Delft Cluster Magazine

Drinking water: transfer of knowledge

Number 5 2008

Delft Cluster

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Delft Cluster is an open network that carries out research into the sustainable organisation of delta areas for the soil, road and hydraulics sectors.

The Delft Cluster programme

Engineering knowledge is the key to finding ways to tackle and improve all aspects of the problems that deltas are facing. Investment in developing this knowledge will mean we can help society find effective solutions to today's problems and those of the future. Such solutions can only be developed in conjunction with businesses and regional authorities that implement and use these solutions, and which provide feedback to developers based on their experience.

Programme design and approach

The Delft Cluster programme comprises six key topics that give a composite picture of the problems that deltas are facing. These six key topics are:

1 Controlled utilisation of the subsoil
2 Low-maintenance infrastructure
3 Decision-making techniques
4 High tide and flooding risks
5 Spatial planning with water
6 Urban water management

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Content

Cross-fertilisation and transfer of

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knowledge

A common aim of drinking water supply and wastewater treatment is to protect public health. Despite this clear link, these activities have for a long time been managed separately in The Netherlands. Water companies were concerned with the 'clean part' of the water chain, while municipalities and water boards performed their roles in the 'dirty part'.

This division has also been apparent in the way in which employees have organized themselves. On the one hand, we saw the foundation of the 'Royal Association of Drinking Water Supply in the Netherlands' (KVWN) in 1899. On the other hand, those involved in wastewater collection, wastewater treatment and water management joined forces in 1958 to form the 'Netherlands Association of Water Management' (NVA). And we could even observe two separate worlds in the field of research. The majority of drinking water research has been carried out by Kiwa Water Research, while the Foundation for Applied Water Management Research (Stowa) managed an important share of research concerned with wastewater. The Delft University of Technology was one of the few institutes that carried out both drinking water and wastewater research from the earliest days.

During the last decade, a trend has developed towards greater integration and mutual strengthening of those involved with the water chain, mainly because of political pressure. This led to the formation of Waternet in Amsterdam, for example. Waternet is the first 'water cycle company' in The Netherlands, offering combined management of drinking water, wastewater, surface water and groundwater. Also, after a relatively long familiarization period, KVWN and NVA are planning to merge during the course of 2008. They will together form the new 'Waternetwork', a platform for the exchange of knowledge and experience via meetings, excursions, international contacts and publications.

Research activities related to drinking water and wastewater have also become more intertwined over time, for example within the Centre of Excellence for Sustainable Water Technology (TTI-W) and within the Delft Cluster Research Programme. Nowadays, treatment technology for drinking water production is adapted and applied in wastewater treatment, so providing a means of complying with the rather strict water quality standards of the European Water Framework Directive.

This special edition of the Delft Cluster magazine describes recent developments in drinking water research. A number of key persons also present their views on – and the outcomes of – this research.

As chairman of the KVWN, I am gratified to see that the first appearance of this edition coincides with the last drinking water conference of the (soon to be merged) KVWN, entitled 'Water in transition'.

I am extremely pleased to present this magazine, in the hope that it will not only lead to improved drinking water supply, but also to the cross-fertilisation of ideas that will advance research into wastewater treatment. I sincerely hope that it will act as another (albeit small) stimulus for further integration of research and management in the water cycle.

Roelof Kruize
CEO Waternet

kvwn
Koninklijke Vereniging voor
Waterleidingbelangen in Nederland

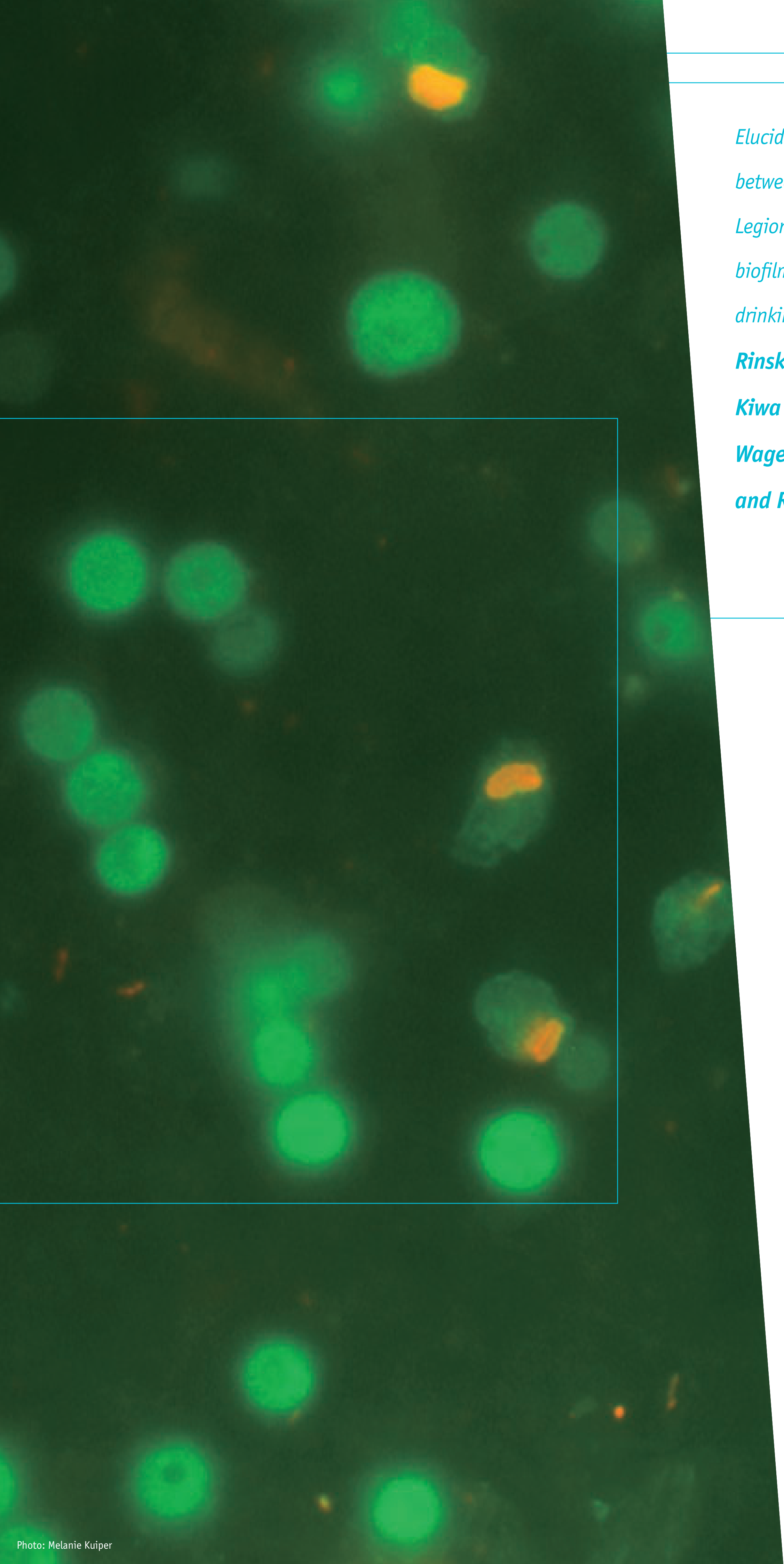


Photo: Melanie Kuiper

Elucidation of relationships between free-living protozoa, Legionella pneumophila and biofilm concentrations in drinking water

Rinske Valster,

Kiwa Water Research / Wageningen University and Research Centre

Figure 1
Legionella pneumophila cells (orange) in free-living protozoa (green).

