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Practical Paper

Drinking water treatment technologies in Europe: state of the art – challenges – 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 produced 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. Challenges for the European drinking water sector are the contamination of raw water sources with emerging substances, absence of disinfection and the potential formation of disinfection by-products. These challenges entail research needs such as 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 safeguard the hygienic quality of drinking water, and the optimization of disinfection processes and strategies.

Key words | advanced treatment, conventional treatment, disinfection, drinking water treatment, emerging substances, Europe

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INTRODUCTION

Eureau is the European Federation of National Associations of Water and Wastewater Services (Eureau 2009, 2012). Eureau gathers together 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), two European Free Trade Association (EFTA) countries (Norway and Switzerland) and two 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 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. First, to promote the interests

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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 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)). Second, with a clear picture of the drinking water supply in Europe, Eureau is able to identify challenges for the drinking water sector. Third, with this knowledge Eureau can identify research needs and influence policy-making at EU level in the field of research and development.

In this paper the results of the survey are presented, challenges for the European drinking water sector identified and research needs described.

METHODS

A questionnaire was sent to all members of Eureau. 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.

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

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[c] without treatment	No post-treatment
	Conventional treatment	Aeration and/or RSF[a]	CSF[b]	Surface water + AR[c] with treatment: aeration and/or CSF[b]	Post-treatment: aeration and/or RSF[a]
	Advanced treatment	Carbon filtration, AOP[d], membranes, desalination, etc.	Carbon filtration, AOP[d], membranes, desalination, etc.	Surface water + AR[c] with treatment: advanced treatment like carbon filtration, AOP[d], membranes, desalination, etc.	Post-treatment: carbon filtration, AOP[d], membranes, desalination, etc.
	Conventional + advanced treatment	Aeration and/or RSF[a] + advanced treatment	CSF[b] + advanced treatment	Surface water + AR[c] with treatment: aeration and/or CSF[b] + advanced treatment	Post-treatment: aeration and/or RSF[a] + advanced treatment

[a]Rapid sand filtration.
[b]Coagulation/sedimentation/filtration.
[c]Artificial recharge.
[d]Advanced oxidation processes.

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[a]	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[a]	2.2	0
Lithuania[a]	3.3	0
Luxembourg	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[a]	2.0	0
Spain	45.2	60
Sweden	9.1	100
Switzerland	7.5	100
United Kingdom	61.1	54

[a]Not Eureau member.

European citizens to whom drinking water is supplied by utilities part of 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 as follows:

- 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 for (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.

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.

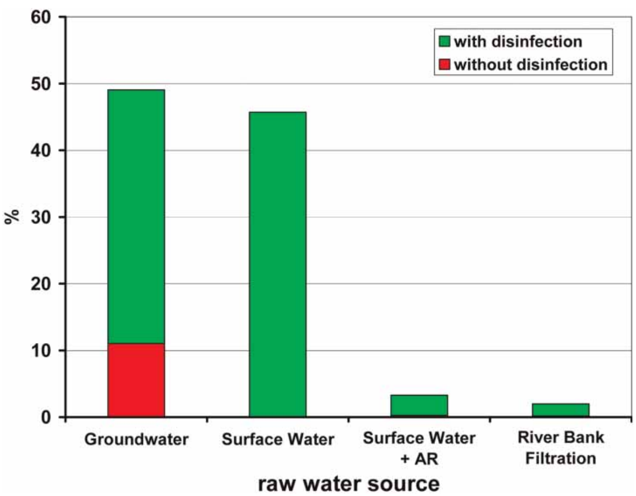

Figure 1 | Raw water sources for drinking water production used in Europe.

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% of 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% of 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, where surface water is disinfected, chlorine disinfection is applied to 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%).

