Mäkinen Riika (editor)

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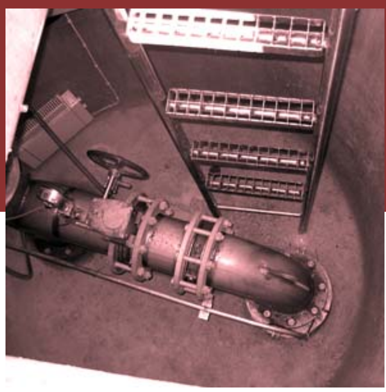
Summary report



Publications of Finnish Institute of Drinking Water 5

DRINKING WATER QUALITY AND NETWORK MATERIALS IN FINLAND

SUMMARY REPORT

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[1]Finnish Institute of Drinking Water/Prizztech Ltd.

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Abstract

This report is a summary of the following three publications of the Finnish Institute of Drinking Water:

I. Publications of Finnish Institute of Drinking Water 1, Materials in Contact with Drinking Water in Finland 2007 [Kekki et al. 2007, in Finnish],

II. Publications of Finnish Institute of Drinking Water 2, Water Quality in Finland in Years 1984 – 2006 [Keinänen-Toivola et al. 2007, in Finnish],

III. Publications of Finnish Institute of Drinking Water 4, Quality of Finnish Drinking Water from Raw Water to Consumers' Tap in Years 1999 – 2007 [Ahonen et al. 2008, in Finnish].

A revision of EU's drinking water directive (DWD) and construction product directive (CPD) is in progress and recently a new acceptance scheme for materials and products in contact with drinking water was drafted (European Acceptance Scheme, EAS). At the EU level, it is essential to make sure that the special characteristics of Finnish drinking water and water management are taken into consideration when new regulations are being drafted to ensure that these regulations will also be suitable for Finnish conditions.

Since 2005 several studies have been conducted in Finland and these form the basis for the revision of the above mentioned directives and a discussion of the suitability of the long planned EAS into Finnish conditions.

The study "Water Quality in Finland in Years 1984 – 2006" [Keinänen-Toivola et al. 2007, in Finnish] aimed to collect public data about the quality of drinking water in Finland. This study determined that drinking water in Finland mainly fulfils the demands and recommendations of the Finnish decree on drinking water and data on concentrations of different parameters are rather readily available.

The follow-up study "Quality of Finnish Drinking Water from Raw Water to Consumers Tap in Years 1999 – 2007" [Ahonen et al. 2008, in Finnish] intended to provide a broad perspective of the quality of drinking water in Finland by collecting detailed data from different size waterworks in all parts of the country. The study included wells, water cooperatives, as well as small, medium-sized, and large waterworks.

The material study of FIDW "Materials in Contact with Drinking Water in Finland 2007" [Kekki et al. 2007, in Finnish] was aimed to review the materials, coatings, and sealings used in the distribution and the real estate networks from the water intake or purification plants up to the consumer's tap in Finland. These materials and the drinking water can undergo complex interaction phenomena whereupon the quality of drinking water may deteriorate and unwanted changes occur in the materials.

This summary report shows that Finnish drinking water is of high quality and therefore safe and hygienic to use when compared to the quality requirements and recommendations. Quality monitoring of drinking water in Finland is primarily monitored by the Finnish decree on drinking water that concentrates on health based parameters. However, the quality of drinking water is affected also by many technical parameters that are not required to be measured but these can have a significant impact on the long term durability of the networks.

In Finland and some other countries e.g. Latvia and Japan, it has been demonstrated that microbial growth is phosphorus limited instead of carbon limited and therefore analysing phosphorus compounds would be important if one wishes to evaluate the growth potential of microbes. According to the above mentioned studies the median for TOC concentration was 1.9 mg/l in water provided by the waterworks. The median concentration of phosphate phosphorus ranged from 1.5 to 6 μg/l. In addition, rather high concentrations of aluminium, nickel, manganese, and iron are present in Finnish drinking water and this should be taken into consideration when EAS is being drafted.

About 8 % of the waterworks in the study provided water whose pH was below the lower guide value stated in the decree (6.5). In order to prevent aggressivity of drinking water additional limit values for sulphate and chloride have been provided. All samples were in accordance with the additional limit value with respect to sulphate but 10 % of waterworks provided water that exceeded the additional limit for chloride. With respect to alkalinity, hardness, and concentration of carbon dioxide there is no guide or limit values in the Finnish decree on drinking water. The median values for alkalinity, hardness, and CO_2 in the study were 0.2 – 1.8 mmol/l, 0.2 – 0.7 mmol/l, and 2 – 30 mg/l, respectively.

The objective of this summary report is to present the situation in Finland and to highlight the Finnish perspective on the revisions of DWD and CPD and to influence the drafting of EAS.

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1 Introduction

A revision of EU's drinking water directive (DWD) and construction product directive (CPD) is in progress and recently a new acceptance scheme for materials and products in contact with drinking water was drafted (European Acceptance Scheme, EAS). In EAS, the test methods for products are mainly based on existing methods already being used in one or more member states. It has not yet been fully clarified whether these test methods are suitable for all of the EU member states.

At the EU level, it is essential to make sure that the special characteristics of Finnish drinking water and water management are taken into consideration when new regulations are being drafted to ensure that these regulations will also be suitable for Finnish conditions. In Finland, the legislation and administration concerning drinking water has been divided between three ministries. The Ministry of Agriculture and Forestry is in charge of water management generally, the Ministry of Social Affairs and Health has the responsibility for the legislation concerning quality and monitoring of drinking water, and the Ministry of the Environment oversees the building regulations. The local health authorities monitor the quality of drinking water.

Within the limits stated in DWD, the quality of drinking water may vary significantly and the directive does not contain requirements or guide values for all of the water quality parameters that are mentioned in the EAS or otherwise essential for the network materials. The amount of information collated on technical and microbiological quality of drinking water varies substantially between the member states, thus EU has not attempted to systematically collect data. The member states report to the Commission mainly compliance and deviations from the DWD and this only applies to the large waterworks.

Since 2005 several studies have been conducted in Finland and these form the basis for the revision of the above mentioned directives and a discussion of the suitability of the long planned EAS into Finnish conditions.

One study "Water Quality in Finland in Years 1984 – 2006" [Keinänen-Toivola et al. 2007, in Finnish] aimed to collect public data about the quality of drinking water in Finland. This study determined that drinking water in Finland mainly fulfils the demands and recommendations of the Finnish decree on drinking water and data on concentrations of different parameters are rather readily available. Nevertheless, additional data on technical and microbiological characteristics of drinking water which are relevant with respect to interactions between the network materials and drinking water was needed.

The follow-up study "Quality of Finnish Drinking Water from Raw Water to Consumers Tap in Years 1999 – 2007" [Ahonen et al. 2008, in Finnish] intended to provide a broad perspective of the quality of drinking water in Finland by collecting detailed data from different size waterworks in all parts of the country. The study included wells, water cooperatives, as well as small, medium-sized, and large waterworks.

The distribution network and pipelines in real estates contain many materials that are in contact with drinking water often for several days, sometimes even longer. These materials and the drinking water can undergo complex interaction phenomena whereupon the quality of drinking water may deteriorate and unwanted changes occur in the materials.

The material study of FIDW "Materials in Contact with Drinking Water in Finland 2007" [Kekki et al. 2007, in Finnish] was aimed to review the materials, coatings, and sealings used in the distribution and the real estate networks from the water intake or purification plants up to the consumer's tap in Finland. The study is based on surveys, interviews, information on internet pages of manufacturers, and it reviewed both the Finnish and international literature. The study presents data on the characteristics of different materials and their possible effects on the quality of drinking water.

This present report is a summary of the three above studies. The objective of this summary report is to present the situation in Finland and to highlight the Finnish perspective on the revisions of DWD and CPD and to influence the drafting of EAS.

This report has been funded by the Finnish Ministry of Social Affairs and Health.

2 Drinking water

2.1 Definition

According to the Finnish law of health protection (Chapter 5) drinking water means “1) all water that is meant for drinking, food preparation, or other domestic purposes regardless of whether the water is transmitted through the distribution network, tanks, bottles, or containers; and 2) all water that is used in the food industry for production, processing, storage, and entry on the market” [Parliament of Finland 1994]. Natural mineral water or water for medical purposes is not drinking water. Water used as drinking water cannot be insanitary. In addition, drinking water has to be also otherwise suitable for use and it cannot cause harmful erosion or lead to the formation of harmful deposits in water pipes or control units.

2.2 Legislation

2.2.1 Drinking Water Directive, DWD

The EU drinking water directive 98/83/EY [Council of EU 1998] defines the minimum requirements of the sanitary quality of drinking water within the EU. The purpose of the directive is to protect consumers of drinking water within the European Union and to make sure that water is aesthetically clean and without unpleasant taste, odour or colour. The directive lists 48 microbiological and chemical parameters which should be monitored regularly. The limit values listed in the directive are based on the guidelines of World Health Organisation [WHO 2004]. The member states of the EU must adhere to at least the same demands and recommendations as in the directive but it is also possible to set additional national regulations. At the present moment, the drinking water directive is being revised.

2.2.2 Legislation in Finland

In Finland, the requirements and recommendations for the quality of drinking water are defined in the Finnish decree on drinking water issued by The Finnish Ministry of Social Affairs and Health [Parliament of Finland 2000] (Decree Relating to the Quality and Monitoring of Water Intended for Human Consumption). The decree is based on the drinking water directive and concerns all water that is 1) provided at least 10 m^3 per day or for 50 people, 2) used for food production intended for human consumption, or 3) distributed to be used as drinking water as a part of public and commercial operation. In Finland, drinking water means cold water and the quality monitoring sample is always taken from flushed water.

The decree defines the minimum requirements and it details the quality related demands and guide values for microbiological, chemical, technical, and radioactive parameters which are listed in the Table 1. Compliance with the quality requirements should be monitored in the distribution network at the point where water is taken from the consumers tap. The waterworks providing drinking water is responsible for the adherence to the quality requirements up to the point where a real estate is connected to the distribution network. The owner of a real estate is responsible for ensuring that the quality of water does not decline in the real estate network in such a way that water no longer meets the quality requirements. The Finnish decree on drinking water has tighter limit values set for chloride (Cl^-) and sulphate (SO_4^{2-}) than the drinking water directive in order to prevent corrosiveness of drinking water (Table 1, notions [h] and [o]). In addition, the Finnish decree on drinking water has a limit value for chlorophenols though these compounds are not included in the drinking water directive.

Table 1. The requirements and guide values defined in the Finnish decree on drinking water [Parliament of Finland 2000] and some other parameters mentioned in this report.

Parameter	Maximum concentration	Unit	Requirement, guide value or no limit value
Acrylamide[a]	0.10	µg/l	requirement
Alkalinity	-	mmol/l	no limit value
Aluminium (Al)	200	µg/l	guide value
Ammonium (NH_4^+)	0.50	mg/l	guide value
Antimony (Sb)	5.0	µg/l	requirement
Arsenic (As)	10	µg/l	requirement
Benzene	1.0	µg/l	requirement
Benzo(a)pyrene	0.010	µg/l	requirement
Biofilms	-	e.g. cfu/cm^2	no limit value
Boron (B)	1.0	mg/l	requirement
Bromate (BrO_3^-)[b]	10	µg/l	requirement
Clostridium perfringens[c]	0	cfu/100ml	guide value
1,2- dichloroethane	3.0	µg/l	requirement
Mercury (Hg)	1.0	µg/l	requirement
Enterococcus	0	cfu/100ml	requirement
Epichlorohydrine[a]	0.10	µg/l	requirement
Escherichia coli	0	cfu/100ml	requirement
Fluoride (F^-)	1.5	mg/l	requirement
Phosphate (PO_4^{3-})	-	mg/l	no limit value
Phthalates	-	µg/l	no limit value
Odour and taste[d]		no unit	guide value
Oxidizability (COD_{Mn})[e]	5.0	mg/l	guide value
Oxygen (O_2)	-	%	no limit value
Carbon dioxide (CO_2)	-	mg/l	no limit value
Cadmium (Cd)	5.0	µg/l	requirement
Calcium (Ca)	-	mg/l	no limit value
Camphylobacteria	-	e.g. cfu/ 100 ml	no limit value
Chlorophenols total[f]	10	µg/l	requirement
Chloride (Cl^-)[g, h]	250	mg/l	guide value
Total alpha (tot α)	-	Bq/l	no limit value
Total phosphorus (tot P)	-	mg/l	no limit value
Total nitrogen (tot N)	-	mg/l	no limit value
Coliformic bacteria	0	cfu/100ml	guide value
Hardness	-	mmol/l	no limit value
Chromium (Cr)	50	µg/l	requirement
Copper (Cu)[i]	2000	µg/l	requirement
Legionellas	-	e.g. cfu/100 ml	no limit value
Dissolved organic carbon (DOC)	-	mg/l	no limit value
Lead (Pb)[i]	10	µg/l	requirement
Magnesium (Mg)	-	mg/l	no limit value
Manganese (Mn)	50	µg/l	guide value
Assimable organic carbon (AOC)	-	µg/l	no limit value
Molybdenum (Mo)	-	µg/l	no limit value

Sodium (Na)	200	mg/l	guide value
Nickel (Ni)[i]	20	µg/l	requirement
Nitrate (NO_3^-)[j]	50	mg/l	requirement
Nitrite (NO_2^-)[j]	0.5	mg/l	requirement
Norovirus	-	e.g. pc/100 ml	no limit value
Total organic carbon (TOC)[k, l]	-	mg/l	guide value
Plate count (22˚C)[k]	-	cfu/100 ml	guide value
pH[g]	6.5 – 9.5	no unit	guide value
Polycyclic aromatic hydrocarbons[m]	0.10	µg/l	requirement
Radon (Rn)	-	Bql/l	no limit value
Iron (Fe)	0.2	mg/l	guide value
Turbidity[d, n]	-	NTU	guide value
Selenium (Se)	10	µg/l	requirement
Silicate (SiO_2)	-	mg/l	no limit value
Zinc (Zn)	-	µg/l	no limit value
Sulphate (SO_4^{2-})[g, o]	250	mg/l	guide value
Cyanides	50	µg/l	requirement
Electrical conductivity[g]	250	mS/m	guide value
Tetrachloroethene and trichloroethene, total	10	µg/l	requirement
Tin (Sn)	-	µg/l	no limit value
Titanium (Ti)	-	µg/l	no limit value
Biocides[p, q]	0.10	µg/l	requirement
Biocides total[p]	0.50	µg/l	requirement
Trihalomethanes total[b, r]	100	µg/l	requirement
Tritium (^3H)[s]	100	Bq/l	guide value
Total indicative dose[s]	0.10	mSv/a	guide value
Vinyl chloride[a]	0.50	µg/l	requirement
Bismuth (Bi)	-	µg/l	no limit value
Colour[d]	-	mg/l	guide value

- No limit value
[a] Concentration is calculated according to the maximum amount released or dissolved from the used polymer stated in the product description.
[b] Lower concentration must be sought without weakening the disinfection efficiency.
[c] Measured if raw water is surface water.
[d] Acceptable to users, no unusual changes.
[e] Not necessarily needed to be measured if TOC is measured.
[f] Tri-, tetra- and pentachlorophenol
[g] Water must not be corrosive.
[h] To prevent corrosion of pipe materials, the concentration should be below 25 mg/l.
[i] Sample from user's tap, concentration calculated to be analogous to weekly average.
[j] Maximum concentration of nitrite in water leaving waterworks is 0.10 mg/l. (Conc. of nitrate/50)+(conc. of nitrite/3) must not exceed the limit value of 1.
[k] No unusual changes.
[l] No need to measure if oxidizability (COD_{Mn}) is determined and the amount of distributed water is below 10 000 m^3/d.
[m] Benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, indan-(1,2,3-cd)-pyrene.
[n] Turbidity of the water leaving surface-water waterworks should be below 1 NTU.
[o] To prevent corrosion of pipe materials, the concentration should be below 150 mg/l.
[p] Organic insecticides, herbicides, fungicides, nematocides, acaricides, algaecides, and rodentacides; organic antislime agents; other equivalent products as well as their metabolites, degradation products and reaction products.
[q] Limit value for aldrin, dieldrin, heptachlorine, and heptachloroepoxide is 0.030 µg/l.
[r] Chloroform, bromoform, bromide chloromethane, dibromochloromethane.
[s] Total indicative dose of tritium and radioactivity does not need to be measured if earlier studies show these values to be clearly below the limit values. Radon, its degradation products, tritium or potassium-40 (^{40}K) are not included in the total indicative dose.

In addition, the Finnish Ministry of Social Affairs and Health has issued a decree concerning requirements and recommendations for the quality of drinking water in small waterworks [Parliament of Finland 2001]. The decree concerns 1) waterworks that provide water less than 10 m^3 per day or for less than 50 people, 2) food companies that are not applicable for the Finnish decree on drinking water [Parliament of Finland 2000], and 3) separate household wells. Some guide values or demanded limit values differ in these two above mentioned decrees. There is a limit value for 51 parameters in the Finnish decree on drinking water but a total of 17 of these limit values are different in the decree concerning small waterworks.

Limit values for ammonium nitrogen and chloride are lower for small waterworks. Unlike the Finnish decree on drinking water, the decree on small waterworks does not have limit values for *Clostridium perfringens*, sodium, totally organic carbon, heterotrophic plate count, tritium, and total indicative dose. In contrast, for radon there is a limit value in the decree on small waterworks but not in the decree on drinking water. There are differences in these two decrees in terms of turbidity, colour, odour, and taste criteria. In the decree on small waterworks the criteria for separate wells used by a single household are less strict than for other small waterworks with respect to coliformic bacteria, manganese, radon, and iron. Limit values for arsenic and fluoride are higher for the kind of water delivered from small waterworks that is not intended for either human consumption or food production.

2.3 Quality control and reporting

The quality of drinking water in Finland is monitored by local health authorities. The supervising authority and the plant providing drinking water must together prepare for regular monitoring, that is there has to be a plant-specific monitoring research program which includes plant's own monitoring and the food producing company's own monitoring. Regular monitoring includes check monitoring and audit monitoring. Check monitoring is used to collect data on quality of drinking water, and to monitor the efficiency of water treatment, and to ensure the fulfilment of quality demands. Audit monitoring is used to establish whether the demands and recommendations in Annex 1 of the Finnish decree on drinking water have been fulfilled. In check monitoring, the minimum parameters to be determined are: odour, taste, turbidity, colour, pH, electric conductivity, iron, manganese, nitrite (if chloramine is used for disinfection), aluminium (aluminium compounds used in water treatment or an abundance of these compounds in raw water), ammonium, *Clostridium perfringens* (if surface water used as raw water), *Escherichia coli*, coliformic bacteria, and the possible additional analyses defined in the monitoring research program.

The local health authorities deliver every year information on water quality of large waterworks (>1000 m3/d or >5000 people) to provincial government that drafts a summary of results and submits it to The National Public Health Institute of Finland. The National Public Health Institute of Finland prepares every three years a national report to the European Commission. In recent years, the report has been published by The National Product Control Agency of Finland. There are about 170 large waterworks (>1000 m3/d or >5000 people) in Finland obliged to report to the Commission. They provide water to approximately 3.8 million consumers i.e. 73 % of population in Finland [Zacheus 2006]. Part of the official reports delivered to the Commission contains average values and those are utilized in this summary report. [Zacheus 2004, Zacheus 2005]. Part of the official reports contains only information on exceedings of the limit values of the DWD but not numeric data [Zacheus 2002, Zacheus 2006].

2.4 Distribution in Finland

In 2001, 90 % of the population (4 654 000 people) in Finland was within the centralized water distribution [Finland's environmental administration 2005]. However, the number of households relying on well water was still quite extensive. The field of waterworks in Finland is fragmented; if one divides the whole volume of water supply services into four parts, then one quarter is managed by the five biggest waterworks, which sales volumes account for over 25 m€/works and which have large personnel 100 – 350. The next quarter is handled by approximately 30 waterworks with sales volumes of 4 – 25 m€/works and with personnel of 25 – 100. Almost 200 waterworks manage the next quarter, with sales volumes of 0.4 – 4.0 m€/works and small personnel numbers i.e. 3 – 25 people. The rest, the last quarter is the responsibility of nearly 800 small waterworks, which sales volumes are less than 400 000 €/works and with few staff 0 – 3 individuals.

Surface waters, groundwaters, and artificial groundwaters are used as raw water in the production of the drinking water distributed in Finland. The large waterworks exploit mainly surface waters (70 works), artificial groundwaters are used by some scores of works, the remaining small waterworks utilize mainly groundwaters. Depending on the method of assessment, the number of the latter can range from 1000 to 1600. It has been estimated that of the 408 million m^3 of distributed drinking water in 2001 39 % was surface waters and 61 % was ground or synthetic groundwaters [Finland's environmental administration 2005].

Drinking water distributed in Finland by the waterworks has usually high quality in terms of hygiene. The quality of drinking water is affected by many factors, for example raw water (soil, basin), water treatment techniques (sedimentation, filtration, disinfection), network (materials, biofilm), and use (flow). Surface water used as raw water normally contains little mineral salts but an abundance of humic substances. Surface water is always treated before it is fed into the distribution network because the quality of surface water as such does not qualify for the regulations and recommendations given for drinking water.

Natural waters used as raw waters have a range of qualities depending on the surrounding soil and bedrock. Approximately half of Finnish drinking water is produced from surface water with the other half being obtained from groundwater. The problem with surface waters is their high concentration of organic carbon which might cause taste and odour in the water and act as a nutrient for microbes. Surface waters are normally treated chemically, filtered, neutralized with alkaline chemicals, and disinfected before distribution. Groundwaters are usually soft and in some cases they are neutralized but only disinfected in a few works. In Finland, groundwater is quite often used as such because of its good hygienic quality, especially in small waterworks. Acidic and soft drinking water might corrode metals which can be one significant factor when considering the origin of leakages.

Conditions in Finland differ from many other countries in Europe. There is less risk of dissolution of metals in drinking waters from Central Europe compared to Finland because groundwaters in Central Europe are hard due to the typical soil and bedrock conditions. In addition, alkalinity is substantially higher than in Finland and thus usually waters are always treated.

Although drinking water is of good quality as it is fed from the waterworks into the distribution network, the quality can decline significantly when it is in the network because of corrosion, biofilms, or substances dissolving from the network materials. The substances dissolving from the materials originate either from the material itself or from the traces of the organic chemicals used in the manufacturing process. Some of the dissolved substances can act as nutrients for microbes whereas some might be biocidic (i.e. prevent the growth of microbes) or biostatic (i.e. impair the growth of microbes).

3 Presentation of the quality parameters

3.1 Figures

The results are presented in summary figures whose structure and details are explained below in Figure 1. Box plot figures are made from waterworks-specific mean values when numeric values were available. The groundwater data (GTK and SYKE), the STUK data and the waterworks data from the additional measurements are presented from the results of the separate analyses. The figures show the mean value, percentiles 5, 25, 50 (=median), 75, and 95 as well as minimum and maximum values. A percentile is the value of a variable below which a certain percent of observations will fall. Thus the 20th percentile is the value (or score) below which 20 percent of the observations may be found. The term percentile and the related term percentile rank are often used in descriptive statistics as well as in the reporting of scores from norm-referenced tests. The 25th percentile is also known as the first quartile; the 50th percentile as the median.

A limit value or guide value of the Finnish decree on drinking water [Parliament of Finland 2000] is marked with a horizontal line and a value on the right. The code for the water type is marked below the x-axis (“Total” in Figure 1) and below that is the number of waterworks providing the data (n=57). With respect to the groundwater data (GTK and SYKE), the STUK data and the waterworks data from the additional measurements the symbol “n” depicts the number of the separate analyses. In some figures, the y-axis is modified in order to show all the essential information. Abbreviations used in the figures are presented in Table 2.

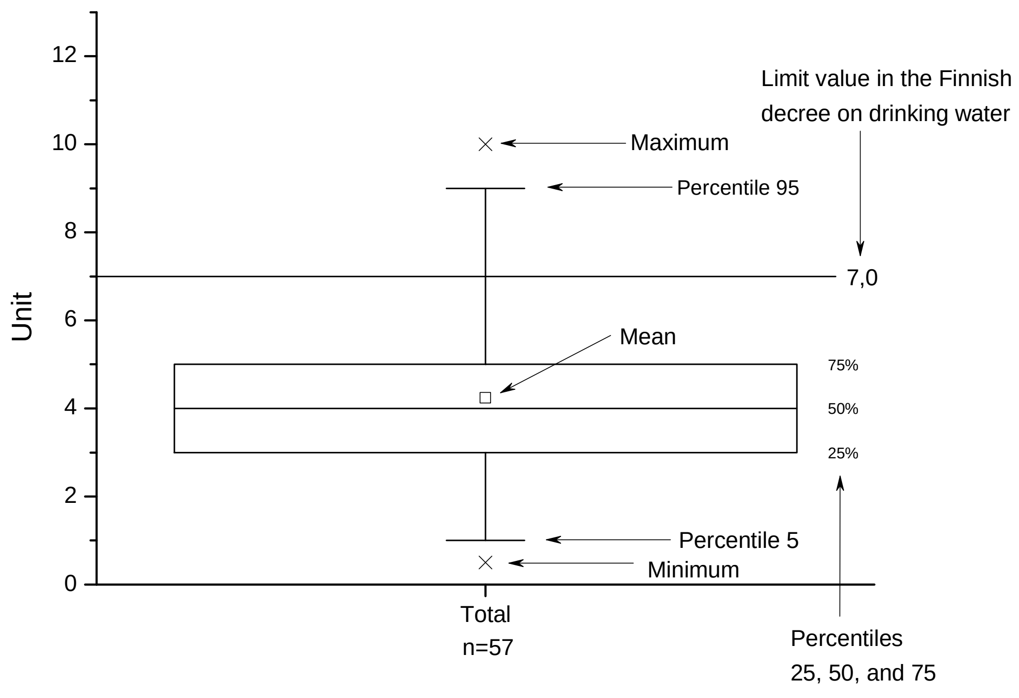

Figure 1. Presentation of results [Ahonen et al. 2008].

Table 2. Abbreviations used in figures.

Abbreviation	Explanation
Total	All waterworks
>1000 m3/d	Large waterworks, water production >1000 m^3/d
10–1000 m3/d	Medium-sized waterworks, water production 10–1000 m^3/d
<10 m3/d	Small waterworks, water production <10 m^3/d
ND	Size of waterworks, source of water or neutralization of water not defined
G	Groundwater
S	Surface water
AG	Artificial (artificially recharged) groundwater
SE	Sea water
GB	Groundwater of bedrock, data from STUK
GS	Groundwater of soil, data from STUK
GWd	Dug wells, the groundwater data from GTK and the well water data from STUK
GWdib	Wells drilled into bedrock, the groundwater data from GTK and the well water data from STUK
GWs	Single well, the groundwater data from Finland's environmental administration
GWm	Raw water combined from several wells, the groundwater data from Finland's environmental administration
Alk +	Water leaving waterworks is neutralized
Alk -	Water leaving waterworks is not neutralized
X1	Water that is pumped from waterworks into the network
X2	Stagnated network water
X3	Water that is collected from a network point after flushing

3.2 Introduction to results

Results for parameters describing quality of drinking water are subdivided into seven categories: microbes, nutrients for microbes, metals, chemicals and organic substances, non-metals, technical quality of water, and radioactivity. There is an introduction to each group which represents a summary figure of that groups' parameters and their effects and harm are described. In addition, the possible routes of entry of the parameters to drinking water and ways to diminish harmful effects are described.

The percentiles presented in the figures show the portion of the results (number of waterworks or number of the analysis results (for GTK, SYKE, STUK and the additional measurements)) that lie within a certain concentration range. 50 % of the results are between the percentiles 25 and 75 and 90 % between the percentiles 5 and 95.

For different size waterworks there are different regulations whose limit and guide values for some parameters differ slightly. The groundwater data (wells) from SYKE could not be compared to the relevant regulations because no information on the amount of used water per day was available. In these cases, separate wells were classified as being in the range of the Finnish decree on small units and waters combined from several wells in the range of the Finnish decree on drinking water.

4 Microbes

Many types of microbes can be present in drinking water and for some of these limit values and recommendations are available in the Finnish decree on drinking water (Indicators, Figure 2). These indicator microbes are used, as their name expresses, to indicate pathogen microbes whose recognition is time and labour consuming. In addition to the indicator microbes, the drinking water networks might contain large number of other microbes some of which are hazardous to human health and some are harmless (Table 3). Microbes can cause sanitary, esthetical, and technical problems (e.g. colouring of laundry and water fittings) and even metal corrosion. Factors affecting microbial growth are fairly well known and several methods to impede growth are being used.

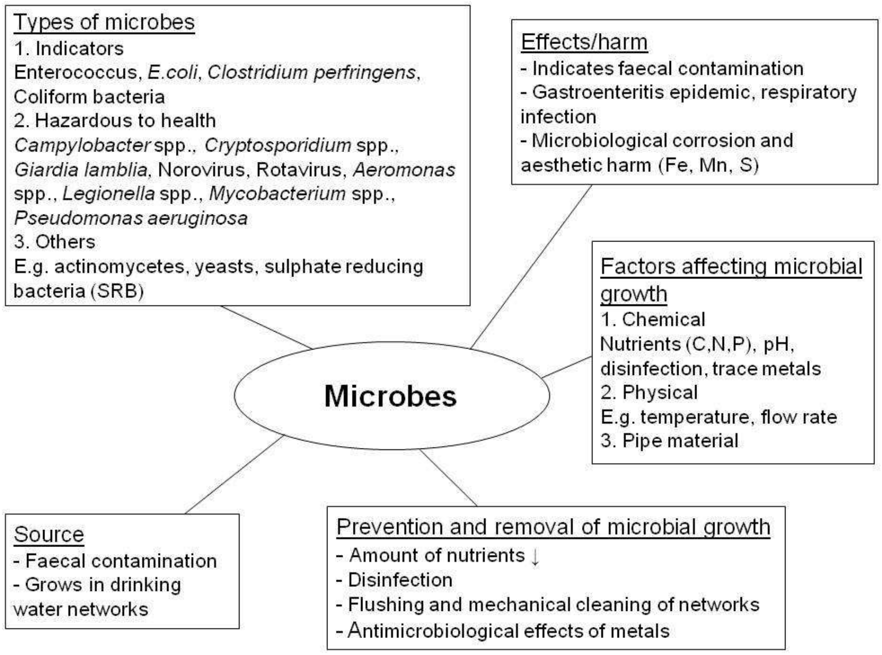

Figure 2. Microbes in drinking water.

