

Performance of 21 Public Natural Swimming Pools (NSP) from 2015 – 2023

Hannes Kurzreuther, Sofia Čvoro, Polyplan - Kreikenbaum Gruppe GmbH

Abstract

The following study examines operating data from 21 public natural swimming pools (NSP) in the operating period between 2015 - 2023. The analysed parameters were chosen according to the current FLL- guideline¹. All data sets are taken from the current database for NSPs (DANA 2.0)². The analysis of the data showed that the tested systems function in accordance with the requirements of the FLL - guideline. The total number of limit value and recommended value violations was 2 -4.8%. The mean values of the treated water also remain within the permissible thresholds.

1. Background

NSPs are pools with biological water treatment. The used treatment processes purify the water using plant and animal organisms and microorganisms supported by filtration mechanisms.

In Germany, the first guideline for NSPs was published in 2003. This was revised in 2011¹ and has been valid for both planning and operation ever since. In order to examine how public natural outdoor pools work in practice, 21 pools were selected for evaluation (Table 1). The selection criterion was that as much of the required data as possible was available in the period 2015-2023 in DANA 2.0.

Table 1 Evaluated pools, master data and mean values

No.	Total surface [m ²]	pool volume [m ³]	Dry pool [m ²]	filter	Submerged filter [m ²]	Nominal number of visitors	Years
1	2299	2260	538		673	1012	2015-2023
2	980	2000	900		200	1571	2015-2023
3	3480	4415	750		303	1600	2015-2023
4	1285	1620	1200			1700	2015-2023
5	4650	4200			900	477	2021-2023
6	1950	3332	600		800	1500	2019-2023
7	1595	3190	750			1512	2019-2021
8	1595	3100	510		224,4	3036	2015-2023
9	570	835	114		65	294	2021-2023
10	1875	2340	375		340	950	2015-2023

¹ FLL (2011) Recommendations for Planning, Construction, Servicing and Operation of Outdoor Swimming Pools with Biological Water Purification (Swimming and Bathing Ponds), Forschungsgesellschaft Landschaftsentwicklung Landschaftsbau e. V.

² Kurzreuther, Stocker, Bruns (2022) DANA 2.0 – Monitoring und Steuerung von Naturfreibädern, Archiv des Badewesens, Bädertechnik, Wasseraufbereitung, 10/2022, 672-683

No.	Total surface [m ²]	pool volume [m ³]	pool Dry [m ²]	filter	Submerged filter [m ²]	Nominal number of visitors	Years
11	2280	2530	1325			2650	2015-2021
12	566	764			130	477	2022-2023
13	1709	2526	183		230	984	2022-2023
14	1510		405		270	700	2015-2023
15	1545	2637	480			1060	2015-2023
16	1775		520		350	1148	2015-2022
17			810		240	790	2018-2022
18	705	1015	360		110	760	2015-2023
19	490				305	243	2018-2023
20	2613	3855	204		150	745	2015-2023
21	1480	2295	265		231	1512	2020-2023
MV	1748	2524	572		325	1177	

Depending on availability the following parameters were examined for all pools (Table 2). The differences in the data situation for the various pools are mainly due to the fact that the parameters recommended by the FLL guidelines, apart from the hygiene parameters, are recommendations and not obligations. Accordingly, the pools or the local authorities themselves decide on the scope of testing in their facilities.

Table 2 Limit values and recommended values for different operational monitoring parameters

Parameter	Pool water		Clear water	
	Limit value	Recommended value	Limit value	Recommended value
General	Number of bathers / day	-	pool specific	-
Chemical and physical data	Acid capacity	-	≥ 2.0 mmol/l	≥ 2.0 mmol/l
	Ammonium	-	≤ 0.3 mg/l	≤ 0.1 mg/l
	Conductivity	-	200 – 1000 µS/cm at 25 °C	200 – 1000 µS/cm at 25 °C
	Nitrate	-	≤ 30.0 mg/l	≤ 30.0 mg/l
	Oxygen saturation	-	80 - 120%	≥ 80 %
	Total Hardness	-	≥ 1.0 mmol/l	≥ 1.0 mmol/l
	Total Phosphorous	-	≤ 0.01 mg/l	≤ 0.01 mg/l
	Visibility depth	-	1,80 m	-
	Water temperature	-	≤ 25 °C ³	≤ 25 °C
pH	-	6.0 - 8.5 ⁴	6.0 - 8.5	
Hygienical data	Enterococci	≤ 50	-	-
	Escherichia Coli	≤ 100	-	-
	Pseudomonas aeruginosa	≤ 10	-	-
Biological data	Phytoplankton Biolvolume	-	≤ 1.0 mm ³ /l	-
	Zooplankton Filtrationrate	-	-	-

³ Elevated temperatures of no more than 28 °C can be tolerated for up to five days.

⁴ Up to pH 9.0 as an exception

The pH value and the oxygen saturation were determined on site using hand-held measuring devices. All other parameters were measured by specialist laboratories. The respective measuring methods were all based on the standard specifications of the FLL - guideline.

For all parameters, the mean values with the respective standard deviation, the maximum values and the percentage of limit or guideline value exceedances are given. The pool water data is shown divided into swimmers' pool data and non-swimmers' pool data. The clean water data shows data from the two most common filter types: submerged filters and irrigated gravel filters (dry filters).

2. Data evaluation

2.1. General data

2.1.1. Number of bathers per day

A pool-specific nominal number of visitors is defined for each pool as part of the design process. At maximum design, the nominal number of visitors is one bather per 3.5m³ of pool water volume per day.

The following figure shows the nominal number of visitors for all pools, the average number of visitors per day including standard deviation, the maximum number of visitors per day and the percentage of days on which the nominal number of visitors was exceeded. The value on the right-hand side shows the mean values for all pools combined.

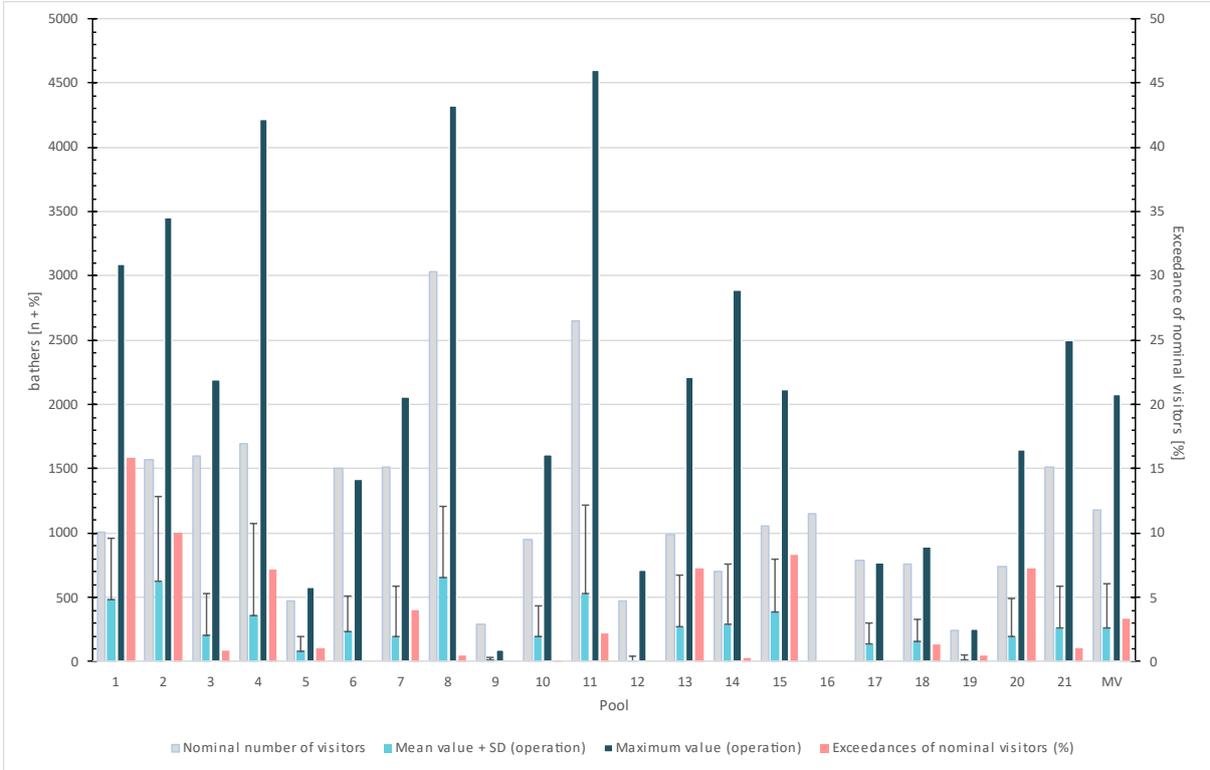


Figure 1 Nominal number of visitors, Mean value + standard deviation, maximum values and exceedances of nominal bathers, Mean value of all pools, n= 13384

The pools were designed for nominal visitor numbers of 477 to 3036 bathers per day. The average nominal visitor number was 1177 bathers/day. The data shows that the pools were operated on average within the designed load during the period under review. The average number of days on which the nominal number of visitors was exceeded was 3.4%. The maximum, however, was 16%. It is important to stress that the FLL calculation formula takes into account that the nominal number of visitors can be exceeded on 7 days per season. On average, the number of days this was exceeded was around 4. Only in 2 pools (1+2) the nominal number of visitors exceeded on more days on average. However, as will be shown in the further data, these pools did not show any particular anomalies.

2.2. Chemical and physical data

2.2.1. Visibility depth

The easiest way to determine water quality is to measure the depth of visibility, as many impurities have an effect on water turbidity. In addition, the depth of visibility is also an important monitoring parameter for pool operations, as it is the basis for the public safety obligation within the pools. Drowning people can only be seen and rescued if there is sufficient depth of visibility.

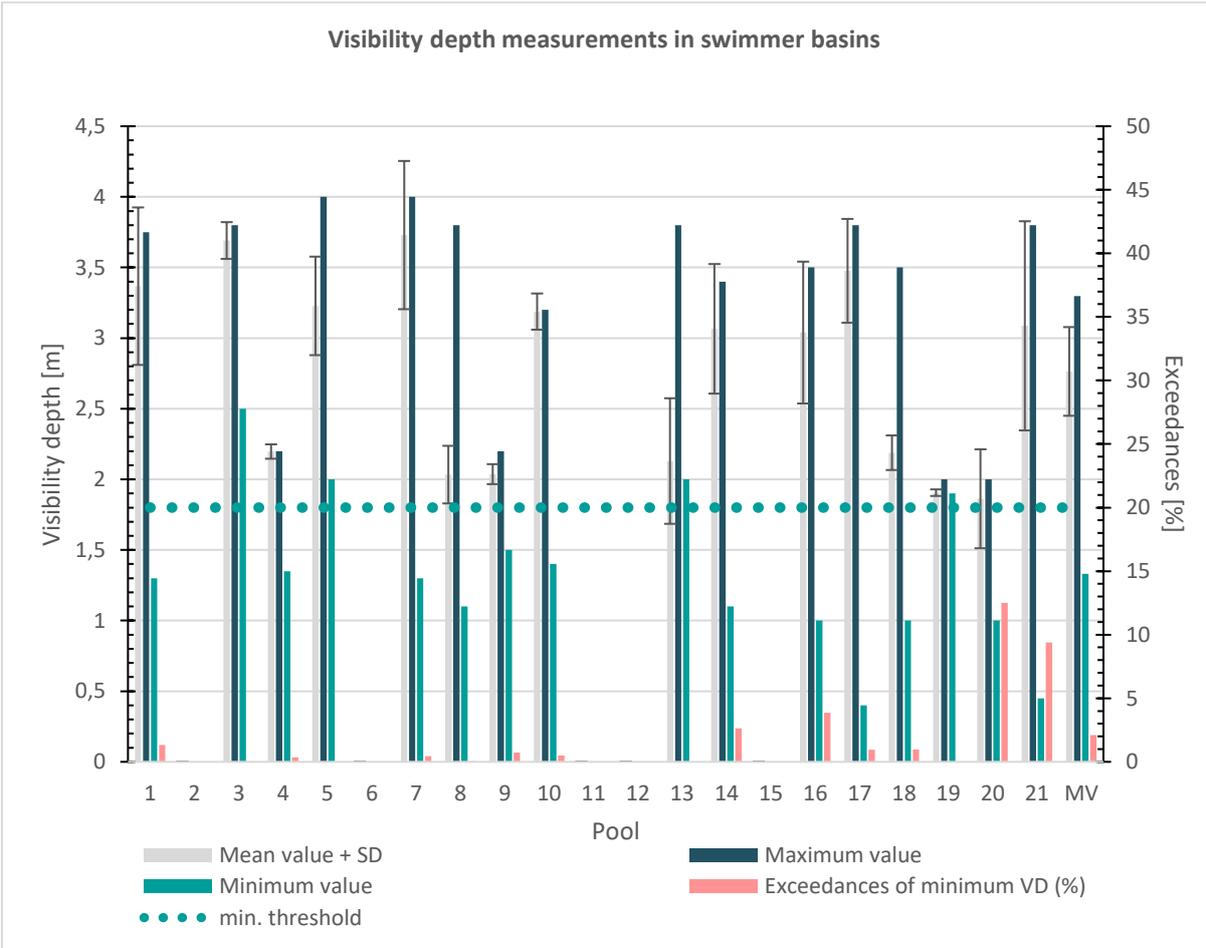


Figure 2 **Visibility depth – Swimmer basins**, mean value + standard deviation, maximum value, minimum value, minimum recommended value, MV = mean value of all pools, n=13029

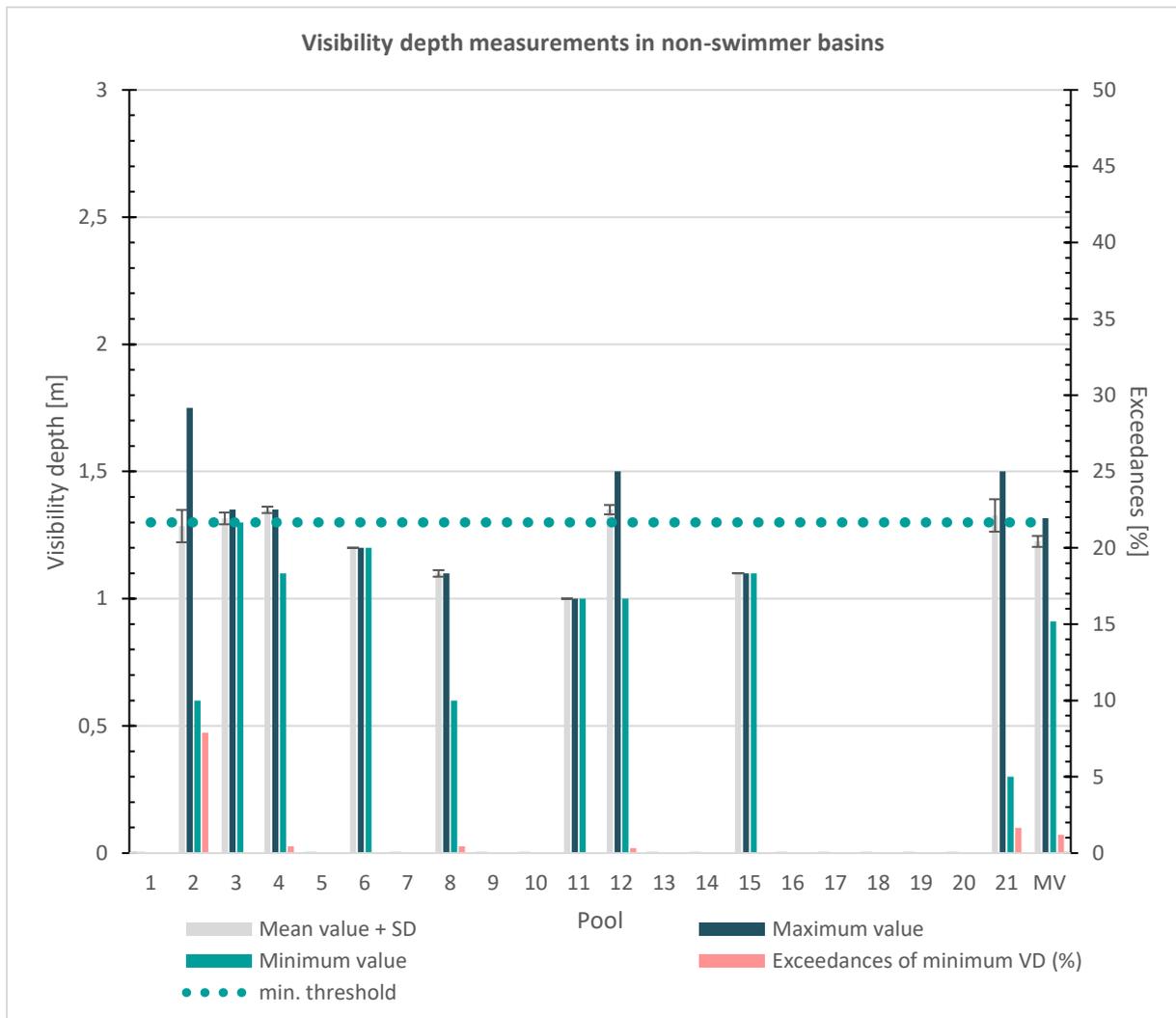


Figure 3 **Visibility depth – Non swimmer basins**, mean value + standard deviation, maximum value, minimum value, MV = mean value of all pools, n=9397

The data show that the average visibility depth in all swimmer basins was 2.76 m, with a minimum requirement of 1.8 m. An exceedance was observed on 2 % of the measurement dates. The visibility is usually measured several times a day. Accordingly, the 2% does not correspond to the opening days.

The visibility in the non-swimmer pools was mostly down to the bottom. This is particularly evident from the low standard deviations.

2.2.2. pH value

The pH value is normally measured daily on site in the pools. The pH value is easy to measure and shows the ratio of acids and bases. The recommended values are between 6 and 8.5 and in exceptional cases 9. The value for optimum operation is between 8.0 and 8.3. Lower values indicate unwanted acid inputs. Elevated values are usually an indicator of increased phytoplankton growth.



Figure 4 pH –Swimmer basins, mean value + standard deviation, maximum value, minimum value, minimum recommended value, MV = mean value of all pools, n=9762

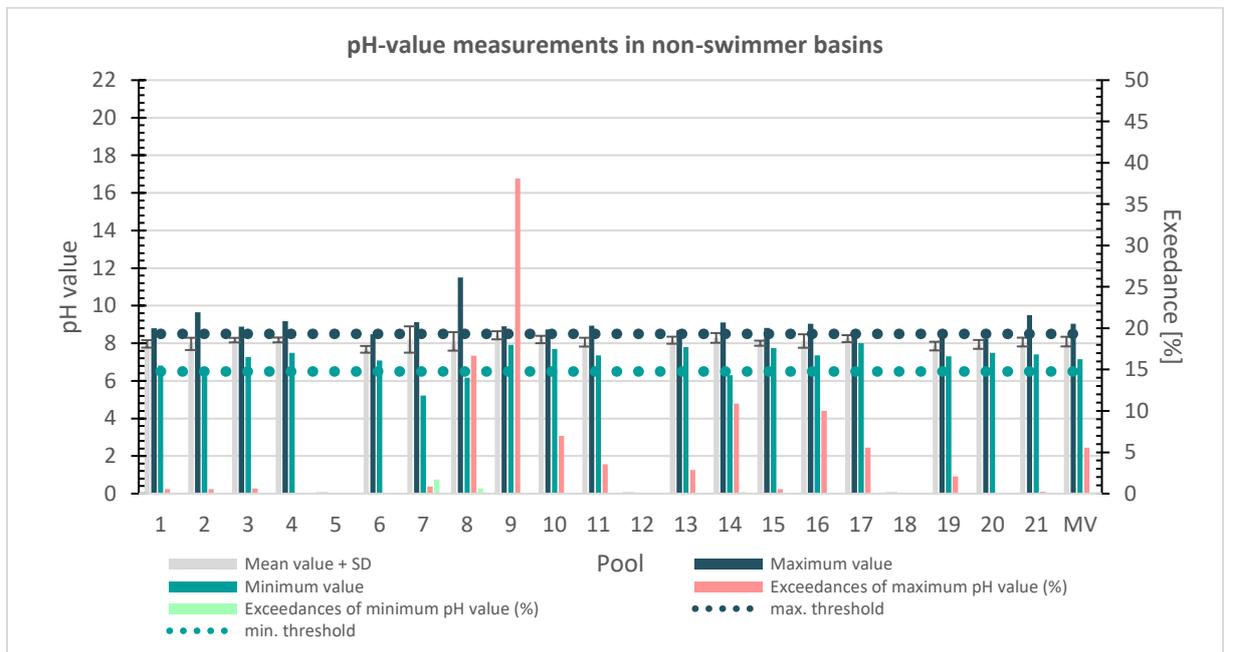


Figure 5 pH – Non-swimmer basins, mean value + standard deviation, maximum value, minimum value, maximum and minimum recommended value, MV = mean value of all pools, n=8620

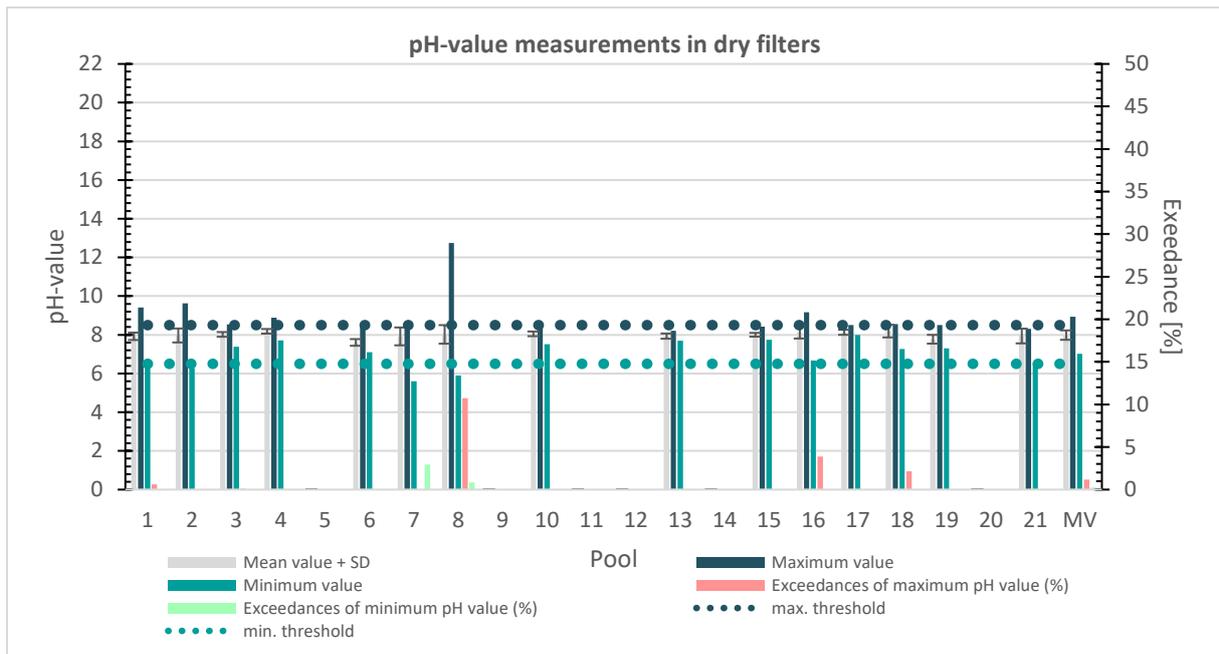


Figure 6 **pH – clear water – dry filter**, mean value + standard deviation, maximum value, minimum value, maximum and minimum recommended value, MV = mean value of all pools, n=8437

