Hygienic quality of public natural swimming pools (NSP)[†]

Stefan Bruns and Christina Peppler

ABSTRACT

Natural swimming pools (NSP) have become more popular in the past 20 years, both for private and public use, but their hygienic status remains a matter of discussion. Elimination rates in NSP are well defined for *Escherichia coli*, enterococci and *Pseudomonas* but a lack of knowledge exists regarding elimination rates in NSP concerning the parasitic protozoans *Giardia* and *Cryptosporidium*. First studies indicate that in-situ zooplankton filtration proved to reduce these protozoans efficiently: the in-situ elimination of *Cryptosporidium* is dependent on the population of zooplankton. In the 50% percentile the elimination rate is four times faster than in the chlorinated pool. The ex-situ elimination of *Cryptosporidium* in an NSP is approximately 10% faster than in a chlorinated pool. In ex-situ treatment of NSP the elimination rate reached 2 log-steps versus 1 log-step in chlorinated pools. For the further development of NSP for the best possible hygiene and health status some elementary questions, stated in this paper, will have to be solved in the next years or decades.

Key words | *Cryptosporidium*, *Giardia*, in-situ disinfection, natural swimming pools, NSP

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[†]This work describes the in-situ (water treatment inside the pool) and ex-situ water treatment (water treatment via external water treatment plants) of NSP, and the influence of zooplankton in existing NSP on the elimination rate of *Cryptosporidium* and *Giardia*.

INTRODUCTION

Natural swimming pools (NSP) operated by biological water treatment first appeared in the 1980s in Austria, a country in which swimming in natural waters has a long tradition. Neither the population nor the governing authorities have ever had reservations about swimming in natural water. This is probably why construction of the first public NSP in Austria was granted government approval in 1991. Since then, the idea of swimming in artificially designed facilities without chemical disinfection has spread rapidly. The current worldwide situation of NSP is published by the IOB, the International Organization for natural bathing waters http://www.iob-ev.eu/. A comprehensive review of the structure, function and limnology of NSP and applied water treatment is given by Spieker *et al.* (2013).

As in a chlorinated pool NSP work with both internal and external disinfection: the German regulation for NSP, the FLL regulation, classifies water treatment in internal (in-situ) and external (ex-situ) procedures (FLL 2011). The ex-situ mode consists of different bio-filters and hydrobotanic plants. The in-situ procedure is regarded to be largely based on the zooplankton filtration, considered to be the major factor contributing to water purification (Bruns & Schwarzer 2013).

Today the concept of NSP is common in Europe, with current estimates indicating in excess of 20,000 swimming pools in Europe, most of which are being used privately. Notably there are over 900 public swimming pools belonging to hotels, communities and campsite. The establishment of the online-database 'DANA' (database for natural swimming pools), developed in an R&D project funded by the DBU (Deutsche Bundesstiftung Umwelt – German Federal Environmental Foundation) proved to be supportive for the perception of NSP as a biologically and technically well controlled system (Bruns 2013). Still there are critical voices supposing that NSP bear a higher risk concerning bacterial infections compared to chlorinated pools. This attitude apparently is supported by the shorter elimination time for the guideline

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parameters *Escherichia coli*, enterococci and *Pseudomonas aeruginosa* in chlorinated pools with an external water treatment compared to NSP. Notwithstanding this the popularity of NSP has continuously been increasing during the last 20 years. The research presented here reflects one aspect of a long-term development taking place during the last 16 years, rendered by different international bodies, hygienic institutes, universities, associations and companies. This paper presents a first estimate of the potential elimination rate for protozoans such as *Giardia* and *Cryptosporidium* in NSP. These are the most frequently identified pathogenic protozoan parasites worldwide with increasing medical and economic consequences (Redder *et al.* 2010; Fletcher *et al.* 2012 give a comprehensive review on epidemiology, prevention and control of protozoan parasites).

Elimination is achieved by two major processes:

1. in-situ disinfection via water purification within the pool
2. ex-situ disinfection via external water purification.

IN-SITU DISINFECTION

In Germany there are several studies available on pathogen elimination resulting from zoo plankton grazing, referred to as 'internal disinfection'. Bruns & Wunderlich (2010) and Eydeler & Spieker (2010) have dealt extensively with this topic, particularly as it affects public pools with biological water purification, particularly NSP.

