Municipal Waste Water Treatment Plant (WWTP) Effluents

a Concise Overview of the Occurrence of Organic Substances

Rhine Water Works
The Netherlands

Dr. Ir. Eric S.E. van Beelen

July 2007

Municipal Waste Water Treatment Plant (WWTP) Effluents

a Concise Overview of the Occurrence of Organic Substances

Dr. Ir. Eric S.E. van Beelen

July 2007

Table of Contents

1

Summary

Micro pollutants in wastewater are a challenge to wastewater professionals. The presence of contaminants in WWTP effluents may cause a severe risk for the drinking water preparation. Upon discharge of the effluent into the receiving water body dilution and further degradation will occur. Nevertheless, some of the compounds might enter the drinking water treatment process, especially the process of those drinking water companies which produce drinking water from surface water. Although advanced oxidation steps are often used in the drinking water treatment process, these technologies are no guarantee for the complete removal of such compounds. Many different micro pollutants can be found in effluents of WWTPs. For most of the compounds found in the WWTPs the removal efficiencies are high (up to 98%). They are, however, not sufficient for complete removal. In addition to the intrinsic stability of the substances this efficiency is dependent on volatilization, adsorption and polarity of the compound. This study highlights some of the most persistent pollutants which can be found in WWTP effluents. For each compound class, an evaluation of its removal efficiency and occurrence in WWTP effluents is given. It may be concluded that the aim of the RIWA, i.e. a surface water quality that allows simple treatment to be sufficient for the production of good quality drinking water, is far from being reached.

Samenvatting

Er worden veel verschillende microverontreinigingen aangetroffen in de effluenten van rioolwaterzuiveringen. De verwijdering van deze microverontreinigingen is niet alleen voor de rioolwaterzuivering deskundige een uitdaging, maar ook voor de drinkwaterproductie kunnen deze stoffen een risico opleveren. Ondanks dat door verdunning en degradatie de concentratie van een gedeelte van deze microverontreinigingen zal verminderen, zal een gedeelte ook zijn weg vinden naar de grondstof voor de bereiding van drinkwater. Hoewel er geavanceerde zuiveringstechnieken gebruikt worden voor de bereiding van drinkwater kan, zeker wanneer oppervlakte water gebruikt wordt voor de bereiding van drinkwater, niet worden uitgesloten dat een gedeelte van deze verontreinigen in het eindproduct zelf terecht komt. In de effluenten van rioolwaterzuiveringen worden verschillende stoffen aangetroffen. De verwijderingsefficiëntie van deze stoffen, die kan oplopen tot 98%, varieert sterk en is onder meer afhankelijk van de vluchtigheid, adsorptie en polariteit van de component. Daarbij worden lang niet alle componenten volledig verwijderd. De stoffen die voorkomen in de effluenten van de rioolwaterzuiveringsinstallaties vormen dan ook een potentieel risico voor de drinkwater productie. In dit rapport wordt een aantal stofklassen uitgelicht waarvan de componenten relatief vaak worden aangetroffen in effluenten van rioolwaterzuiveringsinstallaties en die mogelijk een risico zijn voor de productie van drinkwater. Voor elke stofklasse wordt daarbij een overzicht gegeven van de verwijderingsefficiëntie en van de concentraties waarbij deze stoffen in de effluenten van rioolwaterzuiveringsinstallaties worden aangetroffen.

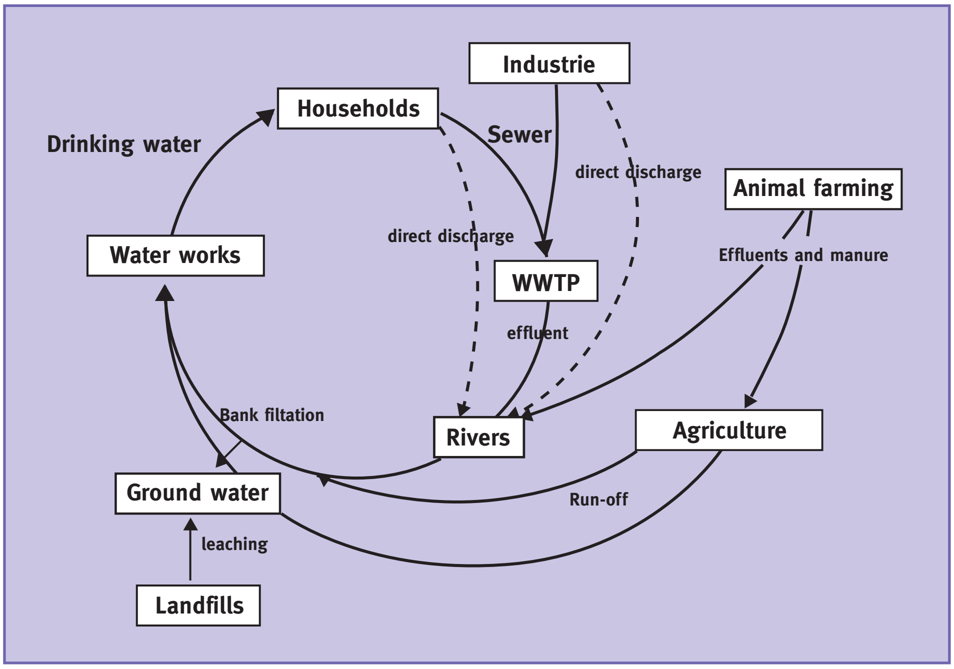
List of abbreviations

AS	Aromatic sulfonates
BFRs	Brominated flame retardants
CVO	Centre for Addiction Research/Centrum voor Verslavingsonderzoek
CAS	Conventional Activated Sludge
EDC	Endocrine Disrupting Compounds
ES	Emerging Substances
MBR	Membrane Biological Reactor
PAH	Poly Aromatic Hydrocarbons
PBBs	Polybrominated biphenyls
BFRs	Brominated flame retardants
PPCPs	Pharmaceuticals and Personal Care Products
RIWA	Association of River Water Companies
RIZA	Dutch national Water authority/Rijksinstituut voor Integraal Zoetwaterbeheer en Afvalwaterbehandeling
STP	Sewage Treatment Plant
US	United States (of America)
WWTP	Waste Water Treatment Plant
VEWIN	The Association of Dutch Water Companies
VROM	Dutch Ministry of Environment/Volkshuisvesting Ruimtelijke Ordening en Milieubeheer
XTC	Ecstacy

3 Introduction

One of the key issues in water-resource management is the (indirect) re-use of waste water for drinking water supply or for industrial or agriculture purposes because of the scarcity of pristine waters (Figure 1). In this context, the fate and effects of organic contaminants in sewage water entering the environment has gained more attention. Several studies have been carried out to investigate the occurrence of organic contaminants in sewage water. These studies varied widely in the substances studied; for instance pharmaceuticals, diagnostic contrast products, personal care products, antibiotics, estrogens and pesticides. Recently, a number of studies concerning the fate of organic contaminants in wastewater have been carried out. Most current WWTPs are not really designed to treat these type of substances and a high part of emerging compounds and their metabolites may escape elimination in WWTPs and enter the aquatic environment via sewage effluents.

Figure 1: The role of WWTP in the watercycle.



This review gives a comprehensive overview of research topics concerning the occurrence of organic substances in effluents of Domestic WWTP's (DWTP's). Especially the consequences of the presence of remaining organic contaminants in WWTP effluents for the drinking water production will be presented here. The first part of this report mainly focuses on the occurrence and removal of organic contaminants in WWTPs. First, a short overview is given of the different types of WWTP. In addition, the removal of organic contaminants is discussed as a function of the complexity of a WWTP. The potential risks of industrial wastewater plants will briefly be discussed. Finally, the consequences for the production of drinking water will be addressed and some conclusions and recommendations are given.

4

The wastewater treatment plant process

4.1 Basics of waste water treatment

Sewage is created by residences, institutions, and commercial and industrial establishments. It can be treated close to where it is created (in septic tanks, onsite package plants or other aerobic treatment systems), or collected and transported via a network of pipes and pump stations to a domestic treatment plant. Industrial sources of wastewater often require specialized treatment processes. (Domestic) wastewater (or sewage water) treatment is the process of removing the contaminants from wastewater. It includes physical, chemical and biological processes. Its objective is to produce a treated effluent and a solid waste or sludge suitable for discharge. This sludge may also be reused. The sludge is often inadvertently contaminated with toxic organic and inorganic compounds. Typically, sewage treatment involves three stages, called primary, secondary and tertiary treatment.

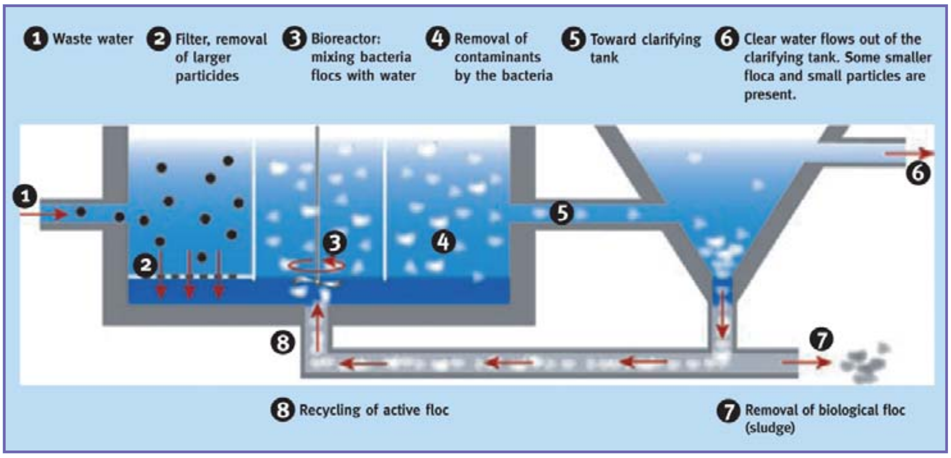
Primary treatment is intended to reduce oils, grease, fats, sand, grit, and settle-able solids. This step is done entirely mechanically by means of filtration and sedimentation.