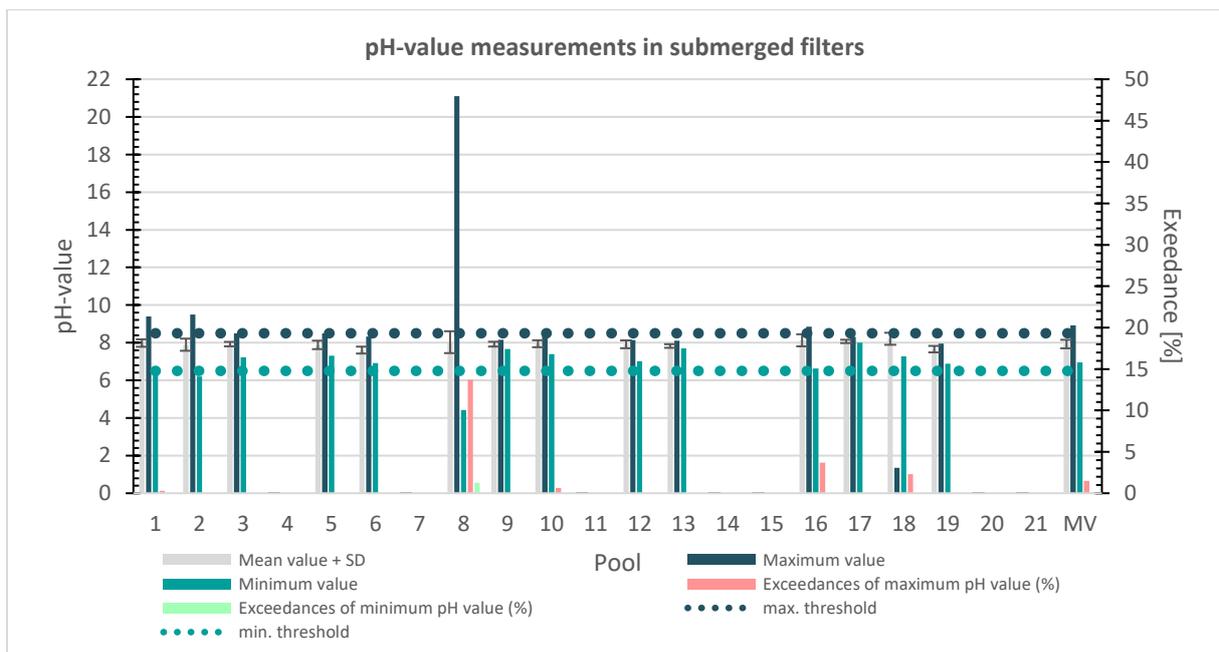


Figure 7 **pH – clear water – submerged filter**, mean value + standard deviation, maximum value, minimum value, maximum and minimum recommended value, MV = mean value of all pools, n=8628

The mean value in the swimmer pools was 8.06 and in the non-swimmer pools 8.09. The values in the clean water were reduced both in the dry filters (mean value 7.99) and in the submerged filters (mean value 7.93). There were hardly any exceedances or undercuts of the guideline values.

This reduction is mainly due to the decomposition of phytoplankton in the filter. The values thus indicate that the filters are functioning. Nevertheless, the actual pH value reductions caused by

phytoplankton degradation will probably be higher, since the lime material in the filter always shifts the pH value slightly upwards.

2.2.3. Acid capacity

The acid capacity is a measure of the buffering capacity of water and thus of the ability to keep the pH value stable against acid inputs. It indicates how much acid a defined amount of water can absorb until a certain pH value is reached. In natural water, the acid capacity is based on the buffering effect of dissolved carbonates and hydrogen carbonates. The acid capacity therefore also forms the basis for calculating the carbonate hardness. In the pH range between 4.3 and 8.2, carbonates are mainly present as hydrogen carbonates. The acid capacity up to pH 4.3 is therefore a direct measure of the hydrogen carbonate content of the water.

An acid capacity of ≥ 2.0 mmol/l is recommended for sufficient buffering.

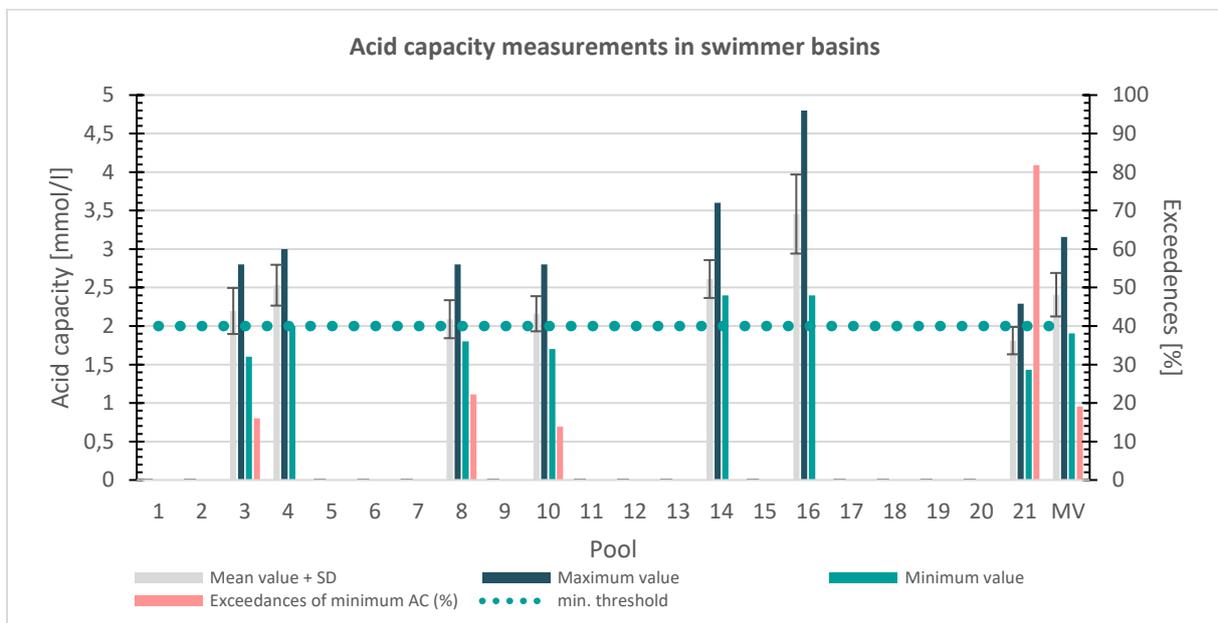


Figure 8 Acid capacity – swimmer basins, mean value + standard deviation, maximum value, minimum value, minimum recommended value, MV = mean value of all pools, n=260

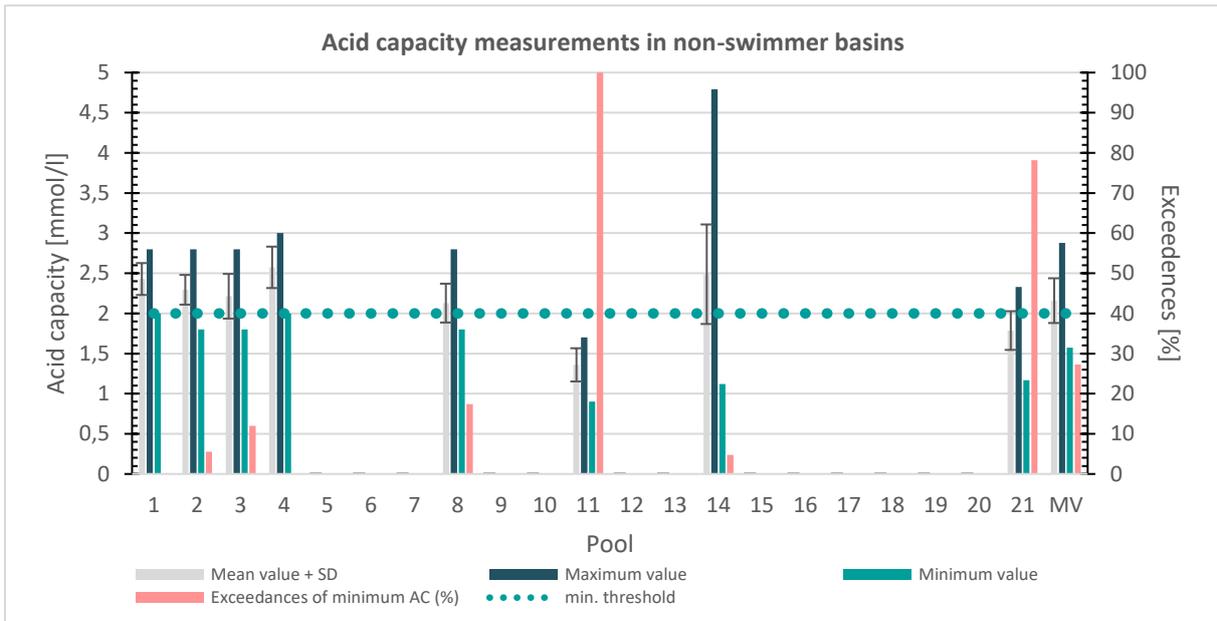


Figure 9 Acid capacity – Non - swimmer basins, mean value + standard deviation, maximum value, minimum value, minimum recommended value, MV = mean value of all pools, n=254

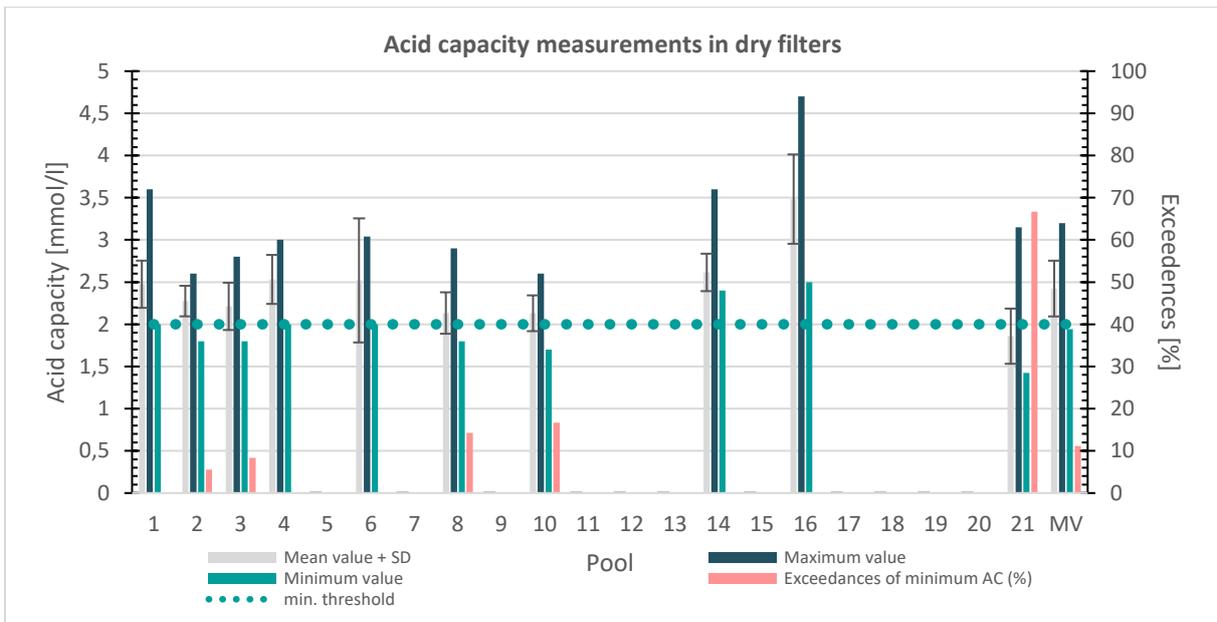


Figure 10 Acid capacity – clear water – dry filter, mean value + standard deviation, maximum value, minimum value, minimum recommended value, MV = mean value of all pools, n=308

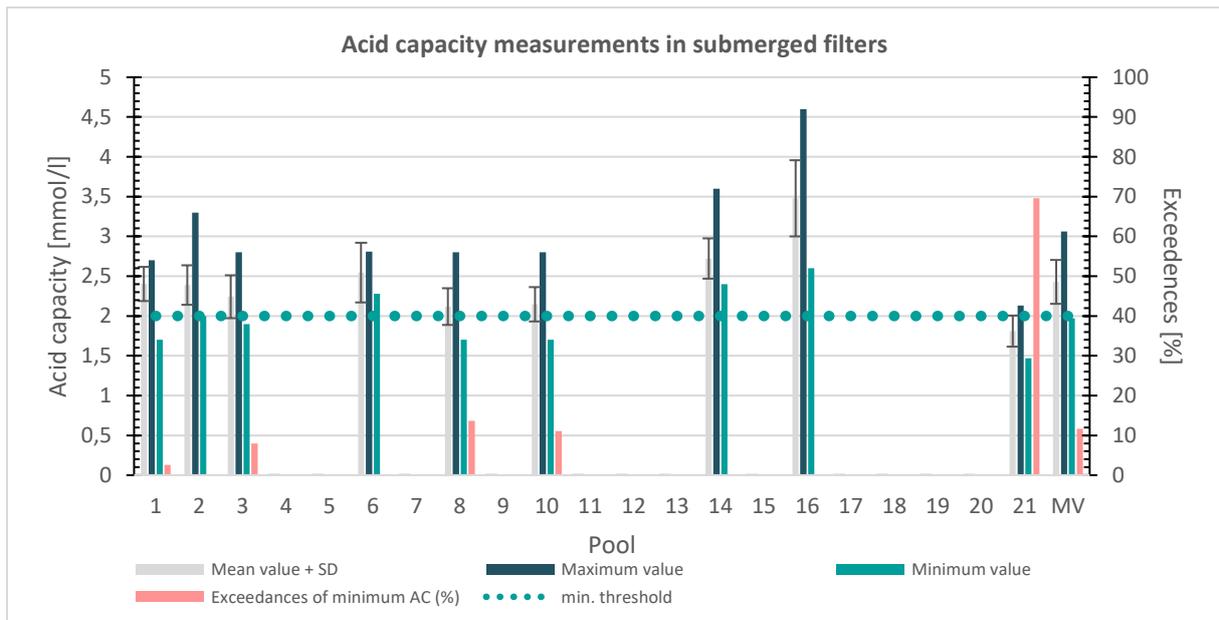


Figure 11 **Acid capacity – clear water – submerged filter**, mean value + standard deviation, maximum value, minimum value, minimum recommended value, MV = mean value of all pools, n=238

The acid capacity was on average above the guideline value at all measuring points. Since all of the systems examined use filters with limestone, these ensure a continuous increase in the acid capacity, so that the guideline values can be met even with filling water with low acid capacity values in the system.

2.2.4. *Oxygen saturation*

Oxygen saturation is also measured daily in the pools. If the oxygen saturation is too low, this indicates excessive consumption by microbial decomposition processes of organic substances. If the oxygen saturation is too high, this is due to excessive phytoplankton growth. The recommended values are between 80 and 120 % oxygen saturation.

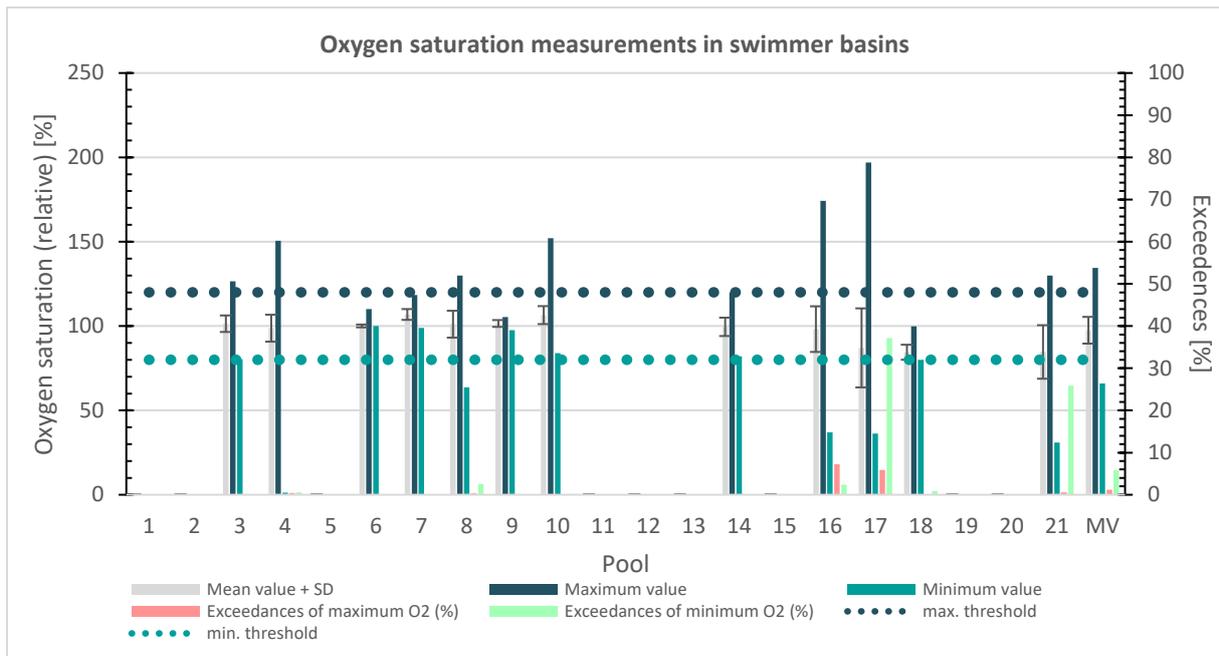


Figure 12 **Oxygen saturation – Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum and minimum recommended value, MV = mean value of all pools, n=6986

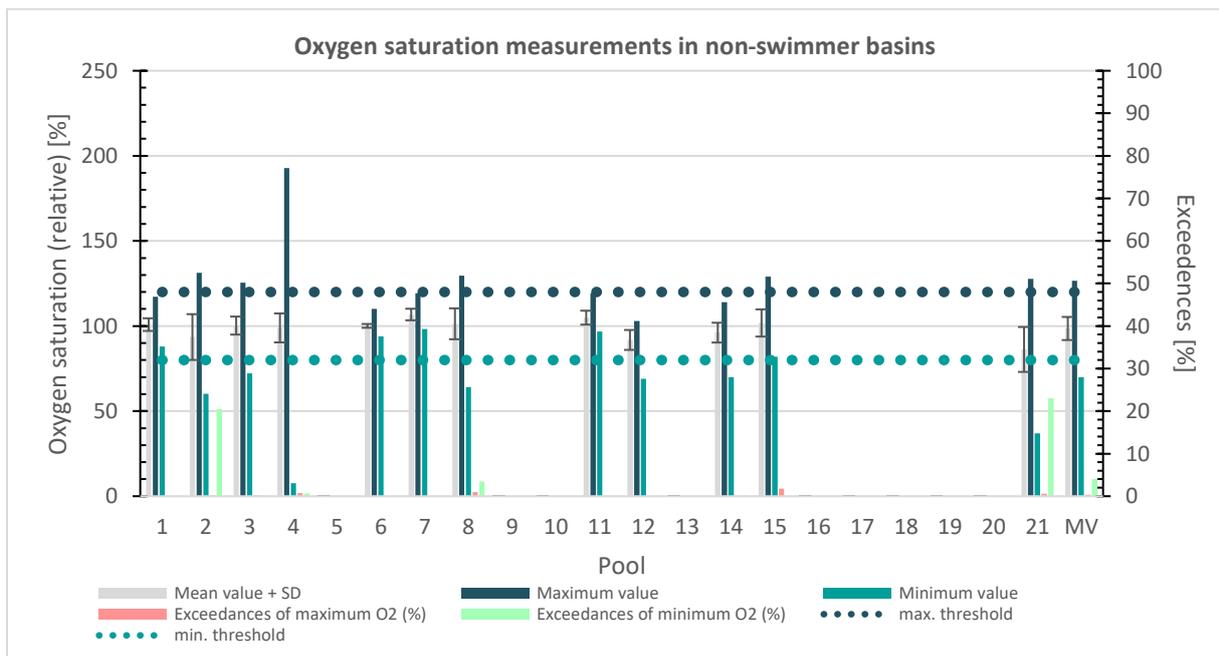


Figure 13 **Oxygen saturation – Non - Swimmer Basins**, mean value + standard deviation, maximum value, maximum and minimum value, minimum recommended value, MV = mean value of all pools, n=5496

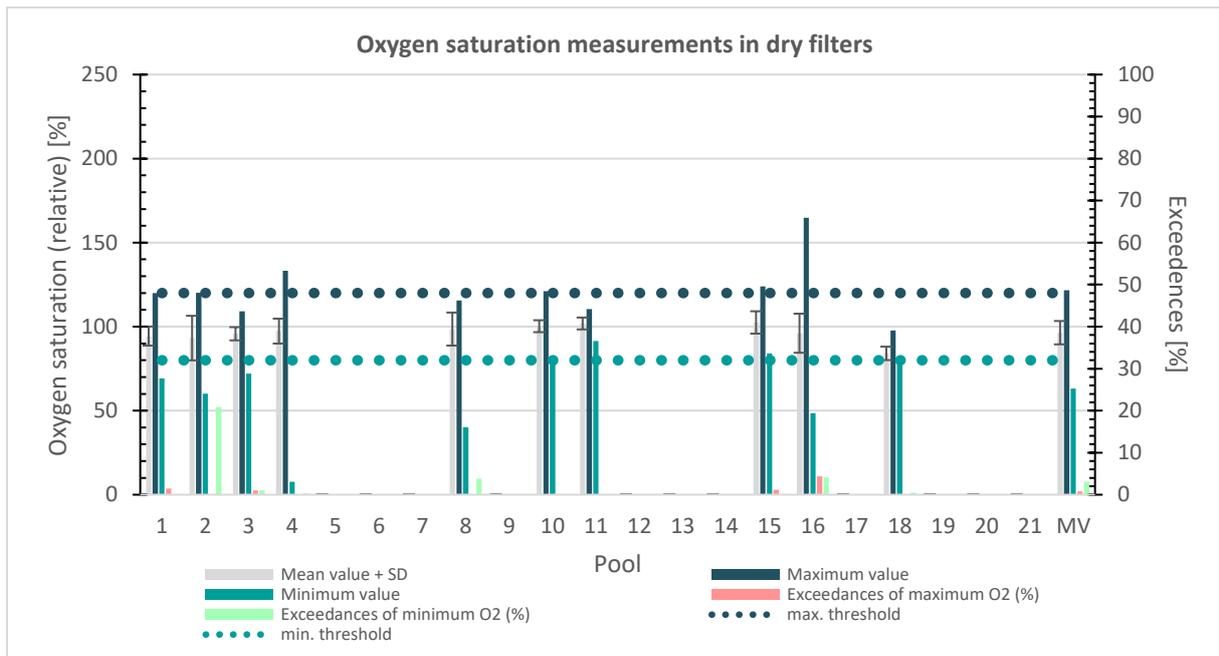


Figure 14 **Oxygen saturation – Clear water dry filter**, mean value + standard deviation, maximum value, maximum and minimum value, minimum recommended value, MV = mean value of all pools, n=5945

