DEFINITION AND QUANTIFICATION OF ANTHROPOGENIC INITIAL AND CONTINUAL BIOCHEMICAL BATHING LOAD IN SWIMMING POOLS

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ABSTRACT
Reduction of disinfection by-products (DBP) is one of the main research areas in today's swimming pool studies. Although the focus always has been at the removal of DBP and precursors for DBP present in the pool water, prevention of the DBP formation needs further research. This study focuses on reduction of the anthropogenic bathing load, which is the main source for building blocks for DBP. A standardised method was developed to determine the bathing load based on a shower cabin and definitions for different kinds of bathing loads were formulated. Next to the initial bathing load, the continual bathing load and accidental bathing load are described in this paper. Time series experiments were used to study the initial bathing load and on-site experiments at 4 different swimming pool sites were used to determine the initial bathing load. The initial bathing load was found to be 305 mg/bather for TOC (total organic carbon), 80 mg/bather for TN (total nitrogen) and 1,764 ng/bather for ATP (Adenosine-triphosphate). For the determination of the continual bathing load a standardised method was developed based on a submerged muscular exercise, using an aqua-nordic-walker. The continual bathing load was determined at 439 mg/bather for TOC and 120 mg/bather for TN. It was found that the total bathing load could be reduced by willing bathers with 51% and 74% for TOC and TN load respectively.

Keywords	Bathing load, Pool water treatment, DBP reduction

INTRODUCTION
Swimming pool pollution is mainly caused by bathers. Although there is also a non-anthropogenic bathing load, this paper will focus on the anthropogenic pollutants and will describe definitions for bathing load. In literature, both *bathing load* and *bather load* are used to describe the number of bathers as well as the amount of pollutants introduced by bathers (Powick, 1989; WHO, 2006; Zwiener et al., 2007). Also other descriptions are used like *bather shedding and microbial load* (Elmir, 2009) or *polluting load* (Powick, 1989). These different descriptions are used because there is no clear definition to describe bathing load. Clear definitions are necessary to determine, discuss, predict, manage and control the bathing load.

Bathing load can be divided in many different ways. Figure 1 shows the division by sources, individuals and types. The source of the pollutants can be anthropogenic or non anthropogenic. Anthropogenic bathing load are all pollutants carried into the pool water by human bathers like sweat, urine, hair, cosmetics, but also saliva, vomit and faecal matter. Non anthropogenic bathing load are all pollutants entering the pool water through different routes. These different routes are:

- Introduction of supplement water, which can be refreshment with tap water or reuse of treated backwash water.
- Cleaning activities; chemicals and pollutants removed with chemicals from pool basin walls or pool

surrounding can enter the pool water depending on the cleaning procedures and pool construction.

- Use of materials for the pool water treatment installation and for the construction of the pool basin and storage tanks. Some pollutants can be released from materials like plasticizers from plastics used for the piping of the pool, or calcium from concrete surfaces like uncoated storage tanks, overflow edges and grout spacing between the tiles in the pool.
- Introduction through other routes, like windblown debris in outdoor pools, bird and animal pollutants and dust.

There are also anthropogenic pollutants entering the swimming pool water through different routes, like anthropogenic pollutants on the pool surroundings entering the pool as a result of bad cleaning procedures, or anthropogenic pollutants in reused backwash water due to the poor retention of urea in reverse osmosis membranes. These last anthropogenic pollutants do not count as anthropogenic bathing load because they are not carried actively into the pool by bathers and cannot be influenced by the bathers themselves.

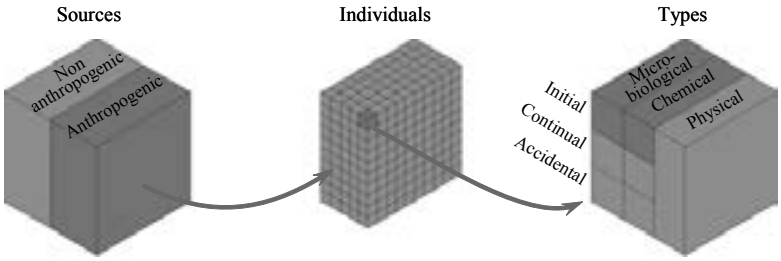

Figure 1 Division of bathing loads

The type of bathing load can also be very different. It can be microbiological, chemical or physical, where physical bathing load is simply the number of bathers in the pool. The physical bathing load can be presented as the number of bathers present in a pool basin at one time or a summation of bathers over a daily or any other period. The physical bathing load must be presented with the periodicity of the load to state clearly what number of bathers is presented. The microbiological bathing load is the sum of all microbiological matter, like bacteria on the bather's skin or hair, or fungi on the pool surrounds, or *Legionella* in the refreshment water. This cannot be one number because it presents different microorganisms. The microbiological bathing load must be presented with its introducer and the name of the concerning microorganism, like *anthropogenic E. coli load*. The chemical bathing load is the sum of all chemical matter, like urea, creatinine and hippuric acid in sweat from bathers, or cleaning chemicals on the pool surrounds, or natural organic matter in refreshment water. The chemical bathing load must be presented with its introducer and the type of chemical, like *anthropogenic urea load*. Finally, the occurrence of the bathing load is a measure of the moment at which the pollutants are released and can be initial, continual or accidental. The initial bathing load is introduced during a short timeframe and will be a matter of minutes when anthropogenic bathing load is concerned but can go up to weeks or months when non anthropogenic pollutants are the issue, like the release of plasticizers from used plastics. The continual bathing load is continuously introduced like sweat release from swimmers or the release of calcium from uncoated concrete surfaces. The accidental bathing load is a result from accidents occurring in the pool, like the release of urine, vomit and faecal matter by bathers, or the introduction of waste water due to a broken pipe passing through the storage tank.

None of the previous divisions for bathing load where found in scientific literature and are introduced by the authors of this paper. Ways to determine, manage and control bathing load also play a role in formulating the definitions for the bathing load. The objective for the study presented in this paper

was to define the different types of bathing load and to quantify the anthropogenic individual initial biochemical bathing load.

When entering a swimming pool, bathers introduce pollutants to the swimming pool water. These pollutants are suspended and colloidal compounds, micro-organisms and soluble substances (Powick, 1989). Suspended solids are substances like skin particles, hair or organic and inorganic substances that float, suspend or settle in the swimming pool water. The suspended and colloidal solids have a big influence on pool water turbidity which should be kept low to visually detect early cases of drowning. Micro-organisms can get into the pool water in different ways. Faecal-derived micro-organisms enter the water when a person has an accidental faecal release (WHO, 2006). Non-faecal human micro-organisms enter the pool as skin that has been shed, saliva, mucus or vomit (WHO, 2006). Some bacteria can accumulate in biofilms and from there recontaminate the swimming pool water. Soluble substances can be divided into organic and inorganic material. Organic matter consists of substances such as ammonium, urea, creatinine, lactic acid and amino acids. Inorganic matter includes substances like chloride, sodium, potassium, calcium and sulphate (Kuno, 1956). These soluble substances can be either precursors for disinfection by-products or nutrients for micro-organisms and are introduced from the bather's hair, skin, sweat and bathing wear, but also from accidental releases of urine, faecal matter or vomit.

The control and management of biochemical bathing load is an important aspect of pool water quality control. It is however unclear what the results of specific acts are, such as pre-swim showering or wearing a swim cap. On the other hand it is a matter of common sense to know that pre-swim showering and wearing a swim cap does reduce the individual bathing load. Although having a pre-swim showering is part of most Dutch swimming pool's policies, supervision on the actual pre-swim showering is not well maintained. This is the same for almost all other countries. Iceland is the exception that proves the rule. In Iceland, pre-swim showering is also mandatory, but in addition bathers have to take a nude shower and pool staff will send bathers back that didn't shower. Wearing a swim cap is not obliged in Dutch pools. Wearing a swim cap used to be obliged in Germany until the '80s, and is still obliged in many pools in Italy or Russia. Whereas pre-swim showering is originated from a hygienic point of view, wearing a swim cap is not. Swim cap is used to prevent hair from getting into the technical installations where they could not be removed easily.

Control of anthropogenic biochemical bathing load of a swimming pool can be obtained by influencing the biochemical bathing load per bather or adjusting the occupancy rate of the swimming pool. Because adjusting the occupancy rate is mostly not desirable, reducing the bathing load per bather should be the focus. Before focusing on ways to reduce the personal biochemical bathing load, clear definitions of the biochemical bathing load are needed. As mentioned before, anthropogenic biochemical bathing load can be divided in three parts:

- initial biochemical bathing load (L_{ibc});
- continual biochemical bathing load (L_{cbc}), and;
- accidental biochemical bathing load (L_{abc}).

The total anthropogenic biochemical bathing load (L_{tbc}) is the sum of the three parts;

$$L_{tbc} = L_{ibc} + L_{cbc} + L_{abc}$$

The initial biochemical bathing load is the amount of pollutants that enter the pool during the first period of swimming. The initial biochemical bathing load can very easily be reduced by pre-swim hygiene, e.g. showering, or wearing a swim cap. This initial biochemical bathing load consists of residue of evaporated sweat and pollutants on the skin. The pollutants are produced during pre-swim activities of the bather. The pollutants are also added on the skin by the bathers themselves like cosmetics or hair products.

The continual bathing load is the amount of pollutants that enter the pool after the first period of the remaining swimming visit. This load is mainly determined by a swimmer's type of pool activity (i.e. level of exercise), the pool water temperature, the percentage of the body submerged and the duration of the visit. The continual bathing load consists mainly of sweat and skin particles. The continual bathing load is less compliant than the initial bathing load. Influencing the continual bathing load means

influencing the bather's activities, the pool water temperature or the duration of the visit.

Like its name, the accidental bathing load refers to the amount of pollutants that enter the pool during accidents like faecal, urine and vomit release. Accidental release is caused by behaviour as well as accidents. Both can be prevented through information provided to bathers and swimming pool staff, but cannot be eliminated entirely.

Although there have been many publications on reduction of disinfection by-products in swimming pools since Rook published the existence of trihalomethanes in 1977 (Rook, 1977) there is only limited information about bathing load. Recent literature, published in the last 10 years, with data on biochemical bathing load reduction is not available. This is remarkable because reduction of the bathing load is an important factor for the reduction of disinfection by-products (Borgmann-Strahsen, 2003; Eichelsdörfer, 1980; Hery, 1995; Lahl, 1981; WHO, 2006; Zwiener et al., 2007).

