Drinking Water Treatment Technologies in Europe: State of the Art – Vulnerabilities – Research Needs

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Abstract
Eureau is the European Federation of National Associations of Water and Wastewater Services. At the request of Eureau Commission 1, dealing with drinking water, a survey was made focusing on raw drinking water sources and drinking water treatment technologies applied in Europe. Raw water sources concerned groundwater, surface water, surface water with artificial recharge and river bank filtration. Treatment schemes concerned no treatment, conventional treatment, advanced treatment and conventional plus advanced treatment. The response covered 73% of the population to which drinking water is supplied by the utilities joint in Eureau. Groundwater and surface water are the major raw water sources (>90%). In total, 59% of the drinking water supply concerns not-treated drinking water or drinking water treated with only conventional technologies, while 12% of the drinking water is not disinfected. Vulnerabilities of the European drinking water supply are the contamination of raw water sources with emerging substances, the absence of disinfection and the potential formation of disinfection by-products. Based on this, research needs are the development of quantitative structure activity relationships (QSARs) to better understand and predict the removal rates of treatment technologies for emerging contaminants, the introduction of Water Safety Plans to prevent hygienic contamination of drinking water, and the optimization of disinfection processes and strategies.

Keywords
Advanced treatment; conventional treatment; disinfection; drinking water treatment; emerging substances; Europe

INTRODUCTION

Eureau is the European Federation of National Associations of Water and Wastewater Services (Eureau 2009, Eureau 2012). Eureau gathers 10,000 water and wastewater utilities across Europe that provide sustainable water services to around 405 million European citizens. At present, the membership covers 23 out of 27 EU member countries (all but Estonia, Lithuania, Latvia and Slovenia), 2 EFTA (European Free Trade Association) countries (Norway and Switzerland) and 2 observer members (Croatia and Serbia). Hence, Eureau is the voice of Europe's drinking and wastewater operators and reflects the full diversity of the European water service industry across Europe. The mission of Eureau is to promote the common interests of its members to the European Community institutions and to keep its members informed of relevant developments in the European arena.

In practice this results in the following activities: (1) to promote the common interests of the European water service sector to the EU institutions and stakeholders; (2) to enable its members to adequately deal with opportunities and threats arising from EU policy and its national implementation; (3) to support members' networking.

Within Eureau, Eureau Commission 1 deals with drinking water. At the request of Eureau Commission 1 a survey has been carried out focusing on the type of raw water sources and the

drinking water technologies applied in Europe. The aim of this survey was threefold. Firstly, to promote the interests of the European drinking water sector, it is essential to have a clear picture of the raw water sources and treatment technologies applied in the drinking water supply. With such knowledge Eureau is better able to comment and react to new policies being developed at the EU level with respect to drinking water issues (revisions and development of guidelines and regulations such as the European Drinking Water Directive (European Union 1998) and the European Water Framework Directive (European Union 2000)). Secondly, with a clear picture of the drinking water supply in Europe Eureau is able to identify strengths and weaknesses in drinking water supply. Thirdly, with knowledge of the strengths and weaknesses Eureau can identify research needs and influence policy making at the EU level in the field of research and development.
In this paper the results of the survey will be presented, strengths and weaknesses of the European drinking water supply will be identified, and research needs will be described.

METHODS

To all members of Eureau a questionnaire was sent. Four different categories of raw water sources were distinguished: groundwater, surface water, surface water with artificial recharge, and river bank filtration. Within each category, four treatment schemes were defined:

- no treatment
- conventional treatment
- advanced treatment
- conventional plus advanced treatment

In Table 1 the treatment schemes for each raw water source are described in more detail. In the case of surface water with artificial recharge, the conventional and advanced treatment technologies may be used either before or after the soil passage. In the case of river bank filtration, the conventional and advanced treatment technologies are used after the soil passage. In total this results in 16 typical systems. Eureau members were asked to divide the yearly drinking water production over these 16 systems in m^3/year, and to specify the population served with each system. In addition, members were asked whether the drinking water is disinfected and if so, which kind of disinfection process is applied.

Table 1. Raw water sources and treatment schemes.