The study of Eydeler & Spieker (2010) on 13 NSP was carried out in Germany with the aim of recording semi-qualitative data on the zooplankton population. The tests detected the presence of the genera Flagellata, Ciliata, Rotatoria, Cladocera and Copepoda (Table 1).

The measurement of zooplankton was performed according to FLL (2011) guidelines, by using a plankton net (55 μm gauze) with attached volume calibration cone to take the sample. The net is to be drawn as far as possible over the entire water column, and the sample of zooplankton is to be preserved in 4% formaldehyde for further determination. The Federal Environmental Agency recommends sampling every week during the first year of operation. If the microbiological limits are not reached in 95% of the samples, sampling can be reduced to every two weeks.

Table 1 | Filtration rates of zooplankton, taking into consideration minimum (Fmin), maximum (Fmax) and average (Fav) specific filtration (Eydeler & Spieker 2010)

Zooplankton	Minimum Fmin ml/Ind./d	Maximum Fmax ml/Ind./d	Average Fav ml/Ind./d
Ciliata	0.012	0.163	0.0875
Rotatoria	0.007	16.992	8.5
Copepoda	0.048	129.6	64.824
Cladocera	0.096	66.48	33.288

The NSP were assigned to two different groups, depending on the individual turnover rate, in order to evaluate a potential difference between pools with high filtration rates (2.6 to 10 $*day^{-1}$) and those with low filtration rates (0 to 2.5$*day^{-1}$):

Group 1: a low filtration rate was identified if turnover values were between 0 and 2.5 times per day.
Group 2: a high filtration rate was defined for turnover values between 2.6 and 10 times per day.

The results are indicated in Figure 1. The maximum filtration rate occurs with approximately 20 $m^3/m^3/d$, the 10 percentile occurs with approximately 0.04 $m^3/m^3/d$.

Figure 1 shows the internal filtration rate via zooplankton in m^3 per m^3 (basin volume)/d. It shows that the 30th percentile of the filtration rate is between 94 and 118 $l/m^3/d$. The maximum detected rate, which is not shown in Figure 2, was 20,000 $l/m^3/d$ or 20 $m^3/m^3/day$.

According to Connelly *et al.* (2007) the elimination rate for *Giardia* and *Cryptosporidium* can be assumed as 1 log step.

EXTERNAL DISINFECTION

Disinfection via external water treatment is crucial in ensuring the safety of the system for both users and the environment. A study on the elimination of microorganisms with substrate filters for small bathing ponds carried out by the German Federal Environmental Agency (Grunert *et al.* 2009) showed that it is possible to achieve an *Escherichia coli* elimination rate of two log steps – representing a

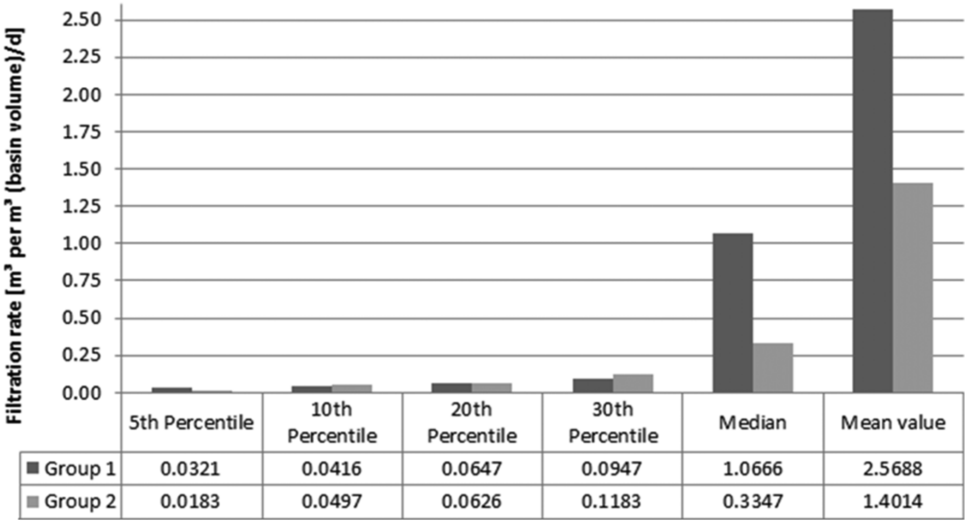

Figure 1 | Results of zooplankton filtration rates (in-situ), assigned to pool group 1 (high filtration rate of water treatment) and pool group 2 (low filtration rate of water treatment) (Bruns & Wunderlich 2010).

