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MaiD

Report 1

Nordic drinking water quality

A Nordic Innovation project

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Preface

This document is the first report (Report 1) of the Nordic cooperation project entitled: "MaiD - Material and product innovation through knowledge based standardization in drinking water sector". The project has been funded by the Nordic Innovation and the MaiD project partners in Denmark, Finland, Norway and Sweden. MaiD was implemented from May 2014 to June 2017. The background for this project has been the different practice to verify that drinking water products are fit for use (i.e. in accordance with the regulations) in the Nordic countries. The practice and regulations are also different for indoor and outdoor water installations among these countries. Hence, different burdens regarding approval testing and certification for the industry operating on the Nordic market are created, which makes it challenging to maintain a level playing field.

The main objective of MaiD was to identify the key components that should be included in the national approval procedures in the Nordic countries in order to safeguard drinking water, material quality and ensure a level playing field. The recommendations to the national procedures have been based on European standards and practice as far as possible. The report has been prepared by the following institutions in the project steering committee: SINTEF Building and Infrastructure (Norway), Satakunta University of Applied Sciences (SAMK)/WANDER (Finland), Swerea KIMAB (Sweden) and Danish Technological Institute (Denmark).

The report has been written as recommendations to the Authority Advisory Group (AAG) and the Industry Advisory Group (IAG) which have contributed with information regarding current legislation, certification and approval practice, potential innovation hindrances etc. The following institutions have been participating in these two advisory groups (alphabetic order):

City of Gothenburg, department of sustainable waste and water (Sweden) (AAG)
Cupori (Finland) (IAG)
Danish Environment Protection Agency (Denmark) (AAG)
Danish Industry (Denmark) (IAG)
Danish Transport, Construction and Housing Authority (Denmark) (AAG)
ESBE AB (Sweden) (IAG)
Finance Norway (Norway) (IAG)
Finnish Association of Mechanical Building Service Industries (Finland) (IAG)
Kiwa Sweden (Sweden) (IAG)
Ministry of Environment, Department of the Built Environment (Finland) (AAG)
Ministry of Social affairs and Health (Finland) (AAG)
National Board of Housing, Building and Planning (Sweden) (AAG)
National Food Agency (Sweden) (AAG)
Nordic Brass Gusum (Sweden) (IAG)
Norske Rørgrossister Forening (Norway) (IAG)
Norwegian building authority (Norway) (AAG)

Norwegian Food Safety Authority (Norway) (AAG)
Norwegian Water BA (Norway) (IAG)
Oras (Finland) (IAG)
FM Mattsson Mora Group (Sweden) (IAG)
Raufoss Water and Gas (Norway) (IAG)
Rørentreprenørene (Norway) (IAG)
Rørforeningen (Denmark) (IAG)
Standards Norway (Norway) (AAG)
Scandinavian Copper Development Association (IAG)
SP Technical Research Institute of Sweden (Sweden) (IAG)
Swedish Association of Plumbing and HVAC Contractors (Sweden) (IAG)
Swedish Chemicals Agency (Sweden) (AAG)
Uponor (Finland and Sweden) (IAG)
VA og VVS produsentene VVP (Norway) (IAG)
Valves & Fittings of Sweden (Sweden) (IAG)
Veltek (Denmark) (IAG)

Table of Contents

1 Aim

The aim of the study was to collect data of the water characteristics for the Nordic region and to identify possible Nordic requirements regarding water quality that needs to be addressed in existing test methods and standards to ensure at least the present level of protection regarding health and safety.

2 Test waters of standards for material and product assessment

2.1 Metals

2.1.1 Dynamic rig test for assessment of metal release (EN 15664)

The standard **EN 15664-1 (2014) Influence of metallic materials on water intended for human consumption — Dynamic rig test for assessment of metal release — Part 1: Design and operation** specifies the test method for providing information on metal release over time from metallic materials into drinking water. The method is used for the acceptance of metal alloys to be used in drinking water installations in some countries, e.g. Germany. Part 2 (Test waters) of the standard defines the requirements for test waters used in the rig test (Table 1). The test specimens are prepared with the same material composition that is seeking acceptance. The dimensions for the test specimens are given in the EN 15664-1. The water samples for metal analysis are taken after 4 hours' stagnation.

Table 1. Test water characteristics for testing reference materials (EN 15664-2, 2010).

	Characteristics	pH	Alkalinity mmol/l	Sum of [Cl] and [SO_4^{2-}] mmol/l	Oxygen	TOC mg/l
Test water 1	Very hard neutral water	7.1 to 7.5	> 5	> 3	> 70 % saturation	> 1.5
Test water 2	Soft water, weakly acidic	6.7 to 7.1	0.5 to 1.3	-	> 70 % saturation	-
Test water 3	Soft water, alkaline	8.0 to 8.4	0.7 to 1.3	-	> 70 % saturation	-

2.1.2 Nordic product acceptance test (NKB test)

The Nordic test for Pb and Cd release from brass components is a short-term leaching test for the assessment of products, not materials. Normally one sample is tested for product approval.

