Animals in drinking water distribution, old topic - new perspective

HANS JÜRGEN HAHN*, NORBERT KLEIN**

Summary
Animals in drinking water distribution! A strange statement even for many experts! Nevertheless, multicellular animals can be found in almost every pipe network, sometimes in very high densities, a phenomenon that is regularly encountered in practice. It is mainly caused by a thick biofilm or one that has grown excessively during operation and the presence of stagnation zones. Animals are therefore indicators of other facts. These include inappropriate materials in the pipe network, extended retention times due to demographic change, increased water temperatures in summer due to the shallow installation depth of the pipes. New findings shed new light on the subject. Groundwater ecology provides important information. The species spectrum, occurrence and distribution of animals in the network provide important information on the condition of the systems. This is because pipeline networks are artificial ecosystems. Modern intensive cleaning methods for pipelines help to get problems under control. They may be required on a regular basis as maintenance measures or, in critical cases, extend the time window until the affected drinking water distribution system can be renovated.

Introduction
Drinking water distribution networks are nothing other than artificial groundwater ecosystems. The authors reported on this habitat together with U. Szewzyk and M. Mayer [1]. Like all habitats, the pipe networks are also colonized, especially by biofilms with bacteria, fungi, protozoa, but also by multicellular animals, so-called metazoans. Drinking water distribution networks are therefore living systems. Again and again, when working on house filters or taking samples at hydrants, but also through calls from customers, of

This phenomenon can be seen in the Humans are also an ecosystem [2]. Even the loneliest person has never been completely alone. He is a universe of tiny creatures. Bacteria, protozoa and fungi make up 90 percent of what we consider to be our bodies. On one

The body's own cells are therefore about
10 Cells of our colonizers. In the course of evolution, many colonizers have mutated into vital symbionts. They are therefore more than just compatible, but extremely useful comrades without whom we could not exist [2]. Life is not sterile.

The same applies to drinking water, our most important resource. The fact that it is as clean as we know and value it is primarily the result of biological processes [3]. It is therefore never sterile. The Drinking Water Ordinance regulates the requirements with limit values and technical measure values and refers to other regulations and ordinances with the term "generally recognized rules of technology". DVGW Code of Practice W 270 [4] applies to biofilms on materials. It describes a test procedure to determine the microbial growth on materials. Here, colonization with firmly adhering biofilms is desirable and even a prerequisite for suitability in the drinking water sector. They are proof that no toxic substances migrate from the materials. Fouling as a voluminous, scrapable biofilm is only permitted up to certain limit values. DVGW Guideline W 271 [5] deals with animals in water supply systems. It is currently being revised and adapted to the latest state of knowledge.

Especially in distribution networks, biological processes are of great importance for the quality of drinking water - for better or for worse. Knowledge of these processes is therefore an essential prerequisite for quality control!

quality assurance in the water supply. In the following, the habitat of drinking water distribution networks is therefore first presented as an ecosystem. The focus here is on the interrelationships that enable colonization as a phenomenon and specifically cause mass occurrences as a problem. Sustainable control strategies are required to solve the problem. Possible methods are presented.

Fundamentals of network ecology or: from phenomenon to problem
Animals in drinking water distribution networks are often colloquially associated with the term water isopods. However, this is only true in a few cases, mostly in northern Germany. In central and southern Germany, the common isopod *Asel- lus aquaticus*, a crustacean, is rare in drinking water supply systems. Animal inhabitants in the system here tend to be other crustaceans, e.g. water fleas or jumping lice, and more frequently true groundwater isopods of the genus *Proasellus*; bristle worms and threadworms are also regularly found.

A very important criterion for understanding the conditions in the system is (I) the contrast between surface species such as *Asellus aquaticus* and groundwater forms such as *Proasellus sla- vus* (Fig. 1). Another very helpful approach is (II) the understanding of drinking water distribution networks as ecosystems.

