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- guideline[1]. 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 and median 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 2011[1] 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 (Fehler: Referenz nicht gefunden). 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 pool surface [m²]	Total pool volume [m³]	Dry filter [m²]	Submerged filter [m²]	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

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 pool surface [m²]	Total pool volume [m³]	Dry filter [m²]	Submerged filter [m²]	Nominal number of visitors	Years
10	1875	2340	375	340	950	2015-2023
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 in CFU/100 ml	Enterococci	≤ 50	-	-	-
	Escherichia coli	≤ 100	-	-	-
	Pseudomonas aeruginosa	≤ 10	-	-	-
Biological	Phytoplankton Biovolume	-	≤ 1.0 mm³/l	-	-

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

data	Zooplankton Filtration Rate	-	-	-	-

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 median was used for hygiene parameters, as it is less sensitive to occasional high CFU/100 ml outliers than the mean. 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. Data collection and data quality

The data used for the analysis were obtained from laboratory analyses, permanently installed sensors and handheld measuring devices. Data were entered into the DANA 2.0 platform by the operators of the studied swimming facilities. The datasets were screened for data quality, and clearly identifiable erroneous entries were excluded. The number of available measurements varied considerably between parameters and facilities. Consequently, the results describe the available operational monitoring data and should not be interpreted as a controlled, representative sample of all public NSPs.

2.2. General data

2.2.1. *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.

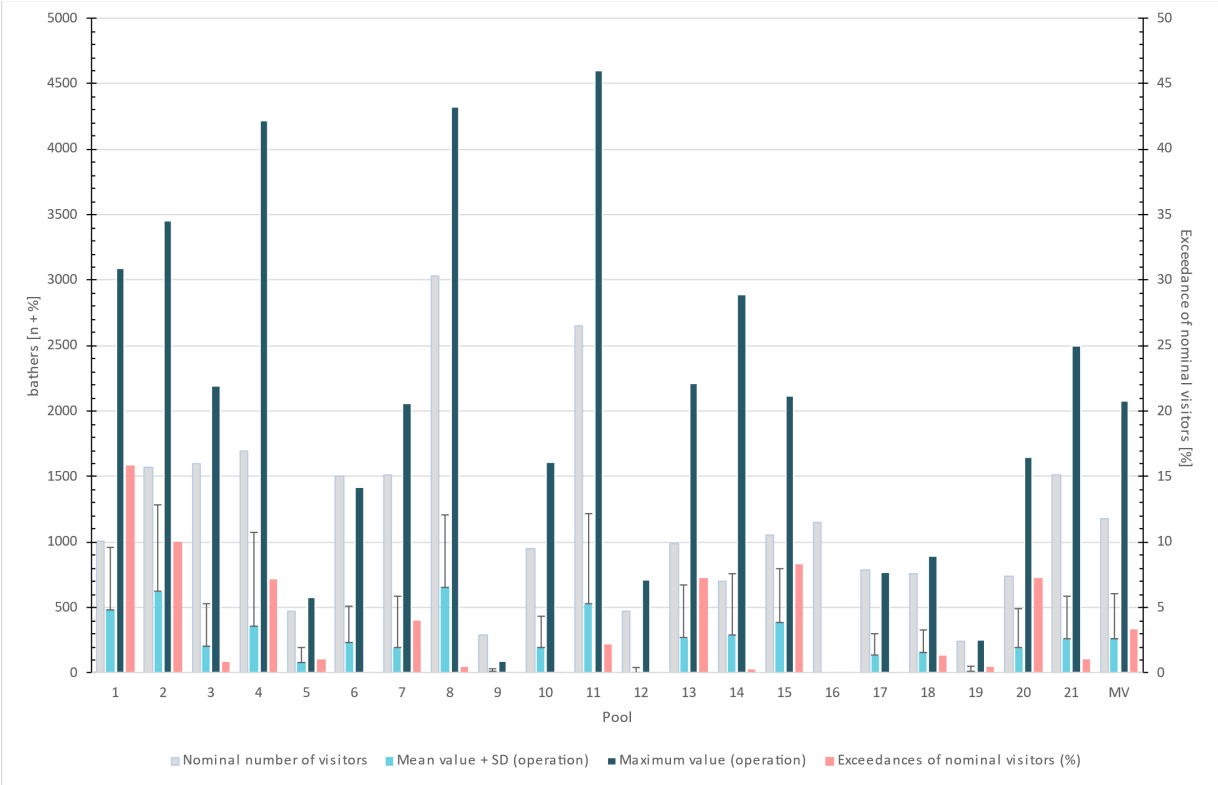


Figure *1* **Nominal number of visitors**, Men value + standard deviation, maximum values and exceedances of nominal bathers, Mean value of all pools, n= 13384

