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Pool Hygiene

From 100 years of chlorine disinfection to a biological future

Dr. Jakob Schelker

Biotop P&P International GmbH

Topics & Questions

- Historical background – The discovery of chlorine and its effects
- How did the first chlorine pool come about?
- How harmful is chlorine? What is the current state of knowledge?
- How can pathogenic bacteria be removed biologically?
- Future challenges for swimming ponds and natural pools: water temperature!
- The good news at the end

Historical background – The discovery of chlorine and its effects

What is chlorine?

- Known as a chemical element since 1808 (Humphry Davy)
- Highly reactive with almost all materials
- Hardly reactive when present as chloride anion (Cl_2)

→ Sodium chloride (NaCl)

The discovery of the effects of chlorine

- Bleaching agents: (Eau de Javel, 1792) and calcium hypochlorite (1799)
- Description of the disinfecting effect from 1845 in Vienna and 1867 in London
- First experiments for drinking water supply in 1892 in Hamburg, Germany, and in 1897 in Maidstone, UK.

→ Germicidal effect of chlorine for water generally known from ~1900

Medical research from 1840 to 1910

- **Ignaz Semmelweis** (1847) Calcium hypochlorite for hand cleaning
- **John Snow** (1849) Cholera caused by pathogens in drinking water
- **Joseph Lister** (1867) "Antiseptic surgery"
- **Louis Pasteur** (1881) Research on disinfection and vaccination
- **Robert Koch** Discovery of the pathogens that cause tuberculosis (1882) and cholera (1885)

Ignaz Semmelweis

→ In many cases, infections are still a death sentence!

Zeitgeist around 1900

- *Belle Époque*
- Enormous technical and cultural progress

- **Cholera epidemic in Hamburg in 1892**
  - 16,956 people ill
  - 8,605 deaths!

→ **Modern times, but still many epidemics**

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How did the first chlorine pool come about?

The First Chlorine Pool


THE BOSTON
MEDICAL AND SURGICAL
JOURNAL

VOLUME CLIX

Carolus Cobb (1908) on swimming in pools:

"The mystery of it is not that people infected the nose, throat, and ear by this contaminated water, but that they insist on putting their heads under it.

→ Infections were commonplace when swimming!

The First Chlorine Pool

- **John Bunker** experiments with pool water and calcium hypochlorite at Brown University (Rhode Island):
  - 2L bottles
  - Entire pool

SPECIAL ARTICLES

THE HYGIENE OF THE SWIMMING POOL.*

By JOHN W. M. BUNKER, A. M.,
Brown University.

Of late years the general use of swimming pools has brought up a new problem in sanitation, the problem of the hygiene of the swimming pool. It has been suggested that the swimming pool may be a source of danger as well as one of benefit to the user. To remove such possible danger has been the purpose of the experiments here described. All work was done on the pool at Brown University.

→ First chlorine pool goes into operation in **1909**

The First Chlorine Pool

The First Chlorine Pool

Pool remains in operation until the 1940s.

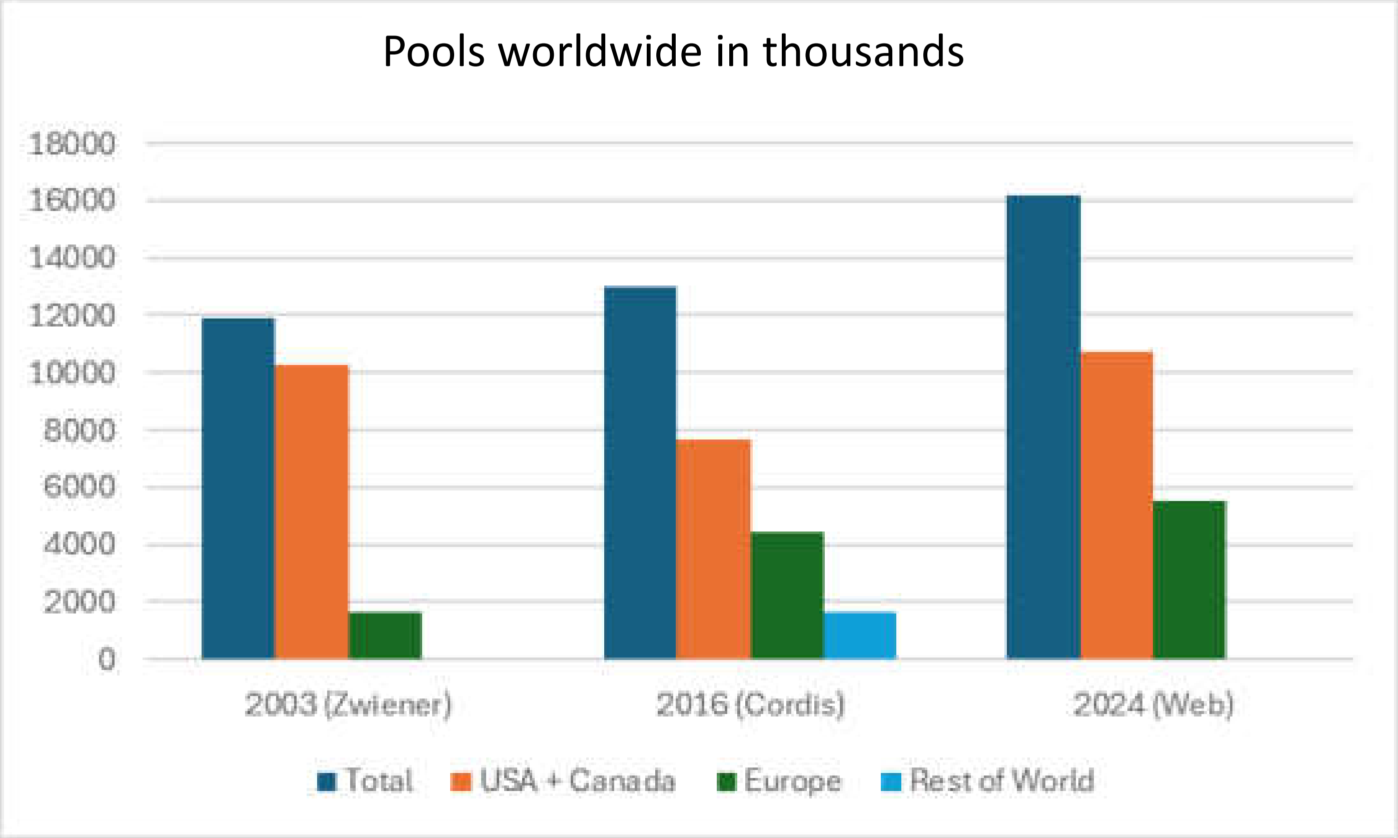
→ Chlorine is becoming established as the ultimate disinfection method for pools!

→ Where are we today?

The pool industry today

Where do we stand today?

- Between ~12 and ~16 million pools worldwide*
- ~95% disinfected with chlorine*
- Around 50-60% above-ground pools (US and FR)*



* All data is <u>very uncertain</u>; some of it comes from online sources

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How harmful is chlorine?
What is the current state of knowledge?