		Raw water source			
		Groundwater	Surface water	Surface water + artificial recharge	River bank filtration
Treatment scheme	No treatment	-	-	surface water + AR[3] without treatment	no post treatment
	Conventional treatment	aeration and/or RSF[1]	CSF[2]	surface water + AR[3] with treatment: aeration and/or CSF	post treatment: aeration and/or RSF[1]
	Advanced treatment	carbon filtration, AOP[4], membranes, desalination, etc.	carbon filtration, AOP[4], membranes, desalination, etc.	surface water + AR[3] with treatment: advanced treatment like carbon filtration, AOP[4], membranes, desalination, etc.	post treatment: carbon filtration, AOP[4], membranes, desalination, etc.
	Conventional + advanced treatment	aeration and/or RSF[1] + advanced treatment	CSF[2] + advanced treatment	surface water + AR[3] with treatment: aeration and/or CSF[2] + advanced treatment	post treatment: aeration and/or RSF[1] + advanced treatment

[1]Rapid Sand Filtration; [2]Coagulation/Sedimentation/Filtration; [3]Artificial Recharge; [4]Advanced oxidation Processes

RESULTS

Responses

In total 23 Eureau member countries responded to the questionnaire (Table 2). The figures cover 58% of the population of Europe (in total 512 million citizens) and 73% of the European citizens to which drinking water is supplied by utilities joint in Eureau (in total supply to 405 million citizens). Of the responders, not all were able to deliver a complete dataset according to the required information. Some remarkable observations from the responses are:

- for the individual countries that delivered data, the data cover between 5% and 100% of the population in these countries;
- in case more detailed information was asked (the use of specific treatment schemes within a specific category of raw water source) it was easier to deliver production figures in m^3/year than the number of citizens supplied. For the total yearly production, the number of citizens supplied were available;
- in all cases it was possible to answer the question whether the drinking water is disinfected or not. However, in many cases it was not possible to specify the disinfection method.

Table 2. Responses from Eureau members.

Country	Number of citizens (millions)	Response (%)
Austria	8.3	100
Belgium	10.6	100
Bulgaria	7.35	71
Croatia	4.4	0
Cyprus	0.8	100
Czech Republic	10.3	100
Denmark	5.4	100
Estonia[1]	1.3	0
Finland	5.3	100
France	63.7	100
Germany	82.2	67
Greece	11.2	100
Hungary	10.0	0
Ireland	4.4	93
Italy	59.6	8
Latvia[1]	2.2	0
Lithuania[1]	3.3	0
Luxemburg	0.5	100
Malta	0.4	100
Netherlands	16.4	100
Norway	4.7	100
Poland	38.1	5
Portugal	10.6	100
Romania	21.5	0
Slovakia	5.4	20
Slovenia[1]	2.0	0
Spain	45.2	60
Sweden	9.1	100
Switzerland	7.5	100
United Kingdom	61.1	54

[1] Not Eureau member

Raw water sources

Figure 1 shows the raw water sources used for drinking water production in Europe. Groundwater and surface water have the largest contribution. Surface water with artificial recharge and river bank filtration have minor contributions. Surface water with artificial recharge especially can be found in Germany, the Netherlands and Sweden, while river bank filtration is typical for Germany, the Netherlands and Great Britain. In 88% of the drinking water production schemes a disinfection method is applied. In the case of groundwater, 22.5% of the water produced is not disinfected. Almost all drinking water produced from surface water is disinfected (99.9%). In the case of surface water with artificial recharge 92.2% is disinfected and in the case of river bank filtration 90.1% is disinfected.

