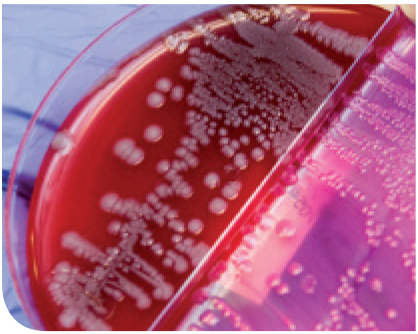
BMBF funding measure

NaWaM

RiSKWa

Risk Management of Emerging Compounds and Pathogens in the Water Cycle

Handbook of good practice



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1 Introduction

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Drinking water must be clean – just like the rivers, lakes and groundwater from which it is sourced. To ensure this also in the future, water utilities and wastewater treatment plant operators are managing all these resources with foresight. They use the latest methods and technologies available to identify, assess and eliminate risks as early as possible, and to address their consequences. The main challenge to cope with is the diversity of pollutants and pathogens in terms of both, their assessment and their elimination. But also every individual citizen can, and must, contribute. Due to our modern and rapidly changing world new disruptive factors continually arise, also from private households: residues of pharmaceuticals, traces of pollutants or newly spreading pathogens.

With a view to chemical substances, everyday commodities are meanwhile causing a problem, like for example shampoos and fragrances, pharmaceuticals, hormones, sunscreens, detergents, but also biocides and flame retardants from textiles with such finishes. All these substances which do not normally occur in nature but are manmade and found in the environment in small amounts are referred to as “anthropogenic micropollutants”. They can nowadays be detected in very small concentrations in the water. Some of them are not biodegradable and accumulate in the food chain. Assessing their effects on human health and the environment represents an important task for the future. Climate and demographic change alter the risk potential of pathogens as some of them are not eliminated in wastewater treatment plants. The relevance of antibiotic resistances is on the rise as well.

These challenges were addressed within the BMBF funding measure *“Risikomanagement von neuen Schadstoffen und Krankheitserregern im Wasserkreislauf (RiSKWa)“* (Risk Management of Emerging Compounds and Pathogens in the Water Cycle, RiSKWa): over a period of five years, scientists, industry, public authorities and practice cooperated closely and, in a dialog with all relevant stakeholders from water management, healthcare and public sectors, elaborated the results presented herein. They developed new approaches for evaluation, technology and management, and tested them under real-life conditions. RiSKWa produced interesting innovations, for example in the field of “micropollutants”: in this context, some of the projects expanded the to date very difficult detection of unknown substances. Others collected data on the impact of advanced wastewater treatment and thereby facilitated the discussion on whether and where such treatment is to be introduced in the future. As protection against harmful effects of pathogens new processes were developed that allow for an easy detection and evaluation of such substances. Communication and educational measures were central elements of RiSKWa as well.

Overall, the funding measure produced new insights and progress in the fields of “risk identification”, “risk management“ and “risk communication”. The quintessence for water management practice has now been compiled in this handbook. For a sustainable management of our valuable resource “water”, it recommends various optional measures to avoid and reduce the input of pollutants and pathogens into water bodies. Concrete case studies illustrate a preventive water conservation.

This handbook of good practice addresses all actors in water and wastewater management, local governments and public authorities. It is structured along the different phases of risk management. Each chapter is preceded by RiSKWa’s key messages to the practitioners. They are followed by the main results of the twelve joint research projects. This structure provides the users of this handbook with a quick overview on the solutions offered by RiSKWa for practical application.

Interested users are invited to also contact the RiSKWa experts: Table 1.1 shows a list of the coordinators of the joint research projects. Such dialog will certainly provide further insights – after all, all joint research projects acquired extensive knowledge and experience reaching well beyond the framework of this handbook of good practice.

Table 1.1: Overview on the joint research projects, broken down by their thematic priorities

Name of the joint research project	Project coordinator
Urban areas	
ASKURIS: Anthropogenic trace organic compounds and pathogens in the urban water cycle; assessment, barriers and risk communication	Prof. Dr. Martin Jekel TU Berlin email: martin.jekel@tu-berlin.de
SAUBER+: Innovative concepts and technologies for the separate treatment of wastewater from healthcare facilities	Prof. Dr. Johannes Pinnekamp RWTH Aachen email: sekretariat@isa.rwth-aachen.de
ANTI-Resist: Analysis of antibiotics and antibiotic resistances in the urban wastewater and development of suitable strategies and an early warning and monitoring system taking the example of the City of Dresden	Prof. Dr. Joachim Fauler TU Dresden email: joachim.fauler@tu-dresden.de
Rural areas	
AGRO: Risk management of micropollutants and pathogens in rural karst catchments	PD. Dr. Tobias Licha Georg-August-University, Göttingen email: tlicha@gwdg.de
Risk AGuA: Risks posed by wastewater from intensive animal farming for ground and surface water in agricultural areas	Prof. Dr. Wolfgang Dott RWTH Aachen email: wolfgang.dott@post.rwth-aachen.de
Catchment areas	
TransRisk: Characterization, communication and minimization of risks associated with the occurrence of emerging contaminants and pathogens in the urban water cycle	Prof. Dr. Thomas Ternes German Federal Institute of Hydrology, Koblenz email: ternes@bafg.de
RISK-IDENT: Assessment of previously unknown anthropogenic trace contaminants and action strategies for risk management in aquatic systems	Dr. Marion Letzel Bavarian Environment Agency, Wielenbach email: marion.letzel@lfu.bayern.de

Name of the joint research project	Project coordinator
Catchment areas	
Sichere Ruhr (Safe Ruhr): Bathing water and drinking water for the Ruhr Area	Dr.-Ing. Wolf Merkel IWW Water Centre, Mülheim an der Ruhr email: w.merkel@iww-online.de
SchussenAktiv*plus*: Reduction of micro-pollutants and bacteria by further treatment of wastewater treatment plant effluents and mixed water from rain overflow basins of different sizes to further improve the water quality of the River Schussen, a tributary to Lake Constance	Prof. Dr. Rita Triebskorn Eberhard-Karls-University, Tübingen email: rita.triebskorn@uni-tuebingen.de
Drinking water supply	
PRiMaT: Preventive risk management in drinking water supply	Dr. Frank Sacher TZW: DVGW Water Technology Center, Karlsruhe email: frank.sacher@tzw.de
RiMaTH: Risk management of drinking water in building installations – fast detection methods for bacterial contaminants and monitoring of decontamination measures	Dr. Wolfgang Fritzsche Leibnitz Institute of Photonic Technologies e.V., Jena email: fritzsche@ipht-jena.de
TOX-BOX: Hazard-based risk management of anthropogenic trace substances for protection of the drinking water supply	Dr. Tamara Grummt Federal Environmental Agency (UBA), Bad Elster email: tamara.grummt@uba.de

2 Occurrence of micropollutants, pathogens and antibiotic resistances in the water cycle

Authors: *Prof. Dr. Thomas Ternes, Dr. Frank Sacher, Dr. Marion Letzel, Prof. Dr. Martin Exner, Prof. Dr. Thomas Schwartz*

Key messages

Key message 1: With the results from RiSKWa modern and fast methods for detecting and quantifying anthropogenic micropollutants, pathogens, and antibiotic resistances are available.

Key message 2: With the introduction of new methods and the newly developed, publicly accessible database "STOFF-IDENT", emerging micropollutants relevant for the aquatic environment and their transformation products can be identified and quantified.

Key message 3: In the medium to long term, molecular biological methods can complement the standardized culture techniques for a faster and more distinct identification of microbiological risks.

Key message 4: Many of the micropollutants, pathogens, and clinically relevant antibiotic resistances identified in the context of RiSKWa can be found in the entire urban water cycle (wastewater – surface water– groundwater – drinking water).

Key message 5: Wastewater systems are important point sources for the discharge of pathogens, clinically relevant antibiotic resistances, pharmaceutical residues, and many other micropollutants into the aquatic environment. Prescription numbers allow for a first estimate of the release of human pharmaceuticals into the municipal wastewater.

Key message 6: Emerging micropollutants as well as pathogens, and antibiotic resistances need to be taken into account and partly integrated into present and future regulatory frameworks such as the German Wastewater Directive.

2.1 Chemical contaminants

Occurrence of micropollutants in the water cycle

A number of joint research projects within the BMBF funding measure RiSKWa have focused on the occurrence of micropollutants in different compartments of the water cycle.

RiskAGua analyzed the emission and persistence of veterinary pharmaceuticals and their distribution in the environmental compartments soil, groundwater and surface water. A nationwide screening of biogas plants only in isolated cases produced antibiotics concentrations of more than 1 mg/kg of utilized waste. Especially for representatives from the generic group of tetracyclines, a reduced concentration downstream of the biogas plant was found. Studies involving the spiking of antibiotics to manure showed that chlortetracycline, tetracycline, sulfamethazine and sulfadiazine can partially be eliminated in the fermentation process (cf. Fig. 2.1). Analyses of the transport behavior of antibiotics also revealed that 90-100% sorb relatively well to soil particles or are degraded. Only a very small portion enters the adjacent water bodies via surface runoff and soil erosion. Numerical modeling has shown, however, that even a minor transport leads to the spreading of these substances into other environmental compartments.

A heavy metal screening of three biogas plants confirmed that, with the exception of copper and zinc which are regularly used as animal feed additives, no further metal ions are found in relevant concentrations. However, the copper and zinc concentrations in each sample were two to five times higher than the precautionary values specified for clay and silt-containing soils. The low bioavailability of the heavy metals in addition suggests a concentration in the farmland.

ANTI-Resist analyzed the release of frequently prescribed antibiotics into the urban wastewater taking the example of the City of Dresden. Besides identifying the relevant antibiotics from outpatient and inpatient treatment also adequate analytical methods for the detection and quantification of the original substances in wastewater, sewage sludge, sediment, biofilm from the wastewater system and surface water were developed [Schubert et al. 2015].

Fig. 2.1: Application of liquid manure (© Margit Power-Fotolia)

Thanks to a small sample volume and a quick LC-MS/MS method it was possible to perform a 15-month monitoring program with daily sampling at various sampling points in the Dresden-Kaditz wastewater treatment plant (population equivalent PE 740,000). The catchment area of the Dresden-Kaditz wastewater treatment plant is mainly of an urban nature so that it can be rightfully assumed that antibiotic emissions from industry and commerce are negligible. An examination of the antibiotic concentrations measured in the influent and effluent of the wastewater treatment plant produced antibiotic-specific elimination rates with a high degree of fluctuation. For macrolide antibiotics (clarithromycin, azithromycin, roxithromycin) and trimethoprim, the long-term study showed no, or only very small, eliminations. Cefuroxim, by contrast, was eliminated to a substantial degree ($Median_{influent}$ 1621 ng/l; $Median_{effluent}$ 598 ng/l) [Rossmann et al. 2014]. In this context, it must be mentioned that cefuroxim, besides the penicillins piperacillin, penicillin V and amoxicillin, ranks among the most frequently prescribed antibiotics in the catchment area of the Dresden-Kaditz wastewater treatment plant (on average 0.95 mg/inhabitant) as it is frequently used in both, outpatient and inpatient treatment, while the prescribed volumes of macrolides and trimethoprim amount to only 0.07 to 0.28 mg/inhabitant [Marx & Kühn, 2014].

By correlating the prescription volumes with data on metabolism and excretion it is possible to forecast the amount of antibiotics released into the wastewater [Timpel et al. 2015]. The hydrodynamic sewer system simulation allowed for a high-resolution display of the antibiotics load at the inlet of the central wastewater treatment plant of the City of Dresden. The quality of the forecast for persistent antibiotics such as sulfamethoxazole is good while it is rather poor for easily biodegradable compounds. The emissions of easily degradable antibiotics can therefore not be estimated with sufficient degree of precision without a chemical analysis. In addition, it must also be noted that, in the case of mixed water, the antibiotics adsorbed in the sewage system are released again to the inlet as a result of remobilization, shearing and elution processes. In rainy weather, the combination of higher particulate and dissolved concentrations leads to a higher load for the wastewater treatment plant (cf. Fig. 2.2) and also to an increased substance discharge into the adjacent waters.

Fig. 2.2: Municipal wastewater treatment plant (© Ruhrverband, Essen)

The joint research project **SAUBER+** examined the emission of pharmaceutical residues from healthcare facilities. The project focused not on general hospitals, but on a psychiatric clinic, a nursing care home as well as a clinic specializing in orthopedics. With regard to the pharmaceuticals concentrations it showed that, with a few exceptions, the emissions from the health care facilities examined were lower than those from private households.

In the framework of the joint research project **SchussenAktiv*plus***, the effects of an extended wastewater treatment and of combined wastewater and storm water overflow basins in the catchment area of the river Schussen were investigated. In total, the water samples were tested for approx. 140 micropollutants of which, on average, around 55 were detected in the three wastewater treatment plant inlets under analysis. The scope of the analyses covered the substance groups benzotriazoles, complexing agents, pesticides, active pharmaceutical ingredients, X-ray contrast media, antibiotics, endocrine disrupting compounds, trialkyl phosphates, aliphatic amines, artificial sweeteners and perfluorinated compounds. The number of positive findings was reduced by 17-34% in conventional wastewater treatment, whereby the concentration level of the micropollutants detected was significantly reduced overall. This was in particular owed to a few compounds such as the chelating agent nitrilotriacetic acid or the two artificial sweeteners cyclamate and saccharin which were in some cases detected in the three-digit µg/l range at the wastewater treatment plant influent, but can be easily degraded in the biological wastewater treatment stage. A commercial-scale treatment with powdered activated carbon in the Ravensburg wastewater treatment plant resulted in a reduction in the number of detected micropollutants from 56 substances found in the influent to 41 found in the effluent of the biological treatment stage to just 24 substances in the effluent of the activated carbon stage.

In the influent of a constructed wetland, besides the typical wastewater-borne substances also micropollutants, like for example the herbicide mecoprop, were detected which are washed away and/or mobilized during periods of heavy rainfall. In the river Schussen (cf. Fig. 2.3), around 30 micropollutants could be detected on average upstream of the Ravensburg wastewater treatment plant and approx. 35 micropollutants downstream of the plant. After implementing the fourth treatment stage, the number of positive findings in the surface water downstream of the wastewater treatment plant was slightly reduced. In the river Schussen, the highest micropollutant concentrations of EDTA, guanyl urea, acesulfame, iomeprol and metformin were measured, thus reflecting the impact of urban wastewater.

Fig. 2.3: River Schussen in Baden-Wuerttemberg (© University Tübingen)

Tab. 2.1: Concentrations [µg/l] of seven sartans as well as of carbamazepine and acesulfame in Bavarian wastewater treatment plant effluents, surface waters and one bank filtrate well

	n	candesartan	eprosartan	irbesartan	losartan	olmesartan	telmisartan	valsartan	carbamazepine	acesulfame
Wastewater treatment plant effluent	30	0.46	0.73	1.25	0.21	0.74	0.68	1.10	0.65	25
Surface waters	8	0.085	0.039	0.043	0.015	0.068	0.053	0.13	0.088	1.14
Bank filtrate	8	0.031	<LOQ	0.004	<LOQ	0.049	0.007	<LOQ	0.051	0.57

<LOQ: Concentration below the limit of quantification, n: number of samples analyzed

In the joint research project **RISK-IDENT,** wastewater treatment plant effluents, surface waters and bank filtrates were tested for numerous drugs, biocides, industrial chemicals and pesticides. In addition to indicator substances such as carbamazepine and acesulfame, which are measured in routine analyses, also so far less known substance groups were analyzed. One example are the antihypertensive sartans, the consumption of which has strongly increased in recent years. Table 2.1 shows the mean concentrations of the seven most frequently detected sartans and of the indicator substances carbamazepine and acesulfame.

All sartans were found in the wastewater treatment plant effluents at concentrations ranging between 0.2 and 1.1 µg/l. Via the surface waters in which all sartans were measured in concentrations similar to those of the indicator substance carbamazepine, in particular candesartan and olmesartan reach the bank filtrate. The other – structurally similar – sartans are largely separated by bank filtration. The poor biodegradability and the lower sorption due to the lower K_D-value of candesartan and olmesartan must be mentioned as a possible reason for this [Bayer et al., 2014].

In the joint research project **ASKURIS,** the occurrence of organic micropollutants in a semi-closed urban water cycle in Berlin was examined where the main emission source was treated urban wastewater. In the case of Lake Tegel (average wastewater content approx. 30%), extensive target and non-target analyses (i.e. analyses for known and unknown substances using special analytical techniques, cf. "Identification of emerging micropollutants by non-target analysis") on a long list of already known substances and of new emerging substances were performed. The measured concentrations of micropollutants from different origins were found to be within the usual range for urban wastewaters (from ng/l to ca. 30 µg/l in single cases).

Dilution of the urban wastewater in the Lake Tegel water cycle can be easily quantified by way of persistent organic micropollutants such as carbamazepine. In the drinking water produced from Lake Tegel via bank filtration and artificial groundwater recharge, some persistent micropollutants can be found which were sometimes already known before the start of the project (e.g. carbamazepine). However, also several new substances, like for example gabapentin and valsartan acid with concentrations of up to 1 µg/l were detected.

In the joint research project **TransRisk,** analytical methods for 84 individual substances were developed. The analyzed micropollutants can be divided into the following substance groups (number of micropollutants indicated in brackets): sweeteners (5), pharmaceuticals, including X-ray contrast media (RCM) (64), melamine (2), benzotriazoles (3), benzothiazoles (6), pesticide metabolites (4) and nitrate (1). The occurrence of the organic micropollutants in the water cycle with a view to the impact of point sources was measured seven times at 20 sampling sites in the water protection area "Donauried-Hürbe". For an indicative evaluation of all measurements performed in the project (around 10,000 individual values), a parameter sum was formed for each substance group, i.e. the concentrations of the individual substances of a group were aggregated. For each sampling site and each parameter sum, the median was divided into three categories. The results are shown in Tab. 2.2.

The substance groups were used as indicators for the impact of (I) municipal wastewater treatment plants (WWTP) (including wastewater seepage in the sewer system due to leaking sewers), (II) discharges from road traffic and (III) agriculture. In the influent and effluent of municipal WWTP, the wastewater indicators sweeteners, pharmaceuticals, melamine and benzotriazoles were found to be nearly all positive at the highest category. The impact of road traffic via runoff water on the wastewater of WWTPs was measured using the indicator substance group of benzothiazoles, but was mainly found at concentrations in the middle range. The values for pesticide metabolites attest to the impact of agriculture in all groups of sampling sites. This is probably attributable to the predominantly agricultural character of the Donauried region used as a model site

Tab. 2.2: Use of indicators to assess the release of anthropogenic micropollutants in the region under analysis

Groups of sampling sites	Sampling site	Indicator group						
		Wastewater Treatment Plants				Road Traffic	Agriculture	
		Sweeteners	Drugs/RCM	Melamine	Benzotriazoles	Benzothiazoles	Pesticide Metabolites	Nitrate
Raw wastewater	Influent WWTP Langenau	+	+	+	+	o	o	-
	Influent WWTP Steinhäule	+	+	+	+	+	o	-
	Wastewater of Clinical Health Center Ulm	+	+	o	+	-	o	-
Treated wastewater	Effluent WWTP Langenau	+	+	o	+	o	o	o
	Effluent WWTP Steinhäule	+	+	+	+	o	o	o
Road runoff water	Storm water basin Schammenbach	-	-	o	-	o	o	o
	Storm water basin with overflow Rammingen	-	-	-	-	-	o	o
Hotspots groundwater	Ochsenhölzle	o	-	o	-	-	o	+
	Nerenstetten	o	-	-	-	-	o	o
	Lone, spring	-	-	-	-	-	o	o
	Danube, Leipheim	o	o	o	o	-	-	o

Criteria for the categorization (median concentration):

(-): < 0.1 µg/l For nitrate: (-): < 10 mg/l

(o): 0.1 – 1 µg/l (o): 10 – 50 mg/l

(+): > 1 µg/l (+): > 50 mg/l

for this analysis. In the sampling site group road runoff water, the parameter sums were only slightly higher for melamine and benzothiazoles. The occurrence of pesticide metabolites and nitrate clearly shows the impact of extraneous water from agricultural origins, for example from field boundary drainage. A heterogeneous situation was found for the group "Hotspots groundwater". The wastewater indicators, which in the case of the sampling sites at a landfill can probably be attributed to substances inside the landfill, as well as the indicators for agriculture were both found to be positive. In the surface waters of the rivers Nau and Danube used as receiving waters, the wastewater impact could be clearly detected using the corresponding indicators. An agricultural impact could equally be verified. Only the water from the spring of the river Lone did not show any significant wastewater impact.