The pools were designed for nominal visitor numbers of 477 to 3,036 bathers per day, with an average nominal visitor number of 1,177 bathers/day. On average, the recorded visitor numbers remained within the design loads during the study period. The nominal visitor number was exceeded on an average of 3.4% of recorded days; the highest pool-specific frequency was 16%. The FLL design approach allows for exceedances on up to seven days per season. On average, approximately four days of exceedance per season were recorded; pools 1 and 2 exceeded this number more frequently. No obvious anomalies were identified for these pools in the descriptive water-quality summaries; however, a direct relationship between daily visitor load and water quality was not statistically tested.

2.3. Chemical and physical data

2.3.1. *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.

2.3.2. *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=9832

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=8438

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 7.92). There were hardly any exceedances or undercuts of the guideline values. It can be assumed, that the high pH-values of pool number 8 result from a lack of calibration of the measurement instruments.

The lower pH values in the treated water are consistent with microbial degradation and associated changes in the carbonate system. However, pH is also influenced by dissolved carbon dioxide, alkalinity and mineral dissolution; this difference alone cannot establish filter treatment performance or quantify phytoplankton degradation. Limestone-containing filter materials may additionally influence pH and alkalinity.

2.3.3.*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 mean acid capacity was above the guideline value at the monitored measuring points. Limestone-containing filter materials can contribute to maintaining acid capacity through dissolution. The extent of this contribution depends on water chemistry, carbon dioxide availability and hydraulic conditions; compliance cannot be attributed to the filter material alone.

2.3.4. *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, within the recommended range at all measuring points. Mean values were 98% in swimmer basins and 97% in non-swimmer basins, compared with 95% in the treated water from dry filters and 90% from submerged filters. Lower oxygen saturation in treated water is consistent with oxygen consumption during biological processes, although other factors may contribute. Differences between filter types may reflect their aeration and hydraulic conditions, but the monitoring data alone do not establish a causal explanation.

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

2.3.5. *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 guideline[5].

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

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

Swimmer and non-swimmer basin temperatures were evaluated separately. The reported mean values, including standard deviations, were below 25°C, while the maximum recorded temperature was 30°C. Despite the generally shallower water in non-swimmer basins, there was no consistent increase in their reported mean temperatures. Mixing, hydraulic connections, make-up water and local conditions may influence this observation; the present data do not identify their relative contributions.

2.3.6. *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

5 The FLL's follow-up guideline will probably be published under the auspices of the DGFdB at the end of 2027. More details can be found there.

Figure 21 **Total phosphorous – Clear water submerged 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

2.3.7. *Nitrogen compounds - ammonium and nitrate*

Ammonium can originate from the decomposition of nitrogen-containing organic material, including biomass, and from inputs associated with bathers. Under aerobic conditions, ammonium can be oxidised to nitrate by nitrifying microorganisms. Elevated ammonium concentrations may reflect increased inputs, insufficient nitrification or unfavourable operating conditions; they do not by themselves demonstrate a failure of microbial aerobic degradation. The recommended concentration is lower in treated water (≤ 0.1 mg/L) than in pool water (≤ 0.3 mg/L). Nitrate may be taken up by plants and may also enter with fill-up 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.

2.3.8. *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 µS/cm) can indicate contamination. If the values are too low (<200 µS/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 µS/cm) and the non-swimmer pools (375 µS/cm) was in a similar range to the pure water in the dry filters (379 µS/cm) and the submerged filters (361 µS/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.

2.3.9. *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 layer[6]. Higher lime contents are also always accompanied by high hydrogen carbonate contents, which in turn increases the buffering capacity of the water. It is also important to adapt the selection of plants in the NSP to the respective lime content[7][8][9].

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

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

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

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

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.