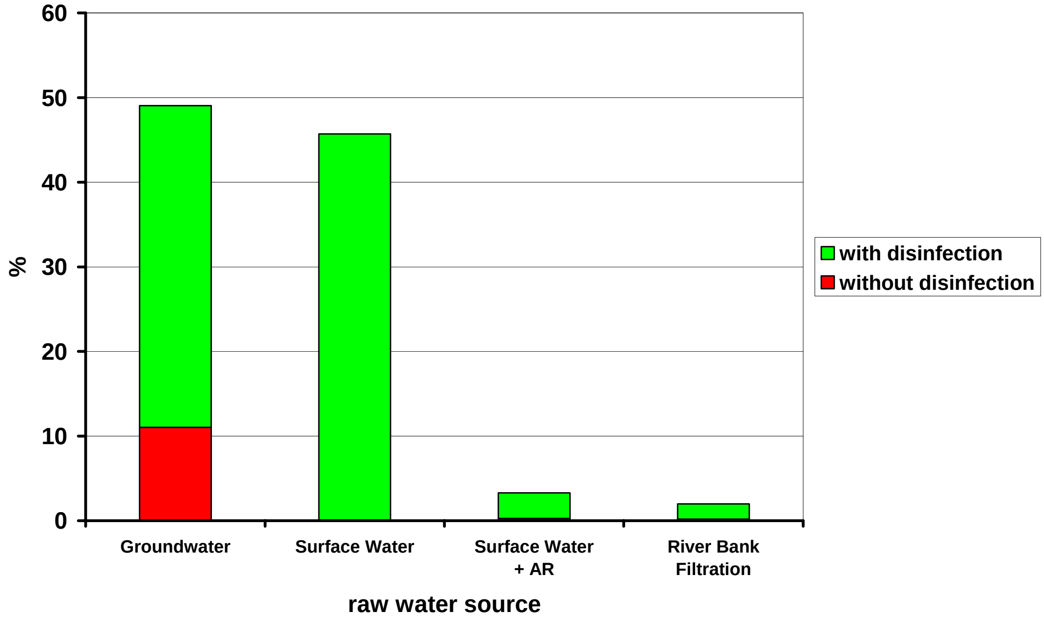

Figure 1. Raw water sources for drinking water production used in Europe.

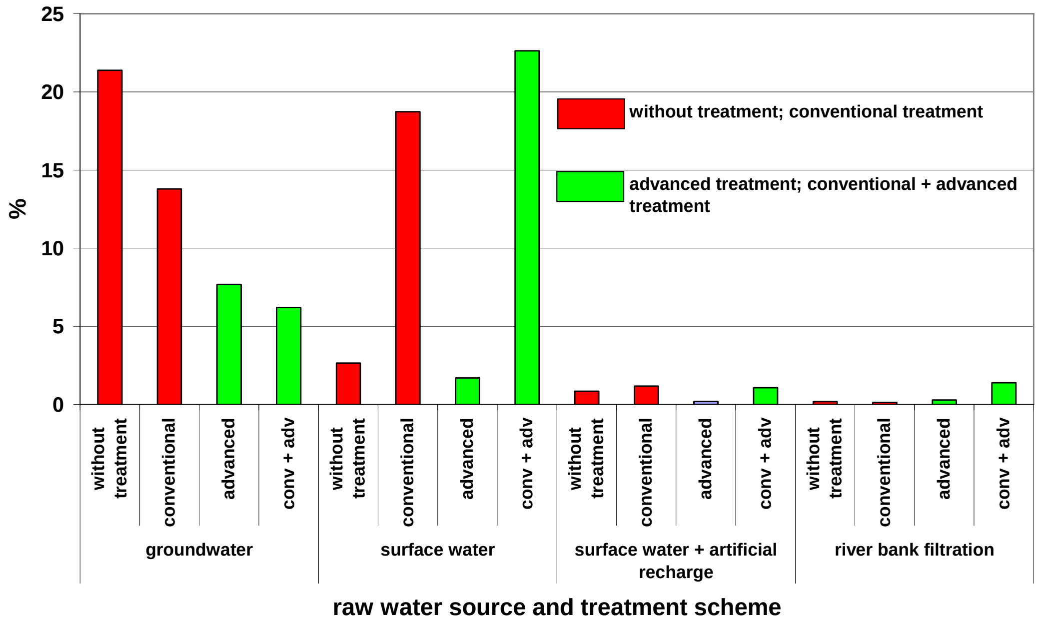

Figure 2. Raw water sources and treatment schemes.

Treatment schemes

Figure 2 shows the treatment schemes applied for drinking water production from the four raw water sources. For groundwater, 71% of the drinking water produced from groundwater is not treated or treated with a conventional system. This contributes for 35% to the total drinking water production. Of the drinking water produced from surface water, 47% is not treated or treated with only a conventional system. This contributes for 22% to the total drinking water production. Taking into account also surface water with artificial recharge and river bank filtration, in total 59% of the drinking water produced in Europe is not treated or only treated with a conventional system.