To document the increased vulnerability of karstic aquifers, specific contamination sources and scenarios in the catchment area at the model site Gallus spring (cf. Fig. 2.4) in the Swabian Alb region were identified, characterized and systematically analyzed in the joint research project **AGRO**. The spring water was monitored for a total of more than 50 different organic micropollutants such as pharmaceuticals, pesticides, corrosion inhibitors, stimulants and sweeteners. 38% of the substances were detected at least once. The concentrations ranged between 1.1 ng/l and (in rare cases) over 100 ng/l. The most frequently detected substances were the pesticides and pesticide metabolites metazachlor, atrazine and desethyl atrazine, the stimulant caffeine and its metabolites, the antiepileptic drug carbamazepine as well as the X-ray contrast media iohexol and iopromide.

The analyses attested to a long-term contamination with highly persistent substances such as the herbicide atrazine which was banned in Germany in 1991 (up to 5.8 ng/l) or the sweetener acesulfame (ca. 20 ng/l in the runoff during dry weather periods). At the Gallus spring, a method for the quantification of fresh contamination with untreated wastewater was established using the wastewater indicator caffeine. Moreover, the ratio of the concentrations of valsartan and its transformation product valsartan acid was identified as a promising indicator for the performance of a wastewater treatment plant. Generally, a significantly lower detection frequency of wastewater-borne micropollutants was found in comparison to the values measured in the year 2010. Most probably, this drop in wastewater contamination is attributable to sewer modernization and an upgrading of the storm water basin with overflow in the catchment area.

Fig. 2.4: Gallus spring (© AGRO)

Occurrence and formation of transformation products

Transformation products (TPs) of micropollutants are increasingly moving into the focus of scientific interest. TPs result from abiotic or biotic transformations of anthropogenic compounds in living organisms, wastewater treatment plants, the environment and also in water treatment. Frequently, several TPs are formed from a single substance, thus significantly increasing the number of substances in the water cycle (cf. Fig. 2.5).

The active pharmaceutical ingredients and metabolites excreted by humans as well as the large number of chemicals used in households and industrial plants enter the municipal wastewater treatment plants via wastewater. In the WWTPs, many of these substances are not mineralized, i.e. metabolized to carbon dioxide or biogenic digestible substances, but only slightly transformed. In most cases, this transformation leads to TPs with a higher polarity than the original substances. The following enzyme-catalyzed reactions were observed in activated sludge treatment, for example: mono- and dihydroxylations, alcohol and aldehyde oxidations, hydrolysis of esters and amides, decarboxylations, N-dealkylations and N-deacetylations. Given their high polarity, the TPs that formed during wastewater treatment often directly enter the surface waters and from there in some cases also the groundwater as well as, in singular cases, the drinking water.

Some of the TPs that are formed during wastewater treatment are toxicologically precarious (e.g. N-nitrosodimethylamine, NDMA). For the risk assessment it is therefore mandatory to integrate the formation

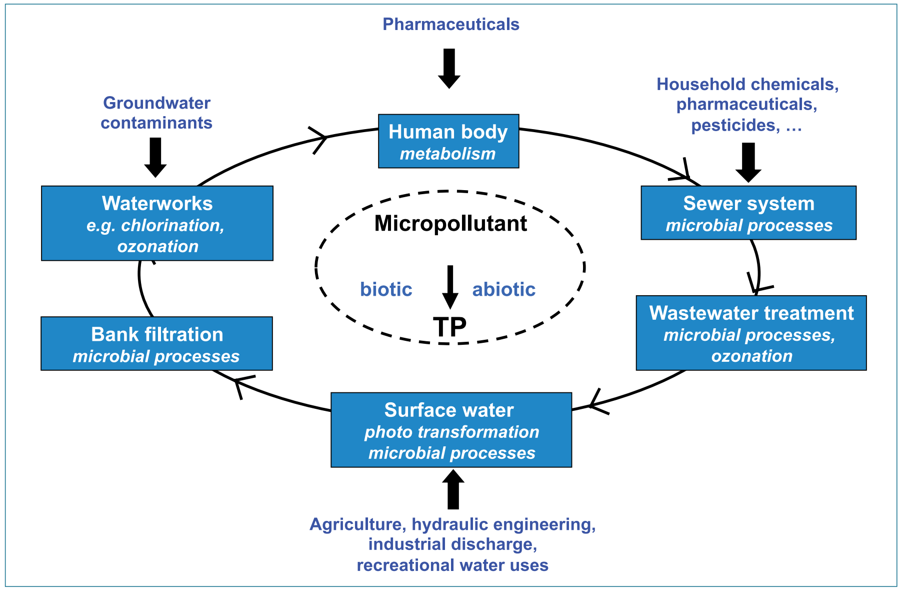

Fig. 2.5: Formation of transformation products in the urban water cycle

and removal of (eco-)toxicologically relevant TPs into the monitoring programs. However, for the vast majority of the micropollutants it is as yet not known to which TPs they are transformed in biological wastewater treatment.

One focus of the projects **RISK-IDENT** and **TransRisk** was on identifying the micropollutant TPs that form in the biological wastewater treatment stage. To this effect, the TPs of selected micropollutants such as sartans, the metabolites of carbamazepine and the antiviral drug acyclovir were identified. Using various eco-toxicological tests it was also examined to which extent the transformation products formed are eco-toxicologically relevant (cf. Chapter 3).

In the joint research project **RISK-IDENT,** the transformation processes of various micropollutants were examined in laboratory-scale WWTPs and in aquifer columns. The tests focused on numerous pharmaceuticals, biocides, industrial chemicals, and pesticides. The TPs that are formed from these original substances were then forecast using in-silico methods and, in a next step, analyzed in the WWTP processes and column eluates by non-target screening (cf. “Identification of emerging micropollutants by non-target analysis”). Sartans, for example, were degraded at varying degrees in lab-scale WWTPs; in the process, numerous TPs are formed, some of which could be identified (valsartan acid, amino-valsartan, irbesartan-TP446). The reference substances of individual TPs were synthesized and the TPs were included in the water monitoring programs of the pertinent authorities. In this context, TP446 of the active ingredient irbesartan was found in concentrations of up to 0.44 µg/l in WWTP effluents and of up to 0.09 µg/l in Bavarian rivers.

TransRisk examined the transformation of biocides and active pharmaceutical ingredients in biological wastewater treatment from laboratory-scale via pilot-scale to full-scale. In this context, the complete transformation pathway was elucidated in each case, whereby the mass balances from the original substance to the metabolites excreted by humans through to the TPs formed in the WWTPs could be closed. In addition to mass-spectrometric methods and nuclear magnetic resonance (NMR) spectroscopy also computer-assisted prediction models were used to identify the TPs and the transformation pathways. One example is the main metabolite of carbamazepine, 10,11-dihydro-10,11-dihydroxycarbamazepine (DiOHCBZ), which could be detected in WWTPeffluents as well as in surface waters and even in the drinking water [Kaiser et. al, 2014]. In some instances, the concentrations of DiOHCBZ were even higher than those of the active pharmaceutical carbamazepine. Also the main metabolite of the anticonvulsant oxcarbazepine, 10,11-dihydro-10-hydroxycarbamazepine (10OHCBZ), could be found in the effluents of municipal WWTPs and German rivers and streams. These metabolites and oxcarbazepine were further transformed in activated sludge treatment. Seven TPs could be identified in this process. The TPs of DiOHCBZ, 10OHCBZ and oxcarbazepine could be quantified in WWTP effluents as well as in rivers and streams, in groundwater and even in the drinking water. In addition to the original substances, in particular 9-carboxy-acridine (9-CA-ADIN) was found at concentrations of up to 0.92 µg/l in WWTP effluents and of up to 0.19 µg/l in the drinking water. Also other TPs, such as BaQD (1-(2-benzoic acid)-(1H,3H)-chinazolin-2,4-dion) and acridone were detected in relevant concentrations in those samples.

In another example, the antiviral drug acyclovir was transformed to a single TP, namely carboxy-acyclovir, upon contact with activated sludge. Carboxy-acyclovir can be found in surface waters at concentrations of up to 2 µg/l, in the groundwater (up to 0.25 µg/l) as well as in the drinking water (up to 0.040 µg/l).

In the **PRiMaT** and **TransRisk** projects also TPs that form by ozonation were identified, quantified and evaluated as to their eco-toxicological effects (cf. Chapter 3).

In the **TransRisk** project, carboxy-acyclovir was for example transformed to the stable oxidation product COFA (N-(4-carbamoyl-2-imino-5-oxoimidazolidin)formamido-N-methoxyacetic acid) by ozonation. This oxidation product also showed an increased algal toxicity. COFA was found in the lower nanogram per liter range in the drinking water downstream of a water treatment step using ozonation and activated carbon. Moreover, COFA can also be formed in significant concentrations (> 1 µg/l) during the ozonation of wastewater. However, COFA was not eliminated by bio-active granular activated carbon (GAC) filters and biofilm filters which established after the ozonation step.

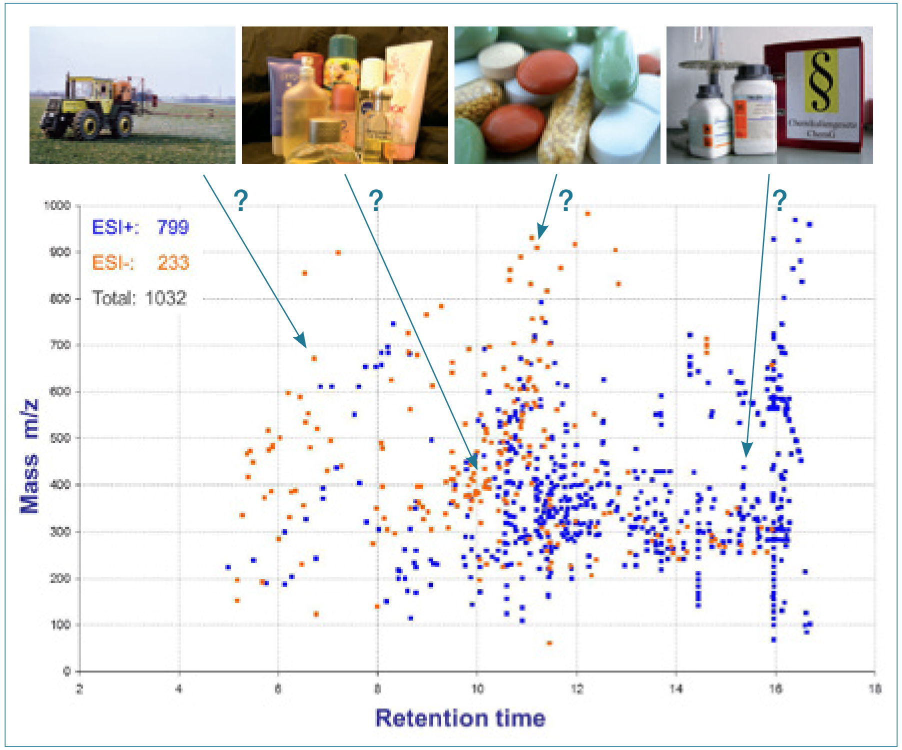

Fig. 2.6: In unpolluted groundwater around 1,000 signals were detected by non-target analysis which can only seldom be assigned to known substances. Wastewater samples produce a multiple of the signal number found in groundwater samples.

Under the **PRiMaT** project, a strategy for analyzing ozonated waters with regard to TP formation was developed. For the analytical characterization, an ion chromatographic separation was combined with a total of five different detectors. With these combinations it was possible to identify and quantify TPs, to calculate element-specific mass balances and also to draw conclusions as to the degree of oxidative degradation. For acesulfame, for example, three oxidation products were detected after UV-radiation which could be identified as acetate, amidosulfonic acid and carboxylic acid of acesulfame.

Identification of emerging micropollutants by non-target analysis

Around the world, more than 100 million substances are known. Of these, more than 100,000 are produced on an industrial scale and have the potential to be hazardous for the environment. The largest part of these micropollutants and their TPs are currently not captured in routine analyses. At the same time, modern analytical methods such as liquid chromatography in combination with high-resolution and accurate mass spectrometry offer a growing number of options for identifying unknown substances in the water or determining known substances. With so-called "non-target analyses" thousands of mostly unknown substances are detected (cf. Fig. 2.6). A special challenge in this context is the efficient use of the measurement data to determine the structure and unequivocally assign a substance.

In the joint research project **ASKURIS,** a procedure for non-target analysis was developed in collaboration with the equipment manufacturers to evaluate the data on organic micropollutants in the water cycle collected with modern analytical equipment. To simplify the evaluation of water samples, the project **RISK-IDENT** developed the STOFF-IDENT database. For nearly 8,000 chemical substances it provides substance properties such as molecular mass, molecular formula, chemical structure or the hydrophobicity required for standardizing the retention time. This database in particular lists substances that are relevant for the aquatic environment. These include chemicals that were registered in the framework of the REACH Directive as well as pesticides, biocides and pharmaceuticals and their TPs. After project completion the Bavarian Environment Agency will continue to operate and update this database and make it available to the public free of charge.

STOFF-IDENT was tested on surface water and bank filtrate samples where around 267 substances were identified of which 38.2% were pharmaceuticals, 37.8% REACH chemicals, 16.5% pesticides and 7.5% other substances. According to the validations performed to date, an identification probability of around 70% can be achieved with STOFF-IDENT.

Another database used in this context is DAIOS (Database Assisted Identification of Organic Substances). In the framework of the joint research project **ASKURIS,** DAIOS was re-programmed for a more efficient identification, optimized user-friendliness and a simplified extension of the database. In this way, two complementary databases are now available: while STOFF-IDENT mainly contains physico-chemical data, DAIOS provides, *inter alia*, information on degradation pathways and MS/MS fragments. In the follow-up project FOR-IDENT, both databases will be combined on one work platform together with additional software tools.

Over and beyond this, also so far unidentified substances such as gabapentin, pregabalin and valsartan acid were identified in the joint research project **ASKURIS** using polar separating agents in combination with high-resolution mass spectrometry.

In the joint research project **RISK-IDENT,** several substances typically found in surface waters and bank filtrates that had so far been disregarded could be identified with the help of STOFF-IDENT and reference substances. Examples include transformation products of the antihypertensive irbesartan, vulcanization accelerators, UV filter substances as well as other industrial chemicals. As a result of these findings, some of the newly identified substances have now been included in the official water monitoring program.

In the framework of **TransRisk,** a new group of substances relevant for the aquatic environment, the quaternary phosphonium compounds (QPVs), was identified with the help of non-target analysis and STOFF-IDENT. This substance group includes methyltriphenylphosphonium cation, ethyltriphenylphosphonium cation and methoxymethyltriphenylphosphonium cation. For these quaternary phosphonium compounds a quantitative LC-MS/MS method was developed and validated [Schlüsener et al., 2015]. QPVs were primarily found at higher concentrations in rivers containing treated wastewaters from the chemical industry. Specifically, high concentrations of QPVs were detected in the small rivers of the Hessian Ried region with concentrations of up to 2.5 µg/l ethyltriphenylphosphonium cation, for example. Save for one exception, the QPVs were not detectable in the effluents of municipal WWTPs. This supports the thesis that QPVs mainly enter the aquatic environment via industrial WWTPs. Furthermore, so far unknown substances were identified in influents and effluents of municipal WWTPs. Using reference materials, it was possible to confirm the presence of the pharmaceutical residues lamotrigine, lamotrigine-N2-glucuronide, sulpiride and amisulpride in WWTP effluents as well as in rivers and streams.

2.2 Microbiological contaminants

This chapter in many respects refers to explanations given in the RiSKWa status paper "Bewertungskonzepte der Mikrobiologie mit den Schwerpunkten neue Krankheitserreger und Antibiotikaresistenzen" *(Microbiological risk assessment concepts with a focus on emerging pathogens and antibiotic resistance)*, which comprises the results of the RiSKWa interdisciplinary topic "Bewertungskonzepte der Mikrobiologie" *(Microbiological risk assessment concepts)* [Exner & Schwartz, 2015].

Occurrence of pathogenic and opportunistic-pathogenic microorganisms

In the joint research projects **SchussenAktiv*plus*** and **TransRisk,** wastewater treatment plants with conventional treatment technology and various designs were examined for *E. coli*, enterococci, staphylococci, and *Pseudomonas aeruginosa* concentrations. High frequencies (abundances) of opportunistic-pathogenic bacteria were detected in the influents of municipal wastewater treatment plants and, in particular, in hospital effluents, whereby staphylococci (*S. aureus* and coagulase-negative staphylococci, CNS) were more frequently found in hospital effluents. The elimination performance of the WWTPs for the mentioned bacteria groups amounted to up to 2 log levels. Specifically, the reduction potential was of up to 90% for enterococci and of up to 50% for *Enterobacteriaceae*, for example. No elimination by conventional wastewater treatment was found for *P. aeruginosa*. Fig. 2.7 shows bacterial colonies on a selective culture medium.

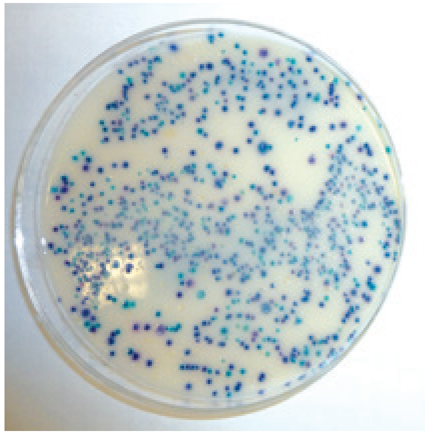

Fig. 2.7: Selective cultivation of pathogenic microorganisms (© T. Schwartz, Karlsruhe Institute of Technology (KIT))

The analyses performed in the framework of the **TransRisk** project produced a clear reduction of the overall bacterial load of up to 90% as a result of ozone treatment. For the specific bacteria markers, a reduction after ozone treatment of up to 2 log levels for enterococci and 0.2 log levels for *Enterobacteriaceae* at a specific ozone dose of 0.85 mg/g DOC was found. The reduction efficiency was significantly lower for *Pseudomonas aeruginosa*, albeit against the backdrop of a lower abundance in the original population. In the framework of the **SchussenAktiv*plus*** project, ozonation of treated wastewater resulted in an additional reduction in the range of 0.3 (staphylococci) to 1 log level for *E. coli* and enterococci compared to the wastewater treatment plant effluent after conventional cleaning.

In the context of the joint research project **Sichere Ruhr,** the water of the river Ruhr was analyzed for microbial contamination. The Ruhr is contaminated by fecal matter from numerous wastewater treatment plants, which explains the high number of positive findings for *E. coli*, coliform bacteria, coliphages, and aeromonads. With regard to enteral viruses, mainly the data relating to rota-, noro-, and enteroviruses are interesting from the viewpoint of infectiology. In line with the occurrence of the respective infections among the population, rota- and noroviruses can be evidenced in surface waters, especially during the winter season. As a consequence of the different influents from wastewater plants and also via diffuse discharge paths, higher concentrations of pathogens in the receiving water can be found especially after strong rains. After precipitations, the Ruhr is contaminated to such an extent that the hygienically acceptable bathing water quality required for public bathing can only seldom be achieved. During the bathing season, for example, just under 15% of the *E. coli* discharge into the Ruhr originates from diffuse discharge paths close to the surface water, especially from agriculture, and around 60% from the overflows of various rain reservoirs and other not clearly identifiable sources.

In the joint research project **Sichere Ruhr,** 184 samples were examined over a period of 15 months. In this process, *Cryptosporidia* were found in 29% of all samples and Giardia in 78% of the samples. During the entire period covered by the study, rotaviruses were found in 9.8% of the samples. Noro- and enteroviruses were detected in 29.5% and 22.3% of the samples, respectively. The statistical evaluation of the data did not show any correlation between the pathogen concentrations measured and the abundances of the indicator organisms *E. coli* and intestinal enterococci. Also the concentrations of coliphages and various human pathogenic viruses (adeno-, polyoma-, entero-, and rotaviruses) did not correlate.

Under the **SchussenAktiv*plus*** project, the populations of *E. coli*, enterococci, and staphylococci in two surface water bodies were examined in a culture process. While the population counts of *E. coli* and enterococci were 0.6 to 0.8 log levels lower than in the wastewater treatment plant effluents, the population count of staphylococci was about one log level higher.

Moreover, in the framework of the **PRiMaT** joint research project, comparative measurements on PCR-based test methods were conducted in the laboratories of different institutions, e.g. for the determination of adenoviruses. The results showed a very good correlation. The average deviation for adenoviruses amounted to 0.4 log levels.