Table 3. Microbes of drinking water divided into faecal and network growing.

Grow in the network	Faecal
Hazardous to health	**Hazardous to health**
Aeromonas spp.	*Campylobacter* spp.
Legionella spp.	*Cryptosporidium* spp.
Mycobacterium spp.	*Giardia lamblia*
Pseudomonas aeruginosa	Norovirus
	Rotavirus
Others	
Actinomycetes	**Indicators**
Heterotrophic microbes	*Clostridium perfringens*
Yeasts, moulds, fungi	Enterococci
Nitrification bacteria	*Escherichia coli*
Iron and manganese oxidizing bacteria	Coliform bakteria
Sulphate reducing bacteria (SRB)	

4.1 Microbes subject to quality standards

4.1.1 Enterococci

Enterococci are faecal indicator bacteria. Samples exceeding the limit value of 0 cfu/ml stated in the Finnish decree on drinking water were present both in waters provided by waterworks and in waters of the groundwater data from SYKE. The occurrence of *enterococci* was far more common in waters from individual wells and several wells combined compared to the water provided by waterworks, 20.0 and 0.7 %, respectively.

4.1.2 Escherichia coli

Escherichia coli is a faecal indicator bacterium. Samples exceeding the limit value of 0 cfu/100 ml stated in the Finnish decree on drinking water were observed both in waters provided by waterworks and in waters of the groundwater data from SYKE. The occurrence of *E. coli* was far more common in waters from individual wells and several wells combined compared to the water provided by waterworks, 22.0 and 0.10 %, respectively.

4.2 Microbes subject to quality recommendations

4.2.1 Clostridium perfringens

Clostridium perfringens is a faecal indicator bacterium. It is rarely detected, of all the samples in this study only 0.03 % (2/7076 analyses) contained *Clostridium perfringens*.

4.2.2 Coliformic bacteria

Coliformic bacteria reflect the general quality of drinking water, the efficiency of water treatment and disinfection, and the possible pollution caused by surface water drainage.

Samples exceeding the guide value of 0 cfu/100 ml stated in the Finnish decree on drinking water were observed both in waters provided by waterworks and in waters of the groundwater data from SYKE. The occurrence of coliformic bacteria was far more common in waters from individual wells and several wells combined compared to the water provided by waterworks, 28.0 and 0.9 %, respectively.

4.2.3 Heterotrophic Plate Count, HPC

The heterotrophic plate count is one way to estimate the amount of heterotrophic bacteria, yeasts, and moulds in drinking water. HPC reflects the general quality of drinking water but does not indicate faecal pollution.

Additional measurements carried out in the autumn 2007 were done in order to determine the possible effects of the state of the network and sampling method e.g. on HPC in drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. The highest HPC was observed in stagnated water, the median and maximum concentration was 23 and 1100 cfu/ml, respectively. In water pumped from the waterworks into the network and in flowing network water HPC's were in the approximate same order with the medians being 1 and 3 cfu/ml, respectively.

Deviations from the recommendation in the Finnish decree on drinking water "no abnormal changes" were observed both in waters provided by waterworks and in waters of the groundwater data from SYKE. In all, 2% of the waters provided by waterworks had abnormalities. The median concentrations were about the same order of magnitude (0 – 3 cfu/ml) in waters that were either pumped into the network at the waterworks, taken from faucets after flowing, or in the groundwater data from SYKE. In stagnated water i.e. water taken from faucets which had not been opened, the median was higher, 23 cfu/ml.

Summary of the microbes in drinking water:

Water provided by the waterworks was of good microbiological quality and safe to use. However, a small proportion (0.03 – 0.90 %) of samples analyzed contained at least one of the faecal pollution indicating microbes described above. In well waters, microbes were observed more often than in waters provided by waterworks, i.e. 20 % of their samples contained the microbes mentioned above.

5 Nutrients for microbes

Large variety of compounds is capable of acting as nutrients for microbes. Some of these compounds have limit values or guide values in the Finnish decree on drinking water, for example nitrate and nitrite have limit values and ammonium and total organic carbon (TOC) have guide values (Figure 3). Nutrients for microbes can affect human health either directly (e.g. by causing methemoglobinemia) or indirectly by increasing microbial growth. Nutrients for microbes can end up in drinking water from many sources and there are several ways available to prevent them causing any harm.

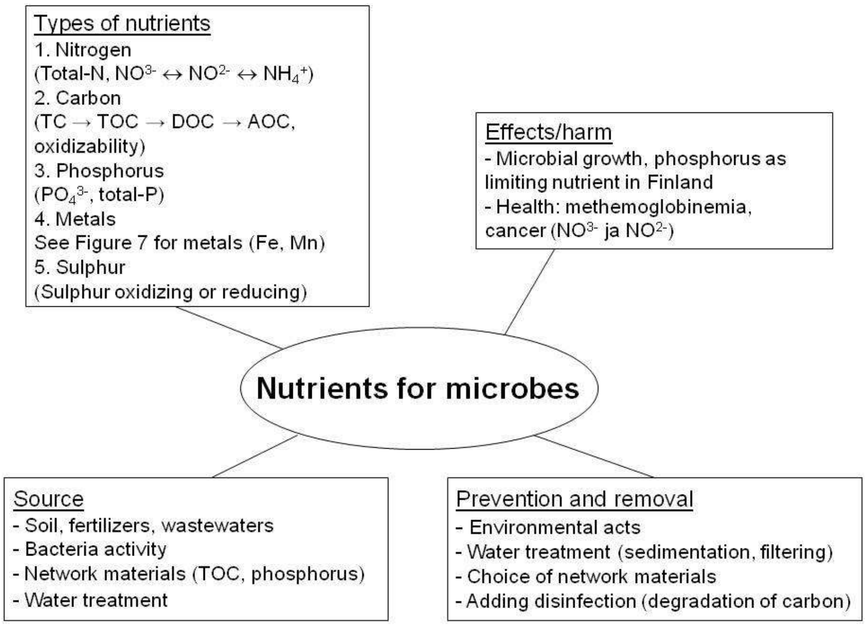

Figure 3. Nutrients for microbes in drinking water.

5.1 Nutrients for microbes subject to quality standards

5.1.1 Nitrate (NO_3^-)

The limit value for nitrate is based on the harmful health effects of nitrite which is formed when nitrate is reduced. In drinking water, nitrate can origiante from compounds leaching from soil (e.g. fertilizers), waste waters and rain waters.

Additional measurements carried out in the autumn 2007 were conducted in order to determine the possible effects of the network and sampling method e.g. on the concentration of nitrate in drinking water. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were of a similar order in all water types in the study concentrations varying between 1.1 and 1.7 mg/l. The maximum concentration of a single sample was observed in water pumped into the network.

The median concentrations of nitrate in the study were <0.2 – 3.1 mg/l. The lowest median concentration was in drilled wells and the highest in water provided by waterworks using artificial groundwater. samples exceeding the limit value of the Finnish decree on drinking water were observed in individual well water samples: soil wells, drilled wells, and wells from the SYKE data.

5.1.2 Nitrite (NO_2^-)

The limit value for nitrite in the Finnish decree on drinking water is based on the level which can cause harmful health effects. Nitrite can be an indicator of water pollution but its occurrence might also result from bacterial activity.

The range of the median concentrations of nitrite in the study was 0.01 – 0.11 mg/l. The lowest median concentration of 0.01 mg/l was observed in groundwater wells from the SYKE data and the highest level was detected in large waterworks. With the exception of one well water sample, all analyses results were adherent to the Finnish decree on drinking water.

5.2 Nutrients for microbes subject to quality recommendations

5.2.1 Ammonium (NH_4^+)

The guide value for ammonium in the Finnish decree on drinking water is based on its ability to be oxidized to nitrite or nitrate and to cause a sharp unpleasant taste or odour in the water. In drinking water, ammonium might originate from the biodegradation of nitrogen based organic compounds.

Additional measurements carried out in the autumn 2007 were conducted in order to determine the possible effects of the network and sampling e.g. on the concentration of ammonium in drinking water. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. With the exception of a few samples all results were below detection limit (<0.003 or <0.007 mg/l). Thus it seems that neither the state of the network nor sampling method has any effect on the concentration of ammonium in drinking water.

The median concentrations of ammonium in the study ranged from 0.003 to 0.200 mg/l. The lowest median concentrations (<0.003 and <0.007 mg/l) were observed in waterworks data taken during the supplemental measurements. Groundwater wells from the SYKE data had the median concentration of 0.01 mg/l and the highest median concentration of 0.20 mg/l was observed in small waterworks. With the exception of one well water sample, all analyses results were in accordance with the Finnish decree on drinking water.

5.2.2 Total organic carbon (TOC)

Total organic carbon (TOC) indicates the amount of organic substances in drinking water as carbon concentration. Organic matter, as such, is not harmful to health but it adds colour and taste to water and acts as a nutrient for microbes. The recommendation in the Finnish decree on drinking water is that TOC concentration should have “no abnormal changes”.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of state of the network and sampling method e.g. on the concentration of TOC in drinking water. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. The concentrations of TOC were around the same order of magnitude in all water types in the study, with the median concentrations varying between 1.1 and 1.3 mg/l (Figure 4E).

There is no numeric guide value for TOC in the Finnish decree on drinking water. The median concentrations in the study ranged from 1.0 to 2.6 mg/l.

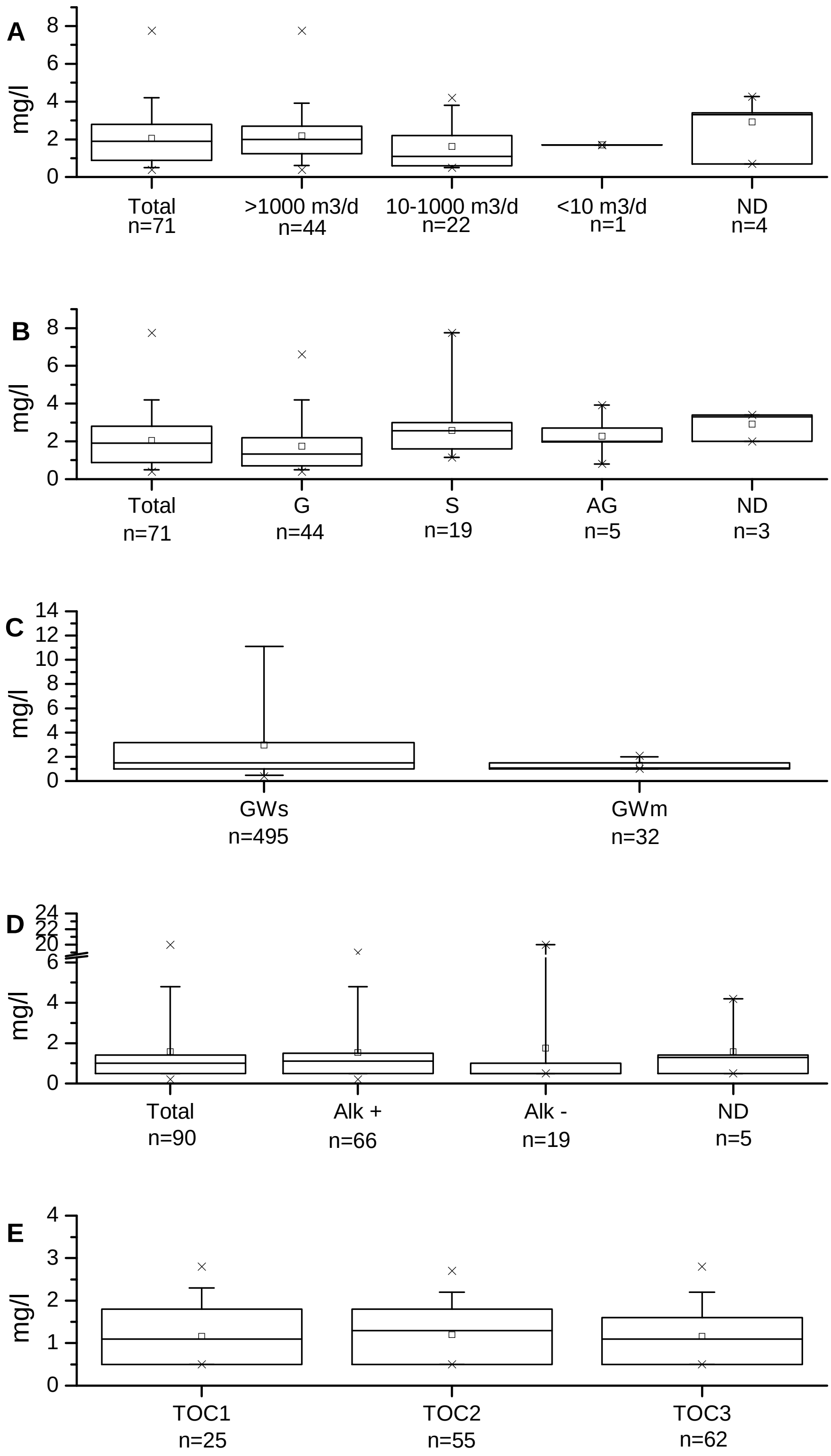

Figure 4. TOC. Concentration in drinking water provided by waterworks (A and B) and in well waters from the SYKE data (C) in the years 2000 – 2007. Plot D displays the relationship between water neutralizing with alkaline chemicals (Alk) and TOC in waters pumped into the network from the waterworks. The effects of state of the network and sampling method on the TOC concentration in drinking water provided by waterworks in 2007 (E). TOC1 is water pumped from waterworks into the network, TOC2 is stagnated network water, and TOC3 represents flowing network water. Data from plots D and E is not included in plots A or B. The maximum value GWs 22 mg/l is not shown in the figure.

5.2.3 Oxidizability (COD_{Mn})

Oxidizability represents the amount of organic matter in water. Solid particles of organic matter might have attached to them heavy metals, chemicals, and bacteria. The determination of oxidizability is based on the ability of potassium permanganate to oxidise organic matter.

The median concentrations of oxidizability in the study ranged from 0.6 to 1.8 mg/l. The lowest median concentration was observed in water combined from several wells (SYKE data). Waterworks, separate wells from the SYKE data, and drilled wells had the median concentrations of 1.0 – 1.2 mg/l. Samples from a few waterworks and well water from the SYKE and GTK data were higher than the guide value in the Finnish decree on drinking water.

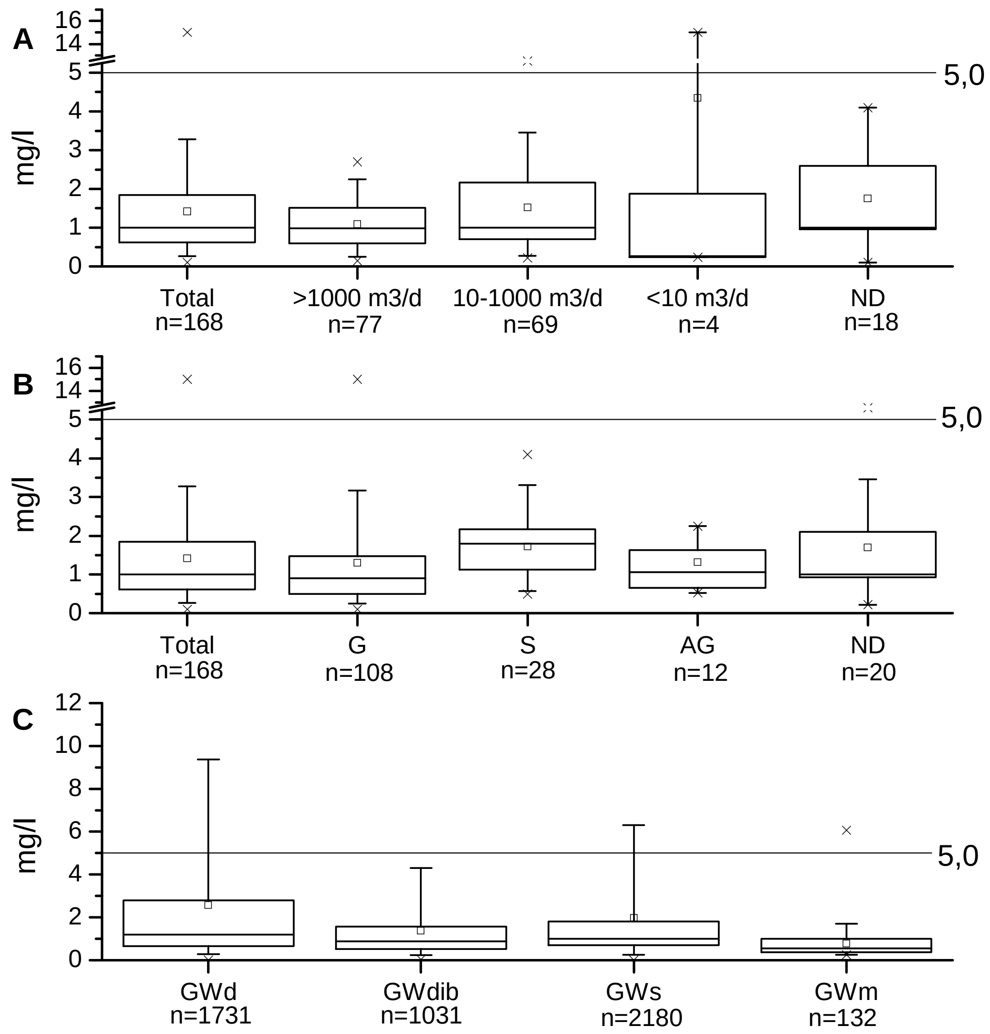

Figure 5. Oxidizability. Concentration in drinking water provided by waterworks in the years 2000 – 2007 (A and B), and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum values that are not visible in plots are 10-1000 m^3/d 8 mg/l, ND 8 mg/l, GWd 46 mg/l, GWdib 21 mg/l, and GWs 94 mg/l.

5.3 Other nutrients

5.3.1 Phosphorus

Phosphorus is usually present in drinking water as phosphate. In Finland, phosphorus is the limiting factor for microbial growth in drinking water and in biofilms.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of state of the network and sampling method e.g. on the concentration of phosphate phosphorus in drinking water. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. In water pumped into the network the median concentration was 1.5 µg/l (Figure 6B). In stagnated and flowing water, the concentrations were somewhat higher, with the median concentrations being 3.0 and 3.5 µg/l, respectively.

There is no guide value for the phosphorus concentration in the Finnish decree on drinking water. The median concentration of phosphate phosphorus in the study varied between 1.5 and 6.0 µg/l.

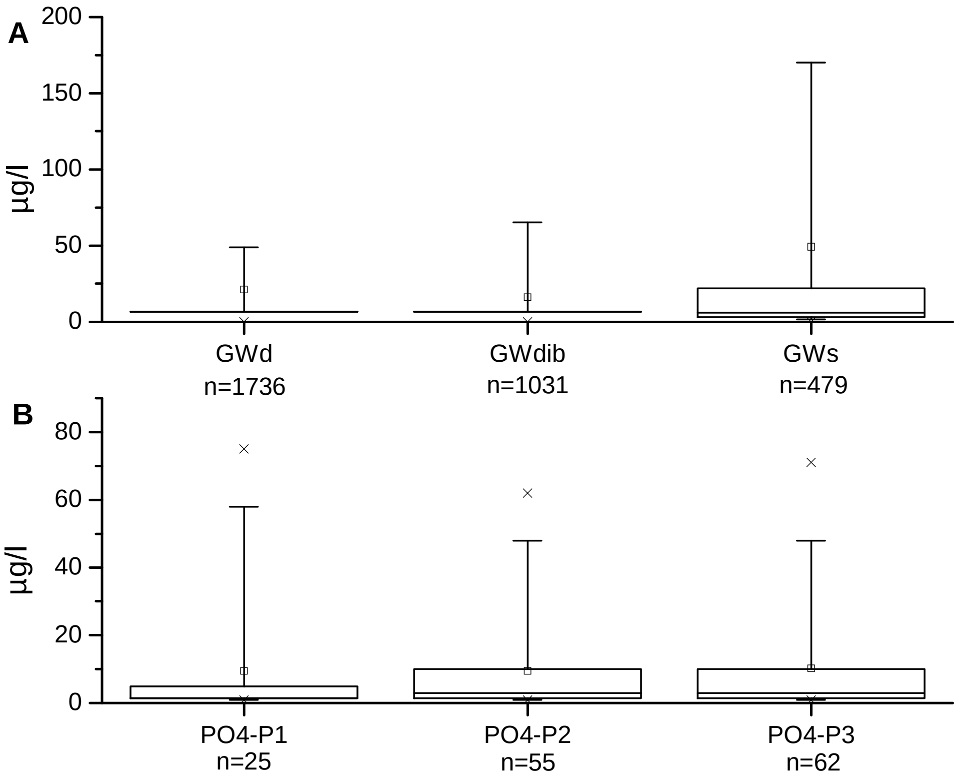

Figure 6. Phosphorus. Concentration of phosphate phosphorus in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (A). The effects of the network and sampling on the phosphate phosphorus concentration in drinking water provided by waterworks in 2007 (B). PO4-P1 is water pumped from waterworks into the network, PO4-P2 is stagnated network water, and PO4-P3 is flowing network water. The maximum values that are not visible in plots are GWd 2190 µg/l, GWdip 346 µg/l, and GWs 1600 µg/l.

Summary of the nutrients for microbes:

Water provided by the waterworks and well water was in accordance with the Finnish decree on drinking water with respect to the nutrients for microbes. The median for TOC concentration was 1.9 mg/l in water provided by the waterworks. The median concentration of phosphate phosphorus ranged from 1.5 to 6 µg/l in the study.

6 Metals

The Finnish decree on drinking water has a limit value or a guide value for many metals (Figure 7). Metals can affect human health, can lessen the technical and aesthetical quality of drinking water, and can promote microbial growth in many ways. Metals can enter the drinking water from the soil, from materials in the drinking water network or as a result of human activity. There are several factors which influence the dissolution of metals from the network materials. Dissolution can be prevented by modifying the technical properties of water or by altering the types of materials used in the pipeline network.

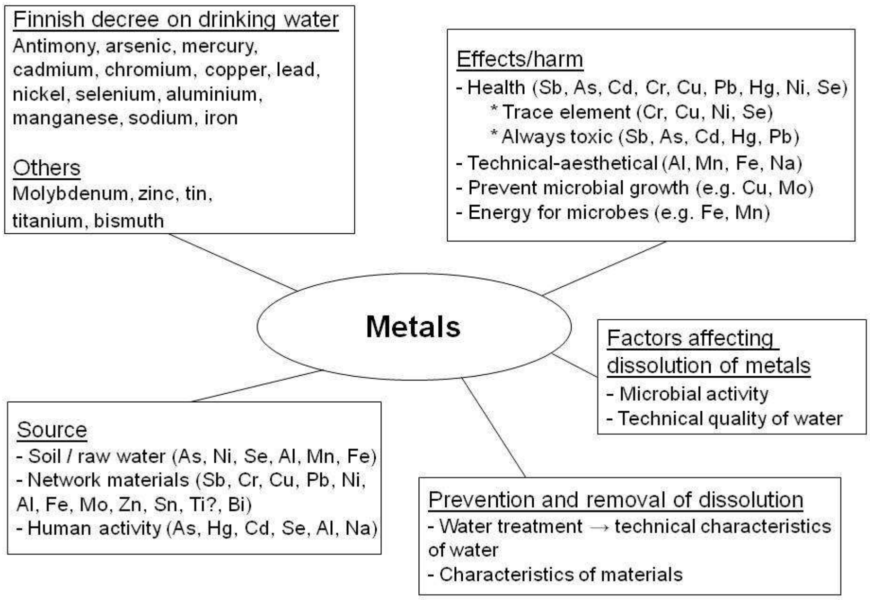

Figure 7. Metals in drinking water.

6.1 Metals subject to quality standards

6.1.1 Antimony (Sb)

Antimony can gain access to the drinking water from brass used in the network materials and from tin-antimony alloy used as soldering material. The limit value in the Finnish decree on drinking water is based on antimony's toxicity.

Range of the median concentrations of antimony in the study was 0.02 – 1.00 µg/l. The lowest median concentration of 0.02 µg/l was observed in the groundwater data from GTK (soil wells and drilled wells). Well waters from the SYKE data had the median concentration of 0.11 µg/l. Water provided by waterworks and water combined from several wells had the median concentration of 1 µg/l. The antimony concentrations in waters in the study were adherent to the Finnish decree on drinking water except for samples from one waterworks and occasional soil well.

According to EAS, a suggested limit value for the dissolution of antimony when metal alloys are being tested is 2.5 µg/l which is 50 % of the limit value in DWD and the Finnish decree on drinking water (5.0 µg/l). Almost all, 99.5 % of the waterworks in the study provided water whose antimony concentration was below 2.5 µg/l and thus the proposed limit value of EAS is suited for the conditions in Finland.

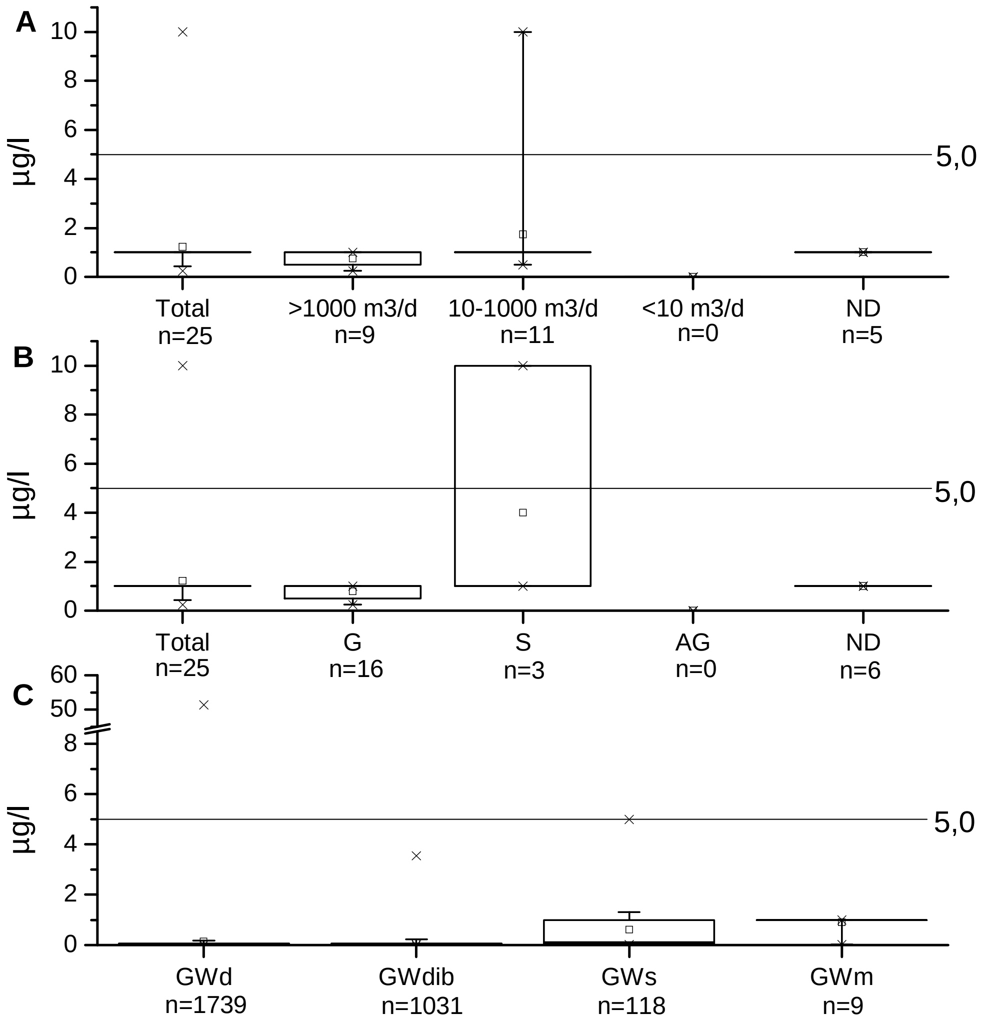

Figure 8. Antimony. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C).

6.1.2 Arsenic (As)

Arsenic is a toxin which can appear in drinking water from soil, bedrock, and certain chemicals.

Additional measurements carried out in the autumn 2007 were done in order to determine the possible effects of the network and sampling method e.g. on the concentration of arsenic in drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. With the exception of a few samples all specimens were below detection limit (<1 µg/l). At this detection sensitivity it appears that neither the state of the network nor sampling method has any effect on concentration of arsenic in drinking water.

The median concentrations of arsenic in the study ranged from 0.1 to 1.7 µg/l. The lowest median concentration of 0.1 µg/l was observed in soil wells. In drilled wells, the median concentration was 0.4 µg/l. Well wat ers from the SYKE data, water combined from several wells, and water provided by waterworks had the median concentrations of 1 µg/l. The highest median concentration of 1.7 µg/l was observed in a medium-sized waterworks. All types of water in the study had occasional specimens exceeding the limit value of the Finnish decree on drinking water.