The first approach provides information about the living conditions in the network in the sense of a bioindication, while the second allows a risk assessment to be carried out:

Figure 1: Common water isopod *Asellus aquaticus* (left) and groundwater isopod *Proasellus slavus* (right). The common water isopod is a typical surface form with pronounced pigmentation and strong reproduction. It likes to live in organically polluted ponds and flowing waters. Under certain conditions, however, it also colonizes water supply systems, where it can become a problem.
The colorless, blind groundwater isopod *Proasellus slavus* reproduces very slowly and is extremely sensitive to pollutants. It is therefore considered a quality feature rather than a problem in pipe networks.

Photos: Thomas Kuska (*Asellus aquaticus*), Karsten Grabow and Heide Stein (*Proasellus slavus*)

(I) Groundwater versus surface water types

Groundwater and surface water species pursue completely different reproduction and dispersal strategies, and their habitat requirements are also very different. Many surface species are so-called r-strategists, i.e. they are very adaptable and rely on rapid reproduction and dispersal in order to colonize new habitats as well as possible. They are extremely successful at this and can build up mass populations in a very short time under favorable conditions, e.g. with a good food supply and high temperatures. A "beautiful" example of this are aphids, which can appear in huge numbers on fresh shoots in spring. However, r-strategists only cope very poorly with extreme habitats such as groundwater.

Groundwater animals, on the other hand, are considered A-strategists. Their strength lies in their ability to adapt to adverse environmental conditions, i.e. in groundwater primarily a lack of food and oxygen and low temperatures. Groundwater animals react sensitively to higher temperatures. These adaptations go hand in hand with low reproduction rates and long life spans. At the same time, A-strategists are very weak competitors, meaning that they cannot prevail against their surface-water relatives under favorable living conditions. The differences between r- and A-strategists become clear in the example of two French species of the genus *Stenasellus*, one from groundwater and the other from surface waters (Table 1). The same applies to the Central European surface species *Asellus aquati- cus* and the groundwater form *Proasel- lus spec.*

Stenasellus spec.		
Features	A-Strategist, in groundwater	r-Strategist, in surface waters
Embryonic developme nt	9 - 10 months	3 weeks
Juvenile period	5 - 7 years	3 months
Adult time	7 years	6 - 8 months
Lifetime	15 years	1 year
Egg laying frequency	every 2 years	monthly

Table 1: Differences between r- and A-strategists using the example of two French isopod species of the genus *Stenasellus* (modified after Ginet & Decou, 1977 [6])

Table 1 illustrates above all the extremely long development and reproduction period of the groundwater species. Another difference between surface and groundwater species is the number of eggs. For example, the number of eggs is given as two for caterpillar hoppers from groundwater, but 23 for animals from surface waters [7] (see also Fig. 2).

Figure 2: The groundwater-dwelling caterpillar *Arcticocamptus rhaeticus* produces far fewer eggs than related surface species.

Photo: Andreas Fuchs

As a consequence, this means that the regular occurrence of surface types in supply systems

- especially at high densities - is associated with the risk of mass development, whereas this risk hardly exists with groundwater species. The presence of true groundwater animals, in conjunction with the absence of surface species, indicates groundwater-like living conditions with a scarce food supply (= little DOC and little dead organic material) and low water temperatures. Conversely, the regular occurrence of surface species, especially at high densities, indicates favorable living conditions, especially a good food supply. If planktonic forms, e.g. water fleas, are also represented in significant proportions among the surface water species, it can be assumed that there are smaller or larger stagnation zones in the network in question where the animals can survive and reproduce.

Another aspect is also relevant for quality assurance, namely the question of entry paths. Microorganisms or pollutants can also enter the drinking water in the same way as the animals. Is there a permanent entry with the raw water? Was there contamination in connection with construction work on the network or improper work at the waterworks? However, perhaps the entry took place decades ago and an independent fauna exists in the network - the network forgets nothing. How the animals then become established in the system spread, whether and where they can persist, perhaps even form mass populations - this is primarily a question of the pipeline network ecosystem and the key factors at work there.