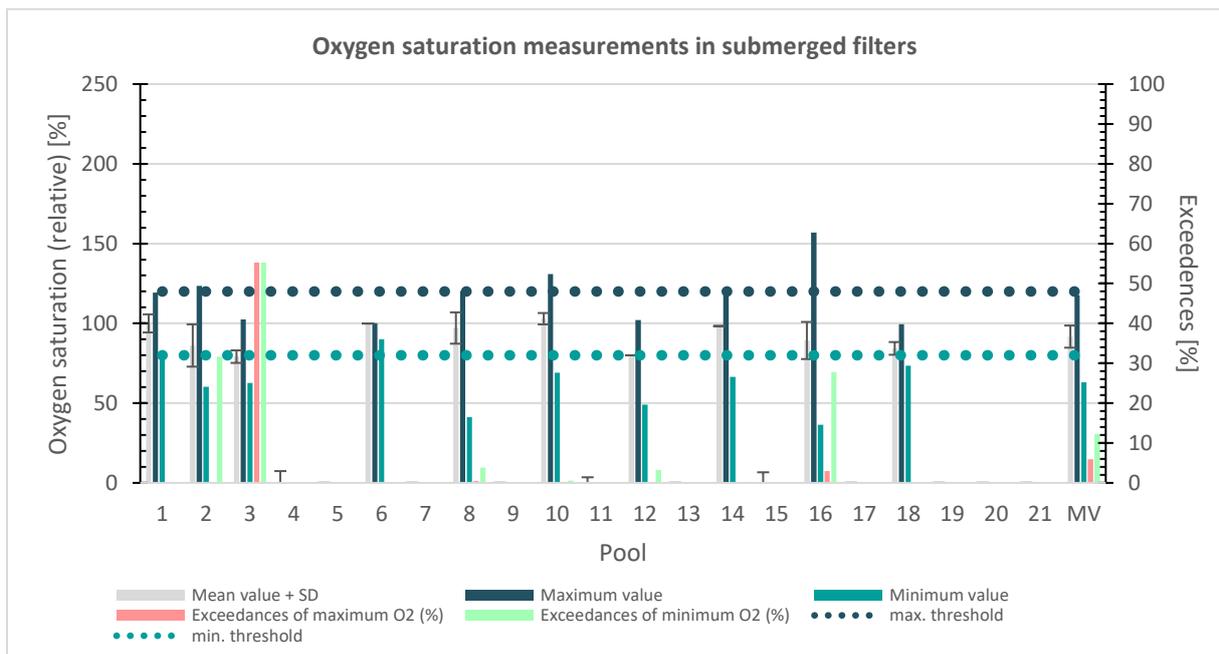


Figure 15 **Oxygen saturation – Clear water submerged filter**, mean value + standard deviation, maximum value, maximum and minimum value, minimum recommended value, MV = mean value of all pools, n=6356

The measured oxygen saturation was on average in the required range at all measuring points. In the swimmers' pool (mean value: 98%) and in the non-swimmers' pool (97%), it was slightly increased compared to the pure water samples in the dry (mean value: 95%) and in the submerged filter (mean value: 90%). The lower values in the filters can be seen as an indicator of biodegradation in the filters. The greater consumption in the submerged filters can be attributed to the fact that the filters are

permanently overfilled, while dry filters are only sprinkled, which means that more oxygen is available to the filter biology.

The values also indicate that aerobic conditions were consistently present in the pools.

2.2.5. Water temperature

The water temperature is of central importance for all biological processes that take place in a natural outdoor pool. Therefore, it is measured daily. The temperature influences both the overall biological productivity and the species composition. Previously, the guideline value was 25°C, with an exceedance of up to 28°C being permitted on a maximum of 5 days. It should be noted at this point that the attitude towards this is currently changing, so that higher temperatures presumably will also be permitted in the upcoming guideline⁵.

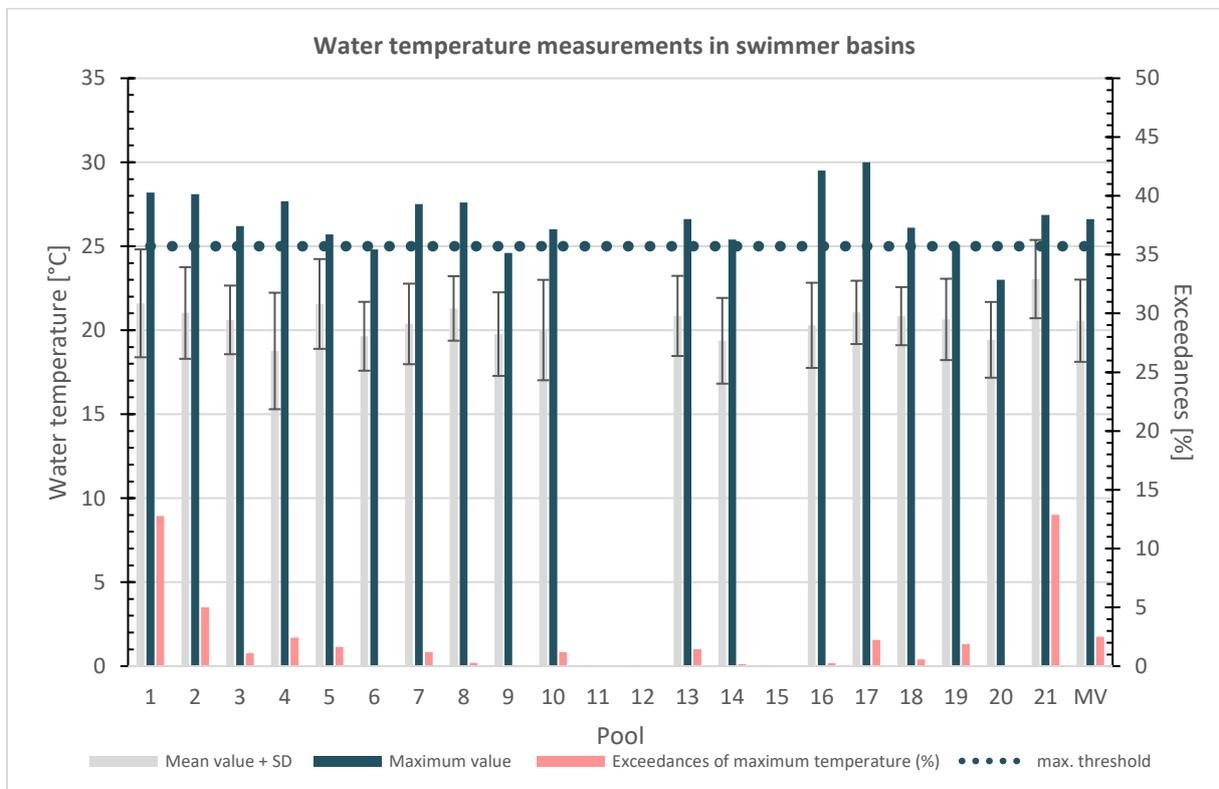


Figure 16 **Temperature – Swimmer basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=331987

⁵ The FLL's follow-up guideline will probably be published under the auspices of the DGFdB at the end of 2025. More details can be found there.

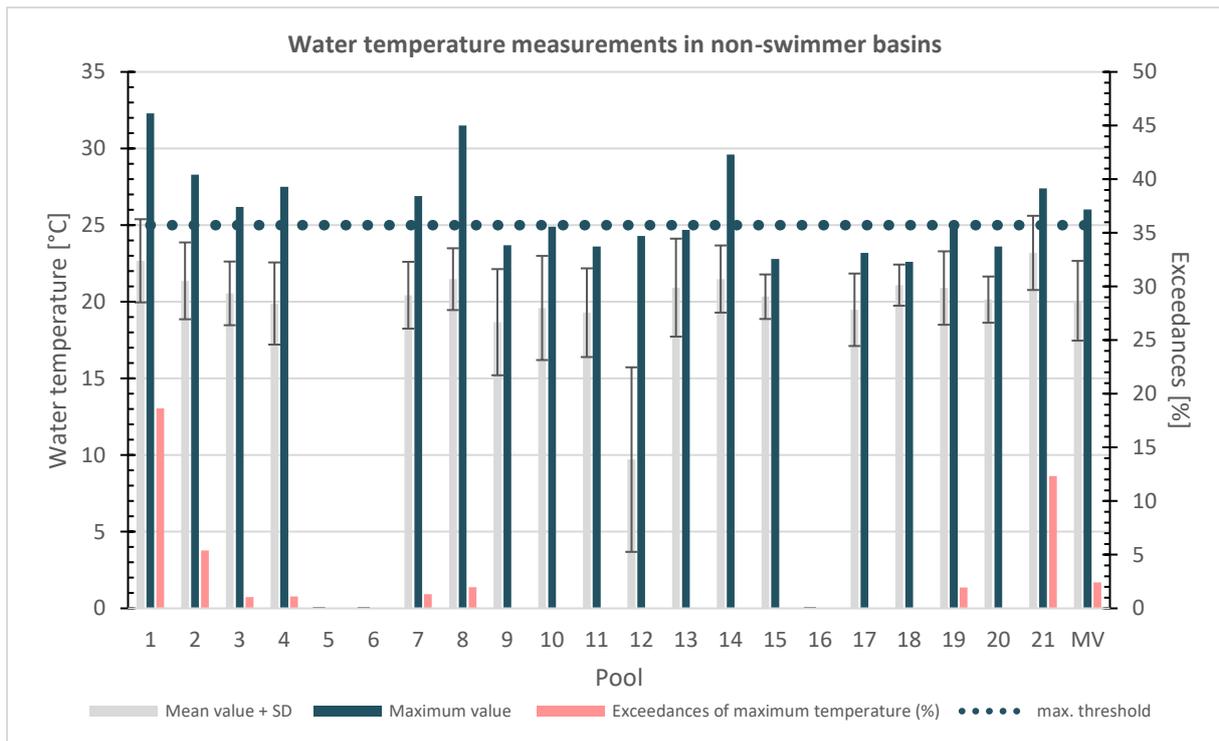


Figure 17 **Temperature – Non swimmer basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=12598

To evaluate the temperature data, swimming pools and non-swimmer pools were evaluated separately. All mean values including standard deviations were below 25°C. The maximum temperature was 30°C. Although the non-swimmer area is always shallower, no noticeable temperature increases were observed here. This is due to the high circulation rates. The main reason why the temperatures always remained below the guideline is that most pools cool with filling water when necessary.

2.2.6. Total phosphorous

The total phosphorus content is the most important nutrient for controlling phytoplankton growth. According to the Redfield ratio, phytoplankton requires a molar ratio of phosphorus to nitrogen to carbon of 1:16:106. Since nitrogen and carbon are usually sufficiently present, phosphorus is usually the limiting factor for growth according to Liebig's minimum law. If phosphorus is reduced, phytoplankton growth is limited. Phosphorus management is therefore of paramount importance in the operation of NSPs and the recommended value is ≤ 0.01 mg/l. In NSPs, this occurs both through biological fixation in plants and biofilms, and through adsorption.

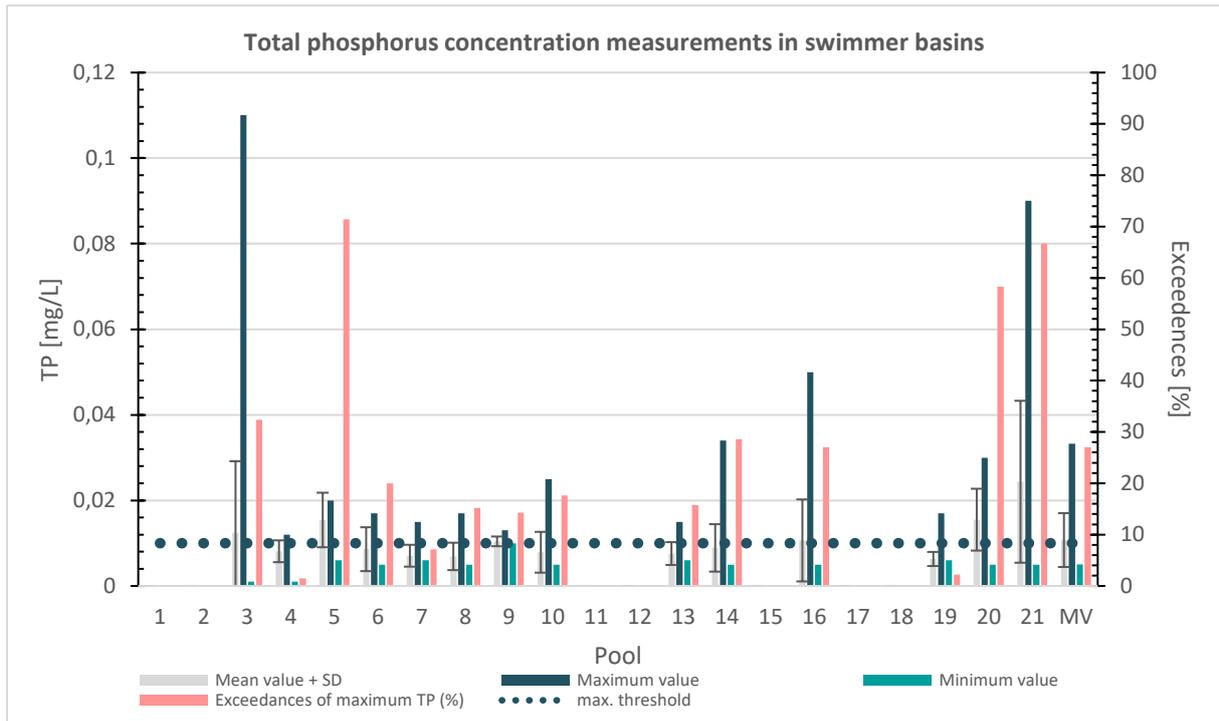


Figure 18 **Total phosphorous – Swimmer basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=472

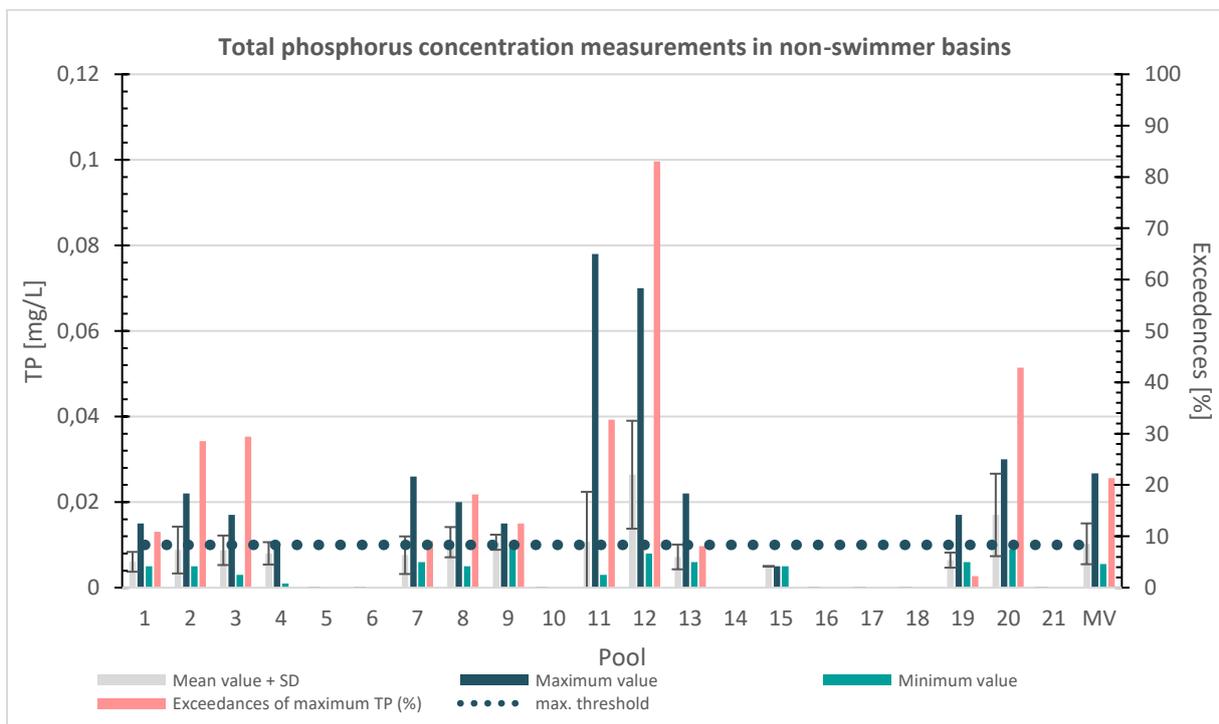


Figure 19 **Total phosphorous – Non - swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=467

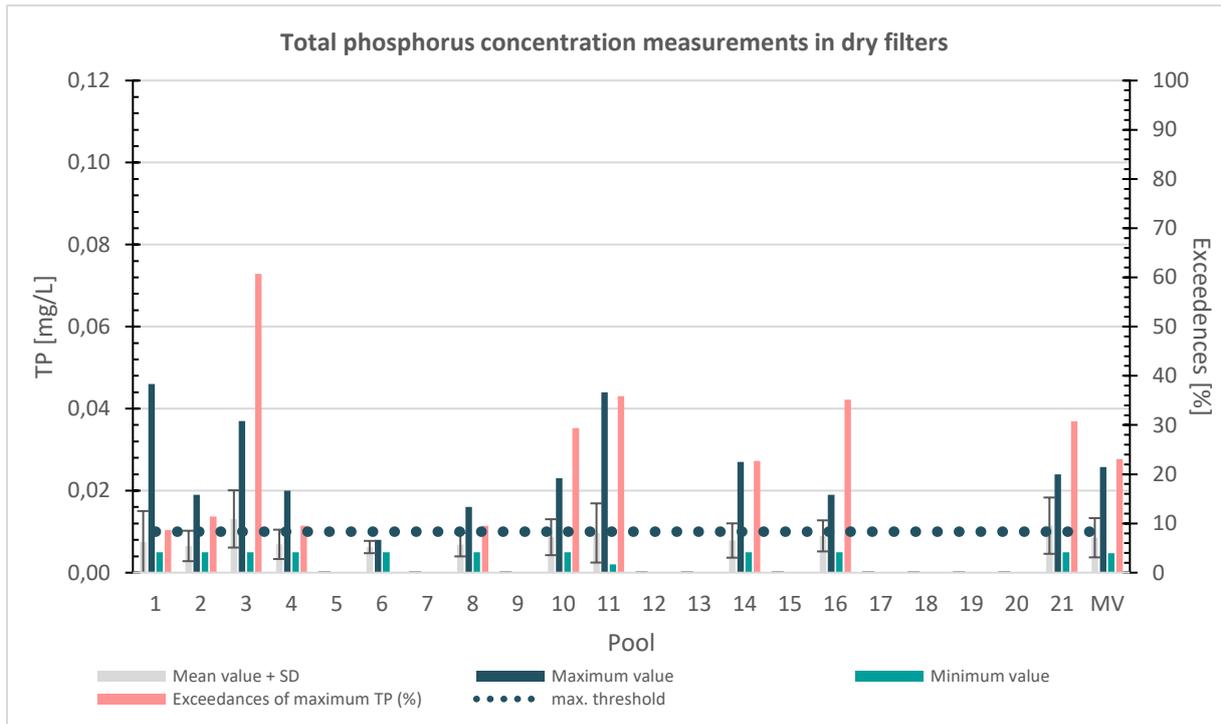


Figure 20 **Total phosphorous – Clear water dry filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=357

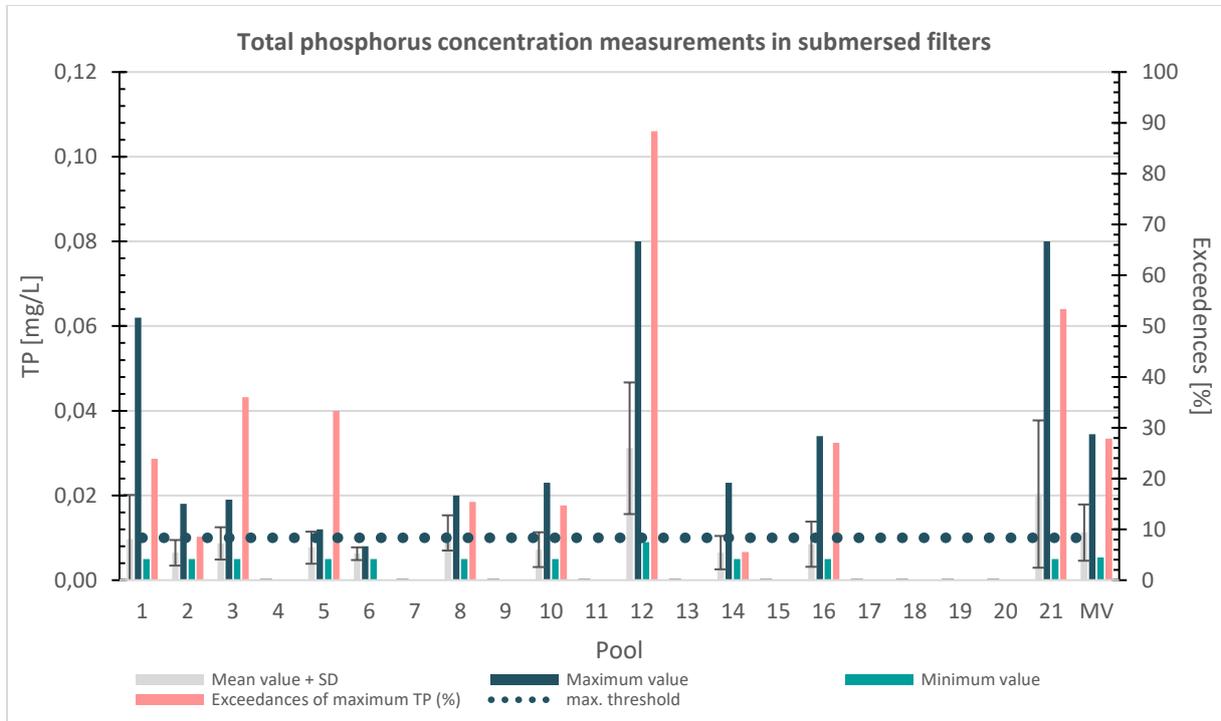


Figure 21 **Total phosphorous – Clear water submersed filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=323

The total phosphorus value was 0.01 mg/l on average at all 4 measuring points and thus exactly within the FLL specifications. A closer look at the data shows an average TP reduction of 21% in the pure water of the dry filters and 15% in the submerged filters (figure 22).