According to EAS, a proposed limit value for dissolution of arsenic when metal alloys are tested is 5 µg/l which is 50 % of the limit value in DWD and also the Finnish decree on drinking water (10 µg/l). Over 99 % of the waterworks in the study provided water whose antimony concentration was below 5 µg/l and thus the proposed limit value of EAS is suited for the conditions in Finland.

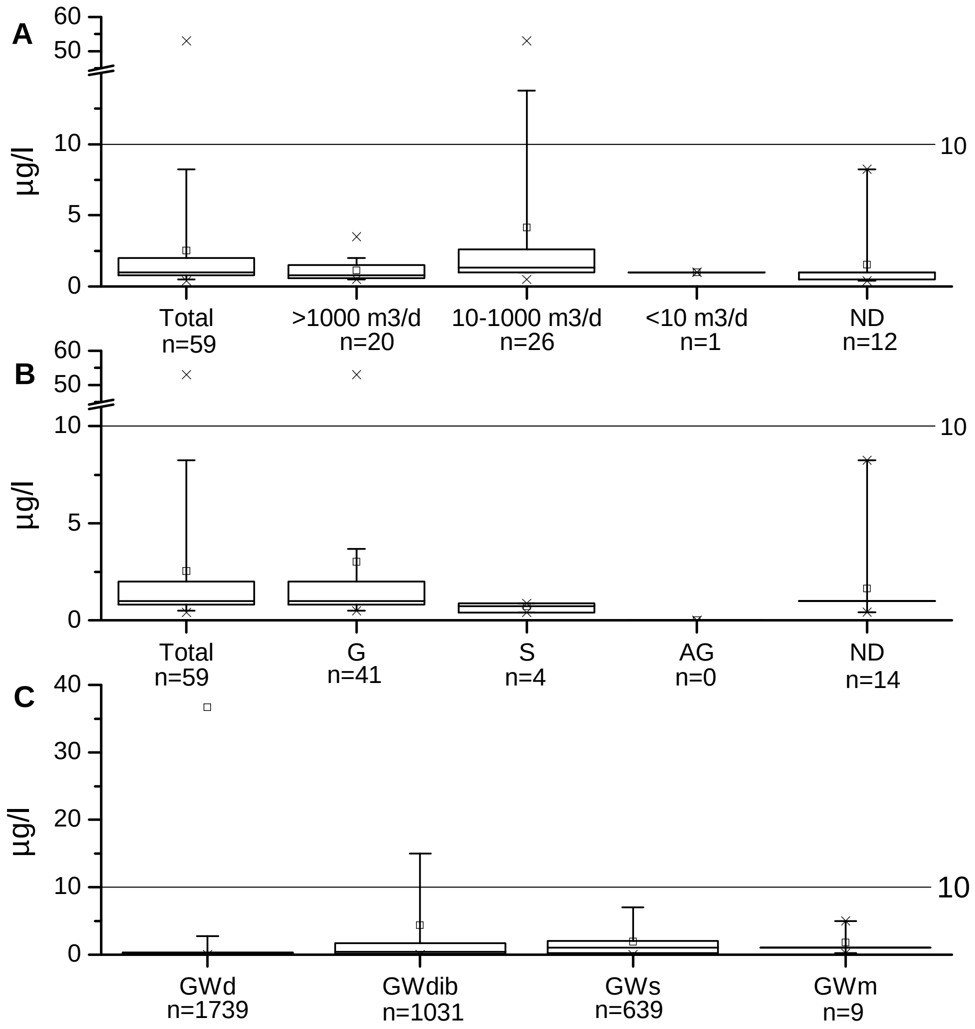

Figure 9. Arsenic. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum concentrations that are not visible in the plots are GWd 10 100 µg/l (10.1 mg/l), GWdib 822 µg/l, and GWs 76 µg/l.

6.1.3 Mercury (Hg)

Mercury is a toxin which is used in the manufacture of a variety of compounds produced by the chemical industry. It is conceivable that mercury gains access to the drinking water from wastewaters, deposits, or the chemicals used in agriculture.

The median concentrations of arsenic in the study ranged from 0.1 to 0.2 µg/l. In all data in the study the concentrations were in accordance with the Finnish decree on drinking water.

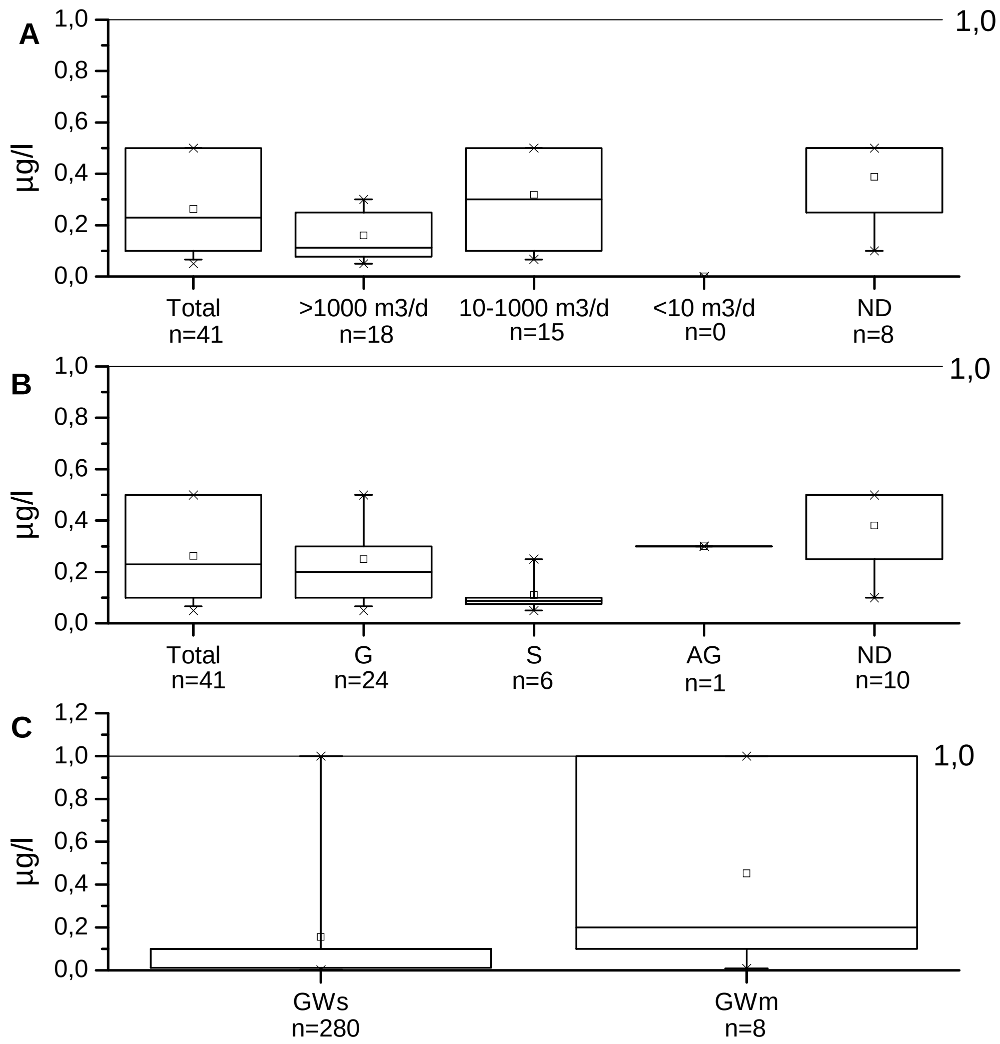

Figure 10. Mercury. Concentration in water provided by waterworks (A and B) and in the groundwater data from SYKE (C) in the years 2000 – 2007.

6.1.4 Cadmium (Cd)

Cadmium is a toxin which is utilized in different aspects of the chemical industry. Cadmium gain entry to the drinking water from wastewaters, air deposits, or fertilizers.

The median concentrations of cadmium in the study ranged from <0.02 to 1.00 µg/l. The lowest median concentration (<0.02 µg/l) was observed in drilled wells. In soil wells and wells from the SYKE data, the median concentration was 0.02 – 0.04 µg/l. Water specimens provided by waterworks had the median concentrations ten times higher than well waters (0.300 vs. 0.003 µg/l). Water combined from several wells exhibited the median concentration of 1.00 µg/l. The results of these analyses in this study were in accordance with the Finnish decree on drinking water except for the occasional soil and drilled well water samples.

EAS has proposed a limit value of 2.5 µg/l for dissolution of cadmium when metal alloys are to be tested which is 50 % of the limit value in DWD and the Finnish decree on drinking water (5.0 µg/l). Water provided by the waterworks in the study had cadmium concentration of 1.0 µg/l or less and thus the proposed limit value of EAS is suited for the conditions in Finland.

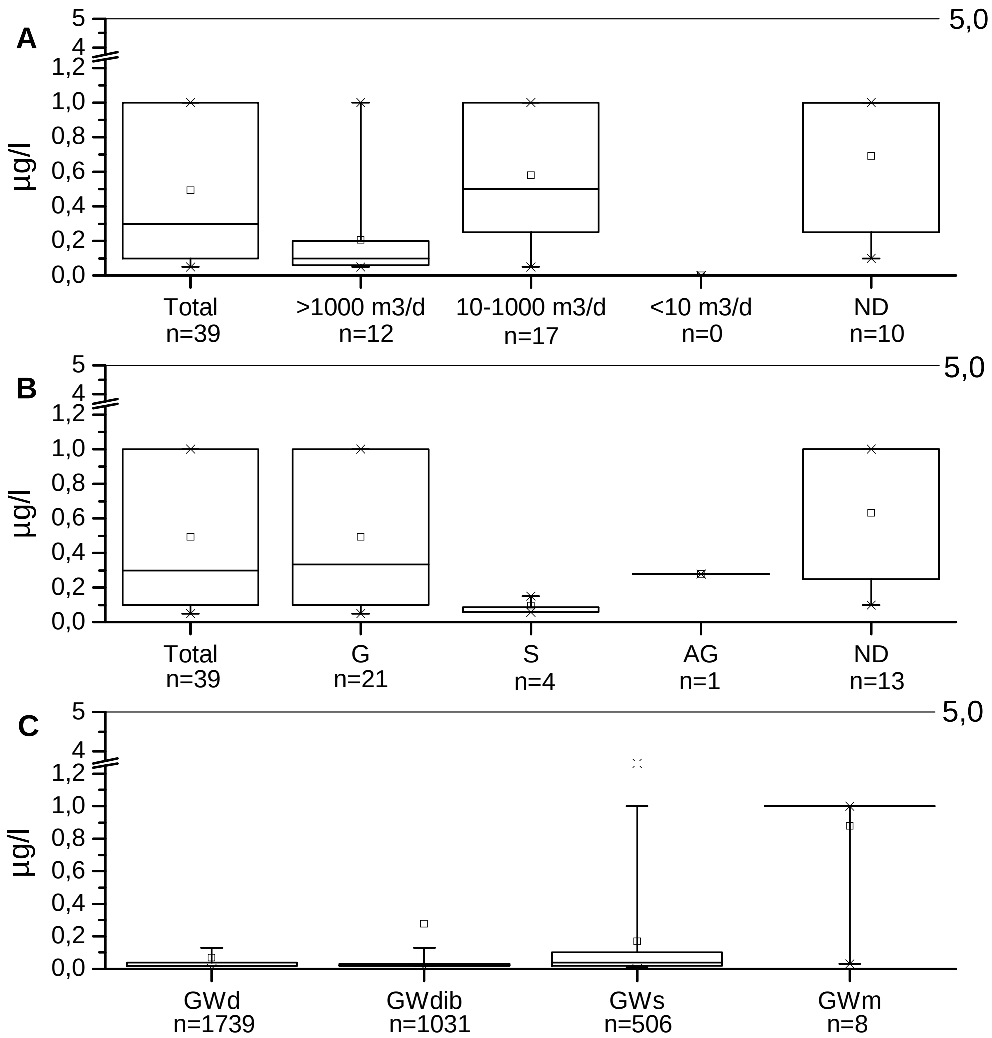

Figure 11. Cadmium. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum concentrations that are not visible in the plots are GWd 7.0 µg/l, GWdib 243 µg/l, and GWs 2.3 µg/l.

6.1.5 Chromium (Cr)

The limit value for chromium in the Finnish decree on drinking water is attributable to its harmful health effects. Chromium present in drinking water originates mainly from the network materials.

The range of the median concentrations of chromium in the study was <0.2 – 5.0 µg/l. The lowest median concentration (<0.2 µg/l) was observed in drilled wells. In soil wells, wells from the SYKE data, and water provided by waterworks, the median concentrations were 0.2, 1.0, and 1.6 µg/l, respectively. The highest median concentration (5.0 µg/l) was analysed in water combined from several wells. The analyses results in the study were in accordance with the Finnish decree on drinking water with the exception of a few well water samples from the SYKE data.

EAS has proposed a limit value of 25 µg/l for dissolution of chromium when metal alloys are being tested which is 50 % of the limit value in DWD and the Finnish decree on drinking water (50 µg/l). Water provided by the waterworks in the study had chromium concentration of 10 µg/l or less and thus the proposed limit value of EAS is suited for conditions in Finland.

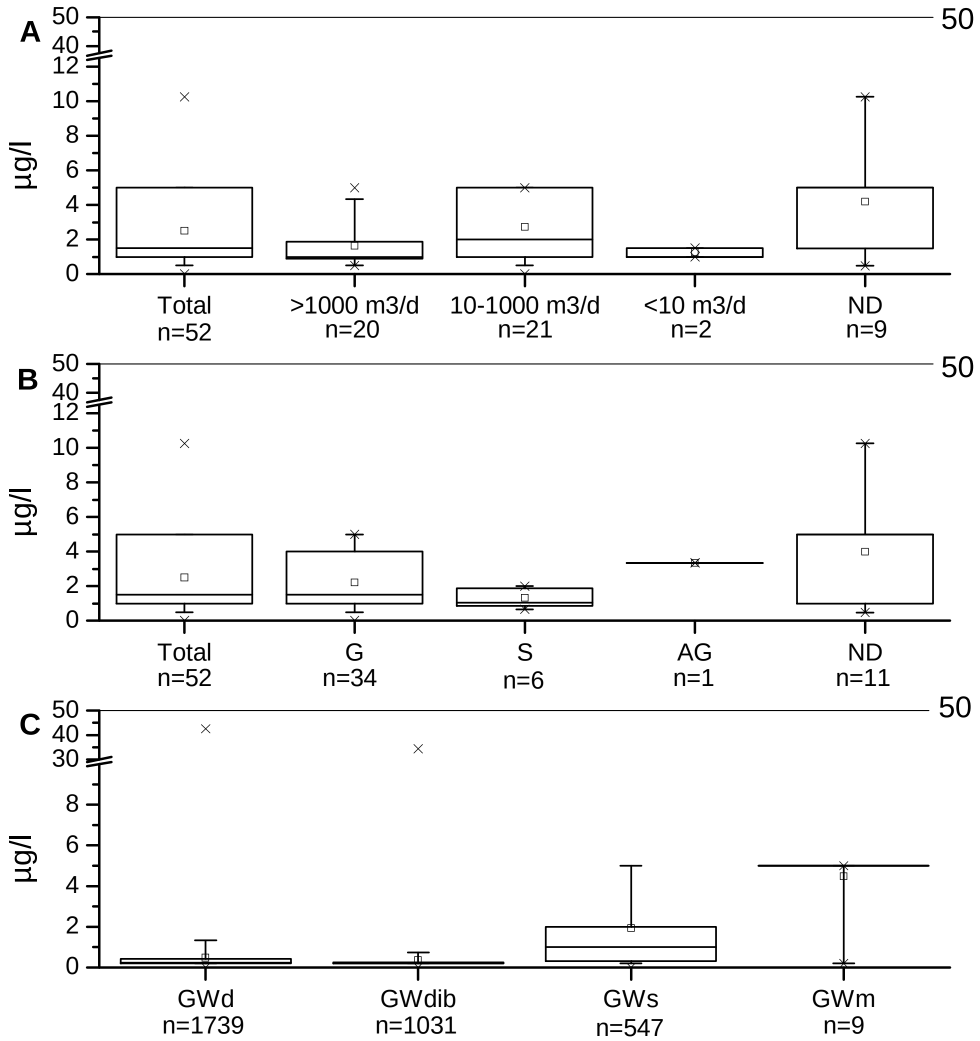

Figure 12. Chromium. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum concentration of GWs 86 µg/l is not visible in the plot.

6.1.6 Copper (Cu)

Copper is an essential trace element for humans but at high concentrations it can cause harmful health effects. Copper in drinking water originates mainly from the copper piping used in real estates for transporting cold and hot water.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of position in the network and sampling method e.g. on the concentration of copper in drinking water. The samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. The highest median concentration of 0.12 mg/l was observed in the stagnated water (Figure 13D). Water pumped into the network and flowing water had the significantly lower median concentrations of 0.003 and 0.011 mg/l, respectively.

The median concentrations of chromium in the study ranged from 0.002 to 0.100 mg/l. The lowest median concentration (0.002 mg/l) was observed in soil wells. Other types of well waters had the median concentrations of 0,004 – 0,020 mg/l. In water provided by waterworks, the concentrations were significantly higher, with the median concentration being 0.1 mg/l. Samples exceeding the limit value in the Finnish decree on drinking water were observed in one waterworks and in occasional well water samples from the SYKE data.

EAS has proposed a limit value of 1.8 mg/l for dissolution of copper when metal alloys are being tested which is 90 % of the limit value in DWD and the Finnish decree on drinking water (2.0 mg/l). Majority of water samples provided by the waterworks in the study had copper concentration of 1.0 mg/l or less and thus the proposed limit value of EAS is suited for the conditions in Finland.

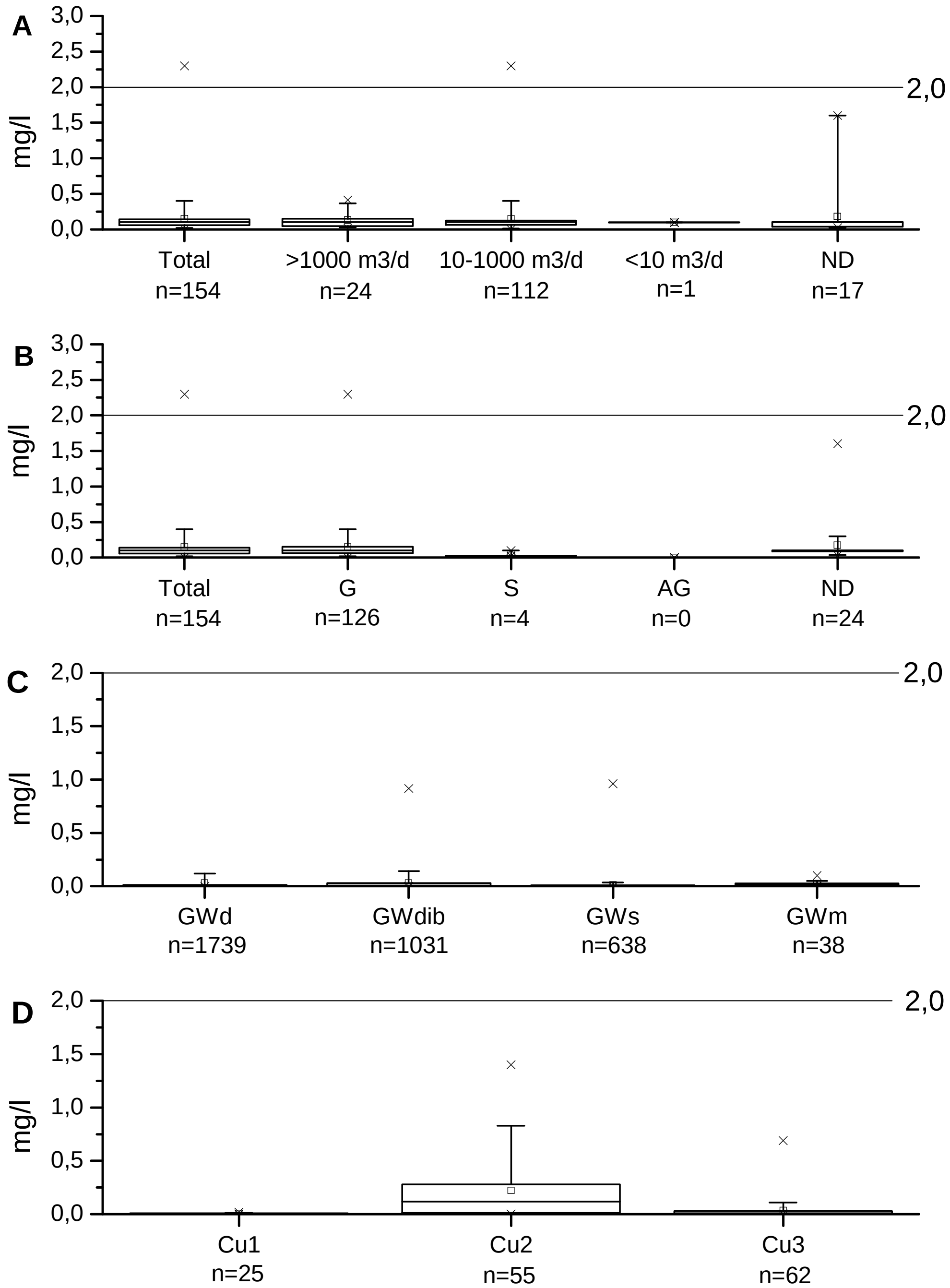

Figure 13. Copper. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The effects of the network and sampling on the copper concentration in drinking water provided by the waterworks (D). Cu1 is water pumped from waterworks into the network, Cu2 is stagnated network water, and Cu3 is flowing network water. The maximum concentration of GWd 4.3 mg/l is not visible in the plot.

6.1.7 Lead (Pb)

Lead is a potent neurotoxin that accumulates in soft tissues and bone over time. Lead might be present in drinking water since lead is used in many metal alloys.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of site in the network and sampling method e.g. on concentration of lead in drinking water. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. With the exception of a few samples all specimens were below the detection limit (<1 µg/l). At this detection sensitivity one can conclude that neither site in the network nor sampling method appeared to have any effect on the concentration of lead in drinking water.

The median concentrations of lead in the study ranged from 0.05 to 5.00 µg/l. The lowest median concentration (0.05 µg/l) was observed in soil wells. In drilled wells and separate wells from the SYKE data, the median concentrations were between 0.15 and 0.40 µg/l. In water provided by waterworks, the median concentration was 1 µg/l. The highest median concentration of 5 µg/l was observed in water combined from several wells from the SYKE data. Water provided by waterworks was in accordance with the Finnish decree on drinking water. A few well water samples exceeded the limit value set in the Finnish decree on drinking water.

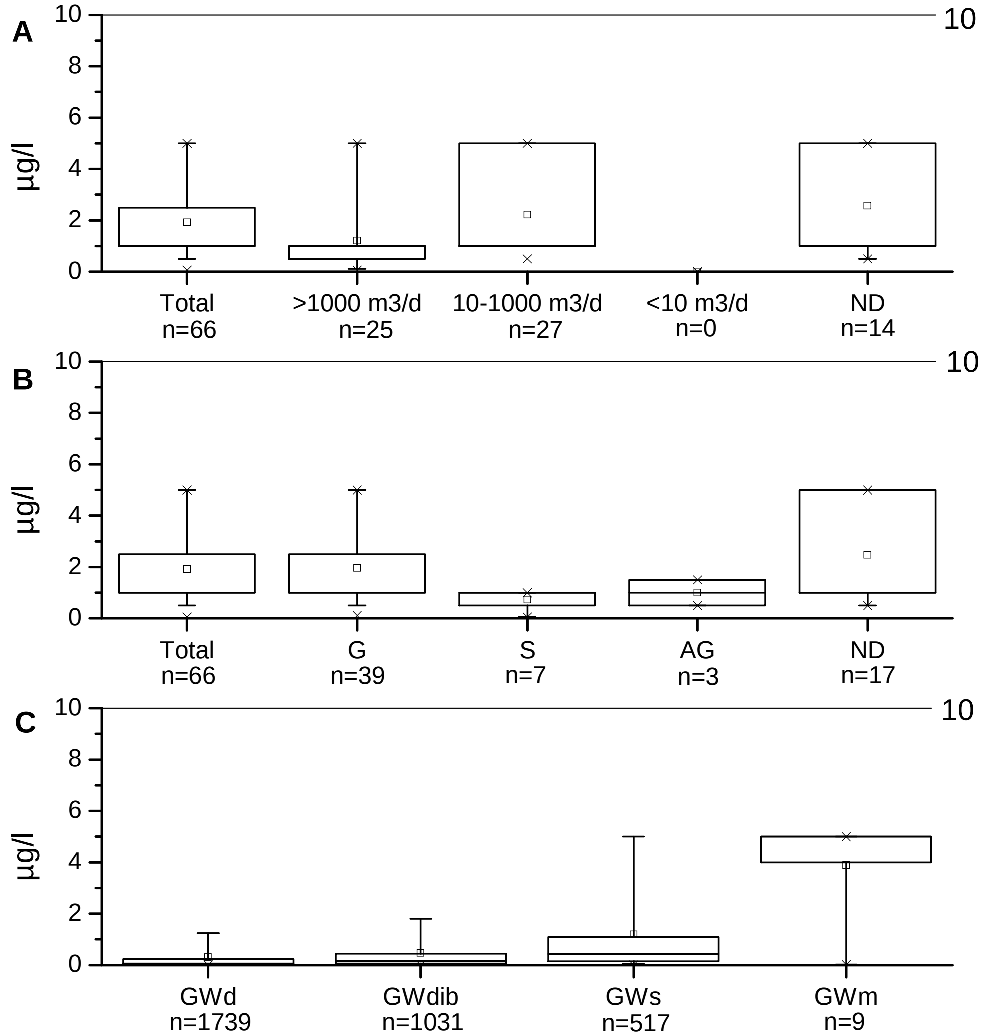

Figure 14. Lead. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum concentrations that are not visible in the plots are GWd 19 µg/l, GWdib 32 µg/l, and GWs 15 µg/l.

EAS has proposed a limit value 5 µg/l for dissolution of lead when metal alloys are being tested which is 50% of the limit value in DWD and the Finnish decree on drinking water (10 µg/l). Water provided by the waterworks in the study had lead concentration of 5 µg/l or less and thus the proposed limit value of EAS is suited for the conditions in Finland.

6.1.8 Nickel (Ni)

Nickel is a potential allergy-evoking metal which may gain access to the drinking water from minerals of soil and bedrock and from metal alloys used in water fittings in real estates.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of state of the network and sampling method e.g. on the concentration of nickel in drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. With the exception of a few samples, all specimens were below the detection limit (<1 or <4 µg/l). At this detection sensitivity, it appears that neither the state of the network nor sampling method has any effect on the concentration of nickel present in drinking water.

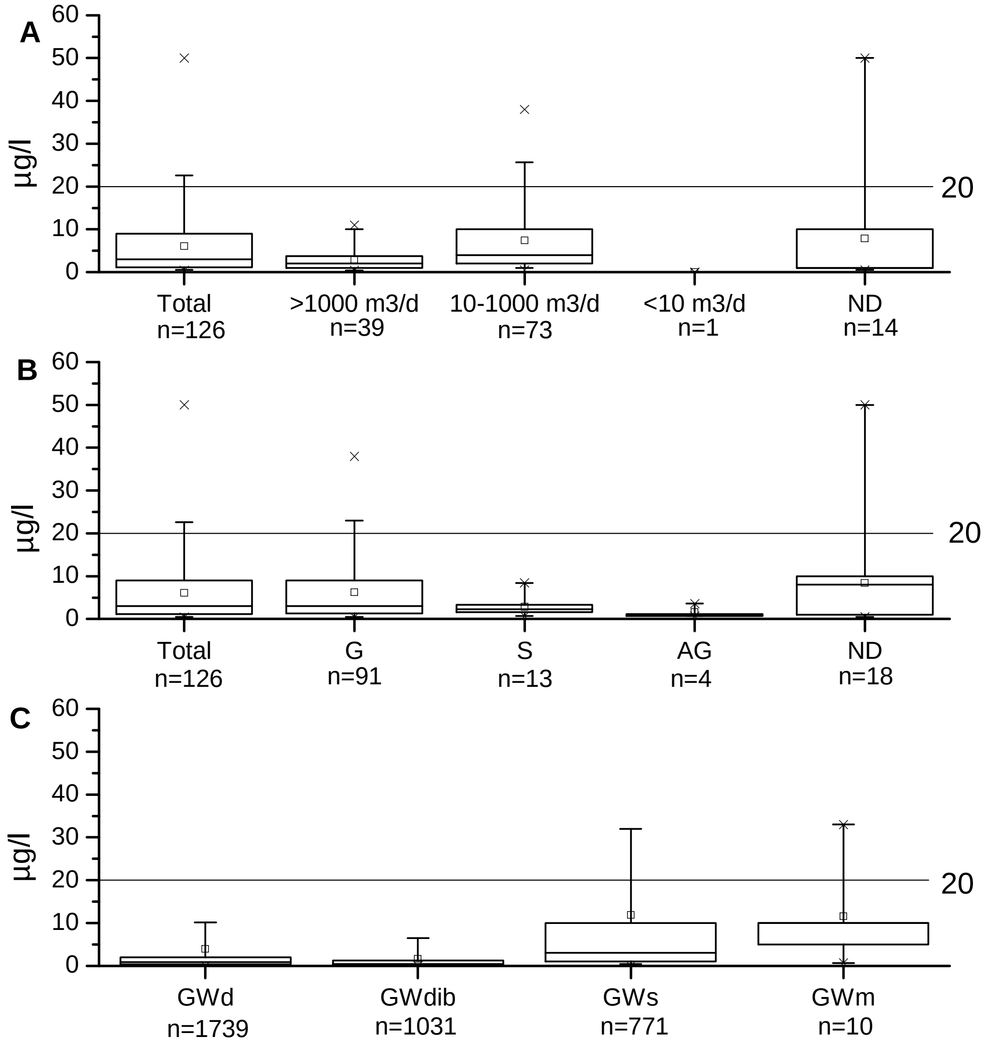

Figure 15. Nickel. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum concentrations that are not visible in the plots are GWd 277 µg/l, GWdib 68 µg/l, and GWs 380 µg/l.