DISCUSSION

Emerging substances: challenges

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 for example, 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 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

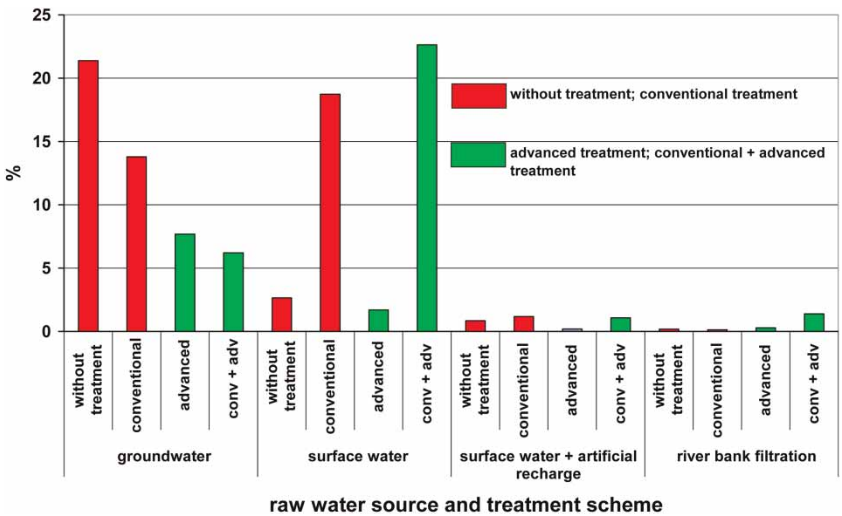

Figure 2 | Raw water sources and treatment schemes.

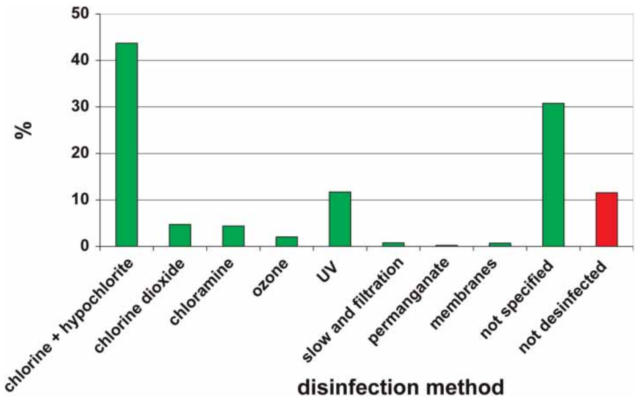

Figure 3 | Disinfection methods used in drinking water production (related to total drinking water production).

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 EU: 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; Mons *et al.* 2013). In addition, the presence of these compounds in the finished drinking water may affect customers' confidence in drinking water.

Looking at 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, 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 (Lekkerkerker *et al.* 2009; Lester *et al.* 2011; Scheideler *et al.* 2011), combination of river bank filtration with granular activated carbon filtration and nanofiltration (Bertelkamp *et al.* 2012) and ion exchange in combination with ceramic microfiltration (Galjaard *et al.* 2011).

The drinking water industry in Europe is facing the presence of emerging substances in raw water sources. Introduction of groundwater protection zones and water resource protection zones is another response strategy of the drinking water companies, in addition to the introduction of advanced treatment schemes. This approach is advocated by the European Water Framework Directive (European Union 2000).

Disinfection: challenges

Two challenges can be identified related to disinfection of drinking water. First, 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. Second, in the case that 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.

Thus, the absence of disinfection, and the application of certain disinfection methods may imply a health risk in specific cases. The challenge to manage the absence of disinfection is the introduction of a thorough risk analysis and evaluation by which the risks of (re)contamination can be quantified and mitigated. The challenge to avoid the introduction of health risks due to the formation of disinfection by-products is the development of new disinfection strategies and methods that avoid the formation of disinfection by-products without violating the supply of hygienically safe drinking water.

CONCLUSIONS

Emerging substances: research needs

The presence of emerging substances in raw water sources is a challenge for the drinking water supply in Europe. Advanced treatment technologies are capable of removing these substances, but they are expensive, 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 EU there are more than 100,000 registered chemicals (European INventory of Existing Commercial chemical Substances, EINECS), of which 30,000–70,000 are in daily use (Schriks *et al.* 2010). A promising approach is using quantitative structure activity relationships (QSARs) or quantitative structure property relationships (QSPRs) 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 & 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 of how to optimize processes. The 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.

Disinfection: research needs

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 (IWA 2004; Bartram *et al.* 2009). Research is necessary to implement this tool, especially for small water supplies where capacity building is required (Van der Hoek 2012). In cases where 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.

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