In the joint research project **RiMaTH,** new methods for detecting pathogens in the drinking water of building installations were developed/validated. The main focus was on Legionella. A comparative study of the legally permitted enumeration method for Legionella in potable water (by culture as per ISO 11731] and [DIN EN ISO 11731-2) and an already standardized quantitative PCR method ISO/TS 12869 was performed. In the framework of the comparative study, around 3,000 samples from drinking water installations in buildings across Germany were tested in parallel for *Legionella spp.* and *Legionella pneumophila* using the culture method and qPCR. In around 84% of the samples, the results of the culture method matched those of the qPCR method.

Occurrence of microorganisms resistant to antibiotics

Culture methods applied in the joint research projects **SchussenAktiv*plus*** and **ANTI-Resist** showed that, for opportunistic pathogenic bacteria, the share of phenotypically identified antibiotics resistances for certain bacteria groups in the wastewater treatment plant was growing while in other groups the share of resistant isolates was declining. Given the significantly lower live colony counts of microorganisms in the wastewater treatment plant effluent as compared to the influent, the – absolute – concentration of opportunistic microorganisms resistant to antibiotics in the effluent was lower than in the influent of the wastewater treatment plants. Antibiotic resistant isolates that also showed multiple resistances were detected irrespective of the sampling point and season.

In the joint research project **TransRisk,** the abundances of clinically relevant antibiotic resistance genes were quantified in the total population of hospital effluents and wastewater treatment plants using molecular-biological methods. The highest abundances of antibiotic resistance genes were measured in hospital effluents. Also in the effluents of wastewater treatment plants a relative increase in the frequencies of certain resistances within the total population as compared to the influent was found.

Also in the framework of the joint research project **ANTI-Resist** the resistances in raw sewage and treated wastewater were quantified by means of molecular-biological methods. The analyses produced a higher abundance of clinically relevant antibiotic resistance genes for *E. coli*, the frequency of which in addition also showed a seasonal pattern.

The joint research projects **ANTI-Resist, TransRisk** and **SchussenAktiv*plus*** evidenced that hospital effluents and municipal wastewaters are important sources for the discharge of bacteria with antibiotic resistances into the environment. Fig. 2.8 shows the fluorescence micrograph of a bacterial flock from an effluent after live-dead staining. In the framework of **TransRisk** and **SchussenAktiv*plus*,** the efficiency of ozonation as an additional wastewater treatment step for the reduction of antibiotic resistant bacteria was investigated. The analyses showed a significant reduction of the total bacterial load, but the share of resistant isolates in the surviving population in the effluent of the ozonation step was in some cases higher. This result gives a first indication about a series of antibiotic resistant bacteria that survive ozonation treatment. However, it is not possible to make a general statement for the behavior of all clinically relevant antibiotic resistant bacteria. No further significant reduction of antibiotic resistant bacteria could be found after passing the filters downstream of the ozonation step.

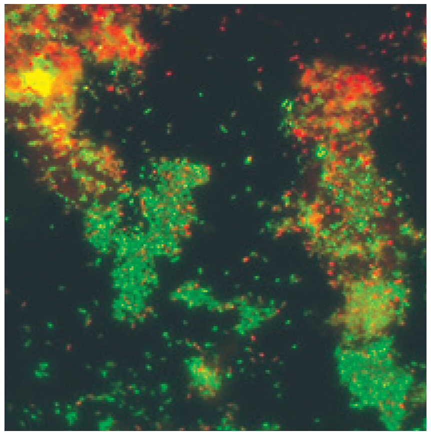

Fig. 2.8: Fluorescence micrograph of a bacteria population
(© T. Schwartz, Karlsruhe Institute of Technology (KIT))

Under the joint research projects **AGRO** and **TransRisk** the water of a karstic spring and anthropogenically contaminated groundwater measuring points were analyzed for antibiotic resistances. It showed that antibiotic resistances were found at all measuring points and that an increased turbidity – e.g. after strong rains or spring runoff – correlated with a rise in the number of antibiotic resistance genes found.

In the joint research projects **TransRisk** and **AGRO,** the antibiotic resistance genes under analysis were found in the surface waters examined and quantified in the total population with the help of molecular-biological methods. The highest concentrations were measured in bacteria populations from surface waters used as receiving waters for local wastewater treatment plants. But resistant genes, although in smaller amounts, were also detected in surface waters without direct influent from wastewater treatment plants.

In the framework of **SchussenAktiv*plus*** it was demonstrated that the resistance level did not change while passing through constructed wetlands and rain water overflow basins. In a column assay on bank filtration conducted in the framework of the **PRiMaT** joint research project, the reduction of resistant bacteria during soil passage was demonstrated. Under **TransRisk,** high bacteria loads and abundances of hygienically relevant bacteria and resistance genes in surface waters were measured, especially after strong rains.

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3 Risk characterization und risk assessment: drinking water, wastewater, ground and surface water

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Key messages

Drinking water

Key message 1: The concept of deriving health-related indicator values, or HRIVs, *(German: gesundheitliche Orientierungswerte, GOW)* supports the implementation of the German Drinking Water Ordinance in those cases where substances are found in the drinking water that have so far not been regulated by a legally binding standard, but which require such regulation in view of their relevance for the drinking water quality. With the HRIV concept of deriving health-related indicator values it is possible to recommend measures also without having legally binding standards in place.

Key message 2: An extension of the HRIV concept by experimental modules allows for a timely collection of data that increase the scientific basis for deriving the HRIVs. This represents an essential element for effective risk management.

Key message 3: With the extended HRIV concept the substances are prioritized and further actions regarding the toxicological assessment are defined.

Key message 4: The toxicological safety of drinking water can be guaranteed by HRIV derivation supported by experimental data.

Wastewater and surface water

Key message 1: Toxic substances in wastewater can be significantly reduced by introducing a fourth treatment stage in wastewater treatment plants.

Key message 2: Chemical loads and their negative impact on aquatic organisms can effectively be reduced for specific substances, for example by means of ozonation and/or adsorption on activated carbon.

Key message 3: All cleaning technologies examined in this context have their pros and cons. It must be clarified on a case-by-case basis which technology is best suited for treating wastewater under the site-specific conditions.

Key message 4: Positive effects on the respective aquatic ecosystem were observed already within one year after the

commissioning of a commercial-scale activated powder unit in a wastewater treatment plant in the Lake Constance catchment area. The health condition of the aquatic organisms can be plausibly correlated to the extension of the wastewater treatment plant.

Key message 5: The system-specific approach of evaluating the substances and their (unknown) transformation products as a mixture based on their eco-toxicological effect proved to be a viable method.

Key message 6: Effects of anthropogenic micropollutants on humans and the environment could not be evidenced in the Berlin water cycle for real concentrations during the period of investigation.

Microbial contamination

Key message 1: Wastewater systems have been identified as important sources for the direct release of opportunistic pathogenic bacteria and clinically relevant antibiotic resistances into the aquatic environment. Adequate technical processes must interrupt these dissemination paths.

Key message 2: To assess the quality of wastewater treatment plant effluents, additional quality characteristics are purposeful and necessary: microbiological indicator parameters (resistance genes, pathogens, viruses) as well as the introduction of monitoring concepts and microbiological regulations.

Key message 3: Molecular-biological methods supplement and complement the standardized cultivation processes for a faster and more comprehensive identification of microbiological hazards in aquatic systems.

Key message 4: New methodological procedures for antibiotic resistances and "new emerging pathogens" need to be integrated into the risk characterization.

Key message 5: Despite a reduction in the total bacteria count as a result of wastewater treatment, e.g. by ozonation, selective processes for microorganisms can be observed that lead to an accumulation of antibiotic resistances and therefore require a specific adaption of the technology in place.

3.1 Toxicological and eco-toxicological assessment

The risk management of anthropogenic micropollutants operates in a field of conflicting interests. On one hand, we have unwanted effects on humans and the environment, on the other hand, we are depending on pharmaceuticals for quality of life improvements. That is why it must be discussed how concrete risks can be reliably assessed.

For the characterization and assessment of micropollutant risks in the environment (groundwater, surface water, wastewater, soil, air) it is essential to know the adverse effects caused by these substances and the threshold values that trigger such effects. Effect-based tests offer the advantage that they collect endpoint-specific effects of chemicals in environmental samples with complex, so far unknown contaminations. Such effect-based tests could be part of an integrated evaluation system for mixed toxicity studies that can be included in the assessment. Effect data are obtained from

Tab. 3.1: Modes of action examined in the RiSKWa joint research projects

Mode of action	ASKURIS	PRiMaT	RISK-IDENT	RiskAGuA	SAUBER+	SchussenAktiv*plus*	TOX-BOX	TransRisk
Toxic effects								
Genotoxicity		o	o	o	o	o	o	o
Neurotoxicity	o					o	o	
Dioxin-like toxicity/Biotransformation	o					o		o
Cytotoxicity, tissue integrity, inflammation			o			o	o	o
Proteotoxicity						o		
Phytotoxicity	o		o			o		
Developmental toxicity			o			o	o	
Reproductive toxicity	o		o			o	o	o
Growth			o	o	o	o	o	o
Ecosystem integrity						o		
Unspecific toxicity, mortality	o		o	o	o			
Hormone-like effects								
Estrogenicity						o	o	o
Anti-estrogenicity						o	o	o
Androgenicity						o		o
Anti-androgenicity						o		o

both (I) laboratory and *in-situ* tests (biotests) which determine the toxicity of chemicals and complex environmental samples by means of mostly standardized processes via apical, population-relevant endpoints (e.g. mortality, development, growth, reproduction) and (II) biomarker studies to evidence reactions in exposed organisms in the field.

In the framework of RiSKWa, biotests with both apical endpoints and biomarkers were used as effect-based methods for assessing micropollutants in the water cycle, in particular in the joint research projects **RISK-IDENT, SchussenAktiv*plus*, TOX-BOX** and **TransRisk.** Individual, effect-related aspects were also examined in the context of the joint research projects **ASKURIS, PRiMaT, RiskAGuA** and **SAUBER+.** In the projects **TOX-BOX** and **PRiMaT,** the main focus was on assessing drinking water-relevant substances and their elimination, while the other joint research projects focused on the effect-based monitoring of micropollutant elimination by various wastewater treatment technologies. The individual methods are described in detail in the RiSKWa compendium "(Öko)toxikologische Bewertungsmethoden" [(eco)toxicological assessment methods]. Table 3.1 provides a summary of the effects analyzed by the abovementioned RiSKWa projects.

In the context of the joint research projects **PriMaT, RiskAGuA RISK-IDENT, SAUBER+, SchussenAktiv*plus*, TOX-BOX** and **TransRisk** the toxic properties of drinking water, wastewater, surface water, and aquatic sediments were examined using a series of biotests and biomarkers. In this context, various modes of action of substance contaminations were examined (cf. Tab. 3.1).

Human toxicological contaminations and their assessment

Anthropogenic micropollutants are relevant for the drinking water and thus potentially also for human health on the grounds of their properties (including polarity, persistence and mobility). Where such substances are analytically detected in the drinking water, they need to be assessed with regard to the applicable German Drinking Water Ordinance, Articles 4 and 6 (Axiom of Concern and Minimization Imperative). To this effect, the health-relevant indicator value or HRIV is used. The HRIV is a health-related precautionary value for substances that can only be analyzed to some extent or not at all in terms of their toxicity for humans. This (non-assessibility) is a criterion that applies almost consistently in the case of anthropogenic micropollutants.

Under the joint research project **TOX-BOX,** *in-vitro* testing strategies to determine the modes of action relevant for humans (genotoxicity, neurotoxicity, endocrine effects) are being developed to derive the HRIV. To assess the relevance for humans, metabolism-competent cell lines are used that have proven to be highly specific regarding the human metabolism. That way, data gaps can be filled and the toxicological safety enhanced. This in turn will ensure that risks are not over- or underestimated – an important aspect with a view to the overall objective of the joint research project: a scientifically based risk management.

Since the HRIV level (as a function of the data available in a range from 0.1 to 3 µg/l) determines the corresponding risk management actions to be taken, a methodological toolbox for collecting the toxicological data needs to be bindingly established. To this effect, general guidelines in the form of decision trees are defined.

A detailed description of the toolbox and the test reports is provided in the guidance document “Hazard-based risk management of anthropogenic micropollutants in drinking water”. The HRIVs derived are published by the German Federal Environmental Agency (Umweltbundesamt, UBA) under the link “http://www.umweltbundesamt.de/sites/default/files/medien/374/dokumente/liste_der_nach_gow_bewerteten_stoffe_2.pdf“).

The endpoint-related test strategy for deriving the HRIVs comprises the following *in-vitro* testing procedures:

- Genotoxicity is analyzed using the ames, umu and micronucleus test.
- Neurotoxicity is tested by measuring necrosis, apoptosis and oxidative stress in liver and nerve cells.
- With the neurite outgrowth assay, neuron-specific effects are demonstrated.

Table 3.1 illustrates the manifestation of neurites. The toolbox for detecting endocrine effects consists of hormone-specific reporter gene assays and the H295R assay.

Eco-toxicological contaminations and their assessment

In the joint research projects **ASKURIS, PRiMaT, RiskAGuA, SAUBER+, SchussenAktiv*plus*, Sichere Ruhr** and **TransRisk,** effects-based tests were used to characterize the efficiency of different treatment technologies and their combination with view to reducing potential toxic and hormonal effects in the wastewater. Another objective was to determine whether, in some cases, also an increase in the toxicity of the wastewater was to be expected when applying these new technologies - as a result of the formation of (possibly as yet unknown) transformation products, for example. In this context, especially tests that map genotoxic effects were important since transformation products frequently exhibit radical characteristics and may interact with the genetic material of organisms.

Besides standardized biotests such as the daphnia or luminescent bacteria test which are suited as screening methods for high toxicity levels and can therefore at best detect incidents in European water bodies, also a wide range of modern, sensitive and to some extent also selective and specific *in-vitro* and *in-vivo* studies were conducted in the framework of RiSKWa. They allowed for an investigation of the biological potentials and effects in their numerous facets ranging from the molecule to the ecosystem.

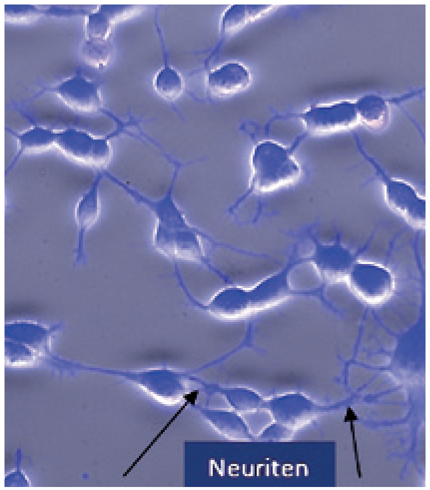

Fig. 3.1: Neurite differentiation of the cell culture SH-SY5Y to asses neurotoxicity
(© E. Dölling, Federal Environmental Agency (UBA), Dessau)

Depending on the planned application, *in-vitro* and *in-vivo* bioassays (laboratory tests) offer specific advantages. In-vivo tests are performed using intact organisms that represent aquatic communities and exhibit a higher ecological relevance as compared to *in-vitro* tests. While acute tests are usually not sufficiently sensitive to be able to asses effects in environmental samples for typical contamination levels, chronic tests are particularly well suited for mapping ecologically relevant effects of substances also in complex cocktails in surface waters, sediments and in wastewater samples.

On the other hand, however, chronic tests are time-intensive and therefore better suited for research purposes than for routine monitoring and only in exceptional cases allow studying specific toxicity modes of action. Although this constraint can be offset by parallel tests with biomarkers in addition to the apical endpoints, it contributes to further increasing the effort required for testing and evaluating the test results. It has therefore proven to be effective to use not only *in-vivo* tests with intact organisms, but also *in-vitro* assays, like for example in the context of the joint research projects **SchussenAktiv*plus*** and **TransRisk**.

Another aspect emerged for example when analyzing the enhanced wastewater treatment technology in a wastewater treatment pilot plant under the joint research project **TransRisk,** was that some of the selected test species in the chronic *in-vivo* tests reacted not only to contaminants in the strict sense, but also showed sensitive reactions to nutrients (nitrogen compounds, phosphorous), increased salt concentrations and filterable suspended matter. These reactions can hide the effects of micropollutants so that, without additional *in-vitro* tests, it cannot be unequivocally clarified whether an impact of the parameters under analysis (e.g. biomass, growth and reproduction) is attributable to the elimination of toxic substances and/or formation of potentially toxic transformation products or to other properties of the effluent (e.g. nutrient concentration).

The benefits of *in-vitro* tests for identifying and assessing the effects on environmental samples in general and on wastewater samples in particular are that such tests are specifically sensitive for a given mode of action and that they are easy and inexpensive to use and thus suited for routine monitoring, on the one hand, while the ecological relevance of the findings is limited because only the potential and not the effect on intact organisms are measured, on the other. Moreover, the high specificity of the *in-vitro* tests reduces the possibilities for detecting transformation products, for example, and extensive test batteries are needed to map a sufficient number of relevant modes of action.

In the framework of the joint research project **TransRisk,** a modular concept for the comparative assessment of enhanced wastewater treatment processes that considers chemico-analytical, eco-toxicological and microbiological parameters was developed. For the eco-toxicological assessment, primarily standardized *in-vitro* test procedures were considered for which either a DIN/ISO standard or a standard operating procedure (SOP) is available. In this context, the following eco-toxicologically relevant activity groups were analyzed:

- **Endocrine activities:** identification of the agonistic (receptor-activating) and antagonistic (receptor-inhibiting) potential regarding the estrogen receptor α (ER α) and the androgen receptor (AR) using recombinant yeast reporter gene assays (YES, YAS, YAES, YAAS). Methodical alternatives include proliferation assays (e.g. e-screen) or reporter gene assays on the basis of cell lines (e.g. ER-Calux, AR-Calux).

- **Mutagenic/genotoxic activities** are identified using the Ames fluctuation test (as per ISO 11350). In addition or as methodical alternatives, other genotoxicity assays (e.g. umu test, Comet assay, micronucleus test) can be used.

- **Cytotoxic activities** are detected with the help of mammal (e.g. GH3) or other vertebrate cell lines (e.g. RTL-W1) or with the help of bioluminescence inhibition in the case of luminescent bacteria.

- **Further activities** can be considered as required, like for example dioxin-like (in **TransRisk** measured with the help of the Yeast Dioxin Screen as a recombinant yeast reporter gene assay), neurotoxic (e.g. inhibition of the acetylcholinesterase) and/or phytotoxic effects (e.g. inhibition of photosystem II).

In the joint research project **SchussenAktiv*plus*** the effects of the large-scale extension of a wastewater treatment plant with powdered activated carbon on an ecosystem of the connected receiving water was investigated. Besides the wastewater samples also the surface water and the sediments were examined for toxic and hormonal potentials. Moreover, the health condition of fish and fish food organisms before and after the extension of the wastewater treatment plant was investigated and compared using a set of different biomarkers as diagnostic tools. This allowed characterizing the general health condition of organisms, on the one hand, but in addition also provided information on specific pollution factors (e.g. genotoxic, dioxin-like or estrogen-like substances), on the other. In parallel to the biomarker studies, in biota trace substance analyses were performed.

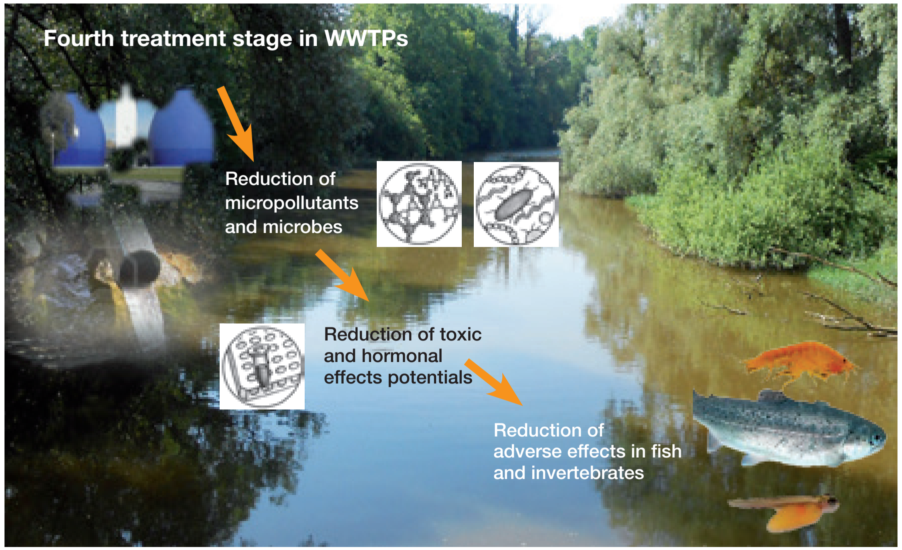

Fig. 3.2: Plausible correlations between the reduction of micropollutants by means of a fourth treatment stage in wastewater treatment plants and an improved health of the ecosystem that could be indexed by means of biotests. (© University Tübingen)

Already 15 months after addition of the PAC filter it was possible to plausibly correlate improvements in the health condition of aquatic organisms to the extension of the wastewater treatment plant. This was the case for both, fish and invertebrate aquatic organisms. Under this joint research project it was possible to develop plausible relationships between the results of *in-vitro* tests for different modes of action (dioxin-like, genotoxic, (anti-)estrogen toxicity) and the effects in organisms either exposed in nature or sampled from there, determined with the help of biomarkers (cf. Fig. 3.2). In addition, it was possible to correlate certain adverse effects in fish and invertebrate animals as well as their reduction after extension of the wastewater treatment plant with the presence of micropollutants or their further elimination in the additional treatment step.