The median concentrations of nickel in the study ranged from 0.4 to 10.0 µg/l. The lowest median concentrations (0.4 and 0.8 µg/l) were observed in drilled and soil wells. The median concentration was 3.0µg/l in water provided by waterworks and separate wells from the SYKE data. The highest median concentration of 10 µg/l was observed in water combined from several wells from the SYKE data. There were samples exceeding the limit value of the Finnish decree on drinking water observed in all types of water specimens in this study.

EAS has proposed a limit value of 10 µg/l for dissolution of nickel when metal alloys are being tested which is 50 % of the limit value in DWD and the Finnish decree on drinking water (20 µg/l). In all, 4 % of the waterworks in the study provided water whose nickel concentration exceeded 10 µg/l. Due to the rather high concentration of nickel in Finnish drinking water, nickel dissolving from materials should be reduced if one wishes to comply with the proposed concentration in the EAS. On the other hand, the limit value proposed by WHO for concentration of nickel in drinking water is 70 µg/l and therefore it is possible that limit values in the DWD, the Finnish decree on drinking water, and also the EAS will be changed. Currently the drinking water directive is being revised (May 2008).

6.1.9 Selenium (Se)

Selenium is a metal present in soil and bedrock which is toxic at high concentrations. Selenium might enter the drinking water supply from the fertilizers used in agriculture.

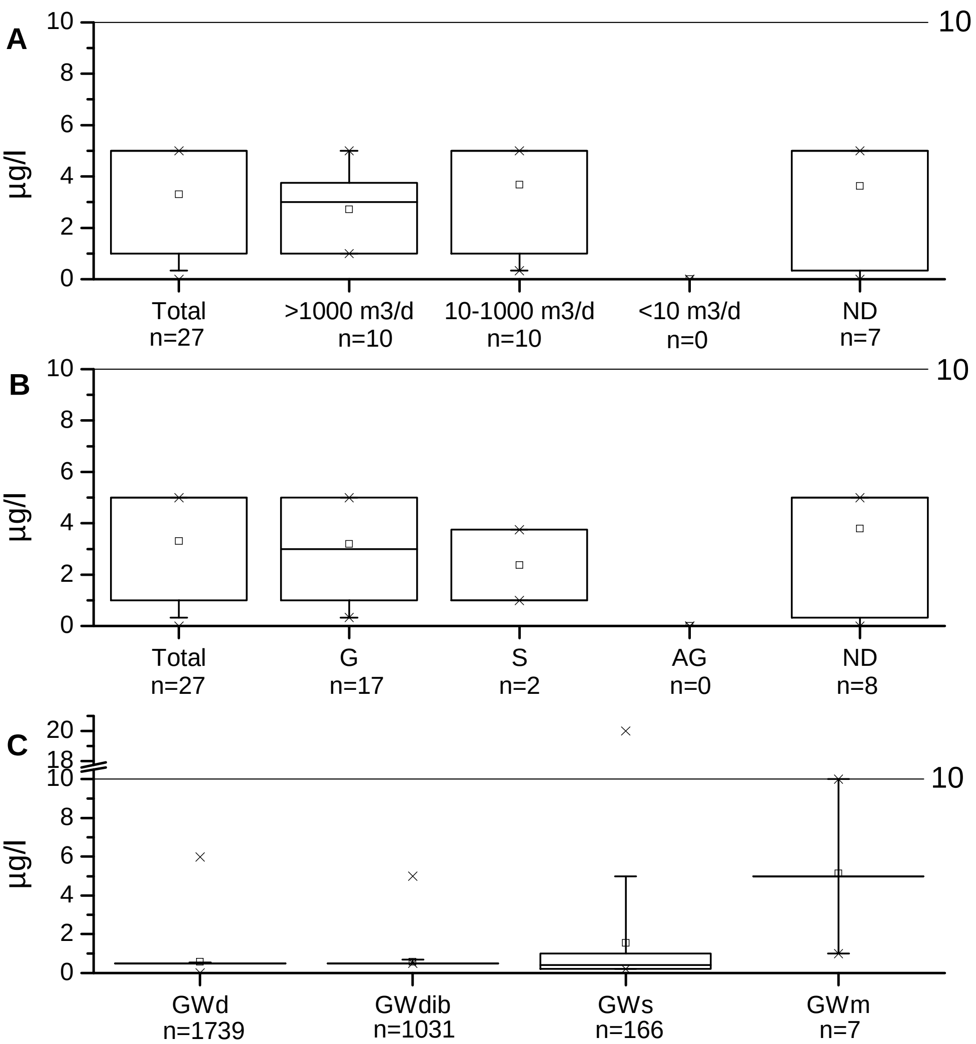

Figure 16. Selenium. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C).

The median concentrations of nickel in the study ranged from 0.4 to 5.0 µg/l. The lowest median concentrations (<0.5 and 0.4 µg/l) were observed in soil and drilled wells and in separate wells from the SYKE data. In water provided by waterworks and water combined from several wells from the SYKE data, the median concentration was significantly higher, 5.0 µg/l. With the exception of one sample from water combined from several wells, all results were in accordance with the Finnish decree on drinking water.

The EAS has proposed a limit value of 5 µg/l for dissolution of selenium when metal alloys are being tested which is 50 % of the limit value in DWD and also of the Finnish decree on drinking water (10 µg/l). Water provided by the waterworks in the study had selenium concentration of 5 µg/l or less and thus the proposed limit value of EAS is suited for the conditions in Finland.

6.2 Metals subject to quality recommendations

6.2.1 Aluminium (Al)

Aluminium is a metal present in soil and bedrock minerals. Aluminium may also originate from chemicals used in water treatment and from the network materials. Some of aluminium in drinking water is bound to organic matter.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of the network site and sampling method e.g. on the concentration of nickel in drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. With the exception of a few samples all specimens were below the detection limit (<10 or <20 µg/l). At this detection sensitivity, it appeared that neither the state of the network nor sampling method has any effect on the concentration of aluminium present in drinking water.

The median concentrations of aluminium in the study ranged from 1.0 to 20.0 µg/l. The lowest median concentration (3.0 µg/l) was observed in drilled wells. In soil wells, wells from the SYKE data, and water provided by waterworks the median concentrations were significantly higher, 20 – 22 µg/l. Three waterworks, soil and drilled wells and separate wells from the SYKE data had some samples exceeding the guide value in the Finnish decree on drinking water. Water combined from several wells from the SYKE data was in accordance with the decree.

The EAS has proposed a limit value of 100 µg/l for dissolution of aluminium when metal alloys are being tested which is 50 % of the limit value in DWD and the Finnish decree on drinking water (200 µg/l). In all, 4% of the waterworks in the study provided a water sample with a concentration of aluminium exceeding 100 µg/l. Due to the fairly high concentration of aluminium in Finnish drinking water, attempts must be made to reduce the aluminium dissolving from materials to achieve water complying with the proposed concentration in the EAS.

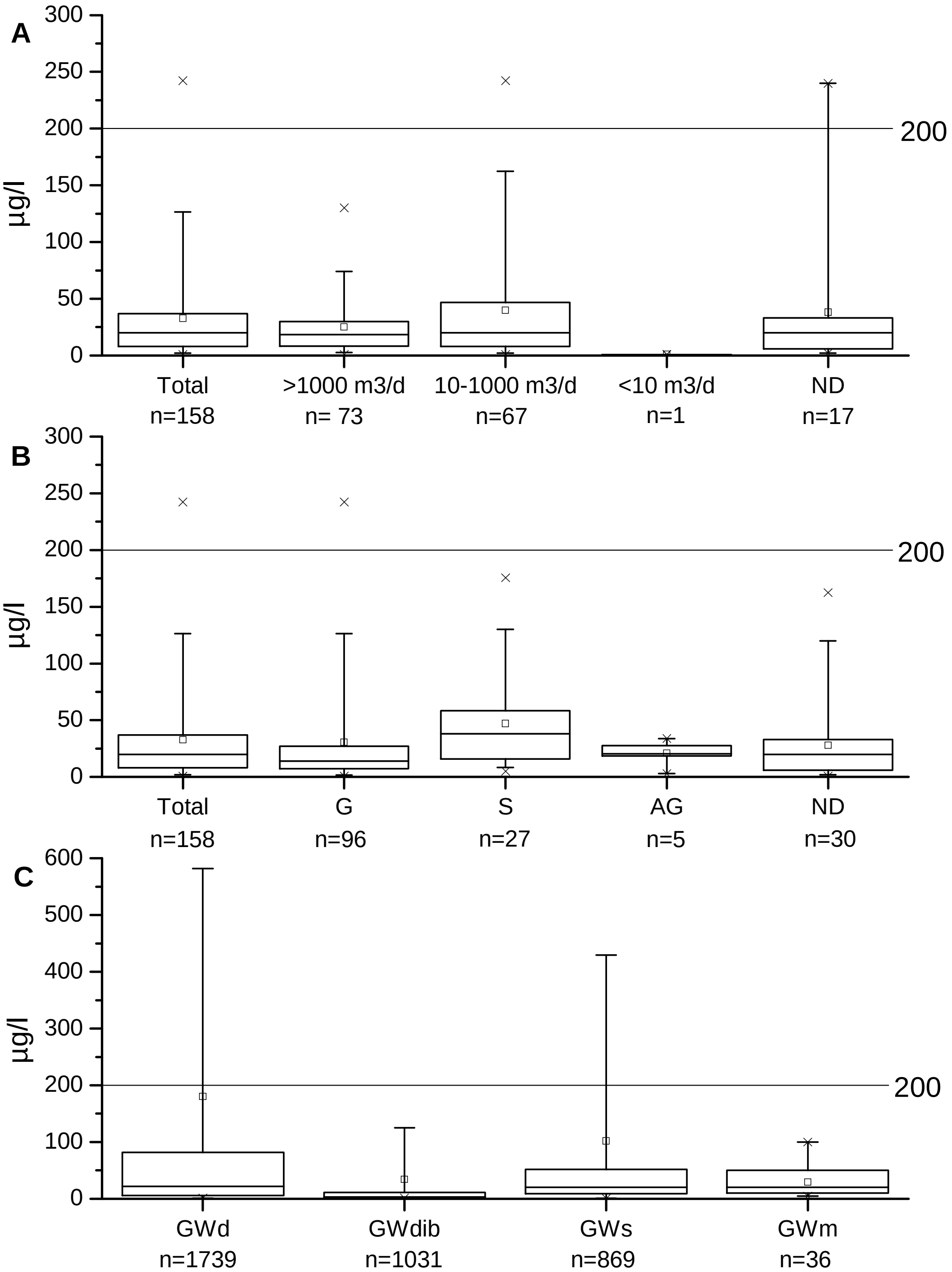

Figure 17. Aluminium. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum concentrations that are not visible in the plots are GWd 25 700 µg/l, GWdib 2 750 µg/l, and GWs 10 000 µg/l.

6.2.2 Manganese (Mn)

Manganese is a metal which might cause a foul taste and odour and black residues fouling pipes and water fittings. Manganese gain access to drinking water from soil and bedrock minerals.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of position in the network and sampling method e.g. on concentration of manganese in drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were around the same order of magnitude, 2.0 – 3.0 µg/l (Figure 18D).

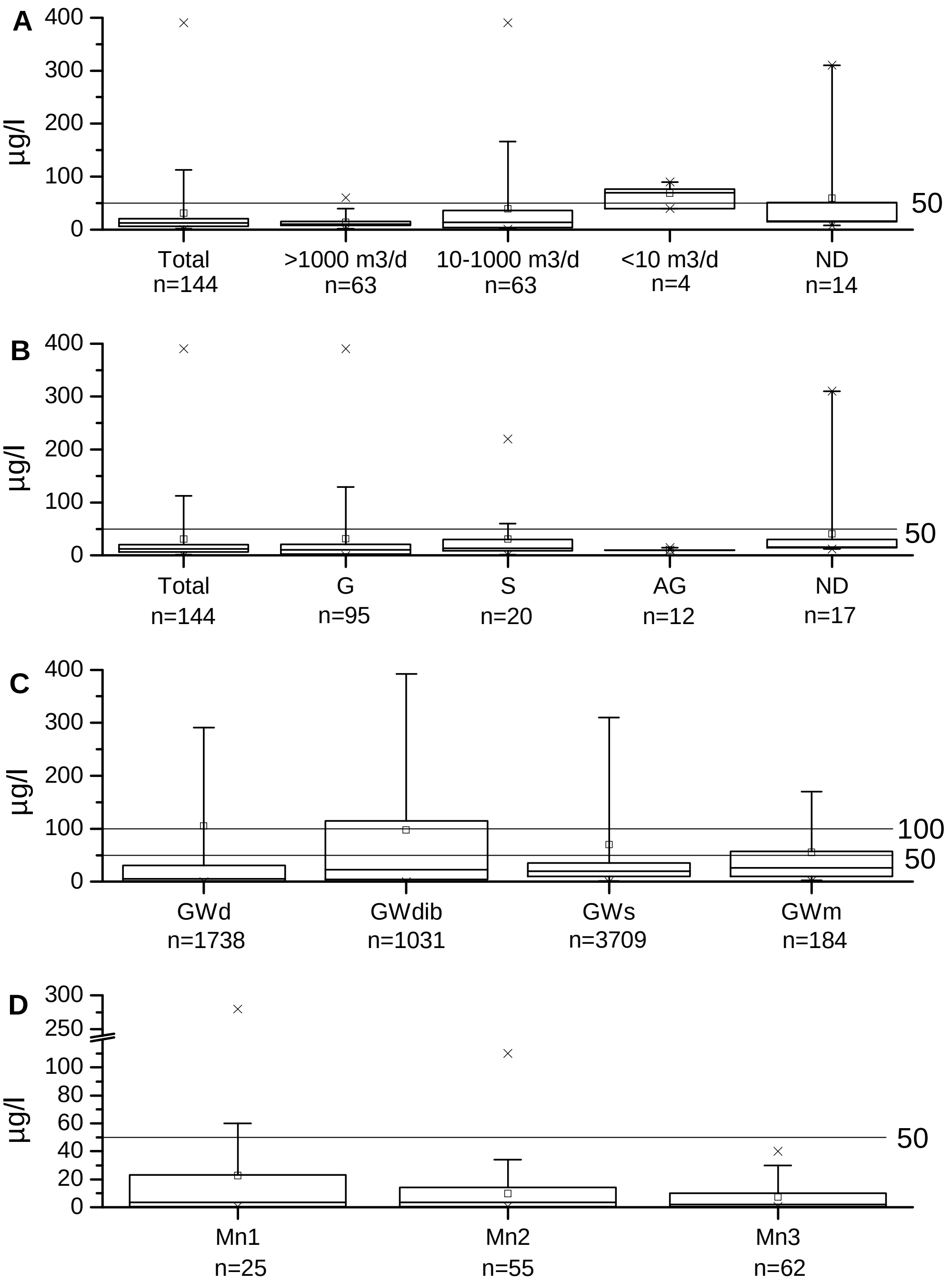

Figure 18. Manganese. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Effects of position in the network and sampling method on concentration of manganese in drinking water provided by waterworks (D). Mn1 is water pumped from the waterworks into the network, Mn2 is stagnated network water, and Mn3 is flowing network water. The maximum concentrations that are not visible in the plots are GWd 15 600 µg/l, GWdib 4 140 µg/l, GWs 12 000 µg/l, and GWm 1 900 µg/l.

The median concentrations of manganese in the study ranged from 2.0 to 73.0 µg/l. The lowest median concentrations (2.0 – 5.0 µg/l) were observed in flowing network water in the supplemental measurements and in soil wells. In water provided by waterworks, the median concentration was 13 µg/l. In drilled wells and water types from the SYKE data the median concentrations varied between 20 – 27 µg/l. Samples exceeding the guide value in the Finnish decree on drinking water were observed in all water types in this study.

The EAS has a proposed limit value of 25 µg/l for dissolution of manganese when metal alloys are being tested which is 50 % of the limit value in DWD as well as the Finnish decree on drinking water (50 µg/l). In all, 7 % of the waterworks in the study provided a water sample whose concentration of manganese exceeded 25 µg/l. Because of the fairly high concentration of manganese in Finnish drinking water, the amount of manganese dissolving from materials needs to be reduced if water is to comply with the proposed concentration in the EAS.

6.2.3 Sodium (Na)

Sodium in drinking water can originate from a variety of sources e.g. soil, bedrock, de-icing salt, and water treatment chemicals.

The median concentrations of sodium in the study ranged from 4.0 to 13.0 mg/l. The lowest median concentration of 4 mg/l was observed in soil wells. In water provided by waterworks and waters from the SYKE data, the median concentrations were 8 – 11 mg/l. The highest median concentration (13 mg/l) was observed in drilled wells. With the exception of samples from one waterworks and the occasional well waters listed in the SYKE data, all results were in accordance with the Finnish decree on drinking water.

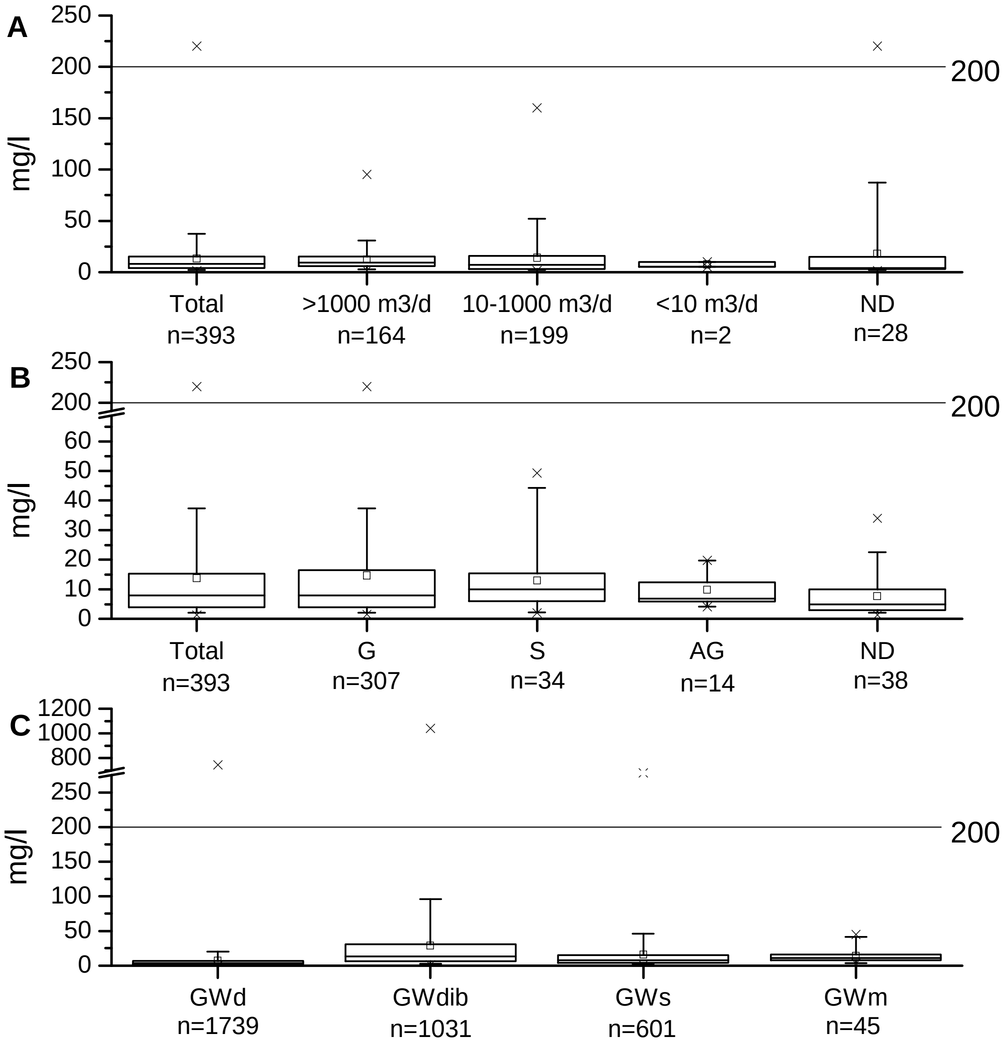

Figure 19. Sodium. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). The maximum concentration of GWs 431 mg/l is not visible in the plot.

6.2.4 Iron (Fe)

Iron is a metal which might cause foul taste and odour and lead to the formation of rust residues on pipes and water fittings. Iron might gain access to drinking water from soil and bedrock and corrosion products from the network materials.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of the state of the network and sampling method e.g. on the concentration of iron in drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were around the same order of magnitude 14 – 25 µg/l (Figure 20D).

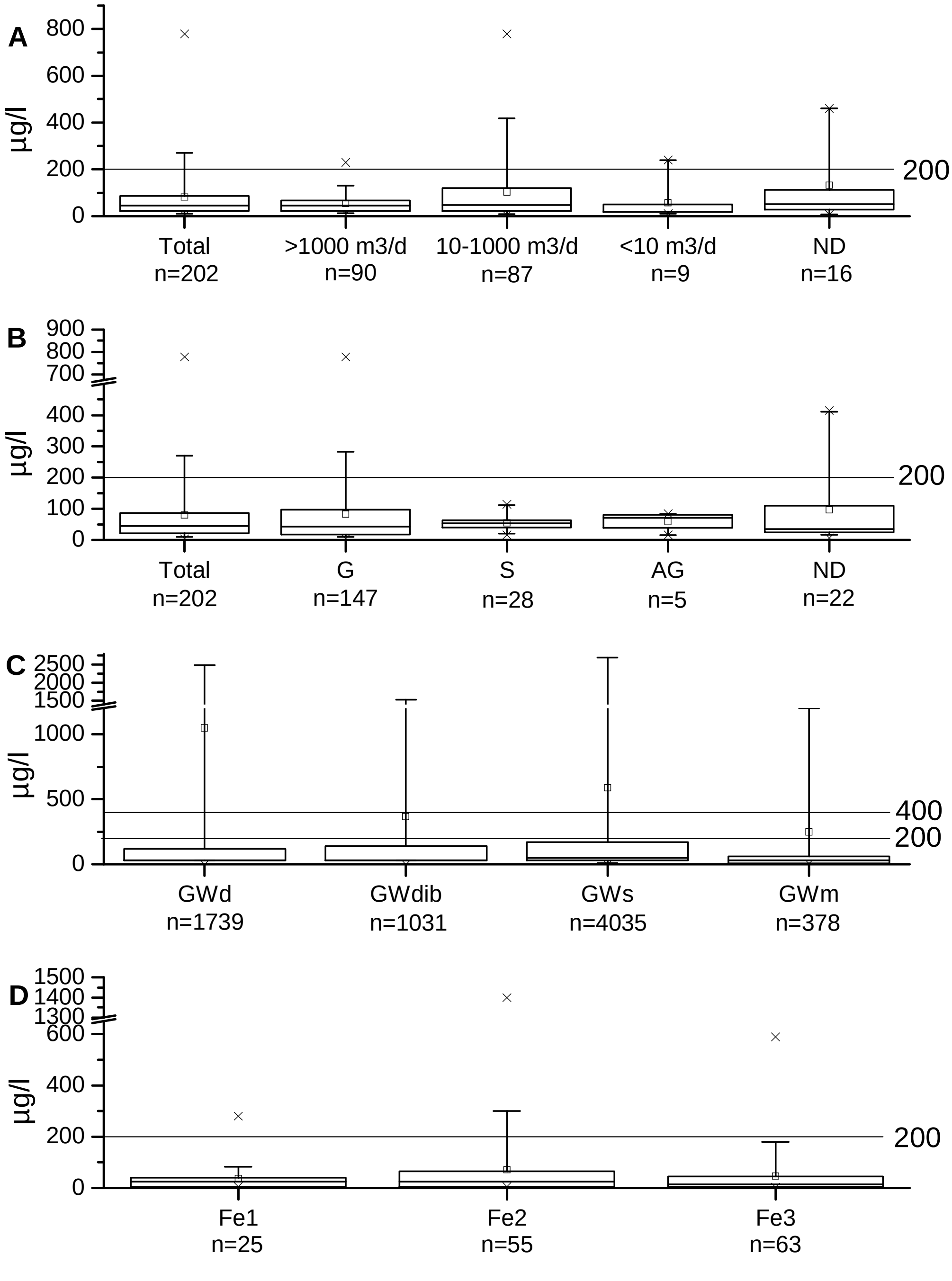

Figure 20. Iron. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Effects of the network position and sampling method on the concentration of iron in drinking water provided by waterworks (D). Fe1 is water pumped from waterworks into the network, Fe2 is stagnated network water, and Fe3 is flowing network water. The maximum concentrations that are not visible in the plots are GWd 133 000 µg/l, GWdib 39 900 µg/l, GWs 85 000 µg/l, and GWm 19 000 µg/l.

The median concentrations of iron in the study ranged from 14 to 71 µg/l. The median concentration was 30µg/l in soil wells, drilled wells, and waters combined from several wells (SYKE data). In water provided by waterworks, the median concentration was 46 µg/l and in flowing network water in the samples for the additional measurements it was 14 µg/l. In separate wells from the SYKE data, the median concentration was 50 µg/l. A few samples exceeding the guide value of the Finnish decree on drinking water were observed in all water types of the study.

The EAS has a proposed limit value of 100 µg/l for dissolution of iron when metal alloys are being tested which is 50 % of the limit value in DWD and the Finnish decree on drinking water (200 µg/l). Quite many, 10 %, of the waterworks in the study provided water whose concentration of iron exceeded 100 µg/l. Due to the fairly high concentration of manganese in Finnish drinking water, attempts should be made to reduce manganese dissolving from materials so that water can comply with the iron guidelines proposed in the EAS.

6.3 Other metals

6.3.1 Molybdenum (Mo)

Molybdenum can gain access to the drinking water network from acid-proof steel used in the network materials.

Information on concentration of molybdenum in water provided by waterworks and the possible effects of the network and sampling on the concentration was collected with additional measurements in the autumn 2007.

Water samples were taken from seven large waterworks (15 intake plants) and six medium-sized waterworks (7 intake plants). Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. In large waterworks, the median concentration was somewhat higher in water pumped from the waterworks into the network (0.4 µg/l) than in both of the network waters (0.1 µg/l) (Figure 21A). With medium-sized waterworks, the majority of the results were below the detection limit. The type of sampling did not seem to have any effect on concentration of molybdenum present in drinking water.

The median concentrations of molybdenum in the study ranged from 0.2 to 2.0 µg/l. There is no limit or guide value for the concentration of molybdenum in the Finnish decree on drinking water. The EAS has proposed a limit value of 10 µg/l for dissolution of molybdenum when metal products are being tested which is 50 % of the suggested limit value in drinking water (20 µg/l). The recommendation from WHO about the concentration of molybdenum in drinking water is 7.0 µg/l. All samples from the waterworks had concentration of molybdenum below 10 µg/l and thus the proposed limit value of EAS is suited for the conditions in Finland.

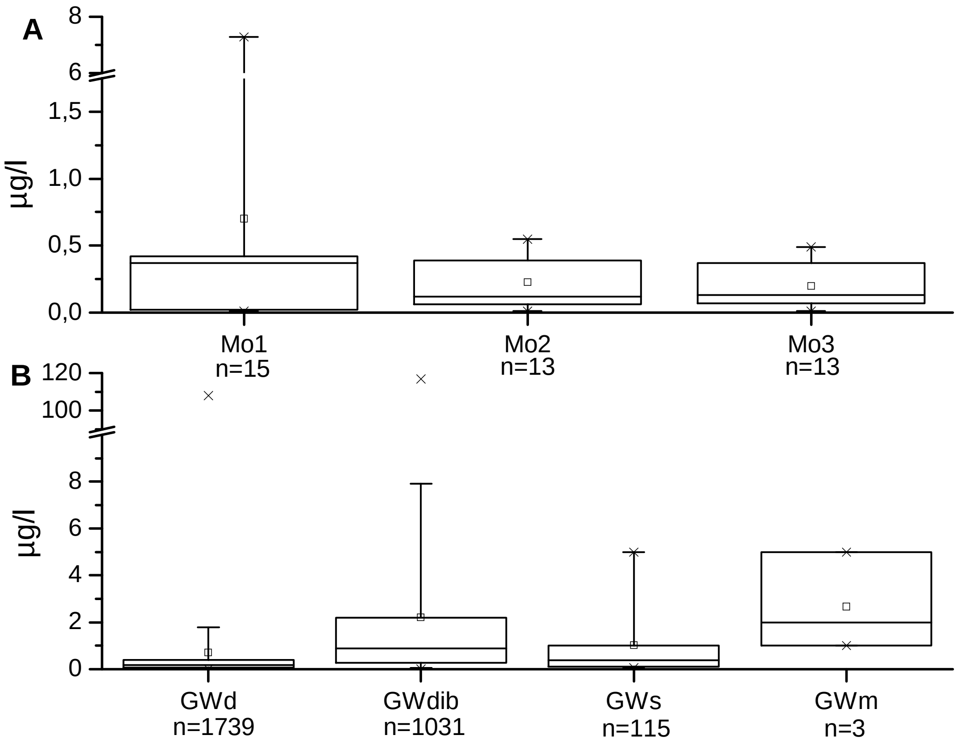

Figure 21. Molybdenum. Concentration in water provided by large waterworks in the year 2007 (A) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (B). Mo1 is water pumped from waterworks into the network, Mo2 is stagnated network water, and Mo3 is flowing network water.

