4.15 NATURAL SWIMMING POOLS

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4.15.1 Introduction

Natural swimming pools are outdoor swimming pools with biological water treatment. They are separated from natural waters and sealed off from the groundwater. They are divided into bathing and treatment areas and must meet defined water quality requirements, especially in the case of pools open to the public.

In contrast to conventionally operated pools, the water in these baths is not treated by chemical disinfection (chlorination), but by means of biological, physical and physical–chemical processes. The biotechnological processes used to treat the water of these baths make use of the ability of living organisms to convert, degrade or incorporate water-polluting substances.

Natural swimming pools are therefore living systems in which the same processes take place as in natural waters. Technical facilities, such as treatment wetlands, support and control these processes with varying intensity.

TWs used for natural swimming pools work under conditions which are quite different from those in wastewater treatment:

- They usually only work in the vegetative season (which is the bathing season);
- Water is continuously treated in a closed-loop process: the treated water is reused for bathing and not released into the environment;
- The concentrations of organic matter and especially nutrients to be treated are very low (phosphorous is in the microgram and not in the milligram range) and so are the pollutant loads to be treated. Hydraulic loading however is high.

4.15.2 Design objectives

The aim of biological water treatment in natural swimming ponds is to provide bathers with hygienically safe and clear bathing water. Bathing and swimming should be safe and an aesthetic pleasure. The hygienic goals can be achieved on the one hand by a sufficient dilution and on the other hand by an appropriate water treatment. It is also important to achieve a very low trophic status so that the growth of planktonic algae and filamentous algae can be minimized by nutrient limitation, more precisely by limiting the concentration of phosphorous in the bathing water (Table 4.9).

4.15.3 Processes required and TW types to be used

Treatment wetlands for natural swimming pools must therefore primarily eliminate pathogens and reduce phosphorous concentrations. They also need to degrade different kinds of organic matter brought into the bath, and to accept high hydraulic loadings, as the water volume of the bath should be continuously treated in a closed-loop process.

Table 4.9 Trophic status and phosphorus concentration of lake water (adapted from Carlson & Simpson, 1996).

Trophic Class	Total P (μg/l)	Suspended Chlorophyl (μg/l)	Transparency (m)
Oligotrophic	<12	<2.6	>4
Mesotrophic	12–24	2.6–20	2–4
Eutrophic	24–96	20–56	0.5–2
Hypereutrophic	>96	>56	<0.25–0.5

Bathers bring pathogens, phosphorous and organic matter – such as grease from sun-tan products – into the pool, the filling water can be a source of phosphorous, and other external inputs such as leaves, dust, birds, etc. can also bring in pathogens, phosphorous and organic matter.

The German Guidelines for the design of public natural pools have established a "bather equivalent" based on an estimated 120,000 CFU/bather of *E. coli* and 75mg/bather for phosphorous (FLL 2011). As phosphorous and *E. coli* concentration are thought to be the two limiting parameters, these "bather equivalents" are used to dimension the treatment facilities for a specific bath.

For the user of the bath, hygiene is the most important issue, so that pathogen removal should be the main focus. As with conventional pools, the hygienic status of the bath is measured through the concentration of the indicator germs *Escherichia coli*, *Enterococcus* and *Pseudomonas aeruginosa*.

For the limnological system, however, what is relevant is essentially the input of phosphorus compounds or the phosphorus concentration, from which the trophic status of the bath is determined. The combined elements of the water treatment must therefore be able to keep the concentration of phosphorus very low (at 10 μg TP/L) in spite of temporarily high inputs. The same holds true for pathogens.

The water treatment facilities for natural swimming pools can either be based on biological or on physical–chemical processes. The physical–chemical treatment is usually a system that extracts dissolved phosphates from the water (such as a phosphate adsorber). Physical–chemical processes may only be used as a supplement to biological treatment. The water which has undergone such treatment must go through a biological treatment for hygienisation before it enters the bathing area (Figure 4.4).

Biological treatment units for natural swimming pools usually belong to one of the following categories:

(1) Planted Vertical Flow filters
(2) with saturated media
(3) freely drained (with unsaturated media)
(4) Unplanted Vertical Flow filters
(5) with saturated media
(6) freely drained (with unsaturated media)
(7) FWS Wetlands
(8) with submerged vegetation
(9) with emergent vegetation
(10) High-rate gravel or technical filters.

For the selection and combination of different water treatment units, their specific elimination rates related to the monitoring parameters *E. coli* and phosphorus as well as the maximum loading rate per square metre are of importance. The German Guidelines have established elimination and loading rates for the design of public natural pools (Table 4.10).