Table 3.2 summarizes the results obtained in the individual RiSKWa joint research projects regarding the effects of micropollutants and their elimination.

Tab. 3.2: Summary of the results achieved by way of assays in the framework of RiSKWa

Joint research project	Results achieved
PRiMaT	A practicable, lab-scale test method was developed that purposefully combines enrichment process and assay. The ozonation of selected trace materials did not produce any evidence about the formation of genotoxic transformation products.
RiskAGuA	The eco-toxicological potential decreases as a result of the fermentation process.
RISK-IDENT	Anthropogenic micropollutants are not completely biodegraded in biological wastewater treatment. Standardized assays (algae growth inhibition test, Ames fluctuation test and 21d daphnia test) showed that both the residual concentrations and also the transformation products that form in the process of wastewater treatment can be eco-toxicologically relevant. Also in the case of a non-toxic wastewater at the inlet, transformation products may form that are harmful for aquatic organisms.

Joint research project	Results achieved
SAUBER+	Untreated raw sewage from two medical facilities, except for an inhibition of bacterial luminescence, did not show any further indications of a measurable biological disruption. In both cases, this bacteriotoxic effect found in the raw sewage could be completely eliminated by treatment in a membrane bioreactor. No further toxicity (genotoxicity, growth inhibition, luminescence inhibition) could be found in the downstream treatment stages using granular activated carbon and/or ozone. By contrast, a clear rise in the toxicity (bacteria toxicity and genotoxicity) was found after treating one of the wastewaters with UV+H_2O_2. This toxicity was attributed to the remaining H_2O_2 and was not found in further test series.
SchussenAktiv*plus*	A reduction of the toxic and hormonal potential in the wastewater by more than 80% was achieved using powdered activated carbon, ozone with and without granular activated carbon and a constructed wetland. Positive effects of a commercial-scale powdered activated carbon filter on the health of fish and fish food organisms were evidenced. Plausible correlations exist between the results of chemical analyses, *in-vitro* tests and biomarker studies. The relevance of answers at lower biological levels (molecules, cells) for ecosystem parameters (macrozoobenthos community) was evidenced.
TOX-BOX	A guideline for defining *in-vitro* test strategies to assess the hazard potential for the relevant endpoints genotoxicity and neurotoxicity as well as endocrine effects was developed and health-oriented indicator values were derived.
TransRisk	A sample treatment method for the *in-vitro* testing of water samples was defined. The examination of endocrine potentials in the influent and effluent of sewage treatment plants in the Donauried region produced an elimination of estrogenic and androgenic activities by ≥ 75% and of anti-estrogenic activities by ≤ 60% as compared to the influent. Anti-estrogenic activities were detected in some groundwater samples. Toxic and hormonal potentials in the wastewater were reduced by means of ozone with and without downstream filter systems. A strong increase in mutagenic and genotoxic effects could not be reduced with a downstream biofilter, but by way of a downstream granular activated carbon (GAC) filtration. A modular concept for the evaluation of advanced wastewater treatment processes on the basis of chemico-analytical, eco-toxicological and microbiological parameters was developed.

3.2 Microbiological assessment

This chapter in many aspects refers to the RiSKWa status paper “Bewertungskonzepte der Mikrobiologie mit den Schwerpunkten neue Krankheitserreger und Antibiotikaresistenzen“ [*Microbiological assessment concepts with a focus on emerging pathogens and antibiotic resistances*] which contains the results of the interdisciplinary topic “Bewertungskonzepte der Mikrobiologie“ [*Microbiological assessment concepts*] [Exner & Schwartz, 2015].

Ultimately, the microbiological assessments are derived from the conclusions of the RiSKWa joint research projects listed in the following.

Sichere Ruhr

- First-time quantitative risk assessment (QMRA) for those bathing in the river Ruhr: Enteroviral infection risk most relevant.
- Successful involvement of the public: high level of interest – understanding – commitment regarding bathing conditions from the media and the public.
- Technical measures for improved hygiene assessed: mixed water – wastewater treatment plant – agriculture are the approaches for improving quality.
- The guide “Flussbaden” [bathing in rivers] describes the legal framework, monitoring, early warning system, hygiene improvement, costs to enable bathing, communication.
- Bathing in German rivers: “Interessengemeinschaft Baden” [Special interest group bathing] starts a trial in the river Ruhr.

TransRisk

- Even after conventional treatment, hospital and municipal wastewaters contribute to the release of facultative pathogenic microorganisms into the aquatic environment.
- Clinically relevant determinants of antibiotic resistance were in some cases found more frequently in the analyzed wastewaters and/or sewage treatment plant effluents than in the carrier organisms (indication of horizontal gene transfer).
- Advanced treatment (so-called fourth treatment stage) at wastewater treatment plants involving technologies such as ozonation leads to a further reduction in the concentration of bacteria and facultative pathogenic microorganisms, but not to their full elimination.
- Bacteria resistant to antibiotics in the wastewater in some cases turned out to be more resistant to oxidative processes and survived the ozone treatment.
- Surface waters impacted by the intake of effluents and even groundwater showed concentrations of facultative pathogenic microorganisms and determinants for resistance to antibiotics in relation to the total population.

SchussenAktiv*plus*

- A wastewater treatment plant with added ozonation step resulted in a further reduction in the absolute concentration of facultative pathogenic microorganisms and bacteria resistant to antibiotics in the sewage treatment plant effluent.
- During the passage across the filter the tests sometimes showed an increase in

the share of antibiotic resistant *E. coli*, enterococci and staphylococci isolates.

- The passage across the constructed wetland resulted in a reduction of the *E. coli*, enterococci and staphylococci ultimately released into the receiving water.

Fig. 3.3: Microbiological assessment concepts facilitate evidencing the effectiveness of constructed wetlands, for example (© M. Scheurer, TZW, Karlsruhe)

ANTI-Resist

- The abundance of *E. coli* was reduced by the sewage treatment plant, but the share of antibiotic resistant *E. coli* did not drop during the passage across the sewage treatment plant.
- The number of multiple resistances in *E. coli* was not significantly reduced by the sewage treatment plant. Despite the reduction, multi-resistant *E. coli* were still released into the downstream water body.
- Independently of *E. coli*, the operating dynamics showed a seasonal pattern at the wastewater treatment plant inlet and effluent including the abundances of antibiotic resistance genes.

AGRO

- Frequent detection of resistance genes in the water of a karstic spring as well as in the surface waters of the catchment area.
- Relevant antibiotic resistance genes could be identified in the karstic spring water under analysis: *sul1*, *sul2*, *dfrA1*, *ermB*.
- Strong rains resulted in a significant increase in the number of antibiotic resistance genes and their gene copies measured in the spring water.

PRiMaT

- Validation of the PCR method successfully conducted by way of comparative measurements in different laboratories.
- Reduction of resistance genes and viruses in a column test on bank filtration.
- Examination and validation of new options (Luminex and EMA/PMA) to evidence human pathogenic viruses in water as an alternative to cell cultures.
- The examination of new methods for evidencing human pathogenic viruses is essential for future analyses of surface water and effluents in regard to their viral load.

RiMaTH

- The detection of *Legionella spp.* in the drinking water by means of molecular biological methods (qPCR as per ISO/TS 12869) is not suited for a risk assessment as it does not allow for conclusions to be drawn regarding the presence of pathogens.
- By contrast, the detection of *Legionella pneumophila* in the drinking water by way of molecular biological methods (qPCR as per ISO/TS 12869) – unlike in the case of *Legionella spp.* – is well suited for a quick, preliminary risk assessment based on an alternative action value yet to be specified until the results determined by culture analyses are available.
- A "conversion factor" of genomic units (GU) and colony-forming units (CFU) cannot be defined.
- The results of the qPCR are not legally robust and so far not suited as a replacement for the culture analyses required by the law.

SAUBER+

- The concentrations of resistant bacteria and the resistance gene spectrum in the wastewater of the healthcare facilities from which samples were taken did not differ much from each other and there is also very little difference between them and the substance concentrations and genes found in municipal wastewater.
- Besides tetracycline resistance genes also extended-spectrum beta lactamase-coding sequences (ESBL, MBL) were ubiquitously detected while methicillin-resistant or vancomycin-resistant bacteria were only found in single instances.
- Analyses of the municipal wastewater system upstream and downstream of a nursing home by way of high-throughput sequencing confirmed the results of culture tests. However, an evaluation of the small differences is difficult given the state of the art of analytical methodology.

In practice, culture-based methods are frequently used for detecting hygienically relevant bacteria. On one hand, this is mainly due to historical reasons since molecular biology and non-cultivation analytical methods are still relatively new, on the other hand the relevant regulation guidelines (e.g. Drinking Water Ordinance, Bathing Water Directive etc.) are based on culture analysis.

More recent results have shown, however, that also non-cultivable bacteria may be present in aquatic samples which are not necessarily dead but in a VBNC (VBNC – viable but not cultivable) condition.

The use of cultivation-independent molecular-biological methods is purposeful because (I) the results are mostly much faster and (II) the number of undetected, non-cultivable but yet present bacteria can be measured. This is necessary to allow for a differentiation regarding the hygienic assessment.

One method for assessing the concentrations of viruses, parasites and bacteria is the quantitative microbial risk assessment (QMRA). To allow a comparison of results at the international level and across disciplines, the DALY (disability-adjusted life years) approach could be used as a basis.

The aquatic environment doubtless plays an important role for the persistence and development of antibiotic resistances. In this context, in particular the horizontal gene transfer as a method of transmitting virulence factors has to be mentioned (Fig. 3.4). This refers in particular to the evolution of new, clinically-relevant antibiotic resistances in the environment without knowledge about the exact development processes.

Data confirm that the origins of clinically relevant resistance genes can also be found in the environment and not only in the clinical field. These findings show the correlation between evolution and spread of antibiotic resistances in hospitals and urban environments. However, no comprehensive data for the environmental field are available that would allow for the assessment of an existing risk posed by antibiotic resistances. Although regulations such as the EU Water Framework Directive [EC Water Framework Directive (2000/60/EC)] demand a good biological and chemical status of water bodies in regard to specific environmental quality standards, pathogens and also specific antibiotic resistant bacteria and/or antibiotic resistant genes are presently not mentioned in national and international regulations – they should, however, be integrated into the respective regulations. This is also mentioned by the WHO.

To this effect, critical areas (e.g. strongly contaminated partial effluents from hospitals or fattening farms) could be purposefully treated with adequate techniques to minimize the bacterial loads and thus the proliferation risk of antibiotic resistances. It should be noted that it is presently not possible to describe the actual situation regarding the spread of clinically relevant antibiotic resistances in the environment.

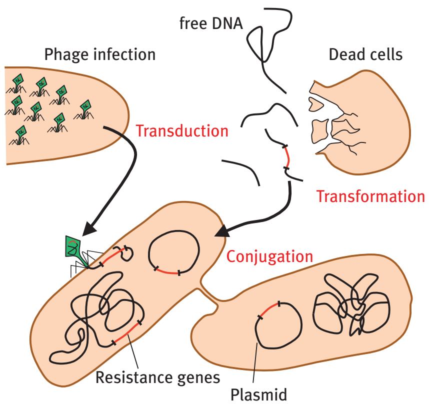

Fig. 3.4: Mechanisms of horizontal gene transfer in the aquatic environment
(© T. Schwartz, Karlsruhe Institute of Technology (KIT))

Some essential parameters for the assessment concepts are: (I) total bacteria count, (II) detection methods (culture-based and/or DNA/RNA-based), (III) frequency of hygienically relevant microorganisms, (IV) frequency of clinically-relevant resistance determinants including mobile genetic elements, (V) detection of multiple resistances, (VI) effect of the treatment technologies (reduction potentials), etc.

Generally, applicable limit values must be defined which – similar to the chemical parameters – will permit to identify a risk potential when exceeded, and result in actions.

3.3 Mobility and persistence

In addition to the toxic assessment of substances also an evaluation regarding their mobility and persistence in the water cycle is needed. Mobile compounds (anions with log D < 2.5 and uncharged compounds with log Kow < 2.5) which are at the same time also persistent (half-life period >100 d), can overcome the barriers in the multi-barrier system (cf. Chapter 5) and thus make their way into the drinking water. Among other substances, gabapentin was detected in the drinking water in the framework of the joint research project **ASKURIS** and valsartan acid in the framework of the joint research project **AGRO**. To better assess the functionality of barriers, the indicator concept was developed for all joint research projects of the funding measure [Jekel et al., 2015].

For a more targeted assessment of mobility and persistence in karstic aquifers, marking tests using typical wastewater-borne micropollutants (acesulfame K, caffeine, ibuprofen, sodium cyclamate, acetaminophen, atenolol, carbamazepine) were for the first time conducted in the framework of the joint research project **AGRO.** Retardation factors and degradation rates in the karstic aquifers were measured to assess the mobility and stability. For none of the substances under analysis a significant retardation could be found. However, it showed that atenolol, caffeine, ibuprofen and acetaminophen are easily degradable in the hydrogeological system of the aquifer. Cyclamate was not degraded during the test period. While the caffeine metabolites under analysis could not be found in the spring water, detection of the atenolol biotransformation product atenolol acid provided evidence of an in-situ biotransformation.

In the framework of the joint research project **RISK-IDENT,** the mobility and persistence of selected substances in laboratory-scale wastewater treatment plants and aquifer columns were examined. Among other substances, the analyses focused on the antihypertensive drug group of sartans. So far, little is known about this substance group although prescription levels have risen sharply in recent years and sartans have at the same time also been prioritized on the grounds of their as yet unknown ecotoxicological effect [Bergmann et al., 2011]. It was striking that the elimination of five structurally related sartans (valsartan, candesartan, eprosartan, irbesartan and olmesartan) in wastewater treatment varied strongly between 8% (olmesartan) and 97% (valsartan) [Bayer et al., 2014]. At ambient pH values, sartans are neither sorptive nor volatile. Since the elimination of sartans therefore occurs mainly by biodegradation, this varying degree of degradation is probably caused by different functional groups within the molecule. It is for example known that the biotransformation of amides is fast [Helbling et al., 2010]. Consistent with the elimination values measured, valsartan and irbesartan, both with an amide function, are degraded faster than candesartan and olmesartan which do not have an amide group. The low sorptive retention and/or the high mobility of sartans is also evidenced by the occurrence of the less easily biodegradable sartans candesartan and olmesartan in the bank filtrate (cf. Chapter 2.1).

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4 Technologies for reducing organic micropollutants and pathogens in aquatic environments

Authors: *Prof. Dr. Martin Jekel, Dr. Laurence Palmowski, Prof. Dr. Johannes Pinnekamp*

Key messages

Key message 1: Multi-barrier systems in drinking water treatment offer a high level of protection from pathogens.

Key message 2: Retrofitting storm water retention basins and wastewater systems represents an essential measure in the catchment area to achieve a sustainable protection of drinking water resources.

Key message 3: Many organic trace substances, (antibiotic resistant) bacteria and eco-toxicological effects can be effectively removed from the wastewater with the available technologies of ozonation and/or adsorption on activated carbon – with additional costs and effects on the environment.

Key message 4: The elimination performance of the individual technologies is dependent on the substances and the ozone and/or activated carbon dosage. However, no single technology is capable of completely removing all contaminants at reasonable effort and cost.

Key message 5: Which technology is best suited for a given site has to be clarified on a case-by-case basis according to the specific conditions of each location. Combinations of different technologies may yield benefits, like for example the elimination of transformation products from ozonation by means of activated carbon adsorption.

Key message 6: Electrochemical oxidation with boron-doped diamond electrodes has established itself as a novel technology for reducing trace substances which cannot be satisfactorily eliminated by means of the standard technologies such as ozonation and activated carbon adsorption.

Key message 7: Most of the pharmaceutical residues, (antibiotic resistant) pathogens and toxic substances can be eliminated from the effluents of healthcare facilities on-site using a variety of technologies.

Key message 8: The processes taking place in a biogas plant significantly reduce the formation of resistant bacteria and resistant genes in wastewaters from intensive livestock farming and lead to a reduction of the risks for humans and animals. Heavy metals (e.g. copper, zinc), by contrast, are not separated during manure fermentation in biogas plants.

4.1 Introduction

With the use of different processes or process combinations it is possible to eliminate micropollutants and pathogens found in raw water and wastewater [DWA, 2015]. In the framework of the RiSKWa joint research projects, a variety of these processes was applied and developed or optimized (cf. Tab. 4.1).

Tab. 4.1: Overview on the technologies for the elimination of micropollutants and pathogens examined in the context of the RiSKWa joint research projects broken down by fields of application.

		ASKURIS	SAUBER+	RISK-IDENT	SchussenAktiv*plus*	Sichere Ruhr	TransRisk	RiskAGuA	PRiMaT
Adsorption	PAC	WW			WW				
	GAC	WW	WW		WW	DW	WW		DW
	Polymer-derived carbon								DW
Oxidation	Ozonation	WW	WW		WW	DW / WW	WW		DW
Radiation and AOP	UV		WW			DW / WW			DW
	UV + H_2O_2		WW						DW
	O_3 + H_2O_2								DW
	H_2O_2								DW
	electro-chem. processes			WW					DW
(Membrane) Filtration	Membrane bioreactor		WW				WW		
	Biofilter	WW					WW		
	Multi-layer filter	WW				DW			
	Slow sand filter	WW			WW	DW			DW
	Pressure-driven membrane processes							AW	DW
	Electrodialysis								DW
Special processes for the treatment of storm water	Constructed wetland				WW	WW			
	Lamella clarifier				WW	WW			
	Performic acid					WW			

Drinking water treatment (DW) | Wastewater treatment (WW) | Treatment of agricultural waste (AW)

The processes of ozonation and activated carbon adsorption are widely used in commercial-scale drinking water treatment and are also increasingly used in advanced wastewater treatment. This reflects in the frequency of the variants examined in the joint research projects. Over and beyond these technologies, some of the projects also examined further processes to assess their adequacy for the elimination of micropollutants and pathogens. The individual processes are introduced in the following before their use in drinking water treatment and wastewater treatment is discussed in a second step.

4.2 Technologies for the elimination of organic micropollutants and pathogens[1]

Adsorption

Activated carbon is used for the elimination of organic micropollutants either in the form of powdered activated carbon which is stirred into the wastewater or in the form of granular activated carbon in fixed bed filters.

Processes based on powdered activated carbon

Powdered activated carbon (PAC) is dosed into the water as a concentrated slurry. In the so-called contact process, PAC is mixed with the water to be treated in a separate, in some cases cascaded, tank (contact tank), and then separated. Separation can be achieved by means of sedimentation with the help of flocculants and flocculation aids. In this case, sedimentation is followed by a downstream filtration step with a sand filter also in order to remove very fine PAC particles. As an alternative to sedimentation other separation processes may be used (fabric filters, membranes, etc.). When used in wastewater treatment, the PAC is added during or after mechanical-biological cleaning. In the latter case, the loaded “excess carbon” can be sent to the aeration tank and removed from the system together with the excess sludge.

For the elimination of a broad range of organic micropollutants in the contact process, PAC doses of 10 to 20 g/m^3, hydraulic retention times in the contact reactor of 30 minutes and PAC retention times in the adsorption stage (consisting of contact tank, sedimentation and sludge recycling to the contact reactor) of 6 to 9 days have proven to be optimal (*inter alia* [Metzger, 2010]).