Previous research on biochemical bathing load was mainly conducted with bathtub experiments. The data from previous investigations, shown in table 1, are dated and seem scattered. However, evaluating the historical data with the results of this study shows a lot of similarities. Klosterkötter reported two experiments, one in which sauna visitors were rinsed and another monitoring a non-chlorinated swimming pool with a dynamic bathing load for 9 hours (Klosterkötter, 1964). During the sauna experiment, 5–84 mg/bather urea was collected, this corresponds with 2.3–39.2 mg N/bather and 3–56 mL of sweat/bather. The initial bathing load within this paper contains 11–359 mg N/bather. This implicates that the initial bathing load represents a significant amount of N, nearly 10 times more then the urea load after a sauna visit. Collection of all the produced sweat after visiting a sauna is easily disturbed. Droplets of sweat can get lost during the walk from the sauna to the rinsing area. If loss of bodymass during the sauna visit is not measured, total sweat production can not be estimated acurately. The second experiment discribed by Klosterkötter concerned a non chlorinated pool where 918 bathers used the pool during a 9 hour period and samples of the pool water were taken periodically. During this experiment it was found that the urea release was much higher compared to the sauna experiment, namely 400–1,200 mg urea/bather corresponding with 186–559 mg N/bather and a sweat production of 0.27–0.8 L/bather. Considering the experiment took place in a 26°C pool, its not likely that the sweat production reaches this high. Its therefore more likely that during this experiment also some accidental urine release occured. Accidental urine release is estimated at 25–50 mL per bather, this corresponds with a urea release of 400–800 mg urea/bather which is within the range of the data from Klosterkötter, leaving some room for some sweat release.

To measure the disinfection byproduct formation of bathers, Eichelsdörfer used a bathtub experiment to rinse participants in a 500 L bathtub at 35°C for 20 minutes (Eichelsdörfer, 1980). The results of these bathtub experiments show a 1.8–7.2 g/bather $KMnO_4$ consumption release and a 0.5–1.4 g/bather DOC release. Compared to the initial DOC load of this paper, 0.03–1.0 g/bather, the results are comparable. As shown in the lab experiments most of the initial bathing load is already removed after 60 seconds of showering, presumably equally during a bathtub. It is also likely that participants have an increased sweat production during a 20 minute bathtub at 35°C because the human body is not cooled enough.

Experiments of Althaus took place in a hot whirl pool at 38°C for 15 minutes with showered and unshowered participants (Althaus, 1981). Although the duration of the shower was not mentioned in the publication, the bathing load measured was 320 mg/bather for TOC load and also 320 mg/bather for the organic N load. The TOC load is in the same range as the results of this paper (305 mg/bather) but the TN load varies from that of this paper (80 mg/bather). It is not clear what causes this difference. The bathing load from the showered participants in the Althaus experiment represents more or less the continual bathing load. A continual bathing load of 1.01 g N/bather within 15 minutes corresponds to a sweat release of 1 L implicating a sweat production of 4 L/h. Even considering the hot water temperature of 38°C, this is a very high sweat production. Variation between all of the participants in the Althaus experiment was very small. If there was a nitrogen source other than sweat in the Althaus experiment, it had to be almost equally for all participants. It is therefore not likely that accidental urine release took place during this experiment.

During the VROM experiments, bathtub as well as pool experiments were conducted (VROM, 1985). During the bathtub experiments 15 participants were asked to bath in a bathtub at 30°C for 15 minutes.

The measured $KMnO_4$ consumption of 1,100 mg/bather corresponds with a TOC load of 305 mg/bather. Although it corresponds exactly with the results in this paper (305 mg/bather) there is a difference because the participants in the VROM experiment did not wet their hair. This implicates that the amount of pollutants on the head is comparable with the amount of pollutants released during the 14 minutes after the 60 seconds of initial bathing load. The nitrogen release of 250 mg/bather on the other hand is significantly higher than the results presented in this paper (80 mg/bather). Reducing the nitrogen release found in the VROM experiments with the 80 mg/bather initial TN load, the remaining 170 mg/bather nitrogen load corresponds with a sweat release of 170 mL/bather within 15 minutes implicating a sweat production of 680 mL/h. During a second bathtub experiment, Dutch and German standards for determining $KMnO_4$ consumption were evaluated. Dutch and German analyses of $KMnO_4$-consumption were found to be dissimilar during the 1980s. The analysis according to German DIN 38409 H4 showed a 20% higher output than the Dutch analysis according NEN 6491 (VROM). Since 1993, both German and Dutch laboratories work according to (DIN or NEN)-EN-ISO 8467 for the analysis of $KMnO_4$ consumption with comparable results. The results found in this evaluating bathtub experiments show a 1,200 mg/bather $KMnO_4$ consumption load after a 20 minutes bathing in a 500L bathtub at 30°C. This KMn04 consumption load corresponds with a 333 mg/bather TOC load. These results are in line with the results of this paper (L_{iTOC} = 305 mg/bather). Combining the VROM data with the results of this paper estimates an initial bathing load of 305 mg TOC/bather (91%) remaining 28 mg TOC/bather for continual bathing load (9%). This 9% continual bathing load corresponds with a sweat release of 50mL within 20 minutes implicating a sweat release of 150 mL/h. A third study described in the VROM report covered a non chlorinated pool experiment where juvenile and adult bathers swum for 1 hour in respectively 30°C and 26°C pool water (VROM, 1985). During the experiment there was no chlorination and also no filtration, but the recirculation was operating normally to have a regular hydraulic mixing in the pool. The measured $KMnO_4$ load of 500 and 1,600 mg/bather for respectively adult and juvenile bathers corresponds with a TOC load of resp. 138 and 444 mg/bather. The measured urea load of 250 and 750 mg/bather for respectively adult and juvenile bathers corresponds to a sweat release of respectively 170 and 500 mL/bather. For the adults, swimming in 30°C pool water, this sweat production of 170 mL/h is rather low considering they have been swimming, not resting. For the juveniles the sweat release of 500 mL/h is rather high, considering a water temperature of 26°C. It is more likely that the juvenile urea release originates mainly from urine, corresponding with approximately 50 mL urine/bather. The sweat/urine release implicates a TOC load of respectively 83 and 420 mg/bather originating from the urea release. Remaining is resp. 55 and 24 mg TOC/bather from a non-urea source. Combining the results with the results of this paper shows a low bathing load, possibly due to a pre-swim shower they might have used (it is not mentioned in the publication). It is also likely that there is biofilm activity on grout spacing and concrete buffer tank walls removing nutrients like carbon and urea from the recirculating pool water resulting in lower measured concentrations.

During another study, shower as well as bathtub experiments were conducted (Keltjens, 1987). The first part of the experiments was a bathtub experiment with 22 participants resulting in a KMn04 consumption load of 1,150 mg/bather, corresponding with a TOC load of 319 mg/bather. All 22 participants did not use a shower before entering the experiment. The TOC load found is low compared to the results of this paper (LiTOC=305 mg/bather) considering the participants have been bathing in 30°C water for 15 minutes and periodically fully submerged. The second part of the experiment was a combined shower/bathtub experiment. Participants first had a 5 minute shower (all shower water was collected) and secondly entered a bathtub experiment. The KMn04 consumption load collected in the shower experiment was 720 mg/bather corresponding with TOC load of 200 mg TOC/bather. The KMn04 consumption load of the following bathtub experiment was 430 mg/bather corresponding with a TOC load of 119 mg TOC/bather. Compared to the results of this study, the initial bathing load in the Keltjens shower experiment was low, 200 versus 305 mg/bather. The continual bathing load of 119 mg TOC/bather corresponds with a sweat release of 239 mL, implicating a sweat production of 956 mL/h. This is rather high considering the low level of exercise (only bathing) and the water temperature of 30°C.

The methodology used in most of these previous experiments was not standardised and was not very well documented, making reproduction of these data impossible. Comparison of the data with the

results from this paper was done with the use of additional data of the sweat and urine composition, shown in table 2. In addition to that, there is no (or only a little) additional information about the participants, like gender and age or hours since last shower, etc. Reports on correlations between different parameters or between parameters and data on a person's hygienic state could not be found in the scientific literature.

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Table 1 Historical data on chemical bathing load

Research	n	$KMnO_4$-consumption mg/bather	DOC mg/bather	Urea mg/bather	Kjeldahl-N mg/bather
(Keltjens, 1987)	$9^{se, up}$	720			
	$9^{be, sp}$	430		185	
	$22^{be, up}$	1,150			
(VROM, 1985)	$15^{be, ap}$	$1,100^{N}$		185	250
	6^{be}	$1,200^{N}/1,400^{D}$			
	$40^{pe, ap}$	500		250	
	$120^{pe, jp}$	1,600		750	
(Althaus, 1981)	$6^{be, up}$	6,640	$1,850^{T}$		1,330
	$20^{be, sp}$	5,440	$1,530^{T}$		1,010
(Eichelsdörfer, 1980)	8^{be}	1,800-7,200	500-1,400		
(Klosterkötter, 1964)	20^{be}			5-84	
	918^{pe}			400-1,200	
^{be} bathtub experiment ^{pe} non chlorinated pool experiment ^{se} shower experiment		^{jp} juvenile participants ^{ap} adult participants		^{sp} showered participants ^{up} unshowered participants	
^{N} analysis according to Dutch standard NEN 6491 ^{D} analysis according to German standard DIN 38409 H4				^{T} TOC concentrations	

Very little historical data was found on microbiological bathing load. Some publications describe outbreaks of different kinds of micro organisms, but the microbiological bathing load of swimming pools is yet not well investigated. Table 2 shows a summary of the studies found. Comparing the results from the historical data with the findings of this paper, show similar results for colony number and *E. coli*, slightly different results for Enterococci different results for Staphylococci. The introduction of these microorganisms have a different origin, *E. coli* and Enterococci are faecal derived and staphylococci are non faecal derived, although also present in faecal matter (WHO, 2006).

Table 2 Historical data on microbiological bathing load

Research Parameter n	(Elmir, 2009) 10^{ap}, 14^{tp}	(Elmir, 2007) 10^{ap}	(VROM, 1985) $15^{be, ap}$	(Althaus, 1981) $6^{be, up}$, $20^{be, sp}$
Colony number (n/bather)			10^8–10^9	$1.5 \cdot 10^{10}$ be, up $7.7 \cdot 10^9$ be, sp
Coliforms (n/bather)			10^6–10^7	$1.4 \cdot 10^5$ be, up $1.5 \cdot 10^6$ be, sp
E. coli (n/bather)				$6.6 \cdot 10^4$ be, up $2.1 \cdot 105$ be, sp
Staphylococci (n/bather)		$6 \cdot 10^6$		0 be, up 0 be, sp
Streptococci (n/bather)				$6.6 \cdot 10^5$ be, up $1.6 \cdot 10^5$ be, sp
Ps.aeruginosa (n/bather)				0 be, up $9.9 \cdot 10^4$ be, sp
Clostridium (n/bather)				0 be, up 0 be, sp
Cand.albicans (n/bather)				0 be, up $2.5 \cdot 10^3$ be, sp
Enterococci (n/bather)	5.8·105 ap $8.2 \cdot 10^4$ tp	6·105		
be bathtub experiment	tp toddler participants ap adult participants		sp showered participants up unshowered participants	

The objective of this study is to determine the initial and continual biochemical bathing load for individuals, and to state out definitions for these types of bathing load.