Free-living protozoa in drinking water

The challenge to deliver high quality drinking water is reflected in the Delft Cluster project Quality 21, whose objective is to deliver top quality drinking water. Via this project, we aim to ensure good drinking water in the 21st century, as well as to keep or improve consumers' trust in drinking water from the tap. One spearhead of the Q21 project is to inhibit the growth of Legionella pneumophila in drinking water treatment systems, the distribution infrastructure, and warm water installations. The aim of this research is to provide data on interactions in microbial communities that are present as biofilms in drinking water systems, in relation to the presence of free-living protozoa that serve as a host for Legionella pneumophila.

Legionella pneumophila can cause an infection of the lungs following inhalation of contaminated water droplets. The first documented outbreak of this disease occurred in Philadelphia in 1976, among 180 persons attending the 56th annual American Legion Convention. Twenty-nine patients died and the disease became known as Legionnaires' disease. A major outbreak of Legionnaires' disease in The Netherlands took place in 1999. Thirty-one visitors at a flower show in Bovenkarspel died as a result of Legionella infection. During the last five years, more than 200 people per year have suffered from Legionnaires' disease in The Netherlands.

Growth of Legionella pneumophila in free-living protozoa

Legionella pneumophila and a number of other species of Legionella multiply in free-living protozoa that live in biofilms (complex aggregations of micro-organisms attached to a surface) in engineered water systems. Multiplication of Legionella pneumophila depends on the presence of free-living host protozoa e.g. Acanthamoeba, Naegleria, Hartmannella, Echinamoeba and Tetrahymena. Free-living protozoa are unicellular eukaryotes that feed on bacteria, fungi, algae and other protozoa. The protozoa can take up Legionella bacteria while grazing on the biofilm. The Legionella bacteria then multiply in the free-living protozoa and finally kill it, so releasing Legionella cells in the drinking water or in the biofilm (Figure 1). Limiting the multiplication of Legionella pneumophila in water systems requires detailed knowledge about their behaviour in these environments. However, information about the identity and numbers of free-living protozoa serving as a host for Legionella bacteria in drinking water and warm water installations is limited. Furthermore, quantitative information about the relationship between numbers of host protozoa and biofilm concentration, as well as the impact of environmental conditions on these relationships, is very scarce.

Identification of free-living protozoa in drinking water

Molecular methods to identify free-living protozoa were applied in two types of treated water and in biofilms from pipe segments in distribution systems. We used treated water from an aerobic groundwater supply with a dissolved natural organic mater of 0.5 mg per litre, and treated water from an anaerobic groundwater supply with a dissolved natural organic mater of 7 mg per litre. This is one of the highest concentrations found in drinking water in The Netherlands.

Eukaryotic communities are highly diverse, and free-living protozoa are ubiquitous in treated water in The Netherlands (Figure 2). The dominant protozoan groups in both water types are Cercomonas species, soil flagellates, and uncultured Cercozoan clones. Approximately 1.2% of the free-living protozoan community in both treated water types may serve as a host for Legionella pneumophila. Acanthamoeba species are a potential host in treated water with a low concentration of organic matter, and Echinamoeba species are a potential host in treated water with a high concentration of organic matter. Many free-living protozoa species are not described in public databases, and good identification of many DNA sequences related to protozoa is not possible. Newly-obtained sequences will improve public databases, and can be used for further identification of free-living protozoa.

Further plans

In addition to identifying free-living protozoa in different drinking water types and in biofilms, we have developed a method to identify the specific protozoa that serve as a host for Legionella pneumophila. In the future, we will apply this identification method to investigate the presence of host protozoa in drinking water and warm water installations and to identify them. Based on the dominant species of host protozoan, we will be able to elucidate the relationship between biofilm concentration and the growth of this host protozoan for Legionella pneumophila.

This knowledge about the growth conditions of Legionella pneumophila in host protozoa will be used to take measures that inhibit the growth of Legionella pneumophila in drinking water and in warm water installations.

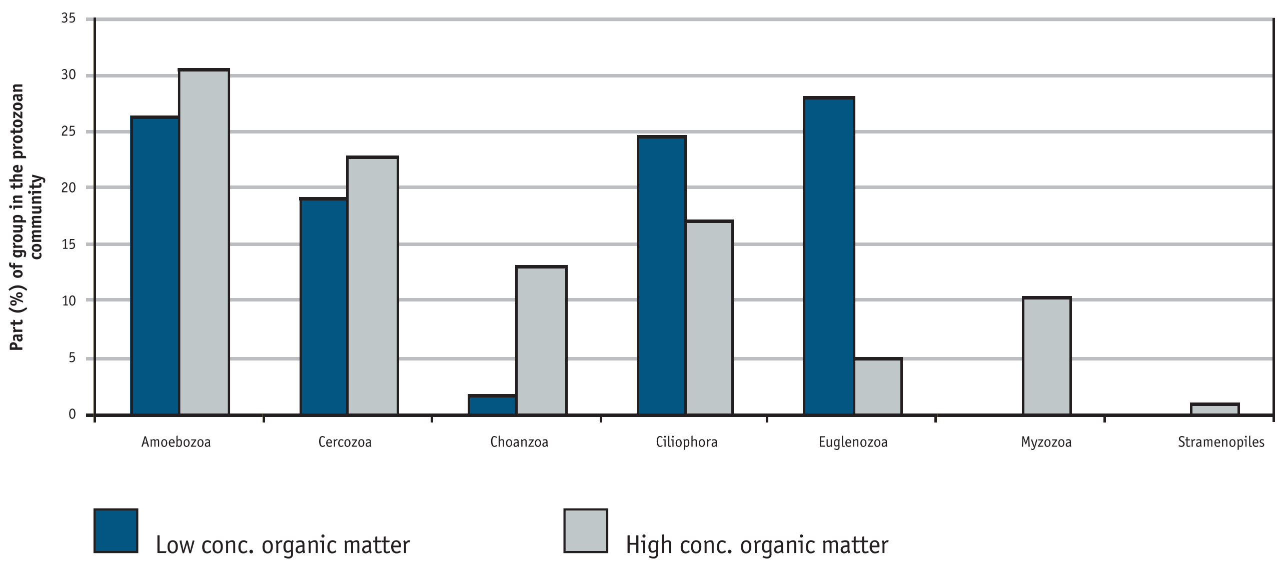


Figure 2

Comparison of the free-living protozoa communities in treated water with a low concentration of organic matter and in treated water with a high concentration of organic matter.