Disinfection methods

As already mentioned, in 88% of the drinking water production a disinfection method is applied. Figure 3 shows the methods used for disinfection, related to the total drinking water production. Because in some cases multiple disinfection methods are applied in one treatment process, the total percentage exceeds 100%. As can be seen in Figure 3, disinfection based on chlorine products (chlorine, hypochlorite, chlorine dioxide, chloramine) is most used. In more detail, in case surface water is disinfected, chlorine disinfection is applied for 62%. For groundwater, surface water with artificial recharge and river bank filtration these figures are 40%, 48% and 75% respectively. UV is used in 12% of the drinking water production, while the use of ozone for disinfection is relatively low (2%).

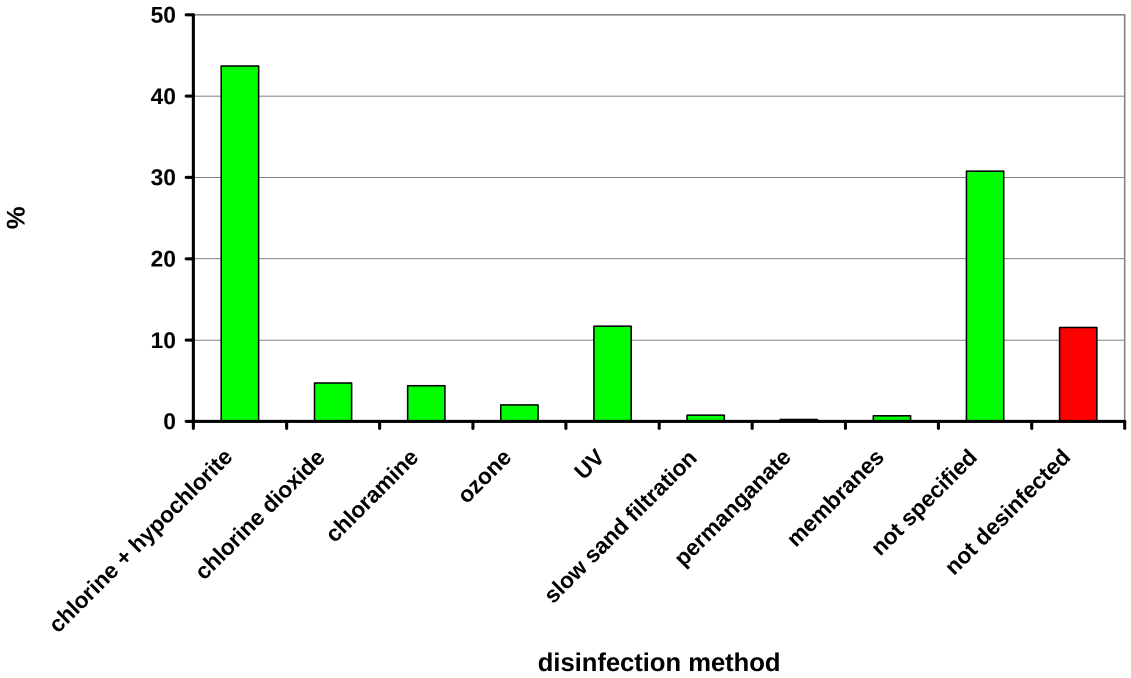

Figure 3. Disinfection methods used in drinking water production (related to total to total drinking water production).

DISCUSSION

Vulnerability for emerging substances

Nowadays, a growing number of emerging contaminants is being discovered in the raw water sources, especially in surface water. Houtman (2010) provides an overview of classes of emerging contaminants that are of relevance for drinking water production. These comprise e.g. endocrine disrupting compounds such as hormones and compounds with hormone-like properties, pharmaceuticals, illicit and non-controlled drugs, sweeteners, personal care products, complexing agents, nanoparticles, perfluorinated compounds, flame retardants, pesticides and fuel additives. According to the World Health Organization (WHO 2012) in the last decade traces of pharmaceuticals, typically at the levels in the nanograms to low micrograms per liter range, have been reported in the water cycle, including surface waters and groundwaters as sources for drinking water, and even in drinking water. Van der Aa et al. (2011) used demographic projections for quantifying future pharmaceutical consumption in the Netherlands and concluded that the total consumption is expected to increase and this may increase the emissions of pharmaceuticals to the water system. Van der Aa et al. (2010) also examined the presence of drugs of abuse and tranquilizers in Dutch surface waters, drinking water and wastewater. Compounds were detected in influents and effluents of sewage water treatment plants, in surface waters of the rivers Rhine and Meuse, in raw waters for drinking water production and in finished drinking water.