MATERIAL AND METHODS

STANDARDISED SHOWER CABIN

A specially prepared shower cabin was used in the experiments to perform standardised shower experiments. This shower cabin (mf. Hellebrekers Technieken, Nunspeet, The Netherlands) consists of a shower base, a framework, shower curtain and a shower nozzle. The polypropylene shower base had a footprint of 0.7 x 0.7 m, and a height of 0.2 m. The shower base drain was fitted with a screw plug. The framework for supporting the shower curtains and shower nozzle was constructed from aluminium piping.

The shower curtains were attached with acrylic rings and black tape to the aluminium framework. The shower curtains were hanging inside the shower base to avoid leakage of shower water. The shower nozzle (Raindance AIR 180 mm, Hansgrohe) was also attached to the aluminium framework at a height of 2.1 m from the shower base (Figure 2). The water flow through the shower nozzle was monitored with a flow indicator (DFM 350 150–1,500 L/h, ASV Stübbe) and varied, pending on the water pressure, between different locations from 6–12 L/minute. The special shower nozzle with a large diameter provided a rain shower instead of a jet shower. This rain shower was chosen to focus on the rinsing effect of water towards pollutants on the skin, comparable with the rinsing effect of bathing. The standardised shower cabin was used for time series experiments as well as on site shower experiments.

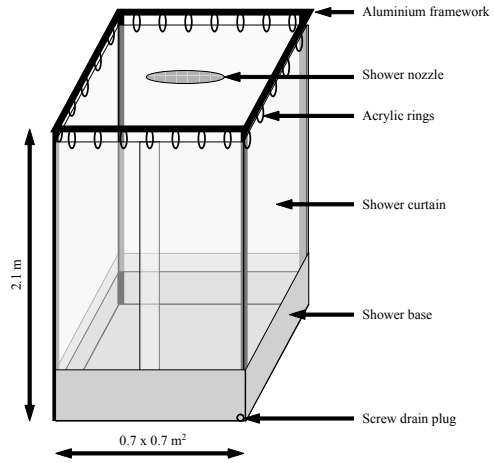

Figure 2 Schematic diagram of shower cabin

STANDARDISED EXERCISE EXPERIMENTS

To determine the continual bathing load, a standardised exercise experiment was developed. For this experiment an Aqua bike (Eyeview systems, Oss, The Netherlands) and an Aqua-Nordic-walker (Kodin GmbH, Gundelsheim, Germany) were used. All experiments were conducted submerged, for this a small polypropylene pool tank was build with recirculation and heating (mf. Hellebrekers Technieken, Nunspeet, The Netherlands). The inside dimensions of the pool tank were 1x2 m footprint and 1.8 m height. The recirculation pump had a capacity of 15m^3/h and the two electrical heaters equipped with a thermostatic control to set the temperature had a maximum heat exchange of 24kW each. The setpoint of the water temperature could range from cold water temperature without heating (10-20°C) up to 40°C. The pool tank was equipped with a water counter to determine the exact water volume in the pool for the experiment.

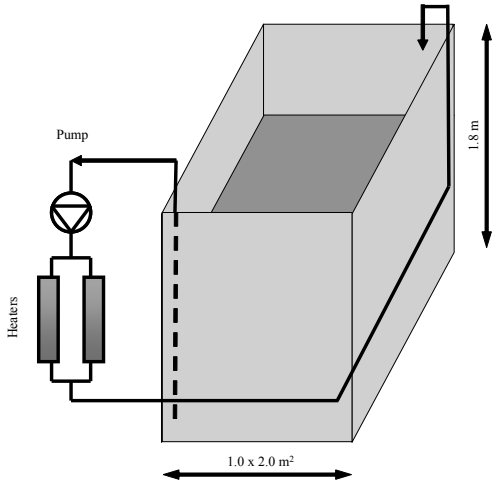

Figure 3 Schematic diagram of cycling tank

TIME SERIES EXPERIMENTS

Time series experiments were conducted in the standardised shower cabin situated at the laboratory at Delft University of Technology. The standardised shower cabin was set on a slight slope (2%) towards the shower base drain to avoid water build-up in the shower base during the experiment. During the time series experiment samples were taken chronologically from the shower bases, with the use of a closable hose connected to the shower base drain. The first 10 samples were taken in 500 mL bottles, which was roughly every 6 seconds; the following samples were taken in 1L bottles. During each shower event, 18-20 water samples were taken. The time series experiment was performed with 12 different participants. The shower water was normal drinking water. This drinking water was distributed without the use of a residual disinfectant according to Dutch drinking water standards, resulting in the absence of disinfection by-products. To avoid the risk of a *Legionella* or other microbiological contamination, all shower water was treated with thermal disinfection. This thermal disinfection was based on a pasteurisation installation for the cold tap water and a boiler for the hot tap water. The pasteurisation installation was designed to heat the cold tap water in a boiler up to a safe temperature-time combination. After pasteurisation, the tap water was cooled down to cold tap water level in a heat exchanger, exchanging heat with the incoming cold tap water. All hot tap water for the shower experiment was also thermally treated in a boiler up to the same safe temperature-time combinations. The cold and hot tap water was then mixed with a thermostatic valve ensuring a constant water temperature during the shower experiments. Before using the standardised shower cabin for an experiment, the shower hose and shower nozzle were disinfected thermally, again according to safe temperature-time combinations. Instead of filling the sample bottles exactly to the 500mL or 1L mark, the exact water volume was determined by weighting the sample bottles before analysis and after emptying. The shower time varied between different participants from 2-5 minutes. A questionnaire was used to collect both general and hygienic information of the participants.

ON-SITE EXPERIMENTS AT SWIMMING POOLS

On-site experiments were conducted with the standardised shower cabin at 4 different public swimming pools; Sportfondsenbad in Delft (n=30), Sportfondsenbad Meerkampsering in Rotterdam (n=59), Dol-fijn in Maassluis (n=25) and Twentebad in Hengelo, outdoor pool (n=27). The standardised shower cabin was placed in the shower area of the swimming pools and connected to the pool's automated shower system. The pool's shower systems were connected to the municipal drinking water system. This drinking water was distributed without the use of a residual disinfectant. To avoid the risk of a Legionella or other microbiological contamination, the automated shower system was weekly disinfected thermally at safe temperature-time combinations according to Dutch drinking water standards. Activation of the shower was done with a wall mounted approaching sensor which is commonly used in Dutch swimming pools. To avoid reactivation of the shower after an experiment, the sensor was covered with a piece of black plastic. The shower system was equipped with a thermostatic valve where cold and hot tap water was automatically mixed to ensure constant water temperature during the experiment. The shower time was different at all locations because of the location's own set points. During the on-site experiments, the shower base drain was closed, resulting in an average water sample per participant. Although hanging inside the shower base, the shower curtain was also taped to the outside of the shower base to avoid contamination of the shower with shower water from the nearby showers. The outdoor pool experiment took place during a tropical Sunday with a maximum air temperature of 34°C. A questionnaire was used in all experiments to collect both general and hygienic information of the participants.

CONTINUAL BATHING LOAD EXPERIMENT

The continual bathing load experiments were conducted at the laboratory of Delft University of Technology. After cleaning the pool tank, the tank was filled with normal drinking water (no residual disinfectant) and the recirculation and heating started to control the water temperature. Participants entering the continual bathing load experiment had a 5 minute shower to remove all initial bathing loads before entering the pool tank. Inside the pool tank the participants conducted a sub maximal physical effort for 30 minutes. During the experiment, the participants heartbeat and body temperature were monitored.

Participants were weighted 5 times during the experiment using a high precision weight scale (JBS IP68 loadcell, 5 g accuracy, mf. BWT, Boxtel, The Netherlands): dry, after showering, twice during the experiment and after the experiment to monitor changes in body weight induced by intensive sweating. After the experiment participants filled out a questionnaire to gain general and hygienic information from the participants.

SHOWER AND SAMPLING PROCEDURES

The on-site experiments were not announced to the bathers, so the bathers were not prepared for the shower experiment or the questionnaire. Participants in the time series experiment and continual bathing load experiments were randomly selected, participants in the on-site experiments were asked to participate in the experiments voluntarily.

Figure 4 Setup continual bathing load

PRE-SHOWER PROCEDURE

Before each shower experiment, both time series and on-site experiments, the shower cabin was prepared as follows:

- Draining the shower base by removing the screw drain plug (only during field experiments);
- Rinsing the shower cabin, curtain and base with normal shower water, using a garden sprayer (mf. Gardena; classic fine sprayer). The garden sprayer was also thermally disinfected at a safe temperature-time combination before use;
- Disinfecting the shower base by spraying a 70% alcohol solution on the shower base and lower 20 cm of the shower curtain with a reaction time of 2 minutes, after which the shower drain was rinsed twice to remove all alcohol residue (only before microbiological sampling);
- Draining the shower base again, leaving only some drops of water, and;
- Replacing the screw drain plug (only during field experiments).

SHOWER PROCEDURE

During the time series experiments, all participants entered the experiment unshowered, wearing normal swim suites and were barefooted. To avoid collection of dust from the surrounding lab by walking barefoot from the changing room to the shower cabin, the participants wore bathing slippers. After entering the cabin, the shower curtain was closed and hung inside the shower base. During the experiment some participants were asked to stand still as others were asked to rub their body. Showering time was varying

from 2–5 minutes, and shower volume flow was determined before and after each experiment. After showering, the participants were asked to leave the shower cabin and fill out a questionnaire.

During the on-site experiments, some of the participants were asked to use a regular shower before entering the shower cabin, while others entered the shower cabin unshowered. Figure 5 shows one of the participants in the shower cabin. All participants entered the shower cabin barefooted. After entering the cabin, the shower curtain was closed and hung inside the shower base. The shower was activated by approaching the infrared sensor. Some participants were asked to use a bathing cap in the shower cabin. After showering, the participants were asked to leave the shower cabin and fill out a questionnaire.