Before testing the components will be flushed with tap water for 1 hour. Test water is synthetic drinking water prepared from 1 litre of demineralised water by adding 50 mg NaCl, 50 mg Na_2SO_4 and 50 mg $CaCO_3$. pH will be adjusted to 7.0 ± 0.1 with CO_2 gas. The alkalinity is around 1 mmol/l.

The component is filled with test water which is changed daily. On 9th and 10th days the water is analysed for Pb and Cd. The released contents of the target elements will be given as a total mass and not as concentration. Thus, the total quantity of metal released from the specific product is considered against health-based criteria derived from a provisional tolerable weekly intake (Engelsen, 2017).

The total released contents of Pb and Cd shall meet the criteria given in the regulation or type approval rules for the specific brass components. The criteria for taps are specified in the NKB test protocols as 20 µg and 2 µg for Pb and Cd, respectively, and are derived from WHO guideline values for drinking water at the beginning of 1980s (Engelsen, 2017). In the Danish and Swedish regulations, a criterion of 5 µg Pb has recently been implemented. It should be noted, that these values for product performance criteria cannot directly be compared to the parametric value for lead (10 µg/l) in the Drinking Water Directive. The limit value for lead in the Drinking Water Directive has been given for weekly average value ingested by the consumer.

In Denmark, also nickel is determined in the NKB leachates for products that are Ni-Cr-plated and three replicate product samples are normally tested.

According to the study performed in Sweden the NKB test method has low reproducibility (Johansson 2012). The test method description needs to be revised in order to ensure a more stable test water. In addition, an evaluation needs to be conducted regarding the number of replicate test products needed in one test. It should be noted that the reasons for varying reproducibility in leaching testing are not only the experimental test procedure. Another reason will be the surface of the product tested, which obviously will vary. In a recent Danish study the NKB test was conducted with 5 replicate samples for 2 different types of kitchen faucets (final products). The repeatability expressed as relative standard deviations were in the range of 13-18% in this study (Kloppenborg and Nielsen, 2017).

2.2 Organic materials

2.2.1 Taste and odour (EN 1420)

The standard **EN 1420 (2016) Influence of organic materials on water intended for human consumption. - Determination of odour and flavour assessment of water in piping systems** specifies the procedures for obtaining migration water for taste and odour assessment. The pre-treatment procedure includes flushing with tap water, stagnation in test water for 24 h and prewashing (flushing) with tap water.

Test water for migration shall be without any odour and flavour, and conform to the reference water in **EN 1622 (2006) Water quality. Determination of the threshold odour number (TON) and threshold flavour number (TFN).** The term reference water is used for water without any perceptible odour and flavour by test panel. Reference water is used for rinsing, dilution and reference. According the NOTE “the reference water can be tap water, mineral bottled water, or prepared according to Annex D of the standard EN 1622. Preferably it should be appropriate to the area and where possible similar in mineral character to the type of water being tested.” Chlorinated test water shall contain free chlorine 1 ± 0.2 mg/l as Cl_2.

The type of the test water (chlorinated or non-chlorinated) and temperature (23, 60 and/or 85 °C) will be specified in product standards or in national regulation.

The results shall be expressed as the threshold odour number and the threshold flavour number according to the procedures described in the standard EN 1622. When comparing results from different laboratories, the method used must be given (Forced/Unforced choice and Triangle/Paired test). According to the standard EN 1420 (clause 11.1), the unforced choice and paired test must be used for drinking water pipes.

2.2.2 Migration test (EN 12873-1)

Migration test procedures are described in the standard **EN 12873 (2014) Influence of materials on water intended for human consumption- Influence due to migration- Part 1: Test method for factory-made products made from or incorporation organic or glassy (porcelain/vitreous enamel) materials.**

Pre-treatment of the test samples includes flushing with flowing tap water for 60 minutes, stagnation where test samples are filled with test water for 24 hours, and prewashing where the test samples are flushed with flowing tap water for 60 minutes and rinsed with test water.

Test water is prepared by reverse osmosis, deionization/distillation or activated carbon filtration, and shall have the conductivity less than 20 µS/cm and with a concentration of total organic carbon (TOC) below 0.2 mg/l.

Test water is either non-chlorinated or chlorinated. Chlorinated test water shall contain free chlorine 1 ± 0.2 mg/l as Cl_2.

The test procedure includes several points, influencing the requirement level, where specification given either in product standards or national regulation is needed. For example, the surface area-to volume-ratio (S/V) of test samples may be specified by national regulations, although according to the standard the S/V should be in the range of 5 to 40 dm^{-1}. The choice of the type of test water (chlorinated or non-chlorinated), test water temperature (23, 60 and/or 85℃), the number of additional migration periods and use of single or duplicate tests will be specified in product standards or national regulation. The conversion procedure where test results are changed to simulate real use conditions (possible concentration at consumer’s tap), as well as comparison with pass/fail values will be specified in national regulations.