The secondary treatment is designed to substantially degrade the organic content of the sewage. In this secondary or advanced treatment step, very often microorganisms are used in the purification step. This biological treatment is an efficient method for the removal and reduction of both organic contaminants as well as for the reduction of the nutrient load. In this purification step, dissolved organic matter is progressively converted into a solid mass by using indigenous, waterborne bacteria. Several methods are being used in modern WWTP's, but the most common method in the Netherlands is conventional activated sludge (CAS). Activated sludge plants use a variety of mechanisms and processes to use dissolved oxygen to promote the growth of a biological floc that substantially removes organic material. It also traps particulate material and can, under ideal conditions, convert ammonia to nitrite and nitrate and finally to nitrogen gas.

In the final (tertiary) treatment step, the organic solids (sludge) are neutralized and then disposed or re-used. The treated water may finally be disinfected chemically or physically for example by micro-filtration or clarifier. The final effluent can be discharged onto a natural surface water body (stream, river or lake).
The Sludge Retention Time (SRT) is the contact time of the waste water with the activated sludge and is an important design parameter for the efficiency of removal of compounds. The purification process of a conventional WWTP is schematically given in Figure 2.[1]

A WWTP is dimensioned on an average wastewater load (amount of sewage and contents in the sewage). A specific situation in a WWTP appears in case of intensive and/or long-term rainfall. In many domestic areas the surplus of rain water will be transported through the normal sewage system. Many WWTP's don't have enough capacity (SRT) to maintain a sufficient purification at high supply of water and the polluted sewage water is directly drained on the surface water without cleavage. For these reasons the policy in the Netherlands is targeted to separate rainwater from the domestic sewage water before 2015.[2,3]

Figure 2: A schematic representation of a conventional WWTP.



Many water authorities in Europe have been investigating the use advanced technologies, such as Ozonation and Membrane Biological Reactors (MBRs) to improve the treatment of waste water. Especially the POSEIDON project, which was carried out within a European Framework, focused on the assessment and improvement of technologies for the removal of persisting organic compounds in wastewater (and drinking water) facilities in order to prevent the contamination of receiving waters, groundwater and drinking water.[4] Within this project many relevant techniques and processes involved in the urban water cycle have been assessed regarding their removal efficiency. One of the technologies studied for the removal of organic contaminants is the Membrane Biological Reactor (MBR). Membrane Biological Reactors include a semi-permeable membrane barrier system either submerged or in conjunction with an activated sludge process.

The membrane is only permeable for water, so the sludge remains inside the biological system. Because the sludge remains in the biological system, MBR's can be loaded higher with organics, and the degradation of organic contaminants is more effective. This reduces the size of the WWTP and the increased removal of all suspended and some dissolved pollutants make the effluent much cleaner than only by means of a conventional WWTP. However, the limitation of MBR systems is directly proportional to nutrient reduction efficiency of the activated sludge process; that is, the higher the nutrient concentration, the lower the removal efficiency of organic contaminants in MBRs. The purification efficiency of a conventional WWTP can drop below 50% while under the same conditions a WWTP with a MBR still may have an efficiency of over 80%.[5,6,7] The costs of building and operating a MBR is usually higher than those of a conventional wastewater treatment. In the Netherlands, some water authorities already implanted MBR in the purification process.[8] Compared to conventional WWT, membrane-assisted biological WWT can only improve the elimination efficiency of pollutants but can not stop entirely the discharge of mainly polar pollutants with the permeates.[9,10] Therefore the treatment process for elimination of hardly degradable polar pollutants which are of environmental relevance, i.e. toxic or mutagenic components, can be optimized only by a modification of the membranes and/or by a modification of the treatment process.

4.2 Principles of removal of organic components in a WWTP

The treatment steps in a conventional domestic WWTP are particularly intended for removing adsorbed components, for aerobic cleavage of organic components and for de-nitrification and de-phosphatation of the waste water. The formed sludge is thickened and removed to a deposit where it undergoes anaerobic decomposition with production of biogas. This gas is reused as energy source in the WWTP purification process and can provide approximately 25 -35% of the total energy needed for the WWTP.[11]

The purification method of WWTP's has been optimized in the past to minimize the euthrophication of the surface water; that is; the removal of nitrate and phosphate has been optimized. Metals are efficiently removed because of their fixation to the sludge. In this process, the removal of organic contaminants did not receive much attention until now. This implies that, particularly with relatively persistent (organic) compounds, it is uncertain whether they will be removed or not. The removal of organic substances depends on several physical and/or chemical properties of the specific substance. Especially the sorption of organic substances on the sludge plays an important role. This sorption can be predicted by the octanol-water partition coefficient log K_{OW} (or log P). During primary sedimentation, hydrophobic substances may adsorb onto settled sludge depending on their log K_{OW} values as follows:[12]

*Table 1: Adsorption potential dependence on log K_{OW}.**

Log $K_{OW} \leq 2.5$	low sorption potential
$2.5 <$ Log $K_{OW} < 4.0$	medium sorption potential
Log $K_{OW} \geq 4.0$	high sorption potential

Many organic compounds have log K_{OW} values below 2,5 and therefore a low sorption potential. The removal of these compounds in conventional activated sludge treatment plants will therefore be relatively low. Especially, the increasing tendency to use less bioaccumulating substances nowadays, implies that more substances with low K_{OW} values will be used. Another aspect in the removal of organic substances is the volatility of a substance. In principle, volatile substances leave the water phase quickly by evaporation during the puri fication process. In general, substances with a Henry constant (H_c) of 10^{-3} atm mol^{-1} m^{-3} or more, will easily be removed by volatilization. As a consequence, the volatilization losses of specific substances during sewage treatment can be predicted based on Henry's constant and log K_{OW} as follows (Table 2).[12]
A third and not less important aspect to consider is the persistence of a substance during the treatment in a WWTP. However this property is in most cases hardly known.

Table 2: Volatilization potential of organic compounds, based on the Henry constant and Log K_{OW}.

$H_c > 1*10^4$ and $H_c / K_{OW} > 1*10^9$	high volatilization potential
$H_c < 1*10^4$ and $H_c / K_{OW} < 1*10^9$	low volatilization potential

** For an overview of Log K_{OW} values for individual substances see annex 1.*

From the parameters mentioned above, one can predict eventual problems for different classes of compounds. In the past decades, some investigations have been performed to investigate and to improve the removal of persistent compounds in WWTP's. Several new purification methods have been tested such as the so-called Membrane Biological Reactor (MBR).[13]

The WWTP's in the Netherlands are optimized to minimize the output of ammonium, nitrate, phosphate and organic matter, so under normal working conditions of the treatment plant these substances will not cause major problems. Studies on the efficiency of WWTPs in Paris showed that tertiary treatment, leads to a significantly decrease of the ammonium-specific load by 40% and notably reduces the amount of organic matter.[14] The removal of metals in WWTP's is over 90%. The only problem can occur when the WWPT become overloaded for instance because of heavy rainfall, in which case the efficiency of the treatment process drops dramatically, depending on the process used (See § 2.1). This scenario is not unlikely, due to the prediction of more frequent and more intense rainfall in the near future due to climate changes.[15]

RIWA
Rijnwaterbedrijven

5

Contaminants in Domestic WWTP Effluents

Over the past years, many studies to investigate the disposal of different (in)organic micro-pollutants to WWTPs have been performed. From these studies it emerged that many compounds from many different sources are occurring in WWTP's influents.[16,17] Inputs of metals to the WWTP's can occur from several sources. Platinum (Pt) is a component in vehicle catalytic converters and emissions occur as the catalytic converter deteriorates. Lead (Pb) can be a problem in districts with extensive networks of Pb pipe work for water conveyance.[18] This can particularly happen in relatively old housing districts. The Pb concentration can be reduced by conditioning the water in order to reduce the metal solubility from the plumbing. Mercury (Hg) is disposed from breakage of thermometers and will probably give fewer problems in the future because of the compulsory use of amalgam separators and by substituting Hg with alternative thermo reactive materials. Organic pollutants which in the past have been frequently studied in WWTP's effluents are Diagnostic contrast media, Endocrine Disrupting Compounds (EDCs) and Hormones, Flame retardants, Household and Personal Care Products (PCPs), Musk fragrances, Nonylphenols (NPs), Pesticides, Pharmaceuticals, Phthalates and Sulfonated Organic Compounds (e.g. LAS). Inputs of these compounds in WWTP influents are due to domestic usage or from industrial sources. There is, however, a clear distinction between WWTP's with wastewater of domestic origin and WWTP's with wastewater from industrial sources. The latter WWTP's require normally a specific treatment step which is adequate to eliminate the specific load of (in)organic pollutants in industrial wastewater. These WWTPs are beyond the scope of this study. In the following paragraphs, the occurrence and removal efficiency and the consequences for drinking water production of the substances mentioned above will be addressed in more detail. The occurrence and removal of biological compounds such as emerging pathogens can be found in the comprehensive review of Hoogenboezem et *al.*[19]

5.1 Organics

There are several regulations which make demands on the occurrence of emerging substances for the production of drinking water. Besides the European Directive,[20] the Dutch government has also addressed several organic contaminants as potentially harmful for the production of drinking water.[21] The Association of Dutch drinking water companies (VEWIN) made an effort in producing a list of potential substances which could be a threat for the drinking water quality. These so called Emerging Substances (ES) are divided into seven classes which differ in relevance and toxicity (Table 3). Many of these compounds are identified in effluents of WWTPs and/or surface water.

Table 3: Emerging substances classification (VEWIN)

Substances with high relevance		Substances with high relevance	
1A	1B	2A	2B
toxicologically relevant and detected in Dutch drinking water in relevant concentrations (none determined)	not toxicologically relevant and detected in Dutch drinking water receiving media attention (e.g. pharmaceuticals)	toxicologically relevant; not detected in Dutch drinking water; detected in drinking water Europe/US (e.g. phthalates)	toxicologically relevant; not detected in Dutch/Europe/US drinking water; receiving media attention (e.g. flame retardants)

One of the most recent concerns associated with environmental contaminants is that some of these chemicals may interfere with hormones. These compounds are referred to as endocrine disruptors because they disrupt normal functioning of the endocrine system. Endocrine systems are complex mechanisms, coordinating and regulating internal communication among cells. Endocrine systems release hormones that act as chemical messengers. The messengers interact with receptors in cells to trigger responses and prompt normal biological functions such as growth, embryonic development and reproduction.[22] The contaminants with endocrine disrupting behavior can be found in different sources, such as industrial applications, pharmaceuticals, personal care products (PPCP) and/or pesticides.