2.4. Hygienical data

To monitor the hygienic quality of the bathing water, Escherichia coli, intestinal enterococci and Pseudomonas aeruginosa are examined. Bathers are an important potential source of microbiological contamination, but other sources, including animals, surface runoff and fill-up water, may also contribute. Indicator-organism concentrations provide relevant information for operational hygiene monitoring but do not quantify all possible pathogens or exclude their presence. Public NSPs therefore use stricter operational assessment values for E. coli and enterococci than the statistical classification values under the EU Bathing Water Directive. Pseudomonas aeruginosa is additionally monitored because it can occur independently of faecal indicators and can colonise technical systems and biofilms.

2.4.1. *E. coli and Enterococci*

E. coli are facultative anaerobic bacteria with a temperature range of 21°C to 49°C[10]. 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 circumstances[11].

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 infections[12].

The FLL guideline refers to operational assessment values of 100 CFU/100 mL for Escherichia coli and 50 CFU/100 mL for intestinal enterococci. In contrast, Directive 2006/7/EC classifies the quality of inland bathing waters using percentile-based datasets: for the category “good”, the 95th-percentile values are 1,000 CFU/100 mL for E. coli and 400 CFU/100 mL for intestinal enterococci; for “excellent”, the corresponding values are 500 and 200 CFU/100 mL. These statistical quality classes are not single-sample operational limits and are therefore not directly comparable with the FLL values.

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

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

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

Figure 39 **E.coli – Swimmer Basins**, median, maximum value, minimum value, maximum limit value, MV = mean value of all pools, n=967

Figure 40 **E. coli – Non -swimmer Basins**, median, maximum value, minimum value, maximum limit value, MV = mean value of all pools, values=1000 → >1000, n=1286

Figure 41 **E. coli – clear water dry filter,** median, maximum value, minimum value, maximum limit value, MV = mean value of all pools, values=1000 → >1000, n=753

Figure 42 **E. coli – clear water submerged filter,** median, maximum value, minimum value, maximum limit value, MV = mean value of all pools, n=567

The E. coli average median values in the non-swimmer area were on average slightly higher (10.5 CFU/100ml) than the values in the swimmer area (9.9 CFU/100ml). The average median values in the pure water were 5 CFU/100ml in the dry and 2.5 CFU/100ml. The frequency of exceedances in the usage area was 2.7% in the swimmer and 5.1% in the non-swimmer area. The pure water between 1.4% (submerse) and 1.5% (dry).

Figure 43 **Enterococci – Swimmer Basins**, median, maximum value, maximum limit value, MV = mean value of all pools, values=500 → >500, n=971

Figure *44* **Enterococci – Non - Swimmer Basins**, median, maximum value, maximum limit value, MV = mean value of all pools, values=500 → >500, n=1276

Figure *45* **Enterococci – clear water dry filter,** median, maximum value, maximum limit value, MV = mean value of all pools, values=500 → >500, n=654

Figure *46* **Enterococci – clear water submerged filter,** median, maximum value, maximum limit value, MV = mean value of all pools, n=561

The enterococci values were on average between 7.9 and 9.3 CFU/100ml in all areas. The mean values of the limit value violations in the usage areas (swimmer area: 3.9%; non-swimmer area 5.4%) were higher than in the treatment areas (dry filter: 2.9%; submerged filter 2%).

2.4.2. *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 CFU/100 ml) and closure-relevant exceedances (repeated occurrence of > 100 CFU/100 ml)[13]. 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**, median, maximum value, maximum limit value, MV = mean value of all pools, n=870

Figure *48* **Pseudomonas aeruginosa – Non - Swimmer Basins**, median, maximum value, maximum limit value, MV = mean value of all pools, n=1204

Figure *49* **Pseudomonas aeruginosa – Clear water dry filter**, median, maximum value, maximum limit value, MV = mean value of all pools, n=560

Figure *50* **Pseudomonas aeruginosa – Clear water submerged filter**, median, maximum value, maximum limit value, MV = mean value of all pools, n=468

The average median value at all of the measuring points examined was 0.0-0.6 CFU/100ml. The highest exceedance rate was 26.8% in the swimming pool and 29.3% in the non-swimmers' pool. These slightly higher values could be due to greater biofilm abrasion by bathers in the non-swimmers' areas. Average exceedance rates were documented as 6.5% for the swimmers' zone and 9% for the non-swimmers' zone, 8.3% in dry and 5.7% in submerse treatment areas. 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].