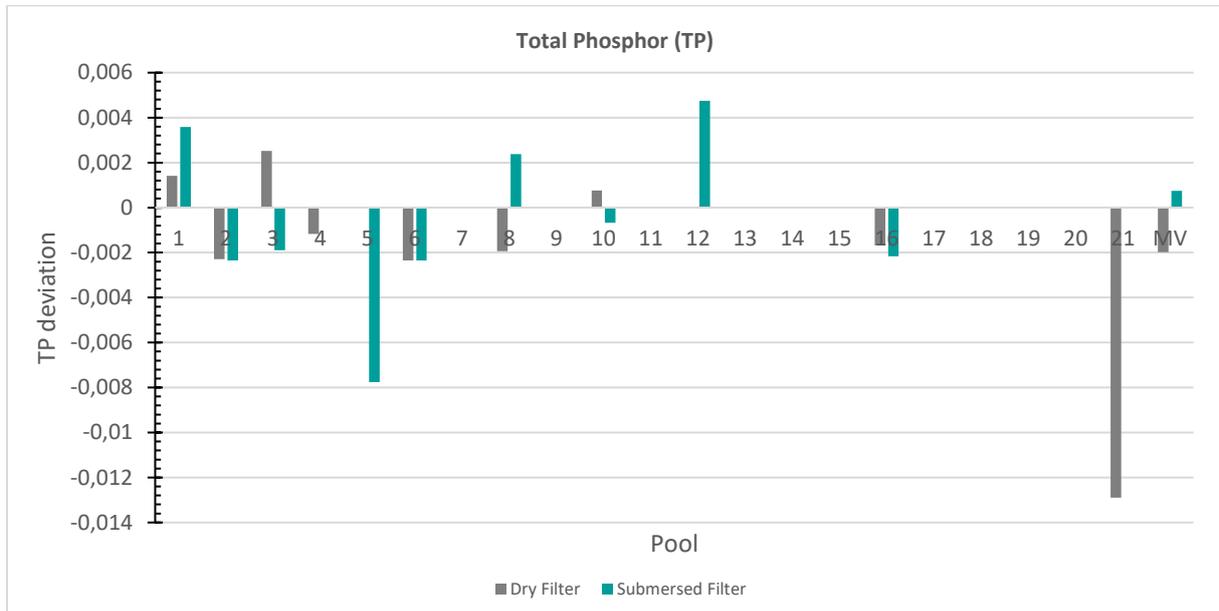


Figure 22 **Total phosphorous – Swimmers + non swimmers area vs. filter area**, deviation between the mean value of the utilization area and the respective filter area measurement values

2.2.7. Nitrogen compounds - ammonium and nitrate

Ammonium is produced by the breakdown of proteins. This can occur in NSPs through the rotting of dead biomass or through the introduction of urine by bathers. Ammonium is then oxidized to nitrate in the filters under aerobic conditions. High ammonium values indicate that microbial aerobic degradation is no longer working. Therefore, the required recommended value in pure water (≤ 0.1 mg/l) is also lower than in pool water (≤ 0.3 mg/l). The resulting nitrate in turn serves as a nutrient base for the plants in NSPs. In addition, nitrate can also enter the pool via the filling water.

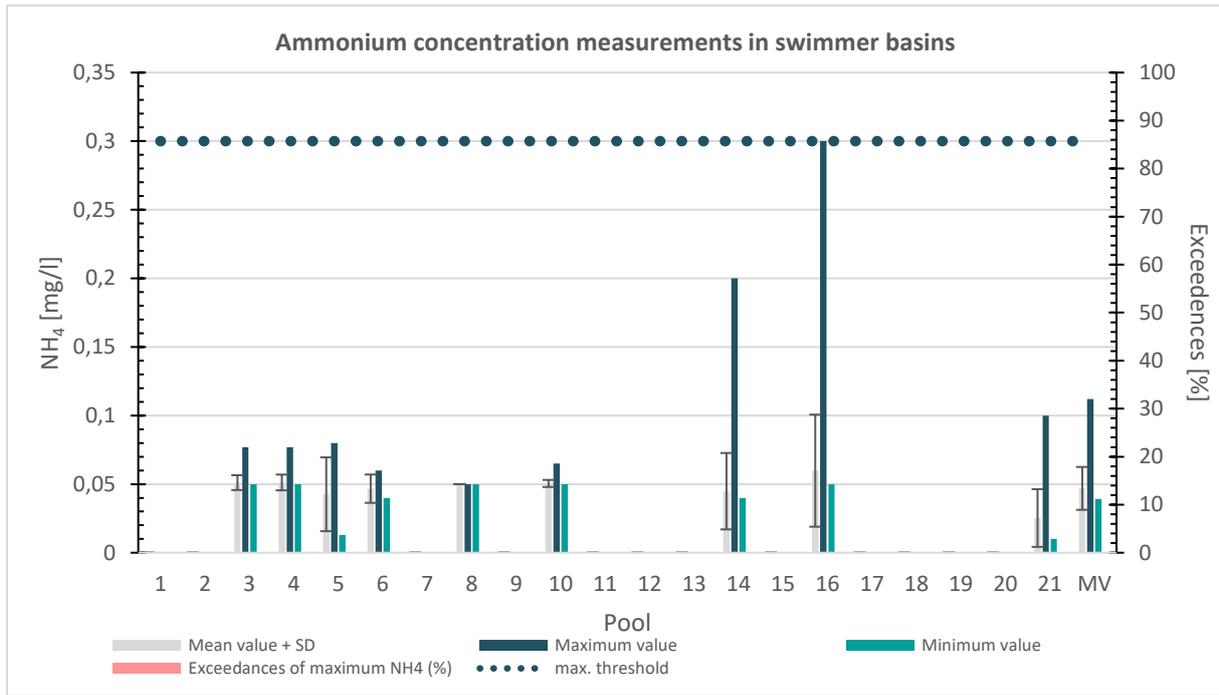


Figure 23 **Ammonium – Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=249

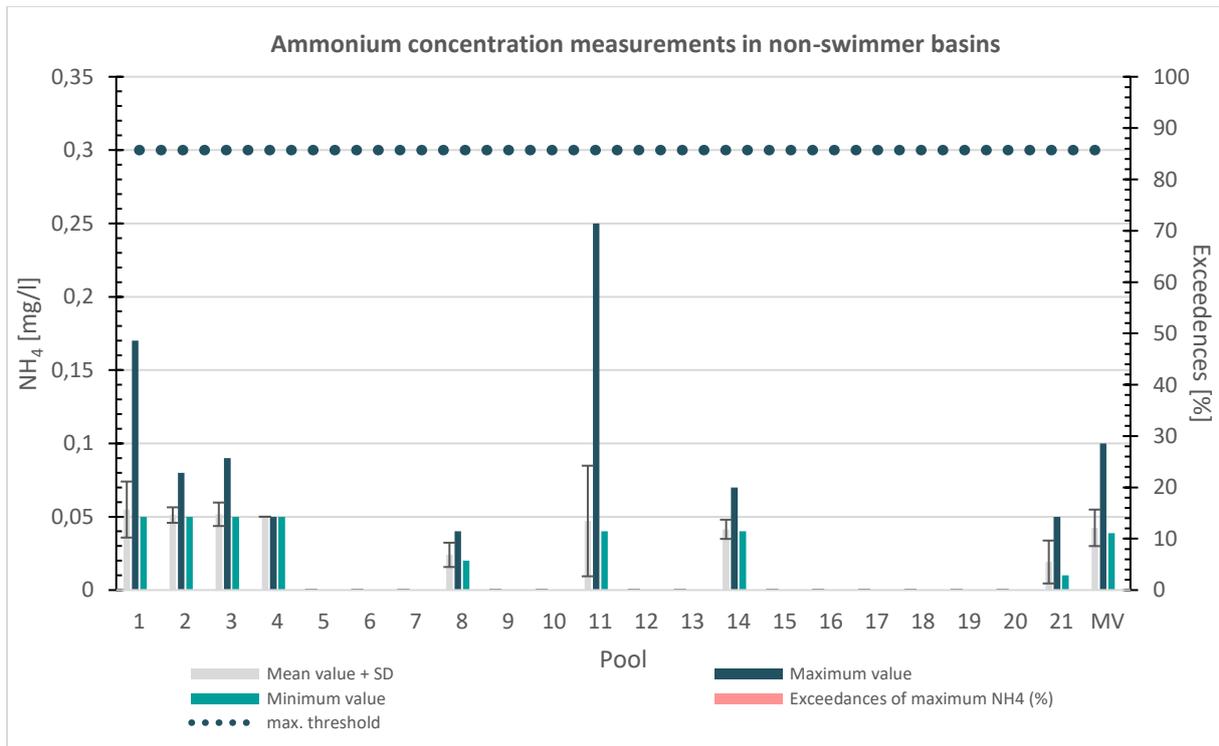


Figure 24 **Ammonium – Non - Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=230

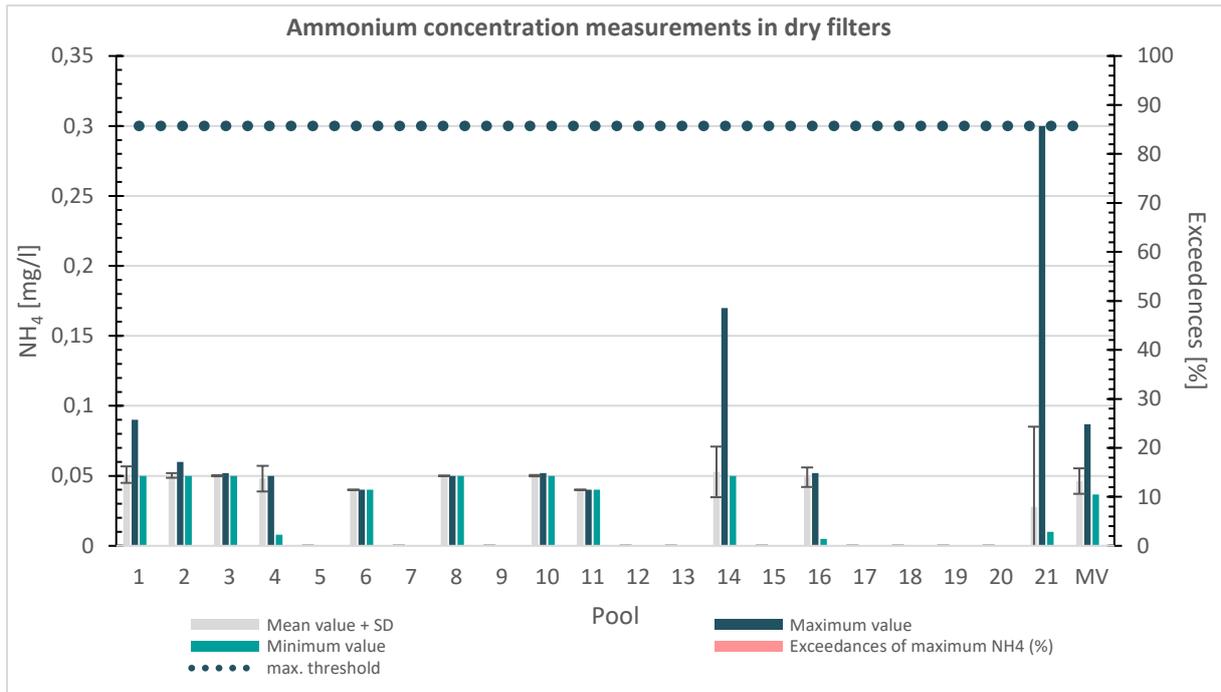


Figure 25 **Ammonium – Clear water dry filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=350

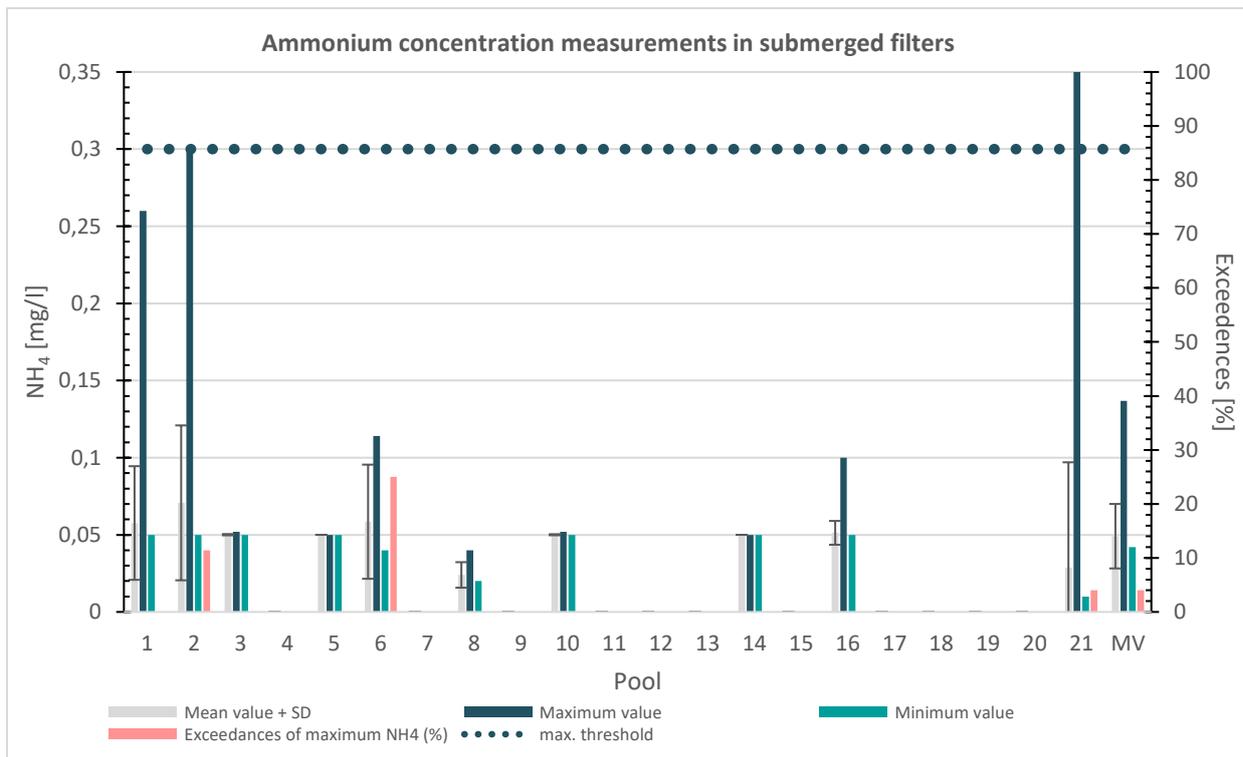


Figure 26 **Ammonium – Clear water submerged filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=265

The average ammonium content in both the pool water and the clear water was 0.05 mg/l. This means that both the pool water and the pure water were well below the recommended maximum values. It

is striking that the highest maximum values were found in the clear water of submerged filters. This shows that this is the place where, compared to the other areas, anaerobic zones can most easily develop, which can inhibit the conversion of ammonium into nitrate. However, this is not a problem in normal operation.

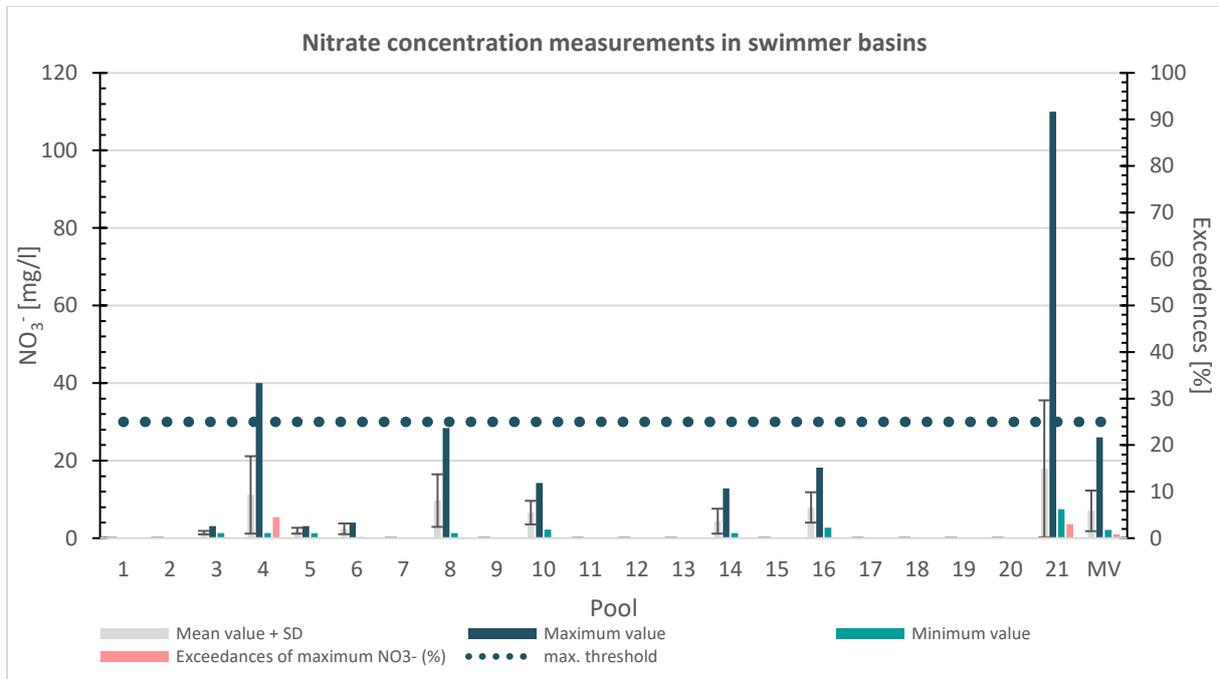


Figure 27 **Nitrate – Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=258

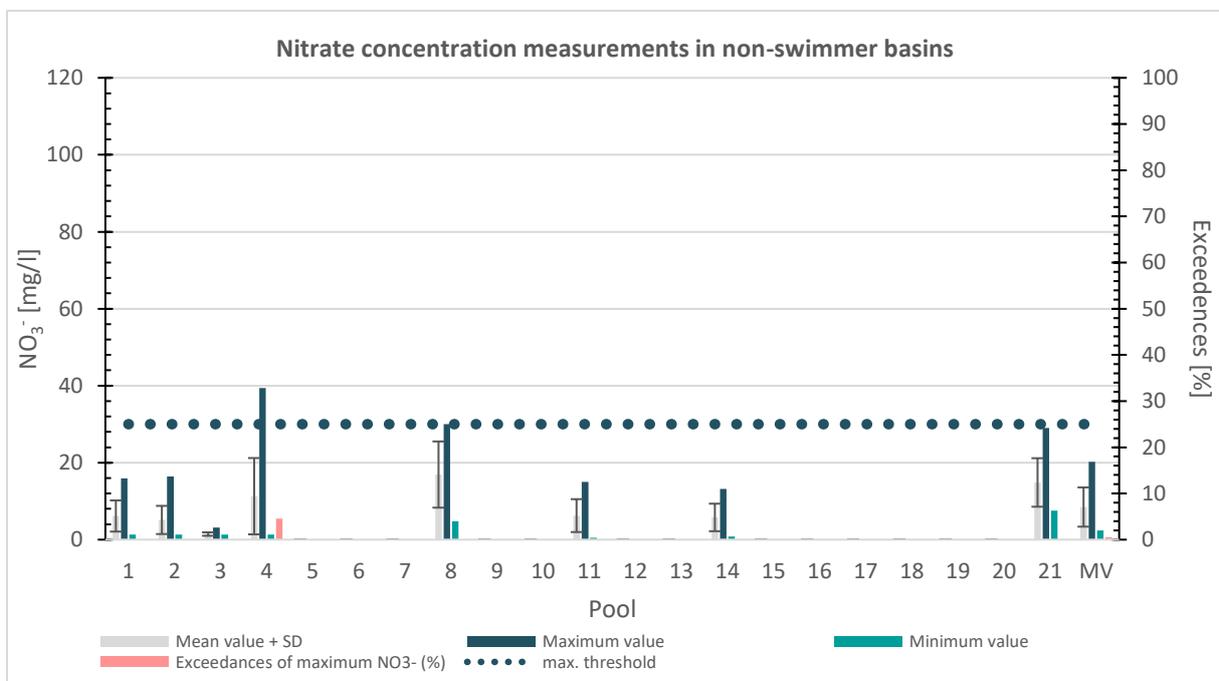


Figure 28 **Nitrate – Non - Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=229

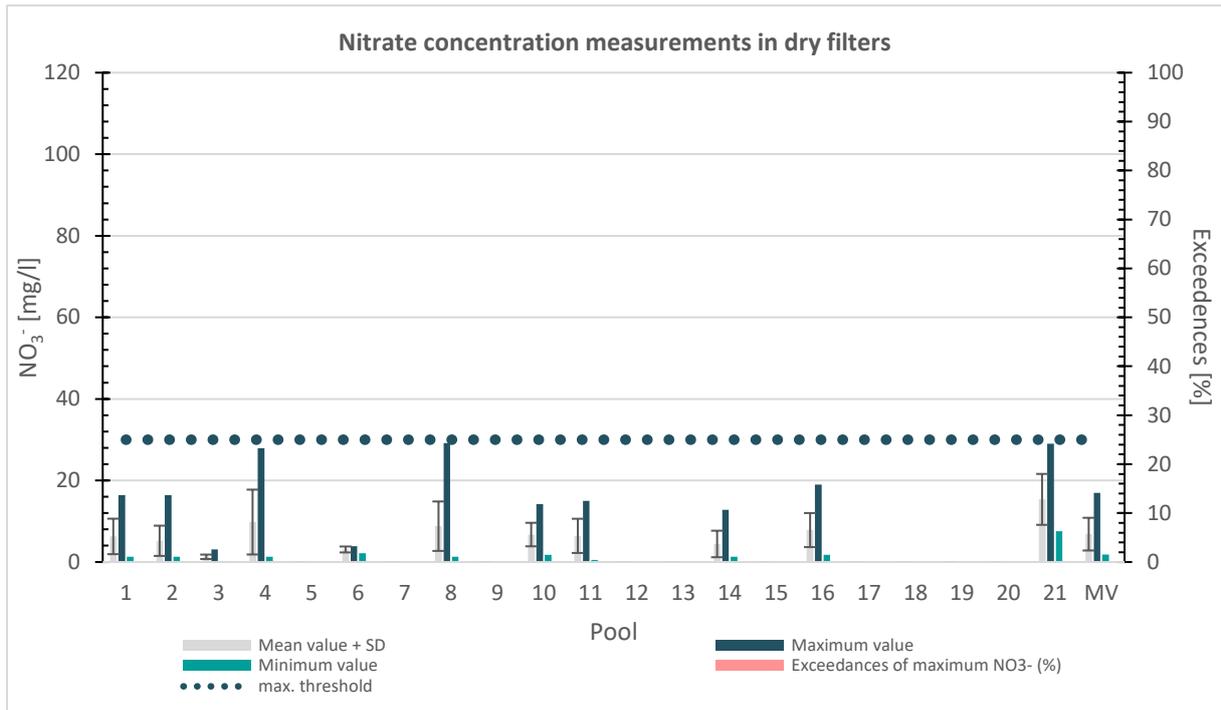


Figure 29 **Nitrate – Clear water dry filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=337

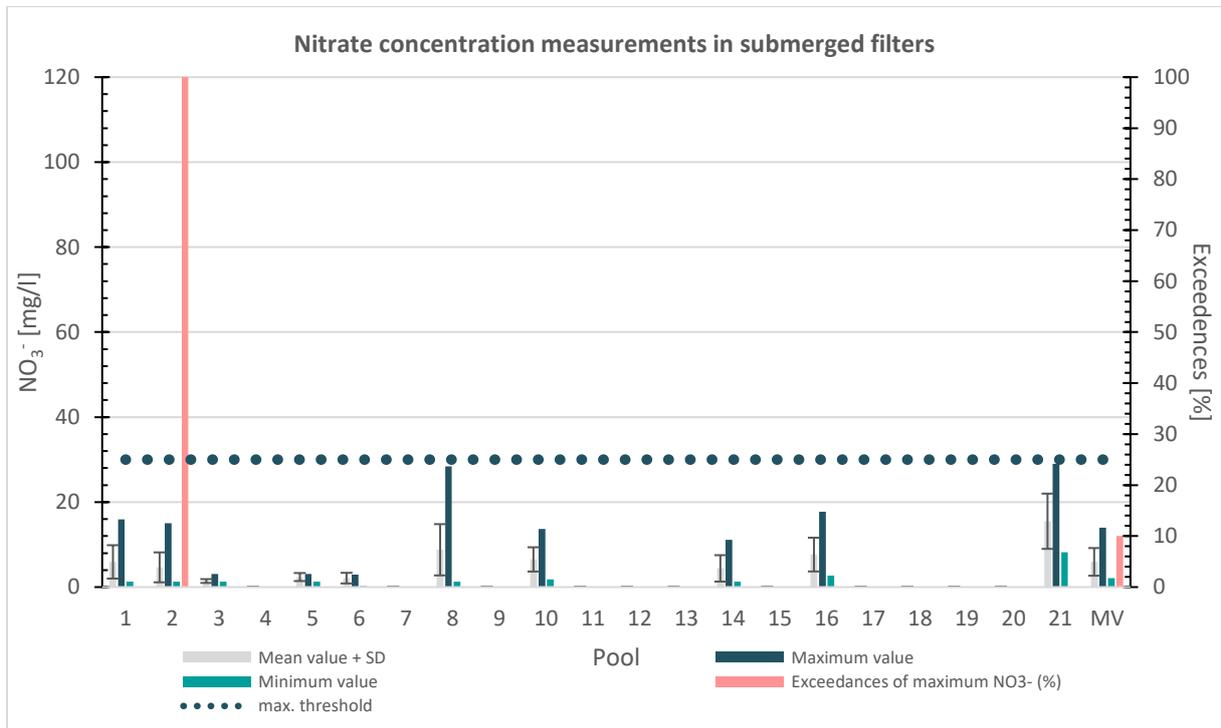


Figure 30 **Nitrate – Clear water submerged filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=285

The nitrate values in the swimmer pools (7.1 mg/l) and the non-swimmer pools (9 mg/l) were slightly higher on average than the values in the clean water of the dry filters (6.8 mg/l) and the submerged filters (5.9 mg/l). This indicates that the plants in the filter areas are breaking down the nitrate. Overall, the nitrate values were well below the recommended maximum values.