In recent years a lot of research has been done by the Association of River Water Companies (RIWA) on the occurrence of organic components in surface water, intended for drinking water treatment. Also the detrimental effects of these substances for the environment have been studied.[23,24]

5.2 Organic Contaminants from Industrial sources

Many organic contaminants originate from industrial applications. In this paragraph an overview is given of the most common contaminants present in WWTP effluents.

5.2.1 Flame retardants

Brominated flame retardants (BFRs) have routinely been added to consumer products for several decades. They are successful in reducing fire-related injury and property damage. So the production and application of these compounds is strongly increasing. Recently, concern for this emerging class of chemicals has risen because of the occurrence of several classes of BFRs in the environment and in human tissue. The increasing production and use of BFRs and the limited knowledge of potential harmful effects heighten the importance of identifying emerging issues associated with the use of BFRs.[25] There are more than 175 different types of flame retardants, which are generally divided into classes that include the halogenated organic (usually brominated or chlorinated), phosphorus-containing, nitrogen-containing, and inorganic flame retardants. The brominated flame retardants (BFRs) are currently the largest market group because of their low cost and high performance efficiency. In fact, there are more than 75 different BFRs recognized commercially.[25] Some of them, such as the polybrominated biphenyls (PBBs), are no longer being produced. Overall, PFRs are very hydrophobic (Log K_{OW} = 5.24–10.3) and are strongly adsorbed on sewage sludge.[27] Due to this strong adsorption on sludge, the concentration in surface water is low and these compounds are not expected to be a risk for the drinking water production. However, the flame retardants tri-2-chloroethyl phosphate and tri-n-butyl phosphate are less hydrophobic (Log K_{OW} = 1.44 resp. 4.0), and are therefore regularly identified in surface waters and sometimes in drinking water.[27]

5.2.2 Fluorinated organic compounds (FOCs)

In recent years Fluorinated Organic Compounds (FOCs) have gained a lot of attention as possible emerging contaminants.[28] Examples of these compounds are perfluorooctane sulfonate (PFOS), perfluoro-octanoate (PFOA), and perfluorooctane sulfonylamide (PFOSA). They are widely used in the manufacture of plastics, electronics, textile, and construction material in the apparel, leather, and upholstery industries. FOCs have been found in blood and environmental samples throughout the world, and recent postnatal studies on developmental and reproductive indices have questioned former findings that these compounds are of low toxicological risk,[29] and more and more concern for endocrine disrupting effects has been published.[30] Studies of biochemical degradation of perfluorooctanesulfonate (PFOS) and perfluorooctanoic acid (PFOA) have been published. Perfluorooctane sulfonate was found to be quite mobile in water and biologically stable.[31] In the US perfluorooctanesulfonate and other perfluorinated surfactants have been found in groundwater samples.

5.2.3 MTBE

MTBE (Methyl-tert-butylether) is a well know additive in petrol. Most abiotic elimination techniques, normally used in wastewater-treatment plants (WWTPs), such as ozonation or adsorption on granular activated carbon, are not very effective for removing MTBE or its main degradation product, TBA (Tertiary Butyl Alcohol) due to the relatively low Log Kow of 1.06.[32] These limitations may generate additional problems for water suppliers and regulators, since TBA may be considered more toxic than its parent compound.[33] Overall, 35-43% of the MTBE is effectively removed in sewage plants, leading to an average concentration in WWTP effluents of 0.1 µg/L MTBE.[34] It should be noted that the majority of this input will result from traffic run-off and from gas stations connected to the WWTPs. Strong fluctuations are, therefore, likely to occur.

5.2.4 Nonylphenols (NP)

Nonylphenols consist of several derivatives such as alkylphenol ethoxylates (APEOs), nonylphenol ethoxylates (NPEOs) and Nonylphenols (NP). Alkylphenol ethoxylates (APEOs) are nonionic surfactants widely used in agricultural, industrial, and domestic applications.[35] They are applied in textile industries in auxiliary's formulations (used in pretreatment operations) or in additives as detergents or wetting agents in wool scouring, hydrogen peroxide bleaching and dyeing processes. Although their environmental acceptability is strongly disputed, APEOs are still among the most widely used non-ionic surfactants.[36] Currently, under optimized conditions, more than 90-95% of these surfac tants are eliminated by conventional wastewater treatment. Even if such high elimination rates are achieved, the principal problem is the formation of treatment-resistant metabolites out of the parent surfactants. The widespread occurrence of APEO-derived compounds in treated wastewaters and the subsequent disposal of effluents into aquatic systems raise concerns about the impact of these compounds on the environment. Studies have shown that their neutral (alkylphenols and short chain ethoxylates) and acidic treatment-resistant metabolites possess the ability to mimic natural hormones by interacting with the estrogen receptor. It was estimated that 60-65% of all nonylphenolic compounds introduced into WWTPs are discharged into the environment; 19% as carboxylated derivatives, 11% as lipophilic nonylphenol ethoxylate (NP1EO) and nonylphenol diethoxylate (NP2EO), 25% as nonylphenol (NP) and 8% as non-transformed nonylphenol ethoxylates (NPEOs).[37] In light of the potentially estrogen mimicking potential of these compounds, the removal efficiencies of these compounds in drinking water production have been calculated (Table 4).[38,39]

Table 4: Removal efficiency of nonylphenol derivates in drinkingwater production

Process	Removal efficiency (%)
Settling and Flocculation followed by rapid Sandfiltration	7%
Ozonation	87%
Desinfection with Chlorine	43%
Activated Carbo Filtration	73%

Although overall, the removal of these compounds in their native form in WWTPs tends to be in the range of 96-100%, it might be preferable to investigate the occurrence of these compounds in the different stages of the drinking water production process to determine their potential risk

5.2.5 Phthalates

Phthalates are organic chemicals produced from crude oil and are the most commonly used plasticizers in the world. The main application is the usage for the production of PVC. Not all phthalates however are used as plasticizers for PVC. Different phthalates keep nail polish from chipping, make perfume linger longer, or make tool handles strong and more resistant to breaking. Others help adhesives; sealants, paint pigments and many other materials perform their jobs better. The emission of such compounds into the environment leads to the risk of human exposure. Some phthalates have been suspected as having a possible estrogenic effect, making them harmful to male reproduction, and possibly playing a role in the development of breast cancer in humans. Phthalates are found in WWTP effluents in different concentrations. Phthalates which have been investigated in WWTP effluents are Dibutylphthalate (DBP); Benzylbutylphthalate (BBP); Bis(2-ethylhexyl)-phthalate (DEHP). The most abundant of the investigated phthalates was DEHP with a measured effluent concentration of 33 µg/L.[40] The concentrations of DBP and BBP were in the range of 0.07-0.33 µg/L.[41]The removal efficiency of phthalates was estimated to be 98% of which 70% is biodegraded and 28% is adsorbed to the sludge.[41] The phthalates are sparingly soluble and the high Kow values (>6) indicate approximate irreversible sorption to suspended matter. The strong sorption combined with half-lives of around 30 hours results in high removal through the WWTP.[42]

5.2.6 Sulfonated organic compounds

Sulfonated organic compounds are important large-volume chemicals in a wide variety of technical products for industrial and domestic processes.[43] For example, substituted benzene and naphthalene sulfonates are used in the chemical industry as intermediates for the manufacturing of pharmaceuticals, dyes and tanning agents.[44,45] Sulfonated naphthalene–formaldehyde condensates are important commercial plasticizers for concrete, dispersants and tanning agents. Sulfonated azo dyes are extensively applied in the textile industry to color natural fibers, inks and pigments.[46] Stilbene sulfonates are applied in the paper industry as optical brighteners. Alkane sulfonates and linear alkylbenzene sulfonates (LASs) are frequently used anionic surfactants in detergents and laundry.[47] Aromatic sulfonates (ASs) are very acidic and strongly hydrophilic compounds. The persistence of the various ASs to degradation is distinct. However, AS-derivatives without a hydrophobic alkyl chain are relatively easily biodegradable compounds. There exist only a few substances which are quite persistent under aerobic conditions (such as 1,5-naphthalenedisulfonate, 1,3,6-naphthalenetrisulfonate and naphthaleneformaldehyde condensates). Because of their low octanol/water partition coefficients (e.g. K_{OW} = 0.115 for naphthalene-1-sulfonate) they possess a high mobility within the aquatic system and have been found in natural waters.[44-47] The concentrations of these more persistent ASs encountered in waste waters from chemical industries and water treatment plants are much higher than in domestic WWTP effluents, and values in the mg/l range have been reported.[44,48] Aromatic sulfonates are regularly found in different waste waters from chemical industries and WWTPs in quite high µg/l concentration ranges.[49] It was shown that some ASs, especially 2-naphthalenesulfonate, are only slightly eliminated by a CAS waste water treatment process and therefore are considered to be quite persistent compounds.[43] In case of a WWTP equipped with a biological treatment, these compounds are removed for 90-100%. This shows the importance of biological treatment for enhancing the performance of WWTPs to remove certain ASs. Linear alkylbenzene sulfonates (LAS) are fairly well removed in WWTP's. Overall, less than 1% is found in the treated water, 84% was biodegraded and 15% was found in the sludge. From these findings, LAS don't seem to be a direct risk for the drinking water production.[41]

5.3 Household and personal care products (PPCPs)

During the last three decades, the impact of chemical pollution has focused almost exclusively on the conventional "priority" pollutants, especially those acutely toxic/carcinogenic pesticides and industrial intermediates displaying persistence in the environment. These chemicals, however, are only a small piece of the total spectrum of possible pollutants. Another diverse group of bioactive chemicals receiving thus far comparatively little attention as potential environmental pollutants includes the active ingredients in personal care products (PPCPs), both human and veterinary, including "nutraceuticals", fragrances and sun-screen agents. These compounds and their sometimes bioactive metabolites may be continually introduced into the aquatic environment as complex mixtures via a number of routes but primarily by both untreated and treated sewage. A very comprehensive review is given by C. G. Daughton and T. A. Ternes about the occurrence, fate and causes of PPCPs in the aquatic environment.[50] The long term effects of many PPCPs in the aquatic environment are presently unknown. Some of these compounds may have endocrine disrupting properties.[51]