Effects of chlorine use

Increased risk of certain diseases (Zwiener et al., 2007)

- Irritation of the eyes and skin
- Breathing difficulties and asthma
  - Development of asthma in children
- Risks of cancer
  - Bladder cancer (1.2-2 times higher risk)

Effects on the environment and humans

- Chlorine in wastewater treatment

Critical Review

Drowning in Disinfection Byproducts? Assessing Swimming Pool Water

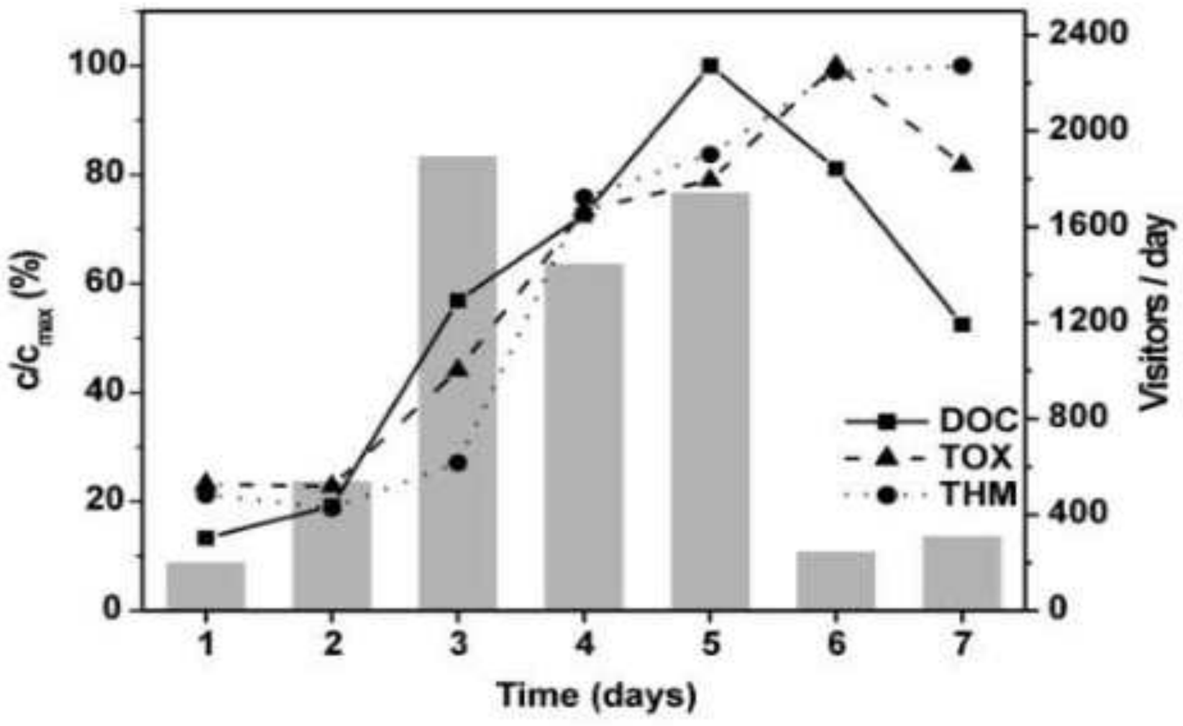
CHRISTIAN ZWIENER,[*,†] SUSAN D. RICHARDSON,[‡] DAVID M. DE MARINI,[§] TAMARA GRUMMT,[∥] THOMAS GLAUNER,[†] AND FRITZ H. FRIMMEL[†]

Engler-Bunte-Institute, Universitaet Karlsruhe, Karlsruhe, Germany, National Exposure Research Laboratory, U.S. Environmental Protection Agency, Athens, Georgia, Environmental Carcinogenesis Division, U.S. Environmental Protection Agency, Research Triangle Park, North Carolina, and Federal Environmental Agency, Bad Elster, Germany

Effects of chlorine use

Effects of chlorine use in pools

- Chlorine reacts with care products (skin creams, sun creams, etc.)
- Health hazards arise from degradation products
  - e.g., trichloromethanes (TMHs) are carcinogenic!

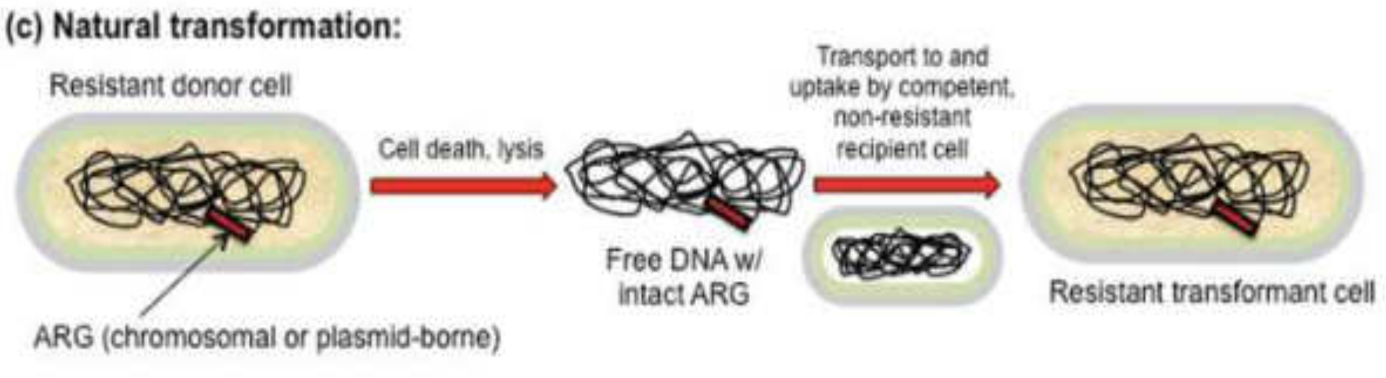


(Zwiener et al., 2007, ES&T)

→ Swimmers are exposed to these substances!

Development of antibiotic resistance

- Chlorine damages cell membranes
- Damaged bacteria absorb DNA from other damaged cells



(Dodd, 2012)

→ Antibiotic resistance genes (ARGs) are exchanged!

Effects of chlorine use

Possible development of antibiotic resistance

Antibiotic resistance genes (ARGs)


The ISME Journal (2020) 14:1847–1856
https://doi.org/10.1038/s41396-020-0656-9

ISME

ARTICLE

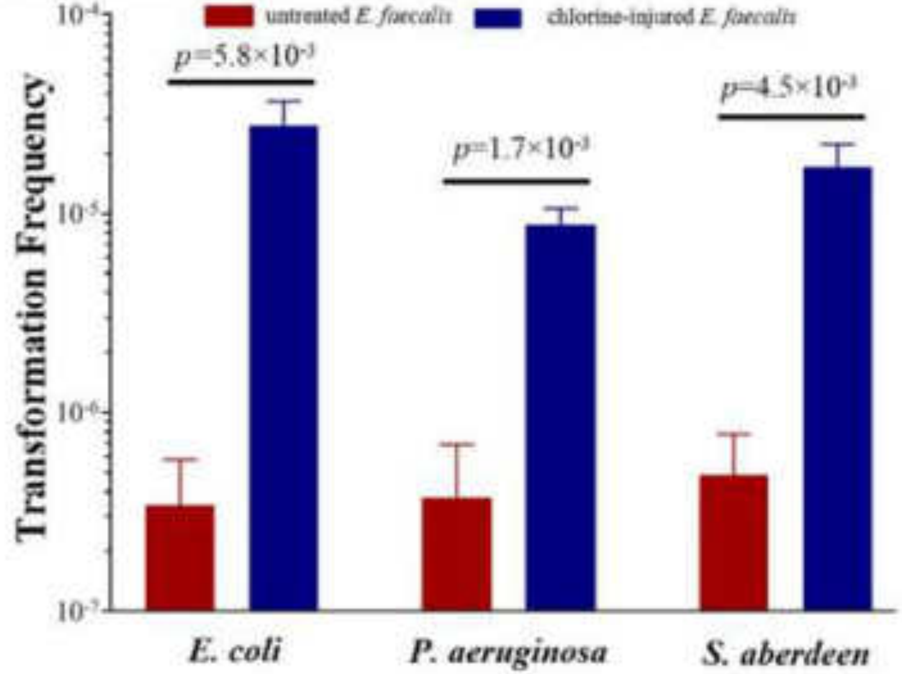
Chlorine disinfection promotes the exchange of antibiotic resistance genes across bacterial genera by natural transformation