Elimination by 1 log step in the pool water	Percentile	In-situ *E.coli* [min]	In-situ Protozoans [min]	Elimination rates	Ex situ Protozoans [min]	Specific elimination rates (water treatment ex-situ)
Chlorinated pool, 0,6 mg/l, 3 Filtration rates/d		3	12000	Protozoans (200 h one Log step)	1230	Protozoans (1.0 Log)
NSP (group 2); 0.04 m³/m³ Zooplankton filtration, 3 filtration rates/d	10%	83800	92000	Protozoans (1 .0 Log/ zooplankton filtration)	1110	Protozoans (2 .5 Log)
NSP (group 2); 0.11 m³/m³ Zooplankton filtration, 3 Filtration rates/d	30%	30500	33500	Protozoans (1 .0 Log/ zooplankton filtration)	1110	Protozoans (2 .5 Log)
NSP (group 2); 1.066 m³/m³ Zooplankton filtration, 3 filtration rates/d	50%	3150	3450	Protozoans (1 .0 Log/ zooplankton filtration)	1110	Protozoans (2 .5 Log)

Figure 2 | Elimination time [min] required to achieve a reduction of *Giardia* and *E. coli* by 1 log step in the pool water, both for in-situ disinfection and ex-situ disinfection of a chlorinated pool compared to an NSP of group 2 (10%,30%,50%) percentile.

degradation rate of approximately 99%. In a study by Bruns & Schwarzer (2013), the University of Hanover (ISAH, unpublished research paper) also carried out tests with coliphages and *Escherichia coli*, using a filter, a water tank and a dosing unit for phosphorus and zooplankton. The test tank was inoculated with coliphages. The elimination rate as a factor of the filter column was 93 to 99% (filter column 0.8 m, filter material: lime-rich chippings (Oolith), particle size 2 to 5 mm diameter, hydraulic load 6 to 24 m³/m²/day). It is known that the elimination and enclosure of pathogenetic microorganisms is mediated by biofilms on the substrate surface.

Redder *et al.* (2010) performed a comparable experiment concerning elimination of *Cryptosporidium* and *Giardia*. From these data it can be surmised that an elimination rate for bacteria and viruses in excess of 90% is possible in external biological water purification systems of NSP.

Chlorine, by contrast, has no serious impact on reducing the concentration of *Giardia* and *Cryptosporidium*. In consequence, for chlorinated pool water there is a low impact of in-situ water treatment on these pathogens. For our considerations we assumed that the external impact caused by a combination of flocculation and downstream filtration will lead to an elimination rate of approximately 1 log step. This assumption is derived from Castro-Hermida *et al.* (2010), who found an elimination rate below 1 log step for combined flocculation and disinfection treatments and it is also supported by Bergstedt *et al.* (2000), who determined elimination rates for the flocculation of parasite-sized particles by employing different coagulants, basically achieving 1 log step reduction. According to WHO (2006) coagulation and filtration are necessary steps for removing *Cryptosporidium* oocysts and *Giardia* cysts and other protozoa that are resistant to chemical disinfection; removal and inactivation of cysts and oocysts (of protozoans) occur only in the fraction of water passing through treatment, and since a pool is a mixed and not a plug flow system, the rate of reduction in concentration in the pool volume is slow.

In NSP the existing zooplankton population has the potential to reduce the number of *Giardia* and *Cryptosporidium* efficiently, i.e. the potential elimination rate can achieve high numbers if the zooplankton population is large. The above mentioned research indicated the high fluctuation of the zooplankton population.

Figure 2 gives elimination times required to achieve a 1 log step reduction for chlorinated and for NSP pools (group 1), based on a numerical calculation using the data presented in Figure 1. The numerical calculation was performed in time intervals of 5 min. For the ex-situ filtration rates of both types of pools, chlorinated and NSP, a water exchange rate of three times per day was set (refer to column 1). Relevant specific elimination rates for the chlorinated pool are listed in the first line.