5.3.1 Musk fragrances

Synthetic musks are a group of chemicals possessing a chemical structure that is not readily biodegradable They are capable of being bioconcentrated in aquatic organisms.[6,52,53] The most frequently used synthetic musks are Musk ketone: 1-tert.-Butyl-3,5-dimethyl-2,6-dinitro-4-acetylbenzene (MK); Musk moskene: 4,6-Dinitro-1,1,3,3,5-pentamethylindane (MM); Musk ambrette: 2,6-Dinitro-3-methoxy-4-tert.-butyltoluene (MA); Musk xylene: 1-tert.-Butyl-3,5-dimethyl-2,4,6-trinitrobenzene (MX) and Musk tibeten: 1-tert.-Butyl-2,6-dinitro-2,4,5-trimethylbenzene (MT). The Log Kow values of these compounds and their metabolites vary from 4.3 to 6.3 and from 4.8 to 5.1 respectively. These synthetic compounds are used as more affordable substitutes for the expensive natural musks (e.g., muscone, civetone, and ambrettolide) present in many perfumes. Based on this Log K_{OW} most of these musks will be more or less efficiently removed by a WWTP treatment. Many manufacturers voluntary are replacing the older and more toxic substances for newer, less persistent and potentially less toxic substances, such as tonalide (AHTN) and galaxolide (HHCB). There are four synthetic musk fragrances accounting for 95% of the total amount used. These are the nitro-musks (musk xylene, used in detergents and soaps, and musk ketone, used in cosmetics) and two polycyclic musks HHCB and AHTN. Synthetic musks enter city sewage systems (presumably from bathing, laundry detergents, and other washing activities), and then the aquatic ecosystem, where they may potentially bioconcentrate and biomagnify in the tissues of aquatic organisms. Fragrances are reported in several studies and they are identified in effluents and surface water.[51,54] Concentrations up to 0,73 mg/l are found in effluents of domestic WWTP.[54] Two nitro musks (musk xylene, musk ketone), a major metabolite of musk xylene and the polycyclic musk fragrance tonalide (AHTN) are suspected of having estrogenic activity.[51] It has been established that the partial removal observed for the two fragrances AHTN and galaxolide (HHCB) during wastewater treatment is mainly due to sorption (log $K_{OW} \geq 4.9$) onto sludge and not to biological transformation.[54] Due to the incomplete removal of fragrances in conventional WWTP, ozonation has been tested as a possible tool for the enhanced removal of fragrances. By applying 10–15 mg/l ozone (contact time: 18 min), most of the musk fragrances were no longer detected.[51]

5.3.2 Sunscreen Agents (SSAs)

Sunscreen agents (SSAs) are more and more widely used for protection against harmful UV radiation. The concentration of these sunscreen agents in water is limited ((0.004 μg/L) and considerable concentrations are found in aquatic organisms (21 μg/kg) indicating that SSAs are able to biocencentrate.[55] The fact that SSAs (e.g., oxybenzone (2-hydroxy-4-methoxybenzophenone) and 2-ethylhexyl-4-methoxycinnamate) can be detected in human breast milk shows the potential for (dermal) absorption and bioconcentration in aquatic species.[56] No data have been published on more recently used SSAs such as avobenzene. A remarkable fluctuation in sunscreen residue levels with higher levels in february and june-august has been observed in the Rhine river and was, tentatively, linked to early spring break (ski?) and summer vacations (Knepper, personal communication, 2004).

5.3.3 Other PPCPs

A wide spectrum of organic substances is included in this group. For instance the compounds chlorophene, 3,4,5,6-tetrabrome-o-cresol, triclosan, 4-methylphenol, which are all disinfectants, are reported and identified in WWTP effluents and/or surface water. Also, dietyltoluamide (DEET, an insect repellant) is regularly reported in WWTP effluents and surface water. Another group of found compounds are the nonionic detergents and their metabolites.[57]

5.4 Pharmaceuticals

Pharmaceuticals are a set of compounds which have obtained increasing attention over the past decade. There are many different compound classes which are intended to affect a specific area of a disease. Recently, it has become clear that the elimination of certain pharmaceutical compounds during wastewater treatment processes is rather low and as a result, they are found in surface, ground and drinking waters.[58] For this reason, pharmaceuticals may be able to cause the same harmful exposure potential as persistent pollutants, since their transformation and removal rates can be compensated by their continuous input into the environment. A few compound classes will be highlighted, either because the concentrations found in water are high, because of their (increasing) high volume usage or because of the persistence of these compounds.

5.4.1 Antibiotics

Antibiotics are mostly penicillins and are widely used. Hospital wastewater effluents are one of the major sources of antibiotics, although wastewater effluents from tropical fish farm plants appeared to be also an important source of antibiotics.[59] Some of these substances show sometimes low adsorbance to sewage sludge (log K_{OW} 1 - 6).[60] Antibiotics such as sulfamethoxazole, trimethoprim, penicillin and caffeine were detected in hospital wastewater at high levels (0.3 – 35 µg/l). Only sulfamethoxazole, trimethoprim and ofloxacin were present in WWTP treated effluent in concentrations ranging from 0.11 to 0.47 µg/l.[60] The substances trimethoprim and ofloxacin are part of the quinolone antibiotics (QAs) which have been widely used for the last 20 years in Europe and the United States.[61] QAs consists of compounds such as pipemidic acid (PIP), ofloxacin (OFL), norfloxacin (NOR), ciprofloxacin (CIP), lomefloxacin (LOM), enrofloxacin (ENR), difloxacin (DIF), sarafloxacin (SAR), and tosufloxacin (TOS). Also antibiotics belonging to the quinolone group, including fluoroquinolones (FQs) are of particular environmental concern, because of the potential inhibition of DNA gyrase, a key enzyme in DNA replication.[62] Ofloxacin, lomefloxacin, norfloxacin and ciprofloxacin are the QAs which are frequently found in WWTP effluents across Europe up to concentrations of 0.3 ug/L.[61] Removal efficiencies of antibiotics in general were estimated between 20 to 70 percent in WWTPs, mainly due to the low K_{OW} value of antibiotics (Log K_{OW} ~ 1). Sulfamethoxazole, found in relatively high concentrations in hospital wastewater, displayed high persistence and is detected at concentrations up to 0.3 µg/L in WWTP effluents.[69]

5.4.2 Antineoplastic drugs

During the past years, the growing use of antineoplastic drugs in cancer therapy is an emerging issue in environmental research and it can be expected, that consumption will increase due to a developing health care system and a higher life expectancy. Cytostatics belong to the CMR (carcinogenic, mutagenic and reprotoxic) drugs. They usually enter the hospital effluents partially transformed or even unchanged via urine and faeces of patients under medical treatment. Therefore, they are assumed to be environmentally relevant compounds. As hospital effluents reach the municipal sewer network generally without any preliminary treatment, hospitals may represent an incontestable release source of anticancer agents. Besides, nearly 80% of cancer therapies are administered in the outpatient treatment ward, i.e. patients leave the hospital after drug application.[63] Subsequently, the drugs are also directly excreted into the municipal sewer network. Their quantification in hospital effluents may serve as a starting point to individualize the magnitude of potential pollution problems. Especially in Germany, investigators have been active in monitoring the fate of cytostatics in the environment after administration to patients. The concentrations of the antineoplastics cyclophosphamide and ifosfamide in the effluents of domestic WWTPs in Germany were determined to be between 6.2–8.5 ng/L and 6.5-9.3 ng/L respectively.[64] In a WWTP of an oncologic hospital in Germany, much higher concentrations in the effluent were observed (0.006–1.9 µg/L and 0.02-4.5 µg/L respectively). No significant reduction during sewage treatment was observed. Treatment of oncologic wastewater in a membrane bio-reactor resulted in concentrations below the limit of detection. Most anticancer drugs are eliminated to a major extent (80%) by sewage treatment plants, either by biodegradation or adsorption.

5.4.3 Diagnostic contrast media

There are two basic types of contrast agents used, one type is based on barium sulfate, the other type on iodine. Triiodinated benzene derivatives are widely used as X-ray contrast agents. The preferential uptake of triiodinated compounds in specific organs enhances the contrast between those organs and the surrounding tissues and enables the visualization of organ details which otherwise could not be investigated. The compounds may be bound either as an organic (non-ionic) compound or as an ionic compound. Ionic agents were developed first and are still in widespread use depending on the examination they are required for. Most commonly used X-ray contrast media are: Diatrizoate (Hypaque 50), Metrizoate (Isopaque Coronar 370), Ioxaglate (Hexabrix), Iopamidol (Isovue 370), Iohexol (Omnipaque 350), Iopromide, Iodixanol (Visipaque 320).[65] These contrast media are applied by intravenous injection and are rapidly eliminated via urine or faeces. Due to the high hydrophicity of the substituted benzene derivatives (Log K_{OW} = -2) they pass wastewater treatment plants without any cleavage and thus, are found in rivers, lakes and even raw drinking water.[66,67] The contrast agent diatrizoate occurs with concentrations up to 5.2 µg/L as is iopromide found in concentrations up to 5.7 µg/L in effluents of WWTPs.[68] These are the most abundant and most used iodated contrast media (ICMs). In specific effluents of WWTPs near hospitals, the concentrations of ICMs can be much higher (up to 1200 µg/L).[69] Secondary treatment and introduction of oxidation steps only enhance the removal efficiency of these iodated agents in a limited way. Even with a 15 mg/L ozone dose, the ionic diatrizoate only exhibited removal efficiencies not higher than 14%, while the non-ionic ICM (diatrizoate, iopamidol, iopromide and iomeprol) were removed to a degree of higher than 80%. Advanced oxidation processes (e.g. O_3/H_2O_2), which were non-optimized for wastewater treatment, did not lead significantly to a higher removal efficiency for the ICM than ozone alone. It is interesting to note the high variation of the influent concentrations for iopromide: the fact that the influent load in a WWTP serving 120,000 population equivalents can vary by more than a factor of seven from one 24 h composite sample to the next suggests that most of this compound is emitted irregularly by a small number of point sources.[70] The metabolites of these contrast media have not been identified yet. The evaluation of the ecotoxicity of triiodinated contrast agents must include the transformation products. No environmental risk has to be expected from the triiodinated contrast media itself,[71] but the metabolites may have an ecotoxicological impact. Most likely, the transformation products carry free amino groups which might be mutagenical, thus, identification of the transformation products is very important.[72]

