2">7</td><td rowspan="2">8</td></tr>
<tr><td>Donnerskirchen (P27)</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td></tr>
<tr><td>Bay of Illmitz (P1)</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td colspan="2">–</td><td>4</td><td>3</td><td>7</td><td>5</td></tr>
<tr><td>Illmitz – Mörbisch (P5)</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>6</td><td rowspan="2">3</td><td rowspan="2">8</td><td rowspan="2">8</td><td rowspan="2">7</td><td rowspan="2">8</td></tr>
<tr><td>Apetlon (P4)</td><td>4</td><td>4</td><td>4</td><td>4</td><td>4</td><td>6</td></tr>
<tr><td>Ruster Poschn (P36)</td><td>–</td><td>–</td><td>–</td><td>–</td><td>–</td><td colspan="2">–</td><td>6</td><td>5</td><td>4</td><td>3</td></tr>
</table>

6.1.7 Methods for the classification of the ecological and chemical status

In Austria, the classification of chemical status follows the national Ordinance on the Quality Status for Ecology in Surface Waters or *QZV Ökologie OG* (BGBl. II Nr. 99/2010 idgF). No *official* classification methods are available for the biological quality elements, but unpublished reports provide classification methods for phytoplankton (Wolfram *et al.* 2011), submerged macrophytes (Pall unpubl., based on Pall *et al.* (2013)) and fish (Gassner unpubl.).

A classification method of hydro-morphology according to the Water Framework Directive is available for Hungary but not for Austria. Boundaries for physico-chemical parameters for the Austrian part of Lake Neusiedl (but only the open lake, not the reed belt) were defined by Wolfram & Donabaum (2010) are included in the *QZV Ökologie OG*. In Hungary, classification methods are available for biological, chemical, and hydro-morphological classifications, too.

Based on measurements or by grouping, the ecological and chemical status of Lake Neusiedl / Fertő was classified for the 2nd RBMP as summarised in Table 9.

6.2 Proposal

6.2.1 General monitoring

6.2.1.1 General remarks

The monitoring of Lake Neusiedl in the fields of hydro-morphology, chemistry and biology aims at providing a comprehensive description of Lake Neusiedl to create a basis for the ecological and chemical classification of the lake, to document short- and long-term

Table 9. Classification of Lake Neusiedl in the 2nd RPMP (2015) in Austria and Hungary.

Country	Austria	Hungary
Surface water body code	10500200	HUAIH070
Category	Natural	Natural
Biological elements (indicating pollution)	Good (B)	Good
Biological elements (indicating hydro-morphological alterations)	Good (B)	
Hydro-morphological elements	ne	High
General physico-chemical element	ne	Good
Specific pollutants (national)	High (B)	Good
Chemical status – without ubiquitous pollutants	High (B)	
Chemical status – ubiquitous pollutants	Moderate (C)	

(B) = based on grouping, (C) = preliminary (no measurements), ne = not evaluated changes due to variation in natural or anthropogenic impacts, and to provide sound data for the elaboration and evaluation of water management measures.

Since the national monitoring (WFD and AHWC) on Lake Neusiedl in Austria and Hungary have been discussed and mutually harmonized since many years, the existing programmes are comparable and in good agreement in many cases, but there are also differences. In addition, some topics have not been sufficiently covered by regular monitoring at all. The following proposal to harmonize the two local operational monitoring programmes touches on three aspects:

- Topics, quality elements and parameters,
- Monitoring sites,
- Frequency of sampling and measurements.