(II) The ecology of the network

Animals in the network are initially a harmless phenomenon that can be observed in practically every water supply system. However, if the animal density gets out of control, a real problem arises. Pipeline networks are artificial habitats, colonized by countless microorganisms, but also by a large number of multicellular animals. In most cases, the raw water has the character of groundwater. It is low in DOC, cold and often also low in oxygen. Groundwater communities are usually referred to as "capped", simplified communities, with few species and individuals that occur in low densities and only reproduce very slowly [8]. The basis of life is the organic carbon deposited from the earth's surface as DOC or particles - and this becomes increasingly scarce with increasing residence time. So Schmalhans is the master chef in groundwater, and surface animals would simply starve to death or perish from lack of oxygen.

These conditions, which indicate excellent water quality, can change in the course of treatment and transportation. In many cases, the water is aerated and then transported via extensive pipe systems. If the pipes are installed at a shallow depth, which has become increasingly common in recent years due to reduced frost depths, the water can heat up to 20 °C or more in summer. The inner surfaces of the system are overgrown with biofilms. These multi-layered biofilms consist of microorganisms and other substances. The microorganisms live on the substances released by organic pipe materials, but above all on the organic substances dissolved in the water. As a result, the biofilms purify the drinking water - an entirely desirable effect if they are adherent. Voluminous biofilm - growth as defined by DVGW worksheet W 270 [4] - is undesirable as a microbial growth. It can partially detach and lead to contamination of the drinking water.

However, biofilms are also a significant habitat for metazoans and at the same time their most important source of food. The conversion of the available DOC to microbial biomass leads to an accumulation of organic material in the system over the years and decades. In dead pipes and stagnation zones, particulate organic material, e.g. detached parts of the biofilm, plant residues and feces of net-dwelling animals, accumulates.

Such conditions - a good food supply, high summer temperatures and a sufficient supply of oxygen - are typical for surface waters. It could also be said that the character of the water changes from groundwater to surface water as a result of treatment and transportation.

The use of these forms of surface can become permanently established in the network and may also cause problems.

As part of quality assurance, regular, indicative sampling with tests for animals is highly recommended.

However, a professional examination is necessary at the latest when the animals are apparently reported on the farm or even by customers. Highly fluctuating or permanently high densities of fifty, one hundred or even more animals per cubic meter of water

Figure 4: Faunistic sampling of the pipeline network. For this purpose, special nets are used to filter the largest possible volumes of water, usually 5 - 10 m3 , and the animals contained therein are then sorted out, counted and determined. In addition, relevant water chemistry parameters are recorded.

water is changed. Corresponding gradients can also be found in groundwater recharge (Fig. 3). Stygoxenes, i.e. surface water inhabitants foreign to groundwater, live in the well-supplied, surface water-influenced areas. As the residence time of the water in the subsurface increases, the food supply, the temperature and the oxygen content decrease, so that the proportion of true groundwater inhabitants (stygobionts) increases compared to stygoxenes. In this transitional area between surface and groundwater, so-called stygophiles can also be found, which are actually surface species, but which can occasionally penetrate into the groundwater for longer periods of time.

Primarily due to the increased temperatures, groundwater species can no longer persist in the networks described above. However, surface species benefit from this: the better the food supply, the higher the summer temperatures and the more extensive the stagnation areas, the greater the likelihood that