5.4.4 Estrogens

The most studied endocrine disruptors are those organic compounds which mimic the hormone estrogen. Estrogenic steroids such as the synthetic steroid hormone 17a-ethynylestradiol (EE2) prescribed as oral contraceptive for birth control or estrogen substitution therapies and the natural hormone 17ß-estradiol (E2) and its main metabolite estrone (E1) are among the most potent EDCs causing effects in aquatic organisms.[73] Several studies have been performed on the determination of the estrogen activity in WWTP effluents.[73,74,75,76,77] On several locations in Europe, (Norway, Sweden, Finland, The Netherlands, Belgium, Germany, France and Switzerland), the WWTP effluents and surface water have been studied for the presence of estrogens.[78,79] Treatment processes included primary and chemical treatment only, but also more advanced treatment processes (e.g. ozone) have been studied. In all studies, significant levels of estrogens are detected in both WWTP influent- and effluent water, ranging from 2 up to 51 ng/L and from 0.5 to 3 ng/L, respectively.[21-23] The highest estrogen values were detected in the effluent of the WWTPs which only used primary treatment (35 ng/L E1, 13 ng/L E2 and 0.05-1,6 ng/L EE2).[74,75] For WWTPs equipped with a secondary treatment, the concentration of E1 and E2 in the effluent was between 0.7–5.7 ng/L and 0.8-3.0

ng/L respectively.[75] The removal efficiency of E1 and EE2 clearly depends on the redox conditions of the purification process. This is partially due to the reduction during this process of E1 into E2. A biological degradation of more than 90% of the E1, E2, and EE2 load can be expected from conventional activated sludge plants and membrane bioreactors. The removal efficiency of estrogens is also known to improve, when sludge retention times increases.[77] This can be ascribed to the relatively moderate log K_{OW} values of estrogens of 3-4 and a very low vapor pressure (Henry constant). The concentration of estrogens in WWTP effluents is found to be proportional to the population numbers of the city associated with the specific WWTP. For example, the stretch of the River Elbe between Dresden and Magdeburg has some big population centers and associated endocrine disrupting effects in the resident fish in some regions have now been detected. In these areas, the addition of tertiary treatments, known to reduce micro-organic pollutants in drinking water purification, such as ultra filtration, ozonation, UV treatment, activated charcoal etc. may need to be considered for the removal of estrogens.

5.4.5 General pharmaceuticals

Anti-inflammatories and analgesics, lipid regulators and ß-blockers are the major groups detected in WWTP effluents across Europe and among them are acetaminophen, ketoprofen, ibuprofen, diclofenac, mevastatin, atenolol, propranolol, sulfamethoxazole, bezafibrate and trimetroprim as the most abundant, with concentrations at high ng/L or low ug/L levels.[80,81] The highest concentrations were detected for acetaminophen (paracetamol) and for antimicrobial trimethoprim, with average concentrations in WWTP effluent of 2.1 µg/L and 0.29 µg/L respectively.[82] Other compounds frequently detected in WWTP samples were carbamazepine and ranitidine, with average concentrations of 400 ng/L for carbamezapine and 135 ng/L for ranitidine in effluent.[83] Different removal behavior was observed for the investigated compounds. Some compounds as the antiepileptic drug carbamazepine were not removed at all in any of the sampled treatment facilities and effluent concentrations in the range of influent concentrations were measured. Other compounds as bisphenol-A, the analgesic ibuprofen or the lipid regulator bezafibrate were nearly completely removed. The drugs detected in the environment were predominantly applied in human medicine. Due to their widespread presence in the aquatic environment many of these drugs have to be classified as relevant environmental chemicals.[84]

5.5 Pesticides

Since the identification of bentazon in drinking water the effects of pesticides on the aquatic environment has gained increasing attention over the past decades.[85] Regulations have solved some of the problems concerning the occurrence of pesticides in water. Pesticide inputs mainly occur due to wash-off of surfaces due to domestic and public use or to bad agricultural practices.[86] Especially the use of pesticides in domestic areas, such as Glyphosate or MCPP, has not gained much attention until recently, so only little is known about their discharge towards WWTP influents. However, pesticide entrance into surface water through WWTP should not be discarded and has to be quantified if efficient pesticide load reduction is contemplated. Notably, pesticides associated with domestic materials such as, e.g. rubber-based roof coverage may significantly contribute to WWTP-inputs through combined rain and sewer piping systems (Müller, personal communication, 2004)

5.6 Party drugs

Other substances which may be of interest in wastewater effluents are the so called life style drugs or party drugs (e.g. defattening pills, Viagra, XTC). These drugs are widely used and there is little or nothing known about the behavior of these substances in the environment. The Dutch “Centre for Addiction Research" (CVO) has performed a social-epidemiological research study in 1999 on the use of MDMA (methylenedioxy-N-methylamphetamine or XTC) and related substances during festivals (raves) in the Nederland's.[87] Normally, around 25,000 people are participating in a festival, like Dance Valley or Sensation, of which about 64 % uses XTC (MDMA) or other amphetamines. The mean dose of the visitors is 2 pills containing 100 mg MDMA each. About 65% of MDMA is excreted in urine unchanged and can be detected up to three days after use.[88,89] These numbers imply that the total amount of MDMA that is excreted during a festival with 25,000 visitors, is about 2,1 kg. A large part of this amount will probably enter into the domestic waste water treatment plants in the shape of a concentrated peak pollution. Because of the illegal character of the production of MDMA, there is hardly any control of emissions of MDMA or derivates into the environment during production or after failure of the production.[90] No information about the physicochemical properties of this compound is available; thus the removal efficiency and persistence of MDMA in WWTP's is unknown. So, further investigations are needed to determine the potential danger of these compounds for the environment. Benzoyl ecgonine, a metabolite of cocain, was detected in the Po river.[91] The levels were fairly low (in the ng/L range) but, even where data on the degradation efficiency in WWTPs is still largely unknown, this indicates an apparent wide-spread use.

RIWA
Rijnwaterbedrijven

6 Conclusions

Micro pollutants in wastewater are a challenge to wastewater professionals. Although there is a great deal of uncertainty concerning the possible detrimental effects on the aquatic ecosystems of many compounds, the precautionary principle, or possibly new scientific evidence, may give rise to more stringent demands on wastewater treatment in the future.
In conventional wastewater treatment plants, a combination of biological treatment with high sludge residence times and ozonation of the effluent seems to be the most promising technology. Ozonation, however, is an energy-intensive technology and is, as shown, not the solution for all micro pollutants present in WWTP effluents. Moreover, in conventional end-of-pipe systems a large part of the pollutants will always be lost to the environment due to leaking and primarily during stormwater overflow conditions.
In the long term, source separation may offer a more sustainable solution to the wastewater problem, notably for a wide variety of biologically active substances. These substances are excreted mostly via the urine. Urine source separation could be an elegant solution to solve the problems of nutrients, hormones and pharmaceuticals since inputs of such substances into the environment due to inefficient removal rates in conventional WWTPs could thus be minimized. Although few technologies for the separate treatment of urine have been developed to date, the higher concentrations of micro pollutants promise more efficient conditions for all removal technologies known from conventional wastewater treatment. Due to the higher concentrations of micro pollutants, biological as well as physical processes are expected to be more efficient in urine than in diluted wastewater. Chemical oxidation (ozonation) may profit from the higher micro pollutant to soluble organic matter ratio in biologically treated urine in comparison to the effluent from a conventional wastewater treatment plant but is on itself not the sole solution. New technologies need to be developed for the complete removal of organic micro pollutants from WWTP effluents.

The presence of contaminants in WWTP effluents is clearly an important source of surface water contamination. Even though a considerable dilution and degradation may occur, the ultimate levels in surface water are still relevant to the water works using this water as the source for drinking water production. Although advanced oxidation steps are often used in the treatment process, these technologies are no guarantee for the complete removal of these compounds, considering the removal efficiencies observed for many of such compounds. The current report, therefore, clearly demonstrates that the aim of the RIWA, i.e. a surface water quality that allows simple treatment to be sufficient for the production of good quality drinking water, is far from being reached.

Literature

Literature

1 *"De opmars van membranen",* A. van Bentem, De Ingenieur, **2006**, 7-8.

2 *"Beleidsbrief regenwater en riolering",* letter to the chairman of the Tweede Kamer der Staten Generaal, the secretary of state VROM, P.L.B.A. van Geel, **2004**.

3 *"Pragmatische Implementatie Europese Kaderrichtlijn Water in Nederland; van beelden naar betekenis",* Kabinetsnotitie van 23 april 2004; Available via www.vrom.nl.

4 *"Assessment of Technologies for the Removal of Pharmaceuticals and Personal Care Products in Sewage and Drinking Water Facilities to Improve the Indirect Potable Water Reuse",* T. A. Ternes, M. J.-Habibi, T. Knacker, N. Kreuzinger, H. Siegrist; POSEIDON; **2006**; Available via http://poseidon.bafg.de.

5 *"Comparison between the conventional anaerobic digestion (CAD) of sewage sludge and its combination with a chemical or thermal pre-treatment concerning the removal of Pharmaceuticals and Personal Care Products (PPCPs)",* M. Carballa, F. Omil, A.C. Alder, J.M. Lema, Water Science and Technology, 53(8), **2006**, 109–117.

6 *"Removal of selected pharmaceuticals, fragrances and endocrine disrupting compounds in a membrane bioreactor and conventional wastewater treatment plants"*; M. Clara, B. Strenn, O. Gans, E. Martinez, N. Kreuzinger, H. Kroiss; Water Research, 39, **2005**, 4797–4807.