What makes the process of harmonization complicate is the fact that there are legal requirements and obligations defined in two national RBMPs, which focus on data needs for the official national reporting to the EU Commission (*e.g.*, results of the surveillance monitoring). In addition, there are data needs beyond the national monitoring, for instance to improve our scientific knowledge about and understanding of hydrological and ecological processes in the lake. In Austria the different finances and competences also play a role: While monitoring under the RBMP (for physico-chemical parameters *cf* chapter 6.1.3.1) is jointly financed by the federal provinces *(Bundesländer)* and the Federal Republic *(Bund)*, the local operational monitoring carried out at the Biological Station Illmitz (chapter 6.1.3.2) is financed by the *Land Burgenland* alone. In Hungary, monitoring programmes under the WFD (defined in the RBMP) and the AHWC are in the responsibility of the government (Ministry for Home Affairs and General Directorate of Water Management Hungary, Government Offices), whilst the local operational monitoring programme design, finance and implementation is the duty of the Nord-Transdanubian Water Directorate.

Overall, however, both monitoring approaches shall provide a comprehensive and correct view of the ecological status of Lake Neusiedl: on a more general level by the national monitoring and legally defined in national ordinances (which complies with the agreement of the AHWC), on a detailed level taking into account local issues by the local operational monitoring.

Since the coordination between different administrative levels (in Austria: Federal Republic, AHWC, Land Burgenland; in Hungary: General Directorate of Water Management, Ministry for Home Affairs and Government Offices WFD, HAWC) is beyond the scope of the Management Plan, we focus on the technical issues and refrain from proposals concerning administrative tasks.

6.2.1.2 Hydro-morphology

A bilateral monitoring group should be established, which periodically plans, carries out and coordinates necessary, cross-border harmonised inventories and analyses on all spatial aspects of the conservation and development of the Lake Neusiedl – Seewinkel – Hanság natural area (spatio-temporal variable processes of reed development, sedimentation, reed use, spatially relevant land use relevant for the lake, ...).

The surface relief of the entire lake basin (sediment upper and lower edge) and the resulting sediment dynamics should become part of a regular monitoring (10 years). We recommend evaluating the morphological changes by means of time series based on historical and current measurements to allow modelling of sedimentation scenarios. Special attention should be paid to dry areas in the reed belt as a function of the water level (new lake level – area/volume key curve!) and to the lake ridge near the open lake ("Seewall"). Calculation and data on evaporation, which have been discussed a lot over the last years, should be made transparent and available.

The survey of reed channel beds, including bed sediment composition should be a part of the hydro-morphological monitoring since it links conveyance capacity to water flows and reveals patterns of matter accumulation within the reed belt and natural channel fill-up.

A continuous measurement of water flow at a few critical channel cross sections is recommended to gain long-term insight into the transport rates of matter between the reed belt and the open lake at different water levels. Operating flow meters would offer direct measurement but are expensive and prone to disturbances. Water level gauges represent a more conventional and robust approach and are linked to flow through water surface slopes and channel flow conveyance capacity. These gauges would be deployed at the endpoints of relevant channel reaches, with a continuous, high-frequency (*e.g.*, 15-minute) recording.

6.2.1.3 Reed belt

Assessment of changes of the reed belt (expansion, density, physiological status) should be not only an issue in short-term projects only but become part of regular long-term monitoring based on cross-border acquisition of homogenized data for joint thematic mapping (homogeneous common classification key!) in intervals of about 10 years. It should include lateral reed growth as well as qualitative aspects to allow correlations of reed classes and hydro-morphological parameters of sedimentary conditions (structure, drying phases, wall formation, ...). The aim is to provide digital reed maps and digital surface models of sediment layers in the entire reed belt. Attention should be drawn on

Schoenoplectus litoralis too. The work on a common reed classification should be done on the AHWC level.

6.2.1.4 Physico-chemical parameters

The results from REBEN clearly demonstrated the importance of the chemical situation in the reed belt for the open lake. It is thus recommended to harmonize and extend the reed belt monitoring network of both local operational monitoring programmes, in co-operation with the competent authorities (*e.g.*, Biological Station Illmitz, Fertőrákos Hydro-meteorological Station, AHWC). They shall provide information on the chemical situation in the littoral zone.

On the long run, data both from the open lake and the reed belt should be the basis for lake-wide assessment of water quality and establish a background database for a new WFD monitoring after 2027, which is not restricted to the open water.