2.2.3 Enhancement of microbial growth (EN 16421)

The standard **EN 16421 (2015) Influence of materials on water for human consumption — Enhancement of microbial growth (EMG)** includes three methods, the BPP-ATP method, the method for biofilm volume measurement and the mean dissolved oxygen depletion method.

2.2.3.1 *Method 1: Measured by Biomass Production Potential (BPP) measured by ATP*

Test water is local tap water, added with an inoculum from surface water (pH 5.5 – 9.0 and Cu < 0.05 mg/l). The quality of surface water and its microbiology will differ dependent on source.

The quality criteria for test water are given in Table 4.1 of the standard. Limitations have been given for pH (6.5 – 8.5), phosphorus 2.0-6.7 mg/l (PO_4^{3-} -P) and nitrogen 5-11.3 mg/l (NO_3^- -N). In addition, maximum concentrations have been set for free chlorine, ammonia-N, copper, silver and TOC (< 2.0 mg/l). The biostability, measured as average maximum concentration of ATP should be < 10 ng ATP/l.

2.2.3.2 *Method 2: Measured by biofilm volume*

Test water must meet the quality of drinking water without chlorine or other disinfectants (EN 16421: 3.7). Test water shall be free from harmful effects on bacteria, and must meet the quality criteria specified in Table 5.1 of the standard. Limit values have been given for pH (≥ 6,5 – ≤ 9,5) and maximum concentrations for chlorine, nitrogen compounds (NO_3^- -N as ammonia-N), copper, silver and TOC (no abnormal change).

2.2.3.3 *Method 3: Measured by mean oxygen depletion*

Test water is drinking water inoculated with a mixture of naturally occurring aquatic microorganisms. The quality criteria for inoculum water and for test water have been given in Tables 6.1 and 6.2 of the standard. Limit values have been set for pH (5.5 – 9.0) and Presumptive pseudomonads (1-250 /100 ml), and minimum value for total Presumptive coliforms (≥ 10 /100 ml). Inoculum water consist of a sample taken from a lowland surface water. The quality of surface water and its microbiology will differ dependent on source.

Quality criteria for test water includes limit values for phosphate (2.0-6.7 mg/l), total oxidised nitrogen (5.0-11.3 mg/l N) and pH (6.5-9.5). Dissolved oxygen must be ≥ 6.5 mg/l. Maximum values are given for total Presumptive coliforms, bacterial colony count after incubation, free residual chlorine (as Cl_2), total residual chlorine (as Cl_2), copper and silver.

2.2.4 GC-MS identification of water leachable organic substances (EN 15768)

The standard **EN 15768 (2015) Influence of materials on water intended for human consumption - GC-MS identification of water leachable organic substances** defines analytical procedures based on gas chromatography and mass spectrometry (GC-MS) used to screen migration waters for organic substances. It may be used in approval procedures to find out possible unknown substances leached into test water from products made of plastics. The method is semi-quantitative.

GC-MS analysis will be performed using migration water prepared according to EN 12873-1.

2.3 Cementitious materials

2.3.1 Tests for taste, odour and TOC (EN 14944-1)

The standard **EN 14944-1 (2006) Influence of cementitious products on water intended for human consumption. Test methods. Part 1: Influence of factory made cementitious products on organoleptic parameters** describes the test procedures to determine the influence of products on the taste, odour, colour and turbidity of test water. The standard is in revision, and the revised standard will include also determination of TOC (new title: Influence of cementitious products on water intended for human consumption. Test methods. Part 1: Influence on organoleptic parameters and migration of organic substances (TOC) from factory made cementitious products).

During the preconditioning the test samples are brought into contact with preconditioning water for five periods; three periods of 24 h, one period of 72 h and one period of 24 h. The preconditioning water has pH of 7.4 ± 0.1, total hardness of 200 mg/l ($CaCO_3$) and alkalinity 244 mg/l (HCO_3^-).

After preconditioning the test samples are brought into contact with test water (reference water) for three periods of 72 h at 23℃ or for 24 h at elevated temperature. Reference water is used as test water representing chlorine-free drinking water. Reference water is natural water without gas and with parameters that conform to the requirements given in Table 1 of the standard. Requirements are set for conductivity (500 ± 50 µS/cm), pH (7.3 ± 0.2), calcium (80 ± 10 mg/l), alkalinity (350 ± 50 mg/l HCO_3^-) and silicate (15 ± 5 mg/l SiO_2). Water should have no taste, odour, colour or turbidity.