7 *"Comparison of the behaviour of selected micro pollutants in a membrane bioreactor and a conventional wastewater treatment plant",* Clara M., Strenn B., Ausserleitner M., Kreuzinger N.: Water Science and Technology 50(5), 29-36 (**2004**).

8 *"Dossier Membraanbioreactoren"*; Waterforum and STOWA; **2006**. Available from: http://www.netserver1.net/waterforum/template_d2.asp?paginanr=76.

9 *"Removal of a broad range of surfactants from municipal wastewater - Comparison between membrane bioreactor and conventional activated sludge treatment."* S. González, M. Petrovic, D. Barceló, Chemosphere, **2006**.

10 *"Assessment of the pollutant elimination efficiency by gas chromatography/mass spectrometry, liquid chromatography mass spectrometry and tandem mass spectrometry Comparison of conventional and membrane-assisted biological wastewater treatment processes"*, H.-Q. Li, F. Jiku, H. F. Schröder, Journal of Chromatography A, 889, **2000**, 155–176.

11 *Rapport STOWA 2005-W04: Literatuurstudie Slibdesintegratie"*, M. van Rens et.al., STOWA, **2005**.

12 *"Pollutants in urban waste water and sewage sludge"*, ICON, **2001**. Avaialble from: http://ec.europa.eu/environment/waste/sludge/sludge_pollutants.pdf.

13 *"The application of membrane biological reactors for the treatment of wastewaters"*, K. Brindle, T. Stephenson, Biotechnology and Bioengineering, **2000**, 49(6), 601-610.

14 *"Determining the domestic specific loads of two wastewater plants of the Paris conurbation (France) with contrasted treatments: A step for exploring the effects of the application of the European Directive"*, J. Garnier, L. Laroche, S. Pinault, Water Research, 40, **2006**, 3257-3266.

15 *"Veranderingen in het klimaat"*, KNMI Brochure, P. Crutzen, G. Komen, K. Verbeek, R. van Dorland, KNMI, De Bilt, **2004**.

16 *"GC/MS-Screening van RWZi-effluenten"*, G. Rinia, R.P.M. Berbee, RIWA, **2006**.

17 *"Assessment of Organic Contaminant Fate in Waste Water Treatment; Selected Compounds and Physicochemical Properties"*, R. E. Alcock, A. Sweetman, K.C. Jones, Chemosphere, 38(10), **1999**, 2247-2262.

18 *“Pollutants in urban waste water and sewage sludge”*, ICON, European Commission, **2001**.

19 *“Influences of sewage treatment plant effluents on the occurrence of emerging waterborne pathogens in surface water”*, W. Hoogenboezem, RIWA, **2007**.

20 *“Directive of the European Parliament and of the Council 2000/60/EC establishing a framework for community action in the field of water policy.”*, European Union,. **2000**.

21 *“Regeling milieukwaliteitseisen gevaarlijke stoffen oppervlaktewateren”*, Ministeries VROM en V&W, Staatscourant, 247, **2004**, 34.

22 *“Developmental effects of endocrine-disrupting chemicals in wildlife and humans.”*, T. Colborn, F. S. vom Saal, A. M. Soto, Environmental Health Perspectives, 101, **1993**, 378384.

23 *“Endocrine disrupting compounds in the Rhine and Meuse basin – Occurrence in surface, process and drinking water”*, RIWA, **2000**.

24 *“Inventory and toxicological evaluation of organic micropollutants -- Revision”*, RIWA, **2000**.

25 *“Bioaccumulation of polybrominated diphenyl ethers in the Lake Ontario pelagic food web”*, M. Alaee, J.M. Luross, D.M. Whittle, D.B. Sergeant, Organohalogen Compounds, 57, **2002**, 427-430.

26 *“The significance of brominated flame retardants in the environment: current understanding, issues and challenges.”* M. Alaee, R.J. Wenning, Chemosphere, 46, **2002**, 579-582. 46:579–582.

27 “Brominated Flame Retardants (PBDE and PBB) in sludge – a Problem?”; Th. Hellström, The Swedish Water and Wastewater Association, report No M 113, 2000.

28 *“Fluorinated alkyl surfactants”*, M.M. Schultz, D.F. Barofsky, J.A. Field, Environmental Engineering Science, 20(5), **2003**, 487-501.

29 *“The developmental toxicity of perfluoroalkyl acids and their derivatives”*, C. Lau, J.L. Butenhoff, J.M. Rogers, Toxicology and Applied Pharmacology, 198(2), **2004**, 231-241.

30 *“Neuroendocrine effects of perfluorooctane sulfonate in rats”*, M.E. Austin, B.S. Kasturi, M. Barber, K. Kannan, P.S. MohanKumar, S.M.J. MohanKumar, Environmental Health Perspectives, 111(12), **2003**, 1485-1489.

31 *“Perfluorooctane sulfonate - a quite mobile anionic anthropogenic surfactant, ubiquitously found in the environment”*, R.J.W. Meesters, H.F. Schroder, Water Science And Technology, 50(5), **2004**, 235-242.

32 *“Voorkomen van MTBE in het”Nederlandse oppervlaktewater”*, G.A. van den Berg, L.M. Puijker, VEWIN, **2005**, 7.

33 *“Analysis, occurrence and fate of MTBE in the aquatic environment over the past decade”*; M. Rosell, S. Lacorte, D. Barcelo; Trends in Analytical Chemistry, 25(10), **2006**, 1016-1029.

34 *“Removal of Persistent Polar Pollutants Through improved treatment of wastewater effluents”*, P-THREE, http://www.pthree.de, **2005**.

35 *“Environmental properties and effects of nonionic surfactant adjuvants in pesticides: a review.”*, K.A. Krogh, B. Halling-Sxrensen, B.B. Mogensen, K.V. Vejrup, Chemosphere, 50, **2003**, 871–901.

36 *“LC–MS–MS analysis and occurrence of octyl- and nonylphenol, their ethoxylates and their carboxylates in Belgian and Italian textile industry, waste water treatment plant effluents and surface waters”*, R. Loos, G. Hanke, G. Umlauf, S. J. Eisenreich, Chemosphere, **2006**.

37 *“Behaviour of alkylphenol polyethoxylate surfactants in the aquatic environment. 1. Occurrence and transformation in sewage treatment”*, M. Ahel, W. Giger, M. Koch, Water Res., 28, **1994**, 1131-1141.

38 *“Analysis and removal of emerging contaminants in wastewater and drinking water”*, M. Petrovic , S. Gonzalez, D. Barcelo, Trends in Analytical Chemistry, 22(10), **2003**, 685-696.

39 *“Analysis and removal of emerging contaminants in wastewater and drinking water”*, M. Petrovic , S. Gonzalez, D. Barcelo, Trends in Analytical Chemistry, 22(10), **2003**, 685-696.

40 *“Risicovolle lozingen op de Maas”*, R.P.M. Berbee, D.F. Kalf, RWS RIZA, **2006**.

41 *“Phthalates, nonylphenols and LAS in an alternately operated wastewater treatment plant—fate modelling based on measured concentrations in wastewater and sludge”*; P. Fauser, J. VikelsØe, P. B. SØrensen, L. Carlse; Water Research, 37, **2003**, 1288–1295.

42 *“Phtalates and Nonyl Phemols in Soil. A Field Study of DIfferetn Soil Profiles;”* J. Vikelsoe, M. Thomsen, E. Johansen, L. Carlsen, NERI technical Report No. 268, **1999**.

43 *“Analysis of polar hydrophilic aromatic sulfonates in waste water treatment plants by CE/MS and LC/MS”*, R. Loos, J. Riu, M. C. Alonso and D. Barcelo, J. Mass Spectrom., 35, **2000**, 1197–1206.

44 *“Synthesis of Sulfonated Naphthalene-Formaldehyde Condensates and their Trace-analytical Determination in Wastewater and River Water”*, C. Redin, F.T. Lange, H-J. Brauch, S.H. Eberle, Acta Hydrochimica Hydrobiologica, 27(3), **1999**, 136-143.

45 *“Selective Determination of Aromatic Sulfonates in Landfill Leachates and Groundwater Using Microbore Liquid Chromatography Coupled with Mass Spectrometry”*, M.J.-F. Suter, MJ-F, S. Riediker, W. Giger, Analytical Chemistry, 71(4), **1999**, 897-904.

46 *“Determination of sulphonated azo dyes in water and wastewater”*, J. Riu, I. Schönsee, D. Barcelo, C. Rafols, Trends in Analytical Chemistry, 16(7), **1997**, 405-419.

47 M.C. Alonso, M. Castillo, D. Barcelo Anal. Chem. 71, **1999**, 2586.

48 F.T. Lange, Vom Wasser, 90, **1998**, 121.

49 *“Identification of toxic compounds in wastewater treatment plants during a field experiment”*, M. Farré, G. Klöter, M. Petrovic, M. C. Alonso, M. J. López de Alda, D. Barceló, Analytica Chimica Acta, 456, **2002**, 19–30.

50 *“Pharmaceuticals and Personal Care Products in the Environment: Agents of Subtle Change?”*, C. G. Daughton, T. A. Ternes, Environmental Health Perspectives, 107(6), **1999**.

51 *“Estrogenic activity of musk fragrances detected by the E-screen assay using human MCF-7 cells”*, N. Bitsch, C. Dudas, W. Körner, K. Failing, S. Biselli, G. Rimkus, H. Brunn, Archives of Environmental Contamination and Toxicology, 43(3), **2002**, 257-264.

52 *“Environmental risk assessment for the polycyclic musks AHTN and HHCB in the EU. I. Fate and exposure assessment”*, F. Balk, A. Ford, Toxicol. Lett., 111, **1999**, 57-79.

53 *“The impact of musk ketone on reproduction in zebrafish (Danio rerio)”*, G. Carlsson, S. Orn, P.L. Anderson, H. Soderstrom, L. Norrgren, Mar. Environ. Res., 50(1-5), **2000**, 237-241.

54 *“Removal of pharmaceuticals and fragrances in biological wastewater treatment”*, A. Jossa, E. Kellera, A.C. Aldera, A. Göbela, C.S. McArdella, T. Ternes, H. Siegrist, Water Research, 39, **2005**, 3139–3152.