Processes based on granular activated carbon

Granular activated carbon (GAC) is used as bed material in filters through which the water to be treated is passing in up- or downflow mode (cf. Fig. 4.1). Activated carbon filters can be operated in parallel and in series. The filter can be designed as a closed or open structure whereby closed pressure filters can achieve higher filtration velocities. In wastewater treatment, GAC filtration is arranged downstream of the mechanical-biological cleaning step.

The usual filtration velocities and empty bed contact times range between 5 and 10 m/h and 10 to 30 min, respectively (cf. [Sontheimer et al., 1985; Metcalf and Eddy Inc., 2004; Worch, 2012]).

In the activated carbon bed, a substance-specific concentration and loading profile develops for the specific water composition and selected process parameters. The location of these profiles in the filter

1 Modified excerpt from [Pinnekamp et al., 2015]

changes over time. The substance-specific elimination performance of the activated carbon filter decreases successively as a function of the water volume treated and the amount of adsorbate (organic micropollutants) contained therein. Once the separation performance is no longer sufficient, the GAC has to be replaced. Unlike powdered activated carbon, GAC can be thermally reactivated and then re-used, however with some losses in the range of up to 10%.

Depending on the solids content in the filter influent and biological fouling, activated carbon filters must be periodically backwashed to remove the separated solids. For an undisturbed formation of the concentration profile the backwash frequency must be reduced to a minimum, for example by means of pre-filtration. In addition to the adsorptive effect biodegradation processes also take place in activated carbon filters [Sontheimer et al., 1985].

Oxidation by means of ozone

Ozone is a very strong oxidant and therefore has the power to chemically oxidize the substances contained in the raw water or wastewater. In this context, a distinction is made between the selective, direct reaction and the unspecific, indirect reaction via the formation of hydroxyl radicals. Besides its oxidative effect ozone is also used for disinfection and discoloration of water [von Gunten and von Sonntag, 2012].

Abb. 4.1: Examination of the adsorptive behavior on granular activated carbon within the joint research project SchussenAktiv*plus* (© SchussenAktiv*plus*)

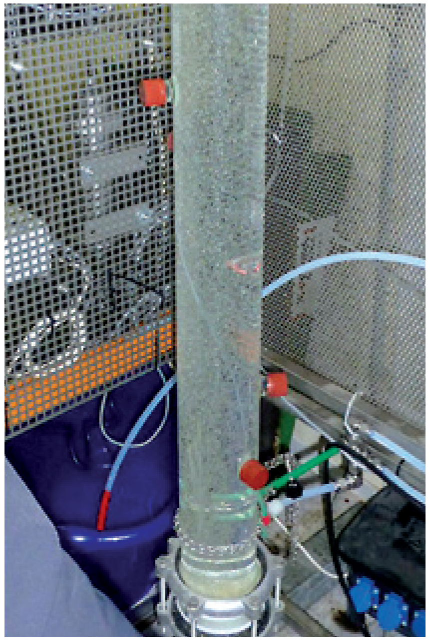

Fig. 4.2: Pilot plant for ozonation within the joint research project SAUBER+ (© ISA, RWTH Aachen)

Ozone is an unstable gas and must therefore be generated on-site from ambient air or stored oxygen. The resulting ozone-containing gas flow is then mixed with the water in a contact reactor (cf. Fig. 4.2). When used in wastewater treatment, an ozonation unit is usually installed downstream of the secondary clarification of a mechanical-biological treatment stage. A sufficient reaction time must be ensured by way of the hydraulic retention time inside the reactor. Given the toxic effect of ozone at high concentrations, adequate safety measures must be taken (e.g. exhaust air treatment to eliminate residual ozone).

The specific ozone dose normally used for eliminating micropollutants is based on an ozone consumption of 0.6-0.8 mg O_3/mg DOC (range from 0.3 to 1.2 mg O_3/mg DOC (cf. [ARGE, 2014])). With this ozone dose, the substances contained in the raw water or wastewater are not fully mineralized but transformed into new substances. The transformation products that form in the ozonation process are usually more easily biodegradable than the original micropollutants. However, the environmental behavior and toxicity of the transformation products have not yet been fully investigated. That is why a biologically active downstream treatment, such as a sand filter, is recommended [Abegglen & Siegrist, 2012].

Radiation and advanced oxidation processes

UV radiation

In drinking water treatment, UV radiation is most frequently used for disinfection and installed downstream of the mechanical, biological and/or chemical process steps. This is also the case in some wastewater treatment plants. If the radiation time and the UV lamps are correctly designed (low pressure lamps with a wave length of 220-280 nm), an effective reduction of bacteria, viruses and parasites is achieved by photolytically destroying the DNA [Metcalf & Eddy Inc., 2004].

With the help of UV radiation, some organic micropollutants (e.g. Diclofenac) are also photolytically degraded. Vacuum UV lamps (wave length <200nm) are used for the non-selective elimination of organic substances in water. In this process, hydroxyl radicals form out of water molecules. These radicals – as already mentioned in the section dealing with the ozone oxidation – exhibit a high oxidation potential and non-selectively oxidize organic micropollutants. However, the energy demand of such UV radiation is very high.

Advanced oxidation processes

Advanced oxidation processes (AOPs) refer to a series of processes for the chemical treatment of mainly organic and, in select cases, also inorganic substances in wastewater treatment or in water treatment by oxidation with hydroxyl radicals. The common trait of all AOPs is the formation of hydroxyl radicals from an oxidizing agent (ozone, hydrogen peroxide, oxygen or water molecules) with an additional energy input (UV radiation or electrolysis) or catalysts (titanium dioxide, polyaniline or iron(II) ions). Once formed, the diffusion-controlled reaction of the hydroxyl radicals with oxidizable substances is normally very fast and unspecific. In this process, organic molecules are fragmented very quickly and may be partially mineralized. This however, requires a very high dosage of oxidants. Many of these AOP variants have so far not made it to the commercial scale, partially because of the relatively high energy demand.

Filtration and membrane filtration

With a filtration or membrane filtration step it is possible to separate particulates and, with certain process variants, also dissolved substances from the aqueous phase.

Sand filters and biofilters

In some wastewater treatment plants a sand filtration step is used for polishing mechanically, biologically and chemically treated wastewater. Where sufficient space is available, mainly for drinking water production, the filtration is not designed as a conventional rapid sand filter with filtration rates of 5-15 m/h, but in the form of a filter with much lower filtration rates in the range of 0.1-0.2 m/h.

In the supernatant water and in the filter body processes are taking place (e.g. solar radiation, UV radiation, biodegradation, adsorption) that eliminate not only the particulate trace substances contained in the wastewater, but also dissolved compounds.

If both oxygen and nutrients are added to the filter in sufficient amounts, a biofilm may form on the filter material. This biofilm can contribute to water purification by means of biological degradation processes. The use of activated carbon as a filter material instead of inert materials (such as silica sand or expanded clay) can improve the elimination of organic substances contained in the water by a combination of adsorption and biodegradation processes.

Membrane filtration

The most frequently used membranes for water treatment are pressure-driven membranes where a pressure differential is created to encourage liquid flow through the membrane (cf. Fig. 4.3). Depending on the size of the retained particles or molecules a distinction is made between microfiltration, ultrafiltration, nanofiltration and reverse osmosis. The pressure required rises as the pore size of the membrane decreases.

Fig. 4.3: Ultrafiltration membranes for the treatment of surface water
(© DECHEMA, Frankfurt am Main)

Given their pore size, microfiltration membranes (pore diameter: 0.1-5 µm) can capture bacteria. Ultrafiltration membranes (0.006-0.2 µm) can additionally remove viruses while organic micropollutants usually pass these membranes due to their small molecule size. Solids accumulating on the membrane reduce the pore size over time so that finer particles can also be separated. Nanofiltration membranes (0.001-0.01 µm) are able to separate nearly all pharmaceuticals. In the case of reverse osmosis, only water, small ions and molecules pass the membrane by solution-diffusion transport mechanism.

In the case of electrodialysis, an electrical field is applied as a driving force for the separation of electrically charged molecules. Its efficiency with regard to charged organic micropollutants is rather low as compared to simple salts. This was demonstrated by the results of the joint research project **PRiMaT**.

Special processes for the treatment of storm water

Storm water treatment mostly consists of separating particulate substances to reduce aquatic pollution. With regard to micropollutants, an improved solids retention during the treatment of combined sewer overflows can enhance the separation of particulate micropollutants. To this effect, lamella clarifiers and constructed wetlands can be used.

Lamella clarifiers

The efficiency of a sedimentation-based separation of solids from combined sewer overflows can be enhanced by reducing the flow rate to values in the range of ≤ 10 m/h. Alternatively, lamella clarifiers can be installed as an addition to existing structures or as a new, stand-alone unit where the effective settling area is increased by means of the lamella. This causes a drop in the flow rate at the lamella to values in the range of 3-5 m/h (corresponding to a tank flow rate of ≤ 30m/h), thus allowing for a good solids separation [Dohmann et al., 2003].

Constructed wetlands

Another option for reducing the solids content is to treat combined sewer overflows in constructed wetlands. In these structures, the combined sewer overflows pass a plant-covered filter which separates and degrades the substances contained in the influent. The effluent of the constructed wetland is then largely solids-free.

By creating a biocenosis in the filter, additional sorption capacities are obtained. This allows for the adsorption of substances such as oxygen-consuming compounds, especially ammonia, and for their biological oxidation during the dry phase until the next rainfall. The concentration of pathogens is reduced to low values [Waldhoff, 2008]. Some micropollutants can be retained and in part biodegraded. Sufficient data are yet not available to assess the processes at work for the respective groups of substances [Tondera et al., 2013].

Performic acid

Performic acid can be used for the disinfection of water and wastewater. The acid oxidative effect destroys the cell walls and the DNA of pathogens. The literature recommends concentrations of 5-6 mg/l and reaction times of 5 to 45 minutes [Gehr et al., 2009; Maya et al., 2012].

4.3 Technologies for the reclamation and treatment of drinking water – micropollutants and pathogens

A safe drinking water supply is based on the choice of high-quality and high-volume water sources. According to the basic principles laid out in the standard DIN 2000 [DIN 2000], groundwater from sufficient depths in well-protected aquifers without anthropogenic pollution is best suited as raw water and usually only requires simple treatment processes (iron and manganese removal, removal of carbon dioxide) without disinfection stage. In regions where these prerequisites cannot be met, frequently additional treatment stages including disinfection are needed.

Hygienically safe drinking water, as based on the WHO Water Safety Plan (and/or the Technical Safety Management (TSM) established by the German Technical and Scientific Association for Gas and Water, DVGW) is ensured by the multi-barrier principle (see also Section 5) involving the elements of protection of the raw water source, a sometimes multi-stage treatment and a qualitatively safe drinking water distribution. The German Drinking Water Ordinance [Trinkwasserverordnung, 2015] in its latest version dated 18 November 2015 specifies the microbiological and chemical parameters for the drinking water quality required at the consumer's faucet. They are complemented by the health-related indicator values (HRIVs) recommended by the German Federal Environmental Agency (Umweltbundesamt) for non-regulated micropollutants that allow for a safe, life-long consumption of the drinking water [Umweltbundesamt, 2015].

Raw water quality impairment of all surface waters, of many groundwaters impacted by surface waters (bank filtrates, artificial recharge) and of groundwaters affected by anthropogenic influences has been a known fact for a long time. In view of the deficits in water pollution control in the years since about 1970 it was already necessary to include additional treatment processes such as ozone and activated carbon to remove micropollutants (such as organic halogen compounds, AOX) that could be detected already at that time. It was possible to manage the hygienic risks with the help of treatment and disinfection technologies. As a consequence, modern drinking water treatment can rely on a long lasting experience and extensive results, specifically for ozone and activated carbon (in particular for fixed bed adsorbers with GAC).

Since the quality of the raw water used usually determines the choice and combination of treatment processes, in the following the main raw water types will be presented as a basis to describe the typical treatment processes with a focus on organic micropollutants and pathogens.

Surface waters

Germany has only a few plants for the direct treatment of river water, e.g. on the Danube or on the river Warnow. The treatment sequence consists of a solids separation step with flocculation and sedimentation followed by a rapid filtration step, an ozonation unit upstream or downstream of the rapid filter, a GAC filtration unit (adsorptive and/or biological as BAC) and a chemical disinfection step using chorine or chlorine dioxide. The elimination of micropollutants is achieved mainly via transformation reactions in the ozonation unit and via adsorption (including biodegradation) in the activated carbon filters. Solids separation processes and disinfection are used for the separation and/or inactivation of the pathogens. This means that, in each case, at least two barriers are created in addition to raw water protection and distribution.

Much more common is the indirect utilization of surface waters via bank filtration (on rivers such as the Rhine, Elbe, Spree and Havel, cf. Fig. 4.4) or artificial groundwater treatment with and without upstream or downstream treatment steps.

One essential step is the well-known and sustainable purification by underground passage with its multiple effects on the substances contained in the water (particles, organic matter, pathogens). However, it was also found that some polar and highly persistent organic micropollutants, like for example the complexing agent EDTA or the pharmaceutical drug primidone, cannot be removed during this filtration step and could therefore even be used as internal tracer substances. Extensive research on underground passage demonstrated an important impact of redox potentials (from aerobic to anoxic to anaerobic) on the degradation performance. The findings show that some substances can only be biotransformed aerobically while others can only be transformed anaerobically. An intentional creation of redox zones is only possible in the case of groundwater recharge, while bank filtration is more frequently aerobic in river waters with a good water quality and almost always anaerobic in bank filtration of lakes. The detailed list of micropollutants that can be degraded in the underground is shown in the guide on micropollutants [Jekel et al., 2013]. The separation of pathogens during

Fig.. 4.4: Bank filtration on the Rhine (© Rheinenergie AG, Cologne) underground passage is normally very good to complete. Here the 50-days rule is often applied which means that a retention time of 50 days in a porous aquifer reliably separates the microorganisms so that a subsequent disinfection is not needed.

Stagnant waters (lakes and reservoirs)

Drinking water reclamation from very well protected lakes and reservoirs mainly relies on a solids separation by means of flocculation and rapid filtration as well as a disinfection step (with UV light or others). Organic micropollutants of anthropogenic origins can be found in catchment areas with pollution from wastewater systems or agriculture or where eutrophication temporarily leads to pollution from algae (odor and taste, algae toxins). In this case the treatment steps ozonation and activated carbon (sometimes added as PAC upstream of rapid filters) are again used, similar to direct river water treatment.

Contaminated groundwater

The large number of contaminated groundwater bodies (contaminated by pesticides and their metabolites, by volatile chlorinated hydrocarbons, by aliphatic and aromatic compounds from mineral oils, abandoned military sites, contaminated soils and soil additives) led to substantial treatment costs and efforts which frequently involve aeration to remove volatile compounds and activated carbon filtration. In the case of severe contamination and of substances that cannot be removed with a technically reasonable effort, the water shall not be used for drinking water as it is no longer possible to assure the water quality.

In conclusion, it can be said that the early integration of advanced drinking water treatment processes (ozone, activated carbon) has significantly contributed to ensuring a safe drinking water quality in Germany. Many experiences from this field can therefore be transferred to ozonation or the use of activated carbon for wastewater treatment, but with significant differences regarding the concentration in organic substances (background level of organic substances in the form of DOC or COD as well as micropollutants).

4.4 Application of emission reduction technologies in wastewater treatment

The input of anthropogenic micropollutants and pathogens into water bodies via the wastewater is widely documented and, in addition to being a hazard for the aquatic habitat, may also affect the quality of the drinking water from bank filtrate, for example.

The reasons for applying a technology or a combination of technologies in wastewater treatment may be:

- Compliance with expected legal requirements
- Precautionary measure to protect drinking water sources
- Reduction of eco-toxicological effects in the water body and/or
- Reduction of hygienic contamination in the water body.

The technologies for the elimination of pathogens, micropollutants and toxic substances in the wastewater examined or applied in the context of the RiSKWa joint research projects can be broken down into three fields of application: advanced wastewater treatment in municipal wastewater plants (the so-called fourth treatment stage) downstream of the final sedimentation (cf. Fig. 4.5), treatment of mixed waters from discharge structures and the separate treatment at point sources (cf. Tab. 4.2). The project results obtained for these fields of application are presented in the following (see also [RiSKWa, 2015]).

Advanced wastewater treatment in municipal wastewater plants

In the joint research project **ASKURIS** it was possible to reduce micropollutant concentrations in the effluent of a municipal wastewater plant by means of both, an ozonation step and the use of activated carbon (PAC and/or GAC). None of the processes showed negative effects of the treatment in terms of genotoxicity. For the ozonation step, a specific ozone dose of 0.7 mg/mg-DOC proved to be sufficient for an advanced removal of many micropollutants detected. The bromate concentration remained below the limit value for drinking water of 10 µg/l. The examination of biological processes introduced downstream of an ozonation step to eliminate transformation products has shown that only in exceptional cases an additional elimination of micropollutants takes place in these downstream biological steps. In the process, the concentration of N-Nitrosodimethylamine (NDMA) could be reduced to values below the limit for drinking water of 10 ng/l. The addition of PAC is also well suited for eliminating various micropollutants, but these are different from those eliminated in the ozonation step. The PAC dosage should be proportional to the DOC whereby PAC/DOC ratios of ca. 1.5 to 2 mg/mg have been found to be adequate.

A diamond electrode was used in the joint research project **RISK-IDENT** to generate highly reactive hydroxyl radicals. The operation showed that this novel, energy-efficient process is easy to handle and that the eco-toxicological effect of the biologically pretreated wastewater can be reduced to values below the detection limit. Further research is still required regarding the minimization of inorganic byproducts that form, like for example chlorate and perchlorate. Potential is found in particular regarding the degradation of micropollutants that cannot be satisfactorily eliminated with usual technologies such as ozonation and activated carbon adsorption. A preliminary estimate of the process costs (plant depreciation, process consumables and energy costs) produced values of 0.08 to 0.2 €/m^3 for the corresponding elimination of micropollutants.

Fig. 4.5: Final sedimentation tank in a conventional waste water treatment plant
(© ISA, RWTH Aachen)

Tab. 4.2: Overview on the examined fields of application in wastewater treatment (including the respective scope of investigation)

Joint research projects	Advanced municipal wastewater treatment	Mixed water treatment in municipal wastewater plant	Separate treatment at point sources
ASKURIS	Elimination of pathogens; Elimination of organic micropollutants; Elimination of toxic, eco-toxic and/or hormonal potentials		
RiskAGuA			Elimination of pathogens; Elimination of organic micropollutants
RISK-IDENT	Elimination of organic micropollutants; Elimination of toxic, eco-toxic and/or hormonal potentials		
SAUBER+			Elimination of pathogens; Elimination of organic micropollutants; Elimination of toxic, eco-toxic and/or hormonal potentials
Sichere Ruhr	Elimination of pathogens	Elimination of pathogens	
SchussenAktiv*plus*	Elimination of pathogens; Elimination of organic micropollutants; Elimination of toxic, eco-toxic and/or hormonal potentials	Elimination of pathogens; Elimination of organic micropollutants; Elimination of toxic, eco-toxic and/or hormonal potentials	
TransRisk	Elimination of pathogens; Elimination of organic micropollutants; Elimination of toxic, eco-toxic and/or hormonal potentials		

Elimination of pathogens — Elimination of organic micropollutants — Elimination of toxic, eco-toxic and/or hormonal potentials

Under the joint research project **Sichere Ruhr,** which focused on reducing microbiological pollution, wastewater plant effluents could be effectively sanitized by means of both UV light and ozonation.

In the framework of the joint research project **SchussenAktiv*plus*** an efficient elimination of micropollutants was observed for all process variants under examination, whereby the performance depended on the respective chemical-physical substance characteristics. The corrosion inhibitor 1H-Benzotriazol, for example, could be eliminated more efficiently with activated carbon than with ozone. For the degradation of carbamazepine, by contrast, ozonation proved to be more effective than activated carbon adsorption. Consequently, a combination of both processes represents the most efficient treatment for the analyzed compounds. The concentration of antibiotic resistant bacteria could be reduced by all processes under analysis, with the most suitable technologies being the combination of ozonation and sand filter as well as ozonation and GAC filtration. For the elimination of hormonal and toxic potentials, also a stand-alone PAC dosage as well as a stand-alone GAC filtration proved to be very effective.