6.3.2 Zinc (Zn)

Zinc might gain access to the drinking water network after dissolving from the galvanized steel and brass used in the network materials.

Information on concentration of zinc in water provided by waterworks and the possible effects of the network and sampling on the concentration was collected during additional measurements in the autumn 2007. Water samples were taken from seven large waterworks (15 intake plants) and six medium-sized waterworks (7 intake plants). Samples were taken from the water being pumped from the waterworks into the network, from stagnated network water, and from flowing network water. The results from these measurements revealed that the concentration of zinc could vary significantly according to the way of sampling (Figure 22A). In water pumped from the waterworks into the network, the median concentration was 2.0 µg/l in large waterworks and 19.0 µg/l in medium-sized waterworks. The clearly higher median concentrations were observed in the stagnated water in both large and medium-sized waterworks, 99 and 31 µg/l, respectively. The maximum concentration of zinc detected was 1400 µg/l. A sample taken after the water had been flowing exhibited median concentrations of 8 µg/l in large waterworks and 2 µg/l in medium-sized waterworks.

The median concentrations of zinc in the study ranged from 2.0 to 99.0 µg/l. There is no limit or guide value for the concentration of zinc in the Finnish decree on drinking water. The EAS has a proposed limit value of 2.7 mg/l (2700 µg/l) for dissolution of zinc when metal products are being tested which is 90 % of the suggested limit value in drinking water and then there is also the WHO's recommendation (3.0 mg/l = 3000 µg/l). In water pumped from the waterworks into the network and in flowing network water the concentration of zinc was 28 µg/l or less. In stagnated water the concentration of zinc was 985 µg/l or less. Therefore, the suggested limit value of EAS is suited for the conditions in Finland.

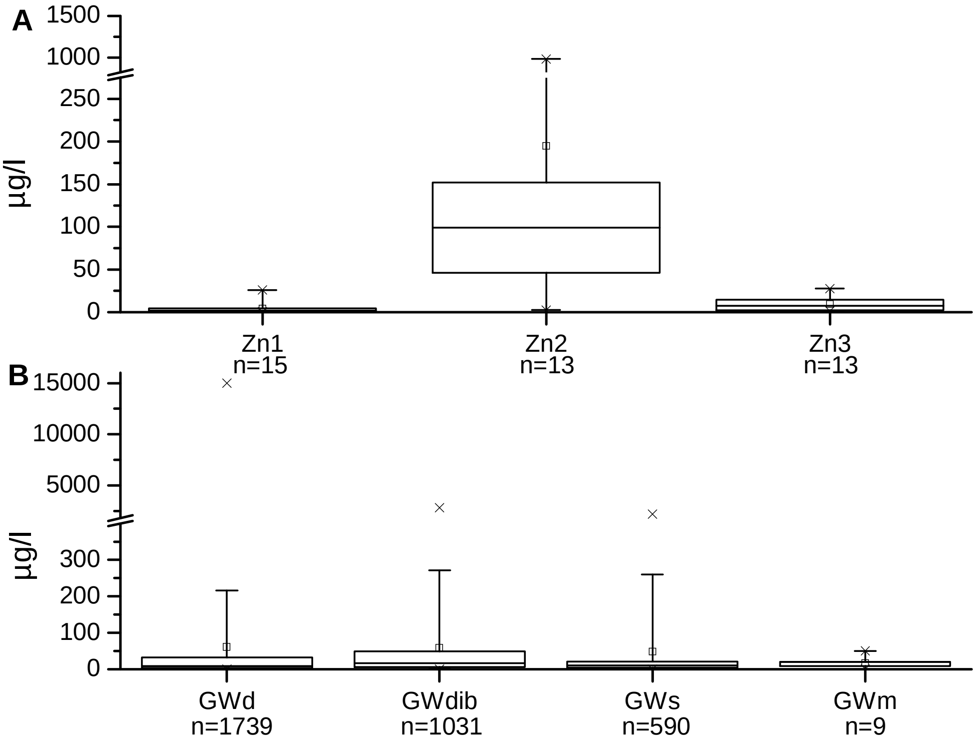

Figure 23. Zinc. Concentration in water provided by large waterworks in the year 2007 (A) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (B). Zn1 is water pumped from waterworks into the network, Zn2 is stagnated network water, and Zn3 is flowing network water.

6.3.3 Tin (Sn)

In the drinking water network, tin can dissolve from metal alloys, coatings, and solders used in the network materials.

Information on concentration of tin in water provided by waterworks and the possible effects of the network and sampling on the concentration was collected with additional measurements in the autumn 2007. Water samples were taken from seven large waterworks (15 intake plants) and six medium-sized waterworks (7 intake plants). Samples were taken from the water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. All results were below the detection limit (<0.05, <0.5, or <1.0 µg/l). At this detection sensitivity it seems that neither the state of the network nor sampling method has any effect on the concentration of tin in drinking water.

The median concentrations of tin in the study ranged from <0.05 to 1.00 µg/l. There is no limit or guide value for concentration of tin in the Finnish decree on drinking water nor any level listed by WHO. According to EAS, a suggested limit value for dissolution of tin when metal products are being tested is 3.0 mg/l (3000 µg/l) which is 50 % of the suggested limit value in drinking water (6.0 mg/l = 6000 µg/l). In the water provided by waterworks concentration of tin was below 1.0 µg/l so the suggested limit value of EAS is suited to the conditions in Finland.

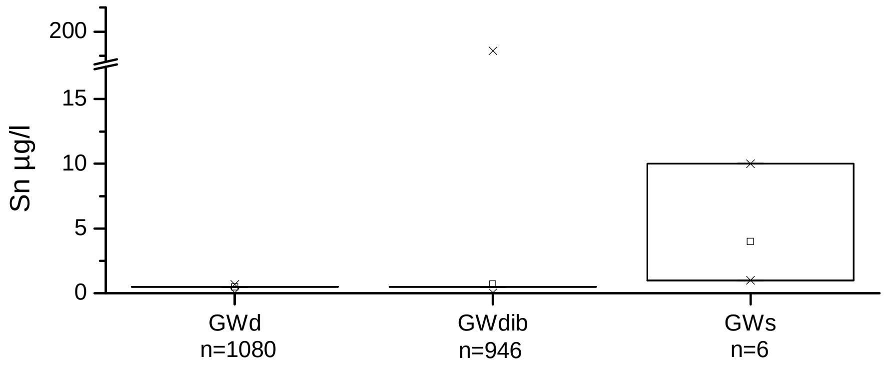

Figure 24. Tin. Concentration in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007).

6.3.4 Titanium (Ti)

Titanium can enter the drinking water network after being dissolved from the metal alloys used in the network materials. Titanium is an impurity in these metal alloys.

Information on concentration of titanium in water provided by waterworks and the possible effects of the network and sampling on the concentration were collected with additional measurements in the autumn 2007. Water samples were taken from seven large waterworks (15 intake plants) and six medium-sized waterworks (7 intake plants). Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. All results were below detection limit (<0.5 or <5.0 µg/l). At this detection sensitivity, neither network site nor sampling method seems to have any effect on the concentration of titanium present in drinking water.

There is no limit or guide value provided for the concentration of titanium in the Finnish decree on drinking water nor is any guide value given by WHO. The EAS proposes a limit value of 7.5 µg/l for dissolution of titanium when metal products are being tested which is 50 % of the suggested limit value in drinking water (15 µg/l). In the water provided by the waterworks, the concentration of titanium was below 5.0 µg/l and thus the suggested limit value of EAS is suited for the conditions in Finland.

6.3.5 Bismuth (Bi)

Information on concentration of bismuth in the water provided by waterworks and the possible effects of the network and sampling on the concentration was supplemented with additional measurements in the autumn 2007. Water samples were taken from seven large waterworks (15 intake plants) and six medium-sized waterworks (7 intake plants). Samples were taken from the water pumped from waterworks into the network, from stagnated network water, and from flowing network water. All results were below detection limit (<0.02 or <1.00 µg/l). At this detection sensitivity, neither the state of the network nor sampling method seems to have any effect on the concentration of bismuth present in drinking water.

The median concentration of bismuth in the study was <1.0 µg/l. There is no limit or guide value for concentration of bismuth in the Finnish decree on drinking water nor one given by WHO. The EAS has a suggested limit value of 9.0 µg/l for dissolution of bismuth when metal products are being tested which is 90% of the suggested limit value in drinking water (10 µg/l). In the water provided by waterworks the concentration of bismuth was below 1.0 µg/l and thus the proposed limit value of EAS is appropriate for the conditions in Finland.

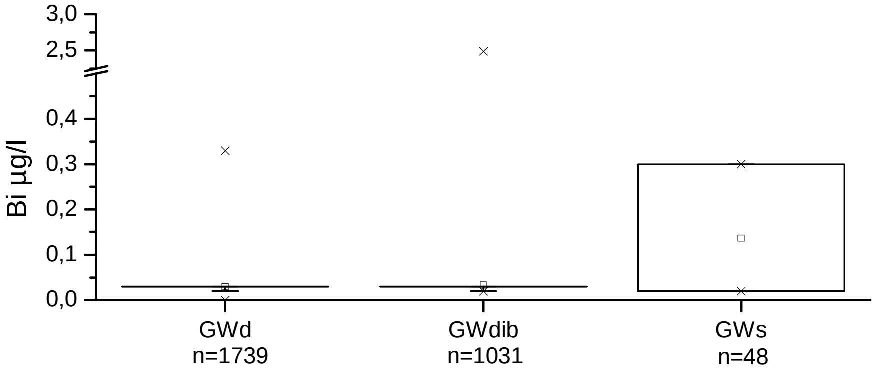

Figure 25. Bismuth. Concentration in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007).

Summary of metals in drinking water:

Water provided by waterworks was in accordance with the Finnish decree on drinking water with respect to antimony, arsenic, mercury, cadmium, chromium, copper, lead, selenium, aluminium, and sodium. Concentrations of nickel, manganese, and iron exceeded limit or guide values of the decree in about 5 % of the water samples provided by waterworks and well waters. Rather high concentrations of aluminium, nickel, manganese, and iron are present in Finnish drinking water and this should be taken into consideration when EAS is being drafted.

7 Chemicals and organic compounds

The Finnish decree on drinking water has limit values for several chemicals and organic compounds (Figure 26). In drinking water these compounds might affect human health or promote microbial growth. These compounds often gain access to drinking water as a result of human activity. In addition to environmental pollution water treatment can be the reason why these compounds enter drinking water or they may dissolve from the network materials. Reduction of the environmental impact can be challenging. Changes in the way that the network materials are chosen and water treatment processes undertaken may represent the techniques to reduce the levels of these compounds in drinking water and in this way to decrease their possible harm.

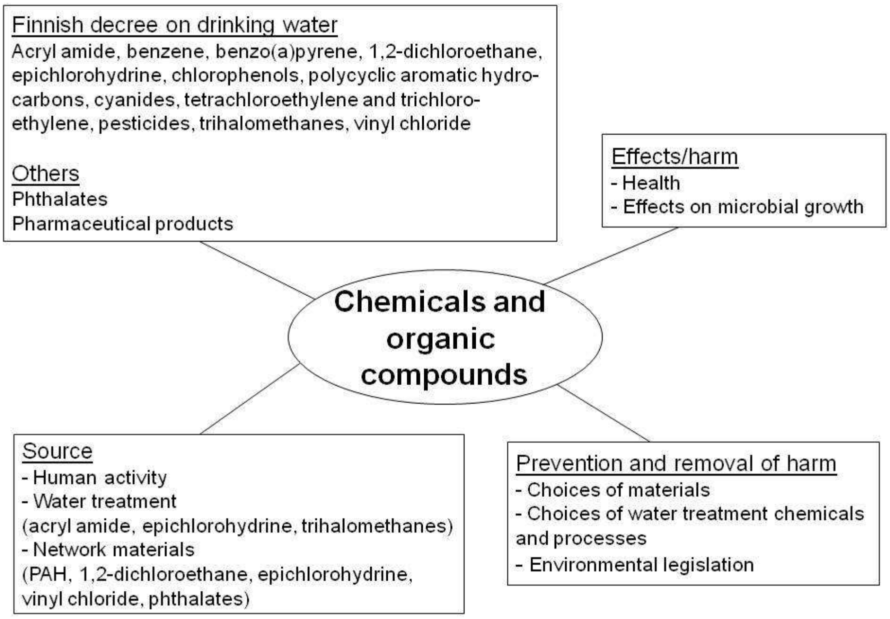

Figure 26. Chemicals and organic compounds in drinking water.

Summary of chemicals and organic compounds in drinking water:

Water provided by waterworks and well water was in accordance with the Finnish decree on drinking water. In a few well samples, the concentrations of benzene and vinyl chloride exceeded the limit values.

8 Non-metals

There are limit values for three non-metals (boron, bromate, fluoride) listed in the Finnish decree on drinking water. The limit values are based on their health effects. Non-metals can gain access to drinking water from soil or from human activities, e.g. ozonization. Several options are available to decrease the harm caused by these non-metals but their origin needs to be taken into consideration when evaluating the options.

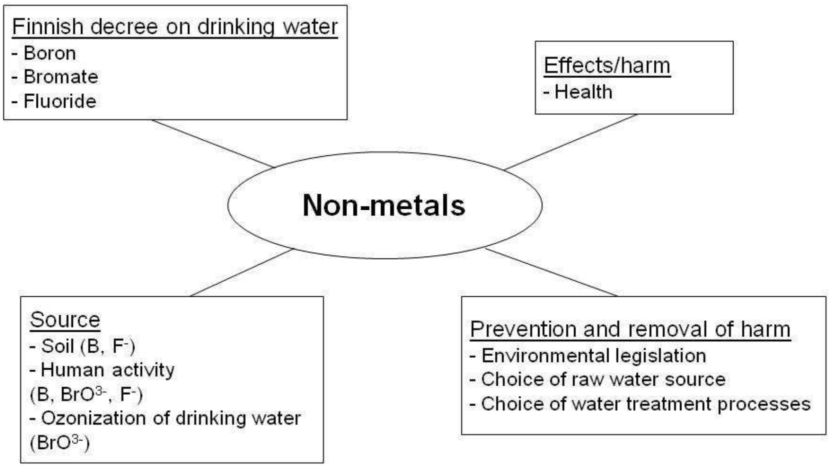

Figure 27. Non-metals in drinking water.

8.1.1 Fluoride (F^-)

The limit value for fluoride (1.5 mg/l) is based on its harmful health effects. Fluoride can enter drinking water from soil and bedrock minerals or via the chemical industry.

The median concentrations of fluoride in the study ranged from <0.1 to 0.4 mg/l. The lowest median concentration was in soil wells. In waters combined from several wells (SYKE data) and water provided by waterworks, the median concentration was 0.1 – 0.2 mg/l. The highest median concentration of 0.4 mg/l was detected in drilled wells. Several samples exceeding the guide value of the Finnish decree on drinking water were observed in soil wells, drilled wells, and separate wells from the SYKE data. In addition, some samples from waterworks exceeded the limit value. All samples from water combined from several wells were in accordance with the Finnish decree on drinking water.

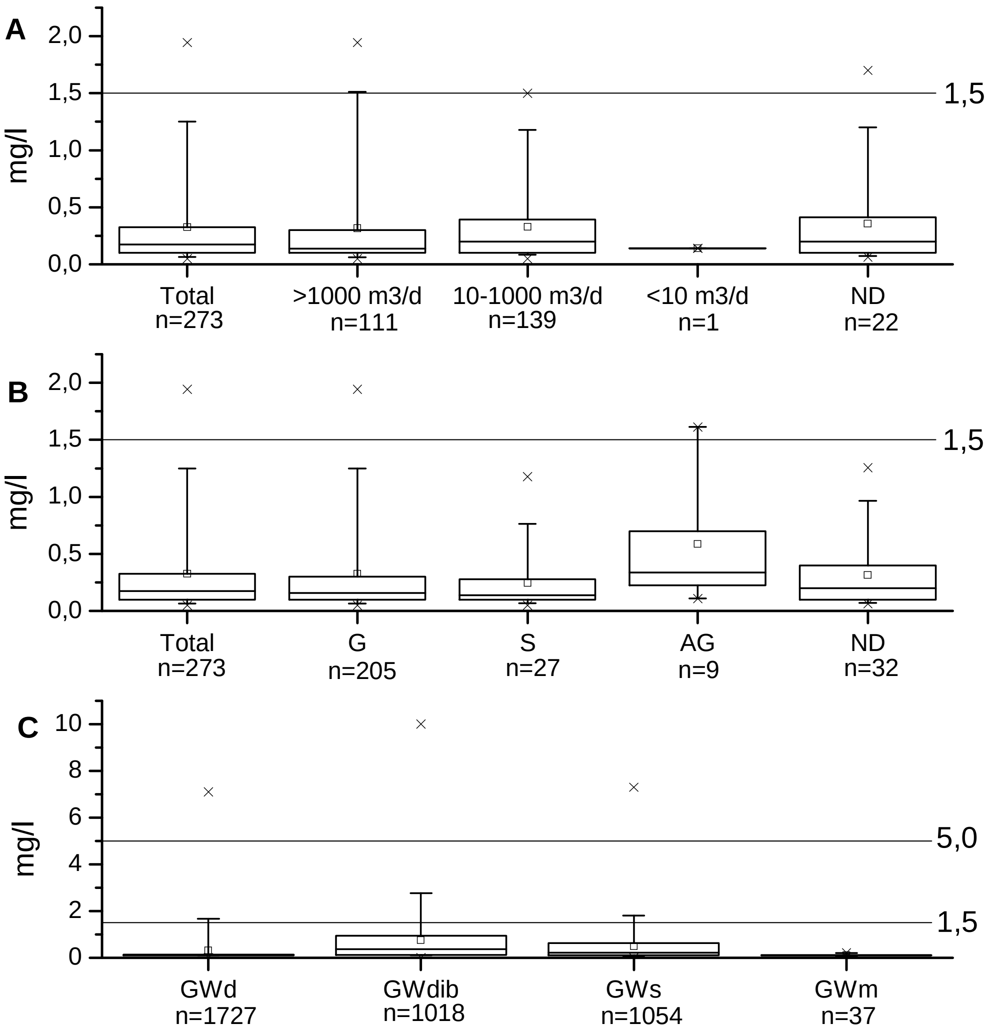

Figure 28. Fluoride. Concentration in water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C).

Summary of non-metals in drinking water:

Water provided by waterworks and well water was in accordance with the Finnish decree on drinking water with respect to boron and bromate. About 2 % of the waterworks in the study provided water samples whose concentration of fluoride exceeded the limit value of the decree. Furthermore, in about 5 % of the well water samples in the study, the limit value for fluoride was exceeded.

9 Technical and aesthetical quality

The quality of drinking water can be influenced by the durability of the metallic, cement based, and plastic network materials since these are subject to corrosion and dissolution. Parameters affecting the technical quality of drinking water are for example pH, alkalinity, hardness, amount of chlorides and sulphates, electric conductivity, and carbon dioxide. Parameters reflecting the aesthetic quality of drinking water include odour, taste, turbidity, and colour, as well as, the levels of iron and manganese. Iron and manganese have been discussed in Chapter 5 (Metals).

There are guide values for some of the above mentioned parameters in the Finnish decree on drinking water (Figure 29) but there are also parameters without guide or limit values, e.g. alkalinity and hardness, even though those can affect the technical quality of drinking water. Parameters discussed in this chapter are related to the aesthetical features of drinking water and the durability of the network materials. The concentrations of these parameters in drinking water are affected by the quality of raw water and water treatment chemicals. The harmful effects caused by these parameters might be reduced by applying suitable water treatment procedures and using compatible network materials.

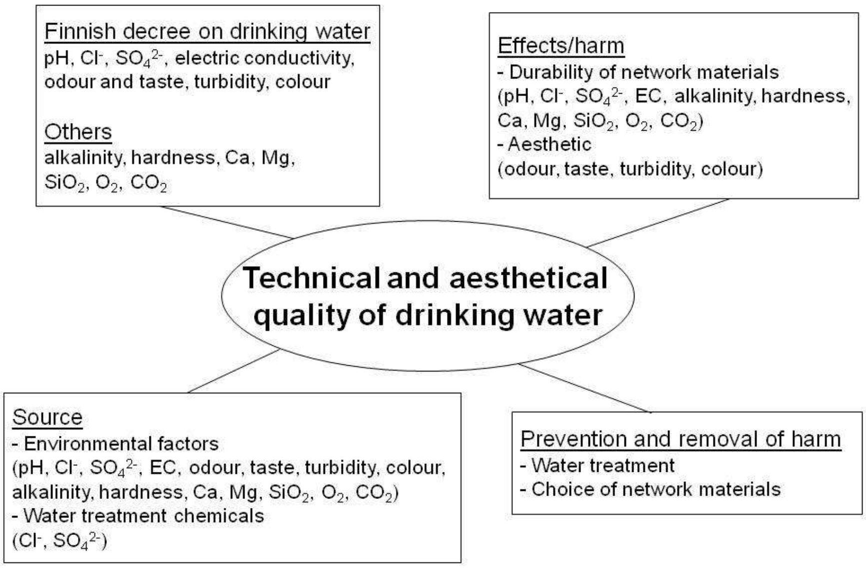

Figure 29. Parameters indicating the technical and aesthetical quality of drinking water.

9.1 Parameters indicating the technical and aesthetical quality subject to quality recommendations

9.1.1 pH

pH value indicates the acid content of water. Furthermore, there is a correlation between the acid content of water and its aggressivity. The guide value in the Finnish decree on drinking water for pH is 6.5 – 9.5.

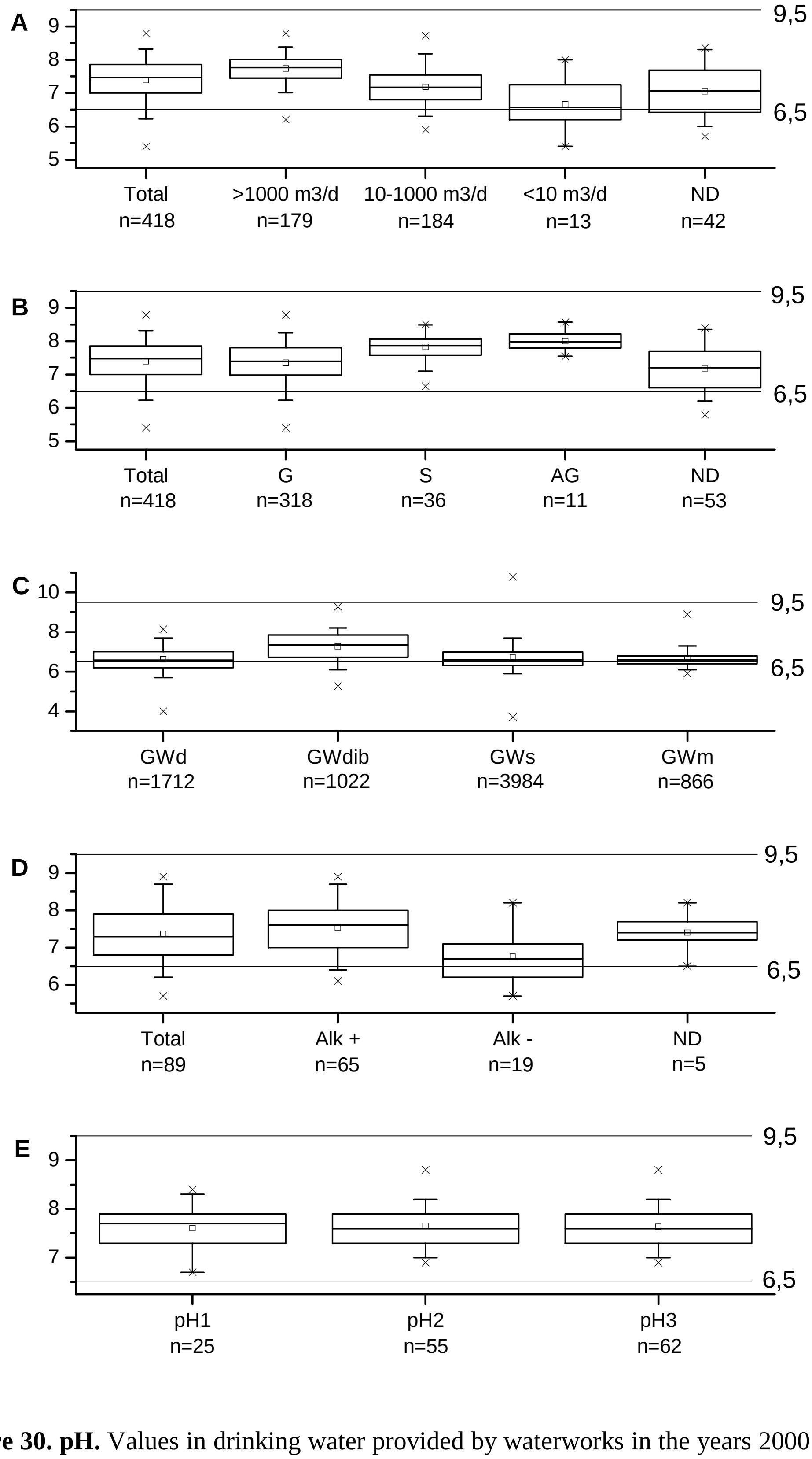

Figure 30. pH. Values in drinking water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Plot D displays the relationship between water neutralizing with alkaline chemicals (Alk) and pH in medium-sized waterworks in 2007. Effects of network and sampling on pH values in drinking water provided by waterworks in 2007 (E). pH1 is water pumped from the waterworks into the network, pH2 is stagnated network water, and pH3 is flowing network water. Data from plots D and E is not included in plots A or B.

In order to establish the correlation between pH and neutralizing techniques, additional measurements were conducted in medium-sized waterworks. A total of 89 waterworks provided data of pH, and 65 of these 89 plants used neutralizing and 19 did not, 5 waterworks did not provide data about their neutralizing practices. The median value of pH in these 89 waterworks was 7.3 (Figure 30D). The median value in the waterworks using neutralizing was almost one unit higher compared to the corresponding value in those waterworks that did not use it, 7.6 and 6.7 respectively. In waterworks using neutralizing, 90 % of pH values were between 6.4 and 8.7 and in waterworks not using neutralizing 90 % of pH values were between 5.7 and 8.2. A few samples of both types of water had pH values below the lower guide value of the decree (6.5), thus being more likely in waterworks not using neutralizing. None of the samples had pH above the higher guide value of 9.5.

Information on values of pH in water provided by waterworks and the possible effects of the network and sampling on the values were collected with additional measurements in the autumn 2007. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. In different types of water, the median values were somewhat the same 7.6 – 7.7 (Figure 30E).

Range of the median values of pH in the study was 6.6 – 8.0. The lowest median values (6.6) were in soil wells, in separate wells from the SYKE data, and in waters combined from several wells (SYKE data). In water provided by waterworks and in drilled wells, the median values were 7.3 – 7.7. All water types contained samples that had values below the lower guide value (6.5) of the Finnish decree on drinking water. These low values were more common in well waters than in waters provided by waterworks, 30 % and 8 % respectively. Only a few samples from well water were above the higher guide value (9.5) of the Finnish decree on drinking water.

9.1.2 Chloride (Cl^-)

The guide value for chloride (250 mg/l) in the Finnish decree on drinking water is based on its taste and the characteristics that induce corrosion. In order to prevent corrosion of the network materials, the decree states that concentration of chloride should be below 25 mg/l. Chloride can access drinking water from soil, de-icing salt, and water treatment chemicals.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of the network and sampling e.g. on the concentration of chloride in drinking water. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were around the same order of magnitude 7.5 – 8.1 mg/l (Figure 31D).

The median concentrations of chloride in the study ranged from 1.0 to 10.0 mg/l. The lowest median values (1.0 and 3.0 mg/l) occurred in soil wells and in drilled wells. In water provided by waterworks and in the groundwater data from SYKE, the median concentrations were between 8.0 and 10.0 mg/l. Water provided by waterworks was in accordance with the Finnish decree on drinking water. In a few well water samples, the concentrations exceeded the guide value of the Finnish decree on drinking water for small units. In about 10 % of the waterworks the guide value stated in order to prevent corrosion (25 mg/l) had been exceeded. In well waters these non-adherent samples were present in 10 – 25 % of all samples.