2.5. Biological data

2.5.1. *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 (Bacillariophycea) and pharyngeal flagella (Cryptophyceae). Cyanobacteria may only occur as accompanying flora. Studies have shown that more than half of the phytoplankton are diatoms[14]. The recommended value for the total biovolume of phytoplankton is ≤1.0 mm³/l. This value corresponds to an oligotrophic state.

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

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 0.55mm³/l and was therefore in the oligotrophic range. The frequency with which the recommended value was exceeded was 5%.

2.5.2. *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 m³ per m³ of pool water. Accordingly, a filtration performance of the zooplankton of 4% of the pool water per day is assumed.

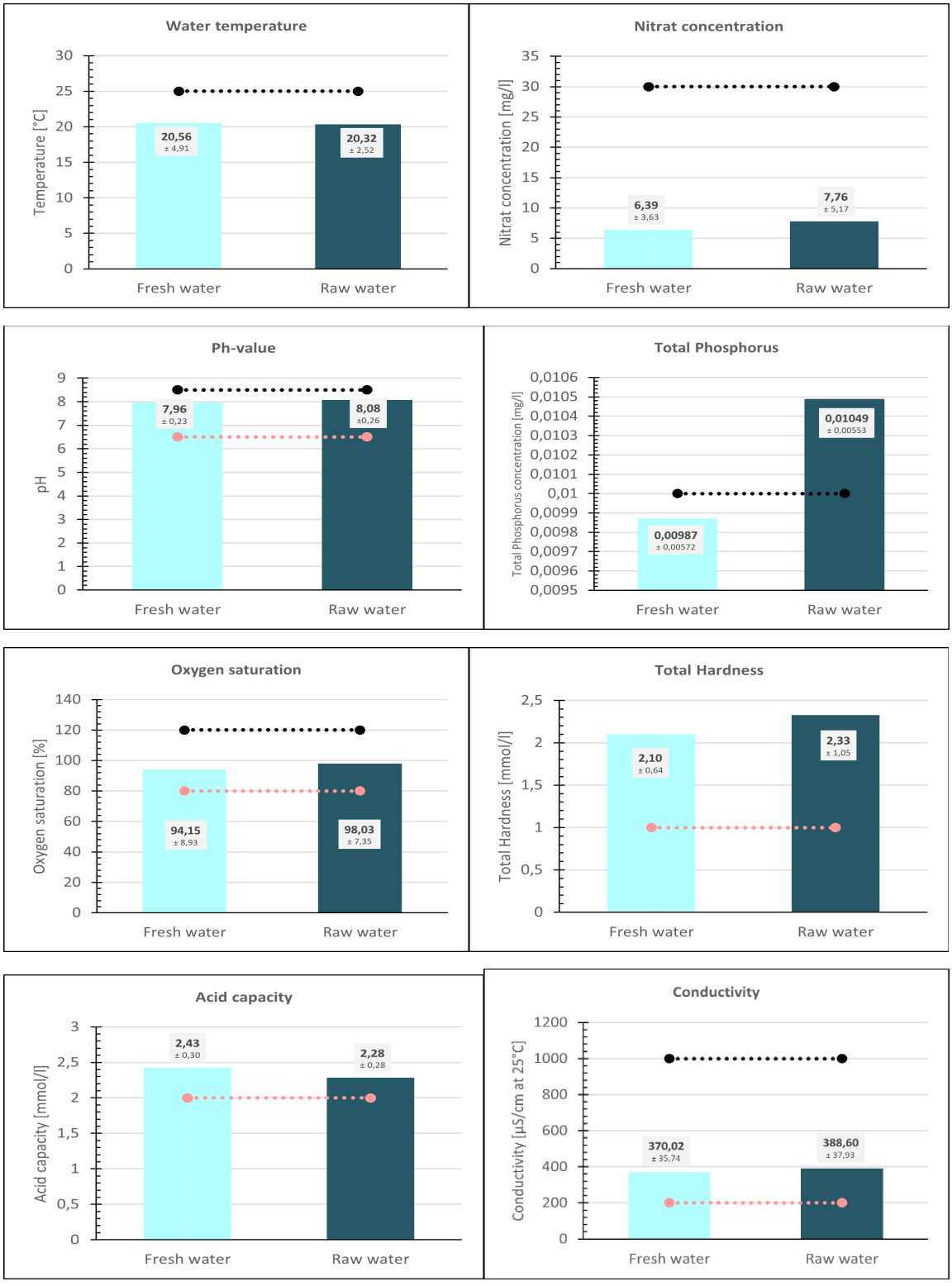
Figure *52* **Zooplankton biovolume – Swimmer basins**, mean value + standard deviation, maximum value, standard value, MV = mean value of all pools, n=132