In the Austrian local operational monitoring, it is strongly recommended to include a sampling point situated directly in the Wulka channel before it enters the open lake to get information on the true import from the Wulka river (*i.e.*, after transformation process during the passage of the Wulka through the reed belt). For comparison, a site situated at the mouth of Rákos patak is included also in the local operational monitoring in Hungary.

In addition, for the Austrian local operational monitoring we recommend including a monitoring point in one of the large open brown water areas, *e.g.*, south of the street to the marina of Illmitz (equal to site IL9 in the sampling campaigns of the project REBEN).

The monitoring sites in bays and bathing areas on the Austrian side (as part of the current monitoring of the Biological Station Illmitz) give a good overview of possible impacts in recreation areas and should remain in the monitoring programme but should be harmonized with the Hungarian local operational monitoring network which is focused on reed belt and channels. They provide information on local aspects and support analyses of lake-wide long-term trends.

Concerning **sampling frequency**: While the four official WFD monitoring sites in the open lake in Austria differ not very much among each other in terms of physico-chemical parameters, they vary a lot temporally. Therefore, we recommend increasing the frequency at the four agreed sites in Austria from 4 times per year to monthly sampling campaigns (like in Hungary). Since monthly sampling is carried in the local operational monitoring by the Biological Station Illmitz anyway, these data should also become part of the WFD monitoring programme as agreed by the AHWC[3]. Currently, data from 4 sampling dates only are used for the WFD classification, while much more data would be available.

Also, at some sites in the local operational monitoring of the Biological Station Illmitz, the monitoring period should be extended to the whole year (like in Hungary and as it was in Austria until 2014; currently only March – October). Since the situation in winter can have a great impact on the development in the following year, data from this period are needed to understand the processes of nutrient transports.

To guarantee a harmonized and consolidated data set, we recommend performing test analyses for **comparison of the laboratories** involved in the chemical monitoring. They should become a natural routine within the quality assurance systems of the laboratories. At present, in Austria the Biological Station Illmitz and in Hungary the GYMSM Kormányhivatal Környezetvédelmi Mérőközpont (Győr-Moson Sopron, County District Office, Environmental Measurement Center), which perform the analyses for the WFD classification, participate in national intercalibrated measurements every year.The list of **parameters** as agreed by the AHWC should be extended and include not only total phosphorus (TP) and ortho-phosphate-P (PO_4-P, as soluble reactive phosphorus) but also the total dissolved phosphorus fraction (DP = TP after filtration). It provides information on the non-reactive soluble phosphorus (polyphosphates, organic phosphorus compounds) as well as the particulate phosphorus fraction. In addition, we recommend including particulate matter (= suspended solids) and the loss of ignition (= organic fraction of suspended solids) in the list of analysed parameters.

Parameters which can be skipped from the AHWC as well as the local operational monitoring programmes are: TOC, COD, total N, Kjeldahl-N and redox potential.

An important issue is the **availability of data to the public**, which is an obligation anyway after the publication of the EU Directive 2003/4/EC of the European Parliament and of the Council of 28 January 2003 on public access to environmental information. The results of the physico-chemical monitoring should be summarised in **annual reports** in the water quality and provided for **download on the homepages** of the competent authorities of the two countries.

[3] In Austria, the limitation to 4 sampling dates per year comes from stable, dimictic, oligotrophic Alpine lakes, where this low number is considered sufficient (*cf* Wolfram & Donabaum 2010). In fast-changing meso- to eutrophic lakes, a higher number of monitoring dates is strongly recommended.

6.2.1.5 Micro-pollutants

Due to the vulnerability of Lake Neusiedl / Fertő for trace substance pollution, a regular monitoring of micro-pollutants

- in the river Wulka before it enters the reed belt,
- after the reed belt, and
- in the lake and at selected monitoring places in the reed belt

is needed (*e.g.*, 12 times sampling in the first year and 6 times in following years) to observe the quality status of the lake as well as the behaviour and long-term trends of selected substances. Thereby, it is questionable to monitor the whole list of regulated substances. In contrast, specific indicator substances for different types of behaviour and those substances, where a risk of exceedance of the environmental quality standards exists, should be selected for this type of monitoring.