Min Jin[1] · Lu Liu[1] · Da-ning Wang[1] · Dong Yang[1] · Wei-li Liu[1] · Jing Yin[1] · Zhong-wei Yang[1] · Hua-ran Wang[1] · Zhi-gang Qiu[1] · Zhi-qiang Shen[1] · Dan-yang Shi[1] · Hai-bei Li[1] · Jian-hua Guo[2] · Jun-wen Li[1]

Received: 9 October 2019 / Revised: 27 March 2020 / Accepted: 2 April 2020 / Published online: 22 April 2020

Abstract
Chlorine disinfection to drinking water plays an important role in preventing and controlling waterborne disease outbreaks globally. Nevertheless, little is known about why it enriches the antibiotic resistance genes (ARGs) in bacteria after chlorination. Here, ARGs released from killed antibiotic-resistant bacteria (ARB), and culturable chlorine-injured bacteria produced in the chlorination process as the recipient, were investigated to determine their contribution to the horizontal transfer of ARGs during disinfection treatment. We discovered *Escherichia coli*, *Salmonella aberdeen*, *Pseudomonas aeruginosa* and *Enterococcus faecalis* showed diverse resistance to sodium hypochlorite, and transferable RP4 could be

Fig. 6: Transformation frequency of RP4 released from killed *Escherichia coli*, *Pseudomonas aeruginosa* and *Salmonella aberdeen* into chlorine-injured *Enterococcus faecalis* or not (10^8 cfu/mL) naturally at pH 7.2 and 20 °C (n = 3; mean ± SD).



→ Increased transmission of ARGs with chlorine!

(Jin et al., 2020, ISME)

→ New field of research; full extent not yet clear

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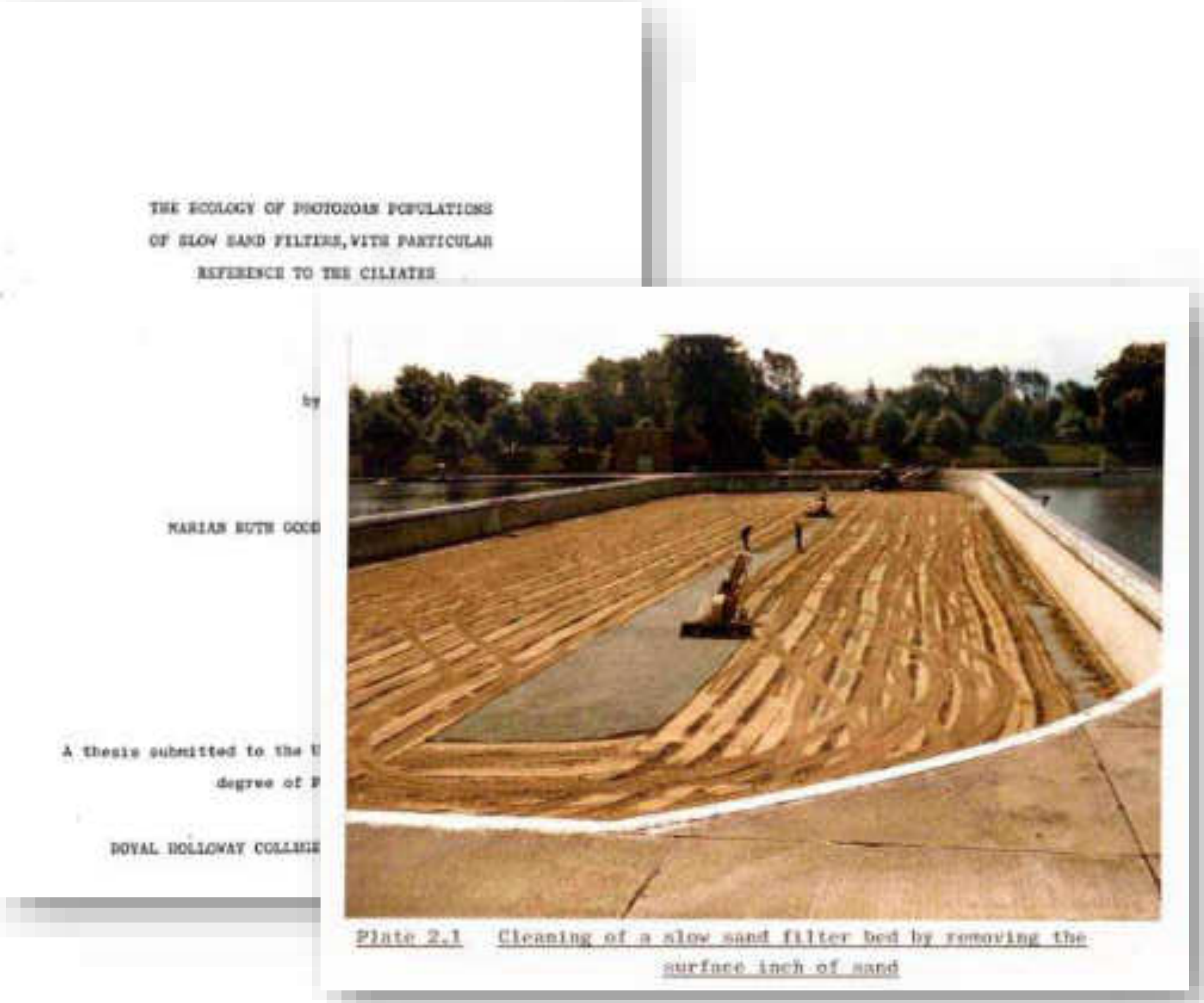
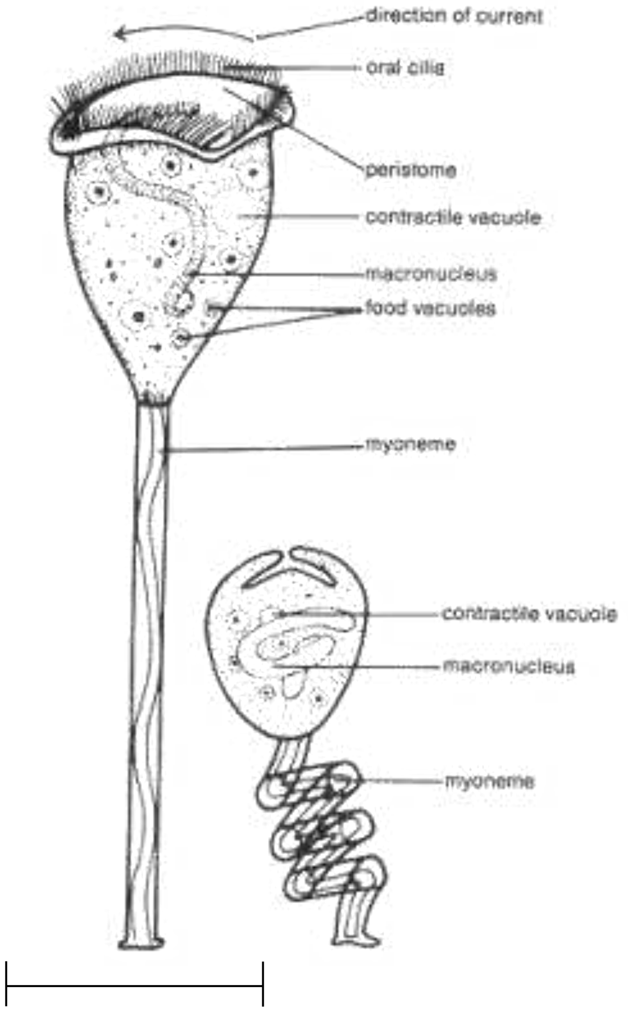
How can pathogenic bacteria be removed from water biologically?