When standards or national regulation require testing in chlorinated water, test water is produced by adding sodium hypochlorite solution into the reference water so that the free chlorine content is 1.0 ± 0.2 mg/l as Cl_2.

The selection of test water (chlorinated or non-chlorinated), temperature (23℃ or specified elevated temperature), the need for chlorination during preconditioning and the number of additional migration periods should be specified in product standards or in national or European regulations.

2.3.2 Migration test (EN 14944-3)

The standard **EN 14944-3 (2008) Influence of cementitious products on water intended for human consumption. Test methods. Part 3: Migration of substances from factory-made cementitious products** specifies the procedure for determine the potential migration of substances from products into test water. The standard is in revision process.

In the precondition procedure, the test samples are brought into contact with preconditioning water for five periods; three periods of 24 h, 1 period of 72 h and a final period of 24 h. The preconditioning water has pH of 7.4 ± 0.1, total hardness of 200 mg/l ($CaCO_3$) and alkalinity 244 mg/l (HCO_3^-).

After preconditioning the test samples are brought into contact with test water for three migration periods of 72 h (23℃) or for 24 h in specified elevated temperature. Test water has pH of 7.0 ± 0.1, total hardness 100 mg/l ($CaCO_3$), alkalinity 122 mg/l (HCO_3^-) and the silica concentration 10 mg/l (SiO_2). Chlorinated test water is produced by adding sodium hypochlorite solution until the free chlorine content is 1.0 ± 0.2 mg/l (Cl_2).

The selection of test water (chlorinated or non-chlorinated), temperature (23 ℃ or specified elevated temperature), and the number of additional migration periods should be specified in product standards or in national or European regulations.

Test conditions do not simulate any service conditions. The conversion procedure for calculating the test results to simulate real use conditions will be specified in national regulations.

3 Quality of drinking water in the Nordic countries

3.1 Water quality data

Water quality data was collected in the MaiD project through a web-based survey. The MaiD steering group members were responsible for contacting the water works in their respective countries.

Parameters being included in the survey of drinking water were the following:

- pH
- alkalinity (mmol/l)
- hardness; Ca, Mg (mmol/l; mg/l)
- chloride (mg/l)
- sulphate (mg/l)
- TOC (mg/l)
- conductivity (µS/cm)

In addition, the following parameters representing nutrients enhancing microbiological growth, were asked:

- ATP (adenosine triphosphate)
- phosphorus (PO_4^{3-} -P)
- AOC (assimilable organic carbon)
- MAP (microbially available phosphorus)

3.2 Data from waterworks

Data on water quality were sent from 107 waterworks (Table 2). In some cases, datasets included several waterworks of the same water supplier.

Information on the drinking water supply in the Nordic countries is found in Annex 1. The total number of large water suppliers is 816 and estimated number of medium-sized water suppliers is 5780. Large waterworks deliver drinking water > 1000 m^3/d or for > 5000 users, and they are covered by EU's Drinking Water Directive and the member states have reporting obligation to the EU Commission. Medium-sized waterworks deliver drinking water 10-1000 m^3/d or for 50 - 5000 users. They are covered by the Drinking Water Directive but the member states have no reporting obligation to the Commission. Small waterworks deliver drinking water < 10 m^3/d or for < 50 persons. They can be exempted from the Drinking Water Directive requirements and they have no reporting obligation to the Commission, unless the water is supplied as part of a commercial or public activity. In Norway, the national Drinking water act is valid for all drinking water. In Finland, the Decree Relating to the Quality and Monitoring of Water Intended for Human Consumption (1352/2015) is for large and medium-sized units and the decree 461/2001, with partly different requirements, is intended for small units.

The number of households relaying on well water or drinking water from very small cooperative water supplies is still quite high. Approximately 11 % of the Nordic population use drinking water of their own wells, and quality of this drinking water is not known (Gunnarsdottir et al. 2016)

Although the number of the waterworks taken part in the survey is not high, the data was sent from the largest water suppliers representing a high number of consumers in respective countries. From Finland and Sweden data was sent also from a group of medium-sized waterworks.

The data collected were not covering all drinking water types in Denmark, but represent well Copenhagen and west coast area. The Norwegian data is estimated to represent about 90 % of the drinking waters in Norway. The Finnish data are from cities with the population of 40 000 – 200 000, and from the Helsinki metropolitan area with 1 million inhabitants. The data does not take into account small waterworks delivering ground water without any treatments. In Sweden, there are around 1750 waterworks, of which 1450 are small waterworks (often delivering water to less than 2000 people) utilizing ground water, 170 are larger water works delivering purified surface water to the larger cities and the rest 130 waterworks are using artificial ground water (i.e. surface water is injected to the ground to add the amount of natural ground water). Around 50% of the water is ground water (half of which is artificial ground water) and 50% is surface water. The large waterworks are well represented, but only one region (Bergslagen) is represented for small waterworks. No waterworks with artificial ground water are represented.