2.2.8. Conductivity

Conductivity is a sum parameter that measures all conductive ions. The majority of the ions are calcium and magnesium ions, which also determine the water hardness. Values that are too high (>1000 $\mu\text{S}/\text{cm}$) can indicate contamination. If the values are too low (<200 $\mu\text{S}/\text{cm}$), aquatic plants usually do not have enough nutrients to grow.

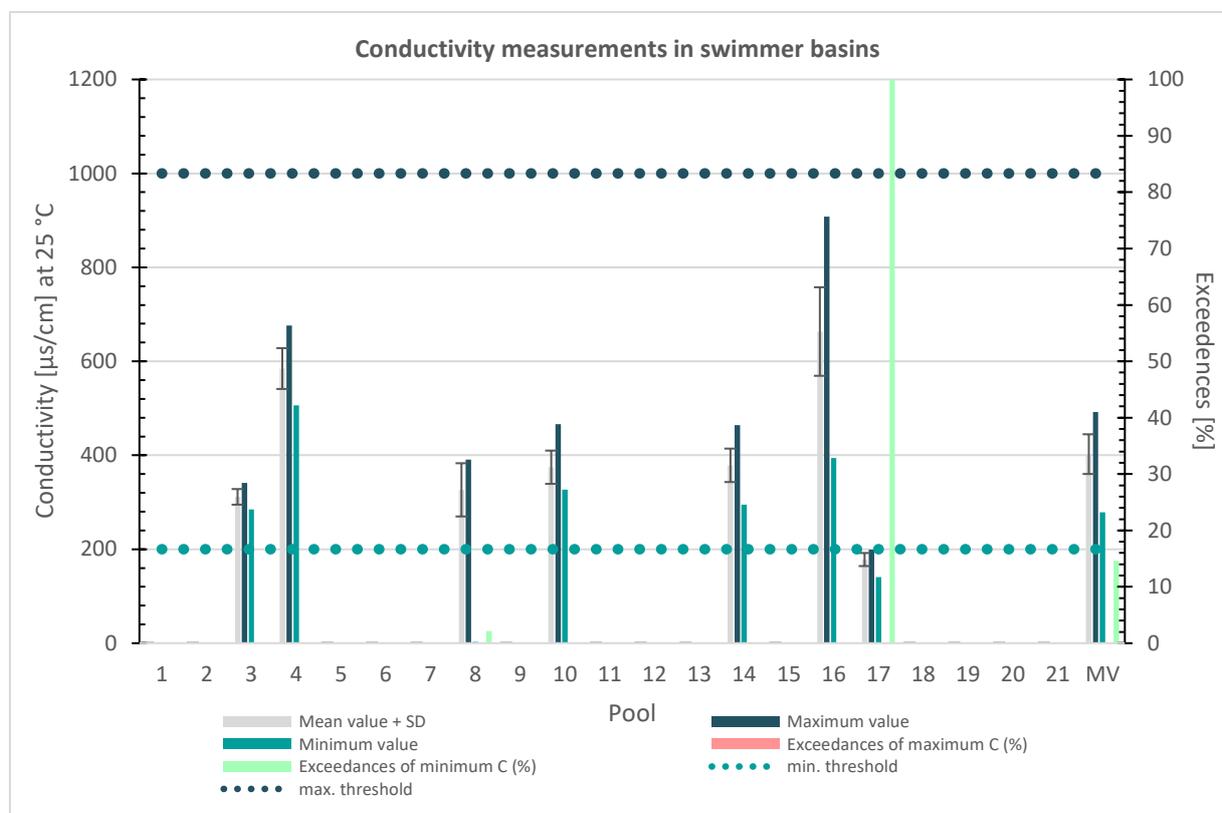


Figure 31 **Conductivity – Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=248

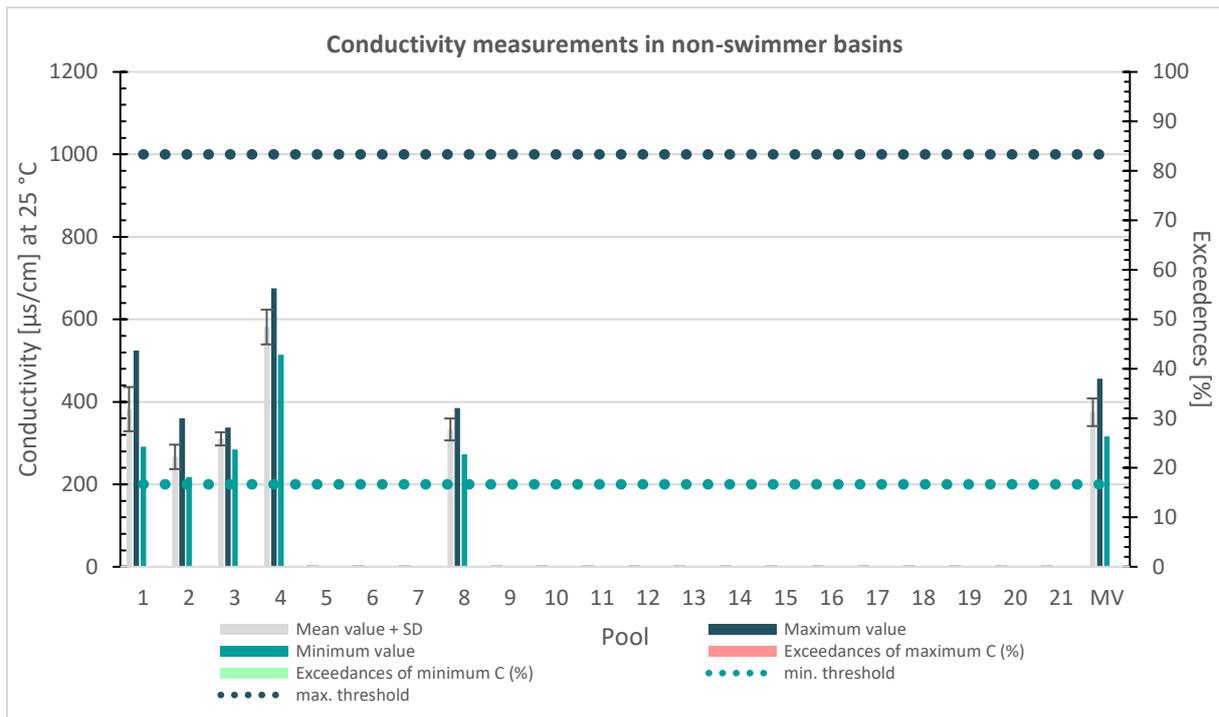


Figure 32 **Conductivity – Non - Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=169

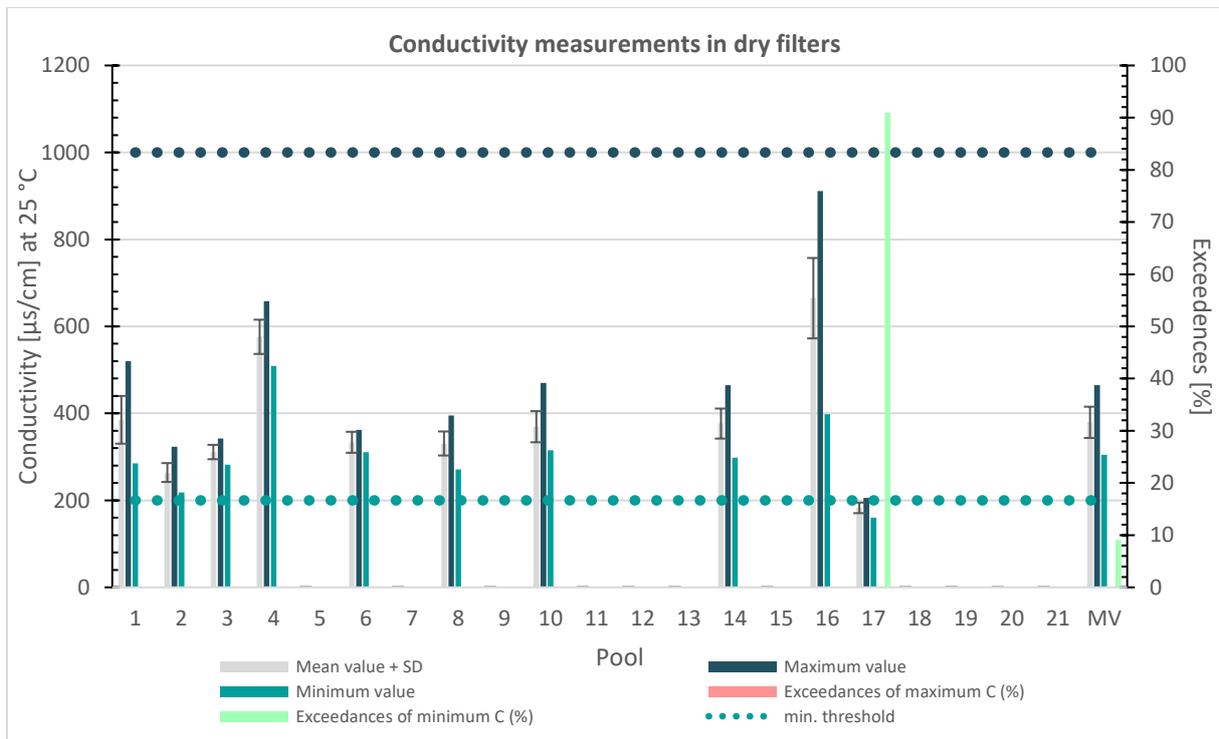


Figure 33 **Conductivity – Clear water dry filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=317

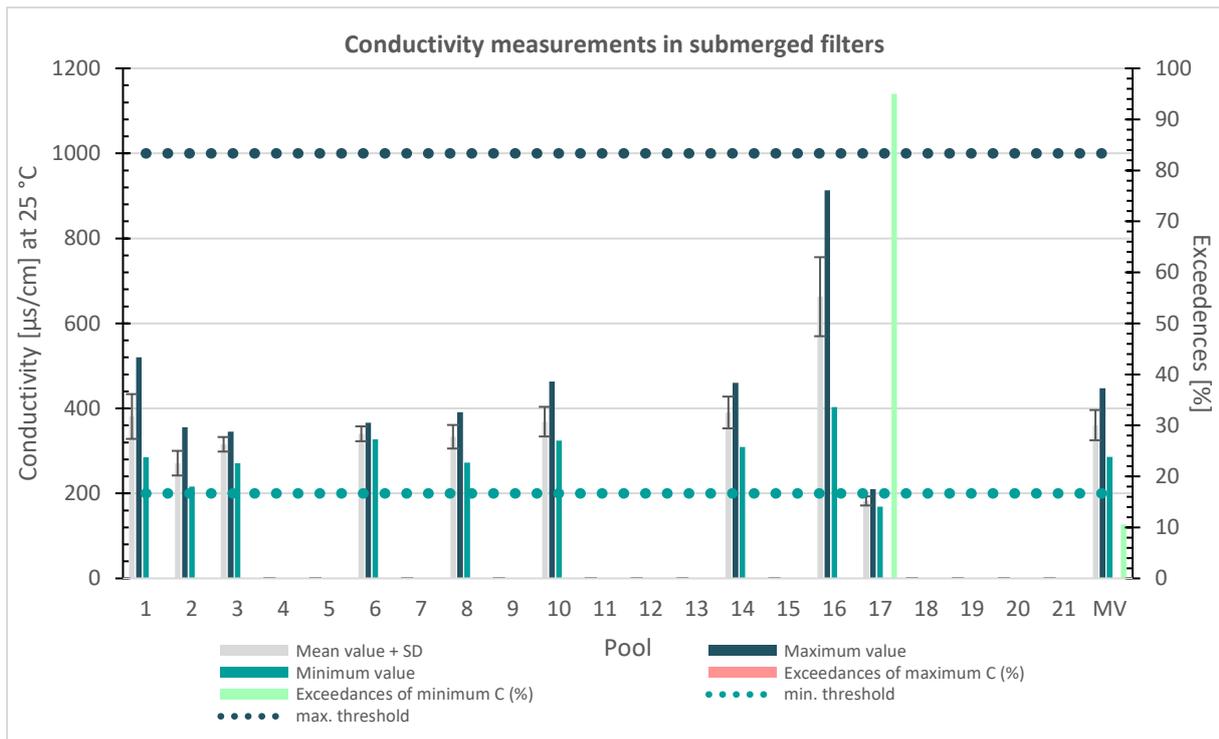


Figure 34 **Conductivity – Clear water submerged filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=290

The conductivity in the swimmer pools (402 $\mu\text{S/cm}$) and the non-swimmer pools (375 $\mu\text{S/cm}$) was in a similar range to the pure water in the dry filters (379 $\mu\text{S/cm}$) and the submerged filters (361 $\mu\text{S/cm}$). A slight tendency towards degradation by the filters can be recognized, but the conductivity is essentially determined by the chemical properties of the filling water. All values were in the lower range of the recommended values.

2.2.9. Total Hardness

The sum of all calcium and magnesium ions is referred to as the total hardness. A distinction is made between soft, medium, hard and very hard water. The recommended value is ≥ 1.0 mmol/l. Water under 1.5 mmol/l is considered soft water. All water in the upper soft range and all water above this is therefore recommended. Water with a low total hardness can absorb more carbonic acid. This so-called aggressive carbonic acid can corrode both calcareous materials such as concrete and iron. Water with a total hardness of >1.5 mmol/l in particular tends to form a lime and rust protection layer⁶. Higher lime contents are also always accompanied by high hydrogen carbonate contents, which in turn

⁶ Grohmann, A. et al. (2011) Wasser: Chemie, Mikrobiologie und nachhaltige Nutzung, De Gruyter, Berlin, New York, p. 284

increases the buffering capacity of the water. It is also important to adapt the selection of plants in the NSP to the respective lime content⁷⁸⁹.

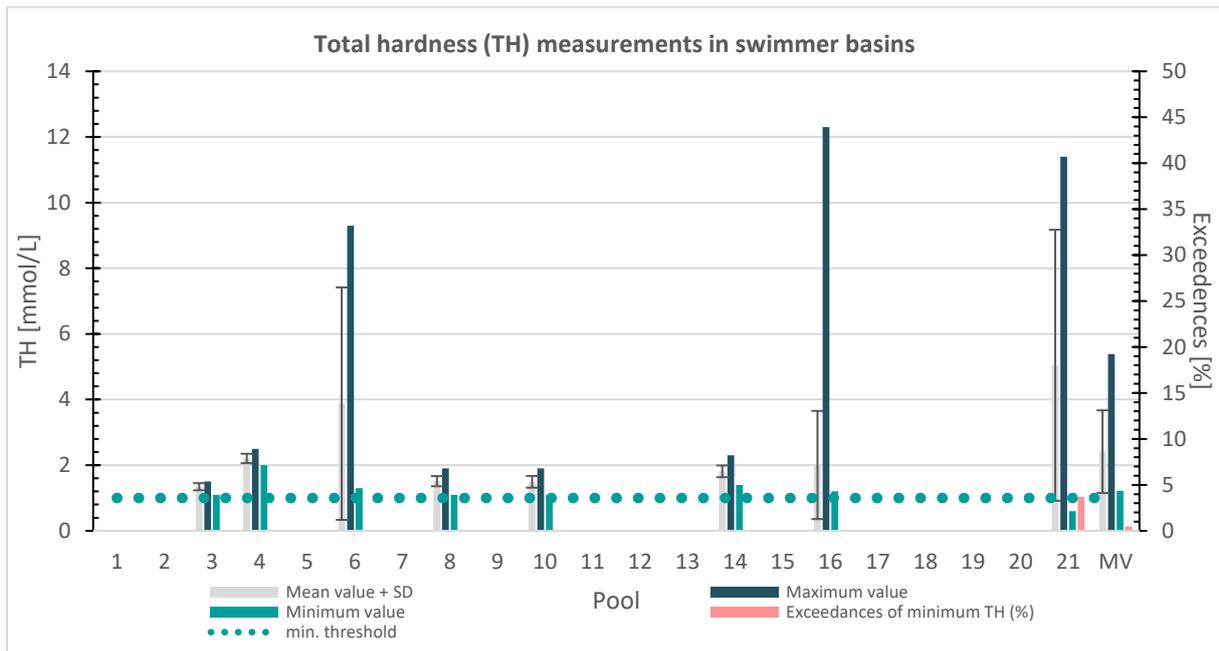


Figure 35 **Total hardness – Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=250

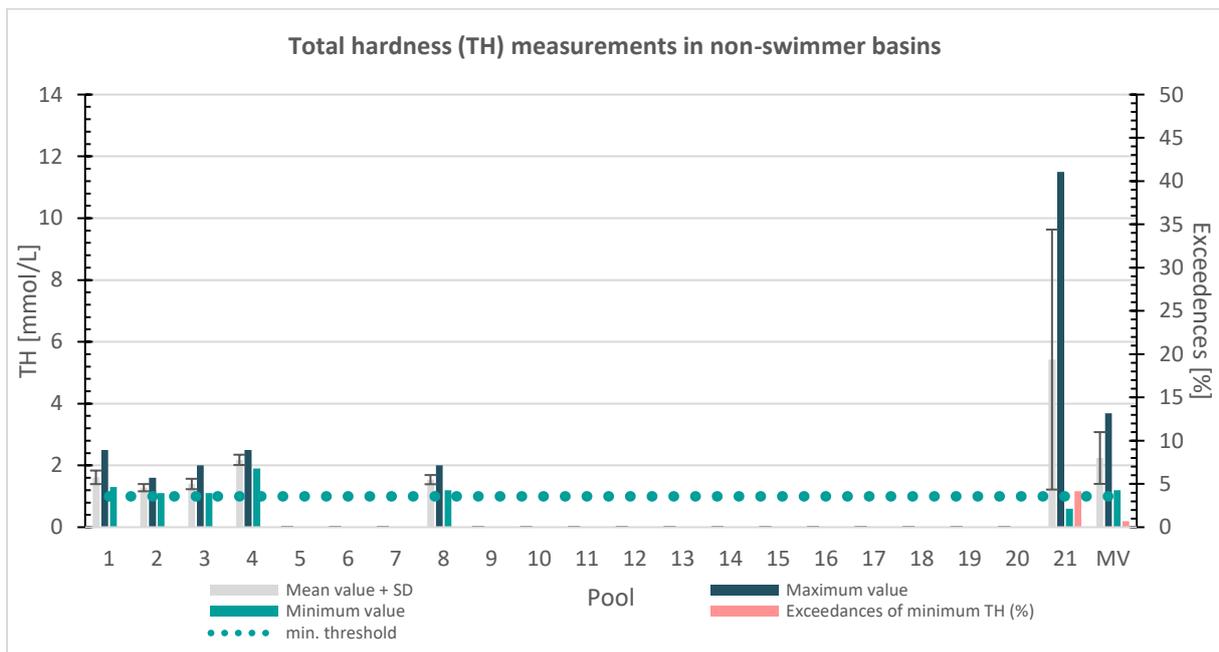


Figure 36 **Total hardness – Non - Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=193

⁷ Ellenberg, Leuschner (2010) Vegetation Mitteleuropas mit den Alpen: In ökologischer, dynamischer und historischer Sicht, UTB, Stuttgart; 6., überarb. Aufl

⁸ Schwarzer, Schwarzer (2008) Schwimmteiche - Planen, anlegen, richtig bepflanzen, Ulmer, Eugen; überarb. Edition

⁹ Kurzreuther (2024) Grün und bunt – Pflanzenauswahl und -pflege für Naturfreibäder, Naturbadinfo 2024, ABS, Arbeitsgemeinschaft Badeeseen & Schwimmteiche, p.7