Filter materials and filter speeds

- Sand filters have been in use for drinking water since around 1840 (London/Hamburg)
- Three main processes
  - Mechanical-physical sedimentation
  - Adhesion of bacteria to surfaces
  - Biological degradation of bacteria



Ciliates, *Vorticella spp*.



Adhesion and degradation of bacteria

- Physical adhesion to the filter material
  - Van der Waals forces bind bacteria to sand grains

- Degradation of bacteria by microorganisms, especially protozoa such as ciliates (Ciliata)

→ Explicit evidence of the degradation process?

How are pathogens broken down?

<u>Question: Who eats *E. coli?*</u>

- Cultivation of *E. coli* in the laboratory with ^{13}C-glucose as a tracer
- Detection of the tracer (^{13}C) in the decomposing organisms

The ISME Journal (2015) 9, 797–808

www.nature.com/ismej

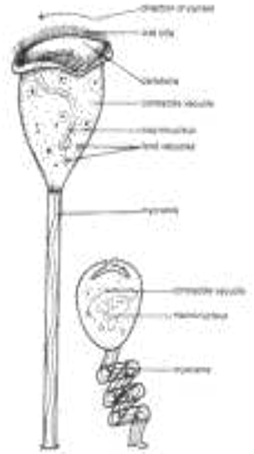
ORIGINAL ARTICLE

Stable-isotope probing and metagenomics reveal predation by protozoa drives *E. coli* removal in slow sand filters

Sarah-Jane Haig[1], Melanie Schirmer[1], Rosalinda D'Amore[2], Joseph Gibbs[3], Robert L Davies[4], Gavin Collins[1,3] and Christopher Quince[1]
[1]School of Engineering, University of Glasgow, Glasgow, UK; [2]School of Biological Sciences, University of Liverpool, Liverpool, UK; [3]Microbial Ecophysiology Laboratory, School of Natural Sciences and Ryan Institute, National University of Ireland, Galway, Ireland and [4]Institute of Infection, Immunity and Inflammation, College of Medical, Veterinary and Life Sciences, University of Glasgow, Glasgow, UK

<u>Result:</u>

- 99% broken down by protozoa, the rest by bacteriophages (viruses)



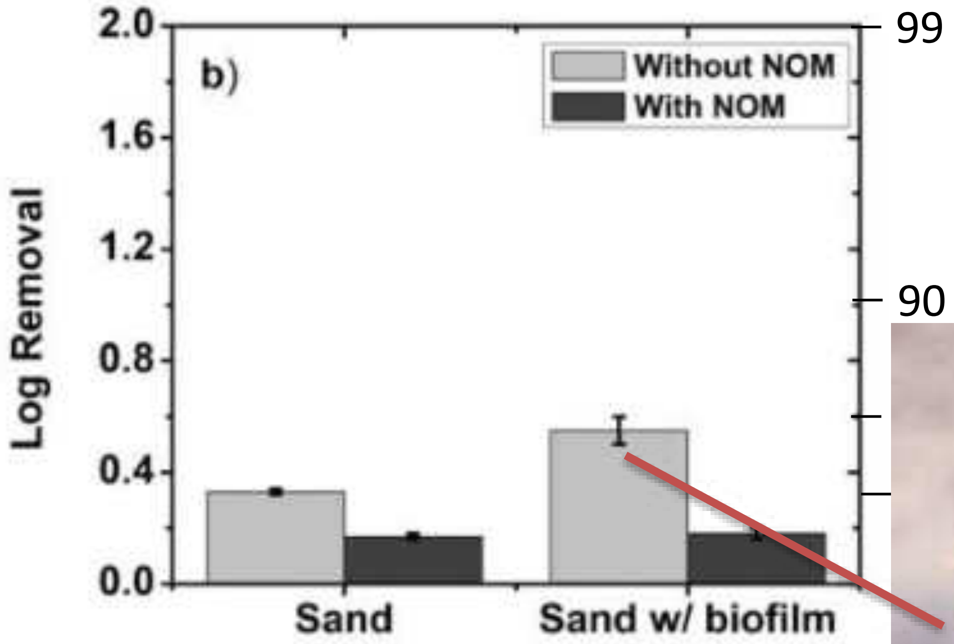
Ciliates, Vorticella spp.

→ Protozoa ("bacteria eaters") become active within a few hours and dominate the degradation!

Degradation of *E. coli* in the biofilter

Improved degradation of *E.* coli

- Growth of a biofilm
- Supply of organic carbon (NOM)



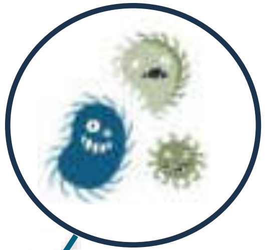
Afrooz & Boehm, PLoS ONE (2016)

→ Cultivate biofilters as "hungry predators"!

→ How effective are modern Biotop Bio-Compact filters?