Photo: iStockPhoto

New distribution discoloured

Photo: United Photos Haarlem

networks minimise water problems

"Discoloured water is an old problem", says Martien den Blanken, director of PWN Water Supply Company. "A problem that leads to numerous complaints every year. It is of course extremely annoying for our customers if discoloured water comes out of their taps. Although there is apparently no health impact, it looks uninviting and may lead to stains when washing clothes. In fact, this phenomenon is the most important reason why customers complain about water quality."

Particles

Den Blanken continues: "In the past, we accepted that discoloured water would occasionally come out of our taps, assuming it was caused by corroding cast-iron pipes. Thanks to research carried out by Jan Vreeburg (see text box p.13), partly within the Delft Cluster Research Programme, we now know that discoloured water is actually caused by small particles that enter the distribution network with the treated water. These particles, which mainly consist of iron and organic material, settle in the network forming a sediment layer. When the flow velocity suddenly increases, some of the sediment can be re-suspended leading to brown or even black discolouration of the water."

Informing customers

"As a drinking water company, we try to keep one step ahead of discoloured water as much as possible. If, for example, we need to do work that may result in discoloured water, we notify our clients in advance and give them information on how to prevent potential problems. As well as this 'planned' type of discoloured water, we are unfortunately also confronted with unplanned discoloured water incidents on a regular basis. A fire-brigade using fire hydrants may disturb the flow velocity enough to whirl up sediment. But discoloured water can also occur in some areas simply due to normal demand. This is the case in areas where sediment rapidly accumulates."

High flow rates

"One way to minimise problems with discoloured water is to ensure sufficiently high flow velocities in the distribution network. This can be done by constructing the network in a certain way, using small diameter pipelines and preventing stagnation areas. In other words, a branched rather than a looped network so that flow velocity throughout the network (especially in the periphery) is high enough to prevent sedimentation. We tested this as part of Vreeburg's research. Once we could measure that the predicted effects actually occurred in practice, we decided to apply this type of self-cleaning network in new construction projects and also when reconstructing existing networks."

Fire brigades

"Before we moved to self-cleaning networks, we communicated a great deal with the fire brigade. Fire brigades are obviously not enthusiastic about this type of network as smaller pipeline diameters mean that less water is available for extinguishing fires. We therefore visited all the fire brigades in our service area to explain our reasons for changing to this new type of network. Our starting point is that the primary function of distribution networks is to provide good quality drinking water; the supply of fire fighting water is a secondary function. This does not change the fact that fire brigades are important customers for us, and that we will help them as much as we can. But during this communication process, we could see a change in the fire brigades' attitude. The thought is beginning to emerge that they should reconsider their dependency on only drinking water networks. This means that more consideration is now being given to large fire-water trucks and the use of surface water."

Preventive cleaning

"In addition to using self-cleaning networks, we have also adopted a different method for cleaning existing networks. Following Vreeburg's research, we use uni-directional water flushing under strict conditions, meaning a minimum flow velocity of 1.5 m/s, a turnover rate of three, and a clear water-front. This means that water used for flushing should only be transported through clean(ed) pipes. The research has shown this to be the most cost-effective cleaning method. Cleaning was previously done in a much more intuitive way, with no means of objectively checking the results. Vreeburg's research has given us this measuring method, the Re-suspension Potential Method, enabling us to clean preventively instead of only as a reaction to complaints."

Different professions

Den Blanken is entirely convinced about the importance of scientific research in the field of drinking water: "The research that we perform as water companies often focuses on application. And actually, until recently, research related to distribution networks was rarely carried out. Distribution was seen more as skilled labour that had no scientific background. For a long time, production and distribution were completely separate worlds. The perception was that the quality of water 'from the tap' was the same as water quality leaving the treatment plant. Vreeburg's research showed that the quality of the distribution system also has a considerable impact on drinking water quality."

Photo: Archive PWN

Research on particles by Jan Vreeburg
(Kiwa Water Research / Delft University of Technology)

The conceptual model of all particle-related processes in a network forms the core of research into particles in drinking water distribution systems. This model is visualised in figure 1.

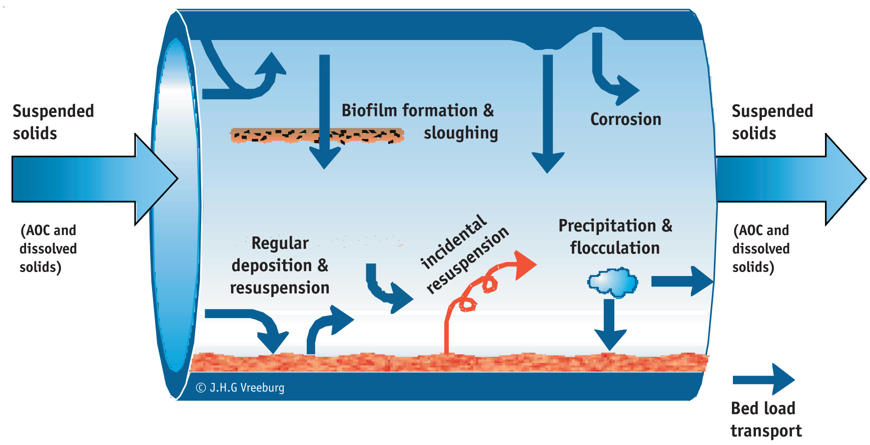


Figure 1 Particle-related processes in a network.
The direction of arrows in the figure indicates the paths that particles follow in the pipe. Vertical arrows indicate particles settling on the pipe wall; horizontal arrows indicate particles moving with the water as suspended solids.

The model is based on the transport of particles through the network, and the possible generation of particles within the network. The main cause for discolouration is the incidental re-suspension of sedimentary deposits formed by the particles. Disturbances leading to this incidental re-suspension can be caused by the use of a fire hydrant, failure of a pipe, or a short period of high demand during warm days.

The following measures can be taken to prevent and control discolouration:

- Improve treatment to decrease the particle load.
- Design the network in such a way that constant high velocity and unidirectional flow is guaranteed.
- Regularly clean the network to prevent the accumulation of sediment.