The average filtration rate measured in the pools examined was 0.26m³/m³/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

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

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



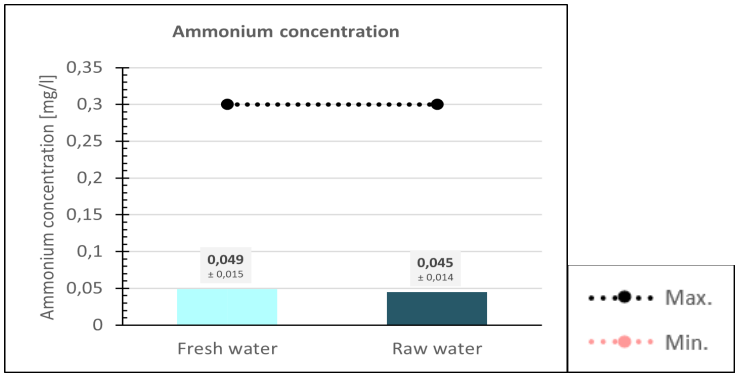


Figure *54* **Mean values of the chemical parameter analysis** over the entire study period, mean values ± standard deviation of each observed parameter in fresh and raw water with accordingly maximum and minimum thresholds due to the FLL guideline

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 ± 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 ± 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 median values of the hygienic parameter measurements for both raw and fresh water fall within the recommended range of bacterial concentrations (Figure 55). The median was selected because microbiological parameters are particularly susceptible to extreme values and often exhibit skewed distributions. In contrast to the mean value, the median is less sensitive to outliers and therefore provides a more robust and representative measure of the central tendency of the observed bacterial concentrations.