Additionally, major events of sediment movement during channel renovation or sediment dredging should be accompanied by dedicated monitoring programs of selected trace substance to control the role of those events on substance mobilization. As above not a long list of parameters but selected indicator substances should be selected for this monitoring activity.

6.2.1.6 Biological quality elements (BQE)

The requirement of the WFD to monitor the BQE and the agreement of the AHWC (Table 7) is largely considered sufficient. However, for **phytoplankton** 4 sampling dates are not enough to give a thorough insight into the algal community in a rapidly changing environment. We recommend monthly intervals during the vegetation period (March – October, 8 dates). However, monitoring can be reduced to 3 sites in Austria (P4, P24[4] and the new site in the reed belt) and 1 site in Hungary. This change would increase the number of samples in Austria from 4 × 4 = 16 to 3 × 8 =24. In both cases, costs and laboratory capacities should be considered. An interim period of monitoring for a few years is recommended to form a database for future amendments of the monitoring programme.

Like for the physico-chemical parameters, a lab comparison test is highly recommended to improve the data consistency, to learn from each other data and to strengthen bilateral expert knowledge.

[4] In the Northern part of the open lake, a mixed sample from P5, P24 and P27 rather than 1 sample from P24 is a possible compromise between reducing the number of sampling sites and covering the variability and diversity of a large part of the lake.

Since **phytobenthos** in lakes is often not a part of WFD monitoring in other Europe, we consider it not necessary to include this BQE in the regular biological monitoring. The project REBEN also revealed significant uncertainties und problems in standardizing the sampling of benthic algae, which made it difficult to provide reliable and representative data. However, since information on phytobenthos can contribute to our understanding of internal processes, this BQE should be included in specific programmes in the future.

The monitoring approach for **fish** and **macrophytes** shall remain as agreed by the AHWC (once in 6 years, ideally covering the whole lake in Austria and Hungary or jointly by two national teams after harmonising the field methodology).

In addition to the four WFD relevant BQE as part of the surveillance monitoring, we recommend including **zooplankton** as additional BQE in the local operational monitoring. Monitoring zooplankton continues a long-lasting and thus highly valuable data series since the 1970s and is a valuable information to understand and correctly interpret monitoring data on phytoplankton and fish. This aspect shall be discussed considering costs and laboratory capacities.

Finally, we propose to initiate an expert group to evaluate options to include **micro-biological** aspects as part of the future biological monitoring.

Like for the physico-chemical parameters, the results of the national monitoring efforts should be summarized to bilaterally agreed **annual monitoring reports** (drafted by the experts involved in the analyses), which shall be made available to the public by providing free download on the homepages of the competent authorities. In Austria, comparable solutions can be found in almost all other Federal provinces, *e.g.*, Institute of Lake Research (KIS) in Carinthia[5], Land Salzburg[6], International Commission on Lake Constance[7].

6.2.1.7 Classification methods

During the intercalibration phase, hundreds of classification methods all over Europe were compared and harmonised (Birk *et al.* 2012). This huge effort included river, lakes, transitional and coastal waters. Among lakes, biological methods in Alpine lakes (Wolfram *et al.* 2009; Wolfram *et al.* 2014a) as well as in Eastern Continental lakes (Borics *et al.* 2018) were intercalibrated. None of these studies included Lake Neusiedl, which – as a unique

[5] https://kis.ktn.gv.at/Informationen/Seenberichte%20%28Archiv%29

[6] https://www.salzburg.gv.at/umweltnaturwasser_/Documents/grabensee_phosphor_neu.pdf (as an example: Lake Grabensee, total phosphorus)

[7] https://www.igkb.org/oeffentlichkeitsarbeit/limnologischer-zustand-des-sees-gruene-berichte/

steppe lake – did not fit to international lake types as defined in EU Commission (2002) and Poikane *et al.* (2014).