For pesticides in drinking water there are limits, set by the European Union: 0.1 µg/l for individual compounds and 0.5 µg/l for the sum of pesticides (European Union 1998). For most other emerging compounds, e.g. pharmaceuticals, there are no drinking water standards. Although one can argue about the toxicological relevance of these compounds at the observed concentrations, long-term effects are less clear as the necessary toxicity data are lacking (Van der Hoek et al. 2008). In addition, the presence of these compounds in the finished drinking water may affect customers' confidence in drinking water.

Looking at the drinking water production in Europe, 59% of the total production is not treated or treated with conventional treatment (Figure 2). For the emerging substances in general, conventional treatment steps do not completely remove these and advanced treatment is required to achieve maximum purification. For pharmaceuticals it is known that conventional treatment processes with coagulation, filtration and chlorination can remove about 50% of these compounds, whereas advanced treatment, such as ozonation, advanced oxidation, activated carbon and membrane processes can achieve higher removal rates, up to more than 90% (WHO 2012). Examples of effective advanced treatment processes are ozone and granular activated carbon filtration (Van der Hoek et al. 1999, Van der Hoek et al. 2000, Boucherie et al. 2010, Van der Aa et al. 2012), nanofiltration (Hofmann et al. 2011), UV/H_2O_2 treatment (Kruithof et al. 2000), combination of UV/H_2O_2/O_3 (Lester et al. 2011, Scheideler et al. 2011) and ion exchange in combination with ceramic microfiltration (Galjaard et al. 2011).

Although the vulnerability of the drinking water supply for emerging substances is mitigated by the use of groundwater protection zones and water resource protection measures, it is clear that the relatively high percentage of 'no treatment' and 'conventional treatment' implies a potential risk for the drinking water supply.

Vulnerability with respect to disinfection

Two vulnerabilities can be identified related to disinfection of drinking water. Firstly, 12% of the drinking water is not disinfected. Although this mainly concerns groundwater (95.5%) which is normally hygienically safe, during treatment and also during distribution contamination may occur (e.g. intrusion of water at low or negative pressure) implying a health risk for the consumers. Secondly, in case disinfection is applied, disinfection by-products can be produced. Chlorine and ozone are used as disinfection chemicals (Figure 3), and both are known for the formation of harmful disinfection by-products. Chlorination may result in the formation of chlorinated organic compounds, as discovered by Rook in 1973 (Rook 1974). Ozonation may result in the formation of carcinogenic bromate, as discovered by Kurokawa et al. at the end of the last century (Kurokawa et al. 1990). Also more recently developed disinfection technologies may result in unwanted effects. Heringa et al. (2011) showed that UV/H_2O_2 treatment of drinking water resulted in an increase of genotoxic activity.

So, the absence of disinfection, and the application of certain disinfection methods imply a health risk and show a potential vulnerability of the drinking water supply in Europe.

CONCLUSIONS

Research needs for the removal of emerging substances

The presence of emerging substances in raw water sources is a potential vulnerability for the drinking water supply in Europe. Advanced treatment technologies are capable to remove these substances, but they are expensive, the removal is not always 100% and the technologies may be quite selective (Houtman 2010). In addition, the number of emerging substances is enormous. In the European Union there are more than 100,000 registered chemicals (EINECS), of which 30,000 – 70,000 are in daily use (Schriks et al. 2010). A promising approach is using QSARs (quantitative structure activity relationships) or QSPRs (quantitative structure property relationships) to correlate the existing knowledge of a compound's chemical structure to water treatment process properties, such as a biological activity or physico-chemical property (Wols and Vries 2012). With the use of QSARs and QSPRs removal efficiencies of treatment processes for certain groups of compounds can be better predicted. In addition, QSARs and QSPRs show which characteristics of a process are important for the removal of specific contaminants or groups of contaminants, and thus give directions how to optimize processes. First steps in the development of QSARs for drinking water processes have been made, e.g for reverse osmosis and nanofiltration (Verliefde et al. 2009), for activated carbon filtration (De Ridder et al. 2010) and for river bank filtration (Bertelkamp et al. 2012). Further research is required to increase the predictability of the QSAR models and to develop QSAR models for other physico-chemical and biological processes. In addition, with a QSAR model