The results of the joint research project **TransRisk** show that transformation products form during the ozonation of biologically treated wastewater. In addition to various micropollutants also two transformation products were found (Tramadol-N-oxide and COFA). The transformation products generated in the ozonation step could not be eliminated in the downstream biofilters. With a downstream activated carbon filter, by contrast, it was possible to separate one of the transformation products identified (Tramadol-N-oxide). Also the micropollutants remaining after the ozonation step could be further eliminated by means of the activated carbon filters. In addition, with the combination of ozonation and activated carbon filtration, it was possible to permanently reduce the (filtered) COD below the limit value of 20 mg/l as per the German Wastewater Levy Act. A return of ozone-treated wastewater to the biological treatment step

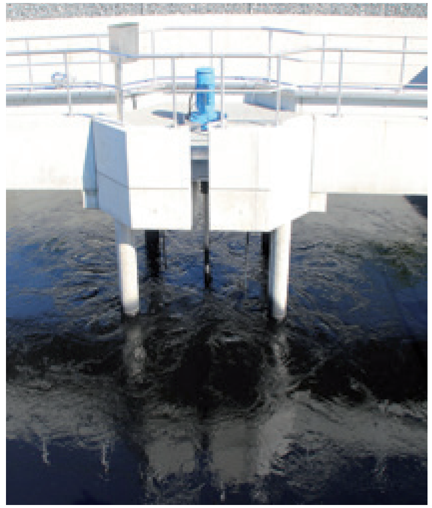

Fig. 4.6: PAC dosing at the Langwiese wastewater treatment plant under the joint research project SchussenAktiv*plus* (© SchussenAktiv*plus*)

did not produce any effect in terms of eliminating micropollutants and the transformation products under analysis. *In-vitro* tests showed a decreasing estrogen-like activity and an increasing anti-estrogen-like activity at higher ozone concentrations. *In-vivo* tests produced no signs of toxicity after the treatment steps. The total bacteria count was reduced by ozonation while the percentage antibiotic resistant bacteria went up.

Mixed water treatment in municipal wastewater plants

In the joint research project **SchussenAktiv*plus*** the retention soil filter, unlike the lamella clarifier, produced good results regarding the separation of micropollutants, bacteria as well as hormone and toxic potentials. The elimination efficiency was comparable to that of a biological treatment step in wastewater treatment plants.

In view of the bacteria and virus input into the water bodies found in the context of the joint research project **Sichere Ruhr** it is advisable to treat the effluents from storm water retention basins to reduce water pollution after rainfall. Depending on the technical options and space available, retention soil filters, lamella clarifies, disinfection with UV light or performic acid may be used.

On-site treatment of wastewater at point sources

The option of separately treating the effluents of healthcare facilities was examined under the joint research project **SAUBER+**. It was possible to demonstrate that pharmaceutical residues, (antibiotic resistant) pathogens and toxic substances contained in the effluents of healthcare facilities can be largely eliminated on-site by means of various technologies. However, no single technology is able to eliminate all contaminants to values below the detection limits at reasonable cost and effort. Furthermore, it showed that an on-site treatment of effluents from healthcare facilities is purposeful only in isolated cases. Healthcare facilities may be significant point sources for individual pharmaceuticals, but generally they are not. For the healthcare facilities examined, no increased input of pharmaceutical residues, toxic substances and antibiotic resistant bacteria or genes as compared to households could be found. Deviations in other healthcare facilities may occur so that case-by-case examinations with targeted analyses are required. To this effect, it is recommended to use the emission check developed in the context of the joint research project **SAUBER+**.

Manure treatment by fermentation in biogas plants was examined in the framework of the joint research project **RiskAGuA.** With this treatment, a reduction of cultivable and known pathogenic bacteria as well as a reduction of resistant genes could be achieved without leading to an accumulation of resistant microorganisms. Treatment in a loop reactor with pressurized membranes resulted in a reduction of the antibiotics concentrations in the fermentation residues and manure while multi-resistant pathogens could be eliminated to some extent.

4.5 Conclusion

The choice of the adequate treatment process for a specific application depends on a number of factors and can be made with the help of assessment criteria that can be weighted with respect to the defined objective for each location. The assessment criteria which are presented in more detail in the guide "Begriffe und Definitionen zu ausgewählten Technologien zur Elimination von Spurenstoffen und Krankheitserregern aus Abwasser" (cf. [Pinnekamp et al., 2015]) (*Terms and definitions for selected technologies to eliminate microorganisms and pathogens in wastewaters*) can be broken down into the following categories:

- Criteria regarding economic efficiency
- Criteria regarding effort/technology/ operations
- Criteria regarding ecology and lifecycle assessment
- Criteria regarding resource and energy consumption
- Criteria regarding operational aspects

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5 Management concepts for dealing with micropollutants and pathogens in the water cycle

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Key messages

Water pollution control

Key message 1: The reduction of pollutant release from agriculture, households and industry, the avoidance of unnecessary use of pharmaceuticals in human and veterinary medicine as well as the development of environmentally safe pharmaceuticals are efficient measures for the protection of water bodies.

Key message 2: Pollution control pays off: German rivers can be suited for temporary use as bathing waters.

Drinking water

Key message 1: The German Drinking Water Ordinance is effectively protecting the population. This is supported by the concept of deriving toxicologically based "health-related indicator values" for today unknown substances in the water cycle that have (so far) not been regulated by a legally binding standard.

Key message 2: The systematic determination, assessment and control of microbiological and chemical hazards at the national and international level follows the WHO Water Safety Plan approach for safe drinking water.

Key message 3: The tried and tested treatment concept of German water utilities applying multiple technical barriers effectively removes pathogens and micropollutants.

Key message 4: The Water Safety Plan approach goes beyond the scope of responsibility of the water utility and covers not only technical, but also organizational measures: consideration of the different barrier effects of karst and porous aquifers, monitoring concepts, protective measures in catchment areas, preventive measures for protection against extreme weather conditions and a responsible operation of domestic installations, for example, are key elements of a proactive risk management as proposed by the multi-barrier concept.

Wastewater

Key message 1: The introduction of an advanced fourth treatment stage in wastewater treatment plants and the upgrading of mixed water treatment improve the ecological water quality and represent effective protective measures for water bodies with a high fraction of wastewater.

Key message 2: Polluted wastewaters from agriculture should be treated whereas, for effluents from healthcare facilities, a separate treatment is only reasonable in exceptional cases.

Key message 3: The extension of selected wastewater treatment plants and targeted measures for mixed water treatment involve a moderate financial burden for the individual citizen.

5.1 Introduction

Micropollutants and pathogens represent a hazard for the water cycle. Risks emanating from them must be controlled adequately. The process applied to ensure an adequate risk control is referred to as risk management. According to DIN EN 15975, a harmonized and systematically process-oriented risk management allows to analyze and compare risks.

In this chapter on "Risk Management" the focus will be on presenting the management concepts used by the joint research projects under the RiSKWa funding measure for the handling of micropollutants and pathogens in the water cycle. The technical processes are described in Chapter 4; the holistic approach of risk management.

Existing risk management concepts originate from various fields of application and differ in terms of their manifestations and legally binding effects. The risk management of the European Bathing Water Directive, for example, involves much more than just two hygienic limit values and covers the complete risk environment of a bathing area.

The multi-barrier concept is another example for a risk management approach that recognizes that an individual barrier may fail in its function to ensure safe drinking water and therefore requires redundant measures. The multi-barrier concept also forms a part of the risk management approach used for the Water Safety Plans of the WHO or serves as a basis for the applicable DVGW (German Technical Association for Gas and Water) regulations for safe drinking water.

The main management approaches for assessing chemical substances and pathogens in the water cycle within the project approaches under the RiSKWa funding measure are presented. These approaches are partly based on each other and therefore not free from methodological overlaps – one example is the multi-barrier concept which is an important element of the Water Safety Plan. To obtain the broadest possible overview on the RiSKWa contributions, methodological uncertainties were in some cases accepted.

Multi-barrier concept

Improving the raw water quality and/or protecting the water quality is achieved by means of a bundle of not only technical, but also organizational and staffing measures in the process chain from the raw water source to the water treatment plant all the way through to the consumer's tap. The multi-barrier concept for ensuring safe drinking water supplies involves the protection of the catchment area as a first barrier, the state-of-the-art sourcing, treatment, storage and transport of the drinking water as a second barrier and the professional domestic water installation as a third barrier. This approach is referred to as "multi-barrier concept". Since many decades it is one of the pillars to provide save drinking water supply in Germany (cf. Fig. 5.1). The concept is based on avoiding the causes for pollution: exclusion or avoidance of quality impairments takes precedence over corrections at a later point that require a lot of effort to be implemented and may in some cases only be of limited effectiveness. It must be noted that each barrier constitutes an important element for the functioning of the overall system – no single barrier must be neglected at the expense of another one. With these steps, the necessary structural quality is ensured.

Fig. 5.1: **Bank filtration on the Rhine (Düsseldorf) – natural barrier for safe drinking water** (© TZW, Karlsruhe)

Water Safety Plan

In the World Health Organisation's guidelines for drinking water quality [WHO, 2005] the application of a systematic and preventive management approach designed specifically for the water supply is recommended - the Water Safety Plan concept (WSP concept). It aims at a customized analysis, assessment and control of risks within a supply system by controlling the processes in the catchment area as well as those used for sourcing, treatment, storage and distribution. The WSP concept has, *inter alia*, been integrated in the DVGW technical rules as Guideline W 1001 [DVGW W 1001].

Health-related Indicator Value (HRIV) concept for the assessment of micropollutants

To assess substances in the drinking water for which an assessable data basis of their toxicological effects on humans is not available or incomplete and whose potential presence in the drinking water is not regulated by a limit value but only by the requirements of Sec. 6(1) of the German Drinking Water Ordinance [TrinkwV 2001], the Drinking Water Commission recommends using a pragmatic, health-related threshold value in the amount of HRIV = 0.1 µg/l as a first assessment basis. Depending on the significance of the toxic end point for human health as well as on the density of the corresponding database it is possible to derive hygienically tolerable lifetime limit values above the HRIV. For substances without effect threshold (genotoxic substances), health-wise acceptable, i.e. risk-based health guidance values also below the HRIV are derived [Umweltbundesamt, 2003].

Quantitative Microbial Risk Assessment (QMRA)

This is a method for determining the risks caused by microbiological hazards due to different exposure routes. Quantitative microbiological risk assessment involves the application of risk assessment principles to estimate the consequences of a potential or actual exposure to different concentrations of microorganisms. The QMRA has four stages: hazard identification, exposure assessment, dose-response assessment and risk characterization.

DALY

DALY is the acronym for disability-adjusted life years or disease-adjusted life years (lost). With this concept, the burden of various diseases for society can be determined. Also the efficiency of prevention and treatment is to become measurable. DALY allows quantifying not only the mortality, but also the impairment of a normal, disease-free life due to an illness, and expressing it as a measured value. In this process, the years of life lost due to premature mortality are combined with the years lost due to disability or disease. The latter is also calculated as the life years lost multiplied by a weight factor that reflects the severity of the disability or disease.

Cost-efficient action programs as per Art. 11 EU-EWFD

The European Water Framework Directive (EWFD) requires the implementation of action programs to achieve the specified quality targets for water bodies by the year 2009 (cf. Fig. 5.2). The selection is to be based on cost-efficiency criteria [EU Water Framework Directive (2000/60/EC)].

EU Bathing Water Directive (2006) and/or NRW Bathing Water Decree (2007)

The Bathing Water Decree of North Rhine-Westphalia (NRW) requires mandatory measurements of indicator bacteria in bathing waters. The limit value for *Escherichia coli* is of 1,800 colony-forming units per 100 milliliters (cfu/100ml). For intestinal enterococci, the limit value is of 700 cfu/100ml. If these values are exceeded during one measurement, a follow-up measurement within four days is necessary. If the results of this follow-up measurement again exceed the limit value, a bathing prohibition will be enacted [EU Bathing Water Directive, 2006] and/or [NRW Bathing Water Decree, 2007].

Abb. 5.2: **Semi-natural water bodies – the mission statement of the European Water Framework Directive** (© H. Feldwisch)

5.2 Development and implementation of management concepts within RiSKWa

The multi-barrier concept is substantiated by the findings from several RiSKWa joint research projects whereby especially the contributions from **AGRO, ASKURIS** and **SchussenAktiv*plus*** should be mentioned. In **AGRO,** the raw water from a karstic spring with a very well characterized catchment area was examined for pathogens and micropollutants using a large variety of methods. The results were correlated to the land use, input and aquifers by means of Microbial Source Tracking and using the micropollutant indicator approach to be able to make a prediction on the effects of management measures. The work performed under **AGRO** focused on the analysis of the catchment area as a basis for measures aimed at reducing and avoiding emissions. With the methods used, the occurrence of micropollutants and pathogens at different climatic conditions (base runoff, extreme groundwater recharge/heavy rainfall, flooding) could be clearly linked to individual events in the catchment area. The technical measures implemented on the storm water retention basin, the limited agricultural use and the changes and adaptation of land uses in the catchment area resulted in clearly reduced concentrations in the base runoff and in the event of strong rainfall. The methods developed can be transferred to other catchment areas and provide a better understanding of the processes as a basis for technical measures and management decisions.

In the joint research project **SchussenAktiv*plus*** the use of activated carbon (PAC, GAC), the combination of GAC and ozonation, the retention soil filter and the lamella clarifier for treating wastewater and mixed water from the storm water retention basin to remove micropollutants, bacteria, substances with toxic and hormone potentials were examined, also with a view to the multi-barrier concept. Various wastewater treatment technologies were evaluated in three wastewater treatment plants regarding their capacity to eliminate micropollutants and microorganisms. The aptitude of granular or powdered activated carbon was examined and granular activated carbon was also tested in combination with an ozonation step. In addition, also the efficiency of a retention soil filter and a lamella clarifier for removing micropollutants and bacteria from mixed water (storm water retention basins) was investigated.

Balances were calculated for the catchment area of the river Schussen and cost-benefit assessments were elaborated. With a view to the cost-efficient action programs required by the EU Water Framework Directive the options for the separation of micropollutants a) by extension of the wastewater treatment plants in the catchment area of the river Schussen and b) by means of retention soil filters as a treatment step downstream of storm water retention basins were evaluated. The resulting additional costs were valued in relation to the elimination potential for the catchment area.

Also in the joint research project **ASKURIS** the barrier "wastewater treatment" was examined with regard to the efficiency of different activated carbon qualities (PAC, GAC) as well as the effect of ozonation in combination with other treatment processes. Results showed that some micropollutants (e.g. sulfamethoxazole, X-ray contrast media) generally show a poor adsorption on activated carbon. In addition to the substance properties also a high sorption competition due to large concentrations of dissolved organic

Tab. 5.1: Contributions to management concepts from the RiSKWa joint research projects

RiSKWa joint research project	Existing management concept	Contributions and results from RiSKWa
AGRO	Multi-barrier concept	Quantification of the influencing factors for the catchment area and development of measures for reduction and avoidance as preventive measures to protect the drinking water catchment area
ASKURIS	Multi-barrier concept	Analysis and assessment of technical measures for raw water treatment as a technical barrier
	Water Safety Plan	Implementation of a Water Safety Plan for a water utility according to WHO and DVGW W 1001
PRiMaT	Water Safety Plan	Database-assisted risk analysis
SchussenAktiv*plus*	Multi-barrier concept	Assessment of new technologies and/or their combination for the treatment of wastewater and mixed water from storm water retention basins to simultaneously remove micropollutants, bacteria as well as toxic and hormone potentials
	Cost-efficient action programs pursuant to Art. 11 EU-EWFD	Cost-benefit concept for the catchment area of the River Schussen
Sichere Ruhr	EU Bathing Water Directive	Risk assessment on pathogens in watercourses (bacteria, viruses, parasites, schistosomes)
	QMRA, DALY concept of the WHO	Risk analysis on the risk of disease, valuation of the health impairment using the DALY concept
TOX-BOX	HRIV concept for the assessment of micropollutants	Guideline for a harmonized testing strategy

carbon was found. In particular, low molecular weight organic substances inhibited sorption on activated carbon as demonstrated by LC-OCD analysis. Low molecular weight organic substances are substances with a molecular mass of up to 800 g/mol. They may involve short-chain aliphates, but also simple aromatic compounds such as benzene. The removal of micropollutants by means of ozone had positive side effects on both, chemical oxygen demand (reduction) and wastewater disinfection. Ozone treatment resulted in the inactivation of bacteria and viruses.

Irrespective of the foregoing the Water Safety Plan as specified by the WHO and DVGW W 1001 was applied to one wastewater treatment plant. In a first step, a risk assessment including probability of occurrence and extent of the damage caused by the respective risk was performed, followed by an evaluation of the findings according to the HRIV concept and an extended monitoring. These measures also included the examination of alternative treatment processes.

Under **PRiMaT,** a database-assisted system for the risk analysis of water catchment areas was created to support this step in the framework of a Water Safety Plan approach. Based on information about land use, this database shows risks that can be related to micropollutants and pathogens. The database currently provides information on the mobility and persistence of 1,100 individual substances for a substance register. This information can be used by the water utility company, for example to derive its monitoring concept for the catchment area. In the framework of RiSKWa, the database-assisted risk analysis was tested in the catchment area of a water works using groundwater and a surface water reservoir.

The European Bathing Water Directive is based on a risk management approach encompassing the catchment area and the surroundings of a bathing area. The resulting risk profile is quite informative for a stagnant water body so that the hygienic protection approach of the Bathing Water Directive specifying concentration limits for the two indicator bacteria *E. coli* and intestinal enterococci is sufficient. The method

Fig. 5.3: Technical barriers in drinking water treatment: pilot rapid filter at the OWA in Berlin-Tegel, joint research project ASKURIS

used in the framework of the joint research project **Sichere Ruhr** was to extend this risk approach also to watercourses that exhibit stronger quality fluctuations. A comprehensive range of pathogens (bacteria, viruses, parasites, bird schistosomes) was examined. Results showed that, in the case of strongly fluctuating concentrations, the indicator bacteria can only map the concentrations of other pathogens to a limited extent. Using the method of Quantitative Microbial Risk Assessment (QMRA), the actual disease risks for swimmers were assessed and related to other life risks by means of the DALY method. In the framework of **Sichere Ruhr,** the comprehensive risk assessment and derivation of DALYs was for the first time also used for assessing bathing waters. This approach can be transferred to other river basins.

Fig. 5.4: Risk management for anthropogenic micropollutants in the water cycle (© DECHEMA)

To support and expand the HRIV approach, the goal of the **TOX-BOX** project was to develop a harmonized testing strategy for an exposure-related and risk-based management of anthropogenic micropollutants. To this effect, generic guidelines in the form of decision trees were defined. Where potential risks and cases requiring regulation are found, this also includes defining possible ways of action. Project activities focused on the following: (I) characterization of the exposure and identification of individual substances relevant for the drinking water; (II) verification of the findings through concentration of water samples; (III) prioritization, development and definition of endpoint-related testing strategies including derivation of assessment criteria; (IV) structuring of the hierarchical testing strategy for the assessment and weighting of toxicity data within the overall process of HRIV derivation. From these results, risk-based and HRIV-based options for action were derived and summarized in a guideline for the risk-based management of anthropogenic micropollutants.

5.3 Development of measures for avoiding/reducing risks

In the majority of the RiSKWa joint research projects, measures for avoiding or reducing risks from pollutants and pathogens in the water cycle were developed. These are listed as an overview in Table 5.2 page 63.

The list is subdivided into "planning/organizational measures" and "technical measures" and indicates the level of realization. In this context, realization can be broken down into the following levels:

- **Conceptualization:** under the joint research project, a risk management approach was conceptualized as a model case for the study focus. This usually involves developing the individual modules and providing an extensive description.
- **Pilot project:** in cooperation with the partners of the joint research project, the risk management approach was tested in a pilot plant and the experiences made were used for further optimization, and documented.

- **Guideline:** the experiences made in the context of the joint research project can be transferred to other users and are made available for further applications in the form of a guideline.

- **Implementation:** in the context of the joint research project the risk management approach has already been implemented in at least one application or specifically scheduled for implementation in the follow-up of the joint research project.

The measures relating to planning/organization shown in Table 5.2 will be briefly presented in the following. For the technical measures, please refer to the detailed description provided in Chapter 4.

Under the **AGRO** joint research project the effects of risk-minimizing measures in the catchment area on the raw water quality at the karst spring could be precisely measured and evaluated using the newly developed indicator approach and microbial source tracking methods. The soil moisture model with a high spatial resolution of groundwater recharge using soil characteristics, together with the groundwater residence time model on groundwater flow, created the basis for predicting the occurrence of pathogens and micropollutants at the spring Gallusquelle. With these findings it was possible to forecast the effects of the planning and organizational measures and of the technical measures.