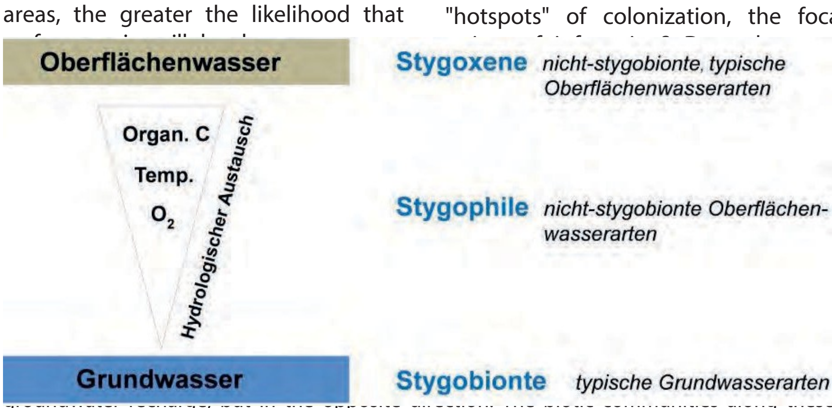
are not only to be taken seriously for aesthetic reasons. The excretions of the animals and their carcasses can lead to an increase in the number of germs in drinking water as a result of a mass occurrence, so that there is also a hygiene problem.

Ultimately, the ecology of the network and its key parameters, the extent of the stagnation zones, the temperature and the DOC of the distributed water, determine whether and where critical meta- zoic colonization occurs.

Solution approaches

In the case of massive metazoan infestation, as with many problem solutions, **it is** first necessary to determine the causes and extent of the problem. The first and most important step towards a sustainable solution is therefore a representative investigation of the network: What is the DOC content of the raw water? What about the biofilms? Where are there areas of stagnation? But above all: where are the

"hotspots" of colonization, the focal



gradients are similar.

the raw water or is it an autochthonous, i.e. independent net fauna?

Such indicative tests can usually be carried out quickly by appropriate specialists (Fig. 4). As the animal populations in the pipeline network can fluctuate greatly, regular monthly to quarterly sampling over the course of a year is also recommended. The further procedure then depends on the findings.

A crucial point for successfully dealing with the infestation is internal communication. Bugs in the network are not a disgrace, but just as commonplace - and in higher densities - just as unpleasant as germs. Dealing with them openly creates the conditions for solving the problem and, above all, the skills for any necessary communication with customers and the media.

Solutions should be pragmatic:
Oversized pipe systems with their usually pronounced stagnation areas can often only be eliminated by completely rebuilding the network.
High DOC levels in the raw water are also difficult to influence. Permanent solutions can therefore rarely be implemented in a timely manner.
However, the animals can be flushed out through intensive cleaning of the pipes, especially the stagnation zones. If the organic deposits and biofilms can also be removed, a significant part of the cause, namely the food source and habitat, is sustainably reduced. In most cases, therefore,

Following cleaning measures, control of the populations by means of targeted monitoring in combination with

Photo: Institute for Groundwater Ecology IGÖ GmbH; Illustration: Sven Berkhoff

be possible with adapted maintenance measures and flushing plans.
An immediate measure is to check the house water filters. These are a barrier for animals. Standard-compliant filters in accordance with DIN EN 13443-1 [9] retain particles > 100 µm and prevent animals from entering the drinking water installation.
Flushing and cleaning measures include:

- Water flushing with high flow rates
- Rinsing with water enriched with carbon dioxide
- Impulse rinsing process for example Comprex cleaning