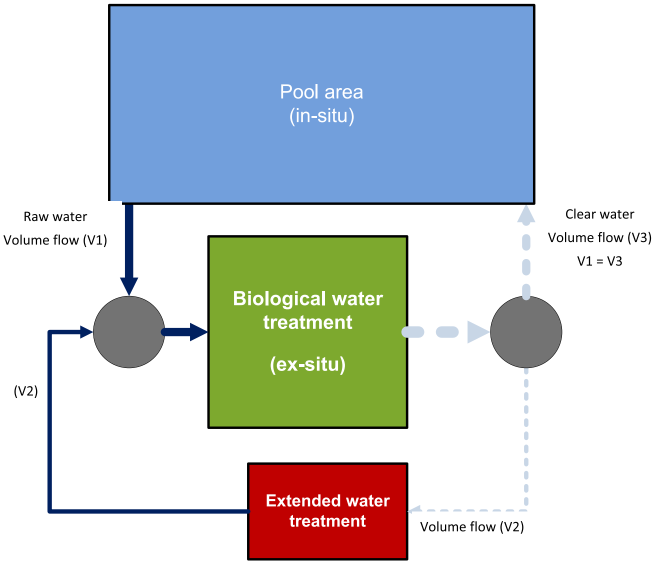

Figure 4.4 Circuit diagram for integrating the physical–chemical water treatment into the biological processes.

These elimination rates and maximum loading are empirical, based on observation from existing facilities. The reason why planted filters should only receive lower loading rates is that the root zone might reduce the volume of the voids in the filter and thus reduce hydraulic conductivity.

High-rate gravel filters or technical filters can have even higher loading rates, but they are not effective for pathogen removal. They do treat organic matter and are used especially for P elimination. Phosphorous is removed with the biological biofilm in the filters, which is often harvested at the end of the bathing season.

Figure 4.5 shows the elimination performance of freely drained vertical-flow filters for *E. coli* under field conditions. It should be noted that the quantification limit for *E. coli* is usually 15 CFU/100 ml. Values below this are given as <15 CFU/100 ml by the laboratories. In the evaluation on which Figure 4.5 is based, the value <15 is set to 15. An elimination of 90%, i.e., by one log level, can therefore only be

Table 4.10 Elimination rates of *E. coli* and phosphorous, and maximum hydraulic loading rates, for different treatment wetlands, according to the German guidelines for public natural swimming pools (adapted from FLL, 2011).

Type of Treatment Unit		**Elimination Rate**		**Max. Loading m^3/day**
		Phosphorus	***E. coli***	
Planted vertical flow	Saturated	20%	90%	3
	Freely drained	20%	90%	3
Unplanted vertical flow	Saturated	20%	85%	5
	Freely drained	20%	90%	10
Surface flow	Submerged vegetation	40%	10%	5
	Emerging vegetation	30%	10%	5

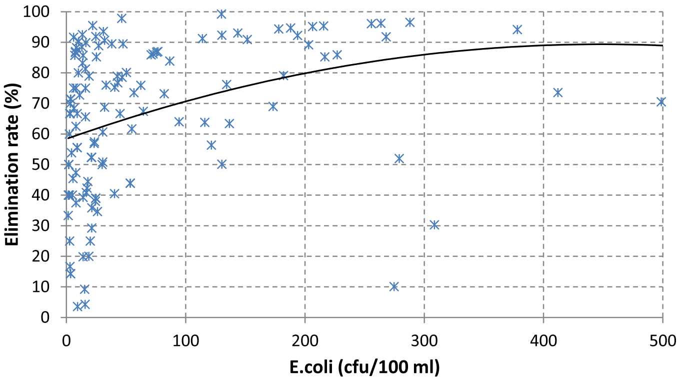

Figure 4.5 Elimination performance of *Escherichia coli* in freely drained vertical-flow filters under field conditions (from monitoring data collected by the DANA database developed by POLYPLAN on public swimming pools from 2005 to 2018.

mathematically proven for inflow concentrations of >150 CFU/100 ml. Since *E.coli* concentration >150 CFU per 100 ml rarely occurs, the evaluation of the monitoring data is of limited use. For this reason, supplementary studies were conducted under standardized laboratory conditions both by the German Federal Environment agency (Grunert *et al.*, 2009) and in the frame of a cooperative research project involving POLYPLAN (Scholz & Frehse, 2004).

Figure 4.6 shows the decrease in the elimination performance of *E. coli* with increasing hydraulic loading of filter columns under laboratory conditions. Elimination rates of 90% (one log level) of the tested unsaturated filter are only achieved for hydraulic loadings below 12 $m^3/m^2/d$ (Scholz & Frehse, 2004).

As far as the elimination of parasitic protozoan pathogens is concerned, the work of Redder *et al.* (2010) proved TWs for wastewater in pilot and field scale to achieve reduction rates of about 2 log for the protozoan pathogens *Cryptosporidium* oocysts and *Giardia* cysts. This is an important advantage for natural treatment systems as especially *Cryptosporidium* oocysts are resistant to chlorination concentrations found in conventional swimming pools (Korich *et al.*, 1990).