55 *“Detection of UV-sunscreen agents in water and fish of the Meerfelder Maar the Eifel Germany”*, M. Nagtegaal, T.A. Ternes, W. Baumann, R. Nagel, UWSF-Z für Umweltchem Ökotox, 9(2), **1997**, 79–86.

56 *“Detection of UV-sunscreen agents in breast milk”*, J. Hany, R. Nagel, Deutsche Lebensmittel 91, **1995**, 341–245.

57 *“Pharmaceuticals, hormones, and other Organic Wastewater Contaminants in U.S. Streams, 1999-2000: A National Reconnaissance”*, D.W. Kolpin, E.T. Furlong, M.T. Meyer, E.M. Thurman, S.D., Zaug, L.B. Barber, H.T. Buxton, Environmental Science & Technology, 36(6), **2002**, 1202–1211.

58 *“Occurrence and biodegradability studies of selected pharmaceuticals and personal care products in sewage effluent”*, J. T. Yua, E. J. Bouwer, M. Coelhan, 86(1-2), **2006**, 72-80.

59 *“Removal Characteristics of Human Antibiotics during Wastewater Treatment in Japan”*, Y. Kobayasi, M. yasojima, K.Komori, Y. Suzuki, H. Tanaka, Water Practice & Technology, 1(3), **2006**.

60 *“Pharmaceutically Active Compounds in Residential and Hospital Efluent, Municipal Wastewater, and the Rio Grande in Albuquerque, New Mexico”*, K. D. Brown, The University of New Mexico,

Albuquerque, New Mexico, Publication No WRP-9, **2004**.

61 *"Determination of fluoroquinolone antibiotics in wastewater effluents by liquid chromatography–mass spectrometry and fluorescence detection"*, H. Nakata, K. Kannan, P.D. Jones, J.P. Giesy, Chemosphere, 58, **2005**, 759–766.

62 *"Quinolone antimicrobial agents: mechanism of action and resistance development"*, L.E. Bryan, J. Bedard, S. Wong, S. Chamberland, Clinical. Invest. Med., 12, **1989**, 14–19.

63 *"Fate of 5-fluorouracil, doxorubicin, epirubicin, and daunorubicin in hospital wastewater and their elimination by activated sludge and treatment in a membrane-bio-reactor system"*, S.N. Mahnik, K. Lenz N. Weissenbacher, R.M. Mader, M. Fuerhacker, Chemosphere,

64 *"Biodegradability of the anti-tumour agent ifosfamide and its occurrence in hospital effluents and communal sewage"*, K. Kümmerer, T. Steger-Hartmann, M. Meyer, Water Research, 31, **1997**, 2705–2710.

65 *"Occurence of triiodinated X-ray contrast agents in the aquatic environment"*, A. Putschew, S. Wischnack, M. Jekel, , Science of the Total Environment, 255, **2000**, 129–134.

66 *"Occurence of triiodinated X-ray contrast agents in the aquatic environment"*, A. Putschew, S. Wischnack, M. Jekel, , Science of the Total Environment, 255, **2000**, 129–134.

67 *"Pharmaceuticals and Personal Care Products in the Environment: Agents of Subtle Change?"*, C. G. Daughton, T. A. Ternes, , Environmental Health Perspectives, 107, **1999**, 907 – 938.

68 *"Ozonation: a tool for removal of pharmaceuticals, contrast media and musk fragrances from wastewater?"*, T.A. Ternes, J. Stuber, N. Herrmann, D. McDowell, A. Ried, M. Kampmann, B. Teiser, Water Research, 37, **2003**, 1976–1982.

69 *"Humane en veterinaire geneesmiddelen in Nederlands oppervlaktewater en afvalwater; een screening in 2002"*, M.S. Schrap, G.B.J. Rijs, M.A. Beek, J.F.N. Maaskant, J. Staeb, G. Stroomberg, J. Tiesnitsch, , RIZA, **2003**, rapport 2003.023. (ISBN 36956234)

70 *"Removal of pharmaceuticals and fragrances in biological wastewater treatment"*, A. Jossa, E. Kellera, A.C. Aldera, A. Göbela, C.S. McArdella, T. Ternes, H. Siegrist, Water Research, 39, **2005**, 3139–3152.

71 *"Environmental risk assessment for the widely used iodinated x-ray contrast agent iopromide"*, T. Steger-Hartmann, R. Lange, H. Schweinfurth, Ecotoxicology Environmental Safety, 42, **1999**, 274-281.

72 *"Biodegradation of the iodinated X-ray contrast media diatrizoate and iopromide"*, W. Kalsch, Science of the Total Environment,225, **1999**, 143-153.

73 *"Determination of estrogen steroids in surface water and waste water by liquid chromatography-electrospray tandem mass spectrometry"*, S. Zuehlke, U. Duennbier, T. Heberer, Journal of Separation Sciences, 28, **2005**, 52–58.

74 *"Validation of a quantitative assay using GC/MS for trace determination of free and conjugated estrogens in environmental water samples"*, Asmaa Mouatassim-Souali, S. L. Tamisier-Karolak, D. Perdiz, M. Cargouet, Y. Levi, Journal of Separation Sciences, 26, **2003**, 105–111.

75 *"Comparing steroid estrogen, and nonylphenol content across a range of European sewage plants with different treatment and management practices"*, A.C. Johnson, H.-R. Aerni, A. Gerritsen, M. Gibert, W. Giger, K. Hylland,M. Jürgens, T. Nakari, A. Pickering, M.J.-F. Suter, A. Svenson, F.E. Wettstein, Water Research, 39, **2005**, 47–58.

76 *"Identification of Estrogenic Chemicals in STW Effluent. 1. Chemical Fractionation and in Vitro Biological Screening"*, C. Desbrow, E.J. Routledge, G.C. Brighty, J.P. Sumpter, M. Waldock, Environmental Science & Technology, 32(11), 199, 1549-1558.

77 *"Removal of Estrogens in Municipal Wastewater Treatment under Aerobic and Anaerobic Conditions, Consequences for Plant Optimization"*, A.Joss, H. Andersen, T. Ternes, P.R. Richle, H. Siegrist, Environ. Sci. Technol., 37, **2004**, 3047-3055.

78 *“Influent- en effluentonderzoek rwzi’s Deel B, hormoonverstorende stoffen”*, Grontmij|AquaSense; **2005**.

79 *“Verwijdering van hormoonverstorende stiffen in rioolwaterzuiveringsinstallaties”*; STOWA, **2003**.

80 *“Multi-residue analysis of pharmaceuticals in wastewater by ultra-performance liquid chromatography–quadrupole–time-of-flight mass spectrometry”*, M. Petrovic; M. Gros; D. Barcelo, Journal of Chromatography A, 1124, **2006**, 68–81.

81 *“Occurrence and reductions of pharmaceuticals and personal care products and estrogens by municipal wastewater treatment plants in Ontario, Canada”*, L. Lishman, S. A. Smyth, K. Sarafin, S. Kleywegt, J. Toito, T. Peart, B. Lee, M. Servos, M. Beland, P. Seto, Science of the Total Environment, 367, **2006**, 544–558.

82 *“Development of a multi-residue analytical methodology based on liquid chromatography–tandem mass spectrometry (LC–MS/MS) for screening and trace level determination of pharmaceuticals in surface and wastewaters”*; Meritxell Gros, Mira Petrovic, Damia Barcelo; Talanta, 70, **2006**, 678–690.

83 *“Occurrence of drugs in German sewage treatment plants and rivers”*, T. A. Ternes, Water Research, 32(11), **1998**, 3245-3260.

84 *“Occurrence and removal of selected organic micropollutants at mechanical, chemical and advanced wastewater treatment plants in Norway”*, C. Vogelsang, M. Grung, T. G. Jantsch, K. E. Tollefsen, H. Liltved; Water Research, 40(19), **2006**, 3559-3570.

85 *“Bentazon in the Rhine, Drinking water and in Rain”*, J.G.M.M. Smeenk; R.C. Lindhout; O.I. Snoek, H2O, 21(7), 1988,183-185.

86 *“Comparing pharmaceutical and pesticide loads into a small Mediterranean river”*, L. Comoretto, S. Chiron, Science of the Total Environment, 349, **2005**, 201– 210.

87 *“Ecstasy in het uitgaanscircuit”*; Sociaal-epidemiologisch onderzoek naar de aard, omvang en risico’s van het gebruik van XTC en andere uitgaansdrugs op houseparty’s”, CVO, **1999**.

88 *“Ecstasy: The clinical, pharmacological and neurotoxicological effects of the drug MDMA.”*, S-J. Peroutka ed., Kluwer Academic Publishers, **1990**.

89 *“Abused drugs II, a Laboratory Pocket Guide”*, J. Wilson, AACC Press. Washington DC, **1994**, p 52.

90 *“NDMA Abuse”*, N.D.Volkow, NIDA REasearch Reports Series, US Department of Health and Human Services; National Institute of Health, **2006**.

91 *“Cocain in surface water: a new evidence-based tool for monitoring community drug abuse*” Zuccato E, Chiabrando C, Castiglioni S, Calamari D, Bagnati R, Schiarea S and Fanelli R, Environm Health: Global Access Science Source **2005**, 4: 14

8

Annex 1:

Sorption, Volatization potentials and removal efficiencies of selected substances in WWTP's.