Experiments on the degradation performance

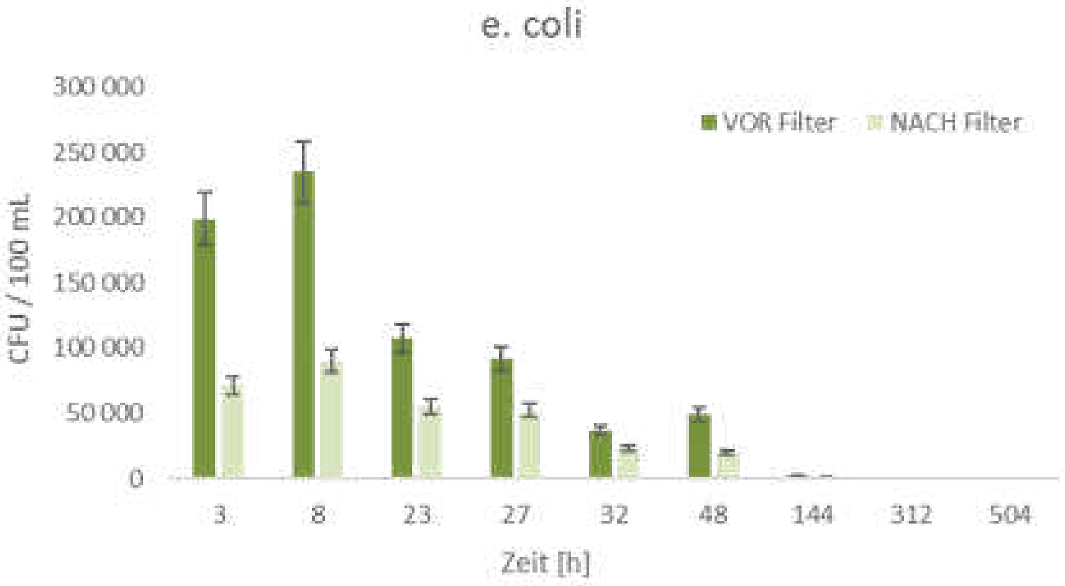
of **Biotop Bio-Compact filters**

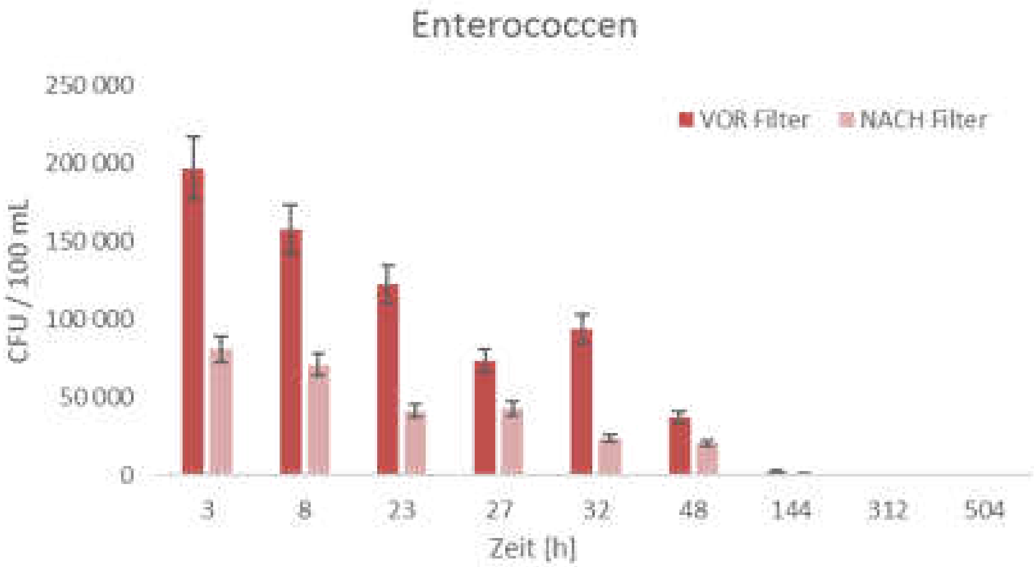


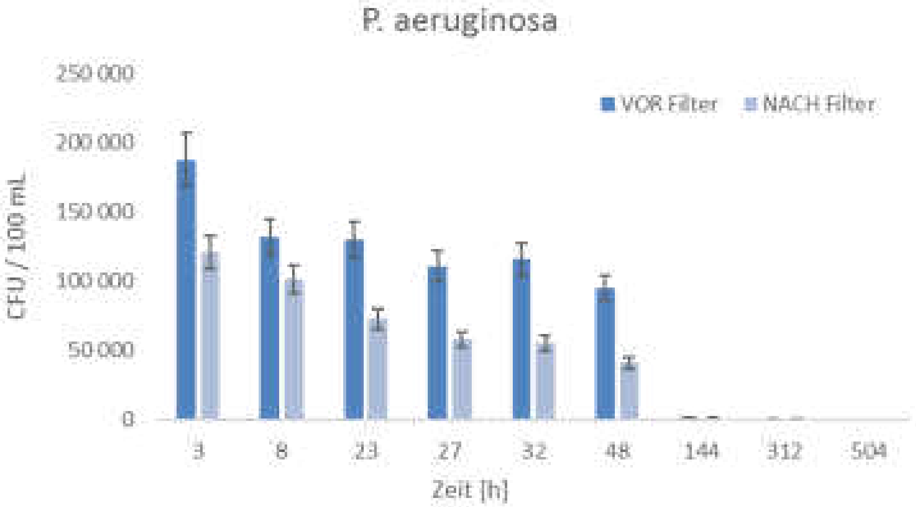
→ Addition of *E. coli, Enterococcus,* and *P. aeruginosa*

Results of hygiene tests – mat filters

Breakdown by biocompact filter: comparison before and after filtering







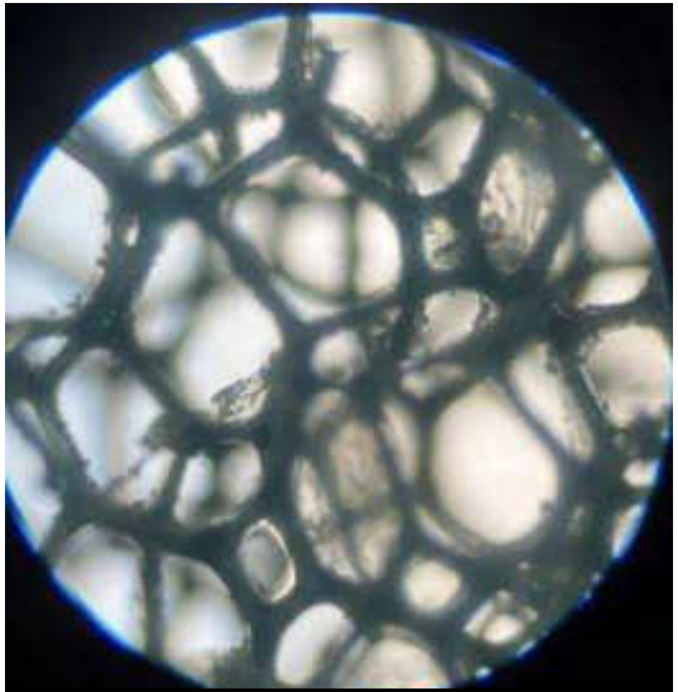
→ Elimination rates according to FLL 2011

Filter materials and filter speeds

High degradation despite small filter size?

- Porosity / usable porosity
- Open pores

Quartz sand 0.5 - 1 mm
60x magnification



Biotop Blue filter mat
60x magnification

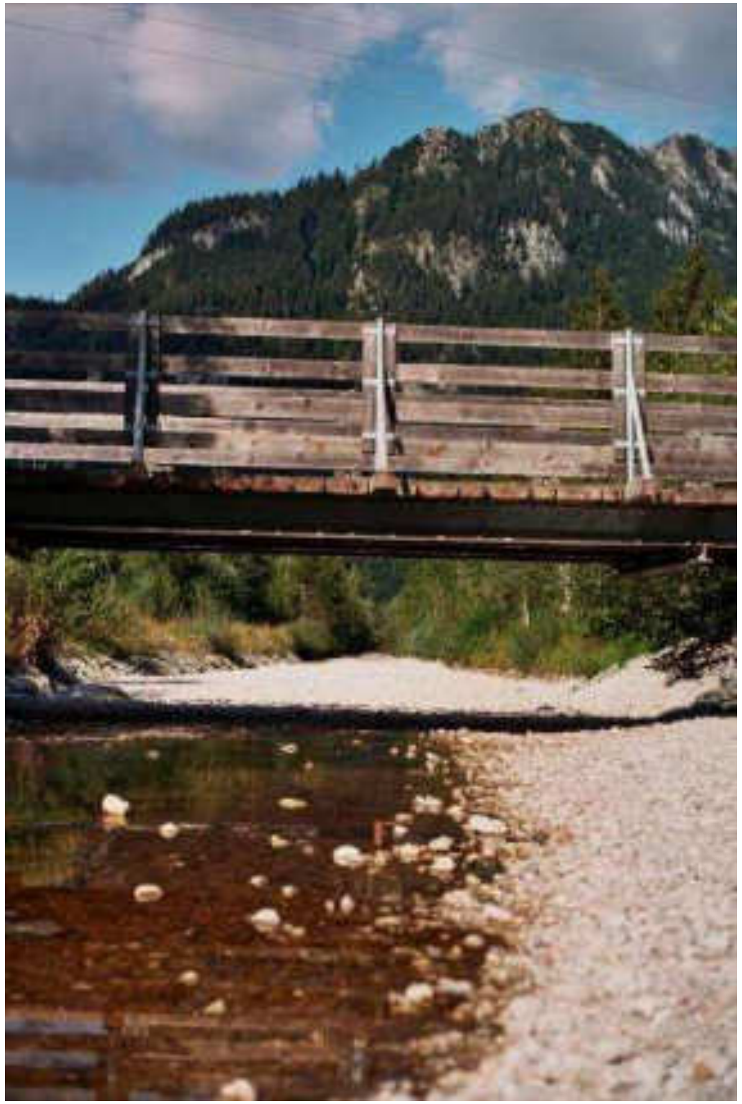
→ Biotop filter mats: Excellent synthetic filter material!