SAMPLING PROCEDURE

Immediately after each shower experiment samples were taken and stored in iceboxes. The samples were transported to a laboratory within 24 hours after sampling. Regularly (before and after) blank samples were taken to determine the local tap water quality. After every sampling procedure, the pre-shower procedure was executed to prepare the shower cabin for the next participant. At the end of the day, again a blank sample was taken to determine the possible accumulation of pollutants in the shower cabin.

Figure 5 Participant using the shower cabin

QUESTIONNAIRE

The visitors who participated in the shower experiments were asked to fill out a questionnaire. The questionnaire was divided into four parts. The first part contained general questions, like; gender, age, weight, hair length, types of swimsuits, put on swim suit at home or at pool, wearing underwear beneath boxer short, wearing bathing cap and hair wet during swimming. The second part of the questionnaire contained personal hygiene related questions like: hours since last shower, hours since last hair wash, recent activity or exercise and normal use of shower before swimming. The third part of the questionnaire contained cosmetics related questions like: use of make-up and type, use of hair products and type, use of body or suntan lotion, use of deodorant and use of perfume. The final part of the questionnaire contained health related questions like: estimation of personal health and complaints concerning skin, stomach/intestine and ear. The questionnaires were undertaken anonymously and were marked as the samples with the participant number.

ANALYTICAL METHODS

Samples were analysed chemically and microbiologically. A different set of parameters was used in each field experiment in order to find the best combination of both chemical and microbiological parameters. During the time series experiments, the initial set of parameters was reduced after observing a high cor-

relation between different parameters. All results were corrected with the values of the blank samples to visualise the anthropogenic bathing load only.

$KMNO_4$-CONSUMPTION

$KMnO_4$-consumption is determined according to NEN-EN-ISO 8467 (NEN, 1993b). The water samples are heated with a known amount of potassium permanganate and sulphuric acid for a fixed period of time. Part of the permanganate is reduced by oxidizable material in the samples and is determined by adding an excess of oxalate solution, followed by titration with permanganate. The results are presented as mg $KMnO_4$ per litre.

TOC, DOC AND POC

Total Organic Carbon (TOC) and Dissolved Organic Carbon (DOC) are determined according to NEN-EN 1484 (NEN, 1997b) using a Shimadzu TOC-Vcph analyser. The water samples for DOC analysis are filtered through a 0.45µm filter to remove particles. Next, the samples are acidized and purged to remove CO_2. Then, samples are injected in an oven at 680°C to oxidise all carbon into CO_2. To determine CO_2, infrared spectrometry is used. High concentrated samples were analysed with a stirring rod in the analyser vial, ensuring a homogeneous sample at the moment of injection. Particulate Organic Carbon (POC) is calculated from the difference between TOC and DOC. The results are presented as mg carbon per litre.

UREA

Urea is determined according to NEN 6494 (NEN, 1984). Urea is converted with urease into ammonium and CO_2; α-ketoglutarate is converted by ammonium with an excess of glutamatedehydrogenase (GLDH) and reduced by nicotinamide-adenine-dinucleotide (NADH) into L-glutamate. The NADH is spectrophotometrically determined and corresponds with half the amount of urea in the original sample. Results are presented as mg urea per litre.

KJELDAHL-N

Kjeldahl-N is determined according to NEN-ISO 5663 (NEN, 1993a). The water samples are mineralized with sulphuric acid to form ammonium sulphate, from which ammonia is released and distilled for subsequent determination by titration with standard acid. The results are presented as mg N per litre.

TN, DN AND PN

Total Nitrogen (TN) and Dissolved Nitrogen (DN) are determined according to NEN-EN 12260 (NEN, 2003) using a Shimadzu TNM-1 analyser connected to the Shimadzu TOC-Vcph analyser. The water samples for DN analysis are filtered through a 0.45µm filter to remove particles. The samples are injected in an oven at 720°C where nitrogen compounds are converted to nitric oxide (NO). Nitric oxide reacts with ozone, emitting light which is detected by a chemiluminescent detector. Particulate Nitrogen (PN) is calculated from the difference between TN and DN. Results are presented as mg nitrogen per litre.

UV 254

For UV absorption, the water samples are placed in a lab analyser (mf. Scan, sensor spectrolyser A-2100-485p0t00-sN0) where UV adsorption is measured at 254nm. Results are presented as Abs/m. High concentrated samples are diluted with demineralised water, results are corrected for dilution.

TURBIDITY

Turbidity is determined according to NEN-EN-ISO 7027 (NEN, 1999) using a Hach 2100p turbidity analyser. Results are presented as FNU.

CHLORIDES

Chloride is determined according to NEN 6470 (NEN, 1997a). The water samples with an excess of chromate are titrated with silvernitrate. Results are presented as mg chloride per litre.

ATP
Adenosine-triphosphate (ATP) is determined with a test kit from Aquatools based on bioluminescence. The water samples are filtrated to concentrate the intracellular ATP (cATP). The cATP is then extracted from the filter with a trisodiumphosphate solution. After dilution of the extracted cATP, the dilute is added to a luciferine/luciferase complex and placed in a luminometer. Results are presented as pg cATP per millilitre. The manufacturer of the test kit provided an approximately relationship between ATP and bacterial counts. According to the manufacturer of the test kit 1pg cATP is interpreted as 1,000 colony forming units (CFU).

PARTICLE COUNTING
Particle counts are determined with a Pacific scientific particle counter using a syringe operated sampler Hiac Royco Model 3000 with a sensor Hiac HRCD-400 HC (2-400µm) and sizing counter Hiac Royco Model 9064. Results are presented as total number of particles per millilitre. High concentrated samples are diluted with demineralised water, results are corrected for dilution.

ESCHERICHIA COLI
The *E. coli* samples were analysed using NEN-EN-ISO 9308-1. Analysis was done by RIVM, Bilthoven, The Netherlands (National Institute for Public Health and the Environment).

ENTEROVIRUSES
The Enteroviruses samples were analysed according to NEN-EN-ISO 7899-2. Analysis was done by RIVM.

STAPHYLOCOCCUS
The Staphylococcus samples were analysed using ISO 6888-1 with a slight modification described in SOP LZO/M127. Analysis was done by RIVM.

MATHEMATICAL CALCULATIONS

CALCULATION OF BATHING LOAD
The individual bathing load is calculated from concentrations to load. The results from the time series experiments were calculated according to:

where:
$L_i=(C_i-C_b)xV_i$

L_i = bathing load in sample i (mg)
i = sample number during time series sampling (-)
C_i = concentration in sample i (mg/L)
C_b = concentration in blank (mg/L)
V_i = volume of sample i (L)

The total bathing load during the time series experiments was calculated as:

$$\sum_{i=1}^{n} L_i$$

where:
n = number of samples during time series experiments (-)

The bathing load from the field experiments with closed shower base drain were calculated according to:
$L=(C_p-C_b)xV_s$

where:
L = participant's specific bathing load, e.g. L_{Kmn04} as the $KMnO_4$-consumption load (mg/bather)
C_p= concentration in participant's shower sample (mg/L)
C_b= concentration in blank (mg/L)
V_s= volume of showering event (L)

Calculation of the bathing load of a short timeframe within the chronological sampling dataset was done by linear interpolation with the nearest sample results. As the shower time was not equal in all on-site experiments, extrapolation of the bathing load was done according to:

$$L_y = L_x \times \frac{\bar{L}_{yc}}{\bar{L}_{xc}}$$

where:
L_y = bathing load in time frame y; f.e. L_{0-60} is bathing load in first 60s (mg/bather)
L_x = bathing load in time frame x; f.e. L_{30-60} is bathing load between 30-60s (mg/bather)
$\bar{L}_{yc}$ = mean bathing load of time series experiments in time frame y; f.e. 0-60s (mg/bather)
$\bar{L}_{xc}$ = mean bathing load of time series experiments in time frame x; f.e. 30-60s (mg/bather)
This last transposing calculation was only used between high correlated results (r^2>0.9).

For calculating the urea and nitrogen concentrations in sweat and urine, the concentrations shown in table 3 are used.

Table 3 Urea, nitrogen and carbon concentrations in human sweat and urine

	Urea	Total nitrogen	Total carbon
Sweat (Gunkel, 1986; Kuno, 1956)	1.5 g urea/L	1.0 g N/L	0.5 g C/L
Urine (Gunkel, 1986; Putnam, 1971)	16 g urea/L	9.0 g N/L	6.4 g C/L

For calculation of the TOC load from the KMn04 load, the following calculation factor was used (Althaus, 1981; Eichelsdörfer, 1980).
$L_{KMn04} = 3.6 \times L_{TOC}$

where:
L_{KMn04} = $KMnO_4$ consumption load (mg/bather)
$_{LTOC}$ = TOC load (mg/bather)

Calculation of relative bathing load

For the time series experiments, the relative bathing load is calculated according to:

$$L_{\%i} = \frac{L_i}{L_1}$$

where:
$L_{\%i}$ = relative bathing load of sample i (-)
L_1 = bathing load of the first sample (mg)

STATISTICAL ANALYSES
Results are assumed to be from random samples. Results from participants wearing a bathing cap during the experiment were not included in the statistical analysis unless specifically mentioned.

Samples were tested for outliers by determining Leverage values and Cook's distances. A closer exam-

ination was done when Leverage values > 0.5 and Cook's distance > 1. The results from the questionnaires were also used to evaluate the outliers. If the outliers were found to be unreliable, they were excluded from the data set.

To find correlations between water quality data, all data was submitted to mathematical software. Within this software, descriptive statistics and the Mann-Whitney test were used to find significant correlations. Correlations are statistically significant when $p < 0.05$. The strength of a correlation between two parameters is given by the coefficient of determination: r_2. An $r_2 \geq 0.64$ or 0.9 indicates a strong respectively very strong relationship between two correlated parameters. This means that 64%, 90% respectively of the values of this parameter can be explained by the results of the correlated parameter.

NUMBER OF PARTICIPANTS

TIME SERIES EXPERIMENTS

For the time series experiments staff and students at Delft University of Technology were asked to participate. 5 Male and 3 female participants joined the experiments.

ON-SITE EXPERIMENTS

For the on-site experiments, average pool visitors were asked to participate in the experiment and use the shower cabin. The selection criteria of pool visitors participating in the research were:

1. Near equal gender distribution
2. Near equal age distribution

A near equal gender distribution is likely for all pool visitors. A near equal age distribution, however, is not likely because lots of children took swimming lessons at these specific swimming pools. Near equal age distribution was chosen to find information on the bathing load of different age categories. Although aiming on a near equal gender and age distribution, in practice this was not gained. All participants were handled anonymously. Each participant was given a unique number, which was also used to label the samples and questionnaires. In total 92 bathers participated in the indoor field experiments (52 male, 34 female and 6 parent+baby) and 27 bathers participated in the outdoor field experiments (15 male and 12 female).