Table 2. Information of waterworks that provided data for the survey.

	Number of waterworks sending data	Raw water type	Size of the waterworks
Denmark	22	100 % ground water	large: 100 % medium-sized: - small: -
Finland	30	33 % surface water 66 % ground/artificial ground water	large: 58 % medium-sized: 42 % small: -
Norway	14	100 % surface water	large: 100 % medium-sized: - small: -
Sweden	41	27 % surface water 73 % ground water	large: 47 % medium-sized: 44 % small: 9 %

3.3 Results

3.3.1 Corrosivity

The requested water quality parameters are not measured in all waterworks. The average values and standard deviation of average values of water quality parameters concerning corrosivity in different Nordic countries are presented in Table 3. Minimum and maximum values of the parameters are shown in Table 4. Most of the data were from the year 2015 and/or 2014. There is a rather high variation in the values and thus in drinking water composition in the Nordic countries.

Table 3. Water quality parameters. The average values and standard deviation (std) of average values of water quality parameters in different Nordic countries.

	pH	Alkalinity (mmol/l)	Hardness (mmol/l)	Chlorides (mg/l)	Sulphates (mg/l)	Conductivity (µS/cm)	TOC (mg/l)*
Denmark -average -std	 7.6 0.2	 3.93 2.6	 2.44 1.2	 49 25	 54 29	 598 229	-
Finland -average -std	 7.97 0.4	 0.96 0.5	 0.61 0.3	 9 8	 24 24	 175 80	 1.34 0.8
Norway -average -std	 7.84 0.3	 0.61 0.2	 0.42 0.1	 7 5	 7 6	 106 24	 2.51 0.9
Sweden -average -std	 8.07 0.2	 1.4 0.7	 0.81 0.4	 13 11	 15 12	 226 87	 2.97 0.8
All -average -std	 **7.95** **0.3**	 **1.24** **0.9**	 **0.97** **0.8**	 **16** **19**	 **23** **23**	 **244** **175**	 **2.1** **1.1**

*Includes only exact values; in some reports data on TOC was given as < 2 mg/l.

Table 4. Water quality parameters. Minimum and maximum values. All data (when reported).

Parameter	Average value	Minimum value	Maximum value
pH	7.95	6.8	9.6
Alkalinity (mmol/l)	1.24	0.2	6.5
Hardness (mmol/l)	0.97	0.1	5.2
Chlorides (mg/l)	16	0.1	145
Sulphates (mg/l)	23	0.3	153
Conductivity (µS/cm)	244	48	1300
TOC (mg/l)*	2.1	0.3	5.3

*Includes only exact values; in some reports data on TOC was given as < 2 mg/l.

Figures 1-8 present the combination of pH value, alkalinity and hardness. The differences in water quality produced from surface or ground water are shown in Figures 1 and 2. Surface water results in rather soft and low-alkaline drinking water, but ground water as raw water results in higher deviation in hardness as well in alkalinity.

All the data from Norway consist of surface water having quite low alkalinity and hardness values (Fig. 3). The Finnish and Swedish data include both surface and ground/artificial ground water (Figures 4-7). The quality of drinking water produced from surface water is very much the same in both countries, but ground water has higher alkalinity in Sweden.

In Denmark ground water is used, and according to the data the Danish drinking water quality is different when compared to other Nordic countries (Fig. 8). Alkalinity is much higher, and hardness as well as chloride and sulphate concentrations are also higher than in the other countries. Unfortunately, the data were not covering all drinking water types, and there is large deviation especially in hardness values in Danish drinking water.

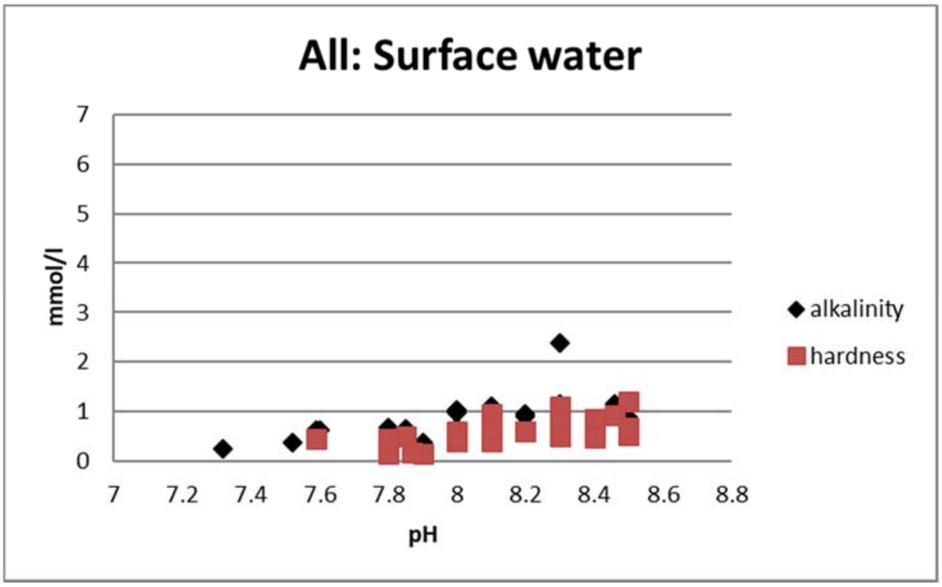

Figure 1. Drinking water quality produced from surface water.