What are the future challenges for swimming ponds and natural pools?

Future challenges

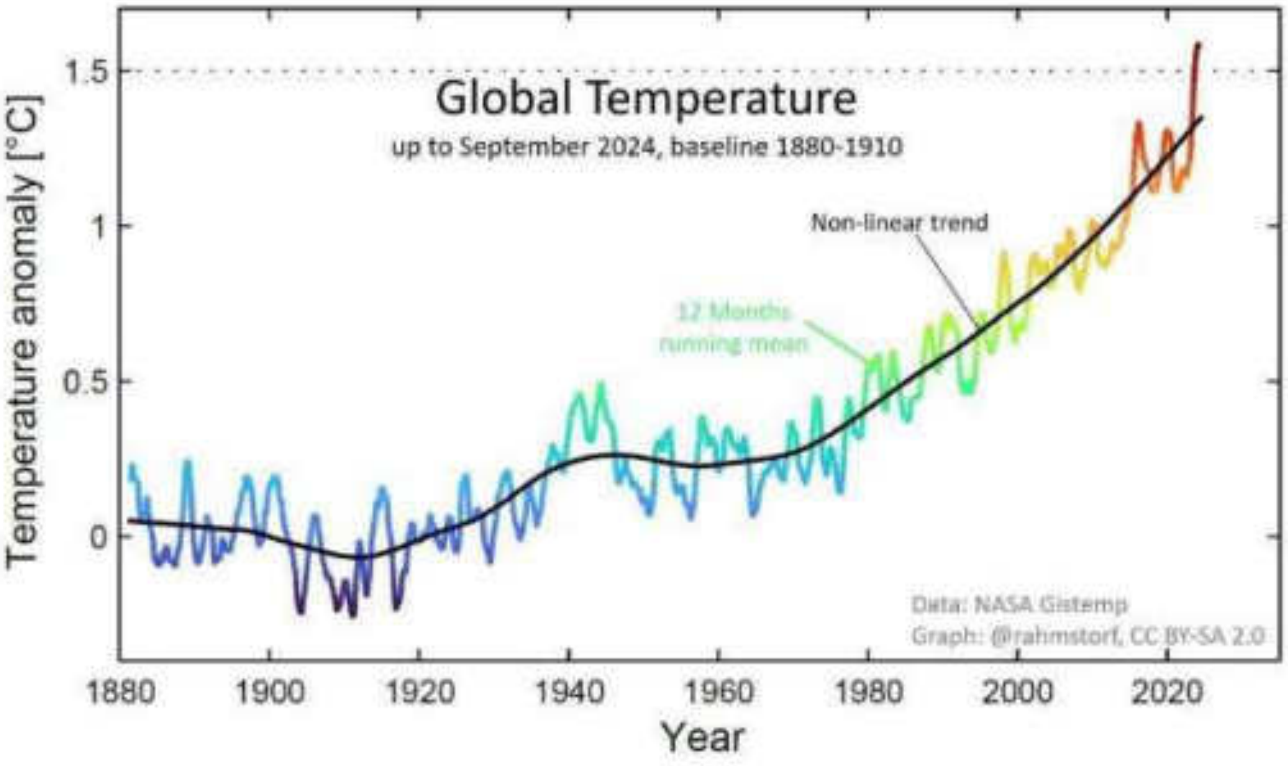
- Damage to the image of natural pools due to „bad" facilities/filters
- More extreme weather events
  - Droughts & water shortages
  - Floods
  - Heat waves/increased temperatures in summer

→ Focus on water temperature and hygiene



Challenges

Climate change



Expectation:

- Heat waves with increased water temperatures in summer
- Heating with heat pumps

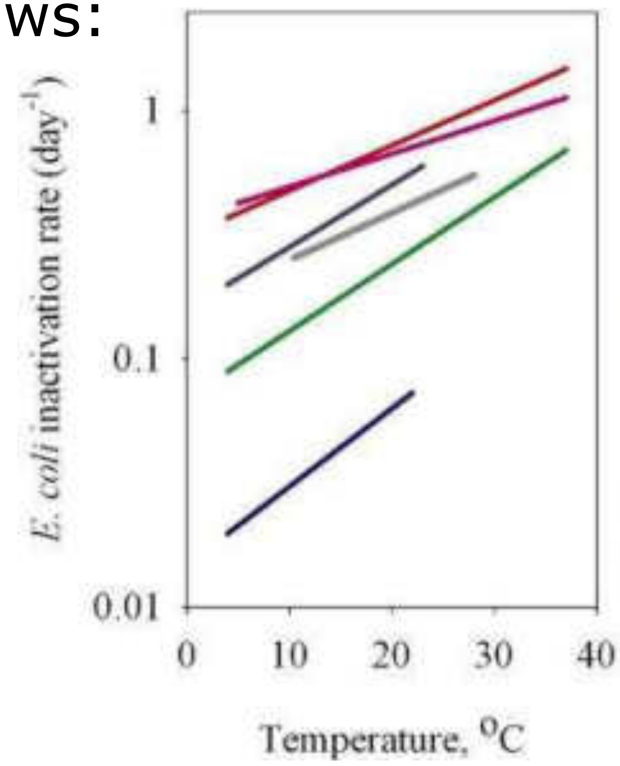
→ What does this mean for the hygiene?

Critical temperature for biological filtration systems?

25... 28 or 32 degrees Celsius?

Good news and (at least) some bad news!

The good news:




SciVerse ScienceDirect

ELSEVIER

WATER RESEARCH

Escherichia coli survival in waters: Temperature dependence

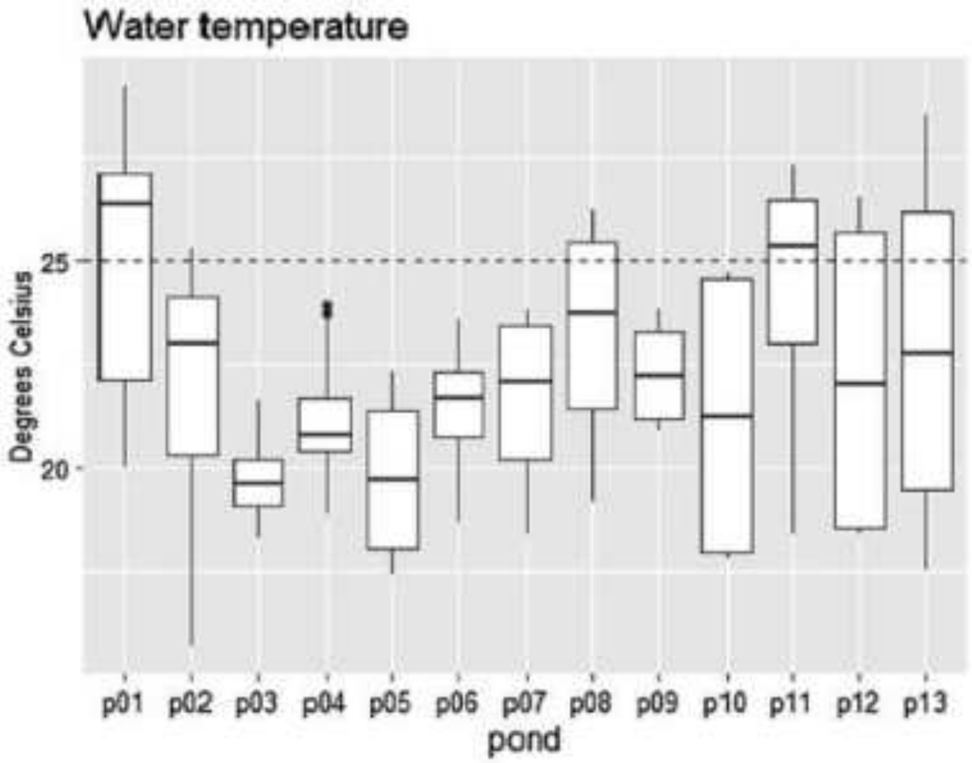
R.A. Blaustein[a], Y. Pachepsky[b,*], R.L. Hill[a], D.R. Shelton[b], G. Whelan[c]

ARTICLE INFO

ABSTRACT

→ E. coli is increasingly being broken down!