The example used was the significant reduction of the contamination with pathogens and wastewater-borne micropollutants (caffeine) thanks to a capacity increase and operational changes to the storm water retention basin (cf. Fig. 5.5). The extension of the storm water retention basins by around 10% and the controlled discharge over time led to a 90% reduction in the concentrations.

Another example was the prohibition by the authorities of a planned agricultural use of land for the free-range husbandry of poultry. Information materials and the presentation of the results to the local authorities and the population to initiate a dialog were able to demonstrate a clear spatial and temporal relationship between the use of substances and their appearance in the Gallusquelle. This was in some cases attributable to singular, directly identifiable actions and resulted in mutually agreed prompt actions aimed at avoiding such input (for the significance of risk communication, cf. Chapter 6). Finally, based on the analyses, it was possible to show that single climatic events (heavy rainfall, snow melt) lead to a significantly stronger pollution of the water with pathogens and chemical substances than the extreme flooding of May/June 2013. With these results, it was possible to communicate that there is no reason to fear that flooding causes health risks due to a deteriorated water quality.

To ensure the successful management of recreational bathing on a river bank, the joint research project **Sichere Ruhr** developed a risk management approach for bathing waters that is about to be implemented in the context of the founding of the "Interessengemeinschaft Baden in der Ruhr" (*English: special interest group bathing in the Ruhr)* on 12 June 2015. The sometimes strongly fluctuating water quality, which can time and again lead to bathing prohibitions, requires a continuous management of the bathing areas and often also immediate action. Such action includes a continuous risk communication with the following elements: continuous maintenance of data on the bathing areas, information about the hygienic water

Tab. 5.2: Measures from the RiSKWa joint research projects for avoiding/reducing risks

RiSKWa joint research project	Measures in the context of risk management concepts
	Planning/organizational measures
AGRO	Use of micropollutants as indicators and pathogens (Microbial Source Tracking) to forecast the input under different scenarios (incl. base runoff, heavy rainfall) as a basis for countermeasures (e.g. limitation of land use for agriculture) (K, U)
SAUBER+	Emission check for environmental officers at medical facilities Controlled drug disposal (K, L) Curriculum for an eco-friendly training of medical doctors (K, P)
Sichere Ruhr	Operational management for riverside bathing areas (L, U) Reduction of diffuse pollution from agriculture (K)
	Technical measures (see Chapter 4)
AGRO	Extension of storm water retention basin and modification of the discharge (already implemented, the effects on the raw water were examined to verify the measure) (U)
ASKURIS	Activated carbon adsorption and ozonation as technical measures (P, L)
PRiMaT	Treatment processes (oxidation, electrodialysis, adsorption) for the removal of micropollutants (K, P)
RISK-IDENT	Reduction of micropollutants by means of AOP - Advanced Oxidation Processes – in wastewater treatment (K, P)
SAUBER+	Advanced wastewater treatment (MBR, ozonation, activated carbon filtration, UV and H_2O_2) (K, P)
Sichere Ruhr	Reduction of pathogens in the effluent of wastewater treatment plants and storm water retention basins by ozone, UV light, performic acid (K, P) Early warning system for the identification of microbiological bathing site contaminations (K, U)
SchussenAktiv*plus*	Activated carbon, activated carbon plus ozonation, use of retention soil filters and lamella clarifiers (P) Assessment of the effects[1] of the commercial-scale extension of the Langwiese (Ravensburg) wastewater treatment plant with a PAC stage on the fish and fish nutritional microorganisms in the river Schussen (U)
TransRisk	Advanced wastewater cleaning (MBR, ozonation, biofiltration, activated carbon filtration (K, P)

(Realization stage: K = Conceptualization, P = Pilot, L = Guideline, U = Implementation planned)

1 Strictly speaking, this is not a "technical measure". From the viewpoint of risk management, it represents a final verification of the technical measure.

quality available at all times as well as warning messages about bathing prohibitions and their revocation via different media at short notice. The organization and performance of hygienic monitoring must be arranged in a close cooperation between the responsible health authority and the operators of the bathing area. Other elements of the risk management are the identification and regulation of conflicting uses for water sports, nature conservation and drinking water protection (cf. Fig. 5.6).

To reduce diffuse emissions in surface waters, organizational measures such as the prolonged storage of farm manure and broader riparian strips to reduce the susceptibility to erosion were conceptualized. For their implementation, voluntary agreements with the farmers in the framework of the collaborative work would be promising. One example to reduce the input from bird droppings would be to enact feeding prohibitions. The realization concept developed taking the example of the river Ruhr was drafted as a guideline for other river basins and metropolitan areas.

The strategies and measures for reducing pharmaceuticals emissions from healthcare institutions in the joint research project **SAUBER+** are based on the precautionary principle. To this effect, information about a controlled and water-conserving disposal of pharmaceuticals was compiled in an information flyer to close the information gap for nursing staff, pharmacists and patients. This information flyer is to reach the intended target groups via adequate multipliers. Moreover, a curriculum for an eco-friendly training including certificate was developed for medical doctors which is to generate a higher awareness of medical professionals regarding the environmental impact of medical care (cf. Chapter 6.6).

Fig. 5.5: Overflow of the storm water retention basin (combined sewer system) after heavy rainfall (© C. Stange, TZW: DVGW-Water Technology Center, Karlsruhe)

Within the joint research project **SAUBER+,** an emission check protocol was developed for medical facilities, to offer on a voluntary an opportunity to assess their own situation and, with a view to the precautionary principle, take measures that help reducing emissions into the aquatic environment. As a first step, assessing the relevance of the targeted institution as an "emitter" based on selected criteria is recommended (in particular the interaction of the institution with the related wastewater treatment plant and the local environment). Should the results show that the situation has to be classified as potentially relevant, a more precise assessment of the emission situation should be performed in a second step. After the evaluation of the emission situation it must be verified in a third step whether improvement measures need to be implemented. If this proves to be the case it is recommended to develop and implement an emission management with actions suited for the specific institution.

Fig. 5.6: Comprehensive actions catalog for the risk management of a bathing water (from: Sichere Ruhr [Schoenemann & Jardin, 2015])

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6 Communication and educational measures

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Key messages

Key message 1: For efficacy, it is important to distinguish risk from crisis communication. Risk communication refers to a process of exchanging information among stakeholders about the magnitude, significance, and control of potential damage. In contrast, crisis communication conveys information and (emergency) strategies in the context of acute and unexpected hazards.

Key message 2: Effective risk communication needs to be targeted to the specific audience and objective. Possible objectives are: sharing information, changing risk perceptions and beliefs, or changing behaviors.

Key message 3: Crisis communication requires fast, accurate, consistent, and trustworthy information. This demands systematic preparation and evaluation.

Key message 4: Substantial knowledge gaps exist with regard to drinking water and micropollutants. These gaps should be closed at an early stage through increased educational efforts.

Key message 5: In terms of communication and educational measures it is important to convey that the efforts made to reduce pharmaceutical residues in the environment primarily relate to precautionary measures and not to protection from concrete hazards.

Key message 6: Target group specific communication and educational measures can convey the need to implement adequate measures to professionals, politicians, and the general population.

6.1 Introduction

Risk communication refers to a process of exchanging information among stakeholders about the magnitude, significance, and control of potential damage. In general, risk communication can pursue three different goals (cf. Fig. 6.1):

1. Sharing information (e.g. with decision-makers, to advise politicians or increase the acceptance of a project or decision)
2. Changing beliefs and general risk perception
3. Changing behaviors

Within the first goal of risk communication, the information provided is often general and unspecific. That is, target audience and intended effect are not clearly specified ("just-say-it" method; [Brewer, 2011; Renner & Gamp, 2014a]). However, if the information provided is not selected according to relevance, comprehensibility, and usefulness to the recipients (e.g. consumers), it is unlikely to receive attention sufficient to affect perceptions and behaviors. Risk communication is, therefore, more effective if tailored to the target audience and delivered with a specific focus and objective.

Regarding the second goal, risk communication can convey facts ('information appeals') that enable more accurate risk perception [Renner et al., 2015; Slovic, 2000]).

Since risk communication often provides numerical information about the probability of a hazard occurring, displaying risk information in a transparent form is utterly important to facilitating understanding [Gigerenzer, et al., 2007; Renner & Gamp, 2014b; Renner et al., 2015]. In addition, risk perceptions are based not only on cognitions but also on intuitive, affect-based processes. These feelings of risk are rapid, largely automatic, and emerged in the course of evolution [Loewenstein et al., 2001; Slovic & Peters, 2006]. Thus, the more a hazard is linked to a negative emotion, the more risky it is perceived [Slovic & Peters, 2006]. Providing emotional pictures and narratives may, thus, be more effective for risk communication than simply presenting numerical facts.

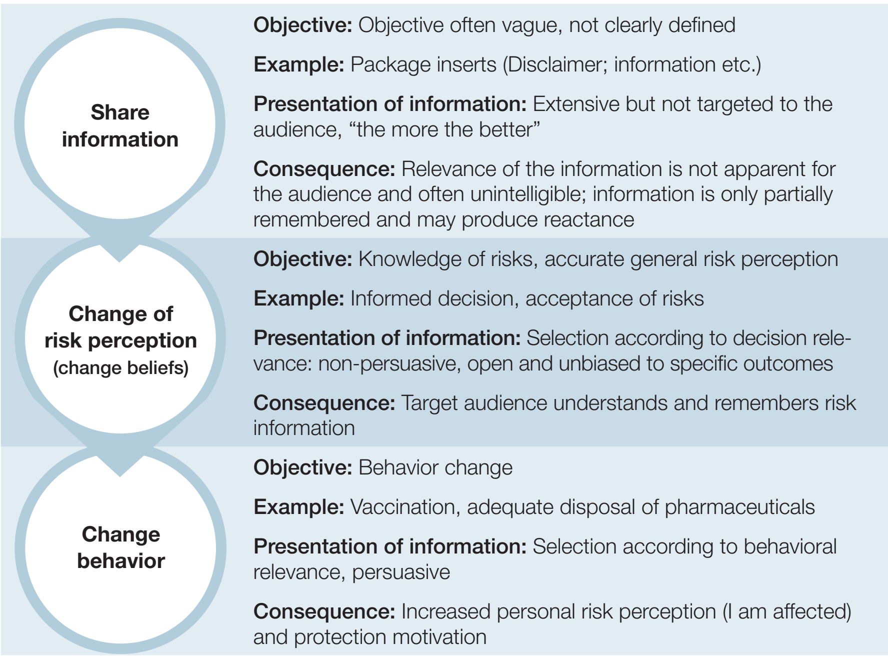

Fig. 6.1: Three potential goals of risk communication (Brewer, 2011; Renner & Gamp, 2014a)

Finally, risk communication may aim to change behaviors. A necessary prerequisite for behavior change is that people feel personally at risk. From a psychological view, it seems inherently plausible that people need to both be aware of an existing health risk ('general risk perception') and feel personally at risk ('personal risk perception') in order to take protective action [Renner et al., 2015; Sheeran, Harris, & Epton, 2013]. However, since people often underestimate personal risk, compared to that of others ('unrealistic optimism or optimistic bias'; see [Renner & Schupp, 2011]), optimistic perceptions about one's own risk might undermine behavior change motivation. Overcoming the optimistic bias is challenging. Risk communication that only provides information and facts about general risk may make people aware of a risk ("Smoking causes coronary heart disease"). However, with this type of message, recipients have to infer the magnitude of their personal risk, leaving considerable leeway for a positive view of one's risk. One possibility to reduce this ambiguity and interpretation leeway about one's personal risk status is to inform people about their health risk through providing personalized risk information (e.g. in the context of a health screening). Various studies show that emotional reactions to such personalized feedback, such as worry, represent an important determinant for behavior change [Brewer, Chapman, Gibbons, Gerrard, McCaul & Weinstein, 2007; Renner & Gamp, 2014b; Renner & Reuter, 2012]).

6.2 Public relations

Public relations have played an important role in all RiSKWa joint research projects as implementing project results depends on successful communication. Accordingly, the local population was informed about the planned measures in order to initiate participation processes, increase acceptance of the planned measures, and inform the professional public about the project contents in a timely manner.

The RiSKWa joint research projects used different forms of public relations. Each research project has its own website; media cooperation, and print information (e.g., flyers) round off the picture (cf. Fig. 6.2).

Special issue "Antibiotics and antibiotic resistances in urban wastewater"

The special issue "Antibiotika und Antibiotikaresistenzen im urbanen Abwasser" (*Antibiotics and antibiotic resistances in urban wastewater*) was published in the Springer magazine "Prävention & Gesundheits-

Fig. 6.2: Public relations in the framework of SchussenAktiv*plus*: open day at the Ravensburg wastewater treatment plant

förderung" (*Prevention & Health Promotion*) (9/2014) (cf. Fig. 6.3). This magazine views itself as a scientific forum in the fields of prevention, individual responsibility and innovative health management. As an educational forum, the target group includes medical professionals, professionals from social sciences, economics and natural sciences, students, stakeholders from politics, health insurance companies, healthcare associations and care providing institutions.

The special issue focuses on results of the joint research projects **ANTI-Resist** as well as on expert contributions from other RiSKWa joint research projects and external research groups. The medical and pharmacological perspectives are combined with analyses from urban water management and microbiology with a focus on the interaction between wastewater treatment plant practice, urban water management and a medically responsible use of antibiotics.

The special issue is aimed at conveying knowledge and sensitizing readers for the relationship between prescribing antibiotics, antibiotic resistance issues and environmental risks. It describes the current state of scientific knowledge regarding the development of a risk management system for preventive health and environmental protection.

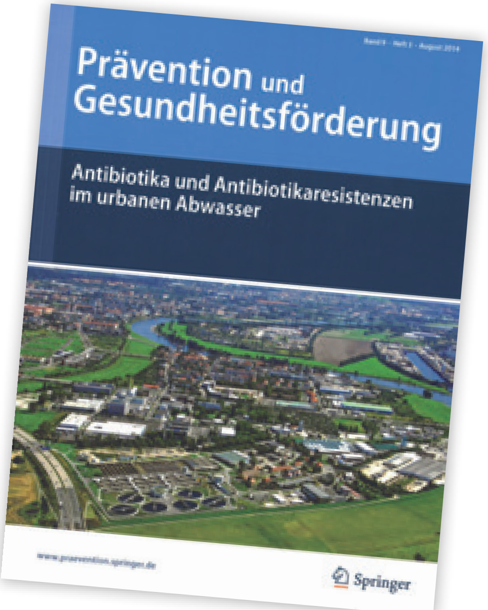

Fig. 6.3: Special publication on the RiSKWa results[1]

Brochure "Im Klartext – Schadstoffspuren im Wasserkreislauf" [2]
(In plain language – Micropollutants in the water cycle)

In the context of the joint research project **TransRisk,** the Institut für Sozial-Ökologische Forschung GMBH, ISOE (*Institute for Social-Ecological Research*) conducted a media content analysis. The conclusion of this analysis was that a future communication strategy on anthropogenic micropollutants in the water cycle should aim at conveying sound procedural knowledge. Based on these results, the German Association for Water, Wastewater and Waste (DWA) published a new "Im Klartext" (*In plain language*) brochure informing interested citizens about micropollutants in the water cycle. Using plain language, the brochure explains how pharmaceuticals and chemicals of daily use enter the aquifer via the wastewater and which damage they can cause. In addition to technical measures the brochure also shows what individuals can do to avoid the release of pollutants into the environment.

1 The special publication is available at: http://link.springer.com/journal/11553/9/3/page/1

2 The information brochure can be obtained from the following source: email: info@dwa.de, Internet: www.dwa.de.

Info campaign "What to do with waste pharmaceuticals?" and info leaflet "Micropollutants"

Under the joint research project **RISK-IDENT,** the Bavarian Environment Agency prepared an information package about the eco-friendly disposal of waste pharmaceuticals that is mainly intended for display in pharmacies. In addition, an information leaflet was developed to sensitize multipliers in environmental consultancy for the topic of micropollutants in water bodies. This publication is also available to the public via the internet.

The information package "Wohin mit alten Medikamenten?" (*What to do with waste pharmaceuticals?*) consists of a flyer, a pocket-size info folding card and a poster. In a Q&A format, these three elements provide information at different levels of detail about the most frequently asked questions regarding the disposal of waste pharmaceuticals. The information package was presented by the two Bavarian State Ministers Ulrike Scharf (Environment and Consumer Protection), Melanie Huml (Heath) and by the Vice Chairman of the Bavarian Pharmacists' Association (BAV) Josef Kammermeier, and promoted in the media of the BAV association (www.lfu.bayern.de/altmedikamente) addressing pharmacies.

The publication "Spurenstoffe im Wasser" (*Micropollutants in the water*) [Bayerisches Landesamt für Umwelt – Bavarian Environment Agency 2016] provides an easily understandable overview on organic micropollutants in aquifers and illustrates the complex risk assessment methods. Practical advice encourages users to reduce the discharge of micropollutants into the water bodies also in their own daily lives. This publication forms part of the series UmweltWissen (*Environmental Knowledge*) which deals with environmental protection in everyday life[3].

Information flyer on the correct disposal of pharmaceuticals[4]

Under the joint research project **SchussenAktiv*plus*,** besides germs and other micropollutants also pharmaceuticals were examined. That is why the "correct disposal of pharmaceuticals" was chosen as the leading subject for public relations. By correctly disposing their pharmaceuticals, individuals can easily make an important contribution to ensuring that less pharmaceutical ingredients are discharged into our water bodies. That is why the clear message "Waste

Fig. 6.4: Information flyer of the joint research project SchussenAktiv*plus* about the correct disposal of pharmaceuticals

3 The publication is available at: www.lfu.bayern.de/umweltwissen

4 This information flyer can be ordered from the following source: email: schneider-rapp@oekonsult-stuttgart.de, Internet: http://schussenaktivplus.de/sites/default/files/Arzneimittel Wasserschutz 8 S. web2.pdf

pharmaceuticals do not belong into the sink or toilet" was at the heart of the campaign. In cooperation with the Ministry of the Environment of Baden-Wurttemberg, a new flyer in German language was developed. This flyer is available in a six-page basic variant for the whole of Baden-Wurttemberg and in an eight-page variant (plus 2 pages on **Schussen-Aktiv*plus*,** cf. Fig. 6.4) in the area examined in the context of the project. The flyer was presented to the public by Minister of the Environment Franz Untersteller and promoted via the Association of Towns and Municipalities. Moreover, the project partners mailed around 20,000 copies of the project-related flyer together with the notification of wastewater fees to users in Ravensburg and four other municipalities in the area. Another 2,000 copies were distributed by other project partners. It would have been desirable if more pharmacies had agreed to display the flyer. In conclusion, it is essential for successful public relations to clarify in advance which routes are to be taken to address the target groups.

The flyer "Arzneimittel verantwortungsvoll entsorgen" (*Responsible disposal of pharmaceuticals*) of the joint research project **SAUBER+**[5] was designed in a similar way.

Map of Germany ('Deutschlandkarte') for pharmaceutical disposal

An Internet-based, interactive map of Germany was developed to easily and comprehensibly display how to dispose of pharmaceuticals across Germany (conceptualization University of Konstanz): www.arzneimittelentsorgung.de. Specifically, the map presents current recommendations on how to dispose of pharmaceuticals at the level of districts and municipalities. Possible methods of disposal in Germany are, for example, domestic waste, hazardous waste

Fig. 6.5: Online map of Germany informing on how to dispose of pharmaceuticals: www.arzneimittelentsorgung.de

5 The information flyer is available at: http://sauberplus.de/index.php/downloads

trucks, recycling yards, or pharmacies (systematic assessment by Ökonsult, Stuttgart). Providing a map illustrating the current methods of disposal enables a risk communication that not only tells people not to discharge pharmaceuticals into the toilet or sink but also provides specific instructions on how to appropriately dispose of pharmaceuticals where they reside. Effectively, this map concentrates multiple existing recommendations for the disposal of pharmaceuticals in Germany (by citizens, healthcare entities, public authorities, the industry, and academia) on one website (cf. Fig. 6.5).