The concept of particle-related processes and the consequences for network operation networks and treatment is widely accepted by Dutch water companies, and also has international appeal. Self-cleaning networks will be implemented within a large water company in the UK, and collaboration will also begin with the Utility Board in Singapore to implement the results of this research.

International aesthetic water quality

Water utilities around the world receive customer complaints regarding water quality. A majority of these complaints are related to dirty or discoloured water events. In the last two years, the Co-operative Research Centre (CRC) for Water Quality and Treatment in Australia and two Delft Cluster institutes (Kiwa Water Research and Delft University of Technology) have successfully exchanged personnel, knowledge and resources to develop tools that allow improved understanding of processes leading to discoloured water.

A number of students and researchers from Australia and the Netherlands have participated in specific research projects. Jasper Verberk from Delft University of Technology has worked for more than a year at the CRC for Water Quality and Treatment in Adelaide, Australia. During this research period, he has introduced several Dutch research tools and methods in Australia. He, in turn, has learnt about Australian tools for research into water quality in the distribution system.

Integration of existing tools to understand sediment behaviour

In Australia, many utilities have an unfiltered water supply resulting in a high discolouration risk. To reduce the amount of customer complaints, water utilities frequently flush their distribution systems. The amount of water used for flushing should be minimal, certainly in periods of drought. The CRC developed a computer model (Particle Sediment Model or PSM) to calculate sediment deposition in the network, but was unable to validate the PSM results as there was no tool

collaboration on

Benefits of international collaborative research on aesthetic water quality issues in distribution systems

Jasper Verberk, Delft University of Technology

Photo: Jasper Verberk


Photo: Jasper Verberk

available to measure sediment load in the network. By introducing the Resuspension Potential Method (RPM) - a tool developed by Jan Vreeburg and the Dutch water companies – the PSM could successfully be validated. Furthermore, the RPM is now used by several Melbournian water utilities to determine the required frequency of mains flushing.

Development and implementation of new on-line water quality measurements tools

In The Netherlands, continuous turbidity monitoring in the distribution network is used to analyse the movement of particles. However, turbidity is an overall water quality parameter and does not provide information about the quantity and nature of particles. On-line particle counting yields more information. In a study of the distribution system of Amsterdam Water Supply conducted by PhD students Lisa Hamilton and Kelly O'Halloran from CRC, multiple particle counters have been used to measure particle transport within the distribution system. By using multiple particle counters simultaneously at different locations in the distribution network, it is possible to observe changes in particle size, number, and volume concentrations.

Information about the composition of suspended particles in drinking water transportation pipelines was derived using the newly-developed Time Integrated Large Volume Sampling (TILVS) method. The TILVS concept was developed by researchers from the Delft University of Technology and CRC. As particle loading in the distribution system is low, standard procedures to measure total suspended solids (TSS) and volatile suspended solids (VSS) cannot be used.

A large volume of water must be filtered to obtain sufficient mass on the filter paper, while rapid clogging of the filter paper occurs due to the large amount of small particles. TILVS is a new tool in distribution water quality research and is extremely useful to pre-concentrate particulate material in order to characterise the composition of particles.

By combining particle counting and TILVS, conclusions can be made about the composition, origin, and changes in time and place of particulate load in the distribution system. This will aid prioritisation for distribution water quality research. Several water companies in The Netherlands and Australia have shown interest in using TILVS in combination with on-line particle counting, in order to understand water quality processes in their distribution systems.

Interaction between treatment and distribution systems: the key to delivering quality

A new large collaboration project on water quality aspects in the distribution system has recently been started. The aim of this project is to identify the effect that differences in water treatment, and hence water quality, may have on the distribution system in terms of particulates, chlorine demand and biodegradable natural organic matter as a nutrient source for biofilms. By using four identical distribution test rigs operating in parallel, and comparing water quality at the end and at selected places within the distribution test rigs, differences caused by the varied water quality entering the test rigs can be observed. Theoretically, any differences will be caused by the water quality, and not the test rigs.

Fruitful international collaboration

In Australia and The Netherlands, there is mutual interest in water quality research in the distribution network, particularly in the field of discolouration. Research programmes in both countries focus on understanding water quality processes in the distribution system. Although the treatment background in both countries is quite different, a number of useful new tools have recently been developed as a result of joint research. By exchanging students and research staff, it has been possible to improve understanding of these tools and to evaluate their use by the water industry in both countries. As well as the introduction of various new tools, such exchange also contributes to better awareness of water problems and the knowledge gaps which exist in the respective countries. Broadening the horizons of students and researchers also leads to better water researchers for the future. The collaboration on discolouration between Australia and The Netherlands has proven to be very successful. In coming years, the collaboration will be expanded further by means of frequent student and research staff exchange.

Removal of pharmaceuticals

with NF and RO

Concern regarding the occurrence of pharmaceutically active compounds (PhACs) in the water system has been growing since the late 1990s. The ever-increasing demand and consumption of pharmaceuticals, combined with an incomplete metabolism in the human body, have led to increasing concentrations in waste water effluents and associated receiving surface water.

A cocktail of pharmaceuticals

In some cases, veterinary pharmaceuticals are also found in surface water as a consequence of run-off from animal feedlots and grazing farmland. Concentrations of pharmaceuticals detected in European surface water are usually in the range of several ng/l. However, maximum concentrations of widely-used pharmaceuticals (such as the antibiotic sulfamethoxazole and the anti-epileptic carbamazepine) can reach up to several µg/l. Removal of these compounds during drinking water production is desirable, since limited knowledge is available about the health effects of consuming drinking water containing a cocktail of pharmaceuticals. Drinking water treatment mostly provides a safe barrier, but in some cases trace amounts of pharmaceuticals can even be found in the drinking water. Even though the concentrations found are still well below the human health limit, research into new techniques for removal of these pollutants is necessary.

Removal of pharmaceuticals from surface water with nanofiltration (NF) and reverse osmosis (RO) membranes

Arne Verliefde, Delft University of Technology / Kiwa Water Research

Victor Yangali-Quintanilla, UNESCO-IHE

Nanofiltration (NF) and reverse osmosis (RO)

Membrane processes such as nanofiltration (NF) and reverse osmosis (RO) are increasingly used in waste water reclamation/reuse and drinking water treatment to remove organic micropollutants (the pollutants are known as micropollutants because they are found in very low concentrations, i.e. below µg/l-level). Within the framework of the Delft Cluster Research Programme, a study was initiated to gain more insight into the mechanisms playing a role in the removal of organic micropollutants using NF and RO membranes.