CONTINUAL BATHING LOAD EXPERIMENTS

For the continual bathing load experiments staff and students at Delft University of Technology were asked to participate. The continual bathing load experiment was done with male participants.

RESULTS AND DISCUSSION

TIME SERIES EXPERIMENTS

A typical graph of the time series experiments is given in figure 6. During the first part of the shower experiment, a fast decrease of the concentration can be observed. After 60 seconds, the reduction of the bathing load is still ongoing, but on a reduced rate. A fast decrease of all other parameters during the time series experiments can also be observed.

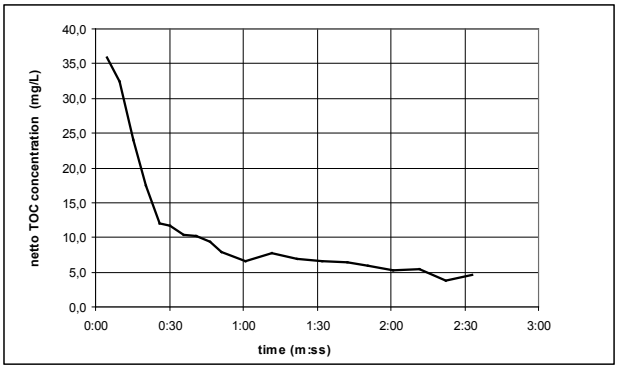

Figure 6 Trend of TOC concentration in each sample bottle for participant A

Table 4 shows the average results of the TOC and TN load in different time frames within the time series experiments for all participants. Because there are no clear definitions for bathing load, it's not clear what time frames should be included or compared. The authors of this paper choose the 15, 60 and 120 second time frames as a first step towards a well grounded definition for bathing load. The bathing load released within the first 15 seconds is very large for TOC and TN, 36% and 42% of the bathing load released within 120 seconds respectively. An almost equal bathing load is released during the following 45 seconds for TOC and TN, 37% and 42% respectively. During the last time frame of 60 seconds, the bathing load is reduced to 27% and 20% of the bathing load within 120 seconds for TOC and TN respectively. According to the results shown in table 3, the reduction of TN compounds during the shower occurs faster than the reduction of TOC compounds. The TOC/TN ratio within the bathing load results do not correspond with the TOC/TN ratio of sweat shown in table 3, where the TN amount equals twice the TOC amount. This implicates a TOC source other than sweat within a swimmer's bathing load. According to the TN results and normal sweat composition, only 11% of the TOC load found in the samples could be originating from sweat.

Table 4 Timeframe results from TOC and TN during time series experiments

Parameter	Time frame (s)	TOC and TN	% of L_{0-120}	Release rate (mg/bather/s)
TOC (mg/bather)	0–15	105	36%	7.0
	15–60	107	37%	2.38
	60–120	80	27%	1.33
TN (mg/bather)	0–15	28	42%	1.87
	15–60	25	38%	0.56
	60–120	13	20%	0.22

Table 5 shows the results of cATP and particle counting in the same time frames shown in table 4. The reduction of cATP load during the first time frame of the experiment is even larger than the reduction of TOC and TN and values 54% of the total cATP load released in a 120 second shower. In contradiction to this, the reduction of particles is much less progressive. During the first 15 seconds 28% of the total particle counting release within 120 seconds was released. During the 15–60 and 60–120 seconds time frames the particle load increases from 32% to 39% of the total particle load released within 120 seconds

respectively. Although it looks like an increase at first glance, the release rates are reduced every next time frame, but not as progressive compared to the cATP reduction.

Table 5 Timeframe results from ATP and particle counting during time series experiments

Parameter	Time frame (s)	cATP and Particle count	% of L_{0-120}	Release rate (ng/bather/s) and (#/bather/s) resp.
cATP (ng/bather)	0–15	1,034	54%	68.9
	15–60	607	32%	13.5
	60–120	276	14%	4.6
Particle count (#/bather)	0–15	67·106	28%	4.47·106
	15–60	76·106	32%	1.69·106
	60–120	93·106	39%	1.55·106

The relative bathing load is shown in figure 7. This graph shows that the parameters TOC, TN, POC, PN and ATP are reduced to 80% of its original concentration after 30 seconds of showering. Reduction below 90% occurs near 1 minute of showering. The results of turbidity, UV 254 and particle counting show a different graph. Although descending as rapidly as the other parameters during the first 30 seconds of showering, they seem to equalize after 30 seconds near 25% of its original concentration. This last group of parameters is all related to particles. It is likely that the behaviour of particles during a shower is different from the behaviour of soluble substances like TOC and TN. In contradiction to this, the cATP, particulate organic carbon (POC) and particulate nitrogen (PN) results, more or less, follows the characteristics of the soluble substances instead of the particle related parameters. Although cATP is originating from microorganisms the behaviour during showering is comparable with soluble substances. The removal of particle based pollutants occurs at a slower rate, which can be explained from its origin. Particles like skin fragments and hair are part of the human body until, in time, they get loose. Even then it will take more energy and thus more time to remove these particles then for example dried sweat residue on the skin. It is not clear why POC and PN follow a different characteristic compared to the particle results.

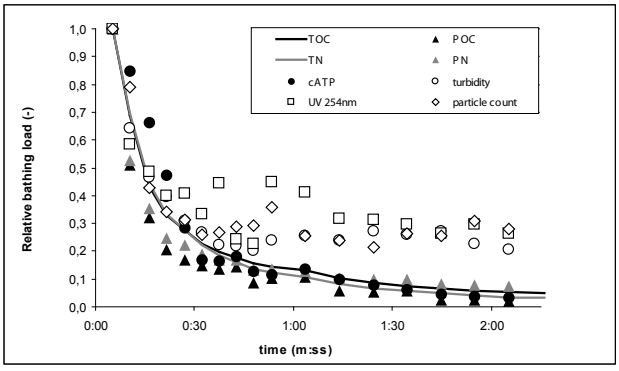

Figure 7 Relative bathing load during all time series experiments

The initial bathing load is a measure for the easily removable pollutants. A pre-swim shower should remove most of the initial bathing load. The time frame to limit the initial bathing load is set to 60 sec-

onds, based on the results of this study. There are four statements supporting this definition, namely;

1) After 30–60 seconds of showering all parameters are descending only slowly or are even equalizing. This means that longer shower time does not significantly remove more pollutants.
2) Common bathers are not willing to use a long pre-swim shower. If bathers use a pre-swim shower, it is most often only a brief shower in the range of 15–30 seconds (information gained through the questionnaires). To encourage bathers to use a pre-swim shower, the time frame should be not too long.
3) The achievement towards bathers when told that they can remove 50% of the initial bathing load with a 15 seconds shower would encourage bathers that never shower to actually have one, and it will also encourage bathers that already used a pre-swim shower to go for the full 100% reduction.
4) Long shower times increase the water and natural gas consumption (if natural gas is used for heating). Unnecessary long showering should not be promoted from an environmental point of view.

It is an awareness problem that bathers do not know the reason why they should use a pre-swim shower. Most bathers do not know that pre-swim showering reduces disinfection by-product levels in the pool and therefore also reduces the irritancy they get from disinfection by-products.

The authors of this paper made clear definitions for the initial, continual and accidental bathing load. The anthropogenic individual initial bathing load is defined as: *The amount of pollutants, chemical, particulate and microbiological, that can be rinsed of a bather's skin during a 60 seconds shower in a standardised shower cabin.*

The anthropogenic individual continual bathing load is defined as: *The amount of pollutants, chemical, particulate and microbiological, that are released by swimmers after 60 seconds of showering in a standardised shower cabin, without any accidental bathing load.*

The anthropogenic individual accidental bathing load is defined as: *The amount of pollutants, chemical, particulate and microbiological, released during all types of anthropogenic hygienic accidents like urine, faecal matter, vomit and blood.*

According to this definition, the anthropogenic individual initial bathing load found during the time series experiments is shown in table 6.

Table 6 Initial bathing load determined during time series experiments

Li TOC 0–60	212 mg/bather
Li TN 0–60	52 mg/bather
Li cATP 0–60	1,641 ng/bather
Li particle count 0–60	144·106 #/bather

Most parameters within the time series experiments are well correlated. Figure 8 shows the correlation between TOC and TN for all participants in the time line experiments. There is a clear linear relationship between TOC and TN present. This correlation is at a high significance level and r^2, namely 0.0001and 0.918. This implicates that 92% of the TN values can be explained by the TOC values and vice versa.

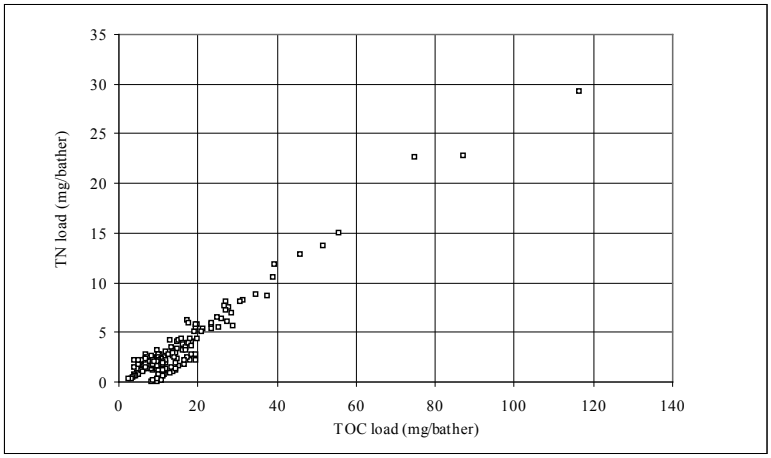

Figure 8 Correlation between TOC and TN for all participants in time line experiments

Figure 9 shows the correlation between TOC and ATP for all participants in the time line experiments. The correlation is not as clear as compared to the TOC/TN correlation, but still at a high significance level (0.0001) but at a lower r^2 level (0.149). This implicates that only 15% of the ATP results can be explained by the TOC values and vice versa.