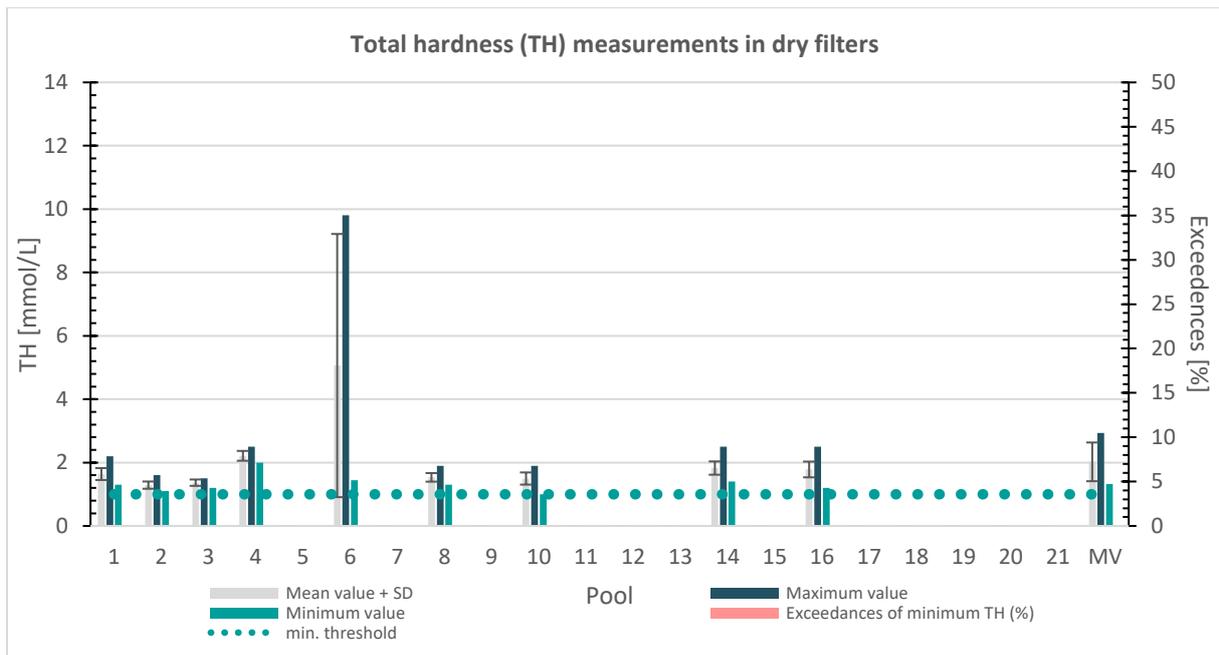


Figure 37 **Total hardness – Clear water dry filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=287

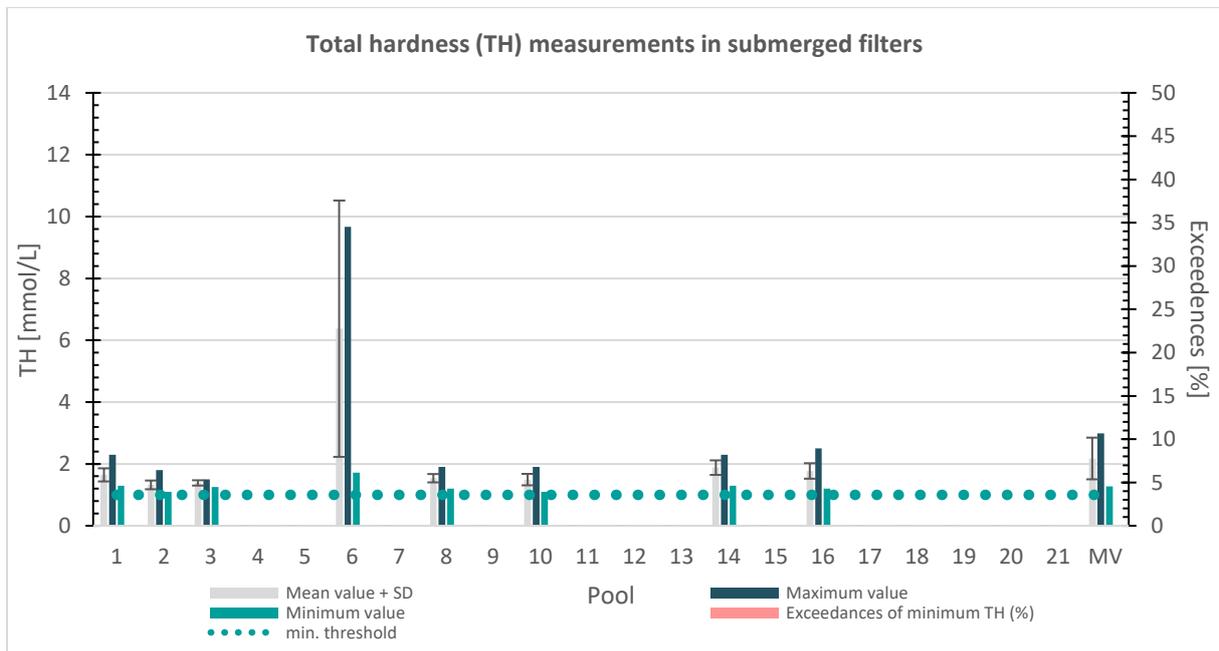


Figure 38 **Total hardness – Clear water submerged filter**, mean value + standard deviation, maximum value, minimum value, maximum recommended value, MV = mean value of all pools, n=261

The total hardness in the swimmer pools (2.41 mmol/l) and the non-swimmer pools (2.24 mmol/l) was slightly higher than the values in the clean water of the dry filters (2.02 mmol/l) and the submerged filters (2.18 mmol/l). The decomposition presumably takes place in the filters via biogenic

decalcification, which is carried out by the biofilms there. All values were well above the recommended minimum value.

2.3. Hygienical data

To monitor the hygienic quality of the bathing water, three germs are examined: *Escherichia coli*, Enterococci and *Pseudomonas aeruginosa*. In small bathing ponds, the hygienic impairment of the water occurs almost exclusively through the bathers themselves. Infected bathers can excrete pathogens in very high concentrations. This can lead to situations in which pathogens are present in higher concentrations than the indicator bacteria. Therefore, the requirements for the hygienic quality of the water, i.e. the concentrations of *E. coli* and enterococci to be maintained, in small bathing ponds are stricter than the requirements of the EU directive for open bathing waters. The parameter *Pseudomonas aeruginosa* was included because it is known that this pathogen can occur in NSPs and is not indicated by the fecal indicators (*E. coli* and enterococci). In NSPs, additional potential growth opportunities for *Pseudomonas aeruginosa* (biofilm formation) are also created by installing technical systems, including for treating the water. They serve as indicator parameters for assessing the overall hygienic quality¹⁰.

2.3.1. *E. coli* and Enterococci

E. coli are facultative anaerobic bacteria with a temperature range of 21°C to 49°C¹¹. Their natural habitat is the intestines of humans and most warm-blooded animals. Some *E. coli* strains are considered facultative or obligate pathogens and can cause infections under certain circumstances¹².

Enterococci are bacteria that grow under aerobic and anaerobic conditions in a temperature range of 10°C to 45°C. They occur in humans and a variety of other warm-blooded animals. Some species such as *E. faecalis* and *E. faecium* are also found in association with plants. Risk groups for infections are primarily hospitalized patients with a generally weakened immune system. Infection occurs primarily through smear or contact infections¹³.

In the FLL guideline, the parameter was derived from the Austrian bathing hygiene regulations⁹. At European level, both are also measured and assessed when assessing bathing water, but with significantly higher limit values. The limit value to which the FLL guideline refers is <100 CFU/100ml for *E. coli* and <50 CFU/100ml for Enterococci. The limit value of the EU bathing water regulations, on the other hand for inland waters, a value of <400 CFU/100ml for Enterococci and <400 CFU/100ml for *E. coli* is required to assess good quality, based on a 95th percentile assessment¹⁴.

¹⁰ Umweltbundesamt (2003): Empfehlung des Umweltbundesamtes. Hygienische Anforderungen an Kleinbadeteiche (künstliche Schwimm- und Badeteichanlagen), Bundesgesundheitsblatt, Gesundheitsforschung, Gesundheitsschutz, 2003, 46:527-529, DOI 10.1007/s00103-003-0627-0

¹¹ Lüders S. (2010) Prozess- und Proteomanalyse gestresster Mikroorganismen, Cuvillier Verlag, Göttingen, p. 6

¹² Bülte M., Goll M. (2006) Pathogene Mikroorganismen, *Escherichia coli*, Eigenschaften, Vorkommen und Präventionsmaßnahmen, B. Behrs Verlag, Hamburg, p. 15

¹³ Gholamreza, D. et al. (2013) Lexikon der Infektionskrankheiten des Menschen; Erreger, Symptome, Diagnose, Therapie und Prophylaxe, Springer, Cham, p. 168

¹⁴ Amtsblatt der EU, Richtlinie 2006/7/EG des Europäischen Parlaments und des Rates vom 15. Februar 2006 über die Qualität der Badegewässer und deren Bewirtschaftung und zur Aufhebung der Richtlinie 76/160/EWG

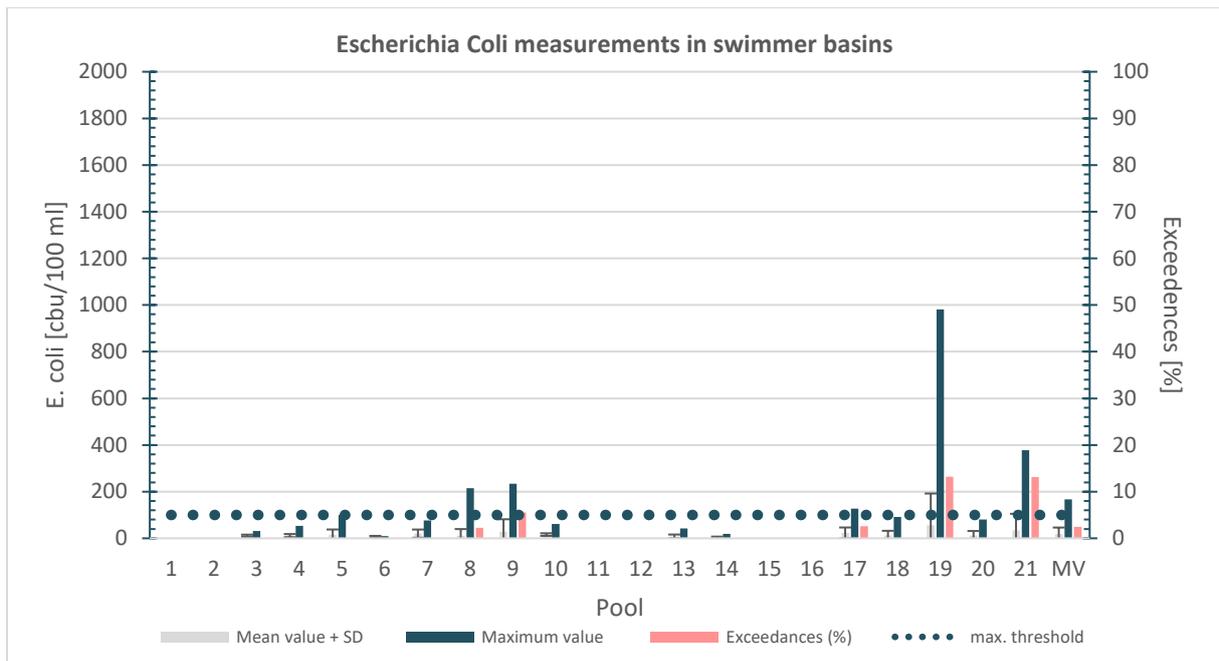


Figure 39 **E.coli – Swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum limit value, MV = mean value of all pools, n=789

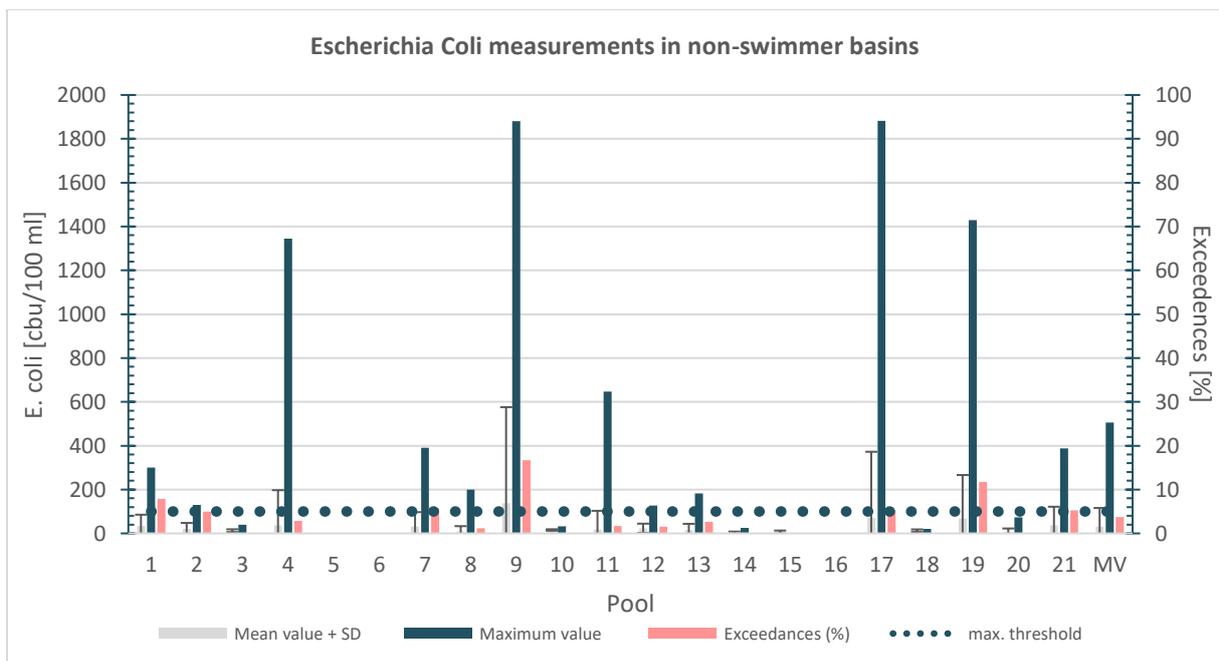


Figure 40 **E. coli – Non -swimmer Basins**, mean value + standard deviation, maximum value, minimum value, maximum limit value, MV = mean value of all pools, values=1000 → >1000, n=1046

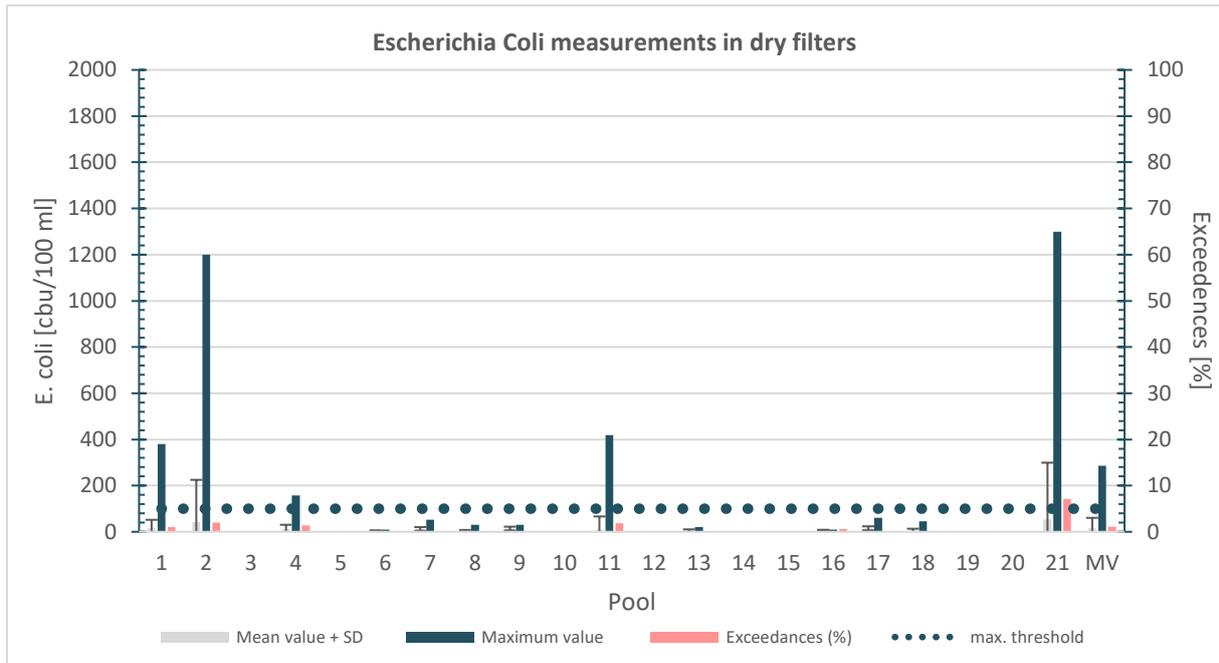


Figure 41 **E. coli – clear water dry filter**, mean value + standard deviation, maximum value, minimum value, maximum limit value, MV = mean value of all pools, values=1000 → >1000, n=1081

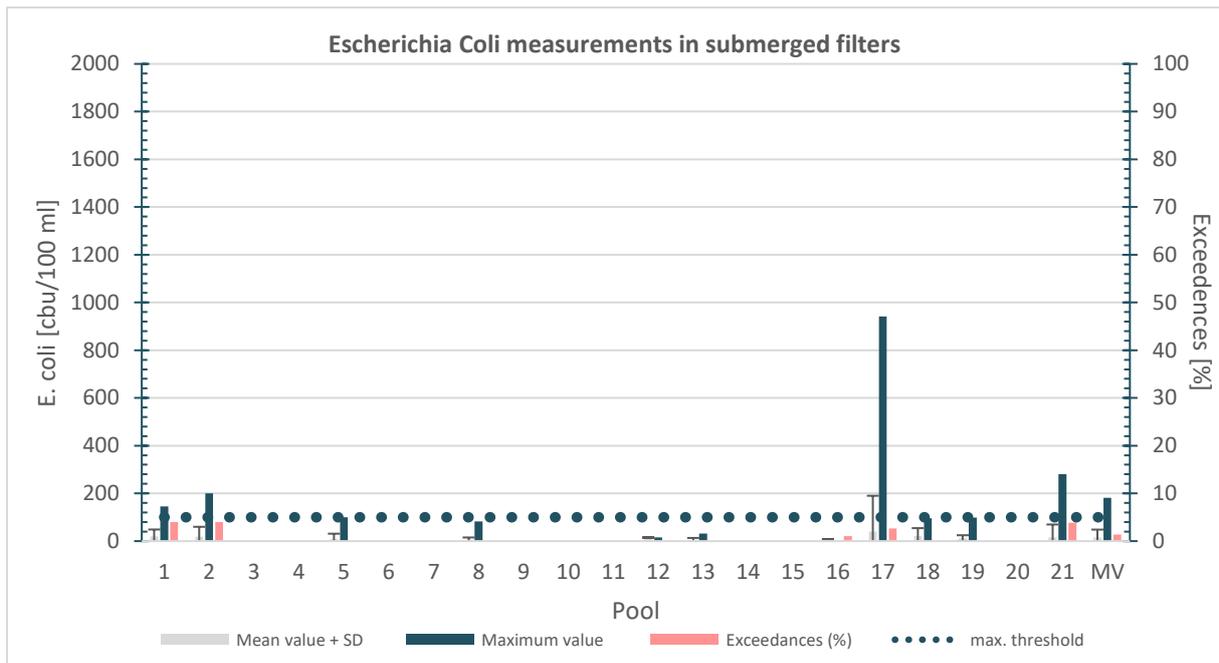


Figure 42 **E. coli – clear water submerged filter**, mean value + standard deviation, maximum value, minimum value, maximum limit value, MV = mean value of all pools, n=1160

The *E. coli* values in the non-swimmer area were on average slightly higher (29 CFU/100ml) than the values in the swimmer area (18 CFU/100ml). The mean values in the pure water were 15 CFU/100ml in both filter types. The frequency of exceedances in the usage area was between 2.4 and 3.7% and in the pure water between 1.1% and 1.4%.

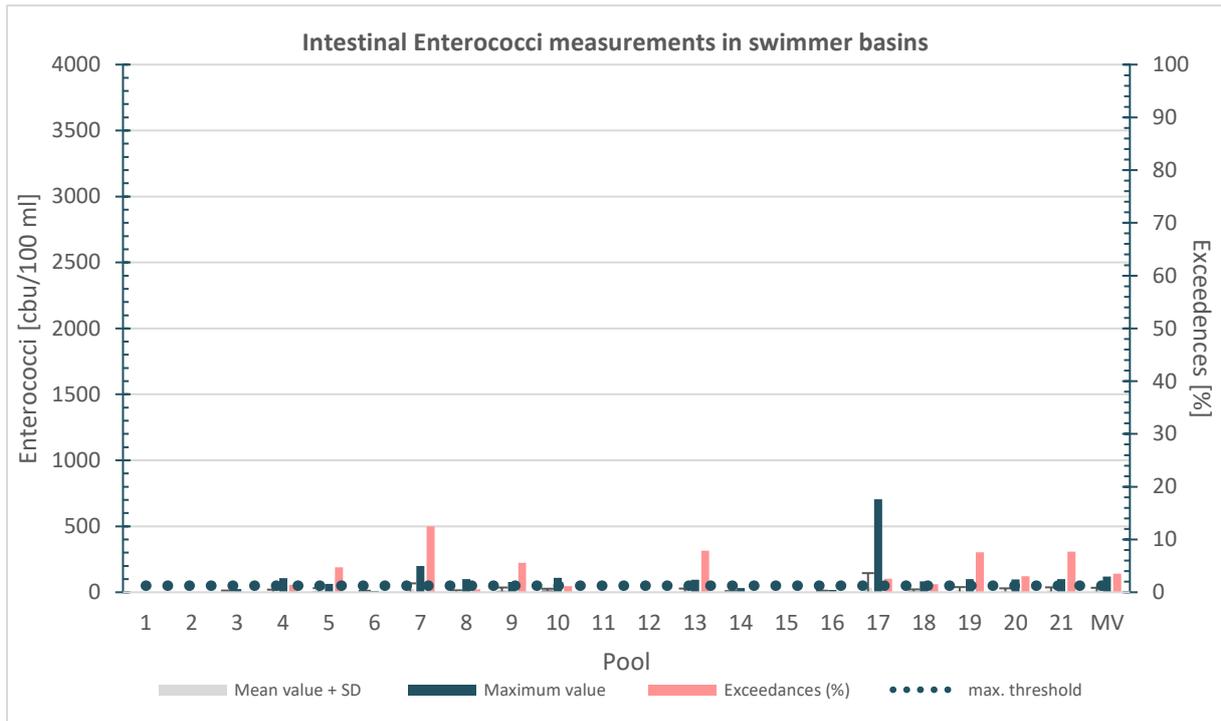


Figure 43 **Enterococci – Swimmer Basins**, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, values=500 → >500, n=827