An NF/RO membrane can be visualised as a dense polymeric matrix with cavities. In figure 1, an extreme case of these cavities is shown (as actual pores). In simple terms, three different mechanisms play a role in removing solutes using these porous membranes:

1. Steric hindrance mechanism

Steric hindrance effects between the membrane matrix and the solute can determine the rejection of a solute: compounds smaller than the average membrane pore size are not removed, while larger solutes are removed. This is comparable to the sieve effect in traditional filtration processes and is schematically depicted in Figure 1.

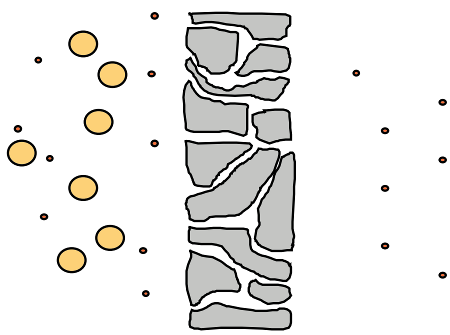


Figure 1
Schematic depiction of the steric hindrance mechanism.

2. Adsorption diffusion mechanism

The hydrophobicity of the solute also plays an important role in the rejection of organic solutes. Hydrophobicity is the 'fear' of water; hydrophobic solutes tend to dissolve easier in oil than in water.

This phenomenon is due to hydrophobic interactions between the solute and the membrane. Contrary to hydrophilic solutes, hydrophobic solutes may adsorb onto hydrophobic membrane material due to Van der Waals interactions. This initially leads to a high removal of hydrophobic solutes. Once the membrane is saturated with the adsorbed solute, the solute easily partitions into the membrane and can pass through the membrane to the permeate side by diffusion (Figure 2). This causes a lower observed rejection by facilitated transport once adsorption equilibrium is reached (i.e. a breakthrough curve is observed). For hydrophilic solutes, only a sieving effect is present and no facilitated transport occurs.

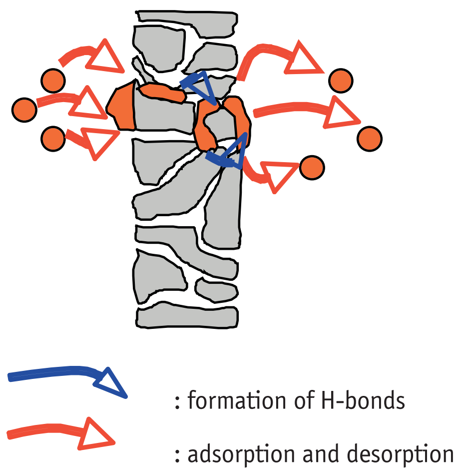


Figure 2
Schematic depiction of the adsorption diffusion mechanism.

3. Electrostatic repulsion mechanism

Finally, electrostatic interactions between solute and membrane can also influence rejection. A high rejection value is usually observed for negatively charged organic compounds. Most of the commercial membranes are negatively charged in a water phase at neutral pH, so negatively charged solutes that approach the membrane surface experience an electrostatic repulsion with the negative functional groups on the membrane surface. They are therefore retained more effectively than neutral solutes. For positively charged solutes however, the opposite is true: positively charged compounds are attracted by the membrane's negative charge, which causes an increase of the solute concentration at the membrane surface and consequently a lower observed rejection (Figure 3).

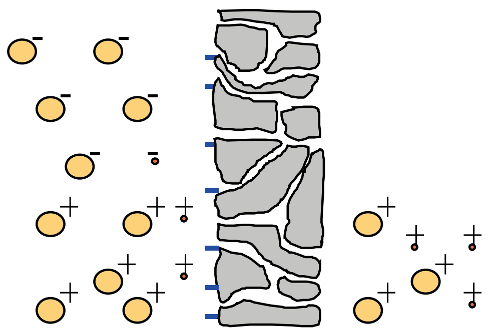
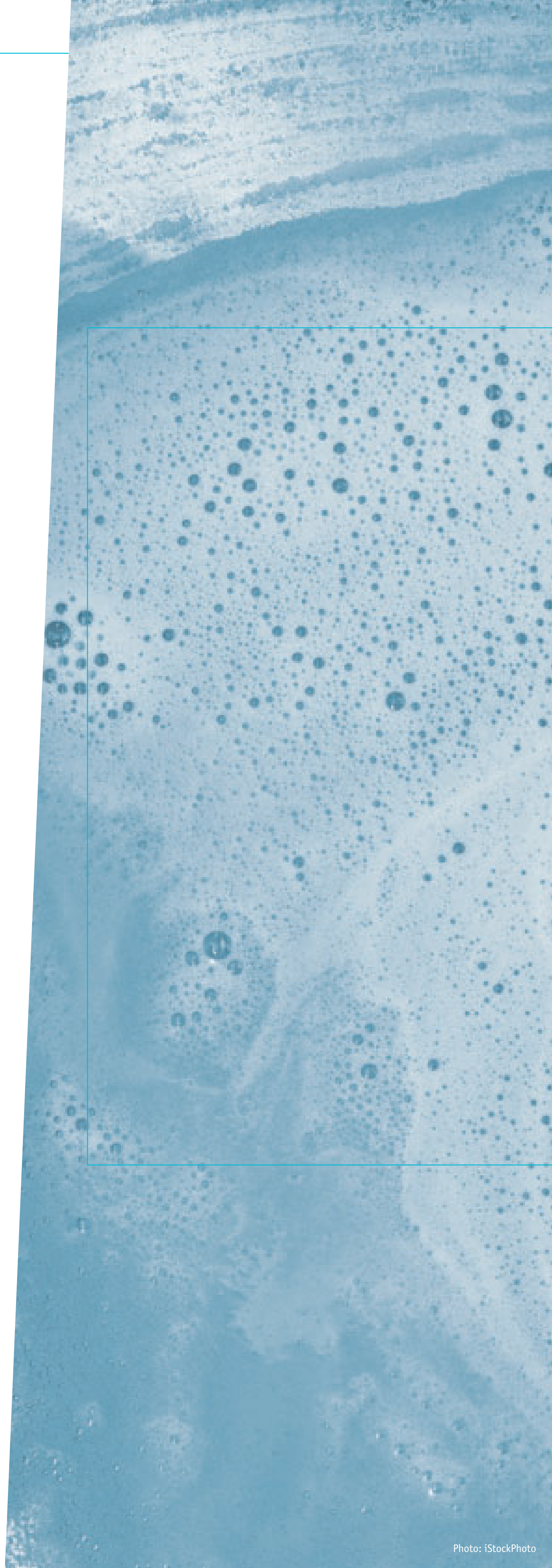


Figure 3
Schematic depiction of the electrostatic repulsion mechanism.