In our view, there is a clear need to compare and harmonize the national classification methods of Austria and Hungary on phytoplankton, macrophytes and fish, but also to harmonize thresholds and class boundaries of physico-chemical parameters. This is not about developing new methods but comparing existing ones, with the goal to adapt the national approaches and, hence, make the ecological status assessment transparent, reproducible, and understandable to the public.

6.2.1.8 Summary tables

Table 10. Proposed monitoring sites for the physico-chemical parameters as part of the joint surveillance monitoring (surv.) according to the national RBMP, carried out under the Hungarian-Austrian Water Commission (AHWC) and as part of the local operational monitoring programme (LOMP) of Land Burgenland and North-Transdanubian Water Directorate. Changes to the existing programme are highlighted in red.

Country	No.	Name of the sampling site	surv.	AHWC	LOMP
Austria	1	Bay of Illmitz			+
	2	Illmitz Resort			+
	4	Open lake, Apetlon / state border	+	+	
	5	Open lake, Illmitz – Mörbisch	+	+	
	6	Reed edge near Mörbisch			+
	8	Bay of Rust			+
	13	Reed edge in front of Donnerskirchen channel			+
		Wulka channel before its mouth into the open lake			new
	18	Breitenbrunn Resort			+
	21	Neusiedl Resort			+
	23	Weiden Resort			+
	24	Open lake, Breitenbrunn - Weiden	+	+	
	25	Reed edge in front of Gols channel			+
	26	Podersdorf Resort			+
	27	Open lake, Donnerskirchen - Podersdorf	+	+	
	29	Reed edge Podersdorf			+
	35	State border South of Mörbisch			+
	36	Ruster Poschn			+
		Brown water reed pool South of the road to Illmitz Resort			new
Hungary	1	Fertőbozi főcsatorna 1			+
	2	Körcsatorna 4			+
	3	Körcsatorna 3			+
	4	Körcsatorna 2			+
	5	Körcsatorna 1			+
	6	Fertőbozi főcsatorna 2			+
	7	Fertőbozi főcsatorna 3			+
	8	Fertőbozi főcsatorna 4			+
	9	Fertőbozi főcsatorna 5			+
	10	Meggyesi szél			+
	11	Madárvárta (HFCS)			+
	12	Fertőrákosi öböl (bay)	+	+	
	13	Herlakni-tó			+
	14	B0			+
	15	Nádas állomás			
	16	Virágosmajori főcsatorna 2			+

Table 11. Proposed parameters and quality elements. Changes to the existing programme are highlighted in red.

Parameter	Investigation period	Frequency per year AT + HU	Monitoring sites
Physico-chemical quality elements			
Secchi depth	Yearly	12x	At all sites
TSS, LOI	Yearly	12x	At all sites
Water temperature	Yearly	12x	At all sites
Dissolved oxygen, O_2 saturation	Yearly	12x	At all sites
pH	Yearly	12x	At all sites
HCO_3, CO_3	Yearly	12x	At all sites
Total alkalinity (ANC)	Calculated	12x	At all sites
Electric conductivity	Yearly	12x	At all sites
Ca, Mg, Na, K, Cl, SO_4	Yearly	12x	At all sites
PO_4-P, Dissolved P, Total P	Yearly	12x	At all sites
Soluble unreactive P, particulate P	Calculated	12x	At all sites
NO_3-N, NH_4-N, NO_2-N	Yearly	12x	At all sites
Chlorophyll-a	Yearly	12x	At all sites
DOC	Yearly	12x	At all sites
TOC, COD, total-N, Kjeldahl-N, Redox	Skipped	–	–
Specific pollutants			
Non-synthetic	Yearly	6–12x	AHWC
Synthetic	Yearly	6–12x	AHWC
Biological quality elements			
Phytoplankton	Yearly	8x	Open lake, at least 1 site in the reed belt
(Phytobenthos skipped)	–	–	–
Zooplankton	Yearly	8x	Open lake, at least 1 site in the reed belt
Submerged macrophytes	Every 6 years	1x	Whole lake
Fish	Every 6 years	1x	Whole lake
Hydrology			
Water level	Yearly	Continually	Existing sites
Water budget	Yearly	1x	Whole lake
Hydro-morphology and reed belt			
Morphology (sediment layers)	Every 10 years	1x	Whole lake
Reed belt	Every 10 years	1x	Whole lake
Bilaterally agreed classification			
Ecological status *)	Yearly	1x	Whole lake
Chemical status **)	Every 6 years	1x	Whole lake