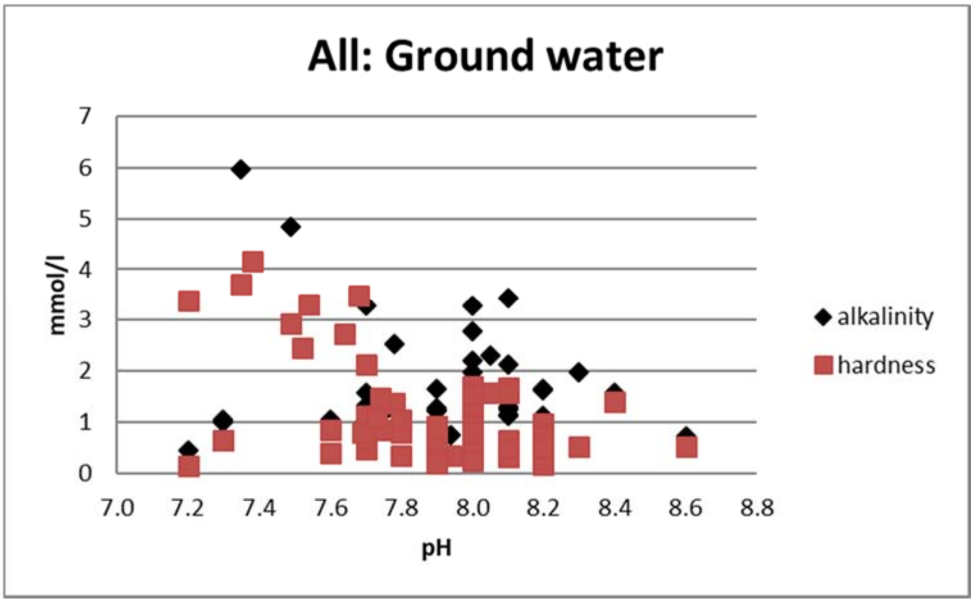

Figure 2. Drinking water quality produced from ground/artificial ground water.

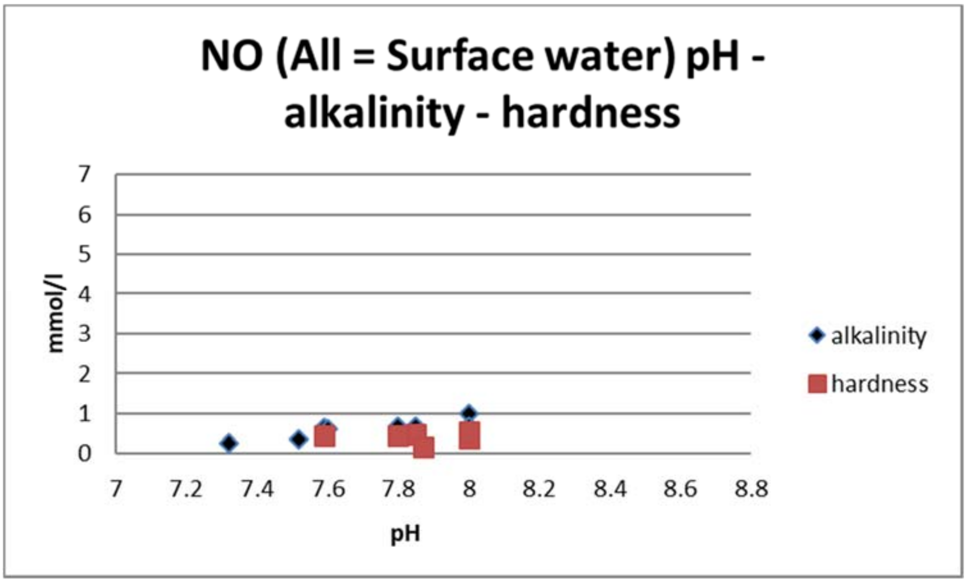

Figure 3. Drinking water quality in Norway (surface water).