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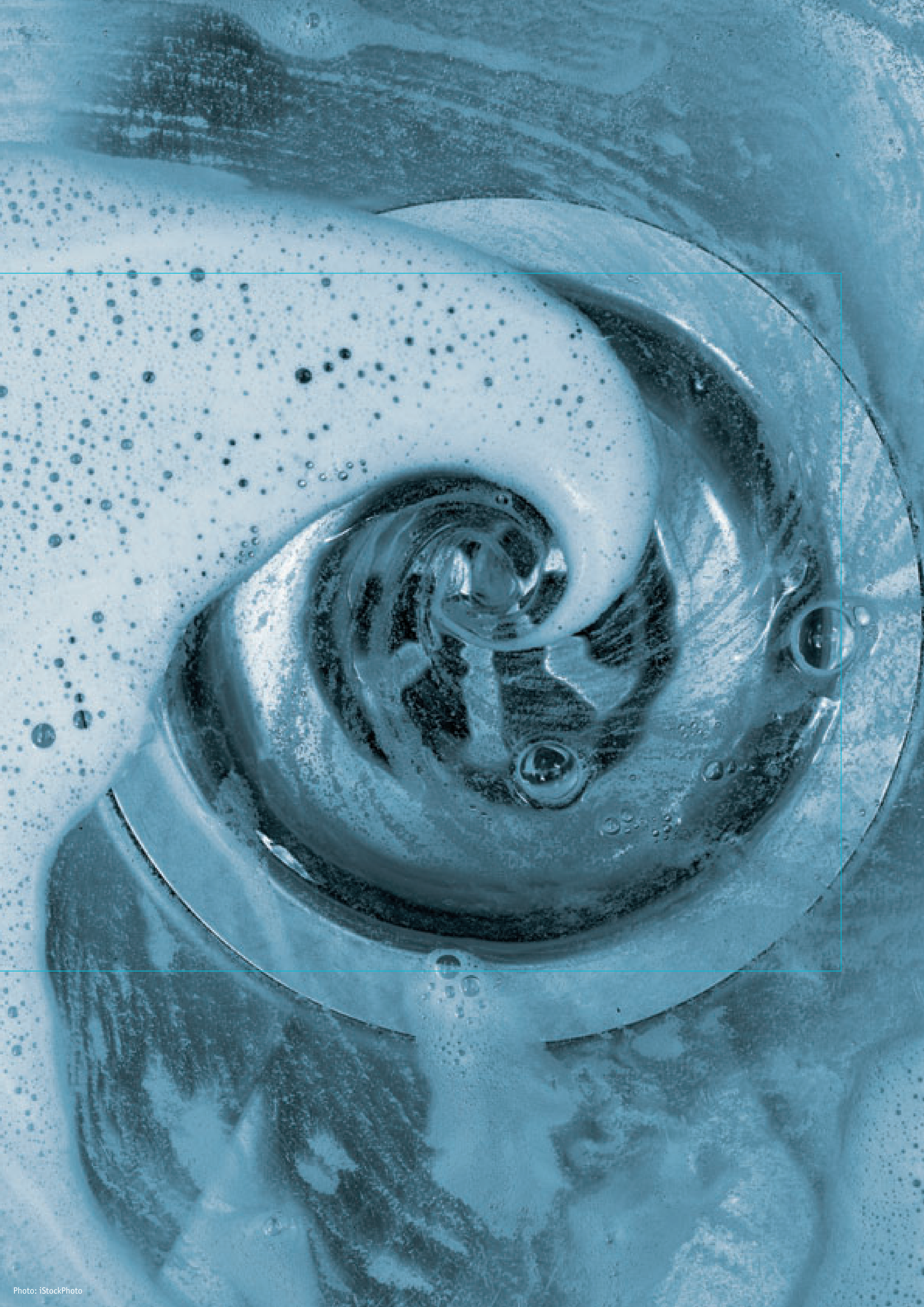

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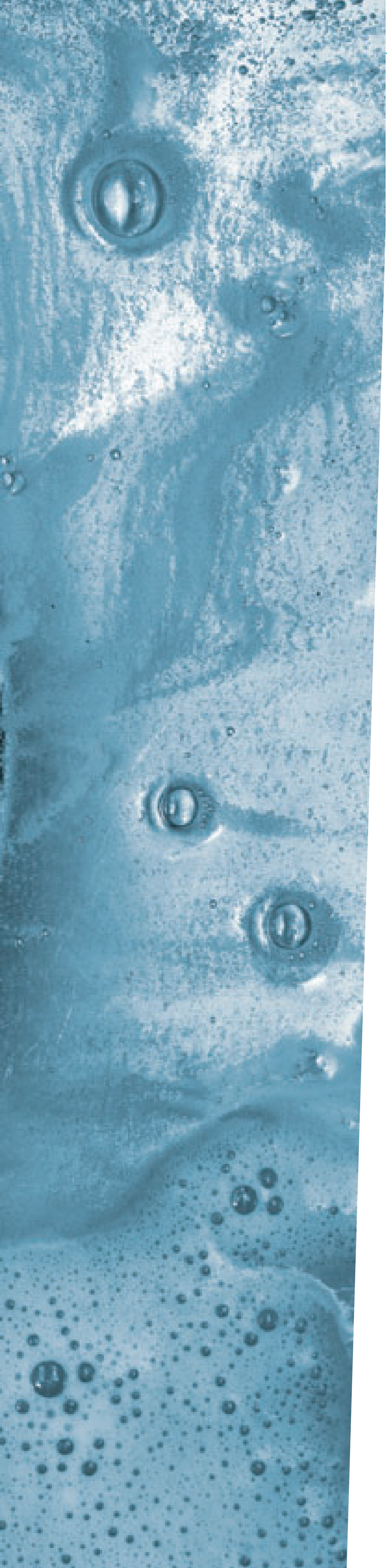

General model

Fouling of the membrane surface is a typical phenomenon that occurs in membrane filtration: when filtering surface water, natural organic matter and colloidal particles in the water may settle on the membrane surface and in the membrane pores, so causing extra resistance against the filtration process. The fouling layer deposited on the membrane surface will cause an alteration of the membrane surface, and thus alterations to the three rejection mechanisms and the rejection of organic pollutants.

The contribution all the rejection mechanisms (and the pollutant, membrane, operational, and feed water parameters) make to the eventual removal of the pollutants was determined and combined into a general model. Using this model, it will be possible to predict rejection values of pollutants in a full-scale plant on a theoretical basis.

Delft Cluster helps to the necessary knowledge

The drinking water research carried out by Delft Cluster mainly focuses on the situation in The Netherlands. However, according to Gary Amy, professor of Water Supply and Sanitation at UNESCO-IHE, the know-how that has been developed can also be readily applied elsewhere, if not now, then certainly in the future.