*) based on the biological quality element phytoplankton and, as supporting elements, the general physio-chemical parameters; in 6-years-intervals macrophytes and fish are included

**) based on the specific pollutants

6.2.2 Specific monitoring requirements

While monitoring programme discussed above concerns regular monitoring under the WFD (surveillance) and in line with the monitoring design agreed by the AHWC, specific issues should be covered by separate monitoring programmes. They can be considered as investigative monitoring *sensu* WFD.

The following two aspects are far from being a comprehensive list of open questions. In this respect we refer to the synthesis report (Wolfram *et al.* 2020b). However, they should become part of an irregular and event-related monitoring.

1. Little (if anything) is known about the **release of nutrients and pollutants** during channel dredging, sediment removal and other **operations in the reed belt** and involving sediment transport. This aspect was mentioned and discussed already earlier (Gunatilaka 1986) and is still an open issue. We recommend dealing with this question in a pilot project, but thereafter, in parallel to the above-mentioned interventions, cause-related investigations in the sense of **evidence preservation** should be carried out. The analyses should include sediment, nutrients, and specific pollutants.

2. In addition to single sampling campaigns like those under the surveillance monitoring and following the AHWC monitoring programme, we recommend to establish regular **online water quality stations** like those used in the current project and described in REBEN report No. 5 (Hainz *et al.* 2020). They provide a unique data base for the documentation of short-term changes in chemistry and allow gaining insight into matter transport, which cannot be easily derived from single measurements. Finally, they are a valuable and database in addition to pressure (water level) probes to extending and evaluating hydraulic modelling. Online stations are especially useful at sites, where accessibility is limited and time efforts for routine sampling is too high. They are of special interest at the mouth of tributaries (Wulka, Golser Kanal, Rákos patak) and during special occasions such as those described in the previous point (channel dredging, operations in the reed belt).

6.2.3 Summary of measures

6-1 Establish a bilateral monitoring group, which periodically plans, carries out and coordinates cross-border harmonised inventories and analyses on spatial aspects including developments within the lake basin and uses in the region with possible impact on the lake

6-2 Regular monitoring of the surface relief of the entire lake basin (sediment upper and lower edge) as well as of the reed belt (lateral growth, qualitative aspects, especially reed channel beds) in 10 years intervals (*cf* measure 4-6)

6-3 Cross-border acquisition of homogenized data and thematic mapping to prepare a homogeneous reed classification key

6-4 Adapt parameters, monitoring sites and sampling frequency for the physico-chemical parameters and the biological quality elements as proposed in Table 10 and Table 11

6-5 Establish an expert group, which evaluates options for including micro-biological aspects as part of the biological monitoring (apart from the hygienic-bacteriological monitoring)

6-6 Make regular comparison tests of chemistry and phytoplankton a natural routine within the quality assurance systems of the laboratories involved

6-7 Intercalibrate and harmonize the national classification methods for the biological quality elements as well as the thresholds (class boundaries) for the relevant physico-chemical parameters

6-8 Prepare annual reports of water quality including the ecological status classification and provide them to the public as free download on the homepages of the competent authorities

6-9 Establish regular investigation programmes in the sense of evidence preservation to document the release of nutrients and pollutants resulting from dredging and other operations in (or close to) the reed belt

6-10 Establish regular online water quality stations for the documentation of short-term changes and matter transport, and as a database for evaluating hydraulic models. They should be used at the mouth of tributaries, but also for the preservation of evidence during short-term impacts. Water level gauges could be deployed also at the endpoints of relevant channel reaches with a continuous, high-frequency recording.