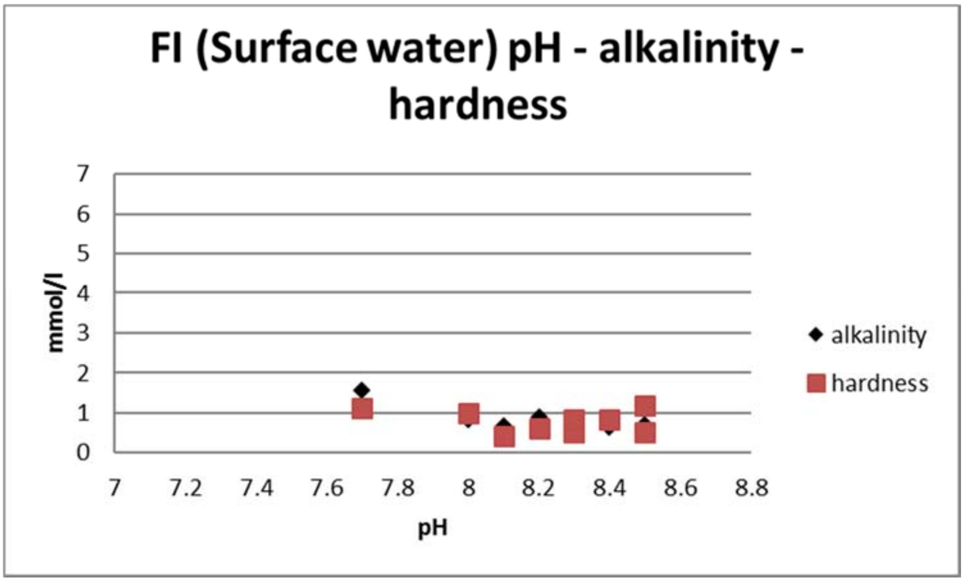

Figure 4. Drinking water quality in Finland (surface water).

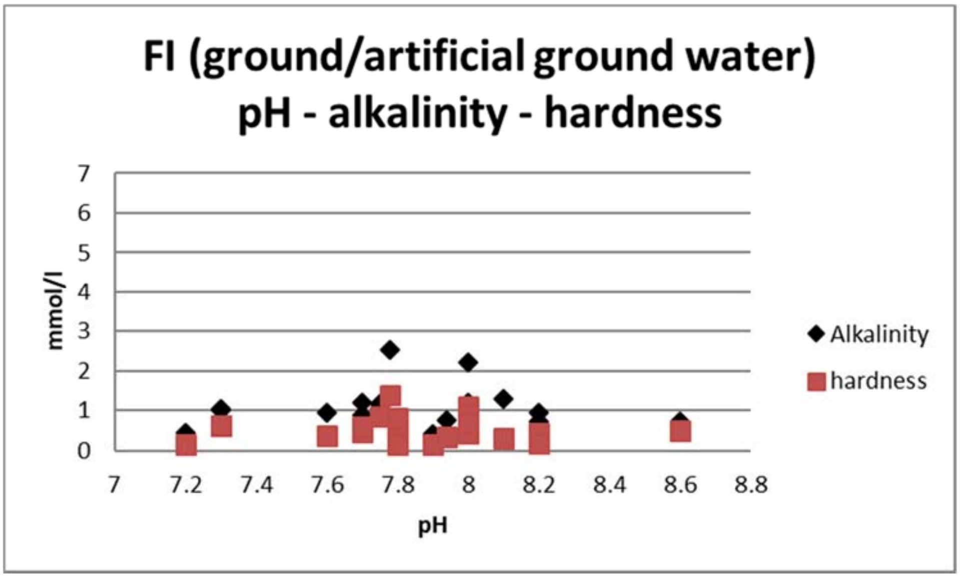

Figure 5. Drinking water quality in Finland (ground/artificial ground water).

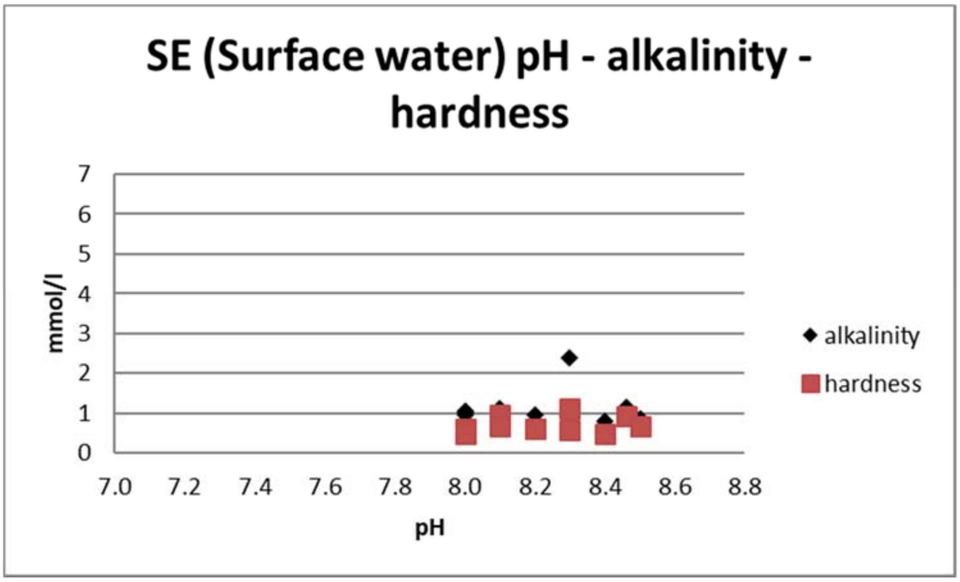

Figure 6. Drinking water quality in Sweden (surface water).