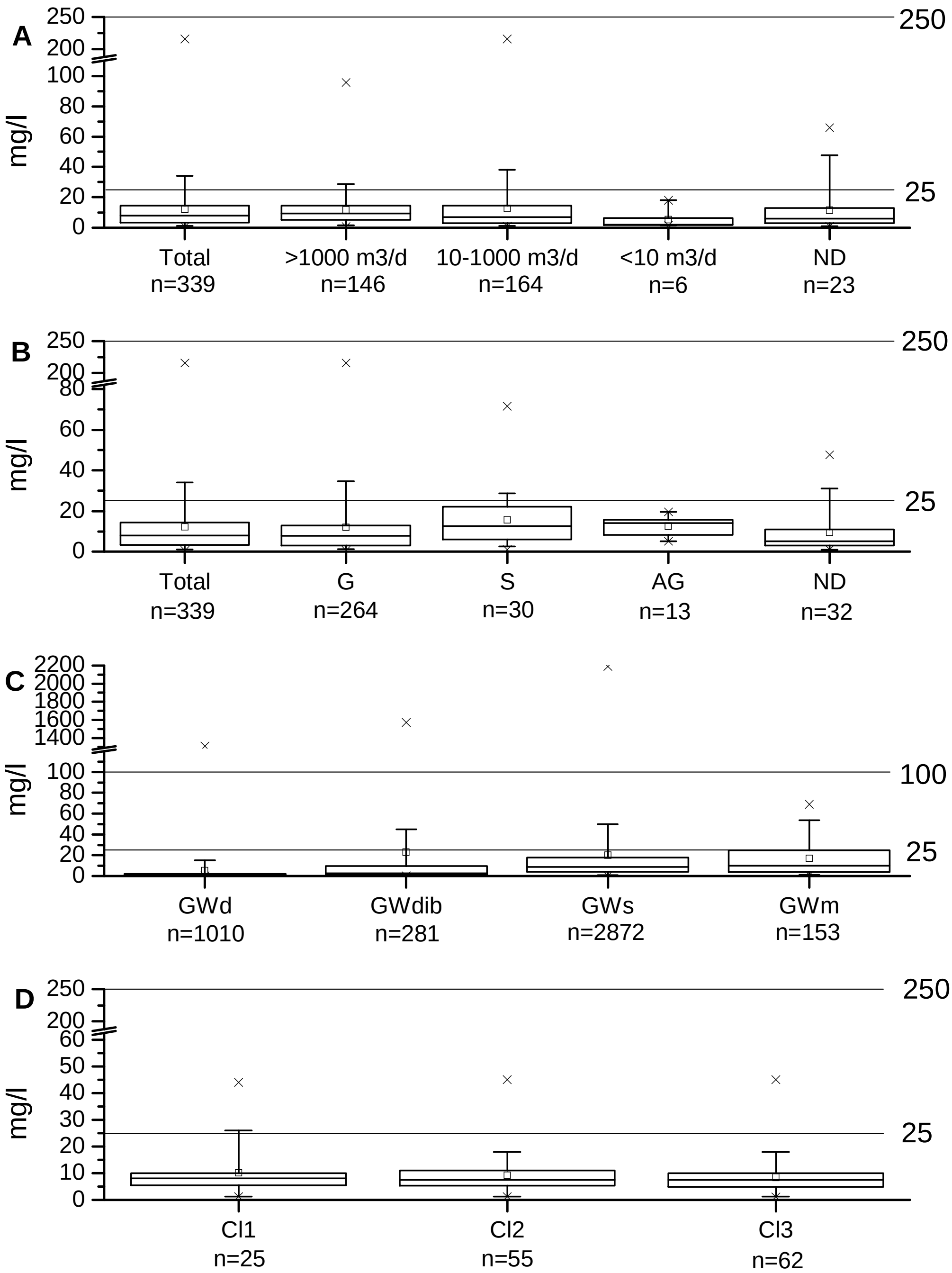

Figure 31. Chloride. Concentrations in drinking water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Effects of network and sampling on pH values in drinking water provided by waterworks in 2007 (D). Cl1 is water pumped from the waterworks into the network, Cl2 is stagnated network water, and Cl3 is flowing network water. Data from plot D is not included in plots A or B.

9.1.3 Sulphate (SO_4^{2-})

The guide value for sulphate (250 mg/l) described in the Finnish decree on drinking water is based on its taste and the characteristics that induce corrosion. It is possible that sulphate present in drinking water originates from soil or from the precipitants used in water treatment.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of the state of the network and sampling method e.g. on the concentration of sulphate in drinking water.

Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were around the same order of magnitude 11 – 21 mg/l (Figure 32D). The highest median concentration was in the water pumped from the waterworks into the network.

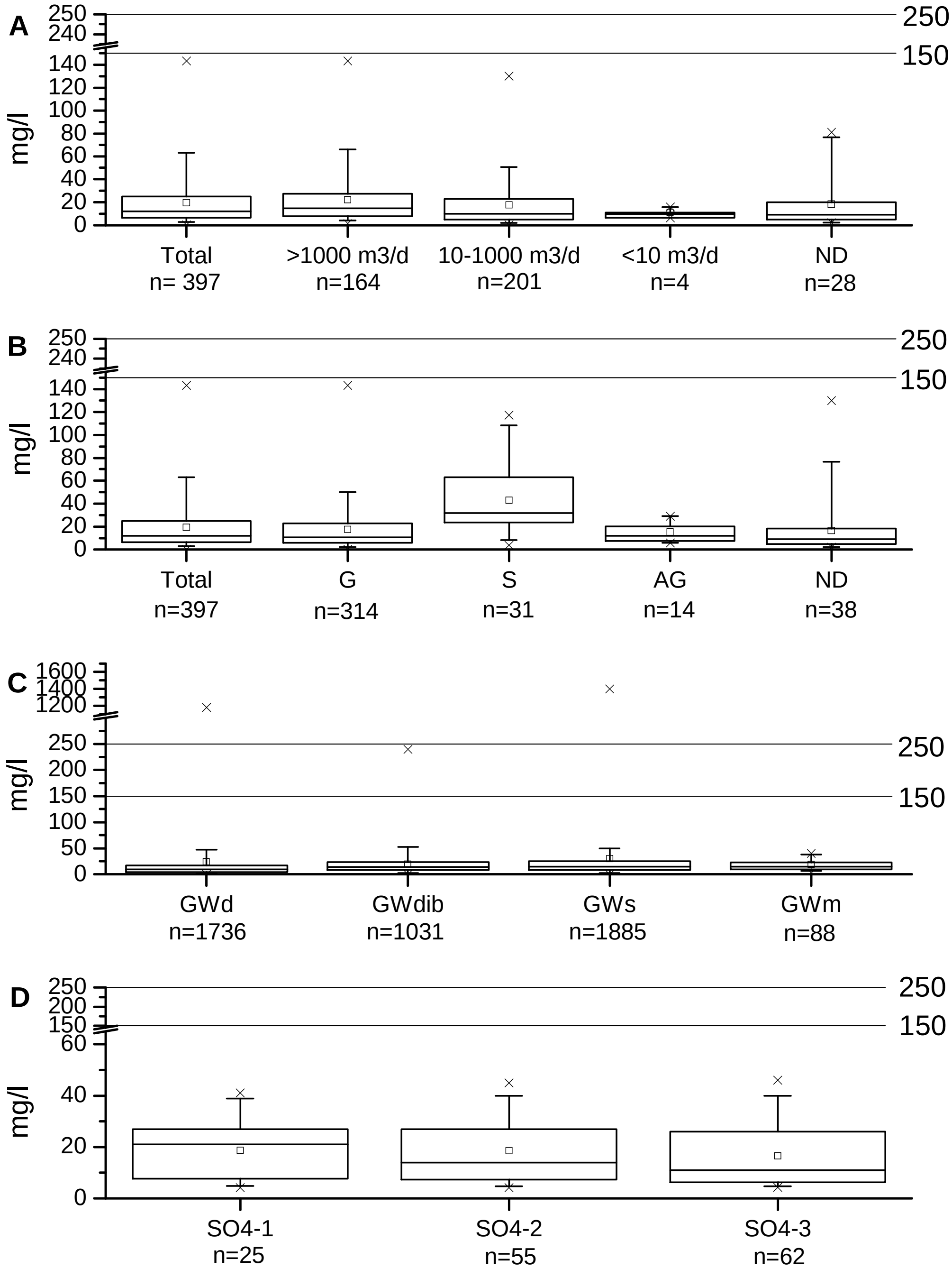

Figure 32. Sulphate. Concentrations in drinking water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Effects of network and sampling on concentration of sulphate in drinking water provided by waterworks in 2007 (D). SO4-1 is water pumped from the waterworks into the network, SO4-2 is stagnated network water, and SO4-3 is flowing network water. Data from plot D is not included in plots A or B.

The median concentrations of chloride in the study ranged from 10 to 32 mg/l. The lowest median values (10 – 12 mg/l) were detected in soil wells and in water provided by waterworks. In drilled wells and in the groundwater data from SYKE, the median concentration was 15 mg/l. The highest median concentration of

32 mg/l was observed in waterworks using surface water. Water provided by waterworks and well water was in accordance with the Finnish decree on drinking water. In a few well water samples, the concentrations exceeded the guide value listed in the Finnish decree on drinking water for small units. Water provided by waterworks was also in accordance with the guide value given to prevent corrosion (<150 mg/l). In a few well water samples, this guide value was exceeded.

9.1.4 Electric conductivity (EC)

Electric conductivity (EC) in drinking water is attributable to the ions of dissolved salts i.e. the type and amount of these ions. The guide value of the Finnish decree on drinking water (at 20 ºC 2500 µS/cm = 250 mS/m) is not based on health effects.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of network site and sampling method e.g. on EC in drinking water. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were around the same order of magnitude 17 – 19 mS/m (Figure 33D).

The median concentrations of EC in the study ranged from 7 to 25 mS/m. The lowest median values (7 – 11 mS/m) were detected in the small waterworks and soil wells. In water provided by waterworks and in the groundwater data from SYKE, the median values were 15 – 19 mS/m. The highest median value of 25 mS/m was in drilled well waters. Water provided by waterworks was in accordance with the Finnish decree on drinking water as were the water samples from the groundwater data from SYKE except for a few well samples.

9.1.5 Odour and taste

Flaws of odour and taste in drinking water are caused by organic compounds, their decomposition products or compounds that can be formed when water treatment chemicals react with organic compounds. the recommendation in the Finnish decree on drinking water states that odour and taste should be “acceptable to consumers with no abnormal changes”.

Almost all of the waterworks in the study provided samples that were in accordance with the Finnish decree on drinking water with respect to odour (90 %) and taste (91 %).

9.1.6 Turbidity

Turbidity in water is mainly caused by clay, iron, and colloidal compounds.

The recommendation in the Finnish decree on drinking water states that turbidity should be “acceptable to consumers with no abnormal changes”. In all, 88 % of the waterworks providing samples in the study were in accordance with the Finnish decree on drinking water as for turbidity. The median values for turbidity in the study were 0.1 – 0.4 NTU.

9.1.7 Colour

Colour in drinking water might be attributable to organic compounds, iron, and manganese. Colour has no direct correlation with the health effects of drinking water.

The recommendation in the Finnish decree on drinking water states that colour should be “acceptable to consumers with no abnormal changes”. Almost all, 90 %, of the waterworks in the study provided samples that were in accordance with the Finnish decree on drinking water as for colour. The median values for colour in the study were 4.0 – 8.0 mg/l.

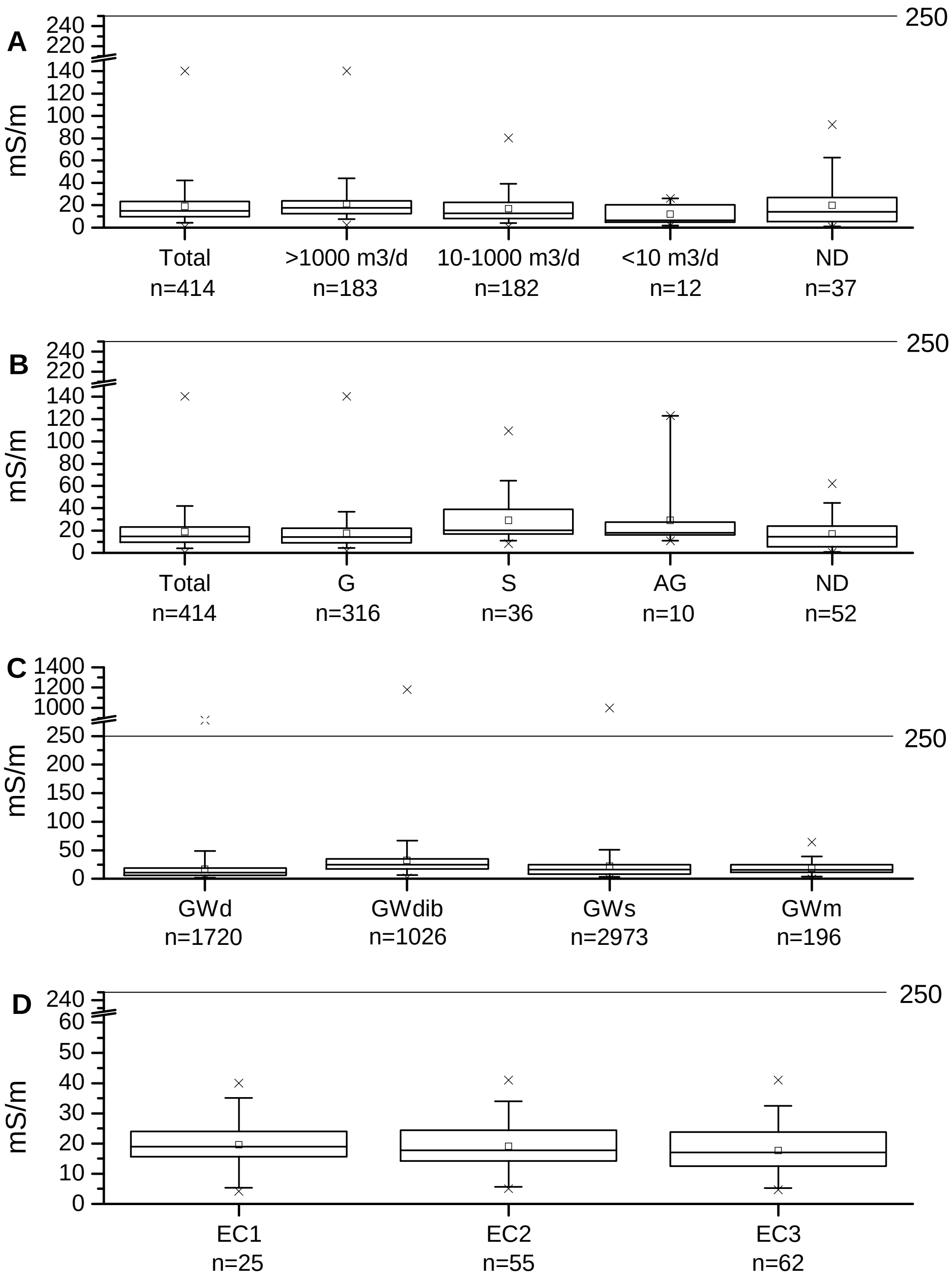

Figure 33. Electric conductivity. Values in drinking water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Effects of network and sampling on EC in drinking water provided by waterworks in 2007 (D). EC1 is water pumped from the waterworks into the network, EC2 is stagnated network water, and EC3 is flowing network water. Data from plot D is not included in plots A or B. The maximum value of GWd 513 mS/m is not visible in the plot.

9.2 Other parameters affecting technical and aesthetical quality of drinking water

9.2.1 Alkalinity

Alkalinity is a measure of the ability of drinking water to neutralize acids i.e. to resist pH changes. Alkalinity is caused by bicarbonates (HCO_3^-), carbonates (CO_3^{2-}), and hydroxides (OH^-). Low alkalinity (<0.6 mmol/l) might cause corrosion of metallic materials.

In order to establish the correlation between alkalinity and neutralizing techniques, additional measurements were conducted in medium-sized waterworks. A total of 89 waterworks provided data of alkalinity and 65 of these plants used neutralizing and 19 did not, 5 waterworks did not provide data about their neutralizing practices. The median value of alkalinity in these 89 waterworks was 0.9 mmol/l (Figure 34D). The median value in the waterworks using neutralizing was twice as high as the corresponding value in those waterworks that did not follow this practise i.e. 1.0 and 0.4, respectively.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of network and sampling e.g. on alkalinity in drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were around the same order of magnitude, 1.1 – 1.2 mmol/l (Figure 34E).

The median values of alkalinity in the study ranged from 0.2 to 1.8 mmol/l. The lowest median values (0.2 – 0.7 mmol/l) were observed in small waterworks, soil wells, and wells in the groundwater data from SYKE. Water provided by other waterworks had the median concentrations of 0.7 – 1.3 mmol/l. In drilled wells, the median concentration was clearly the highest, 1.8 mmol/l.

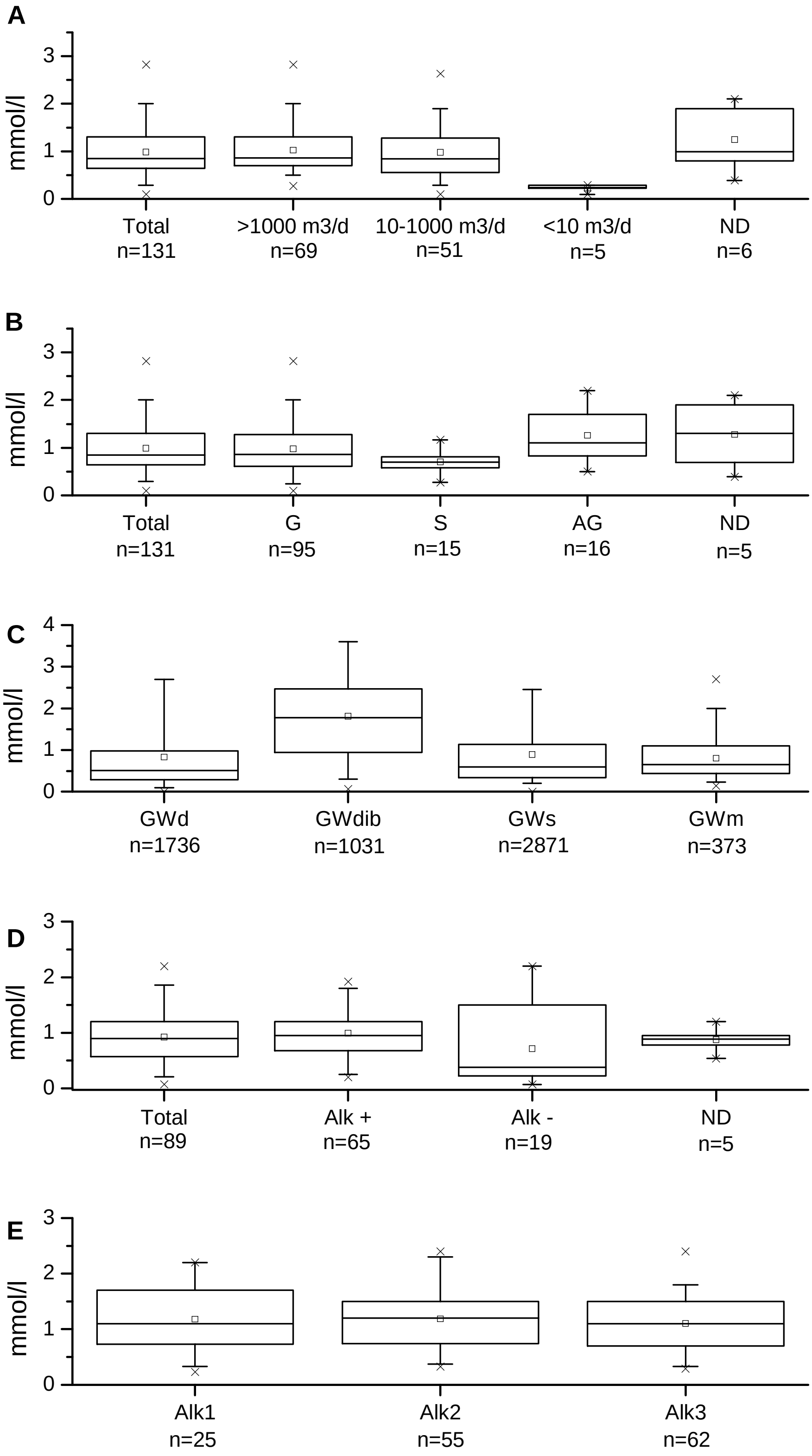

Figure 34. Alkalinity. Concentration in drinking water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Plot D displays the relationship between water neutralizing (Alk) and alkalinity in medium-sized waterworks in 2007. Effects of state of the network and sampling method on alkalinity in drinking water provided by waterworks in 2007 (E). Alk1 is water pumped from waterworks into the network, Alk2 is stagnated network water, and Alk3 is flowing network water. Data from plots D and E is not included in plots A or B. The maximum concentrations that are not visible in the plots are GWd 8.2 mmol/l, GWdib 6.8 mmol/l, and GWs 10.7 mmol/l.

9.2.2 Hardness

Hardness indicates quality of water and is attributable to dissolved mineral salts: calcium sulphates, magnesium sulphates, magnesium chlorides and magnesium phosphates. Hardness can be divided into bicarbonate hardness and mineral acid hardness i.e. temporary and permanent hardness, respectively. Bicarbonate hardness is caused by calcium and magnesium bicarbonates whereas mineral acid hardness is caused by salts of mineral acids (sulphate, chloride, phosphate). Hardness has an effect on the aggressivity of water. Hardness is graded according to concentration: very soft (<0.5 mmol/l), soft (0.5 – 1.0 mmol/l), medium hard (1 – 2 mmol/l), hard (2 – 4 mmol/l), and very hard (>4 mmol/l).

In order to establish the correlation between hardness and neutralizing techniques, additional measurements were conducted in medium-sized waterworks. 90 waterworks provided data of hardness and 66 of these plants used neutralizing whereas 19 did not, 5 waterworks did not provide data about their neutralizing practices. The median value of hardness in these 90 waterworks was 0.4 mmol/l (Figure 35D). The median value in the waterworks using neutralizing was somewhat higher than the corresponding value in those waterworks that did not i.e. 0.4 and 0.3, respectively.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of state of the network and sampling method e.g. on hardness of drinking water. Samples were taken from water pumped from the waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations were around the same order of magnitude 0.4 – 0.6 mmol/l (Figure 35E).

The median values of hardness in the study ranged from 0.2 to 0.7 mmol/l which indicates that waters in Finland are soft and even very soft in some areas. The lowest median values (0.2 – 0.4 mmol/l) were observed in small waterworks, soil wells, and medium-sized waterworks found in the additional measurements. Large waterworks and well waters from the SYKE data had the median concentrations of 0.5 – 0.6 mmol/l. In drilled wells, the median concentration was 0.7 mmol/l.

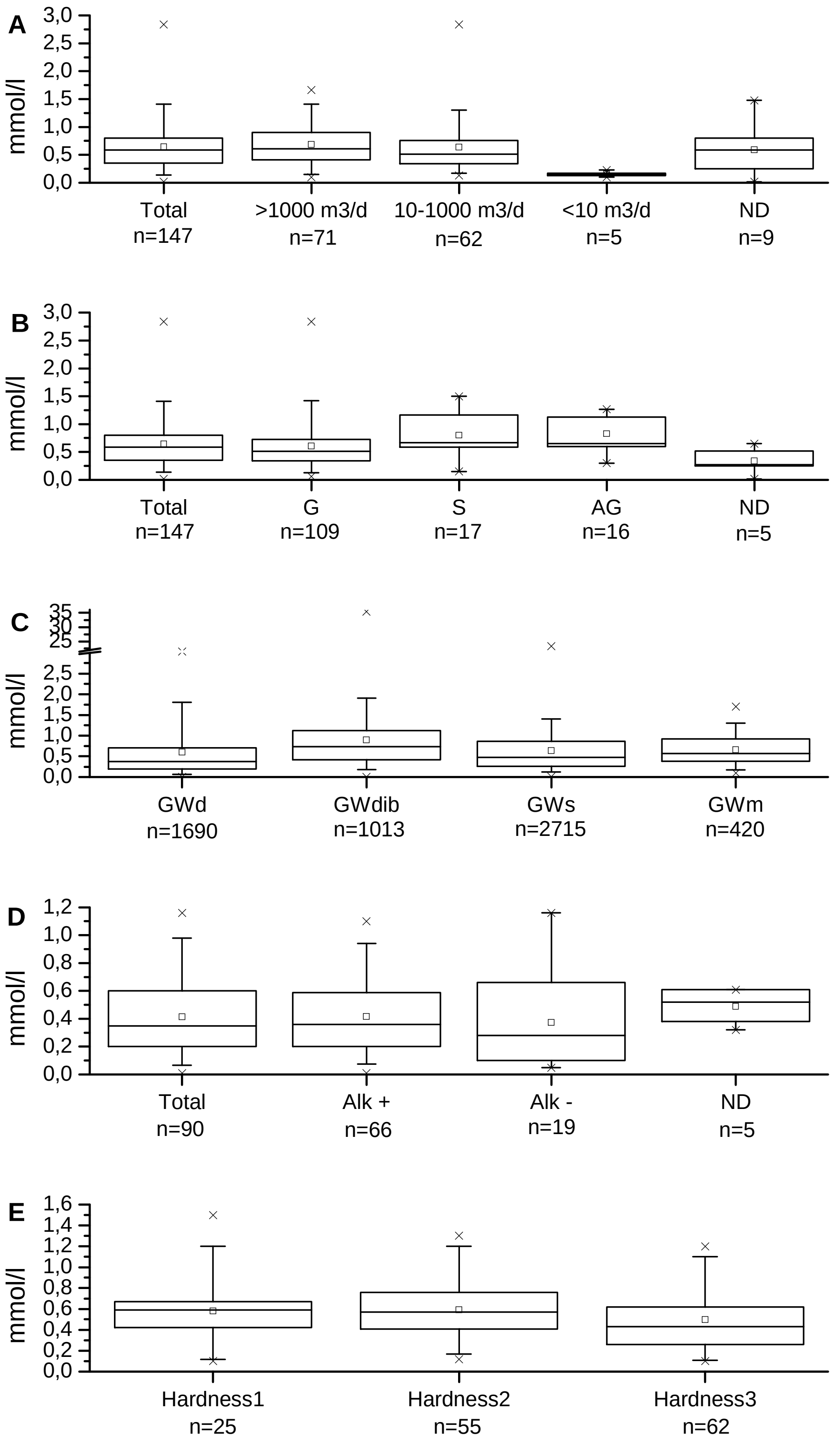

Figure 35. Hardness. Concentration in drinking water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Plot D displays the relationship between water neutralizing (Alk) and hardness in medium-sized waterworks in 2007. Effects of network and sampling on hardness in drinking water provided by waterworks in 2007 (E). Hardness1 is water pumped from the waterworks into the network, Hardness2 is stagnated network water, and Hardness3 is flowing network water. Data from plots D and E is not included in plots A or B. The maximum concentration of GWd 11 mmol/l is not visible in Plot C.

9.2.3 Carbon dioxide (CO_2)

Carbon dioxide is the most important acid in drinking water. Carbon dioxide can gain access to drinking water from the atmosphere and the amount of CO_2 depends on state of equilibrium between the atmosphere and the water. CO_2 has several effects one important being on the aggressivity of water.

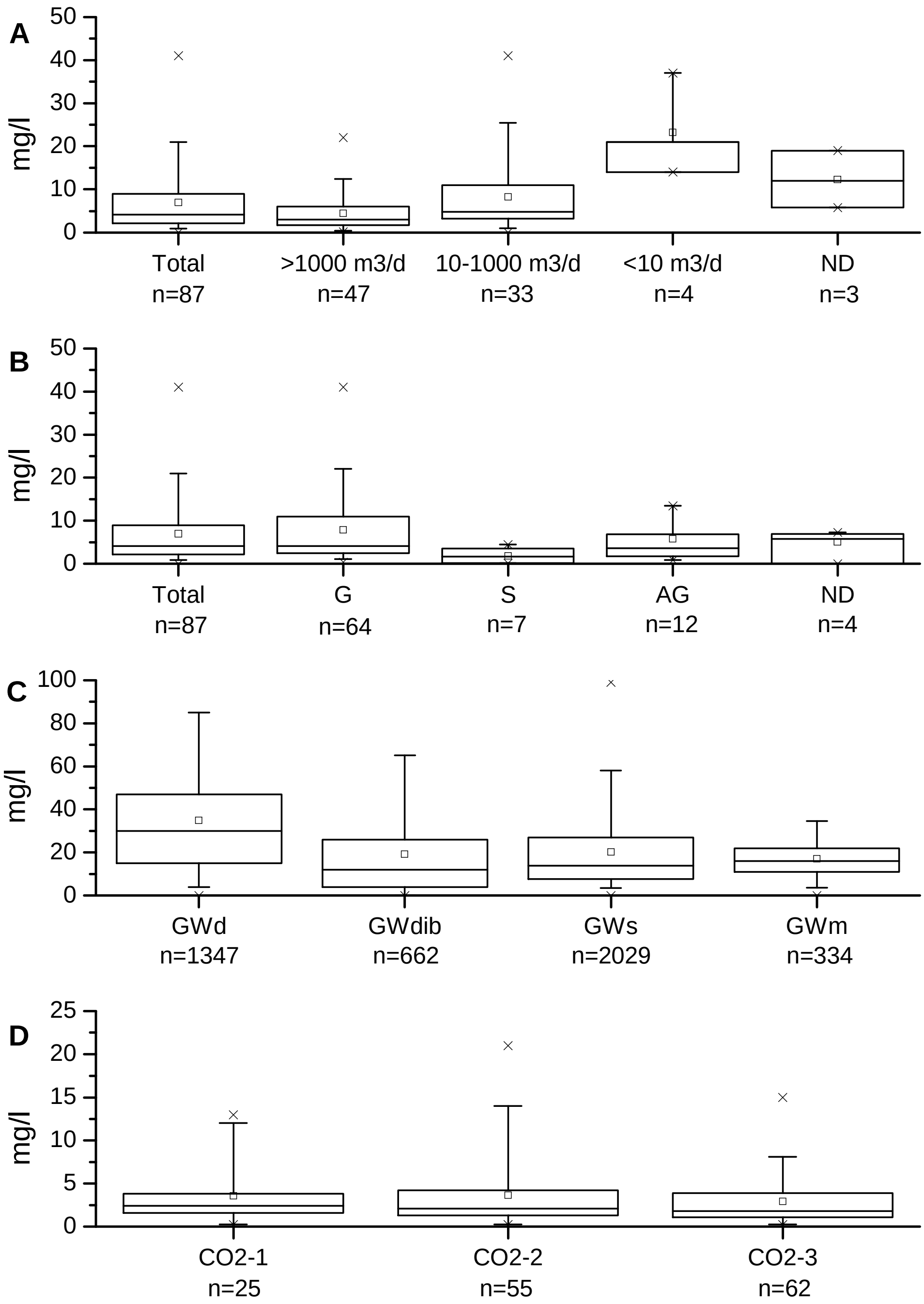

Figure 36. Carbon dioxide. Concentration in drinking water provided by waterworks in the years 2000 – 2007 (A and B) and in well waters from the GTK data (years 1999 – 2006) and the SYKE data (years 2000 – 2007) (C). Effects of network and sampling on concentration of CO_2 in drinking water provided by waterworks in 2007 (D). CO2-1 is water pumped from the waterworks into the network, CO2-2 is stagnated network water, and CO2-3 is flowing network water. Data from plot D is not included in plots A or B. The maximum concentrations that are not visible in the plots are GWd 290 mg/l, GWdib 165 mg/l, and GWm 103 mg/l.