"The drinking water research carried out by Delft Cluster follows two clear paths", explains Amy. "The first involves research into techniques aimed at removing unwanted chemical substances such as pharmaceuticals, hormones and pesticides from drinking water sources, where a great deal of attention is given to membrane filtration.
The second research path focuses on ways to further improve drinking water quality. A central part of this research involves preventing a decrease in quality throughout the distribution network. Both routes are mainly attuned to the Dutch situation. A situation that is unique in the world. Dutch water authorities supply high quality drinking water without using chlorine, and they want to continue doing so in the future. Delft Cluster helps to provide the necessary knowledge."

Purification costs

"Attunement to the Dutch situation means that the knowledge that has been developed is not always directly applicable to the needs of other countries. For example, the research emphasis is on membrane filtration, particularly so-called high-pressure membrane systems for removing chemical contaminants. These systems consist of membranes with extremely small pores. They use a great deal of energy and are linked to relatively high purification costs: approximately € 0.25 per m^3 of drinking water.
Such purification costs are acceptable in The Netherlands, where 1 m^3 of drinking water costs close to € 1.50. However, such costs would not be accepted in the United States where I was born, and where the cost of drinking water is between € 0.25 and € 0.50 per m^3. Distinct from this is the fact that there is still no acknowledgement concerning the problem of chemical contaminants. In this regard, the United States is some 10 years behind The Netherlands."

Bacterial contamination

"And if high-pressure membrane systems are still not being considered in the United States, this is also true for transitional and developing countries where most of the UNESCO-IHE students originate. Bacterial contamination continues to pose the biggest problem in these countries. Membrane filtration can provide the solution here as well. In this case though, it concerns low-pressure systems that

provide

Photo: iStockPhoto

are now being widely used in developing and transitional countries and, within the next decade, possibly in some developing countries. These systems use membranes with relatively large pores and require little energy, reflected in the purification costs of approximately € 0,05 per m^3.
The low costs mean that it will be possible to use these types of systems in countries such as Zambia in the near future."

Export product

The fact that The Netherlands is concerned with knowledge questions that have not yet arisen in most developing and transitional countries in no way means that Dutch know-how is not a good export product, according to Amy: "Because we are at the forefront in the field of drinking water, some of the newly-developed knowledge is perhaps not directly applicable elsewhere - but it will be in the future. Other countries will also set increasingly higher requirements for drinking water quality. What is more, advanced purification technology such as high-pressure membranes – which we want to use to remove specific chemical contamination – can suddenly become topical in other countries too. For example, climate change means that water scarcity in countries such as Yemen is a growing problem, and it is becoming necessary to consider the use of seawater as a source of drinking water.
High-pressure membranes are required for desalination. And what is happening now in Yemen can also happen in many other major cities along the coast, such as Jakarta and Lima. Which is why I expect the interest in membrane systems to increase."

Useful results

Amy continues: "And of course, the research carried out by Delft Cluster also gives results that can be applied directly. For example, we have nearly completed a model that can accurately predict whether certain contaminants can successfully be removed using a specific membrane.
This means that time-consuming and expensive tests will no longer be needed to select the correct membrane in the future. The distribution system research has also yielded many useful results. In the first instance, it is concerned with understanding the origin of discoloured water problems and the methods for preventing this type of problem. But I'm also thinking about the findings of research from one of our MSc students. This research investigated the behaviour of chlorine in distribution systems. Although this is not an issue in The Netherlands, it is in many other countries. If you have a qualitatively poor distribution network, you want to be certain that the chlorine that is added remains in the water - otherwise you run the risk of bacterial infections. In Peru, for example, a cholera epidemic broke out several years ago after the decision was taken to use a lower chlorine dose."