7 RESPONSIBILITIES

In the previous chapters, 33 measures and several sub-measures were defined for the fields

- catchment area,
- tributaries,
- sediment management,
- reed management, and
- monitoring

Some of them are relevant for one country for obvious reasons (*e.g.*, those related to the Wulka), other measures can only be implemented jointly on both sites (*e.g.*, development of cross-border homogenized data sets and maps).

Besides, some measures are of major relevance and shall be within the competence of the Austrian-Hungarian Water Commission, whereas others are beyond the AHWC competence and shall be decided and implemented on national level. Independent of this, information on all measures should be exchanged regularly.

The following tables give an overview of the relevance of the 33 measures and the share of competences among the two countries within and beyond the AHWC.

Table 12. Relevance and competences of the measures.

Measure	Short description	Within AHWC		Beyond AHWC	
		AT	HU	AT	HU
	Catchment				
2-1	Specific concepts for pollution control	+	+		
2-2	Abatement of agricultural erosion			+	(+)
2-3	Evaluate sediment retention basin			+	+
2-4	Emission source and pathway control, investigate pollution behaviour, evaluate costs	+	+		
	Tributaries				
3-1 to 3-4	Diffuse flow of Wulka through reed belt			+	
3-5	Digital elevation model for the Wulka mouth			+	
3-6	Rákos patak retention basin				+
	Sediment management				
4-1	Evaluate regulation order at the weir	+	+		
4-2	Evaluate external water supply	+	+		

Measure	Short description	Within AHWC		Beyond AHWC	
		AT	HU	AT	HU
4-3	Strengthen the existing network in Austria			+	
4-4	Sediment removal on a permanent basis			+	?
4-5	GIS-based documentation of sediment interventions	+	+		
4-6	Cross-border survey of sediment layers to produce digital surface models	+	+		
	Reed management				
5-1	Collate information & document changes in GIS			+	+
5-2	Sustainable reed cutting practice			+	?
5-3	Consider direct or indirect support of sustainable reed harvesting			+	?
5-4	Fire management for removal of old reed stands			+	+
5-5	Evaluate raised threshold levels at the weir	+	+		
5-6	Support exchange between open lake and reed belt … see measures 4-3ff				
5-7	Close knowledge gaps concerning accumulation of organic material	+	+		
5-8	Geodatabase for reed classification and spatio-temporal documentation of interventions in the reed belt	+	+		
	Monitoring				
6-1	Bilateral monitoring group	+	+		
6-2	Regular monitoring of the surface relief of the lake basin	+	+		
6-3	Cross-border homogenized data sets and maps	+	+		
6-4	Adapt physico-chemical and biological monitoring			+	+
6-5	Establish an expert group for microbiology	+	+		
6-6	Comparison tests for chemistry and biology			+	+
6-7	Harmonize national classification methods	+	+		
6-8	Annual reports of water quality for the public			+	+
6-9	Evidence preservation for pollutant release during dredging			+	+
6-10	Online water quality stations and water gauges			+	+

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9 ANNEX

9.1 List of monitoring sites and coordinates of the national monitoring programmes

Table 13. Names and location of monitoring sites in the local operational monitoring for Lake Neusiedl, carried out by the Biological Station Illmitz in Austria and by the Fertő tavi Hydrometeorological Station in Hungary.