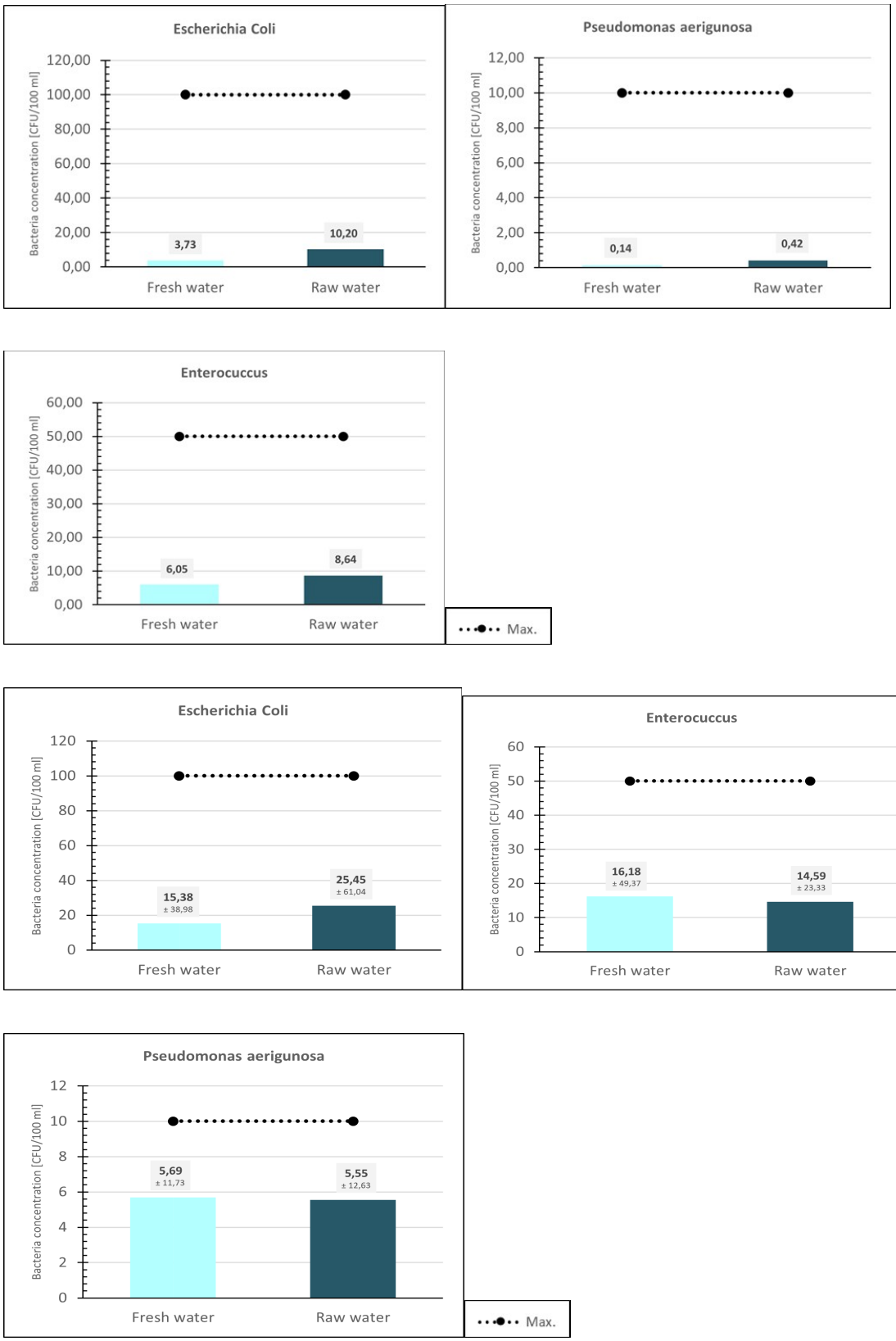


Figure *55* **Mean median values of the hygienical parameter analysis** over the entire study period, averages of the median of each observed parameter in fresh and raw water with accordingly maximum thresholds due to the FLL guideline.

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 ± 0.21. This value is well below the maximum threshold of 1 mm³/l. The mean zooplankton biovolume value is 1,900 mm³/l.