The (first) bad news:



Environment International 137 (2020) 105516
Contents lists available at ScienceDirect
Environment International
journal homepage: www.elsevier.com/locate/envint
ELSEVIER

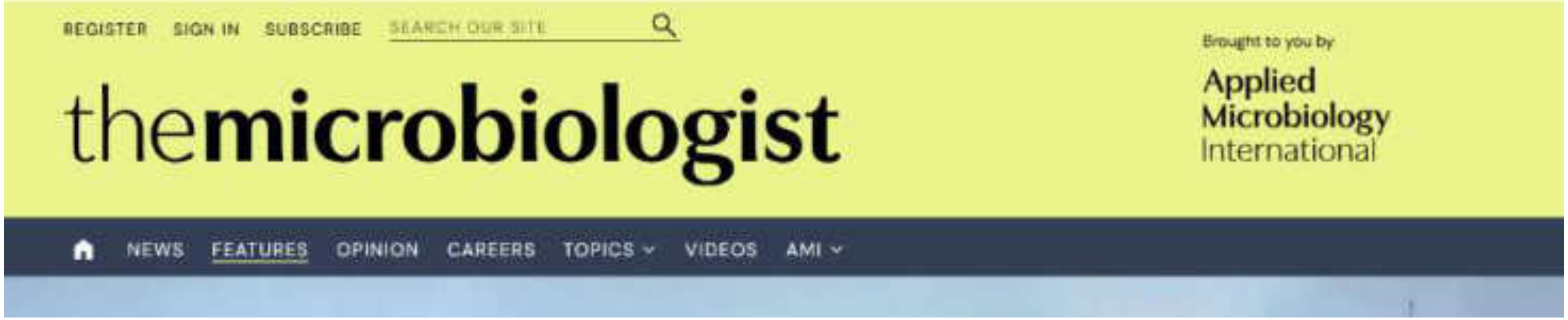
Evaluation of water quality guidelines for public swimming ponds

Franciska M. Schets[a,*], Harold H.J.L. van den Berg[a], Gretta Lynch[a], Sharona de Rijk[a], Ana Maria de Roda Husman[a,b], Jack F. Schijven[c,d]

[a] National Institute for Public Health and the Environment, Centre for Zoonoses and Environmental Microbiology, P.O. Box 1, 3720 BA Bilthoven, the Netherlands
[b] Utrecht University, Faculty of Veterinary Medicine, Institute for Risk Assessment Sciences, Yalelaan 1, 3584 CL Utrecht, the Netherlands
[c] National Institute for Public Health and the Environment, Department of Statistics, Informatics and Modelling, P.O. Box 1, 3720 BA Bilthoven, the Netherlands
[d] Utrecht University, Department of Earth Sciences, Environmental Hydrogeology Group, Princetonlaan 8a, 3584 CB Utrecht, the Netherlands

→ *P. aeruginosa* grows with higher water temperature!

The (second) bad news:



→ Free-living amoebae (FLAs) become a risk factor at temperatures above 30 degrees Celsius!

FEATURES

Free-living amoebae and emerging public health challenges in a warming world

BY SUJANI ARIYADASA, CRAIG BILLINGTON AND LOUISE WEAVER | 27 JANUARY 2025

The year 2023 was the warmest since global temperature records were established in 1850, with the average temperature 1.2 °C higher than the 20th century average of 13.9°C. This was also 0.15°C above the previous temperature record of 2016. Additionally, the highest average global temperatures have all occurred in the past decade (2014-2023). There is an 86% probability that at least one of the next four years (2024-2028) will be warmer than the warmest year on record.

Water temperature

Critical temperature for biological systems?

Above 25...28°C: Strong pathogen growth!

- e.g., *Pseudomonas aeruginosa* infections

Above 30°C: Very dangerous pathogens!

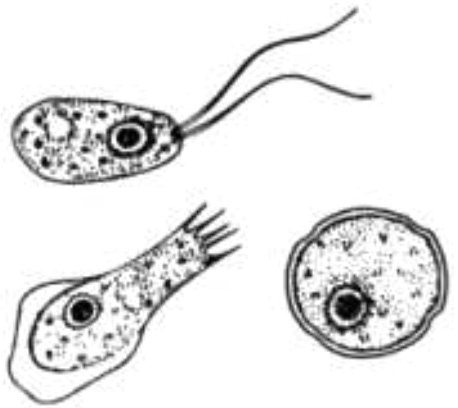
- *Legionella*
- Amoebae, such as *Naegleria fowleri* †

→ Only use tested filter systems

→ Dimensioning according to Norms / officiel guidelines

→ Warn your customers about water temperatures!

Jacob & Tschen (2020)