Country		Sampling site	WGS
Austria	1	Bay of Illmitz	
	2	Illmitz resort	
	4	South state border	N47° 53.97' E16° 48.18'
	5	Illmitz – Mörbisch	N47° 51.19' E16° 45.87'
	6	Reed edge near Mörbisch	
	8	Bay of Rust	
	13	Reed edge in front of Donnerskirchen channel	
	18	Breitenbrunn resort	
	21	Neusiedl resort	
	23	Weiden resort	
	24	Weiden	N47° 41.03' E16° 45.58'
	25	Reed edge in front of Gols channel	
	26	Podersdorf resort	
	27	Donnerskirchen	N47° 45.24' E16° 43.43'
	29	Reed edge Podersdorf	
	35	State border South of Mörbisch	
	36	Ruster Poschn	
Hungary	1	Fertőbozi főcsatorna 1	N47° 41.529' E16° 43.693'
	2	Körcsatorna 4	N47° 39.930' E16° 48.491'
	3	Körcsatorna 3	N47° 39.897' E16° 46.709'
	4	Körcsatorna 2	N47° 40.013' E16° 44.823'
	5	Körcsatorna 1	N47° 40.157' E16° 44.062'
	6	Fertőbozi főcsatorna 2	N47° 40.269' E16° 43.485'
	7	Fertőbozi főcsatorna 3	N47° 39.564' E16° 43.347'
	8	Fertőbozi főcsatorna 4	N47° 38.938' E16° 43.243'
	9	Fertőbozi főcsatorna 5	N47° 38.380' E16° 43.152'
	10	Meggyesi szél	N47° 44.337' E16° 41.100'
	11	Madárvárta (HFCS)	N47° 40.640' E16° 48.491'
	12	Fertőrákosi öböl	N47° 43.426' E16° 41.788'
	13	Herlakni-tó	N47° 41.088' E16° 42.827'
	14	B0	N47° 44.230' E16° 42.932'
	15	Nádas állomás	N47° 42.918' E16° 40.672'
	16	Virágosmajori főcsatorna 2	N47° 43.485' E16° 40.499'

9.2 List of pollutants in the national monitoring in Hungary

Table 14. Parameters investigated in Hungary every 3 years.

As-total µg/l	Trichlorethylene µg/l	PCB-28 µg/l
As-dissolved µg/l	Tetrachlorethylene µg/l	Trifluralin µg/l
Zn-total µg/l	1,3,5-Trichlorobenzene µg/l	Simazin µg/l
Zn-dissolved µg/l	1,2,4-Trichlorobenzene µg/l	Atrazin µg/l
Hg-total µg/l	1,2,3- Trichlorobenzene µg/l	alfa-BHC µg/l
Hg-dissolved µg/l	Pentachlorobenzene µg/l	beta-BHC µg/l
Cd-total µg/l	Hexachlorobenzene µg/l	Lindane µg/l
Cd-dissolved µg/l	Naphthalene µg/l	delta-BHC µg/l
total Cr-total µg/l	2-Methyl naphthalene µg/l	Alachlor µg/l
Total Cr-dissolved µg/l	Acenaphthylene µg/l	Terbutrin µg/l
Ni-total µg/l	Acenaphthene µg/l	Endosulfan I µg/l
Ni-dissolved µg/l	Fluoren µg/l	Endosulfan II µg/l
Pb-total µg/l	Phenanthrene µg/l	Aldrin µg/l
Pb-dissolved µg/l	Anthracen µg/l	Endrin µg/l
Cu-total µg/l	Fluoranthene µg/l	Dieldrin µg/l
Cu-dissolved µg/l	Pyrene µg/l	Chlorfenvinphos µg/l
xylenes µg/l	Chrysene µg/l	Chlorpyrifos µg/l
Benzol µg/l	Benzo(b)fluoran µg/l	p,p-DDD µg/l
Toluol µg/l	Benzo(k)fluoran µg/l	p,p-DDE µg/l
Ethyl-benzol µg/l	Benzo(b+k)fluor µg/l	4,4-DDT µg/l
p-Xylene µg/l	Benzo(e)pyrene µg/l	Total PAH µg/l
o-Xylene µg/l	Benzo(a)pyrene µg/l	heptachlor µg/l
Dichlormethan µg/l	Indeno(1	hexakloro-butad µg/l
Chloroform µg/l	2,3-cd µg/l	Diuron µg/l
carbon tetrachloride µg/l	Dibenzo(a,h)ant µg/l	Izoproturon µg/l
1,2- Dichloroethane µg/l	Benzo(g,h,i)per µg/l	DEPH µg/l