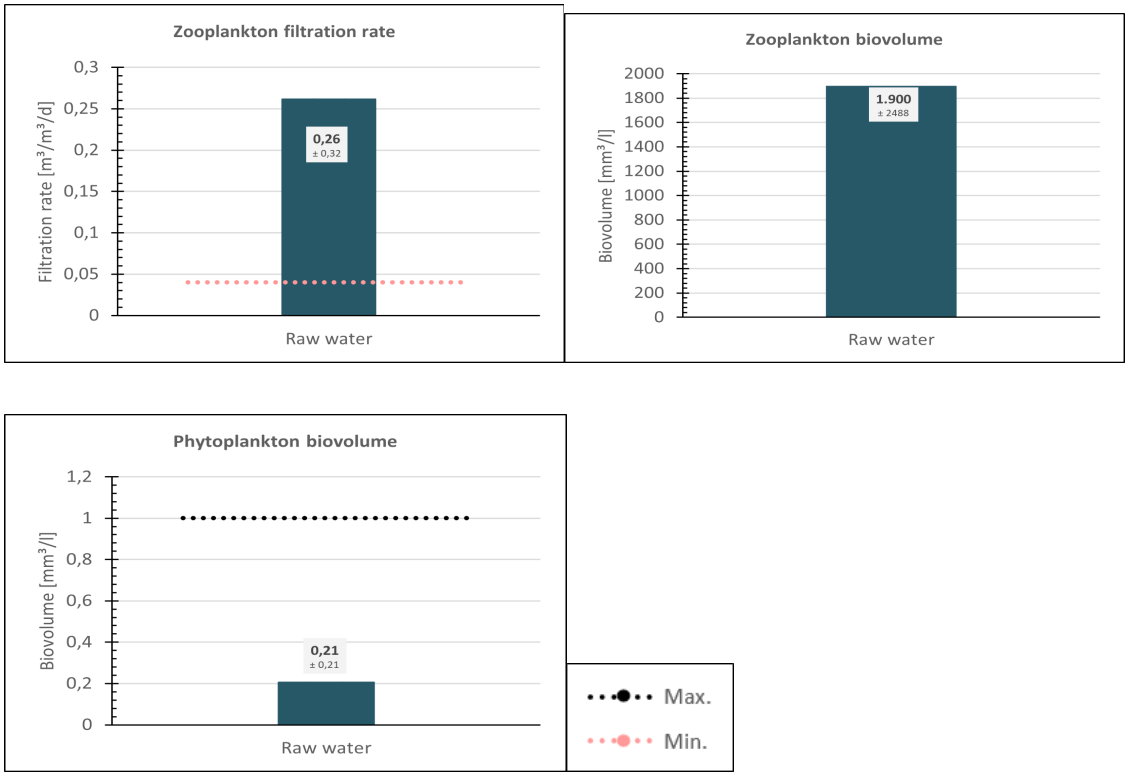


Figure *56* **Mean values of the biological parameter analysis** over the entire study period, mean values ± standard deviation of each observed parameter in raw water with accordingly maximum thresholds due to the FLL guideline.

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 evaluation of long-term operational data from 21 public natural swimming pools (NSPs) shows that the investigated facilities generally operated in accordance with the requirements and recommendations of the FLL guideline. Across the investigated parameters, limit and recommended value exceedances occurred only occasionally, with overall exceedances rates raging from 1.6% - 4.1%. The aggregated values were generally within the specified ranges. Total phosphorus (TP) was the only parameter for which the raw water mean value shows minor exceedances of the recommended value. However, this finding is not unexpected, as the make-up water supplied to NSPs, including groundwater from wells, may already contain elevated phosphorus concentrations. For optimal operation, additional phosphorus removal measures, such as phosphate adsorbers or ferric chloride dosing, are used in some facilities to maintain TP concentrations at the lowest practicable level. The effectiveness of these treatment methods is reflected in the lower TP concentrations observed in the treated water.The long-term operational data from 21 public natural swimming pools (NSPs) indicate that the monitored facilities generally achieved water quality consistent with the examined FLL requirements and recommendations. Exceedances occurred for some parameters and measuring points. Chapter 3 reports exceedances of upper limits in 4.8% of pool-water observations and 4.3% of treated-water observations, and values below lower thresholds in 2.5% and 2.0%, respectively. These aggregated percentages depend on the parameters included and the weighting of observations.

Total phosphorus (TP) was the only parameter for which the raw water mean value shows minor exceedances of the recommended value. However, this finding is not unexpected, as the make-up water supplied to NSPs, including groundwater from wells, may already contain elevated phosphorus concentrations. For optimal operation, additional phosphorus removal measures, such as phosphate adsorbers or ferric chloride dosing, are used in some facilities to maintain TP concentrations at the lowest practicable level. The effectiveness of these treatment methods is reflected in the lower TP concentrations observed in the treated water.

The generally lower reported concentrations of microbial indicator organisms in treated water than in pool water are consistent with a positive contribution of biological treatment. For example, the reported aggregate central values for Pseudomonas aeruginosa were 0.42 CFU/100 mL in pool water and 0.14 CFU/100 mL in treated water; a similar descriptive pattern was reported for E. coli and intestinal enterococci. These concentrations are very low. Their numerical differences must be interpreted cautiously in view of analytical detection and quantification limits, possible non-detect handling and the absence of a documented paired influent-effluent removal analysis.

The facilities were generally operated within their design bather loads. Temporary exceedances of the nominal number of bathers occurred during operation. However, facilities with more frequent exceedances did not show any particular anomalies in the evaluated water-quality parameters. This indicated that the investigated NSPs were able to maintain their treatment performance under the range of operating conditions represented in the dataset.

The availability and number of measurements varied between facilities and parameters, partly because not all operational parameters are monitored at the same frequency. Facilities were selected according to data availability in DANA 2.0, which may introduce selection bias. The findings therefore describe long-term monitoring outcomes for these 21 facilities and cannot automatically be generalised to all public natural swimming pools. The study was not designed as a controlled experimental comparison.

When interpreting the results, the analytical limits of quantification should be also taken into account. This applies to all parameters investigated in this study. Particularly at very low concentrations, the limit of quantification can influence calculated mean and median values. Consequently, small numeric differences at concentrations close to the analytical quantification limit should not necessarily be interpreted as meaningful differences in water quality.

Overall, the analysis demonstrates that the NSPs are capable of maintaining appropriate water quality under practical operating conditions. Values exceeding the recommended limits occurred primarily as isolated 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.