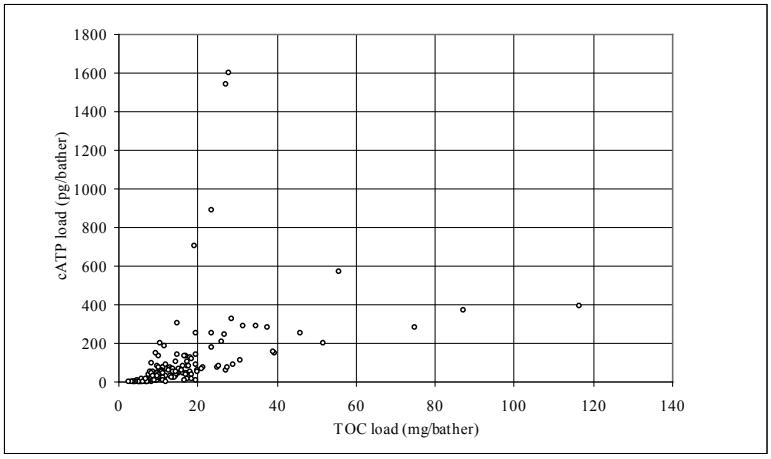

Figure 9 Correlation between TOC and ATP for all participants in time line experiments

All significant correlations are shown in table 7, combined with significance and r^2 level. Parameters can be predicted from the data in this research, especially the parameters with a high Pearson's correlation coefficient. Correlations with an $r^2>0.64$ or $r^2> 0.9$ are marked in table 7. If parameters are highly correlated, less parameters need to be measured in future research. Missing parameters can then be predicted. Sufficient information will be gained in future research if one carbon based, one nitrogen based and one microbiology based parameter are measured like TOC, TN and ATP.

Table 7 Correlation and significance levels of time series experiments

	significance level α			
Parameters	0.0001	0.001	0.01	0.05
TOC	DOC**, POC, TN**, DN*, PN, ATP, turbidity*, particle count			UV254
DOC	TOC**, POC, TN*, DN**, PN, ATP, turbidity*, particle count			
POC	TOC, DOC, TN, DN, PN*, turbidity, UV254, particle count	ATP		
TN	TOC**, DOC*, POC, DN**, PN, ATP, turbidity, UV254, particle count			
DN	TOC*, DOC**, POC, TN**, PN, turbidity*, particle count			ATP
PN	TOC, DOC, POC*, TN, DN, UV254	turbidity		ATP, particle count
ATP	TOC, DOC, TN	POC, turbidity, UV254	DN	PN
turbidity	TOC*, DOC*, POC, TN, DN*, UV254, particle count	PN, ATP		
UV254	POC, TN, PN, turbidity	ATP		TOC
Particle count	TOC, DOC, POC, TN, DN, turbidity			PN
* $r^2 > 0.64$	** $r^2 > 0.9$			

Additionally the influence of shower gel and shampoo on releasing body compounds was investigated. Two experiments were conducted with shower gel and shampoo. During these two experiments the participants were rinsed first in a standardised shower cabin with only water. Both participants where unshowered before entering the experiment and used different time frames. The first participant used a 30 seconds time frame for the blank, shower gel and shampoo experiment, and for the second participant these time frames where doubled. During the blank experiment, all water was collected and a mixed water sample was taken. After cleaning the shower cabin, the participant re-entered and was given a measured amount of shower gel, with analysed TOC/TN concentration. The participants both used a 30 seconds period of rubbing the whole body with shower gel, after which the whole body would be rinsed off during the shower period. Again all water was collected and a mixed sample was taken. Finally after cleaning the cabin again the participant re-entered the cabin and was given a measured amount of shampoo, with analysed TOC/TN concentration. The participants both used a 30 seconds period of hair rubbing, after which the whole body would be rinsed during the shower period. All water was collected and mixed samples were taken. The results are shown in table 8. After measuring the initial bathing load, the bathing load of the following time frames can be estimated using the results from the time series experiments. During the first participant's shower gel experiment, at least 367 mg TOC remained on the participant's skin, not accounting for additional release. For the second participant this was 400 mg TOC after a double rinsing time frame. At least 34% of the dosed TOC, by means of shower gel, could be accounted for in the results. If additional release of TOC by using shower gel is assumed, which is most probable, the remaining part will even be larger. For the shampoo experiment an additional release was measured. For the TN load measurements the results are different. During both the shower gel and shampoo experiment an additional release of TN load was determined. During the shower gel experiment, the additional TN release was determined at 158% and 149% for participant H and I respectively compared to the bathing load from a shower without the use of shower gel. For the shampoo experi-

ment, the determined additional TN release was even larger, namely 1,162% and 943% for participant H and I respectively compared to the bathing load from a shower without the use of shampoo. It is likely that the missing TOC load reported in table 4 originated from shower gel and/or shampoo residue. For the cATP measurements there is also an additional release. Although the cATP was not determined within the shower gel and shampoo, the additional release was determined at 215% and 529% respectively for the shower gel and shampoo experiment. This additional cATP release will even be higher if the shower gel and shampoo also contain some cATP. Although showering with the use of shower gel and shampoo does remove some additional bathing load, it also tends to add TOC load. It is therefore important that after showering with shower gel and/or shampoo, at least 1 minute, but preferably longer, of rinsing is necessary to remove most shower gel and shampoo residue. Removal of all shower gel and shampoo residue is not easily gained because a lot of shower gels and shampoos are designed by their manufacturer to add some compounds to the skin or hair, like moisturising shower gel, or care & repair shampoo.

Table 8 Results from shower gel and shampoo experiments

Participant H					
	parameter	measured	dosed	min. Est.*	residue**
Blank	$L_{TOC\ 0-30}$ (mg/bather)	49.1			
	$L_{TN\ 0-30}$ (mg/bather)	11.3			
	$L_{ATP\ 0-30}$ (ng/bather)	408			
Shower gel	$L_{TOC\ 30-60}$ (mg/bather)	713	1,061	1,080	367
	$L_{TN\ 30-60}$ (mg/bather)	27.6	18.3	21.9	-5.7
	$L_{ATP\ 30-60}$ (ng/bather)	243	n.a.	77.2	-166
Shampoo	$L_{TOC\ 60-90}$ (mg/bather)	811	589	603	-208
	$L_{TN\ 60-90}$ (mg/bather)	31.4	4.9	7.0	-24.4
	$L_{ATP\ 60-90}$ (ng/bather)	278	n.a.	44.2	-234
Participant I					
	parameter	measured	dosed	min. Est.*	residue**
Blank	$L_{TOC\ 0-60}$ (mg/bather)	172			
	$L_{TN\ 0-60}$ (mg/bather)	37.7			
	$L_{ATP\ 0-60}$ (ng/bather)	476			
Shower gel	$L_{TOC\ 60-120}$ (mg/bather)	836	1,172	1,236	400
	$L_{TN\ 60-120}$ (mg/bather)	42.1	20.2	29.0	-13.1
	$L_{ATP\ 60-120}$ (ng/bather)	401	n.a.	81.9	
Shampoo	$L_{TOC\ 120-180}$ (mg/bather)	616	629	671	54.7
	$L_{TN\ 120-180}$ (mg/bather)	32.7	5.2	11.0	-21.7
	$L_{ATP\ 120-180}$ (ng/bather)	303	n.a.	52.4	

n.a. not analysed

* minimum estimated bathing load = predicted load from time series experiments + dosed load

** positive residue means bathing load remained on skin, negative bating load means additional release

ON-SITE EXPERIMENTS AT INDOOR POOLS

All results of the on-site experiments are presented as initial bathing load as defined in this paper. Although all on-site experiments have been carried out using different shower times, the data from the time series experiments were used to calculate the initial bathing load (L_{0-60}) from any other bathing load like L_{0-30} or L_{30-60}. The results from the field experiments show a broad range, best to be presented as frequency distributions. Figure 10 shows an example of the frequency distribution of the $L_{TOC\ 0-60}$ for all participants at indoor pool experiments. All chemical parameters (DOC, TN and DN) follow a similar distribution.

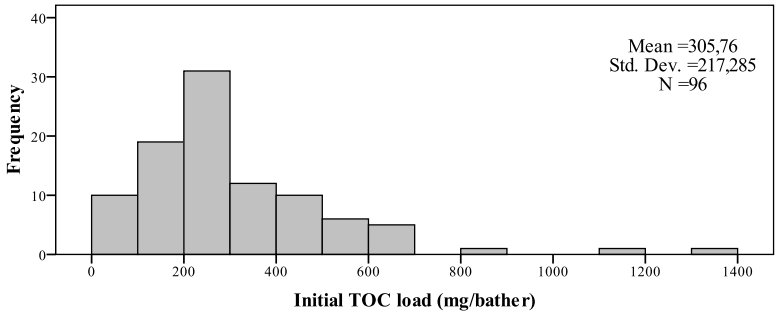

Figure 10 Frequency distribution of initial TOC load for all indoor pool experiments

Another example is given in figure 11, showing the frequency distribution of the $L_{particle\ count\ 0\ 60}$ for all participants at indoor pool experiments. The shape of this distribution is different compared to the distribution curve of the TOC load. However, if the bars of the distribution curve were made smaller, and more bars were used, the distribution would follow a more similar shape. All particulate parameters (POC, PN and particle counting) follow a similar frequency distribution.

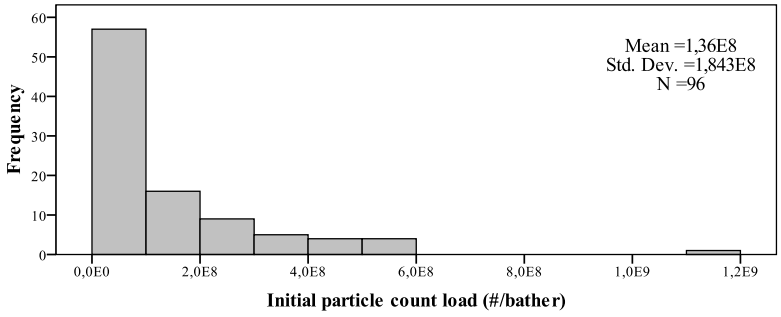

Figure 11 Frequency distribution of initial particle counting load for all indoor pool experiments

Descriptive statistics of the results are shown in table 9. The table also shows the differences between male, female and parent+baby participants. The differences between the three types of bathers are only minimal. Differences between clean and dirty participants are much larger.

