water

Editorial

Evaluation of Invertebrates in Drinking Water Networks

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This Special Issue contributes to the evaluation of various aspects of biological drinking water quality and support both fundamental sciences and practical applications by drinking water companies. The papers present innovative and methodologically new findings from the Netherlands, Denmark, and Germany. Access to drinking water of a sufficient quality is essential to human welfare, but maintaining and safeguarding a good drinking water quality is a complex challenge for water suppliers.

Strategies of providing drinkable tap water are associated with sustainable environmental policy. However, an ongoing occurrence of small invertebrates in drinking water distribution systems (DWDSs) is observed even with the use of groundwater as a water source and with water treatment according to the state of the art. Alternatives in the drinking water supply, such as bottled water or end-of-pipe technologies, with nano-filters for water clients, are not acceptable due to environmental eco-balances.

Drinking water quality is threatened by reduced raw water quality, caused by direct contamination and by climate change effects, such as surface and ground water heating, flood events with the resuspension of river deposits, and low flow rates with a lack of dilution. Climate change effects on surface water quality have been intensively studied for a few decades, but those on groundwater only have been studied with less intensity. Nevertheless, the water quality can be secured by drinking water treatment plants, which can apply step-by-step increased water treatment technologies, and drinking waterworks outlet achieve a good water quality. The comprehensive study of Agudelo-Vera et al. [1] regarding water temperature in drinking water distribution points out that the heating of the water in DWDSs occurs and temperature monitoring in DWDSs is not completed sufficiently.

In DWDSs, water undergoes physical, chemical, and biological processes, which can reduce water quality for users.

The main processes are water heating by climate change effects, the oxidation of soluble ferrous and manganese compounds, and the microbiological assimilation of methane and ammonium. These biochemical processes lead to an increase in microbial biomass and are the basis for the development of a complex, multi-level drinking water pipe biocoenosis, an adapted food chain with (1) bacteria (e.g., *Pseudomonas*, *Aeromonas*, coliform bacteria), forming a biofilm on pipe walls and particle surfaces, (2) some bacteria consumer (amoebae, rotatories, water fleas), (3) detritus feeder (worms such as nematodes, oligochaetes), and (4) some larger consumers such a water snails, mosquito larvae, large oligochaetes, and water lice. DWDSs look similar to a zoo, with a high diversity of invertebrates which reach a body length of several millimeters (snails) to 15 mm (water lice); the largest pipe inhabitant is the oligochaete *Stylodrilus heringianus* with a body length of up to 40 mm [2].

In DWDSs, water temperature, water chemistry, and biodiversity undergo changes between waterworks plant and water consumers. This has been pointed out already by the World Health Organization (WHO) in 2006 with the biological stability of drinking water, who indicated the importance of the biological stability of drinking water in the context of microbiological safety [3]. A comprehensive assessment of the biological stability of drinking water is provided by Prest et al. [4]; biological stability is a complex, multifactorial process that encompasses interactions between water temperature, water chemistry,

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pipe material and structure, water flow velocities, biofilm formation, and colonization by invertebrates. However, up to now, the biological stability of drinking water has not attracted the focus of many drinking water companies, and their knowledge of DWDSs is insufficient. Many of them look at their DWDS as a black box with a clean water feed and an output of water within consumers' households. Knowledge regarding the invertebrate community in drinking water networks is still scarce, and monitoring of DWDSs is not yet the focus of the drinking water pipe management; available data are withheld because of the negative impact on drinking water users. Most of the pipe inhabitants found in drinking water systems are typical freshwater organisms that do not occur in raw water, respectively, and are not typical for drinking water treatment filters.

The occurrence of invertebrates in drinking water networks has been known for at least 100 years, mainly by water lice (*Asellus aquaticus*) and freshwater shrimps (*Gammarus pulex*) which have entered homes via their taps. Some of the more or less anesthetic invertebrates are midge larvae, snails, water lice, and worms, such as oligochaetes and nematodes. Complaints about drinking water quality are common, mainly by water colors (humic substances and pipe corrosion products) and by microbial contamination. Too, visible invertebrates (>0.5 mm) within house filters or in tap water occur and lead to a rejection of the water.

Increasing abundances of drinking water pipe inhabitants, the mass development of some species, and the spreading of some "new" pipe inhabitants such as water snails and chironomid larvae led to this Special Issue on "Invertebrates in Drinking Water Networks". It contributes to a better understanding of the biological stability of drinking water and presents some new methodological approaches to support further research.

The Special Issue presents papers concerning large-scale investigations in different drinking water networks from the Netherlands [5], the role of methane as a substrate for bacteria [6], sediment formation in DWDSs [7], climate change effects on DWDSs [8], and the risk of the mass development of chironomid larvae [9].