Additional measurements were carried out in the autumn 2007 in order to determine the possible effects of state of the network and sampling method e.g. on concentration of carbon dioxide. Samples were taken from water pumped from waterworks into the network, from stagnated network water, and from flowing network water. The median concentrations in all these waters were around the same order of magnitude 2 mg/l (Figure 36D).

The median concentration of CO_2 in the study ranged from 2 to 30 mg/l. The lowest median concentrations (2.0 – 4.2 mg/l) were detected in the water provided by waterworks. In drilled wells and the groundwater data from SYKE, the median concentrations of 12 – 16 mg/l were observed. The highest median concentration, 30 mg/l, was found in soil wells.

Summary of parameters affecting the technical and aesthetical quality of drinking water:

Water provided by waterworks was in accordance with the Finnish decree on drinking water with respect to chloride, sulphate, and electric conductivity. About 8 % of the waterworks in the study provided water whose pH was below the lower guide value stated in the decree (6.5). About 10 % of the results for odour, taste, turbidity, and colour were not in accordance with the recommendations. In order to prevent aggressivity of drinking water additional limit values for sulphate and chloride have been provided. All samples were in accordance with the additional limit value with respect to sulphate but 10 % of waterworks provided water that exceeded the additional limit for chloride.

Well waters were in accordance with the Finnish decree on drinking water with respect to chloride, sulphate, and electric conductivity. With regards to pH, as many as 30 % of the results were below the lower guide value stated in the decree (6.5). With respect to odour, taste, turbidity, and colour of well waters the decree's recommendation is "acceptable to consumers with no abnormal changes". However, the amount of analyses results for these parameters was so low that comparison with the levels stated in the decree was not reasonable.

With respect to alkalinity, hardness, and concentration of carbon dioxide there is no guide or limit values in the Finnish decree on drinking water. The median values for alkalinity, hardness, and CO2 in the study were 0.2 – 1.8 mmol/l, 0.2 – 0.7 mmol/l, and 2 – 30 mg/l, respectively.

10 Radioactivity

There are guide values for tritium and total indicative dose in the Finnish decree on drinking water (Figure 37). In addition, radioactivity of drinking water is regulated by the Finnish Radiation and Nuclear Safety Authority (Regulatory Guide ST 12.3 – Radioactivity of Household Water). A major amount of the radioactive substances in drinking water originate from soil and bedrock, a very small proportion is attributable to human activities. Harm caused by radioactivity can potentially be prevented by choice of location of the waterworks, choice of water source, and water treatment.

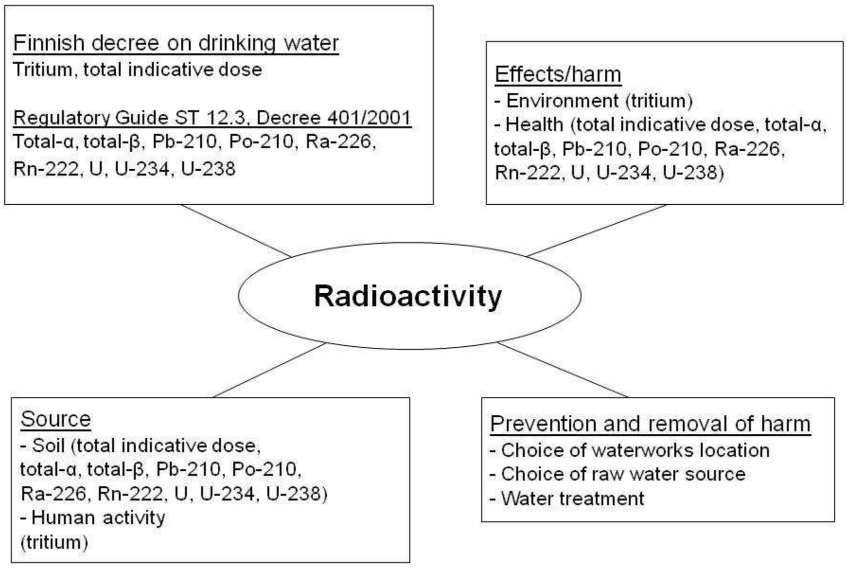

Figure 37. Radioactivity in drinking water.

The majority of internal radiation dose to which people in Finland are exposed is caused by natural radioactive substances. Radiation always poses the risk of inducing cancer. Drinking water containing radon might cause a dose of radiation harmful to the stomach. Radon can be absorbed from the gastrointestinal tract into the bloodstream and furthermore is excreted from the body through lungs by exhalation. A large amount of radon, possibly dissolved in drinking water, is released into the indoor air as a gas for example during laundering or shower. Breathing radon suspended indoor air might increase the radiation dose delivered to the lungs.

Long-lived radioactive substances consumed in drinking water might increase the radiation dose to other internal organs as well. The chemical toxicity of uranium is considered to be a more significant health risk than its radiation dose. However, the guide value for uranium in drinking water is still based on its radioactivity. The toxic effects of uranium are mainly targeted to kidneys and bones.

Summary of radioactive parameters in drinking water:

In surface waters, the activity concentrations of radioactive substances are very low and no samples were detected which exceeded the action limit values of the Finnish decree on drinking water or the Finnish Radiation and Nuclear Safety Authority (Regulatory Guide ST 12.3 – Radioactivity of Household Water). In soil groundwater, a few samples exceeding the action limits have been observed. In bedrock groundwater, the concentrations can be rather high and actions to prevent these limit values being exceeded must be taken.

11 Summary of water quality parameters

A study was carried out in 2007 concerning quality of drinking water to obtain an extensive perspective of the quality of drinking water in Finland by collecting detailed data from different size waterworks around the country. The study included wells, water cooperatives, and small, medium-sized, and large waterworks. Data on drinking water were collected from raw water to the consumer's tap. The study was a follow-up to the study "Water Quality in Finland in Years 1984 – 2006" [Keinänen-Toivola et al. 2007, in Finnish] conducted in FIDW. This follow-up study "Quality of Finnish Drinking Water from Raw Water to Consumer's Tap in Years 1999 – 2007" [Ahonen et al. 2008, in Finnish] indicated that the two greatest lack of information were in the areas of quality of small waterworks and technical quality of drinking water in general.

All significant national authorities that monitor quality of drinking water in Finland (research and/or control) took part in the study. The Geological Survey of Finland (GTK), the National Public Health Institute of Finland (KTL), Finnish Environment Institute (SYKE), and the Radiation and Nuclear Safety Authority of Finland (STUK) have provided their information on water quality which they have collected periodically throughout the years into the study. Health inspectors of counties and communes, waterworks and water cooperatives have participated in the data collection by sending contact information, transmitting already existing data on the quality of water or taking new samples from which several parameters indicative of water quality were analysed. Overall, this study contains the results of about 420 000 separate analyses. All of this data has been collected into a database which can be supplemented and utilized in future studies.

The study clearly showed that collecting data on water quality especially from small and medium-sized waterworks can be a fairly challenging enterprise. Gathering contact information on waterworks took time because that kind of information was not available in a centralized manner. Waterworks seemed to suffer from a lack of resources thus they did not have time to seek and send the sought data even though they were willing to participate in the study. Data received in electronic form were in many file formats. Some waterworks filed data in electronic format while others used only a traditional text-based filing system.

There are 60 parameters described in the study of which 44 are included in the Finnish decree on drinking water. A total of 16 other parameters which are essential e.g. for technical quality of water, EAS, and evaluation of radioactivity of drinking water are described. The parameters discussed in this report that are not included in the Finnish decree on drinking water are:

- Nutrients for microbes: phosphorus
- Metals: molybdenum, zinc, tin, titanium, bismuth
- Technical quality of drinking water: alkalinity, hardness, carbon dioxide
- Radioactivity: total-α, total-β, Pb-210, Po-210, Ra-226, Rn-222, and uranium.

If one assesses the drinking water in Finland in terms of the quality demands and recommendations then one must conclude that it is of high-quality. However, quality monitoring of drinking water is focused on the health-based parameters listed in the Finnish decree on drinking water. Many technical characteristics that are not demanded to be analyzed can affect the quality of water as well. The properties of water will affect the long-term durability of the networks which also has a major financial impact at the national level. Available data shows that Nordic waters are rather similar in many respects.

11.1 Microbes

There is a substantial amount of data available on parameters affecting microbiological quality of drinking water which is in accordance with the Finnish decree on drinking water. With respect to the microbiological quality, one can state that drinking water in Finland is of high-quality.

The results indicate that with regard to the microbes either required or recommended for analysis in the Finnish decree on drinking water, a majority of water provided by waterworks was safe and healthy to use. Almost all, 95 – 98 %, of waterworks provided water in which *Enterococci*, *Escherichia coli* or *Clostridium perfringens* were not detected in any sample during the study period. The corresponding figure for coliformic bacteria and plate count was 79 %. A small number (0.03 – 0.90 %) of all analysed samples contained at least one type of the microbes mentioned above. *Enterococci*, coliform bacteria and changes in plate count were observed most often in small waterworks. *E. coli* was observed in most cases in medium-sized waterworks and *Clostridium perfringens* was observed in one large waterworks using surface water.

Additional measurements indicated that state of the network and sampling method can affect the plate count number. The highest plate count was observed in stagnated network water whereas water pumped from the waterworks into the network and flowing network water had a substantially lower plate count number. Well waters had more microbes: approximately 20 % of well water samples contained the microbes mentioned above though this describes perhaps more the general condition of wells rather than the quality of groundwaters. Between the years 1998 and 2006 in Finland, a total of 16 826 people became sick because of water transmitted epidemics. The most important pathogens were norovirus (72 % of illnesses) and campylobacteria (25 % of illnesses). The microbes causing these water-borne epidemics, e.g. norovirus and campylobacteria, are normally not monitored in drinking water quality control and therefore there is little extensive information on their occurrence. There have been several water-borne epidemics in Finland in which water has assessed as flawless according to the microbiological demands stated in the Finnish decree on drinking water. However, the water-borne epidemics also included serious outbreaks caused by drinking water distributed through the communal waterworks. The number of people infected in these epidemics was counted in the thousands [National Public Health Institute of Finland 2008].

In addition to health effects, microbes affect also durability of the network materials. This subject has been discussed in detail in the two reports made by FIDW: “Materials in Contact with Drinking Water in Finland” [Kekki et al. 2007] and “Failures and service life of materials in drinking water mains and household plumbing in Finland” [Kekki et al. 2008].

11.2 Nutrients for microbes

Information on nutrients affecting microbial growth is available to a variable degree. With respect to nutrients affecting microbial growth the water provided by waterworks and well waters were mainly in accordance with the Finnish decree on drinking water since the concentrations of nitrate, nitrite, ammonium and oxidizability were below the limit and guide values.

The current numerical data on different forms of carbon (TOC, AOC, DOC) is incomplete because for example the Finnish decree on drinking water only demands that the concentration of TOC should exhibit no abnormal changes. In addition, the concentration level of TOC must be monitored only when water provided exceeds 10 000 m^3/d. The amount of organic substance is widely evaluated by oxidizability which does not precisely represent the amount of carbon.

The recommendation is that the concentration of TOC should exhibit no abnormal changes and this was fulfilled in all waterworks that provided data. The median range for TOC was 1.0 – 2.6 mg/l in the whole data of the study. The median concentration of water provided by waterworks was 1.9 mg/l.

The determination of phosphorus compounds is currently not a requirement listed in the Finnish decree on drinking water thus their determination is not conducted frequently. In Finland and some other countries e.g. Latvia and Japan, it has been demonstrated that microbial growth is phosphorus limited instead of carbon limited and therefore analysing phosphorus compounds would be important if one wishes to evaluate the growth potential of microbes.

The National Public Health Institute of Finland has developed a method to determine microbially available phosphorus (MAP) but this method has not yet been applied for the monitoring quality of water at waterworks. Concentrations of MAP in drinking water are very low and it is challenging to reduce them even further through water treatment. The median concentration of phosphate phosphorus in this study was 1.5 – 6.0 µg/l. The concentrations of nutrients for microbes (nitrite, ammonium, oxidizability, TOC) were higher at waterworks using surface water than in those using groundwater. Generally surface waters contain more nutrients since many compounds are flushed into surface water from the soil.

11.3 Metals

Many metals need to be assessed to satisfy both the requirements and recommendations of the Finnish decree on drinking water (antimony, arsenic, mercury, cadmium, chromium, copper, lead, nickel, and selenium) and these have been widely determined in Finland. Water provided by waterworks and well water was compliant with the decree with respect to most of the metals (Sb, As, Hg, Cd, Cr, Cu, Pb, Se, Al, and Na). The concentrations of Ni, Mn, and Fe were above the respective limit or guide value in about 5 % of the samples. Samples exceeding the limit value for Ni were observed especially in medium-sized waterworks. Samples exceeding the limit values for Mn and Fe were observed most often in small and medium-sized waterworks using groundwater. In a significant part of raw water samples, the limit or guide value of metals was exceeded indicating that the problem in the water provided by waterworks was at least partly due to raw water. In waterworks using surface water, the concentrations of metals were lower than in waterworks using groundwater except for aluminium whose concentration was clearly higher in the waterworks using surface water. Some waterworks use aluminium containing chemical coagulant which might have caused this higher concentration. The higher concentration of aluminium might also originate from a higher amount of organic substances able to bind aluminium in waterworks using surface water.

Sampling method was shown to have an effect on the concentrations of copper, iron, and zinc in drinking water. The higher concentrations were observed in stagnated network water than in water pumped from the waterworks into the network or flowing network water. Copper, iron, and zinc can dissolve into drinking water from the network materials. Sampling method did not seem to have any significant effect on the concentrations of manganese, iron, and molybdenum. The concentrations of Al, As, Pb, Ni, Sn, Ti, and Bi were so low that the effect of sampling method was not detectable.

It has been proposed in the forthcoming EAS procedure that metallic products should be tested for dissolving metals. The metals to be tested are those subject to the quality requirements in the Finnish decree on drinking water (Sb, As, Cd, Cr, Cu, Pb, Ni, Se), and some of those subjected to the quality recommendations (Al, Mn, Fe), as well as a few others (Mo, Sn, Ti, Zn, Bi). The suggested limit values for the above mentioned metals in the forthcoming EAS are mainly suitable for Finnish drinking waters (Table 4). The EAS limit value is 50 % of the limit value in DWD for those metals that can be found in raw waters and 90 % for those that mostly dissolve from the network materials. In some Finnish waterworks, the concentrations of Al, Mn, Fe, and Ni are so high that if the maximum amount (limit value) proposed in EAS for metals dissolving from the network materials would be present in water the guide or limit value of the Finnish decree on drinking water would be exceeded. Overall, 4 % of the waterworks would be exceeding the limit concentrations of Ni with the respective figures for Mn and Fe being 7 % and 10 %.

Table 4. Requirements and recommendations for metals in DWD and EAS proposal, and the median concentrations of metals in Finnish drinking water.

Parameter	Required or recommended concentration in DWD (µg/l)	Suggested limit value in EAS[1] (µg/l)	Median concentration in Finnish drinking water[2] (µg/l)	Part of waterworks exceeding suggested limit value in EAS (%)
Subject to quality requirements				
Antimony	5	2.5	0.02 – 1.00	0.5
Arsenic	10	5	0.1 – 1.7	1
Cadmium	5	2.5	<0.02 – 1.00	0
Chromium	50	25	<0.2 – 5.0	0
Copper	2000	1800	2 – 100	0
Lead	10	5	0.05 – 5.00	0
Nickel	20	10	0.4 – 10.0	4
Selenium	10	5	0.4 – 5.0	0
Subject to quality recommendations				
Aluminium	200	100	1 – 20	4
Iron	200	100	14 – 71	10
Manganese	50	25	2 – 73	7
Other metals				
Molybdenum	[3]	10	0.2 – 2.0	0
Zinc	[3]	2700	2 – 99	0
Tin	[3]	3000	<0.05 – 1.00	0
Titanium	[3]	7.5	<5	0
Bismuth	[3]	9	<1	0

[1] Long term testing of metal products
[2] [Ahonen et al. 2008]
[3] No limit or guide value in DWD

11.4 Chemicals and organic compounds

There was less information on chemicals and organic compounds in drinking water available than on other parameters. Information was received from approximately 200 waterworks though only four provided data on acryl amide and not all provided data on the following parameters: benzo(a)pyrene (148 works), epichlorohydride (21 works), trihalomethanes (128 works), and vinyl chloride (87 works).

With respect to chemicals and organic compounds, it appears that Finnish drinking water is in accordance with the Finnish decree on drinking water. In a few well waters, the concentrations of benzene and vinyl chloride were above the limit values. This report does not include any information on biocides.

11.5 Non-metals

With respect to non-metals, there is quite a lot of data on the concentrations of boron and fluoride but numerical data for bromate is presented only in the material of waterworks reporting to the EU (large waterworks). Only a few small waterworks provided data on fluoride.

On average, the concentrations of fluoride and boron have been below the limits set in the Finnish decree on drinking water. However, in some Finnish waters, the concentration of fluoride is a problem: especially in South Finland where more than half of check monitoring samples during the years 1996–1998 had values higher than the allowed maximum concentration (1.5 mg/l). The concentration of bromate has been analyzed in waterworks reporting to the EU but the concentration level has been at most only one tenth of the limit value (10 µg/l).

The concentrations of boron and bromate on average were in accordance with the Finnish decree on drinking water in water provided by waterworks and in well waters. Approximately 2 % of waterworks provided water whose concentration of fluoride was above the limit value of the Finnish decree on drinking water. Samples exceeding the limits were observed in large and medium-sized waterworks using either groundwater or artificial groundwater.

11.6 Technical and aesthetical quality

Numeric data on parameters describing the overall quality of drinking water (odour, taste, turbidity, colour) is not greatly available but according to the values that are available the quality of Finnish drinking water is usually high.

Data on the concentrations of carbon dioxide, calcium, and manganese in water provided by waterworks is very sparse or not at all available. It seems that the concentrations of chloride and sulphate on average have been below the recommendations of the Finnish decree on drinking water. Furthermore, electric conductivity has been only about one tenth of the limit value of the Finnish decree on drinking water.

It is known that quality of drinking water affects the durability of the metallic, cement based, and plastic network materials since certain waters promote corrosion and dissolution. Thus, pH, alkalinity, hardness, amount of chlorides and sulphates, iron, and manganese are usually included in the parameters affecting the technical quality of drinking water.

The Finnish decree on drinking water contains guide values for some but not all of the parameters affecting the technical quality of drinking water. There are guide values for pH, amount of chloride and sulphate, electric conductivity, odour, taste, turbidity, and colour in the decree. However, there are no recommendations about alkalinity, hardness, or carbon dioxide.

There are variable amounts of data available on the parameters describing the technical quality of drinking water. The pH and other parameters which must comply with the Finnish decree on drinking water (chloride, sulphate, EC) are most extensively analysed. In all, 8 % of the average pH values of water provided by waterworks were below the lower guide value of the decree (6.5), the respective figure for well waters was 30 %. Most of these low pH values were observed in small and medium-sized waterworks using groundwater. Thus, elevated corrosiveness of water might be a problem in small waterworks using groundwater that supply water into the network as such without any treatment.

With respect to chloride, sulphate, and EC, the water provided by waterworks was in accordance with the Finnish decree on drinking water. With respect to sulphate, all waterworks and wells were in accordance with the additional guide value set to decrease the corrosiveness of water. However, the additional guide value set for chloride (25 mg/l) was exceeded in 10 % of waterworks and in 10 – 25 % of well water samples. Most of these cases occurred in large and medium-sized waterworks using ground and surface water. Approximately 90 % of all waterworks provided water that was in accordance with the decree with respect to odour, taste, turbidity, and colour. Abnormal changes with these parameters were mostly observed in medium-sized waterworks. Small waterworks provided very little data. Odour, taste, turbidity, and colour of well waters could not be compared to the Finnish decree on drinking water because of inconsistency between the type of results submitted in reports from the waterworks and the requirements stated in the decree (numeric data vs. determined/not determined).

Drinking water that has good technical quality has a composition which also takes into consideration the network materials. The quality of water does have an effect on the tendency of pipes etc. to dissolve. The report made by FIDW "Failures and service life of materials in drinking water mains and household plumbing in Finland" [Kekki et al. 2008] gives scientific research based target values for good technical quality of water with respect to its interaction with metallic and cement based materials. In order for water to be of good technical quality to the two types of material mentioned above, it should have pH 7.5 – 8.0, bicarbonate >60 mg/l, calcium > 20 mg/l, free carbon dioxide <15 mg/l, chloride <100 mg/l, and sulphate <100 mg/l. Target values for plastic materials are not provided because there is not enough scientific data on impact of technical quality of drinking water on the durability of plastic materials. An application directive to the Finnish decree on drinking water [Finnish Water and Waste Water Works Association and The Association of Finnish Local and Regional Authorities 2001] recommends the following values: pH >7.5, alkalinity >0.6 mmol/l, and calcium >10 mg/l.

Table 5 lists the guide and target values of drinking water with good technical quality. The target values are listed from the report of Kekki and colleagues [2008] and from the application directive to the Finnish decree on drinking water [Finnish Water and Waste Water Works Association and The Association of Finnish Local and Regional Authorities 2001]. The guide values are the recommendations in the Finnish decree on drinking water. In addition, the number of waterworks that fulfil the guide or target values of Kekki et al. [2008] is shown. As seen in the table, the guide value for pH is achieved by about 90 % of the waterworks but the target value of Kekki et al. [2008] is met in only about 30 %. Nearly all of the plants, 99 %, that failed to meet the target value were groundwater waterworks. If divided according to size, this group included 28 % of the large waterworks, 70 % of the medium-sized waterworks, and 85 % of the small waterworks. Furthermore, 15 % of the waterworks exceeded the target value of pH 8.0. Low pH values were observed especially in small and medium-sized waterworks.

There was very little information available on the levels of bicarbonate and calcium in drinking water was very little available thus they are not included in this report as such but viewed as alkalinity and hardness. The concentration of bicarbonate can be converted to alkalinity: HCO_3^- 60 mg/l ↔ alkalinity 1 mmol/l. The concentration of calcium can be converted to hardness: Ca 20 mg/l ↔ hardness 0.5 mmol/l. In all, 39 % of waterworks distributed drinking water that was in accordance with the target value for alkalinity [Kekki et al. 2008]. If subdivided according to size, 64 % of the large waterworks, 55 % of the medium-sized waterworks, and 100 % of the small waterworks failed to meet the target value. By water type, 59 % of groundwater, 93% of surface water, and 44 % of artificial groundwater waterworks failed to meet the target value. Low values of alkalinity were observed in all types of waterworks, mostly in small waterworks and in waterworks using surface water. The application directive to the Finnish decree on drinking water [Finnish Water and Waste Water Works Association and The Association of Finnish Local and Regional Authorities 2001] recommends that alkalinity >0.6 mmol/l, and 78 % of waterworks did achieve this target value. 56 % of waterworks reported alkalinity values >0.8 mmol/l.

More than half, 57 %, of waterworks distributed drinking water that was in accordance with the target value for hardness stated below in Table 5 [Kekki et al. 2008]. By size, 32 % of large, 48 % of medium-sized, and 100 % of small waterworks failed to meet the target value. When categorized according to raw water used, 50 % of groundwater, 16 % of surface water, and 13 % of artificial groundwater waterworks failed to meet the target value. In particular, low values of hardness were observed in small and medium-sized groundwater waterworks.

The target value for free carbon dioxide (<15 mg/l) was exceeded in 11 % of waterworks that were all kinds of sized waterworks using groundwater as raw water [Kekki et al. 2008].

Table 5. Guide values and target values for drinking water in order for water to be assessed as having good technical quality.

Parameter	Guide value in the Finnish decree on drinking water	Proportion of waterworks that fulfill the guide value	Target value[b]	Target value[c]	Proportion of waterworks that fulfill the target value[c]
pH	6.5 – 9.5	92 %	>7.5	7.5 – 8.0	33 % (136/418)[f]
Cl^-	<250 mg/l (<25 mg/l[a])	100 % (92 %[a])		<100 mg/l	100 % (422/424)[f]
SO_4^{2-}	<250 mg/l (<150 mg/l[a])	100 % (100 %[a])		<100 mg/l	99 % (404/409)[f]
HCO_3^-	-	-	(>0.6 mmol/l)[d]	>60 mg/l (>1 mmol/l)[d]	39 % (51/131)[f]
Ca	-	-	>10 mg/l	>20 mg/l (>0.5 mmol/l)[e]	58 % (87/149)[f]
Free CO_2	-	-		<15 mg/l	89 % (87/98)[f]

[a] Target value to prevent corrosion
[b] [Finnish Water and Waste Water Works Association and The Association of Finnish Local and Regional Authorities 2001]
[c] [Kekki et al. 2008]
[d] Target value as alkalinity: >1 mmol/l
[e] Target value as hardness: >0,5 mmol/l
[f] Number of waterworks that fulfill/do not fulfill the target value

11.7 Radioactivity

The radioactive components in drinking water included in this report are Total-α, Total-β, Lead-210, Polonium-210, Radium-226, Radon-222 and uranium.

In surface waters, activity concentrations of radioactive substances were very low and no samples were detected exceeding the action limit values of the Finnish decree on drinking water or the Finnish Radiation and Nuclear Safety Authority [1993] (Regulatory Guide ST 12.3 – Radioactivity of Household Water). In soil groundwater, a few cases exceeding the action limits were observed. In contrast, in bedrock groundwater the activity concentrations were rather high and actions to meet the limit values had to be undertaken.

12 Network materials

12.1 Construction Product Directive, CPD

Pipes and other permanently installed components in drinking water systems are construction products that are subject to the Construction Product Directive (CPD) [Council Directive 89/106/EEC, amended by Council Directive 93/68/EEC]. The Construction Product Directive is under revision at the present moment (May 2008).

12.2 Finnish legislation

The first restrictions in Finland concerning water and sewage pipes were described in Helsinki in 1920. The rest of the country followed Helsinki in providing communal restrictions and recommendations. Restrictions concerned mainly protection of the networks from pollution, test pressures, and materials. The construction procedures and fittings mainly followed German standards.

Restrictions and recommendations for real estate water and sewage components have been in place since 1975. In Finland, the materials used in real estate drinking water systems must meet the criteria listed in a decree The National Building Code D1 (Water supply and drainage installations for buildings, Regulations and guidelines) by the Ministry of the Environment [Ministry of the Environment 2007]. The National Building Code contains technical regulations and instructions. These regulations are binding, and relate to the construction of new buildings. The regulations are applicable to renovation and alteration works only insofar as required by the type and extent of the measure and any possible change in use of a building. The instructions are not binding but represent acceptable solutions. In addition, for certain materials and products there are demands for certifications, standard approvals or other acceptance schemes. Surveillance is conducted by the local building inspection authority.

When one considers the situation other than real estates e.g. the structures and pipes of waterworks, the lack of suitable legislation has meant that the standards are useful. In Finland, cold drinking water is not considered to be a food product in a legislative sense but since there is no suitable legislation, the quality inspection of the equipment used in waterworks is undertaken using the requirements for food products.

At the moment (May 2008), structures in real estate are subject to the Finnish decree on drinking water and the restrictions concerning construction. Waterworks must apply the Finnish decree on drinking water in order to ascertain the hygienic and technical quality of water. However, the forthcoming acceptance scheme (EAS) will harmonize products and materials in the distribution and real estate network. Thus, all the materials and products intended for distributing drinking water will be subject to harmonized demands to ensure safe usage.

12.3 Acceptance for construction products and national official acceptance

According to the Construction Product Directive, an acceptance scheme for all permanently installed construction products must be created although requirements and acceptance levels for buildings and construction parts will be still decided nationally. Requirements must be based on European technical specifications in which the characteristics of products are defined as well as test methods, attestation of conformity (AoC) and directions for marking of products. Harmonised product standards and European technical approvements are European technical specifications [Ministry of Environment 2007].

CE-marking intended for construction products is a declaration by the manufacturer that a product meets all the applicable legal provisions set by the European Union. National acceptance procedures will be abandoned when construction products get harmonised EN standards and furthermore CE-marking. However, according to Finnish legislation, CE-marking for a construction product will not be mandatory even after a transition period for the harmonized product standard has been ended.

With respect to the construction products that are in contact with drinking water, in Finland the only requirements for these materials are related to their use in real estates.