Table 9 Descriptive statistics of initial chemical bathing load during indoor pool experiments

	minimum	maximum	average			
			overall	male	female	parent+baby
			n=92	n=52	n=34	n=6
L_{iTOC} (mg/bather)	38	1,361	305	350	261	159
L_{iDOC} (mg/bather)	27	1,008	238	272	207	124
L_{iPOC} (mg/bather)	5	434	66	78	54	35
L_{iTN} (mg/bather)	11	359	80	92	68	42
L_{iDN} (mg/bather)	7	266	63	72	55	27
L_{iPN} (mg/bather)	0	127	17	20	13	15
$L_{iParticleCount}$ (#/bather)	$7.0{\cdot}10^{4}$	$1.2{\cdot}10^{9}$	$1.4{\cdot}10^{8}$	$1.6{\cdot}10^{8}$	$1.1{\cdot}10^{8}$	$8.0{\cdot}1^{07}$

Correlations where found with the data from the questionnaires. Like in the time series experiments, most biochemical parameters are mutually correlating, but also other correlations where found.

Within the male participant group, there are three correlations found between biochemical parameters and questionnaires results, being hair length, type of swimsuit and use of hair products. Participants with hair length from 3–8 cm use hair products more often and have a higher biochemical bathing load. Male participants with longer hair (>15 cm) tend to wash their hair more often use less hair products and have a lower initial biochemical bathing load. The correlation with the type of swimsuit is not clear. Surf shorts tend to have a higher particulate bathing load than other swimsuits, but the highest particulate bathing load originated from a participant wearing tight swim pants.

Within the female participant group, there are also three correlations found between biochemical parameters and questionnaires results, being age, type of swimsuit and time since last hair wash. The influence of the swimsuit is not clear. Participants with a two piece swimsuit (bikini) tend to have longer hair, wash their hair more often, use less hair products and have a lower biochemical bathing load. Older female participants (>60) tend to wash their hair less often, last hair wash is often >72 hours ago, and they also have a higher biochemical bathing load.

During one field experiment, four participants were asked to wear a bathing cap inside the standardised shower cabin. Although no statistic significance can be related to these results, the found bathing load from these participants was 19–70% lower for resp. TOC and TN values compared to the other participants bathing load.

ON-SITE EXPERIMENTS AT AN OUTDOOR POOL

Table 10 shows the results of the outdoor pool experiments. Although the range and mean levels don't differ much from the results of the indoor pool experiments, it should be taken in account that half of the participants had been swimming before joining the experiment.

Table 10 Descriptive statistics of chemical initial bathing load during outdoor pool experiments

	minimum	maximum	average		
			overall	male	female
			n=27	n=15	n=12
L_{iTOC} (mg/bather)	23	1256	338	285	405
L_{iDOC} (mg/bather)	11	968	242	215	276
L_{iPOC} (mg/bather)	12	428	96	70	129
L_{iTN} (mg/bather)	7	284	84	90	77
L_{iDN} (mg/bather)	5	247	73	76	69
L_{iPN} (mg/bather)	2	36	11	13	8

Table 11 shows the results of participants before and after swimming. Both male and female bathing loads are raised in relation to the bathing load determined during the indoor pool experiments. This elevated bathing load is most probably caused by the tropical temperature during that particular day (34°C). According to the results of the questionnaires, 56% of the bathers used sunscreen lotion during this day. Remarkably, the participants using sunscreen lotion had the lowest initial bathing load. Two probable causes can be mentioned, the first is that the sunscreen lotion is not easily removed during a 30 seconds shower; this was the shower time during the outdoor pool experiments. The second probable cause is that participants using sunscreen lotion have a higher personal standard for hygienic care, causing an overall lower bathing load. Another remarkable finding is that participants that already have been swimming, and after that have been sunbathing or playing outside the pool, again had a significant initial bathing load at approximately 50% of the original initial bathing load.

Table 11 Difference between bathing load before and after swimming at outdoor pool experiments

	Participants before swimming		Participants after swimming	
	male	female	male	female
	n=8	n=3	n=7	n=9
L_{iTOC} (mg/bather)	442	836	104	262
L_{iDOC} (mg/bather)	341	688	70	139
L_{iPOC} (mg/bather)	102	148	34	122
L_{iTN} (mg/bather)	120	185	55	41
L_{iDN} (mg/bather)	103	171	46	35
L_{iPN} (mg/bather)	17	14	9	6

Statistic correlations with the outdoor pool experiments could not be obtained because the data set was too small.

MICROBIOLOGICAL DATA

The microbiological data were not collected during the first two on-site experiments at the Delft and Rotterdam pools. During the last two experiments at the Maassluis and Hengelo pools, cATP as well as specific micro-organisms were analysed. The frequency distribution of the cATP results is shown in figure 12. The frequency distributions for all microbiological parameters follow a similar curve.

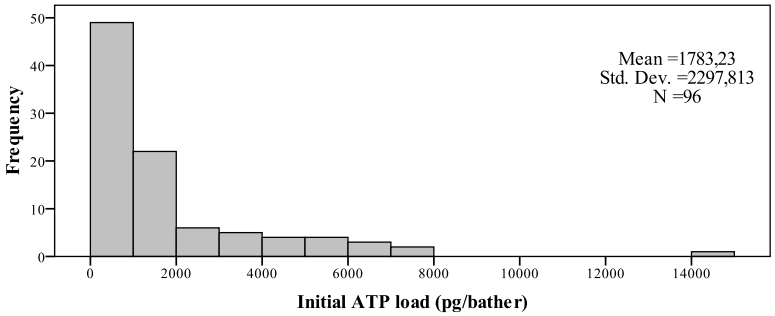

Figure 12 Frequency distribution of initial cATP load for indoor pool experiments

The descriptive statistics of the microbiological results of the in- and outdoor experiments are shown in table 12 and 13. Because some of the participants during the outdoor pool experiment have been swimming, before entering the experiment the data file was split, to compare these groups. Table 14 shows the results of these two groups. It is not clear why the microbiological bathing load of the indoor experiments is higher than the microbiological bathing of the outdoor experiments. Even if compared with the outdoor results before swimming, the microbiological bathing load at the indoor pool is still has a 239% higher cATP load. Three notes should be made:

1) The range of the results from the indoor pool experiments is very wide; f.e. the highest cATP load reaches over 500 times the value of the lowest cATP load. A 2.4 times higher bathing load is not significant higher in terms of microbiology.
2) The number of participants in the outdoor pool experiments is rather small, cATP results were gained from 11 participants who did not swim before entering the experiment against 92 participants in the indoor pool experiment.
3) A large part of the outdoor pool participants used a sunscreen agent (56%). All sunscreen agents contain antimicrobial components to preserve the agent, possibly these antimicrobial compounds also might reduce microbial activity on the bathers skin.

Table 12 Descriptive statistics of initial microbiological bathing load during indoor pool experiments

	minimum	maximum	average		
			overall	male	female
L_{iATP} (ng/bather) n=92	27	1479^{9}	176^{4}	202^{8}	146^{7}
L_i*E. coli* (#/bather) n=22	<25	$1.9{\cdot}10^{6}$	$9.1{\cdot}10^{4}$	$5.6{\cdot}10^{3}$	$1.7{\cdot}10^{5}$
$L_{iEnterococcen}$ (#/bather) n=24	<17	$7.0{\cdot}10^{5}$	$3.1{\cdot}10^{4}$	$1.8{\cdot}10^{3}$	$6.1{\cdot}10^{4}$
$L_{iStaphylococcen}$ (#/bather) n=24	$1.0{\cdot}10^{4}$	$>2.2{\cdot}10^{9}$	$2.5{\cdot}10^{8}$	$3.1{\cdot}10^{8}$	$1.9{\cdot}10^{8}$

Table 13 Descriptive statistics of initial microbiological bathing load during outdoor pool experiments

	minimum	maximum	average		
			overall	male	female
L_{iATP} (ng/bather) n=27	28	2469	601	658	529
L_i *E. coli* (#/bather) n=8	<384	$5.1 \cdot 10^4$	$1.3 \cdot 10^4$	$1.2 \cdot 10^4$	$1.4 \cdot 10^4$
$L_{iEnterococcen}$ (#/bather) n=8	<384	$5.2 \cdot 10^4$	$1.2 \cdot 10^4$	$7.8 \cdot 10^3$	$1.9 \cdot 10^4$
$L_{iStaphylococcen}$ (#/bather) n=8	$8.9 \cdot 10^4$	$4.6 \cdot 10^6$	$2.6 \cdot 10^6$	$2.4 \cdot 10^6$	$2.9 \cdot 10^6$

Table 14 Descriptive statistics of initial microbiological bathing load before and after swimming during outdoor pool experiment

	Participants before swimming		Participants after swimming	
	male	female	male	female
L_{iATP} (ng/bather) n=11/16*	628	1028	692	363
L_i *E. coli* (#/bather) n=4/4*	$1.8 \cdot 10^3$	$7.8 \cdot 10^2$	$2.8 \cdot 10^4$	$2.1 \cdot 10^4$
$L_{iEnterococcen}$ (#/bather) n=4/4*	$1.0 \cdot 10^4$	$5.2 \cdot 10^4$	$4.3 \cdot 10^3$	$2.4 \cdot 10^3$
$L_{iStaphylococcen}$ (#/bather) n=4/4*	$1.4 \cdot 10^6$	$1.8 \cdot 10^6$	$3.9 \cdot 1^{06}$	$3.4 \cdot 10^6$
*number of participants in experiment; before swimming / after swimming				

Approximation of the bacteria release can be gained if the cATP load (ng/bather) is multiplied by 1,000 according to the manufacturer of the used test kit. The approximation of the initial bacterial load ranges 10^7–10^{10} micro-organisms per bather for indoor pools and 10^7–10^9 micro-organisms per bather for outdoor pools, is in line with the historical data shown in table 2.

CONTINUAL BATHING LOAD

Determination of the continual bathing load is a challenge. There are several different kinds of sweating described by Kuno; insensible perspiration, thermal sweating, mental sweating, sweating due to muscular exercise and sweating due to inhalation of carbon dioxide (Kuno, 1956). The main types of sweating occurring in swimming pools are thermal sweating and sweating due to muscular exercise. If the core temperature rises, sweat production will also rise to cool down the human body by evaporating water. The core temperature can rise because of environmental conditions, e.g. warm pool water, or because of muscular exercise, e.g. swimming. Instead of inducing thermal sweating at high pool water temperatures, thermal sweating can be reduced by reducing the pool water temperature. Especially in competition pools where bathers are doing a muscular exercise and therefore producing their own heat. The human body has a sweat production in relation to the core temperature as shown in figure 13 (Kuno, 1956).At low core temperatures there is a continuous insensible sweat production at a low rate to prevent the skin from drying. From a certain core temperature, the sweat production starts rising as a function of the core temperature. This certain core temperature is different for each individual. This sweat mechanism enables human's to keep a steady core temperature, e.g. 37°C, even at tropical environmental conditions like an air temperature of 40°C (Kuno, 1956). In a submerged environment the function of the sweat mechanism becomes different. As the produced sweat will not lead to evaporation when submerged, the cooling effect, normally gained from sweating, is not present in a submerged state. If a swimmer starts sweating as a result of raised core temperature, the core temperature will not be affected by this sweating resulting in an increased sweat production. This combination of high water temperature and muscular exercise can even be dangerous and should be avoided. Competition swimmers will not be able to have a top performance when the water temperature is too high.