According to DVGW Code of Practice W 291 [10], when flushing with water, the flow rate velocity must be between 2 m/s and 3 m/s. This creates a turbulent flow in the pipe. The flow velocity at the pipe wall is about half that in the center of the pipe. In practice, these conditions can only be achieved in pipes up to DN 150 when flushing via hydrants. Even under these conditions, a large proportion of the animals can successfully "cling" to the pipe wall, so that only some of them, especially the planktonic species, are discharged. This is where the idea of flushing with carbon dioxide-enriched water comes in. Carbon dioxide stuns the animals for a short time so that they can no longer "hold on" and are discharged with the water flow.
However, experience has shown that around 10 % of the population remains in the pipe [11], [12]. However, the causes of the infestation - biofilms and stagnation zones with organic deposits - are not changed by the use of CO2, so that with a more or less rapid recovery the animal population can be expected.
The impulse flushing method has proven to be an effective measure when water flushing is no longer sufficient. It is mentioned in the new DVGW Code of Practice W 557 from October 2012 [13] and is therefore considered a generally recognized rule of technology. DVGW Code of Practice W 291 [10] only describes flushing with a water-air mixture. This DVGW worksheet from March 2000 is now due for revision.
Hammann has further developed the impulse rinsing process into the Comprex process. The focus here is on increased cleaning efficiency with reduced water consumption and thus research projects have shown that the effectiveness can be increased considerably by controlling the impulses appropriately. In one test installation, flow velocities of the water blocks of over 20 m/s were achieved. This led to new patent applications and new applications. For example, it was possible to reduce the methacene infestation in a reduced rinsing water consumption. New investigations within the scope of research

Figure 5: Net cleaning with the Comprex process. The detached biofilms stain the rinsing water intensively. At the same time, the animals are also removed - sometimes with thousands of individuals per cubic meter of rinsing water.

Photo: Hammann GmbH

This also mobilized and removed deposits and, above all, the biofilm (Fig. 5). An interesting effect of this measure was that the animal densities in the flushing water could be determined during the cleaning process by taking samples at the discharge point, allowing conclusions to be drawn about the cleaning efficiency [14].
Another result of the research projects is the visualization of cleaning in a test facility made of transparent pipes. Pipe sections with deposits from real pipes can be installed in the test section in order to test the various cleaning processes. In addition, artificial deposits in the form of pieces of steel can also be introduced. Magnets attached from the outside ensure adhesion. This makes it possible to test the cleaning effect at different flow speeds or to compare different methods using magnets of different strengths. The shear force required for mobilization can simply be felt by sliding with a finger or determined using a device consisting of a spring balance and accessories. The video clip of the test system, which was shown at the Wasser Berlin International 2013 trade fair, is available on the website [15].

Case study Stadtwerke Tierstadt

Stadtwerke Tierstadt (SWT, name changed) in southern Germany supplies around 40,000 residents with drinking water. In recent years, meta- zoa, especially woodlice, have been repeatedly detected during maintenance work. Some customers also came forward and complained.

of "animals" in the house filters. SWT reacted prudently, first visiting the affected customers, informing them and reassuring them. Those responsible discussed the infestation internally and looked for possible solutions.

In 2011, the University of Landau and the Institute for Groundwater Ecology IGÖ GmbH,

35 representative sites in the network were examined faunistically for the first time. The findings showed that the isopods were *Proasellus slavus* and thus genuine and unproblematic groundwater organisms that were only found at a few sites. However, in addition to the harmless isopods, exogenous water fleas and copepods were found at many sites, sometimes in densities of over 200 animals/m^3 . As the highest densities were found a t the sites with the highest water temperatures, a seasonal dynamic c o u l d b e assumed.

Therefore, 11 sites were sampled a total of five times from February to October 2012. In fact, a number of sites showed strong seasonal fluctuations in animal densities, with the highest animal densities in summer and fall. These sites were also those with the greatest temperature fluctuations and thus the highest temperatures overall, and almost all of them were located in stagnation zones according to the network plan. High DOC concentrations between 2.1 mg/l and 2.5 mg/l in combination with extensive stagnation areas according to the network plan and high summer water temperatures characterize the SWT supply network as potentially at risk of critical animal infestation.

Shortly after the preliminary investigation in February, additional pipe sections at five of the eleven sites were cleaned using the Comprex impulse flushing process by Hammann GmbH. The follow-up investigation in April showed a significant reduction in animal densities at all sites, at site 1 even by more than 95 % (Fig. 6) - proof of the effectiveness of the cleaning. While the animal densities at sites 3 and 5 remained at a low level and largely inconspicuous until the 4th follow-up examination, the densities at sites 1 and 2 increased with the cleaning process.