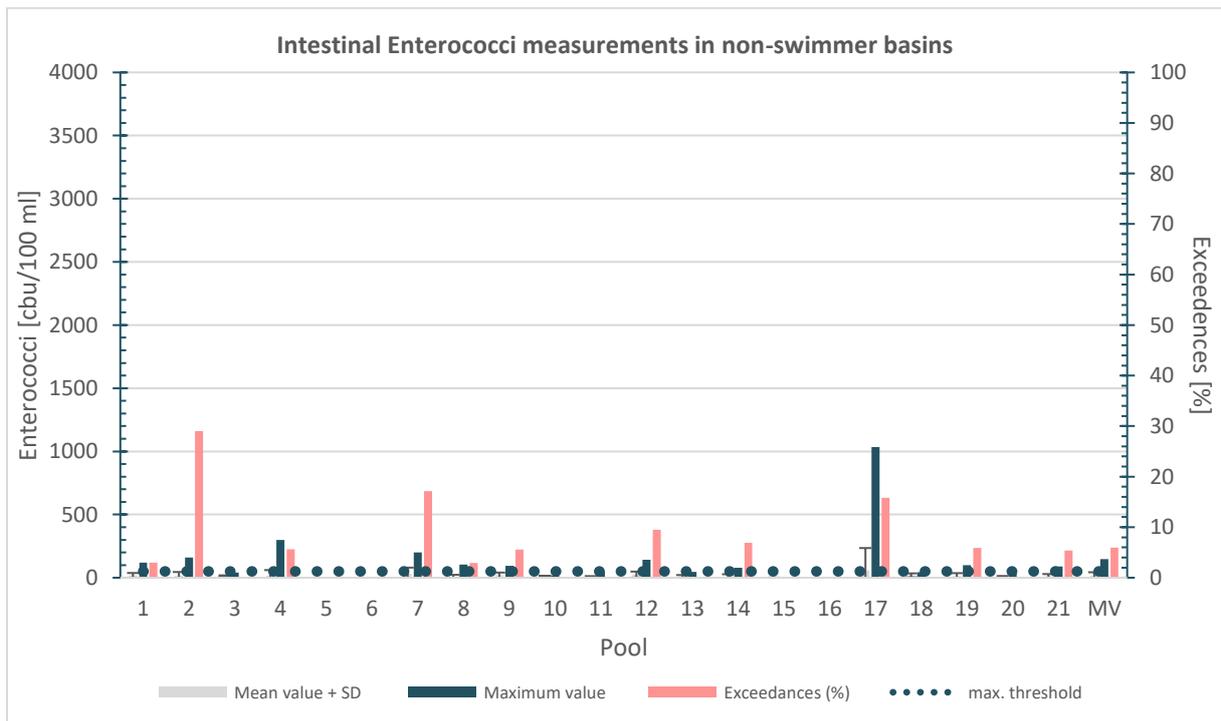


Figure 44 **Enterococci – Non - Swimmer Basins**, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, values=500 → >500, n=1039

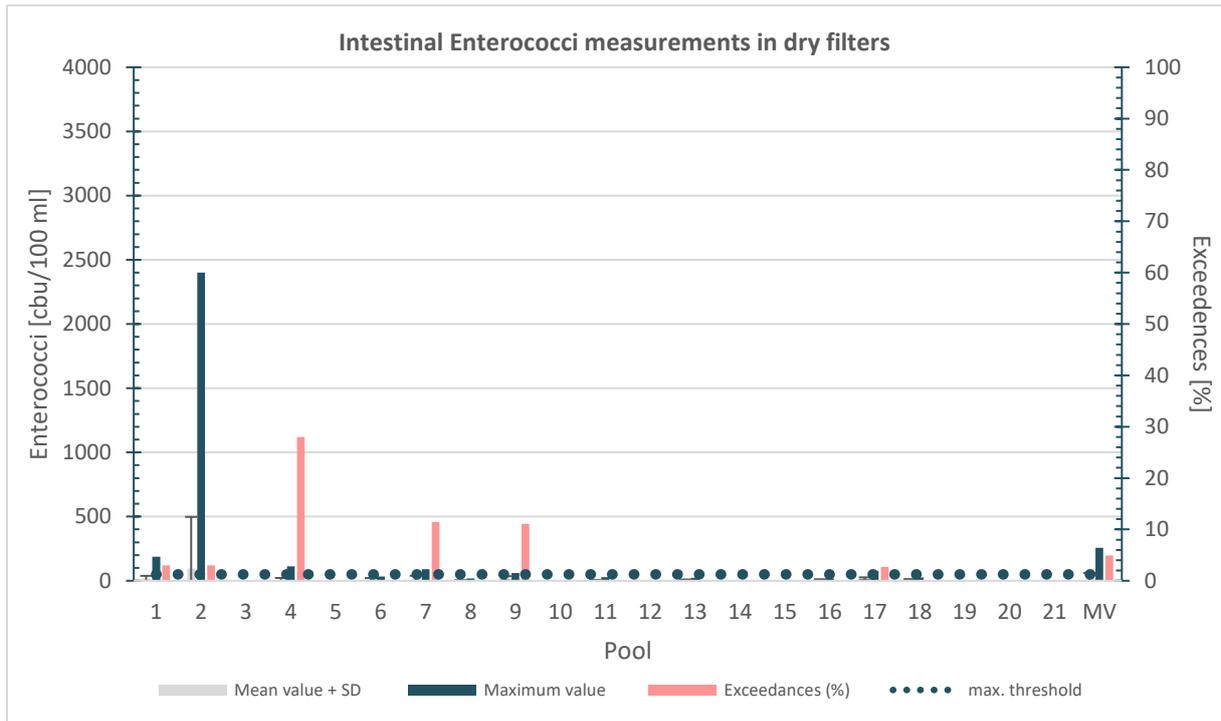


Figure 45 **Enterococci – clear water dry filter**, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, values=500 → >500, n=625

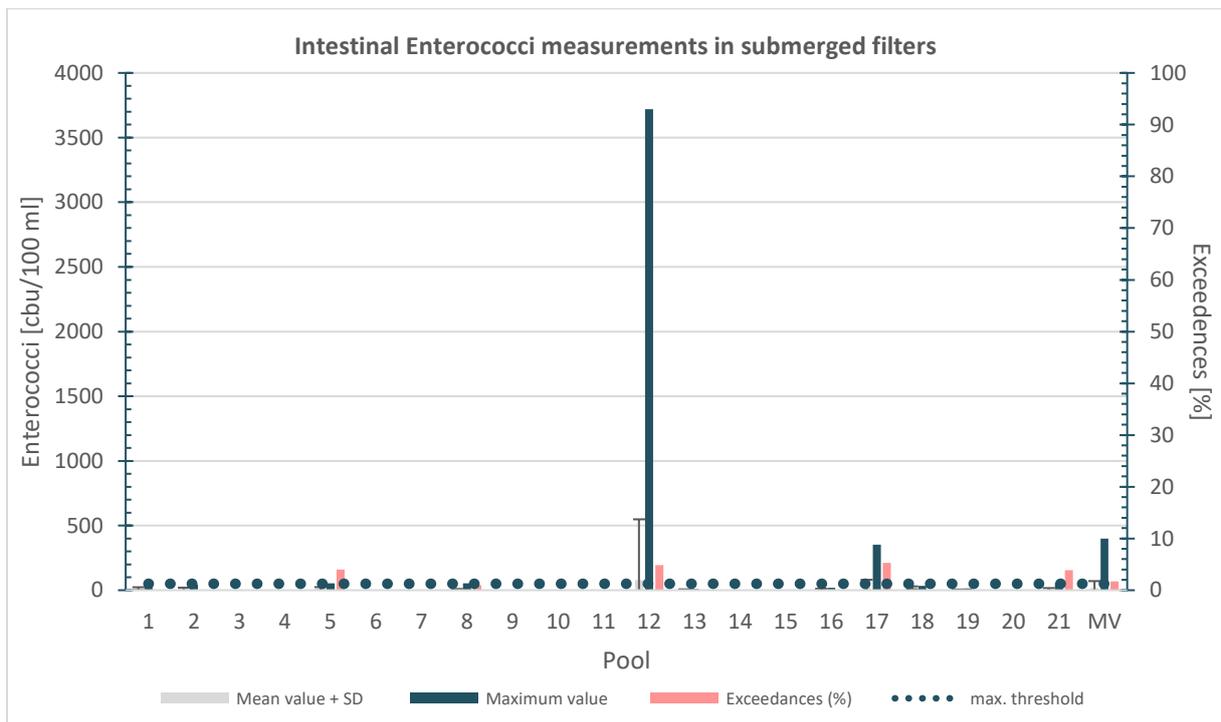


Figure 46 **Enterococci – clear water submerged filter**, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, n=517

The enterococci values were on average between 16 and 18 CFU/100ml in all areas. The mean values of the limit value violations in the usage areas (swimmer area: 2.4%; non-swimmer area 5.6%) were higher than in the treatment areas (dry filter: 3.1; submerged filter 1.7%).

2.3.2. *Pseudomonas aeruginosa*

Pseudomonas aeruginosa is ubiquitous in surface water, groundwater, soil and on plants. The optimal growth temperature is 15–30 °C. *P. a.* is considered a so-called “puddle germ” because it is often found in small remnants of stagnant water. It has the ability to form biofilms and can also multiply in very clean water. *Pseudomonas aeruginosa* can enter the pool via tap water, clogged filters, in biofilms on the pool walls and water play equipment, bathers and possibly also via the introduction of organic and inorganic particles via wind or rain. The limit value is ≤ 10 . There have been numerous discussions in the past about the evaluation of this parameter. For example, the World Health Organization (WHO) distinguishes between requirements for normal operation (< 10 KBE/100 ml) and closure-relevant exceedances (repeated occurrence of > 100 KBE/100 ml)¹⁵. These assessments have already been adopted in parts of Germany and there are currently discussions about implementing them nationwide. In France, for example, this has already happened.

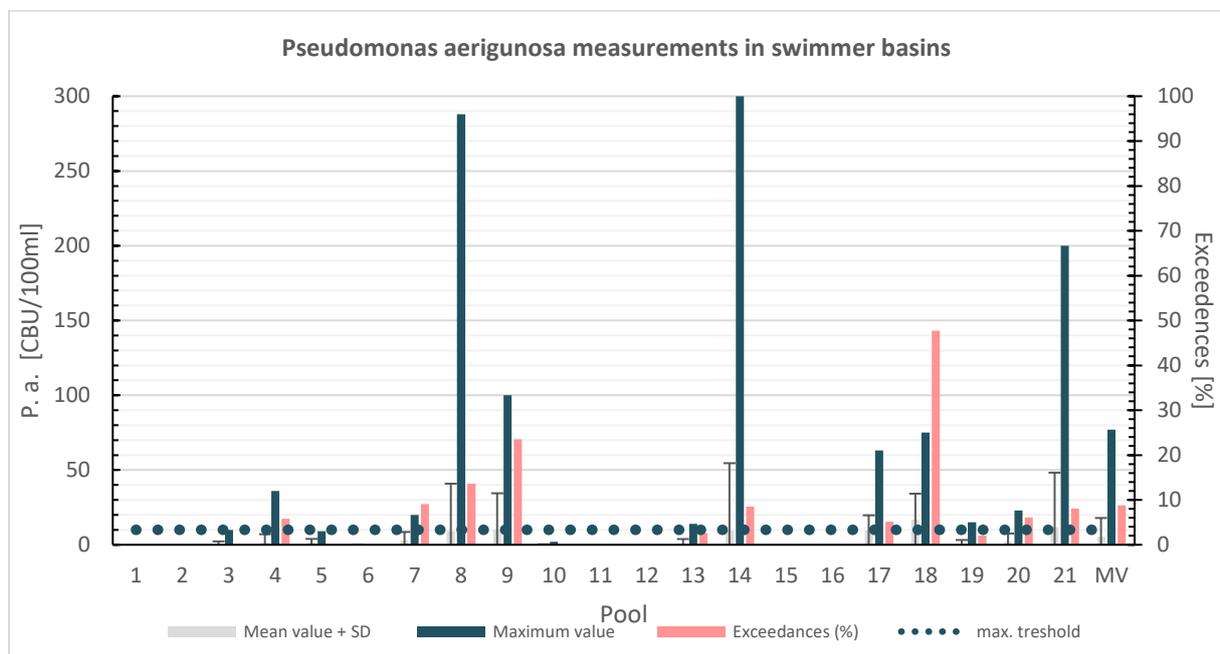


Figure 47 *Pseudomonas aeruginosa* – Swimmer Basins, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, n=793

¹⁵ Kurzreuther H., Bruns S. (2019) *Pseudomonas aeruginosa* in Naturfreibädern – Ursachen, Maßnahmen, Relevanz, Testverfahren und Grenzwerte, Archiv des Badewesens, Wasseraufbereitung, Bädertechnik

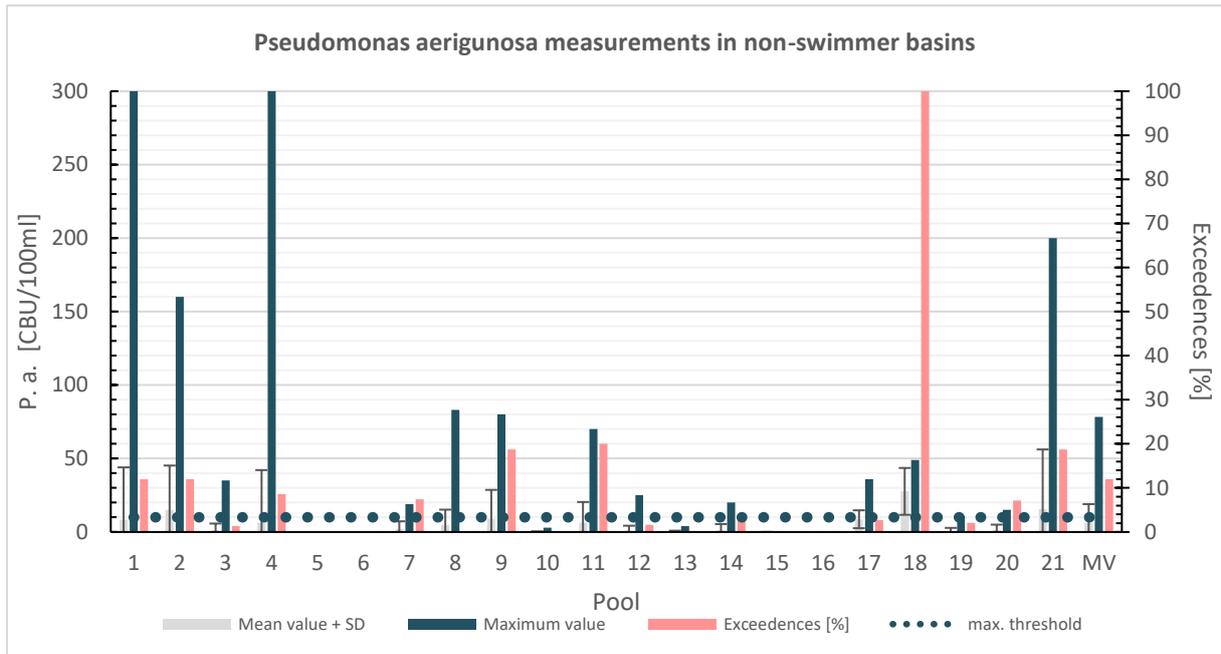


Figure 48 **Pseudomonas aeruginosa – Non - Swimmer Basins**, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, n=947

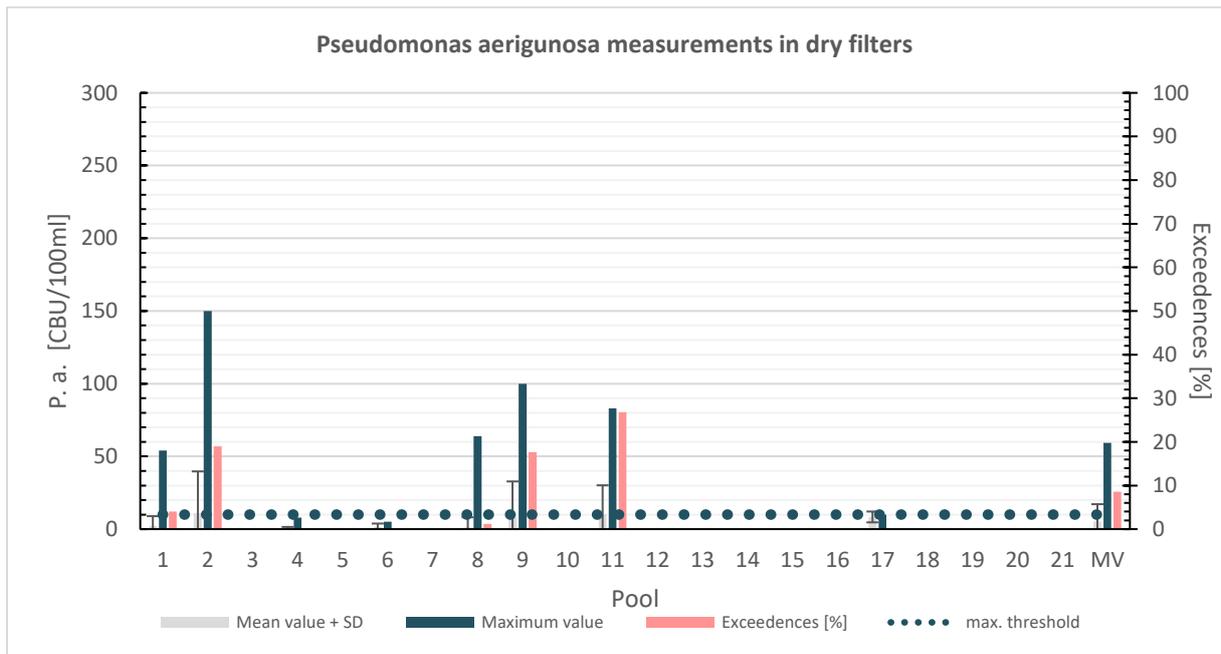


Figure 49 **Pseudomonas aeruginosa – Clear water dry filter**, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, n=447

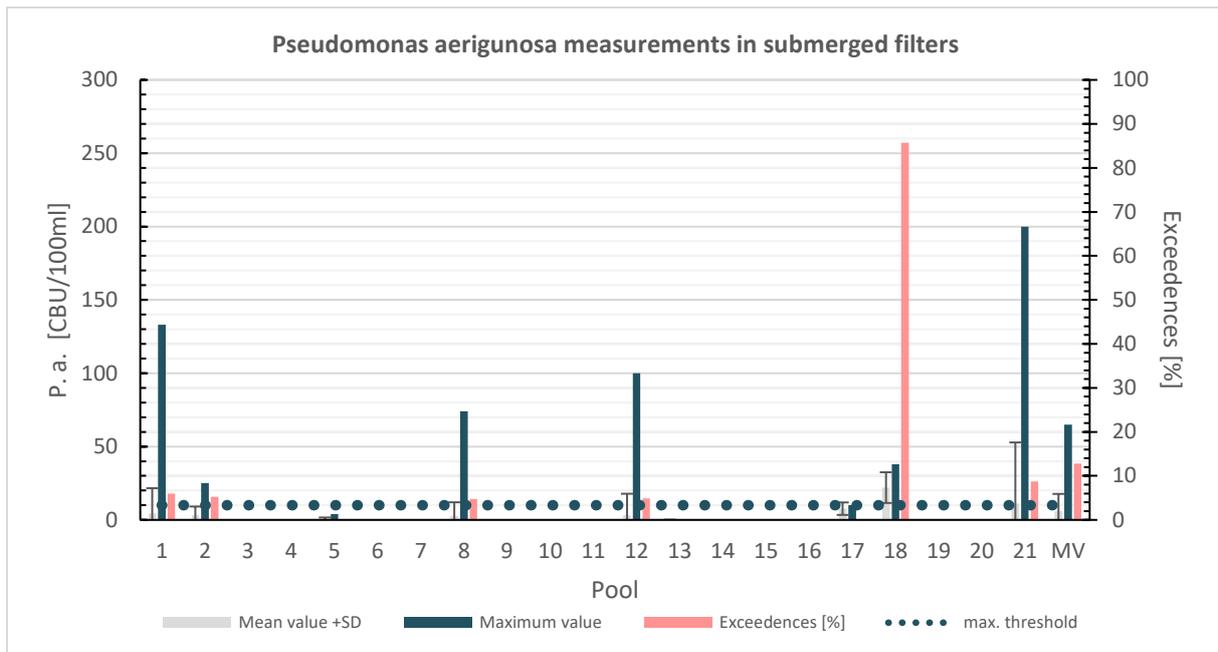


Figure 50 *Pseudomonas aeruginosa* – Clear water submerged filter, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, n=413

The average value at all of the measuring points examined was 5-6 CFU/100ml. The highest exceedance rate was 14% in the swimming pool and 17% in the non-swimmers' pool. These slightly higher values could be due to greater biofilm abrasion by bathers in the non-swimmers' areas. The exceedance rate in the clean water was lower, with the lowest exceedance rate (9%) being observed in the dry filters. If the closure-relevant limit value were to be raised to 100 CFU/100ml in line with WHO guidelines, the percentage of limit value violations could be significantly reduced ¹⁴.

2.4. Biological data

2.4.1. *Phytoplankton biovolume*

The total biovolume of phytoplankton describes the sum of all phytoplankton organisms and is expressed in mm³/l. It consists mainly of green algae (Chlorophyta), diatoms (Bacillariophyceae) and pharyngeal flagella (Cryptophyceae). Cyanobacteria may only occur as accompanying flora. Studies have shown that more than half of the phytoplankton are diatoms¹⁶. The recommended value for the total biovolume of phytoplankton is ≤1.0 mm³/l. This value corresponds to an oligotrophic state.

¹⁶ Polyplan Kreikenbaum (2023) Silicium & Kieselalgen im Naturfreibad - Neue Erkenntnisse aus der Forschung, ABS – Arbeitsgemeinschaft Badeseen und Schwimmteiche, Bremen

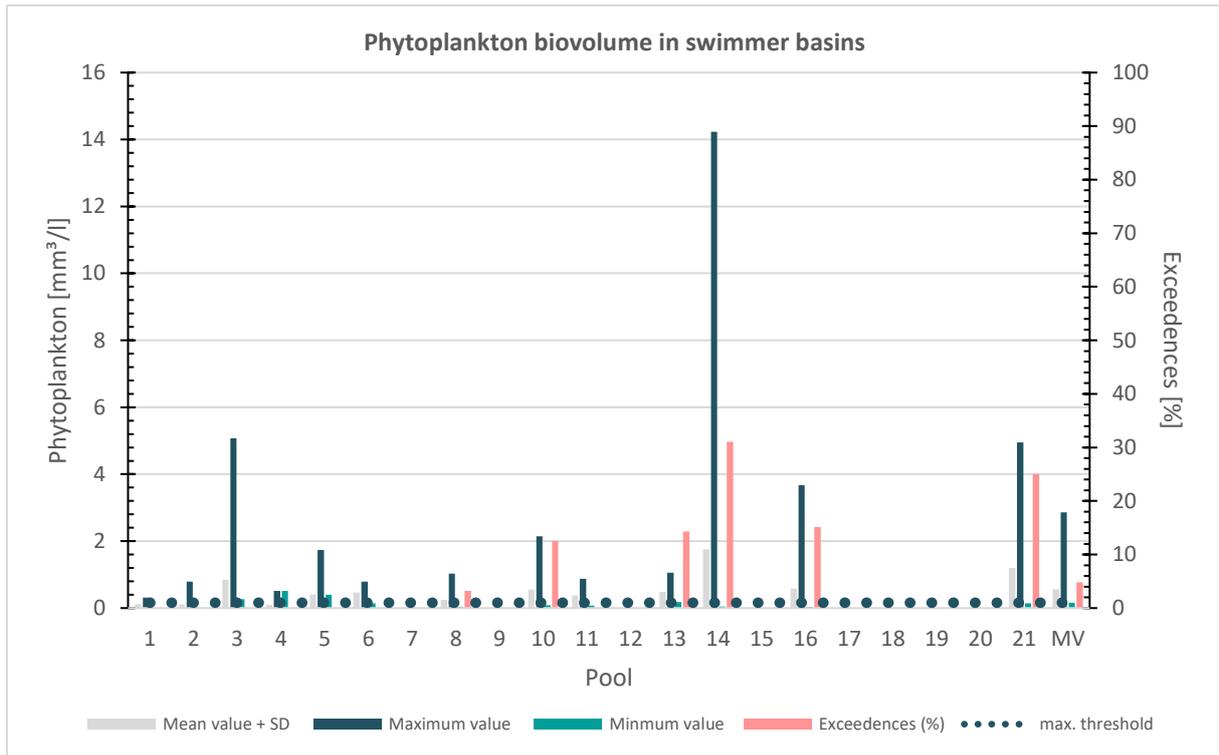


Figure 51 **Phytoplankton biovolume – Swimmer basins**, mean value + standard deviation, maximum value, maximum limit value, MV = mean value of all pools, n=99

The phytoplankton total biovolume averaged $0.55\text{mm}^3/\text{l}$ and was therefore in the oligotrophic range. The frequency with which the recommended value was exceeded was 5%.