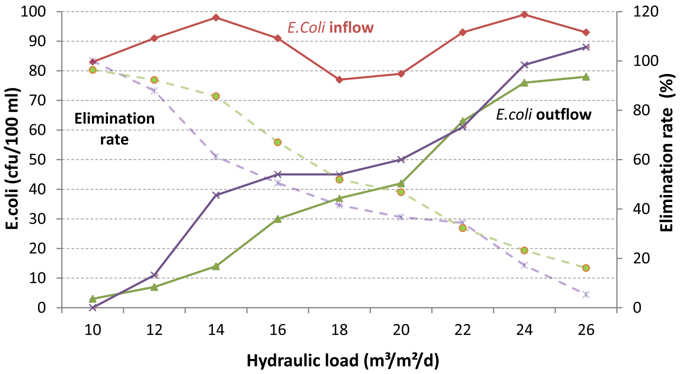

Figure 4.6 Elimination performance of *Escherichia coli* as a function of the hydraulic loading of two unsaturated filter columns (laboratory conditions) (adapted from Scholz & Frehse, 2004).

4.15.4 Specific considerations during design and for construction

As organic carbon concentrations to be treated are very low, so is the oxygen demand in the treatment wetlands. Usually, the dissolved oxygen in the water to be treated is higher than the BOD_5 concentrations, so that even saturated filters can work under aerobic conditions, as long as they are continuously fed with oxygen-rich water. Aquatic plants on the saturated filters further help to maintain oxidizing conditions around their root zones. If required, the nutrients bound in the plants can be finally exported from the bath by harvesting.

Further functions of the plants on the filters are shading and thus cooling the water. They also provide a habitat for a large number of aquatic invertebrates and amphibians. Helophytes with strong root or rhizome growth are often used.

Suitable plants are species of the genera *Carex, Juncus, Schoenoplectus, Bolboschoenus* and *Cyperus*. When choosing a species, it is important to consider whether it is a saturated or an unsaturated filter. Especially for the latter, with intermittent feeding, only very few species can be considered.

Depending on whether or not it is a more technically oriented natural swimming pool, submerged aquatic plants play a different role in *in situ* water purification. In technically oriented baths, submerged macrophytes are usually not used and their function of phosphorous removal is achieved by physical–chemical processes.

In calmer zones planted with submerged macrophytes there is increased sedimentation and thus the elimination or inactivation of nutrients and hygienically questionable bacteria. Furthermore, photosynthesis activity leads to temporarily increased oxygen concentrations in the area or above oxygen saturation.

But the most important role of the plants is their ability of to absorb nutrients such as – and especially – phosphorus. They thus compete with algae (phytoplankton and thread algae), which makes them a stabilizing factor in the ecosystem of a natural swimming pool. Well developed populations of thousand-leaf and pondweed species thus counteract the development of phytoplankton blooms.

Other functions of aquatic plants in natural swimming ponds are shading and cooling zones of relatively shallow water. Shading minimizes the spread of thread algae in shallow water areas, as thread algae compete with aquatic plants not only for nutrients but also for light. Submerged macrophytes form a habitat for many zooplankton species with the space-forming structures of their foliage. Emerged macrophytes provide mechanical protection for the shore areas, which prevents turbidity caused by swirling substrate.

The occurrence of aquatic plants and combinations of different species in their natural habitats are not random phenomena, but rather indicators of very specific living conditions. This basic knowledge of plant sociology is of great importance for the planting of natural swimming pool. In order to ensure good bathing water quality, nutrient-poor conditions should prevail there. Since these conditions can also occur in nature in a very similar way, it is obvious to orientate oneself on naturally formed plant associations.

Plant substrates should be chosen so that the plants can easily root but should not release phosphorous into the water. The substrate mixture and grain size allow a sufficient oxygen supply of the soil. It should be borne in mind that other factors (e.g., insufficient water depth or lack of light) may not allow the aquatic plants to thrive well.

Vascular plants have ecological preferences with regard to important growth factors, which Ellenberg *et al.* (1992) tried to determine with "pointer values" along a new scale. It should be emphasized that this is the ecological behaviour of the species under the natural conditions of socialization. Since the living conditions of the plants in natural swimming pools are very close to those in natural locations, there is no reason why Ellenberg's pointer values should not be used in natural swimming pool planning.

Schwarzer and Schwarzer (2008) see the quality of the filling water as the most important ecological framework condition for the development of the plant population in natural swimming pools. The plant species used in the natural swimming pools are selected in relation to the initial values of the filling water used. This is done using the information provided by Ellenberg *et al.* (1992) on ecological preference; in particular the *R*-value (according to Ellenberg reaction of the water) and the *P*-value (modified according to Ellenberg, called *N*-value there, nutrient supply). In this way – analogous to Stelzer (2003) in natural waters – a correlation is established between water values and plant selection for natural swimming pool projects. Since the plant species selected according to the *R* and *P* values also have a known plant sociological position, i.e., their natural association with other species, this can also be considered in the elaboration of planting plans, whereby the coexistence of the species in nature is taken into account as far as possible.