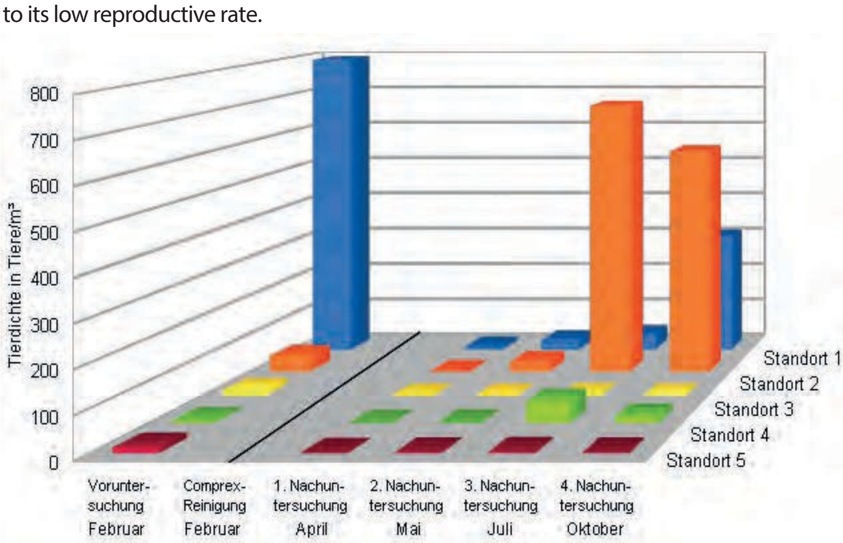
In the 3rd and 4th follow-up surveys in July and October respectively, animal densities increased massively again - to between 300 and around 700 animals/m³ . It is worth noting that during the preliminary survey in February at site 2, the animal density of 50 animals/m³ was high, but significantly lower than at site 1. The sharp increase in the third and fourth follow-up surveys in summer indicates that the heat probably plays a major role in population development at this site. The species identification at sites 1 and 2 provides further indications. The densities of water fleas are striking. They play a much smaller role in winter than in summer and fall.

The findings in detail are also interesting. For example, the groundwater isopod *Proasellus* had completely disappeared after cleaning and could not be found again later. This indicates that the species was able to build up quite high populations in the stagnation zones undisturbed for years, but was no longer able to recover from this intervention in the eight months recorded after the cleaning due to its low reproductive rate.

The population development at sites 1 and 2 was completely different: the animals found after the second follow-up survey were almost exclusively surface water-dwelling water fleas and hoppers. Water fleas in particular, as well as some hoppers, are known for their ability to build up gigantic popu- lations in a very short time as soon as it gets warm. Anyone who has taken a closer look at ponds and pools in spring can confirm this. The data from the other sites also showed that the animals were not introduced by the raw water, but probably originated predominantly from the net's own colonization.

As the identified representatives of the two animal groups live in the open water rather than in the sediment, it can be assumed that the mass reproduction must have taken place in the stagnation zones with little or no flow - i.e. exactly where sites 1 and 2 are located. Furthermore, it can be expected that after the removal of the biofilms, regular water flushing with high flow velocities would be sufficient to keep the semi-planktonic populations small.

This was also one of the recommendations to SWT, namely to draw up a corresponding flushing plan. It was also recommended that the network plan should be used to identify all zones with increased clogging times or stagnation and to examine them for animals. Critical areas could then be cleaned using the impulse method. In the medium term, regular examination of animal densities and monitoring of colonization is recommended.



Conclusion

The example of Tierstadt shows that special behavior, analysis of the net ecology and elimination of the causes, in particular the biofilms and the fauna living in them, help to get the situation under control quickly. However, as the animals cannot be completely removed from the net, a rapid recovery of the semi-planktonic water fleas and hoppers can always be expected in critical areas. The same should also apply to systems infested with water isopods. This makes it all the more important to identify and clean all "hotspots", to continue monitoring the populations after cleaning and to consistently implement maintenance measures.