Research needs for disinfection

Although not in all cases disinfection of drinking water is required due to an excellent quality of the raw water source (especially groundwaters), still contamination of the water may take place during water abstraction, treatment and distribution. Therefore, it is important to know the risks and to manage the risks adequately. An important tool to reach this objective is the use and implementation of Water Safety Plans as promoted by the World Health Organization and IWA (Bartram et al. 2009, IWA 2004). In case disinfection is needed, the focus is on the prevention or restriction of the formation of disinfection by-products. Therefore research is needed into process conditions that minimize disinfection by-product formation, and the development of disinfection processes and drinking water treatment schemes that avoid the formation of disinfection by-products. The so-called "Dutch approach", in which the use of chlorine is abandoned and no persistent disinfectant is used (Van der Kooij et al. 1995), is a good example of this latter approach.

References

Bartram, J., Corralis, L., Davison, A., Deere, D., Drury, D., Gordon, B., Howard, G., Rinehold, A. and Stevens, M. (2009). Water safety plan manual: step-by-step risk management for drinking-water suppliers. Report WA 675, World Health Organization, Geneva, Switzerland.

Bertelkamp, C., Reungoat, J., Botton, S., Cornelissen, E., Ghadiri, E., De Jonge, M.,, Singhal, N., Van der Hoek, J.P. and Verliefde, A.R.D. (2012). Transformation of organic micropollutants during river bank filtration: laboratory versus field data. In Proceedings of the Singapore International Water Week, 1-5 July 2012, Singapore.

Boucherie, C., Lecarpentier, C., Fauchon, N., Djafer, M. and Heim, V. (2010). "Ozone" and "GAC filtration" synergy for removal of emerging micropollutants in a drinking water treatment plant? Water Science & Technology: Water Supply, 10(5), 860-868.

De Ridder, D.J., Villacorte, L., Verliefde, A.R.D., Verberk, J.Q.J.C., Heijman, S.G.J and Van Dijk, J.C. (2010). Modelling equilibrium adsorption of organic micropollutants onto activated carbon. Water Research, 44, 3077-3086.

Eureau (2009). EUREAU statistics overview on water and wastewater in Europe 2008 – Country profiles and European Statistics. Report of the European Federation of National Associations of Water and Wastewater Services, Eureau, Brussels, Belgium.