Compound	Cas nr	Log P	Hc	Hc/Kow
Iohexol	66108-95-0	-3.05	2.66E-29	2.98E-26
Metformin	657-24-9	-2.64	1.69E-14	7.38E-12
iopamidol	60166-93-0	-2.42	1.14E-25	3.00E-23
iopromide	73334-07-3	-2.05	1.00E-28	***1.12E-26***
tetracycline	60-54-8	-1.30	4.66E-24	***9.30E-23***
diatrizoate	737-31-5	-1.28	-	-
norfloxacin	70458-96-7	-1.03	***8.70E-18***	***9.32E-17***
chlorotetracycline	57-62-5	-0.62	***3.45E-24***	***1.44E-23***
lomefloxacin	98079-51-7	-0.30	***1.35E-18***	***2.69E-18***
enoxacin	74011-58-8	-0.20	***1.14E-21***	***1.81E-21***
sulfadiazine	68-35-9	-0.09	***1.58E-10***	***1.94E-10***
caffeine	58-08-2	-0.07	***1.90E-19***	***2.23E-19***
cotinine	486-56-6	0.07	***3.33E-12***	***2.83E-12***
atenolol	29122-68-7	0.16	***1.37E-18***	***9.48E-19***
sotalol	3930-20-9	0.24	***2.49E-14***	***1.43E-14***
ranitidine	66357-35-5	0.27	***3.42E-15***	***1.84E-15***
ciprofloxacin	85721-33-1	0.28	***5.09E-19***	***2.67E-19***
dimetridazol	551-92-8	0.31	***3.49E-07***	1.71E-07
phenazone	60-80-0	0.38	***6.65E-10***	***2.77E-10***
cimetidine	51481-61-9	0.40	***9.50E-16***	***3.78E-16***
acetylsalicylic acid	103-90-2	0.46	***6.42E-13***	***2.23E-13***
paracetamol	103-90-2	0.46	***6.42E-13***	***2.23E-13***
sulfamethizole	144-82-1	0.54	***2.63E-14***	***7.59E-15***
lincomycine	154-21-2	0.56	***3.00E-23***	***8.26E-24***
salicylic acid	69-72-7	0.64	***7.34E-09***	1.68E-09
diclofenac-Na	15307-79-6	0.70	-	-
enrofloxacine	93106-60-6	0.70	***1.50E-18***	***2.99E-19***
sulfamethazine	57-68-1	0.89	***3.05E-13***	***3.93E-14***
sulfamethoxazole	723-46-6	0.89	***6.42E-13***	***8.27E-14***
trimethoprim	738-70-5	0.91	***2.39E-14***	***2.94E-15***
aminopyrine	58-15-1	1.00	***1.38E-11***	***1.38E-12***
dimethylaminophenazone	58-15-1	1.00	***1.38E-11***	***1.38E-12***
chloroamfenicol	56-75-7	1.14	***2.29E-18***	***1.66E-19***
codeine	76-57-3	1.19	***7.58E-14***	***4.89E-15***
tri(2-chloroethyl)phosphate	115-96-8	1.44	***3.29E-06***	1.19E-07
phenol	108-95-2	1.46	***3.33E-07***	1.15E-08
acetophenon	98-86-2	1.58	-	-

Sorption, Volatization potentials and removal efficiencies. (continuation)

Compound	Cas nr	Log P	Hc	Hc/Kow
flumequine	42835-25-6	1.60	***2.67E-13***	***6.71E-15***
phtahlicphtalic anhydride	85-44-9	1.60	***1.63E-08***	***4.09E-10***
tylosin	1401-69-0	1.63	***5.77E-38***	***1.35E-39***
Sulfadimethoxine	122-11-2	1.63	***1.30E-14***	***3.05E-16***
acebutolol	37517-30-9	1.71	***3.01E-20***	***5.87E-22***
bisoprolol	66722-44-9	1.87	***2.89E-15***	***3.90E-17***
metoprolol	37350-58-6	1.88	***1.40E-13***	***1.85E-15***
4-methylphenol	106-44-5	1.94	***1.00E-06***	1.15E-08
oxprenolol	6452-71-7	2.10	***6.35E-13***	***5.04E-15***
clindamycine	18323-44-9	2.16	***2.89E-22***	***2.00E-24***
N,N-diethyl-toluamide (DEET)	134-62-3	2.18	***2.08E-08***	***1.37E-10***
carbaryl	63-25-2	2.36	***3.27E-09***	***1.43E-11***
diethylphtalate	84-66-2	2.42	***6.10E-07***	2.32E-09
estriol	50-27-1	2.45	***1.33E-12***	***4.72E-15***
carbamazepine	298-46-4	2.45	***1.08E-10***	***3.83E-13***
estrone	53-16-7	2.45	***3.80E-10***	***1.35E-12***
clofibric acid	882-09-7	2.57	2.19E-08	***5.89E-11***
roxithromycine	80214-83-1	2.75	-	-
dilttiazem	42399-41-7	2.79	-	-
betaxolol	63659-18-7	2.81	1.45E-13	***2.25E-16***
methyl-parathion	298-00-0	2.86	1.00E-07	***1.38E-10***
erythromycine	114-07-8	3.06	5.42E-29	***4.72E-32***
ketoprofen	22071-15-4	3.12	2.12E-11	***1.61E-14***
naproxen	22204-53-1	3.18	3.39E-10	***2.24E-13***
naphtalene	91-20-3	3.30	0.00044	2.21E-07
bisphenol-A	80-05-7	3.32	1.00E-11	***4.79E-15***
testosteron	58-22-0	3.32	3.53E-09	***1.69E-12***
tetrachloroethylene	127-18-4	3.40	0.0177	7.05E-06
1,4-dichlorobenzene	106-46-7	3.44	0.00241	8.75E-07
3-tert-butyl-4-hydroxy anisole	25013-16-5	3.50	1.17E-06	***3.70E-10***
carazolol	57775-29-8	3.59	5.56E-16	***1.43E-19***
tri(dichlorisopropyl)phosphate	13674-87-8	3.65	2.61E-09	***5.84E-13***
cis-androsterone	53-41-8	3.69	2.79E-08	***5.70E-12***
lindane	58-89-9	3.72	5.14E-06	***9.79E-10***
ethanol,2-butoxy-phosphate	78-51-3	3.75	1.20E-11	***2.13E-15***
diazinon	333-41-5	3.81	1.13E-07	***1.75E-11***
progesteron	57-83-0	3.87	6.49E-08	***8.75E-12***

Sorption, Volatization potentials and removal efficiencies. (continuation)

Compound	Cas nr	Log P	Hc	Hc/Kow
fenoprofen	31879-05-7	3.90	-	-
equilenin	517-09-9	3.93	-	-
17a-ethinil estradiol	57-63-6	3.94	7.94E-12	***9.12E-16***
ibuprofen	15687-27-1	3.97	1.50E-07	***1.61E-11***
fluoxetine	54910-89-3	4.05	8.90E-08	***7.93E-12***
flurbiprofen	5104-49-4	4.16	5.26E-09	***3.64E-13***
muskambrete	83-66-9	4.17	-	-
chloroprene	120-32-1	4.18	9.96E-09	***6.58E-13***
indomethacine	53-86-1	4.27	3.13E-14	***1.68E-18***
2,6-di-tert-butyl-1,4-benzoquinone	719-22-2	4.42	1.64E-08	***6.24E-13***
musk xylene	81-15-2	4.45	-	-
anthracene	120-12-7	4.45	5.56E-05	1.97E-09
phenanthrene	85-01-8	4.46	4.23E-05	1.47E-09
diclofenac	15307-86-5	4.51	4.73E-12	***1.46E-16***
triphenyl phosphate	115-86-6	4.59	3.31E-06	***8.51E-11***
mestranol	72-33-3	4.68	-	-
triclosan	3380-34-5	4.76	4.99E-09	***8.67E-14***
gemfibrozil	25812-30-0	4.77	-	-
pyrene	129-00-0	4.88	1.19E-05	***1.57E-10***
2,6-di-tert-butylphenol	128-39-2	4.92	3.15E-06	***3.79E-11***
chlorpyrifos	2921-88-2	4.96	2.93E-06	***3.21E-11***
butylated hydroxytoluene	128-37-0	5.10	4.12E-06	***3.27E-11***
fluoranthene	206-44-0	5.16	8.86E-06	***6.13E-11***
fenofibrate	49562-28-9	5.19	-	-
dieldrin	60-57-1	5.40	1.00E-05	***3.98E-11***
4-nonylphenol	104-40-5	5.76	3.40E-05	***5.91E-11***
cis-chlordane	5103-71-9	6.10	0.000347	***2.76E-10***
bis(2-ethylhexyl) adipate	103-23-1	6.11	4.34E-07	***3.37E-13***
benzo[a]pyrene	50-32-8	6.13	4.57E-07	***3.39E-13***
di (2-ethylhexyl)phthalate (DEHP)	117-81-7	7.60	2.70E-07	***6.78E-15***
cholesterol	57-88-5	8.74	0.000167	***3.04E-13***
coprostranol	360-68-9	8.82	-	-
1-tert-butyl-3,5-dimethyl-2,4,6-triaminobenzene		-	-	
1-tert-butyl-3,5-dimethyl-2,				
4-diamino-6-nitrobenzene		-	-	
1-tert-butyl-3,5-dimethyl-2-amino-4,6-dinitrobenzene		-	-	
1-tert-butyl-3,5-dimethyl-4-amino-2,6-				
dinitrobenzene		-	-	
3,4,5,6-tetrabromo-o-cresol	576-55-6		-	-
amidotrizoïc acid		-	-	
anhydro-erytromycine	-	-		
bezafibrate	41859-67-0		-	-

Sorption, Volatization potentials and removal efficiencies. (continuation)

Compound	Cas nr	Log P	Hc	Hc/Kow
celestoide		-	-	
fenofibric acid	42017-89-0		-	-
galaxolide	1222-05-5		-	-
iopremol		-	-	
iotalaminic acid		-	-	
iotrolan	79770-24-4		-	-
ioxitalaminic acid		-	-	
lidocaïne		-	-	
methylbenzylidene				
camphor	36861-47-9		-	-
musk ketone	81-14-1	-	-	
musk moskene	116-66-5			
musk tibetene	145-39-1			
ofloxacin	83380-47-6			
oxytetracycline	6153-64-6			
propanolol	-			
tonalide	1506-02-1			

Sorption, Volatization potentials and removal efficiencies. (continuation)

Notes:
Notes:

Notes:

RIWA
Rijnwaterbedrijven

Colofon

HET WATERLABORATORIUM

Author: Dr. Ir. Eric S.E. van Beelen

Quality Assurance: Dr. Jan Kroesbergen

Publisher: Association of River Waterworks – RIWA

Design: Meyson Communicatie, Amsterdam

Print: ATP Digitale Media

ISBN: 978-90-6683-124-7

Groenendael 6
NL - 3439 LV Nieuwegein
The Netherlands
T +31 (0)30 600 90 30
F +31 (0)30 600 90 39
E riwa@riwa.org
W www.riwa.org

Association of River Waterworks - RIWA