Intensive cleaning, possibly combined with an inspection of the fittings, helps to create clean conditions and safety in the pipe network. Together with animals, biofilms (food source for metazoa) and deposits (nesting potential for microorganisms and animals) are mobilized and removed. In addition to cleaning, the inspection of gate valves indicates which valves are actually functioning after upgrading. Due to the number of upgraded valves, cleaning measures can pay off because they no longer need to be replaced. Furthermore, the subsequent cleaning reliably removes the deposits and biofilms detached from the valves from the pipe network [16] [17].

Literature

[1] 27th Oldenburg Pipeline Forum, Program page 22, block 27 http://www.iro - online.de/cpme - dia/downloads/program_forum _2013-74.pdf: Rohrleitungen im Zeichen des Klimawandels, Tagungsband zum 27. Oldenburger Rohrleitungsforum; Schriftenreihe aus dem Institut für Rohrleitungsbau Oldenburg Band 38; Vulkan Verlag ISBN 978-3-8027-27777-1; Lebensraum Trinkwasserleitungsnetze im Fokus des Klimawandels page 137 - 158

[2] Blech, J.: Leben auf dem Menschen; rowolth Sachbuch rororo ISBN 978-3-499-62494-0

[3] Avramov, M., Schmidt, S. I., Griebler, C. , Hahn, H. J. & Berkhoff, S. (2010): Services of groundwater ecosystems. - KW Korrespondenz Wasser- wirtschaft 3, 2, 74-81

[4] DVGW Code of Practice W 270, Increase of micro-organisms on works surfaces

materials for the drinking water sector - Testing and evaluation
[5] DVGW Guideline W 271, Animal organisms in water supply systems
[6] Ginet, R., Decou, V. (1977): Initiation à la Biologie et à l'Écologie Souterraine, Jean Pierre Delarge, 345 p., Paris
[7] Schminke, H. K., Preuss, G. (2004): Groundwater is alive!, Chemie in unserer Zeit 38, 340-347, Wiley-Verlag, Wein- heim
[8] Gibert, J. & Deharveng, L. (2002): Subterranean Ecosystems: A truncated functional biodiversity, BioScience 52, 6, 473-481
[9] DIN EN 13443-1, Systems for the treatment of drinking water inside buildings - Mechanically acting filters - Part 1: Filter fineness 80 µm to 105 µm - Requirements for design, safety and testing
[10] DVGW Code of Practice W 291, Clean- and disinfection of water distribution systems
[11] Drinking water: Zero diet for the as- sels, WAH starts CO2 flushing process on Monday; Märkische Allgemeine from April 3, 2009
[12] Supply: Woodlice came from Falkensee, cause of drinking water contamination clarified with "high scientific certainty"; Märkische Allgemeine from March 24, 2009
[13] DVGW Code of Practice W 557, Cleaning and disinfection of drinking water installations
[14] Berghoff, S.: Effectiveness of a biofilm reduction on metazoan infestation in the drinking water supply network; gwf-Was- ser Abwasser, June 2012 pp. 681 - 682
[15] http://www.hammann-gmbh.de/
[16] Klein, N.: Cleaning, disinfection and valve inspection; 3R (2011) No. 12, pp. 860-863
[17] Klein, N. and Hammann, H.-G.: Cleaning as a measure for the safe operation of pipelines; 3R (2012) No. 11, pp. 918-922

*PD Dr. Hans Jügen Hahn, University of Koblenz-Landau, Institute for Environmental Sciences, Fortstr. 7, 76829 Landau; Tel.: 06341/280-31590, Fax 06341/280-31591,
Email: hjhahn@uni-landau.de

**Dr. Norbert Klein, Hammann GmbH, Zweibrücker Straße 13, 76855 Annweiler; Tel.: 06346/3004-42, Fax 06346/3004-56,
Email: n.klein@hammann-gmbh.de