Figure 2 illustrates following aspects:

1. The ex-situ elimination of *Cryptosporidium* in the NSP is approximately 10% faster than in the chlorinated pool, as seen by the 2.5 log step elimination rate in the NSP instead of the much lower elimination rate of 1 log step in the chlorinated pool.
2. The in-situ elimination of *Cryptosporidium* is dependent on the population of zooplankton. In the 50% percentile the elimination rate is four times quicker than in the chlorinated pool.

In Figure 3 the corresponding turnover rate is computed, which is necessary to reduce the concentration Co to C10%. The calculation has been done according to the following formula

$$C = Co^{*}e^{-(V/Vo)*f} \quad (1)$$

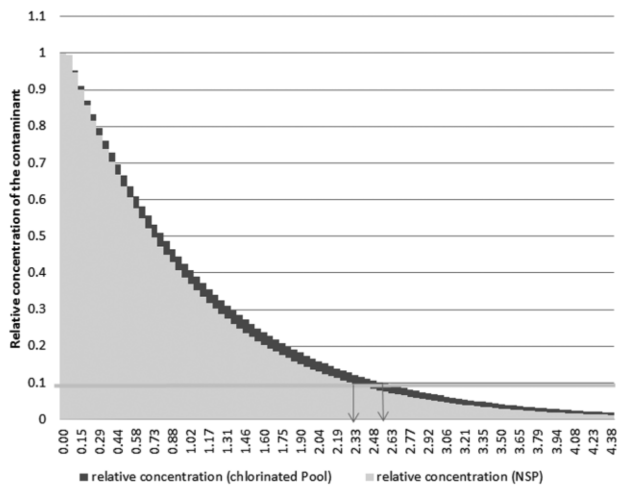

Figure 3 | Relative concentration of *Giardia* or *Cryptosporidium* in relation to the turnover rate.

where:

Vo = Water volume of the basin
V = Treated water
e = Euler's number
f = elimination rate of the treatment 90% (f = 0.9)

The results show that it will take approximately 2.3 water exchanges in an NSP and 2.55 water exchanges in a chlorinated pool to reduce the internal concentration of *Giardia* or *Cryptosporidium* to 10% by external water treatment. If the zooplankton population reaches the Median value, it will filtrate the water approximately 1 time/24 h. In this case the necessary water exchanges by water treatment will be reduced to 1.3 in the NSP in comparison to approximately 2.4 in the chlorinated pool.

Figure 3 only addresses the ex-situ disinfection and not the in-situ disinfection.

SUMMARY AND FURTHER RESEARCH REQUIREMENTS

These first research findings indicate the following:

1. Concerning the effectiveness of the biological elimination of *E. coli* the chlorinated pool will be much more effective than any NSP.

2. Concerning protozoans, the NSP will achieve better elimination rates in-situ with a probability of approximately 60% and ex-situ with a probability of 100%.

Further research has to be done to answer the following questions:

1. Is the elimination rate for *Giardia* and *Cryptosporidium* as determined by Connelly *et al.* (2007) for one species of zooplankton (*Daphnia*) applicable to all occurring zooplankton species, as required to be determined by the FLL (2011), or are there species-specific elimination rates?
2. Will zooplankton predominantly filter water in regions of higher feed density (a realistic scenario)? This fact would improve the actual, real elimination rate.
3. Is the population of the plankton distributed more or less homogeneously, so that we can assume the same feeding rate all over the water column?
4. Are there other aspects of the internal water treatment of NSPs which may cause pathogen reduction, besides the grazing rate via zooplankton?

In addition, Bonilla *et al.* (2015) recommended further studies to improve recovery and to minimize variability in quantification of protozoans, especially with regard to recoveries at lower concentrations, typically observed within recreational waters.

For the further development of NSP for the best possible hygiene and health status, these elementary questions will have to be solved in the next years or decades.

REFERENCES

Bergstedt, O., Rydberg, H. & Werner, L. 2000 Flow cytometry as an operational tool to improve particle removal in drinking water treatment (pp. 147–157). In: Hermann H. Hahn, Erhard Hoffmann & Hallvard Odegaard (eds), *Chemical Water and Wastewater Treatment VI; Proceedings of the 9th Gothenburg Symposium 2000*, 2–4 October 2000, Istanbul, Turkey, Springer, 378 pp.

Bonilla, J. A., Bonilla, T. D., Abdelzaher, A. M., Scott, T. M., Lukasik, J., Solo-Gabriele, H. M. & Palmer, C. J. 2015 Quantification of protozoa and viruses from small water volumes. *Int. J. Environ. Res. Public Health* **12** (7), 7118–7132. Published online 24 June 2015. doi: 10.3390/ijerph120707118. PMCID:PMC4515645.