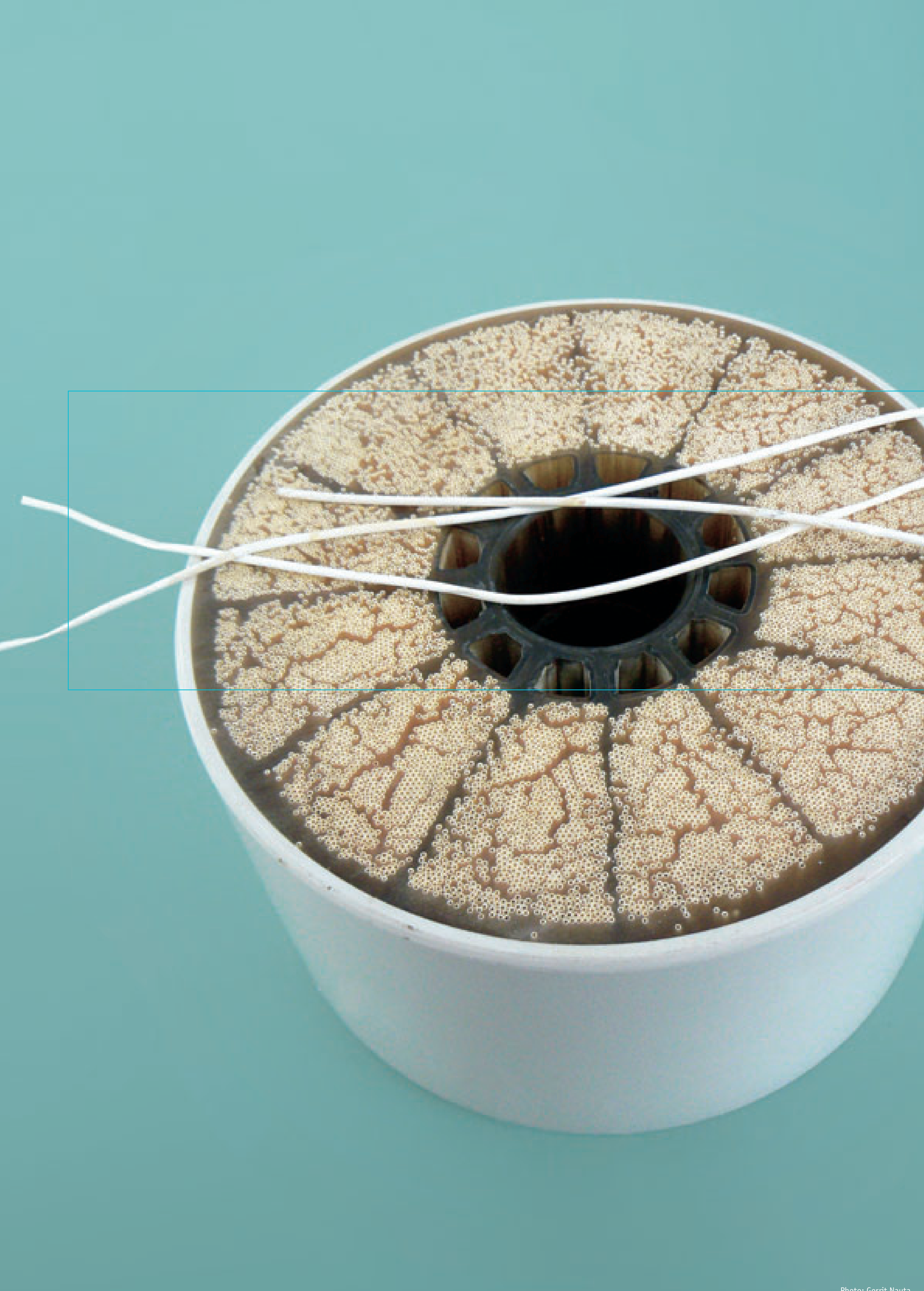

Photo: Gerrit Nauta

The discipline of knowledge management

The Knowledge Cycle

The Delft Cluster Research Programme was founded to meet the knowledge requirements of organisations involved in the development and management of delta areas. Through this open network of research institutions, knowledge and experience is widely shared to obtain high level output. Implementation of knowledge takes place by means of close collaboration with stakeholders.

Determining knowledge needs, sharing information, and implementing results of research are all part of what we call the 'Knowledge Cycle' (figure 1). Addressing all stations of this cycle is essential to good (i.e. eventually useful) applied science. The Knowledge Cycle itself illustrates part of what is generally called the discipline of 'knowledge management': an array of tools and practices applied by organisations to identify, create, share, store, present, and disseminate knowledge. This article explains the different steps in the Knowledge Cycle, with specific references to the way it has been applied to water management.

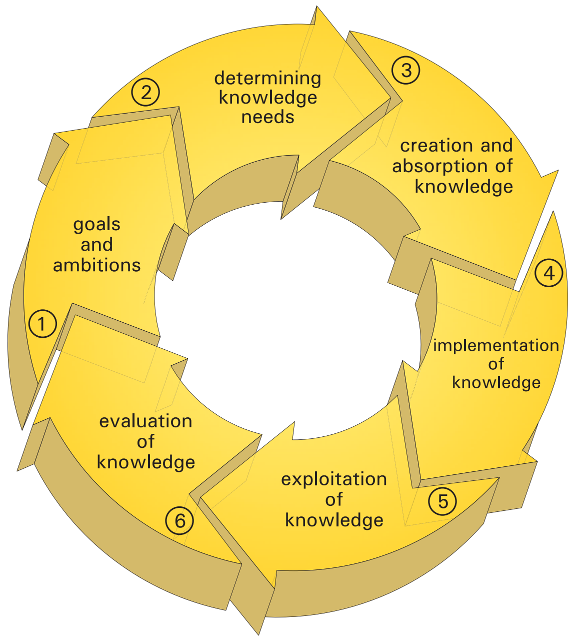

Figure 1
The Knowledge Cycle.

Ambitions and knowledge needs

The first stage of the Knowledge Cycle involves identifying the relevant social and technological trends, and the way in which these trends will influence society. Jules-Verne-like visions of the future are sometimes constructed that suggest how society could look in 10 to 20 years from now.

The Delft Cluster institutes involved stakeholders – water companies, water boards, industries – in analysing their ambitions and accomplishment strategies within the context of a continuously changing world. The knowledge required to deploy these strategies was then determined, together with the extent to which this knowledge was already present within the organisation. If vital knowledge was lacking, how this could be obtained in a timely fashion was determined.

Knowledge creation and anchoring for future use

Although research is a sound means to obtain knowledge, it is sometimes also possible to simply buy readily-available knowledge elsewhere. In this third phase of the cycle, we also examine available knowledge that needs to be saved for the future. Is knowledge shared in an appropriate way? Or is it only available for a particular 63-year-old researcher?

Knowledge management: essential to collaborative research

Willem Koerselman, Kiwa Water Research

Photo: Ewout Staartjes

In such cases, we have to look at how knowledge can be preserved for the organisation when this researcher begins his well-earned retirement. How do we ensure that knowledge is preserved for the future? Storing it all via intranet is certainly not the solution! Intranet is only capable of storing information. Although it is extremely useful, it is often forgotten that knowledge is more than just information. It also comprises a range of competencies and (especially) experience to apply the information correctly. By definition, knowledge is within people and never within systems. Knowledge is the ability to apply information. After all, a word processor doesn't make you a writer.

Implementation of knowledge

In the next step of the Knowledge Cycle (stage 4), we concentrate on effective dissemination of the research results (knowledge) to those who will work with this information. Within the Delft Cluster Programme, this often means the transfer of knowledge from one organisation (the knowledge institute) to another (the organisation that will apply the knowledge). Knowledge management offers a variety of tools to facilitate this knowledge transfer. Digital tools are all too familiar, but they don't suffice in transferring the knowledge to the end user. This nearly always involves physically bringing people together: researchers, and end users of the knowledge. Ideally, the end users are already closely involved with the actual research. If this is the case, a process of continuous iteration can start between knowledge development and future application of this knowledge. This limits the risk that, despite a clear definition of the knowledge needs, knowledge is developed that insufficiently meets the needs of the end user.

Exploitation of knowledge

"The proof of the pudding is in the eating" is certainly applicable to knowledge. Only when knowledge is being implemented does it become clear whether it is practically viable or not. Problems in applying the knowledge often emerge during the implementation phase. It is of the utmost importance that end users can turn to the knowledge institutes for help at this point. Practical experience in the application of knowledge ("this works in situation A, but doesn't in situation B") must be fed back to the researchers, so that the knowledge can be improved and adjusted to actual situations. Once again, an iterative process involving close communication between researchers and end users is of vital importance.

Evaluation of knowledge

Although the final phase of the Knowledge Cycle is probably the most important, it is often omitted. In stage 6, we check whether all the steps have in fact contributed to realising the goals that were set. After all, that was the original intention. What went wrong en route? Where did it go wrong? And most importantly why did it go wrong, and how can we do better next time? We strive to further improve the Knowledge Cycle during this stage and to learn from experience. Knowledge institutes and knowledge users need to work together in doing so.

Colophon

Delft Cluster Magazine is Delft Cluster's International corporate magazine, distributed to Delft Cluster participants, the relevant (sector) parties, governments, foreign information institutes, and educational establishments. Delft Cluster Magazine is free of charge; our intention is to contribute to disseminating information and stimulating a social dialogue about our vulnerable delta.

Publication

1,000 copies

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Cover photograph

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Issue

2008

Delft Cluster Magazine

Drinking water: transfer of knowledge