Eureau (2012). EUREAU – European Federation of National Associations of Water and Wastewater Services. Available at: http://www.eureau.org (accessed 30 August 2012).
European Union (1998). Council Directive 98/3/EC of 3 November 1998 on the quality intended for human consumption. Official Journal of the European Community, 5.12.98, L330/32 – L330/54.
European Union (2000). Directive 2000/60/EC of the European Parliament and the Council of 23 October 2000 establishing a framework for community action in the field of water policy. Official Journal of the European Community, 2000, L327/1 – L327/73.
Galjaard, G., Martijn, B., Koreman, E., Bogosh, M. and Malley, J. (2011). Performance evaluation SIX-Ceramac in comparison with conventional pre-treatment techniques for Surface Water Treatment. Water Practice & Technolgy 6(4), doi:10.2166/wpt.2011.066.
Heringa, M.B., Harmsen, D.J.H., Beerendonk, E.F., Reus, A.A., Krul, C.A.M., Metz, D.H. and IJpelaar, G.F. (2011). Formation and removal of genotoxic activity during UV/H_2O_2-GAC treatment of drinking water. Water Research, 45, 366-374.
Hofmann, R., Amiri, F., Wilson, S., Garvey, E., Metcalfe, C., Ishidi, C. and Lin, K. (2011). Comparing methods to remove emerging contaminants and disinfection by-products at pilot scale. Journal of Water Supply: Research and Technology – AQUA, 60(7), 425-433.
Houtman, C.J. (2010). Emerging contaminants in surface waters and their relevance for the production of drinking water in Europe. Journal of Integrative Environmental Sciences, First published on: 24 September 2010 (iFirst: http://dx.doi.org/10.1080/1943815X.2010.511648).
IWA (2004). The Bonn Charter for Safe Drinking Water. Report International Water Association, September 2004.
Kruithof, J.C., Kamp, P.C. and Finch, G.R. (2000). UV H_2O_2 treatment. "The ultimate solution for pesticide control and disinfection". In Proceedings AWWA Annual Conference, Denver 2000, USA.
Kurokawa, Y., Maekawa, A., Takahashi, M. and Hayashi, Y (1990). Toxicity and carcinogenicy of potassium bromate – a new renal carcinogen. Environmental Health Perspectives, 87, 309-335.
Lester, Y., Avisar, D., Gozlan, I. and Mamane, H. (2011). Removal of pharmaceuticals using combination of UV/H_2O_2/O_3 advanced oxidation process. Water Science & Technology, 64(11), 2230-2238.
Rook, J.J. (1974). Formation of haloforms during chlorination of natural water. Water Treatment Examination, 23(2), 234-243.
Scheideler, J., Lekkerkerker-Teunissen, K., Knol, T., Ried, A., Verberk, J. and Van Dijk, H (2011). Combination of O_3/H_2O_2 and UV for multiple barrier micropollutant treatment and bromate formation control – an economic attractive option. Water Practice & Technology 6(4), doi:10.2166/wpt.2011.063.
Schriks, M., Heringa, M.N., Van der Kooij, M.M.E., De Voogt, P.and Van Wezel, A.P. (2010). Toxicological relevance of emerging contaminants for drinking water quality. Water Research, 44, 461-476.
Van der Aa, L.T.J., Kolpa, R.J., Rietveld, L.C. and Van Dijk, J.C. (2012). Improved removal of pesticides in biological granular activated carbon filters by pre-oxidation of natural organic matter. Journal of Water Supply: Research and Technology – AQUA, 61(3), 153-163.
Van der Aa, N.G.F.M., Dijkman, E., Bijlsma, L., Emke, E., Van de Ven, B.M., Van Nuijs, A.L.N., and De Voogt, P. (2010). Drugs of abuse and tranquilizers in Dutch surface waters, drinking water and wastewater – Results of screening monitoring 2009. Report 703719064/2010, National Institute for Public Health and the Environment, Ministry of Health, Welfare and Sport, RIVM, Bilthoven, The Netherlands.
Van der Aa, N.G.F.M., Kommer, G.J., Van Montfoort, J.E. and Versteegh, J.F.M. (2011). Demographic projections of future pharmaceutical consumption in the Netherlands. Water Science & Technology, 63(4), 825-831.
Van der Hoek, J.P., Hofman, J.A.M.H. and Graveland, A. (1999). The use of biological activated carbon filtration for the removal of natural organic matter and organic micropollutants from water. Water Science & Technology, 40(9), 257-264.
Van der Hoek, J.P., Hofman, J.A.M.H. and Graveland, A (2000). Benefits of ozone-activated carbon filtration in integrated treatment processes, including membrane systems. Journal of Water Supply: Research and Technology-Aqua, 49(6), 341-356.
Van der Hoek, J.P., Stoks, P., Mons, M. and Van der Kooij, D. (2008). Visie op en streefwaarden voor milieuvreemde stoffen in drinkwater (Vision on and guidelines for anthropogenic substances in drinking water). H_2O, 41(4), 33-35.
Van der Kooij, D., Drost, Y.C., Hijnen, W.A.M., Willemsen-Zwaagstra, J., Nobel. P.J. and Schellart, J.A. (1995). Multiple barriers against micro-organisms in water treatment and distribution in the Netherlands. Water Supply, 13(2), 13-23.
Verliefde, A.R.D., Cornelissen, E.R., Heijman, S.G.J., Verberk, J.Q.J.C., Amy, G.L., Van der Bruggen, B. and Van Dijk, J.C. (2009). Construction and validation of a full-scale model for removal of organic micropollutants with NF/RO. Journal of Membrane Sciences, 339(1-2), 10-21.
WHO (2012). Pharmaceuticals in drinking-water. Report WA 30.5, World Health Organization, Geneva, Switzerland.
Wols, B.A. and Vries, D. On a QSAR approach for the prediction of priority compounds degradation by water treatment processes. Water Science & Technology, 66(7), 1446-1453.