According to the building legislation, a product belonging to real estate construction territory of application can obtain a national type approval in Finland. This is granted mainly for five years at a time and includes quality monitoring by a third party. Applying for type approval is voluntary and therefore the authority granting building licence cannot demand the use of type approved products. Usage of products that are outside type approval is subject to a specific building licence and competence of these products e.g. with test reports is indicated, if necessary [Lindqvist et al. 2000].

The products in drinking water systems that are subject to type approval are plastic and copper pipes, water fittings, valves, and metallic fittings. The directions for approval have been and will be renewed in such a way that they include the test methods of the European product standards. At the end of 2006, renewed directions existed for copper pipes, water fittings, and check valves [Ministry of Environment 2006a, b, c].

Directions for type approval include technical requirements, minimum requirements for quality monitoring, and health based requirements for some parameters. However, some factors e.g. microbiological growth, are not tested in Finland.

If a product can obtain CE-marking, this will be the primary guarantee of quality and type approval can no longer apply to this product. In this case, the product standard must contain all the essential requirements stated by the CPD.

12.4 Market-based approvals

The materials used in the distribution network have no corresponding type approvals in contrast to the situation for water equipment in the real estates. These networks contain standardized products that are in accordance with either the Finnish, German, American, or Dutch standards. The suitability, quality, materials used in the products in the distribution networks are not monitored by any authority.

Accordance to the standard of a product can be shown with the FI-marking provided by Inspecta Certification Ltd. (former SFS-marking). In this case, quality monitoring is based on not only the product standards but in addition on special directions set by Inspecta Certification Ltd. There is also the Nordic Poly Mark, a Nordic quality mark for PE and PVC pressure pipes of the distribution networks, which was implemented in 2005 and will replace national marks of accordance to standard. FI-marking and Nordic Poly Mark are completely voluntary, thus they do not bind the authorities in the way that type approval does.

12.5 Material survey of drinking water networks

The manufacture and distribution of drinking water includes the raw water intake, water treatment, and delivery through the network to the users. Waterworks are responsible for the quality of drinking water up to the point where the service line of a real estate is connected to the network. However, responsibility for monitoring continues all the way to the consumer’s tap. The owner of a real estate is responsible for the service line and the network within the real estate, and also for any possible effects on the quality of drinking water that are caused by the real estate network materials.

The focus of the study “Materials in Contact with Drinking Water in Finland” [Kekki et al. 2007] was to define the materials used in the Finnish water distribution networks and supply systems in houses from the waterworks to the consumer’s tap. Coatings and gasket materials were also identified. The structure, composition, manufacture, use, fittings and interactions between water and the materials were identified. The results in the study are based on surveys, interviews, manufacturers’ websites and Finnish and foreign literature.

This data is needed for many purposes e.g. in the preparation of the European product acceptance system for materials in contact with tap water (European Acceptance Scheme, EAS). EAS also extends to the construction materials in contact with drinking water in the distribution networks and the water supply systems in houses.

The surveys related to the materials in contact with drinking water were sent out in summer 2006 to waterworks and product manufacturers and importers. A total of 48 waterworks responded to the survey. They account for approximately 56 % of the water supply (231 million m^3) and 50 % of the population in

Finland (2.27 million). Their networks cover approximately 15 000 km of pipelines, 18 % of the whole distribution network. Furthermore, 10 manufacturers and importers also responded.

The networks can be divided into the underground distribution networks of the waterworks and the real estate networks in buildings. This division is based on legislative aspects, differences in responsibilities, history, and used materials. In this report, the service lines are included in the distribution network because their materials are similar to those used in the distribution networks.

Materials and products in contact with drinking water of both the distribution networks and the real estate networks need to be discussed together since both the networks and the materials used in the networks are equally important in determining the quality of the water. At the moment, both networks are utilizing metallic, organic (plastics, rubbers), and cement-based materials. Pipes, coatings, and seals exhibit the most extensive variety of different materials.

12.6 Finnish network materials

Table 6 lists the materials used in the distribution and the real estate networks in Finland. It is noteworthy that the name of a material might have been the same for the last 100 years but its composition or application might have changed substantially. Cast iron has been used both in coated and uncoated forms, thus its properties have been different. Table 6 lists also materials that have been used in Europe but whose usage in Finland is not known. All the materials used are listed regardless of the amounts used.

The history of organized water management and materials in Finland started at the end of 19th century when the Swiss engineer Robert Huber made a proposal to build a water network in Helsinki [Karjalainen 1995]. Buildings had mostly cold water pipes; warm water was available to only a few sites. The use of warm water increased intensively only in the 1950s. In the early days of the network construction, metallic materials were used almost without exception, e.g. steel, brass, copper, and grey cast iron. Brass was used mainly for joints and copper for warm water pipes.

The use of plastic pipes started in Finland in the 1950s. From that time onwards, their use in the distribution networks has increased. The variety of plastics has increased and plastics are utilized in the real estate networks to an increasing extent. At the same time, some kinds of plastics are no longer marketed. The 1980s introduced PEX (cross linked polyethylene) and 2000s multilayer plastic pipes with aluminium foil, also known as composite pipes. Plastics and rubbers are the only types of materials that are equally broadly installed in both the distribution and the real estate networks. Some of the previously used materials e.g. asbestos cement and uncoated carbon steel are no longer installed in the new drinking water networks. Lead pipes have never been used in Finland.

Especially in large and middle-sized waterworks in Finland, it was found that the piping materials used and their proportions in the distribution networks were as follows: high density polyethylene 29 %; ductile iron 22 %; polyvinylchloride 17 %; grey cast iron 10 %; plastics (not defined) 10 %; low density polyethylene 3.2%; asbestos cement 2.8 %; others (mostly carbon steel) 2.8 %; middle density polyethylene 2.5 %; stainless steel 3 %. The overall proportion of plastics was 61 %, the proportion of cast iron 33 % and other materials 6 %. Large and middle-sized waterworks tended to use a greater variety of pipe materials than small waterworks.

The principal materials used in the supply systems to houses are copper, brass, stainless steel, galvanised steel and polyethylenes. The main pipe materials tended to be copper and polyethylenes. Other materials e.g. cement-mortar, bitumen, epoxides, rubbers, polyesters and polytetrafluoroethylene are in use as coatings in the water distribution networks and house plumbing.

Table 6. Installed and previously installed materials and products in the distribution and the real estate drinking water networks in Finland. Date when a material has been introduced and when its installation has been terminated in the drinking water networks.

Material	Products in distribution network	Products in real estate networks	Introduced	Installation terminated
		Inorganic materials		
		Metals		
Aluminium	fittings (flange)	faucets (parts), pumps (parts)	not known	in use
Grey cast iron	pipes, valves (main), fittings	water meters (main)	ca. 1880	in use (installation of pipes finished ca. 1980)
Copper	pipes (service line)	fittings, pipes, boilers (coating)	1890s[a]	in use
Brass	fittings, valves	faucets (main), fittings, meters (main), pumps (parts), valves, water meters (main)	beginning of 20th century[a]	in use
Ductile cast iron[b]	pipes, valves (main), fittings	water meters (main)	1958	in use
Bronze	not known	pumps (parts), valves	not known	in use
Red metal	fittings, valves	fittings, valves	not known	in use
Stainless steel[c]	fittings, pumps, pipes, valves (parts)	fittings, boilers (main), meters, hydraulic accumulators (main), pumps, pipes, filters (main), valves	ca. 1940	in use
Galvanized steel	pipes, reservoirs	pipes, hydraulic accumulators (main)	beginning of 20th century[d]	in use
Steel	pipes, reservoirs	not known	n. 1910	in use
		Others		
Asbestos cement[e]	pipes, fittings	not used	ca. 1940	1985

Concrete / cement mortar	coatings (pipes), reservoirs	not used	not known	in use
Enamel	not known	boilers (coating)	not known	in use
		Organic materials		
		Plastics		
ABS	not known	not known	not known	not known
Epoxide plastic (EP)	coatings (SG and steel fittings, water meters), seals (joints in reservoirs)	coatings (pipes)	not known	in use
Chlorinated polyethylene (PE-C)	not known	not known	not known	not known
Glass fiber-reinforced plastic (GRP)	pipes[g]	filters (main)	not known	in use
Polyamide (PA)	fittings (parts), coatings (fittings, valves)	faucets (parts)	not known	in use
Polyacetal (POM)	fittings, valves (main)	faucets (parts), fittings (parts)	not known	in use
Polybutylene (PB)	not known	pipes	beginning of 1980s	beginning of 1990s
Polyesters[f]	coatings (service lines)	filters (parts)	not known	in use
Polyethylene, high density (PEH)	pipes, fittings	hydraulic accumulators (main)	1961	in use
Polyethylene of raised temperature resistance (PE-RT)	not known	composite pipes	beginning of 2000s	in use
Polyethylene, low density (PEL)	pipes	not known	1956	in use
Polyethylene, medium density (PEM)	pipes	not known	1965	in use
Polyethylene, cross linked (PEX)	pipes	pipes, composite pipes	1986	in use
Polyethylene terephthalate (PETP)	pipes/ coatings (service lines)	filters (parts)	not known	in use
Polycarbonate (PC)	not known	pumps (parts)	not known	in use

Polypropylene (PP)	fittings (main)	fittings (main), filters (parts), water meters (parts)	not known	in use
Polysulfone (PSU)	not known	not known	not known	not known
Polytetrafluoroethylene (PTFE)	not known	seals of pipes and valves	not known	in use
Polyvinylidene chloride (PVDC)	not known	not known	not known	not known
Polyvinylchloride (PVC)	pipes, fittings	not known	1961	in use
Polyphenylene oxide (PPO)	not known	pumps (parts)	not known	in use
Polyphenylene sulfide (PPS)	not known	not known	not known	not known
Polyphenylsulfone (PPSU)	not known	fittings (main), faucets (parts)	not known	in use
Styrene acrylonitrile (SAN)	not known	filters (main)	not known	in use
		Rubbers		
Ethylene propylene diene monomer rubber (EPDM)	seals of fittings, pipes and valves, coatings (parts of valves)	seals of faucets, pipes and valves	not known	in use
Fluoro rubbers (FE)	seals of fittings, coatings (valves)	seals of valves	not known	in use
Chloro butyl rubber (CIIR)	not known	seals of pipe fittings	not known	in use
Chloroprene rubber (CR)	seals of pipes	not known	not known	in use
Natural rubber (NR)	coatings (parts of valves)	not known	not known	in use
Nitrile rubber (NBR)	seals of fittings, coatings (parts of valves)	faucets, fittings, seals of filters and valves	not known	in use
Polyurethane (PUR)	not known	not known	not known	not known
Silicon rubbers	not known	not known	not known	not known
Styrene butadiene rubber (SBR)	seals of fittings and valves	not known	not known	in use

	Others			
Bitumen	coatings (pipes, tanks)	not known	not known	beginning of 1980s

not used = material is not known to be used in the network in question.
not known = information has not been obtained but material is/has been used outside Finland.
If in the columns ”Products in distribution network” and ”Products in real estate networks” there is nothing marked in the brackets the material in question is used in both parts and main.
[a] [Karjalainen 1995]
[b] At the moment, the majority of installed products are coated.
[c] Includes acid-proof steel.
[d] [Järvinen et al. 1987]
[e] Not sold in Finland any longer.
[f] PETP and PC belong to polyesters. Products without detailed classification are situated in ”Polyesters” in the table.
[g] As far as known, these kinds of pipes are not in use in Finland.

Some materials have not been installed decades ago but they remain in the networks as long as their technical service life permits. For example, there are still hundred year old cast iron pipes in use as well as galvanized steel and copper pipes installed in the 1940’s.

The materials used in the real estate and the distribution networks differ from each other. In addition, different waterworks might have different selection criteria and therefore use different materials. The selection criteria are affected by waterworks’ own usage experiences.

The length of the networks in Finland has increased as cities expand and rural areas come within range of water management. At the same time, the real estate networks have lengthened as well. Old water pipes are starting to require renovation. In new buildings and when there is reconstruction of the distribution networks, over 90 % of installed pipes are plastic. Nearly all pipes installed in water systems are plastic. At the moment, nearly all installed ductile cast iron pipes and steel pipes are coated inside with cement mortar and quite a few old metallic pipelines have been afterwards coated inside with cement mortar. In fact, in terms of surface area, cement mortar is the most significant material after plastic that is in contact with drinking water in the distribution networks. Different types of trenchless techniques and coating methods have become more and more common in the reconstruction of the distribution networks.

Detailed statistics on the materials used in the real estate networks are not available. Almost without exception, old pipes in buildings are replaced by new ones.

Separate materials differ substantially from each other but there are some general differences between the material groups as well. For example, it is typical that the composition and structure of metals is well known. Dissolution from metals into drinking water can be direct or through biofilm activity but in both cases, the composition of possibly dissolving substances is known and their numbers are limited. One of basic properties of metal piping is the density i.e. their ability to protect drinking water from substances in the surroundings.

Production methods and modulation of the properties of plastics mean that quite a few additives in addition to the basic polymer are used in the manufacture of plastic piping. These additives, their compositions, and effects are not extensively understood. “Recipes” for plastics have been changing over the years and even similar plastic types can differ substantially from each other. One of the basic properties of plastic materials is their permeability, thus substances can migrate to drinking water through plastic. However, permeability varies between different types of plastics and the aluminium foils used in some multi-layer plastics will prevent this migration.

13 Interactions between drinking water and materials

The factors affecting the quality of drinking water include the source of raw water, water treatment processes of waterworks, materials, construction, and stagnation times of the distribution network, pipe materials used in the real estates, and microbiological activity throughout the whole chain of the water distribution. It is possible that the quality of drinking water can decline because of the substances dissolving from the materials or new chemical compounds forming as water and the materials interact (Figure 38).

The solution responses of metallic materials depend substantially on the aggressivity of water. Many metals used in the networks dissolve to some extent in acidic and soft, aggressive carbon dioxide containing water of low alkalinity.

Unhealthy or organic substances acting as nutrient for microbes can dissolve from the organic materials present in the networks. Substances dissolving from organic materials are less well characterized than metallic materials. Many types of products can be produced from a single polymer and many manufacturing processes use several different additives and other substances. In most cases, problems are not caused by the basic polymer but by the additives. Although the amount of additives is usually very small, they might dissolve from the structure more easily and lead to a faulty odour and taste or evoke problems in hygiene. Unwanted degradation or reaction products might also be formed during manufacture. Currently, there is not enough research information on all potential dissolving substances to estimate their health effects.

In addition, concrete and cement mortar surfaces react with water and especially in the early days of their use this could cause the pH level of water to increase. Cement mortar contains organic and inorganic additives and thus harmful substances or nutrients for microbes might dissolve from the material. Dissolution is most intense in the early days of use of a material and usually it decreases in time.

Harms caused by substances dissolving from materials might be avoided by sluicing enough water throught he pipe before use especially if water has stagnated e.g. left standing overnight. Warm or stagnated water should not be used for drinking or cooking.

13.1 Biofilms

Even though drinking water is cleaned and disinfected in waterworks, the network always contains microbes which form fairly rapidly a biofilm on all material surfaces which are in contact with drinking water. With respect to microbial growth, no significant differences have been discovered between different materials. Biofilms in water are formed on all surfaces because water always contains the nutrients that are essential for micro-organisms and biofilm formation. There are micro-organisms both in water and in biofilms though substantially more are present in biofilms.

Biofilms might cause problems in drinking water distribution. Certain types of bacteria can cause turbidity and poor taste and odour and even microbiological corrosion of metallic materials. Biofilms might also increase growth and distribution of insanitary bacteria. The temperature of surface waters in Finland varies extensively with the seasons but the temperature of groundwaters is fairly stable [Miettinen et al. 1996a]. The increase of temperature during the summer months does seem to excessively increase the microbiological activity, especially in drinking water made from surface water.

The rate of biofilm formation depends on many factors, but the most important limiting factor is the sufficiency of nutrition. The critical factor for microbiological growth is the amount of nutrition that is easily available to microbes. This nutrition can be supplied by the water itself or it might be dissolved from the materials in the distribution network. In Central Europe and North America, assimilable organic carbon (AOC) is found to be the limiting nutrient for microbial growth in drinking water and biofilms [van der Kooij 1992, LeChevallier et al. 1987]. In many other countries e.g. Finland, Latvia, Lithuania, and Japan that have substantial amounts of organic carbon in raw waters, the limiting nutrient is phosphorus instead of carbon [Lehtola et al. 2004, Miettinen et al. 1996b, Sathasivan et al. 1997]

One reason to explain why phosphorus is the limiting nutrient is that precipitation (coagulation and flocculation) as a water treatment process is more efficient at removing phosphorus than carbon. In drinking water, the concentrations of microbially available phosphorus (MAP) are very low and therefore the determination of MAP with current techniques can be challenging as its concentration declines drastically during the water treatment. The median range of phosphate phosphorus in Finnish drinking waters is 1.5 – 6.0 µg/l. In contrast, the median range for TOC is 1.0 – 2.6 mg/l.

In EAS, organic materials are tested for their potential to cause the formation of biofilms. The proposed EAS material tests might not be suitable as such for Finnish conditions because of the different quality of water.

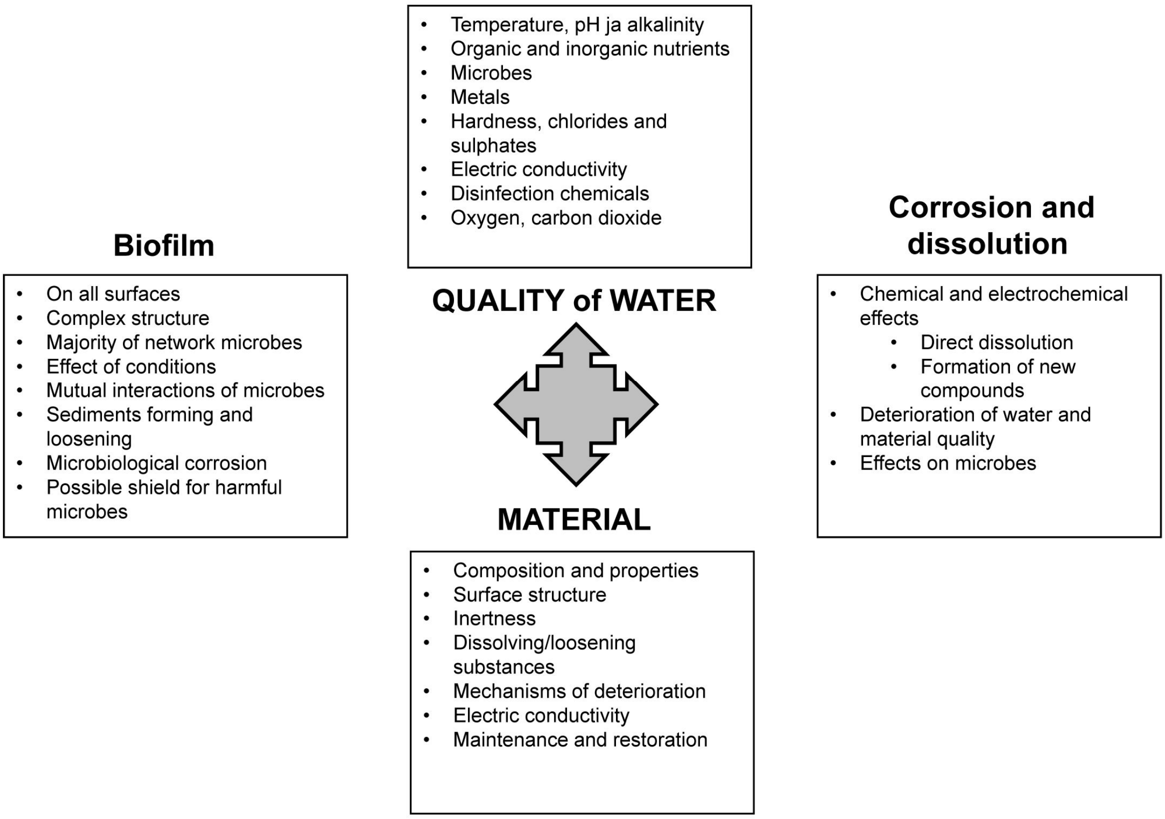

Figure 38. Interactions between materials and water.

Disinfection is used to destroy microbes in drinking water. Ozone and UV has effect only in the waterwork site while in the network they have no effect. Chlorine based disinfectants also act within the network. Free chlorine is consumed rapidly in the network while monochloroamine has an effect also against biofilms and its impact lasts longer [LeChevallier ym. 1988]. Previously there was a concern that chlorination could lead to the formation of mutagenic by-products. In Finland, concentrations of chlorine in the networks are usually low, 0.3 mg/l for groundwater plants and 0.5 mg/l for surface water plants.

13.2 Aggressivity

According to the DWD and the Finnish decree on drinking water, aggressivity of water is not allowed. However, aggressive water is not defined in these regulations. According to research data, metallic and cement based materials should have following target values to achieve non-aggressive water [Kekki et al. 2008]:

- pH 7.5 – 8.0;
- Alkalinity >60 mg HCO_3^- /l,
- Calcium >20 mg/l;
- Free carbon dioxide <15 mg/l;
- Chloride <100 mg/l; and
- Sulphate <100 mg/l.

Table 5 (page 65) collates the target values mentioned above and the guide value of the Finnish decree on drinking water. In addition, Table 5 reveals the proportion of Finnish waterworks that provide water in accordance with these values. It can be seen that the guide value for pH is reached in 90 % of waterworks but the target value in only about one third of waterworks. About half of waterworks fell below the target value of pH 7.5, nearly all of these waterworks used groundwater. Furthermore, 15 % of waterworks were above the target value of pH 8.0. Low pH values were observed especially in small and medium-sized groundwater waterworks.

In all, 39 % of waterworks provided water that was in accordance with the target value for alkalinity. All small waterworks, over half of medium-sized waterworks, and 64 % of large waterworks failed to achieve the target value. Low values of alkalinity were observed in all types of waterworks, though mostly in small waterworks and surface water waterworks.

In all, 57 % of waterworks provided water that was in accordance with the target value for hardness. All small waterworks, nearly half of medium-sized waterworks, and about third of large waterworks failed to achieve the target value. In particular, low values of hardness were observed in small and medium-sized groundwater waterworks.

Achieving the target values for chloride and sulphate should not represent a problem. The target value for free carbon dioxide (15 mg/l) was exceeded in about one tenth of waterworks and these cases included all kinds of waterworks sizes using groundwater.

14 Conclusions

The study shows that Finnish drinking water is of high quality and therefore safe and hygienic to use when compared to the quality requirements and recommendations. Quality monitoring of drinking water in Finland is primarily monitored by the Finnish decree on drinking water that concentrates on health based parameters. However, the quality of drinking water is affected also by many technical parameters that are not required to be measured but these can have a significant impact on the long term durability of the networks.

14.1 General matters to be considered in DWD revision

Sampling

Sampling affects the concentrations of several parameters e.g. metals in drinking water. EU countries have different national protocols on whether a sample is taken from stagnated or flushed water. A sampling method to be used should be declared clearly but there needs to be flexibility in the directive. When defining a sampling method, sampling locations and parameters to be analyzed need to be stated but flexibility based on national usage habits should be included.

Nutrients for microbes

Present DWD recommends that there should be no abnormal changes in TOC concentration. To secure general hygiene of drinking water, a numeric guide value for TOC concentration should be defined but different concentration levels in EU countries should also be observed.

Metals

A limit value for uranium should be defined in the new DWD because of its chemical toxicity.

Chemicals and organic compounds

Concentration of acryl amide, epichlorohydrine, and vinyl chloride should be determined analytically and not simply estimated by some mathematical formula.

Radioactivity

A limit value for radon should be defined in the new DWD. In addition, analysis of polonium and lead should be added to the monitoring research program of waterworks using drilled well water.

14.2 Finnish drinking water in relation to DWD revision and EAS preparation

Nutrients for microbes

The high natural concentration of TOC in Finnish drinking water should be taken into consideration in the preparation of EAS.

Metals

When drafting limit values for metals in EAS, the rather high concentrations of aluminium, manganese, nickel, and iron in Finnish drinking water should be taken into account.

Test waters in EAS

The study by Ahonen and colleagues [2008] showed clearly that drinking water distributed from different waterworks is rather heterogenic, thus local drinking water as such is not usually suitable to be used as EAS test water. Instead, synthetic waters are used in material testing. The long-term behaviour of products in local waters and real-life conditions must be known in order to prove that quality of water and the network materials do not unnecessarily weaken each others' quality. However, real-life usage conditions might sometimes be such that approved product might cause problems locally. In these situations, mutually agreed plans of action will be needed in Finland.

14.3 Surveillance system for quality of drinking water

There is no publically easily available and comprehensively accessible information on the quality of water in waterworks in Finland. In addition, centralized contact information of waterworks and water co-operations are not available. Information on water from large waterworks is reported to the EU and collected in a summary report but information on smaller waterworks is not collected. According to the monitoring research programs, information on parameters other than those mentioned in the Finnish decree on drinking water is also collected but this information is not accessible to the public. Large waterworks do place some numeric information about the quality of water on their internet pages but this is fairly rare with smaller waterworks.

It is recommended that there should be created a public and comprehensive database on the quality of drinking water as well as the activities of waterworks and water co-operations distributing drinking water in Finland. This database could make it easier to make direct contact with waterworks and it would help authorities in preparative work on EU legislation. The Ministry of Social and Health is preparing an environmental health care data system (in Finnish: ympäristöterveydenhuollon kohdetietojärjestelmä) to collect information on the quality of drinking water for administrative usage. Communities will provide their information on the results from official supervision monitoring activities to this database starting in the beginning of 2010. This database certainly will improve the Finnish situation but at the moment this information is not intended to be made available to the general public.

Nevertheless, as this system is being planned, it would be reasonable to note that those parameters that the Finnish decree on drinking water recommends "no abnormal changes" are included. For these parameters, the actual numeric analysis values should be stored in the system since most likely waterworks must them analyze. Availability of this information would ease the comparison of different waterworks and drafting summaries of Finnish drinking water. In addition, it should be discussed whether values of alkalinity and hardness from those waterworks analysing them could be added to the system even though the Finnish decree on drinking water does not require analysis of these parameters.

A similar database on the quality of drinking water should be prepared at the EU-level as well; the quality of water can alter significantly within the limits of DWD and an EU-wide database would ease the availability and comparison of water quality in different countries. The summary reports of the EU Commission on water quality in Europe contain information about incidents exceeding the limits set in DWD but no numeric data is accessible. The aim should be to achieve a comprehensive and numeric data including a standardized reporting protocol throughout the EU.

14.4 Network materials

There are many different materials in the distribution network and in the domestic water supply systems that are in contact with drinking water. It must be remembered that drinking water spends most of its time in these networks. Materials and tap water can undergo complex interactions, which can result in the deterioration of water quality and/or the deterioration of materials. Data on materials is one of the topics needed to be considered in the preparation of the European product acceptance system for materials in contact with tap water (European Acceptance Scheme, EAS). EAS encompasses all the construction materials in contact with drinking water in the distribution networks and the water supply systems in houses.

Surveys on materials in contact with drinking water were sent out in summer 2006 to waterworks and product manufacturers and importers and a total of 48 waterworks responded to the survey. They account for approximately 56 % of the water supply and serve 50 % of the Finnish population. In addition, 10 manufacturers and importers also responded.

The results showed that especially in large and middle-sized waterworks in Finland, the pipe materials used with their proportions in the distribution networks were as follows: high density polyethylene 28.6 %; ductile iron 22.5 %; polyvinylchloride 17.2 %; grey cast iron 10.4 %; plastics (not defined) 9.6 %; low density polyethylene 3.2 %; asbestos cement 2.8 %; others (mostly carbon steel) 2.8 %; middle density polyethylene 2.5 %; stainless steel 0.2 %. Altogether the proportion of plastics was 61 %, the proportion of cast iron 33 % and other materials 6 %. Large and middle-sized waterworks utilized more different types of pipe materials compared to small waterworks. The principal materials used in domestic supply systems are copper, brass, stainless steel, galvanised steel and polyethylenes with the main pipe materials being copper and polyethylenes. Cement-mortar, bitumen, epoxides, rubbers, polyesters and polytetrafluoroethylene are also in use as coatings in the water distribution networks and domestic plumbing.

More accurate information on materials that are in use in contact with drinking water is still needed. There is insufficient knowledge about their interactions with water in the Finnish networks. These materials will be a part of the water systems for decades after their installation and knowledge of their long-term behaviour is essential thus it should be studied. Understanding the interaction between water and materials will be of benefit in the understanding and management of the networks and influencing the forthcoming European product acceptance scheme, irrespective of whether it is national-based or Europe-wide.

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Finnish Institute of Drinking Water – FIDW

Finnish Institute of Drinking Water is an independent expert organization that works on a basis of scientific research results.

Finnish Institute of Drinking Water is the specialist in:

- Drinking water quality, materials in contact with drinking water and interactions between them
- EU-standardisation and acceptance schemes of materials and products in contact with drinking water
- Microbiological safety of greenhouse watering and greenhouse cultivation
- Scientific research within the field of drinking water quality and materials.

Key Objectives of FIDW:

- Ensuring and promoting the safety of drinking water quality to the tap of the consumer
- Enhancing of the safety and service life of materials used in water distribution systems and plumbing
- Improving the operating environment of Finnish companies by co-operation with the enterprises and legislative and standardization bodies in EU and nationally
- Enhancing the networking and competence within drinking water field

Activities of FIDW:

- Participation in development of the European Acceptance Scheme (EAS) for materials in contact with drinking water and the related standardisation work
- Projects and research work enhancing the work of legislative bodies and companies
- Organizing seminars, conferences and education
- Networking within the drinking water field

Services provided by FIDW:

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