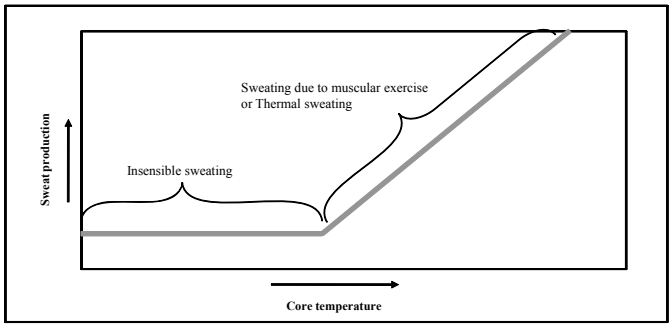

Figure 13 Human sweat production in relation to core temperature (Kuno, 1956)

As the continual bathing load is defined as the amount of pollutants released after the initial bathing load, without accidental bathing load, it is believed that sweating is the main contributor. It is not clear if the bacterial component within the continual bathing load follows the same mechanism as the sweat production. To determine the continual bathing load, participants need to perform a standardised exercise at a standardised submerged environment. Sweat production can be measured as concentration of substances within the pool water, or reduced body weight. Even at a sub maximal level of exercise during 30 minutes the sweat production will be near 0.5 L, corresponding with 250 mg TOC and 500 mg TN. Mixed within a small pool basin of 3,000 L, the effect on TOC and TN concentration will be an increase of only 0.08 mg/L TOC and 0.17 mg/L TN. Measuring body weight of wet participants is also a difficult task and the results are fluctuating.

The results of the continual bathing load experiments are shown in table 15. Although it seems that low water temperatures even have a higher sweat release, it should be noted that the measured TOC and TN concentrations were very low, near the detection limit of the analyser. No conclusions can be drawn from the fact that the TOC/TN release is not in line with the pool water temperature. Each participant joined the experiment at different conditions (water temperature) and differences between participants can be large as shown in the on-site experiments. However, the sweat production during these experiments was low, even at high water temperature and sub maximal muscular exercise. It is often mentioned in publications that swimmers can release up to 1 L of sweat during 1 hour of intensive swimming. Compared to the initial bathing load, the TOC/ TN ratio is not in line with the TOC/TN ratio of human sweat (1/2). Like in the time series experiments it seems there is an additional TOC compound, not introduced by sweat.

Table 15 Continual bathing load

Participant	Water temperature (°C)	Duration (min)	TOC (mg/bather)	TN (mg/bather)	Sweat* (L/bather)
1	34.3	30	435	195	0.2
2	33.2	30	279	75	0.1
3	28.4	30	378	87	0.1
4	25.0	30	720	96	0.1
5	22.2	30	384	150	0.2
average			439	120	
* sweat production according to TN load					

Table 16 shows the composition of the total bathing load. The initial and continual bathing loads are based on the results found in this study. It is not likely that bathers during a normal swimming pool visit sweat as much as the participants did during the continual bathing load experiments. It is clear that for the TOC load of swimming pools, sweating is the main contributor at 47% of the total TOC load. For the TN load, the main contributor is the accidental urine release at 57% of the total TN load.

Table 16 Components of total bathing load

	L_{TOC}	L_{TN}
Initial bathing load (mg/bather)	305 (33%)	80 (17%)
Continual bathing load (mg/bather)	439 (47%)	120 (26%)
Accidental bathing load (mg/bather)*	192 (20%)	270 (57%)
Total bathing load (mg/bather)	936 (100%)	470 (100%)
* only 30 mL urine release/bather included (Gunkel, 1986)		

The swimming pool staff can use the results presented in this study to build awareness among the bathers about their own influence on the pool water quality and thus the joy they experience during the swimming pool visit. With a higher public awareness of the consequences of accidental urine release it should be possible to reduce this type of bathing load among most of the bathers. The results from this paper do not show clearly that reduction of continual bathing load is possible f.e. by reducing pool water temperature. Reducing pool water temperature would increase the risk of accidental urine release. And finally reduction of the continual bathing load is possible at 100% if bathers use a pre-swim shower for 60 seconds. A willing bather is able to reduce its own bathing load, only by using a shower and the toilet, to 439 mg/bather TOC load and 120 mg/bather for the TN load. This is a 53% and a 74% reduction for TOC and TN load respectively. Reduction of bathing load will lead to reduction in chlorine demand and disinfection by-product formation.

CONCLUSIONS

The initial bathing load is a significant part of the total bathing load. Reduction of initial bathing load will reduce the amount of pollutants in swimming pool water significantly. Reduction of pollutants in swimming pool water is essential to reduce the use of chlorine and to reduce the formation of disinfection by-products. Supervision on reduction of initial bathing load from bathers with the use of a pre-swim shower needs to be improved.

The initial bathing load can be defined as: *all chemical and microbiological pollutants that can be rinsed from bathers within 60 seconds using a standardised shower.*

Although the historical data seems very scattered in the first pace, using the results from this paper, the historical data enhances the findings of this paper that the initial bathing load is a significant part of the total bathing load.

The use of a standardised shower to determine the initial bathing load is an easy and reproducible method, allowing researchers to have controllable circumstances in a swimming pool site where the environment is not always as proper as researchers would like it to be.

All chemical parameters used in this paper are mutually very well correlated, implicating that in future research not all parameters need to be monitored. Monitoring of TOC and TN can be sufficient, these parameters are easy to analyse.

The use of hair products and body or suntan lotion increases the initial bathing load. Removal of these products before entering the pool water is essential for remaining low pollutant concentrations in the pool water.

The use of a pre-swim shower at outdoor swimming pools is essential, even if bathers already have been swimming. The influence from body or suntan lotion and dirt gathered on the bather's feet and body needs to be removed before (re)entering the pool water.

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REFERENCES

Althaus, H., Pacik, D., 1981. Antropogene Belastungsstoffe in Hot Whirlpools (Warmsprudelbecken). Archiv des Badewesens, 417-420

Borgmann-Strahsen, R., 2003. Comparative assessment of different biocides in swimming pool water. International Biodeterioration & Biodegradation 51, 291-297

Eichelsdörfer, D., Jandik, J., Weil, W., 1980. Organische Halogenverbindungen im Schwimmbeckenwasser II. Mitteilung: Modellversuche zur Bildung leichtflüchtiger Halogenkohlenwasserstoffe. Z. Wasser Abwasser Forschung 13, 165-169

Elmir, S., Shibata, T., Solo-Gabriele, H., Sinigalliano, C., Gidley, M., Miller, G., Plano, L., Kish, J., Withum, K., Fleming, L., 2009. Quantative evaluation of enterococci and Bacteroidales released by adults and toddlers in marine water. Water Research 43, 4610-4616

Elmir, S.M., Wright, M.E., Abdelzaher, A., Solo-Gabriele, H.M., Fleming, L.E., Miller, G., Rybolowik, M., Peter Shih, M., Pillai, S.P., Cooper, J.A., Quaye, E.A., 2007. Quantitative evaluation of bacteria released by bathers in a marine water. Water Research 41, 3-10

Gunkel, K., Jessen, H. J., 1986. Untersuchungen über den Harnstoffeintrag in das Badewasser. Acta Hydrochimica et Hydrobiologica 14, 451-461

Hery, M., Hecht, G., Gerber, J.M., Gendre, J.C., Hubert, G., Rebuffaud, J., 1995. Exposure to chloramines in the atmosphere of indoor swimming pools. Annals of Occupational Hygiene 39, 427-439

Keltjens, L., 1987. Optimalisering van de bedrijfsvoering in overdekte zwemgelegenheden (Optimisation of management in indoor swimming pools), Publikatiereeks Milieubeheer (Series title Environment). Ministry of VROM, Den Haag (The Hague), p. 153

Klosterkötter, W., 1964. Hygienische Probleme bei der Umwälzung des Badewassers in Schwimmbacken (Hygienic problems with recirculation of swimming pool water). Archiv des Badewesens, 108-112

Kuno, Y., 1956. Human perspiration. Charles C. Thomas, Springfield, Illinois, U.S.A.

Lahl, U., Batjer, K., Duszeln, J. V., Gabel, B., Stachel, B., Thiemann, W., 1981. Distribution and balance of volatile halogenated hydrocarbons in the water and air of covered swimming pools using chlorine for water disinfection. Water Research 15, 12

NEN, 1984. Water - Enzymatic determination of urea content in swimming water. NEN

NEN, 1993a. Water quality - Determination of Kjeldahl nitrogen - method after mineralization with selenium (ISO 5663:1984,IDT). NEN

NEN, 1993b. Water Quality Determination of permanganate index ISO 8467. NEN

NEN, 1997a. Water - Titrimetric determination of chloride according to Mohr. NEN, Delft

NEN, 1997b. Water analysis - Guidelines for determination of total organic carbon (TOC) and dissolved organic carbon (DOC). NEN

NEN, 1999. Water quality - Determination of turbidity. NEN, Delft

NEN, 2003. Water quality - Determination of nitrogen - Determination of bound nitrogen (TN sub b), following oxidation to nitrogen oxides

Powick, D.E.J., 1989. Swimming pools – Brief outline of water treatment and management. Water Science and Technology 21, 151–160
Putnam, D.F., 1971. Composition and concentrative properties of human urine. NASA Contractor Reports
Rook, J.J., 1977. Chlorination Reactions of Fulvic Acids in Natural Waters. Environmenal science & technology 11, 478–482
VROM, 1985. Onderzoek naar filterinstallaties en waterbehandelingssystemen in zwembaden (Research on filtration and pool water treatment in Dutch swimming pools), Publikatiereeks Milieubeheer (Series title Environment), Den Haag (The Hague), p. 43
WHO, 2006. Guidelines for safe recreational water environments
Volume 2; Swimming pools and similar environments. WHO
Zwiener, C., Richardson, S., De Marini, D., Grummt, T., Glauner, T., Frimmel, F., 2007. Drowning is Disinfection Byproducts? Assessing Swimming Pool Water. Environmenal science & technology 41, 363–372