6.3 Risk communication/ risk perception

Risk experts across various disciplines and domains (e.g., health, finance, engineering) commonly define risk as a combination of the likelihood of an occurrence of a hazardous event or exposure and the severity of injury or disease (e.g., lung cancer) caused by it. Accordingly, 'risk' encompasses two core elements: (a) the chance or probability of adverse health outcomes and (b) the severity of the expected adverse outcomes. Risk is thus described as being proportional

Acute hazards		Potential hazards
• Unexpected event • Requires immediate reactions • High stress level	**Characteristics**	• Event has not yet occurred • Requires long term reactions • Low stress level
• Reactive • High stress level • Acute hazard: distinct intense emotions (fear) • High public interest • High relevance for oneself/ one's family • Increased and focused attention • High motivation • Intuitive response and heuristic information processing • Routines, habitual behavior	**Reactions**	• Preventive (prospective) • Low stress level • No acute hazard: little emotion • No/little public interest • No direct relevance for oneself/ one's family • Low attention level • Low motivation level • Rational response and systematic information processing • New behavior/discontinued behaviors
• Crisis communication as part of crisis management that conveys information about acute hazards and measures for damage containment • Clear communication objective	**Communication**	• Risk communication as part of risk management and control that contains information about probability of occurrence and extent and significance of potential damage • Communication objectives are commonly diffuse (knowledge, change of perceptions and attitudes, change in behavior)

Fig. 6.6: Acute crises versus potential risks (Renner & Gamp, 2014a)

to both the probability and severity of the event (risk = probability x severity of the event occurring), implying that greater event likelihood and loss result in a greater overall risk [Renner & Schupp, 2011; Slovic, 2000]. How we respond to risks largely depends on the present hazard and our risk perceptions, i.e. how we think and feel about the risks we face. Different hazards differ across a wide range of characteristics [Centers of Disease Control and Prevention, 2012; Fischhoff, Brewer & Downs, 2011]. Of particular importance regarding the perception and communication of hazardous events is their time of onset. According to the point in time when the damage occurs, hazardous events can be divided into risks and crises. This distinction is relevant for the hazard's characteristics as well as the responses to and communication of the hazard (cf. Fig. 6.6)

Most often, the hazard represents a potential risk which needs to be avoided. Accordingly, risk communication serves as an element of risk management and risk control. It provides information about the probability of the damage occurring in the future as well as the scope and significance of the damage. Since risk communication refers to a potential damage that might occur in the future, i.e. a prospective event, one important challenge is to raise adequate public knowledge and interest. In addition, risk communication may aim to motivate preventive actions and behaviors by revealing positive and negative consequences of favorable and unfavorable behaviors. Thus, as risk communication aims at conveying information and knowledge about a negative event which might occur in the future, it often receives only low or moderate emotional response.

Guideline on strategic risk communication

In the framework of the joint research project **ASKURIS** a so-called institutional field was recast. Recasting was based on the questions of whether and how the Berlin drinking water could be contaminated by anthropogenic micropollutants and multi-resistant germs and how this could be avoided. The recast institutional field included stakeholders involved in water supply and wastewater production (consumers, industrial production, healthcare sector, agriculture as well as water supply and disposal entities) as well as stakeholders who are materially involved in the social construction of risk (media, science, politics and civil society stakeholders). On the basis of this analysis, the following statements for risk communication were derived:

1. *Consumer knowledge and media knowledge.* Overall, media reports about the situation are rather unspecific and abstract. Different media address different target groups. Overall, consumers know very little about water.

2. *Consumers have great confidence in the institutions (politics and water utilities).* Consumers act on the assumption that recommendations are well-founded and expect the institutions to solve water-related problems and provide suggestions and recommendations.

3. *Proposals fit for everyday use.* Water is considered to be very safe. Risk communication aimed at changing behaviors is successful especially in those cases where concrete proposals are given that can be easily integrated into everyday life.

4. *Not all consumers are the same.* Depending on the target group, different communication routes and arguments must be offered.

5. *The consumer is not always the right target group for risk communication.* In expert discussions, risk communication is frequently associated with consumer communication. However, consumers often have no influence on the change in water quality.

6. *Overcoming communication barriers in expert discussions.* Changes in the institutional field frequently fail because the expert discourse is often fragmented into numerous sub-discourses. Preferably, problems are dealt with that relate to a specific phase in the production process. Challenges that cover the entire production chain tend to remain unaddressed.

Risk communication and action guideline for safe bathing

In the context of the joint research project **Sichere Ruhr,** a risk communication concept for bathing in natural water bodies was developed. On a detailed website (www.sichere-ruhr.de), information about the topics Ruhr and water protection was made accessible to a broad public to create an understanding for the risks and challenges of bathing in the river Ruhr. In addition, three workshops were organized to share knowledge and develop an implementation concept for bathing in the river Ruhr. In an analysis of the media discourse, nine success factors for risk communication about "bathing in natural water bodies" were identified:

1. Holistic risk communication
2. Central organization of communication
3. Appeal to common sense and responsibility of the individual
4. Conveying sound practical knowledge and concrete behavioral instructions
5. Fact-based and neutral communication
6. Communication of the nature-oriented aspects of river bathing
7. Trustworthiness of the sender
8. Sensitizing the audience for water as an asset worth protecting
9. Realistic communication of target achievement.

Another analysis of the media discourse showed that, although bathing in rivers and the risks involved are very present in the media, the risks are not communicated with a sufficient level of detail.

The results of the analyses were processed to a concept entitled "Risikokommunikation zum Baden in natürlichen Gewässern" (*Risk communication on bathing in natural waters*) and an action guideline "Umsetzungsszenario zum Baden in der Ruhr" (*Implementation scenario for bathing in the Ruhr*) [Schoenemann & Jardin, 2015] (cf. Chapter 5.2). The participation process was taken up by the Interessengemeinschaft Baden in der Ruhr (or IG Baden in der Ruhr, for short) as a civil society initiative founded on 12 June 2015 with participation of the City of Essen. IG Baden in der Ruhr plans to create several bathing areas on banks of the Ruhr and use the action guideline, the communication concept and the website to this effect.

For an overview on hygienic, engineering and organizational issues involved with regular bathing operations in rivers, please refer to the special issue "Safe Ruhr" of the International Journal of Hygiene and Environmental Health [Kistemann & Flemming, 2016].

Representative survey on the disposal of waste pharmaceuticals

One aspect of the joint research project **TransRisk** involves the adequate communication routes to communicate the problem of micropollutants already to the source of pollution, i.e. to the users of pharmaceuticals, and to address them in a target-group specific way. To this effect, it is necessary to know

- what level of knowledge exists among the population
- which behaviors exist with regard to the disposal of pharmaceuticals
- who is considered to be mainly responsible for solving the problem
- whether a willingness exists to address the issue from a practical perspective
- which target groups can be addressed.

A representative survey for Germany conducted by the ISOE showed that nearly half of the interviewees had never heard about the problem of pharmaceutical residues in the water cycle. In addition, this representative survey of 2,000 interviewees also found that little is known about the causes for the release of the active substances into the water bodies. The survey further showed that incorrect disposal of pharmaceuticals contributes to the problem of pharmaceutical micropollutants in the water cycle. The interviewees were asked whether they would be willing to forego taking pain killers when in pain and use alternative offers instead to help curb the release of pain killers into the water cycle. Their willingness to use alternative medication depends, among other factors, on whether this relates to strong pain (little willingness) or weak pain (higher willingness). A detailed report about the survey results is shown in the magazine "KA Korrespondenz Abwasser" [Götz et al., 2014].

6.4 Crisis communication

While risk communication conveys information about *potential* damages that might occur in the future, crisis communication relates to hazards where an acute damage or 'crisis' has already occurred (see e.g. [Centers of Disease Control and Prevention, 2012; Hyer & Covello, 2005]). Unlike a potential hazard (risk), an acute hazard (crisis) represents an unexpected threat that requires an immediate response that goes beyond, or varies from, the standard routines of the actors. Thus, acute hazards represent a stressor for all stakeholders that evokes significant negative emotions [Glik, 2007]. Because acute hazards are accompanied by an increased level of attention and a high demand for information, fast, accurate, and trustworthy crisis communication is of the highest importance [Centers for Disease Control and Prevention, 2012; Hyer & Covello, 2005]. During a crisis, information is mostly processed "intuitively" and heuristically. Unlike systematic information processing, which involves carefully considering and weighing the consequences of an action, heuristic processing is automatic and fast: People evaluate the overall significance and quality of information based on simple decision-making rules and peripheral environmental cues. Moreover, the motivation to take action is high in crisis situations, and people perform readily available, habitual behaviors as a form of protection.

How can crisis communication succeed? Vincent Covello described a "message mapping" method to prepare effective crisis communication in seven steps. The EPA applied this method taking the example of a hypothetical crisis scenario involving drinking water pollution by pesticides [U.S. EPA, 2007b, 2012; Wood et al., 2012]:

1. Identify stakeholders (e.g., medical staff, drinking water suppliers, public health department, (affected) public)
2. Identify anticipated stakeholder questions and concerns (e.g., "What can you tell us about the water contamination?", "How many people may have been affected?" "How are you going to clean the system?")
3. Identify frequent concerns (e.g., basis information (who, what, where, when, why, how?), health concerns, safety, liability (who is accountable?), duration, decontamination)
4. Develop key messages (e.g., "We are testing water quality throughout the system.")
5. Develop supporting information (e.g., "We are taking samples at various locations.", "[Insert laboratory name] is testing those samples.", "The results of these tests will determine our next steps.")
6. Testing and training (using standardized protocols and information validation by uninvolved experts and practicing communication methods)
7. Delivery (by trained spokespersons, trustworthy people, and institutions)

An important step in the message mapping process is to identify and classify common, and often complex, anticipated concerns into categories (e.g., health trust, safety). In addition, it is important to prepare the relevant "key messages" that, in case of crisis, will be communicated to the public. Extensive guidelines describe the practical implementation of the "message mapping", including example case studies.

In order to communicate rapidly, accurately, and consistently during a crisis, the method is as important as the content [Lofstedt, 2003; Renn, 2008; U.S. EPA, 2007a]. Therefore, it is imperative to systematically implement, practice and apply Standard Operation Procedures (SOPs) and a clear communication process. In crisis situations, the public's trust in the involved and communicating institutions is crucial for crisis management. This trust, in turn, is not only closely related to the perceived competence of the communicator but also the perceived efficiency and fairness of the measures [Lofstedt, 2003; Renn, 2008]. Importantly, the perceived trustworthiness and competence of the communicator is not only inferred from the "facts" communicated. Fast and intuitive judgments based on behavioral (e.g. listening, empathy) and non-verbal, peripheral cues (e.g. eye contact, facial expressions, gestures) are similarly important. Accordingly, practicing communication scenarios is key to an effective preparation of crisis communication (see also [Hyer & Covello, 2005]). The preparation and training of crisis communication is even more valuable if it considers the different phases of a crisis

Pre-Crisis	Initial	Maintenance	Resolution	Evaluation
• Be prepared. • Foster alliances. • Develop consensus recommendations. • Test messages.	• Acknowledge the event with empathy. • Explain and inform the public, in simplest forms, about the risk. • Establish agency and spokesperson credibility. • Provide emergency courses of action, including how and where to get more information. • Commit to stakeholders and the public to continue communication.	• Help the public more accurately understand its own risks. • Provide background and encompassing information to those who need it. • Gain understanding and support for response and recovery plans. • Listen to stakeholder and audience feedback, and correct misinformation. • Explain emergency recommendations. • Empower risk/benefit decision-making.	• Improve appropriate public response in future similar emergencies through education. • Honestly examine problems and mishaps, and then reinforce what worked in the recovery and response efforts. • Persuade the public to support public policy and resource allocation to the problem. • Promote the activities and capabilities of the agency, including reinforcing its corporate identity, both internally and externally.	• Evaluate communication plan performance. • Document lessons learned. • Determine specific actions to improve crisis systems or the crisis plan.

Fig. 6.7: Crisis communication cycle (according to: Crisis and Emergency Risk Communication (CERC) Lifecycle, Centers for Disease Control and Prevention, 2012, p. 9)

as well as the corresponding requirements for communication and actions (cf. Fig. 6.7).

Guideline for risk and crisis communication[6]

Also in the field of drinking water supply we see an increasingly discriminating customer attitude, especially when it comes to microbial and chemical contaminations of the drinking water. In such events, they expect a professional crisis management. This includes a communication that responds to the customers' fears and concerns and provides comprehensible explanations of the causes and the remedial action taken to address contamination. To ensure effective crisis communication in an 'emergency', water utilities are well advised to build up a good reputation through good public relations already during "normal times". The more trust a utility company gains also among critical citizens, local media and politicians, the smaller the risks of "going down" in the event of a real or perceived contamination. It shows that, with regard to microbial contaminations, also the communication crises between water utilities and health authorities are increasingly escalating. In the framework of the joint research projects **PRiMaT,** a practice-oriented guideline for risk and crisis communication in drinking water supply was developed on the basis of, *inter alia*, three workshops with representatives from water utilities and health authorities.

6 This guideline can be downloaded from: www.primat.tv/download/PRiMaT Leitfaden_zur_Risiko_und_Krisencommunication.pdf

6.5 Consultations

To successfully implement the measures derived from the RiSKWa projects it is necessary that they address the needs of the recipients and that users and decision-makers accept them. Early interactions with citizens and stakeholders help identify these needs and facilitate the measures' acceptance. In consultations, the public may either be informed about the objectives and benefits of a planned measure. In addition, the public may be involved even earlier in order to integrate their ideas and collaboratively develop solutions.

Public survey

A representative public survey conducted under the joint research project **Sichere Ruhr** about bathing in the river Ruhr among more than 1,000 households in Essen and neighboring cities showed that designated bathing areas with basic infrastructure (42%) are preferred over dedicated swimming baths in rivers with lifeguards and other infrastructures (31%) and free bathing at river banks (22%). Around 55% of the interviewees would be willing to participate in financing measures aimed at improving the water quality of the river Ruhr. In this context, the direct use of the Ruhr and its lakes as bathing waters is the most frequently mentioned reason for their willingness to pay. Furthermore, the legacy for future generations and the option value, i.e. the possibility to also use the Ruhr as a bathing water were mentioned.

Stakeholder workshops

The joint research project **SAUBER+** under the lead of RWTH Aachen university's Institute of Environmental Engineering examined the release of pharmaceuticals and pathogens from nursing homes, retirement homes, medical centers and hospitals into the water cycle. Representatives from organizations and institutions form industry, academia, society and the health care sector were involved given the fact that, in a transdisciplinary dialog, not only the demands but also the practical knowledge of relevant stakeholders contribute to the success of the joint research project. Together, they developed results and actions. In some cases, the stakeholders can directly contribute to their implementation. First and foremost, the integration of different stakeholders at such an early stage was aimed at driving the development of practice-oriented, viable strategies. At the same time, the stakeholders acted as multipliers in their respective organizations.

During the three-year term of the project stakeholder workshops (6) were held at regular intervals. The workshops involved moderated discussions where the knowledge and interests of the participants were assessed by methods such as the value tree analysis, group Delphi, participatory scenario development, and impact assessment. The information and opinions forwarded by the stakeholders contributed to the development of new action concepts.

Through this active participation, new knowledge was generated on both sides, i.e. researchers and stakeholders from the field, which proved to be essential for the further development of solutions proposals in their research subject.

6.6 Education

Education can also be used as an effective, innovative communication measure. Innovation stems from the fact that educational measures may be developed and implemented as projects evolve rather than simply being applied after the introduction of a new scientific and/or technical development. In RiSKWa, scientists from different fields, such as education and psychology, cooperated with experts working in the field in order to conceptualize and implement various measures. These measures cover a broad spectrum, including conceptual suggestions for the adjustment of curricula, learning materials and platforms, and courses and trainings to the relevant professional groups. Additionally, both teachers and learners act as multipliers of the new projects and measures.

E-learning modules

The joint research project **PRiMaT** developed a portal for teachers/learners (http://www.bayceer.uni-bayreuth.de/primat/). In a modern way, this webpage (designed by the University of Bayreuth) provides qualified information for the general public complemented by different functionalities: an upload/download function, for example, offers the possibility to upload teaching suggestions/materials into the portal also for external users. This function is only available upon registration on the website to monitor which content is loaded onto the portal. A comment function makes it possible to ask questions or to evaluate and discuss teaching suggestions. The teaching suggestions from the University of Bayreuth were uploaded onto the portal and are freely available for registered users. An analysis of the portal user data attests to the willingness and interest in using the portal. Overall, the "traffic" on the website suggests that third parties became users of the portal. Summarizing, it can be said that the portal is already showing first successes after its completion and given its short history, and represents a modern and purposeful information tool.

In addition, an e-learning tool for students was developed in the context of the joint research project **TransRisk** (http://de.dwa.de/forschung-und-innovation.html). In at total of 100 PowerPoint slides, the students were familiarized with the following topics:

- Anthropogenic micropollutants
- Transformation products and their formation (biotransformation, abiotic formation of transformation products)
- Chemical analyses (target/non-target analyses)
- Biological testing processes
- Eco-toxicological evaluation of micropollutants and transformation products
- Toxicological relevance of transformation products and In silico-toxicology (computer-aided processes to assess the toxicity of micropollutants)
- Elimination of micropollutants and transformation products in wastewater treatment
- Indicator substances for the evaluation of technical measures
- Assessment of wastewater treatment technologies with regard to microbiological pollution
- Statutory regulations

School project

Countless situations in daily life and on the job require decisions that need to be based on a differentiated consideration of different positions and solution approaches. Learners should be able to handle this multidimensionality to fully participate in the social discourse. Taking the example of micropollutants and pathogens in the water cycle, a school project for the lower and upper classes of secondary education was conceptualized and tested by the Technical University Dresden in the framework of the joint research project **TransRisk.** The aim of this project is to promote the students' competence to assess scientific problems of daily life.

In role plays, the students participating in the school project develop an expert opinion on anthropogenic micropollutants in the water cycle and offer a recommendation for action regarding the introduction of a fourth treatment stage in the municipal wastewater treatment plant. While familiarizing themselves with the subject, the learners discuss intensively about the different discharge paths of the micropollutants into the water cycle and about possibilities to minimize these emissions. With the help of experiments that recreate models of the proposed advanced wastewater cleaning processes, the learners can understand the modes of action of these new technologies and evaluate their benefits. The learners assess all findings taking into account ecological, economic and social aspects, and summarize them in an expert opinion.

Suggestions for the curricula wastewater technician, wastewater manager

The introduction of new technical processes in wastewater treatment also results in new demands being placed on the experts working in environmental engineering. The results of the joint research projects **TransRisk** were analyzed from a didactic perspective to integrate the research findings into the vocational training and professional qualification curricula as quickly as possible. In particular, the new findings on the characterization of micropollutants, their pathways into the water cycle and the technologies available to minimize their concentrations in the wastewater treatment plant are relevant topics for the professional education.

In the field of vocational training, the "Verordnung über die Berufsausbildung in umwelttechnischen Berufen" (*Regulation on vocational training in environmental professions*) and the "Rahmenlehrplan für den Ausbildungsberuf Fachkraft für Abwassertechnik" (*Framework curriculum for the profession of wastewater technician*) are sufficiently adaptable to also integrate new content into the existing learning fields. When looking at the ecological material cycles and at hygienic aspects in the field of wastewater technology, for example, it is possible to also focus on new findings about micropollutants and pathogens. New technologies in wastewater treatment can in addition also be presented directly after the conventional treatment processes. The number of hours of the individual learning fields has to be adjusted accordingly.

In the context of their professional training to become a wastewater manager, the participants will look extensively into wastewater and environmental engineering processes. Here, too, it would be possible to integrate research findings about extended wastewater treatment processes.

Training for healthcare professionals

Following a survey among medical doctors and nursing care professionals regarding their knowledge about pharmaceutical residues in the water cycle and how they handle them, tailor-made training courses for these two groups of professionals were developed and tested under the joint research project **SAUBER+.**

For medical doctors, the (timely and situationally) adaptable training concept "Antibiotikaresistenzen und pharmazeutische Wirkstoffe im Wasserkreislauf. Risikocharakterisierung und ärztliche Handlungsoptionen" (*Antibiotic resistances and active pharmaceutical ingredients in the water cycle. Risk characterization and options for action for physicians*) was developed. The aim is to create greater risk awareness among physicians and show how this important target group can contribute to reducing aquifer pollution with active pharmaceutical ingredients and pathogens through their (changed) work and behavioral routines.

For nursing care professionals and with a view to their target-group specific requirements (participation in Certified Nursing Education (CNE) in voluntary), attempts were made to make the subject accessible for as many potential addressees as possible. To this effect, a review paper entitled "Gefährliche Rückstände im Klinikabwasser?" (*Hazardous residues in hospital effluents?*) was launched in the publication CNE.magazin[7] currently used by some 460 hospitals to qualify their employees in the field of health and nursing care. Moreover, members of the project consortium regularly published contributions in the employee magazine of the Ortenau Clinic Centre, OKplus, thereby reaching around 5,000 employees and informing them about the project as well as their individual possibilities for action (for further reading see [Adomßent 2015a, 2015b]).

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5 Management concepts for dealing with micropollutants and pathogens in the water cycle

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