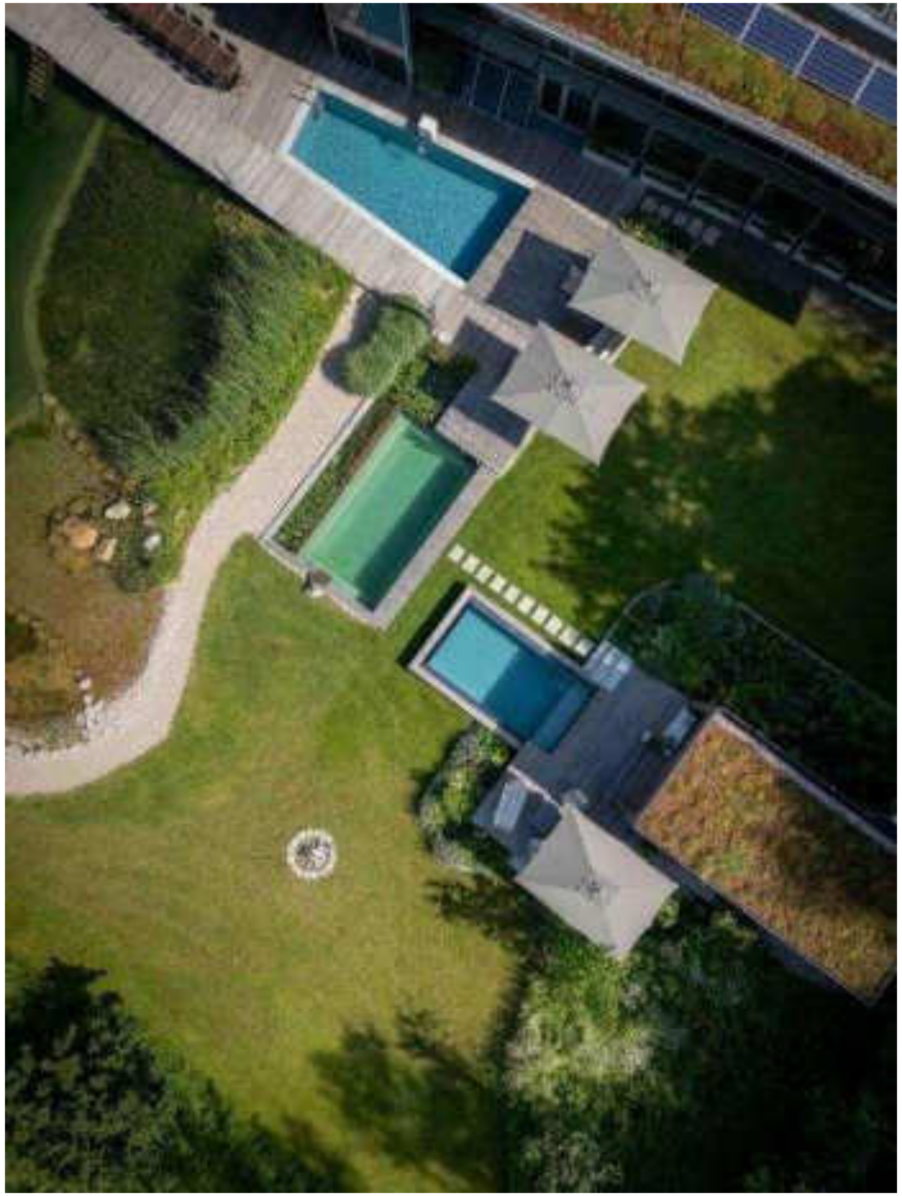


wikipedia.org/wiki/Naegleria_fowleri

Conclusion

- Chlorine has saved many lives!
- Chlorine is no longer appropriate today!
- Effective biological degradation of pathogens is possible!
- Only tested filter systems should be used for ponds and natural pools!
- Water temperatures are a risk factor
  - Further research is needed!

→ Come to the Biotop stand here at the IOB!

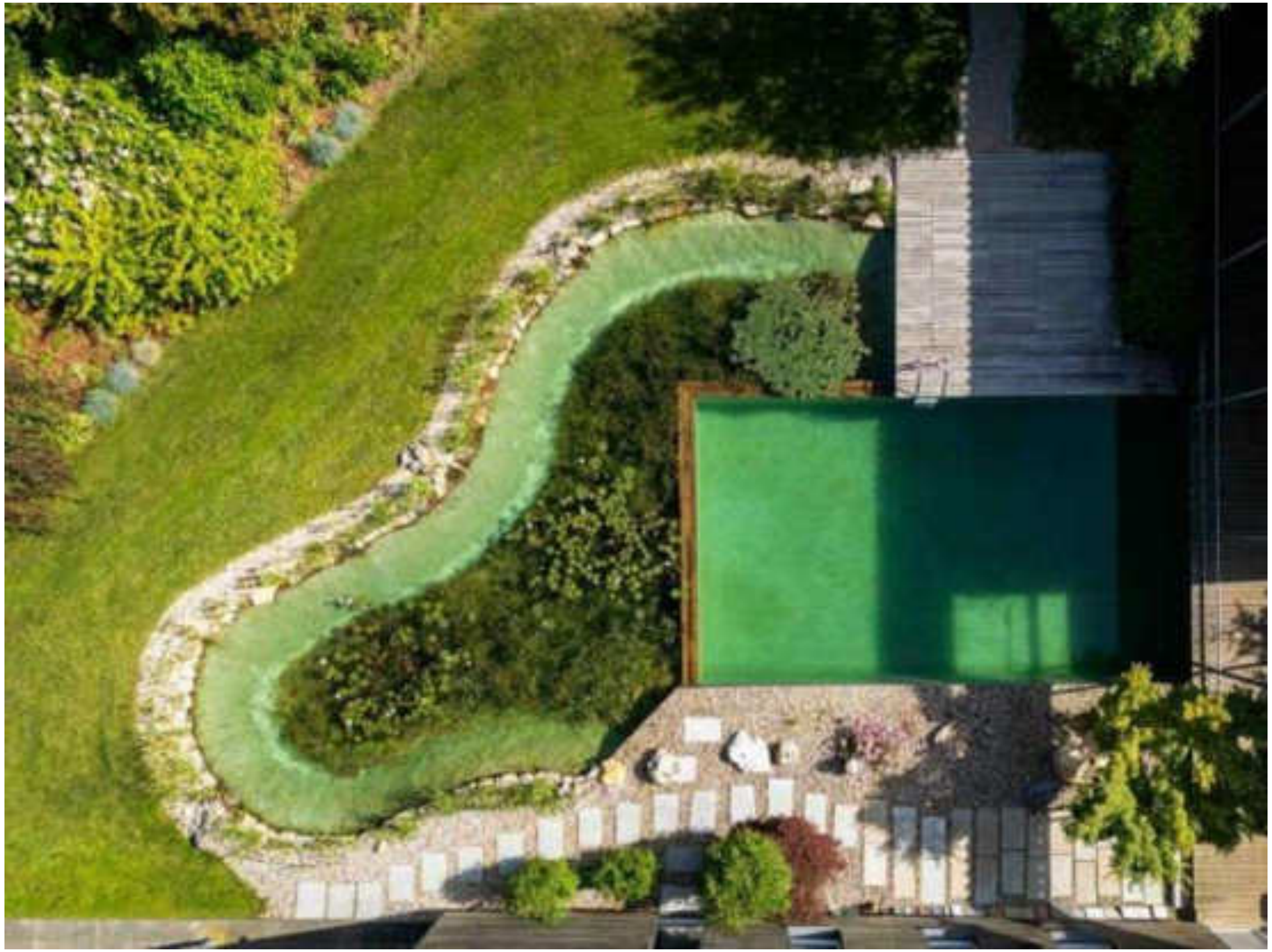


The good news at the end

The really good news:

Our systems can do it!

→ "Our system" has been working reliably for thousands of years!



The good news at the end

SCHWIMMTEICH & Naturpool

Fachmagazin für Planung, Bau und Betrieb

Wie hygienisch ist ein Naturpool?

Während herkömmliche Pool-Systeme auf Desinfektion durch Chlor setzen, nutzen Naturpools und Schwimmteiche den Selbstreinigungseffekt der Natur. Wie hygienisch ist aber natürliches Badewasser? Dr. Jakob Schelker, Experte für Technik und F&E bei Biotop, hat die Antwort.

LERNEN & WISSEN

fe und anorganische Partikel werden in einer Sandfilteranlage mechanisch entfernt. Der Sandfilter wird dann regelmäßig und zumeist automatisch rückgespült, um die Partikel aus dem Sand wieder auszuwaschen. Im Beckenwasser bleiben große Mengen an gelösten Nährstoffen, die aus den zerstörten Zellen stammen, wie auch viel freie DNA-Bestandteile. Die Wirkung des Chlors hält für einige Tage an, dann muss allerdings nachdosiert werden. Geschieht dies nicht, so sind aufgrund der vielen Nährstoffe Idealbedingungen für ein schnelles Wachstum von Bakterien und Krankheitserregern gegeben.

Natürliches Wasser ist gesünder

Aktives Chlor hat zahlreiche negative Eigenschaften - darunter seine zellzerstörende Wirkung. Diese ist auch problematisch für Haut, Zähne, Atemwege und Lunge. Wissenschaftliche Untersuchungen haben gezeigt, dass bestimmte Erkrankungen bei

mung des Filters. Zweitens müssen Einträge von außen, in Form von gefährlichen Keimen, Nährstoffen und insbesondere Phosphor, verhindert werden. Bereits wenige Gramm Rasendünger können in einer

oder bei welchen die Filter nicht korrekt dimensioniert sind. Bei öffentlichen Anlagen besteht zudem das Risiko, dass ein andauernd hoher Badebetrieb die Filteranlagen überlastet.

→ Summary article (in German) on the hygiene of natural pools in **Schwimmteich & Naturpool**, Issue 02-2024

Thank you very much for your attention.

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