Analyses of the life cycle of pipe inhabitants is the basis for any risk management, and some applications are outlined by Gunkel et al. [8] for water lice and Christopher et al. [9] for the mosquito larvae *Paratanytarsus grimmii*. In both papers, population dynamic analyses were applied, and they describe the generation sequence and fertility of the species. Gunkel et al. [8] presents biodiversity and an abundance of pipe inhabitants with the use of more than 1000 hydrant samples, and a high biodiversity is provided. More than 96% of the studied samples were settled by macroinvertebrates (>2 mm); they include some isopods, the water louse *Asellus aquaticus*, the freshwater amphipod *Niphargus aquilex*, some midges and chironomids, oligochaete earthworms, and several species of water snails. Meioinvertebrates (0.1–2 mm) were found in 98% of the hydrant samples (e.g., copepods, roundworms, water mites, water fleas), while microinvertebrates reached an occurrence probability of 100%; microfauna is represented by rhizopods, rotatories, and ciliates. The contribution of Christopher et al. [9] focuses on the mass development and spreading of the chironomid larvae *Paratanytarus grimmii*, which was reported as a new inhabitant of some DWDSs in Northern Europe. Temperature is an important factor for *Paratanytarsus grimmii* growth, fertility, and mortality; the abundance of larvae clearly shows an increase in late summer with >6.000 larvae per m^3 of water, and five generation per year were observed.

New findings regarding the growth factors for pipe inhabitants are presented in two papers. The growth of microbes and invertebrates is supported by the biological instability of drinking water. Several factors are known to support growth, among else, the increasing water temperature by climate change effects, the available nutrients, assimilable organic carbon, as well as substances for biochemical processes such as methane (bacterial methan–oxidizig) and ammonium (nitrification). Two papers concern the biological stability of drinking water. Wagenvoort et al. [5] presents a large-scale study of two DWDSs in the Netherlands supplied with different raw water qualities, eutrophic reservoir water and groundwater, respectively. Differences in bacterial growth were observed by the use of the HPC22 indicator and *Aeromonas*, invertebrate biomass, and the occurrence of water lice *Asellus aquaticus*. An increased reservoir water supply due to groundwater level protection caused the regrowth of *Aeromonas* and invertebrates. Christensen et al. [6] analyzed the effect of methane in a filters of drinking water treatment plant, resulting in an increased biomass of methane and ammonia oxidizing bacteria, as well as of invertebrates in secondary filters. A methane concentration of 0.24 mg L^{-1} caused visible growth, vacuum stripping removed the quantity of methane to 0.03 mg L^{-1}, and such a low amount prevented the growth of methane-oxidizing bacteria. This concentration can be used as a target value for drinking water distributions systems, too.

Most complaints concerning drinking water quality have been provided because of sediment accumulation and turbid or brown water. Prest et al. [7] analyzed a large-scale DWDS at 1 location for 11 years. The sediment volume varied seasonally, but this was linked with the water temperature, invertebrate biomass, and concentration of *Aeromonas*. Especially the large water lice *Asellus aquaticus* contributed to sediment production.

Already in 2004, the WHO suggested that the presence of animals in drinking water systems may affect the microbiological quality of water; three papers support this statement. The paper of Christopher et al. [6] describes the spreading and mass development of a mosquito larvae, the parthenogenetic reproducing *Paratanytarsus grimmii*, which is well known all over the world, but recent occurrences in European drinking water networks show a cause for concern; the mass development of the larvae with a biofouling effect occurs, and this is associated with an increase in coliform bacteria (*Serratia fonticola*). Gunkel et al. [8] points out the risk of some free-living amoebae and ciliates as a host of *Legionella pneumophila* and *E. coli* cells; both remain viable and can multiply. Water lice (*Asellus aquaticus*) supports microbe development by their feces pellets, which serve as substrate especially in stagnant water. The contribution of Wagenvoort et al. [5] confirms the hypothesis that the biological instability of drinking water causes a higher invertebrate biomass, among else, the increased abundance of *Asellus aquaticus*. This causes increased regrowth conditions of *Aeromonas*. Nevertheless, the growth of *Aeromonas* is regulated to other factors, e.g., sediments and/or iron accumulation in drinking water distribution systems.

Climate change effects and the impact of temperature increase on drinking water quality is not yet the focus of the climate change debate. Gunkel et al. [8] summarizes the temperature increase of raw water (lakes, rivers, groundwater), and monitoring data from Northern Germany prove the increase in drinking water temperature within DWDSs. A DWDS temperature is strongly influenced by climate, especially urban heating, soil surface (asphalt and vegetation), ground water level, and operation parameters such as water flow, stagnation periods, etc. The observed temperature increase of 0.73 °C per decade exceeds the warming of the air temperature due to climate change, and at the consumer side, cold drinking water less than 20 °C cannot be guaranteed in summer periods. One effect of increasing temperature in drinking water is the occurrence of a third generation of water lice, *Asellus aquaticus*, leading to the mass development of >800 animals per m^{-3}.

Conflicts of Interest: The author declares no conflict of interest.

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