Bruns, S. 2013 Datenbank für Freibäder mit biologischer Wasseraufbereitung (DANA), Auswertung der Hygienesituation auf Basis der DANA (Database for outdoor pools with biological water treatment (DANA), evaluation of the hygienic situation based on DANA). *AB Archiv des Badewesens* **66** (10), 637–649.

Bruns, S. & Schwarzer, U. 2013 Performance of Public Swimming Ponds – An Overview of Hygiene in Pools with Biological Water Purification. Brochure, 1st edn, 24 pp. Internationale Organisation für naturnahe Badegewässer (IOB), www.iob-ev.eu.

Bruns, S. & Wunderlich, A. 2010 Herleitung einer neuen Berechnungsmethode zur Ermittlung der Nennbesucherzahl (Deliniation of a new method of calculation for the determination of the nominal numbers of visitors). *Archiv für das Badewesen* **63** (5), 279–289.

Castro-Hermida, J. A., García-Presedo, I., González-Warleta, M. & Mezo, M. 2010 *Cryptosporidium* and *Giardia* detection in water bodies of Galicia, Spain. *Water Res.* **44**, 5887–5896.

Connelly, S. J., Wolyniak, E. A., Dieter, K. L., Williamson, C. E. & Jellison, K. L. 2007 Impact of zooplankton grazing on the excystation, viability, and infectivity of the protozoan pathogens *Cryptosporidium parvum* and *Giardia lamblia*. *Applied and Environmental Microbiology* **73** (22), 7277–7282.

Eydeler, I. & Spieker, J. 2010 Keimelimination durch Zooplankton - Wasserreinigung in Schwimm- und Badeteichen (Germ elimination by zooplankton – water purification in swimming and bathing ponds). *Archiv für das Badewesen* **3**, 167–175.

Fletcher, S. M., Stark, D., Harkness, J. & El, J. 2012 Enteric protozoa in the developed world: a public health perspective. *Clin. Microbiol. Rev.* **25** (3), 420–449, doi: 10.1128/CMR.05038-11. http://cmr.asm.org/content/25/3/420.full.pdf+html.

FLL 2011 Richtlinien für Planung, Bau, Instandhaltung und Betrieb von Freibädern mit biologischer Wasseraufbereitung (Schwimm- und Badeteiche) (FLL Landscaping and Landscape Development Research Society: Recommendations for planning, construction, service and operation of outdoor swimming pools with biological water purification (Swimming and Bathing Ponds)), 2011, DIN A4, Brochure, 99 pp.

Grunert A., Arndt, Bartel H, C., Dizer, H., Kock, M., Kubs, M. & López-Pila, J. M. 2009 Entfernung von Mikroorganismen durch Bodenfilter für Kleinbadeteiche (elimination of microorganisms by soil filters for small bathing ponds). *Bundesgesundheitsblatt – Gesundheitsforschung – Gesundheitsschutz* **52**, 228–237. doi: 10.1007/s00103-009-0768-x.

Redder, A., Duerr, M., Daeschlein, G., Baeder-Bederski, O., Koch, C., Mueller, R., Exner, M. & Borneff-Lipp, M. 2010 Constructed wetlands – are they safe in reducing protozoan parasites? *International Journal of Hygiene and Environmental Health* **213**, 72–77.

Spieker, J., Hirch, S., Schwarzer, C., Schwarzer, U., Frehse, H. & Bruns, S. 2013 Freibäder mit biologischer Wasseraufbereitung (Schwimm- und Badeteiche) (Outdoor swimming pools with biological water treatment (swimming and bathing ponds). Chapter VI-2.6 In: *Handbuch Angewandte Limnologie (Handbook of Applied Limnology)* 30, Erg.Lfg. (supplement) 12/12 (M. Hupfer, W. Calmano, H. Fischer & H. Klapper, eds). Wiley-VCH, Weinheim, 28 pp.

WHO 2006 *Guidelines for Safe Recreational Water Environments*: *Volume 2 Swimming Pools and Similar Environments*. World Health Organization, Geneva, Switzerland. http://www.who.int/water_sanitation_health/bathing/srwe2full.pdf.

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