2.4.2. Zooplankton – biovolume and filtration rate

The zooplankton filters both the phytoplankton and other microorganisms such as bacteria. It therefore ensures that in addition to the disinfection of the water in the filter, disinfection also takes place in the pool. There is currently no recommended test value. However, the filtration performance is calculated in the planning with a value of 0.04 m^3 per m^3 of pool water. Accordingly, a filtration performance of the zooplankton of 4% of the pool water per day is assumed.

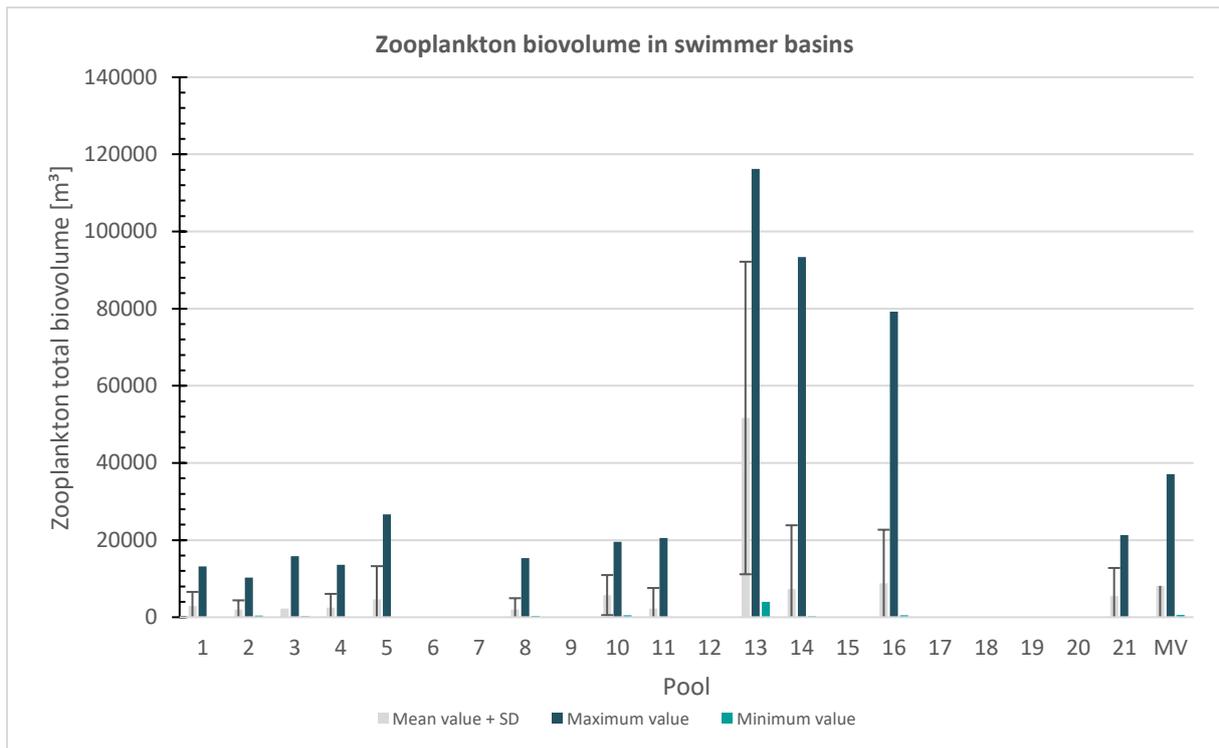


Figure 52 **Zooplankton biovolume – Swimmer basins**, mean value + standard deviation, maximum value, standard value, MV = mean value of all pools, n=132

The average filtration rate measured in the pools examined was $0.26\text{m}^3/\text{m}^3/\text{d}$. This means that on average 26% of the water/day was filtered by the zooplankton. In detail, the filtration rate can vary greatly over the course of the season, as the zooplankton population sizes can fluctuate greatly depending on the available food base. However, the data show that zooplankton make a significant contribution to water treatment.

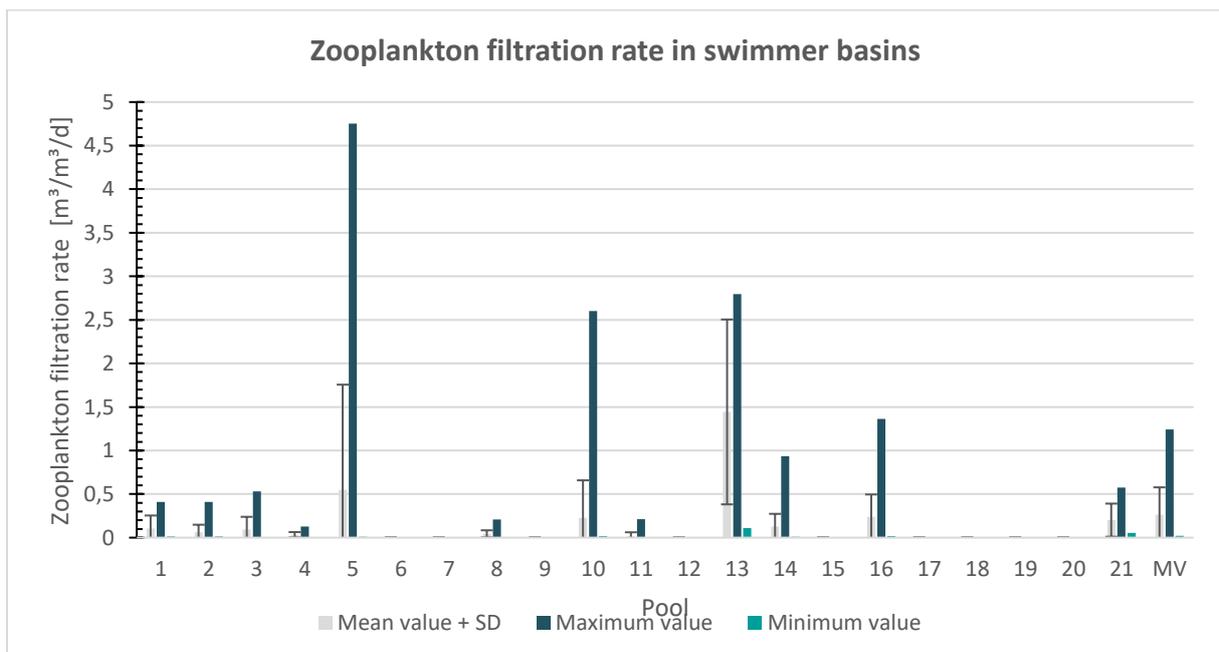


Figure 53 **Zooplankton filtration rate - Swimmer basins**, mean value + standard deviation, maximum value, minimum value, MV = mean value of all pools n=11

2.5. Mean values of all measured parameters over the entire study period

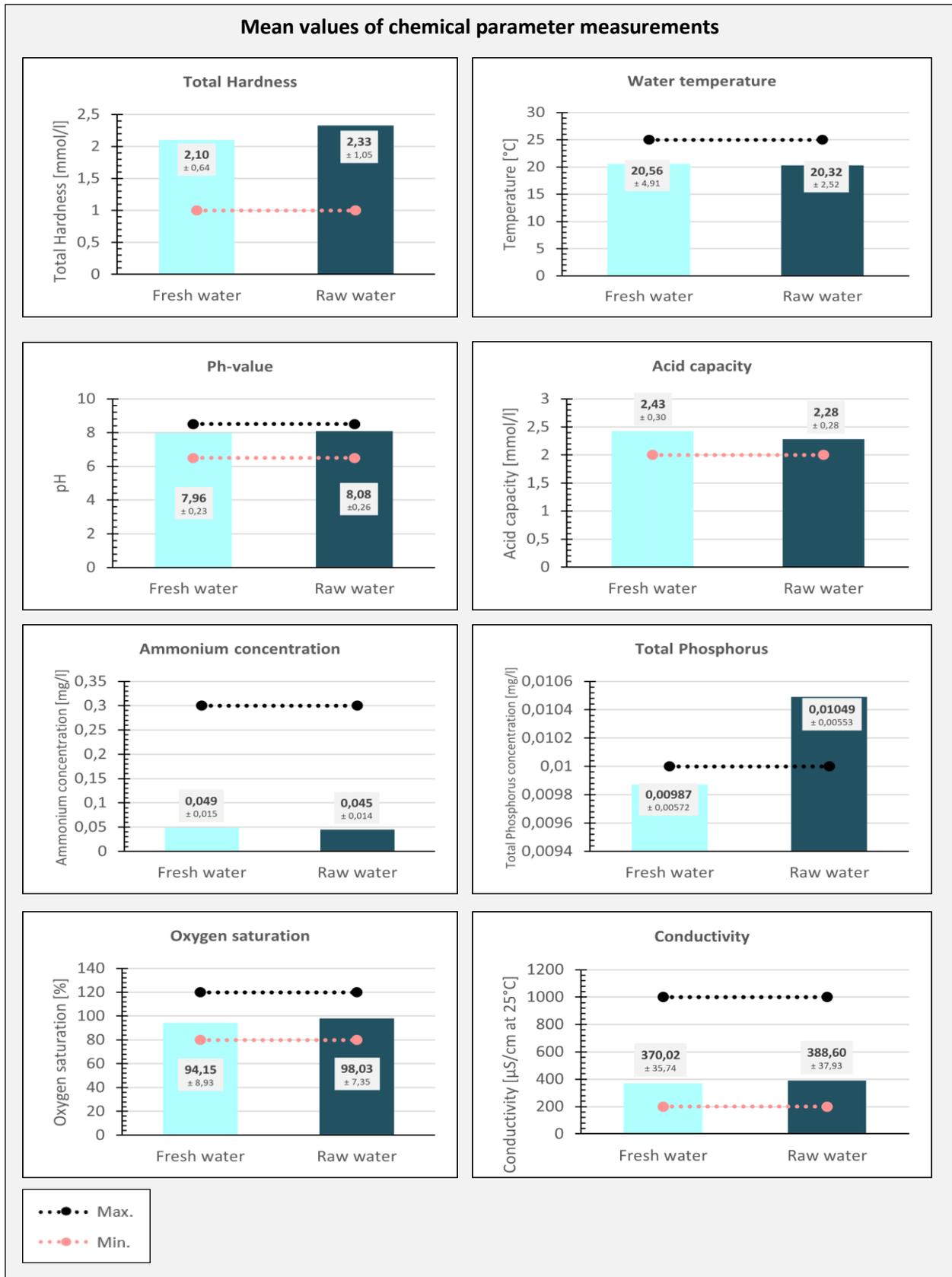


Figure 54 Mean values of the chemical parameter analysis over the entire study period, mean values \pm standard deviation of each observed parameter in fresh and raw water with accordingly maximum and minimum thresholds due to the FLL guideline

The mean values of all measured parameters over the entire study period provide an overview of the observed conditions of the raw and fresh water of the NSPs. With the exception of total phosphorus, the raw water values from the chemical parameter analysis fall within the range of the FLL - guideline values (Figure 54). In this case, the mean value of 0.01049 mg/L \pm 0.00553 slightly exceeds the maximum threshold of 0.01 mg/L, whereas the fresh water mean value of total phosphorus (0.00987 mg/L \pm 0.00572) remains below the threshold. In general, all fresh water values for the hygienic and chemical parameters are within the recommended ranges.

Additionally, the mean values of the hygienic parameter measurements for both raw and fresh water fall within the recommended range of bacterial concentrations (Figure 55).

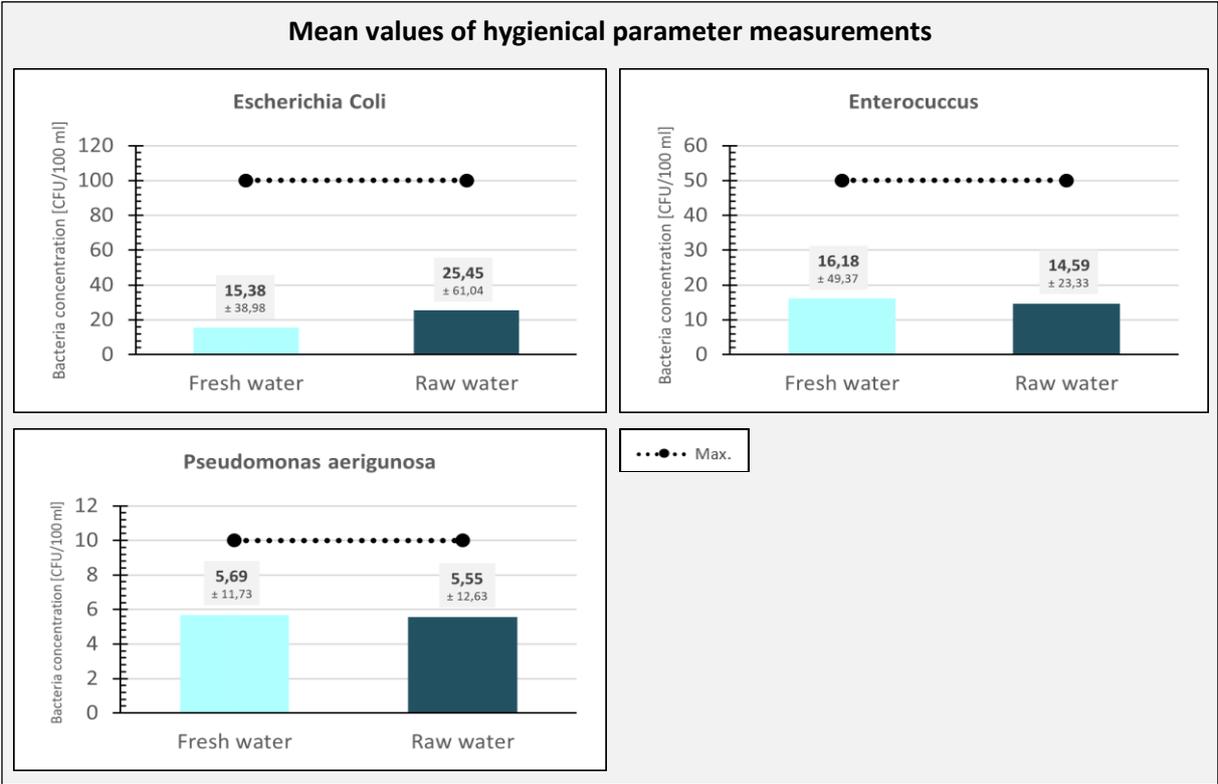


Figure 55 Mean values of the hygienical parameter analysis over the entire study period, mean values \pm standard deviation of each observed parameter in fresh and raw water with accordingly maximum thresholds due to the FLL guideline.

The results of the biological parameter analysis of the raw water, shown in Figure 56, indicate an average amount of phytoplankton biovolume of 0.21 mm³/l \pm 0.21. This value is well below the maximum threshold of 1 mm³/l. The mean zooplankton biovolume value is 1,900 mm³/l.

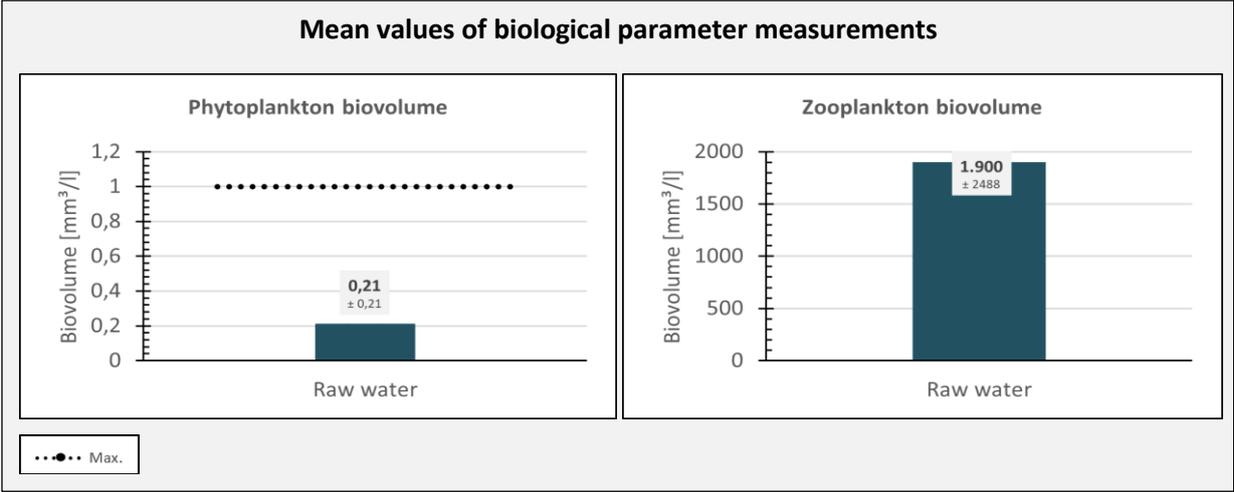


Figure 56 **Mean values of the biological parameter analysis** over the entire study period, mean values ± standard deviation of each observed parameter in raw water with accordingly maximum thresholds due to the FLL guideline.

3. Exceedance of limit values for all parameters at all measuring points over the entire study period

Looking at all measurement parameters at all measuring points in all pools over the entire study period, it can be seen that in 4.8% of the pool water data and 4.3% the clear water data, guideline or limit values were exceeded for parameters for which maximum values are specified or recommended. In the case of parameters for which minimum values existed, the undercutting frequency was 2.5% for pool water and 2.0% for clear water.

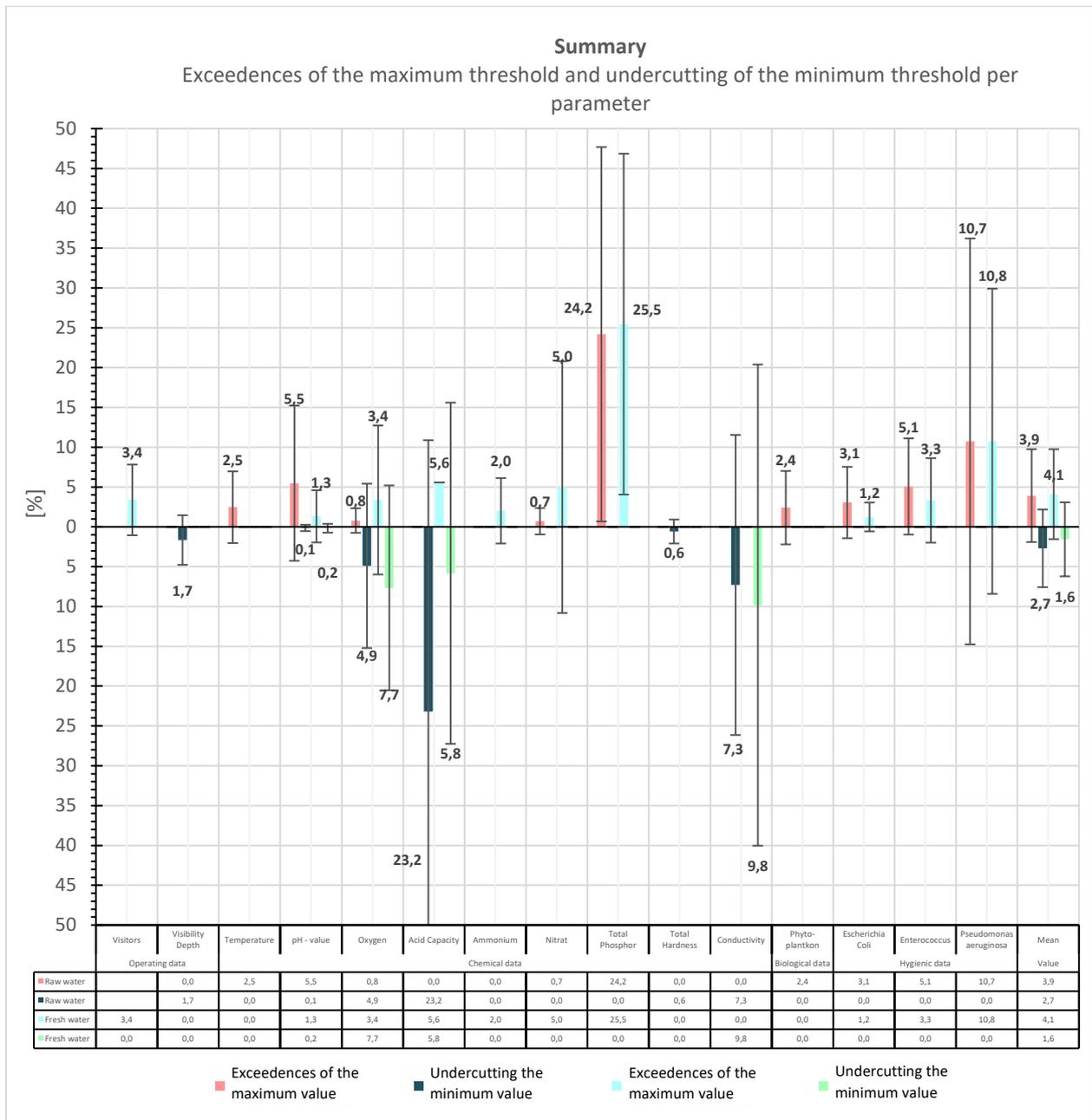


Figure 57 **Exceedance of limit values (%)**, mean value + standard deviation, MV = mean value of all pools, (Vis = Visitors, VD = visibility depth; Temp. = water teperature; Oxy = oxygene saturation; AC = acid capacity; NH4= Ammonium; NO3 = Nitrate; TP = total phosphorous; C = conductivity; Phyt. = phytoplankton biomass; E.coli = escherichia coli; Ent = enterococci; Pseud. = Pseudomonas aeruginosa; MV = mean value), n=472963

4. Conclusion

The analysis of the monitoring parameters from 21 NSPs has shown that the tested systems function in accordance with the requirements of the FLL guideline. The total number of limit violations was 2 - 4.8%. The mean value evaluation show The evaluation of the mean values clearly indicates that all observed values are within the defined thresholds. The only exception here is the amount of total phosphorus, with a minor exceedance in the raw water of 0.00049 mg/l, while the treated water value remains within the specified limits. This confirms that the NSPs function in principle and in practise. Measured values outside the recommended values occur as individual events that can be remedied by adjusting and optimizing the operational management. NSPs therefore represent a technically and biologically functional option for swimming in public outdoor pools in a natural and living water without chemical disinfection and its by-products.