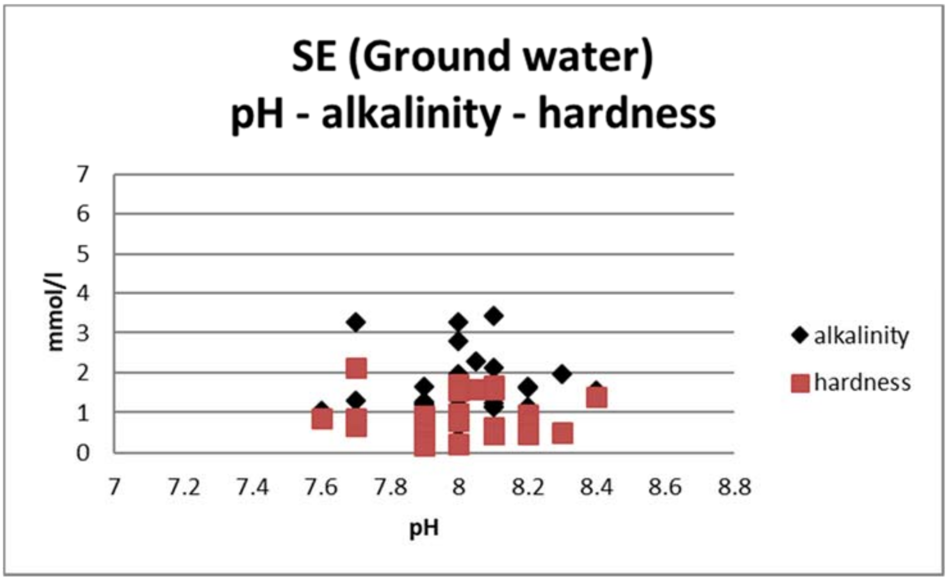

Figure 7. Drinking water quality in Sweden (ground water).

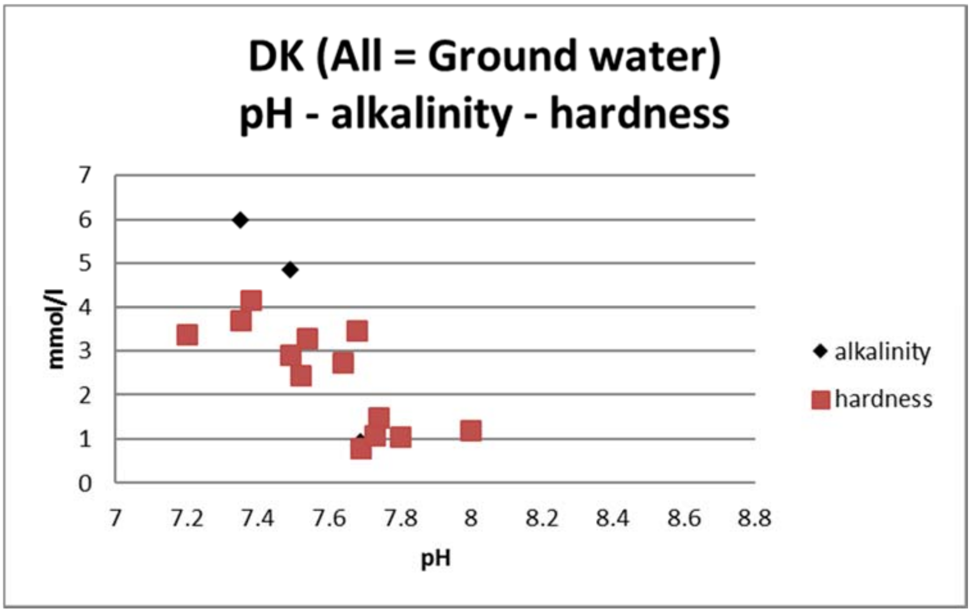

Figure 8. Drinking water quality in Denmark (ground water).

Chloride and sulphate concentrations have an influence on the aggressivity of water. In Figure 9 the highest values for both of those parameters are from Danish data. In the test water 1 (EN 15664-2) also water quality parameters like the sum of chlorides and sulphates as well as TOC are used (Figures 10 and 11). In several reports data on TOC was given as < 2 mg/l. This information is not included into the Figure.

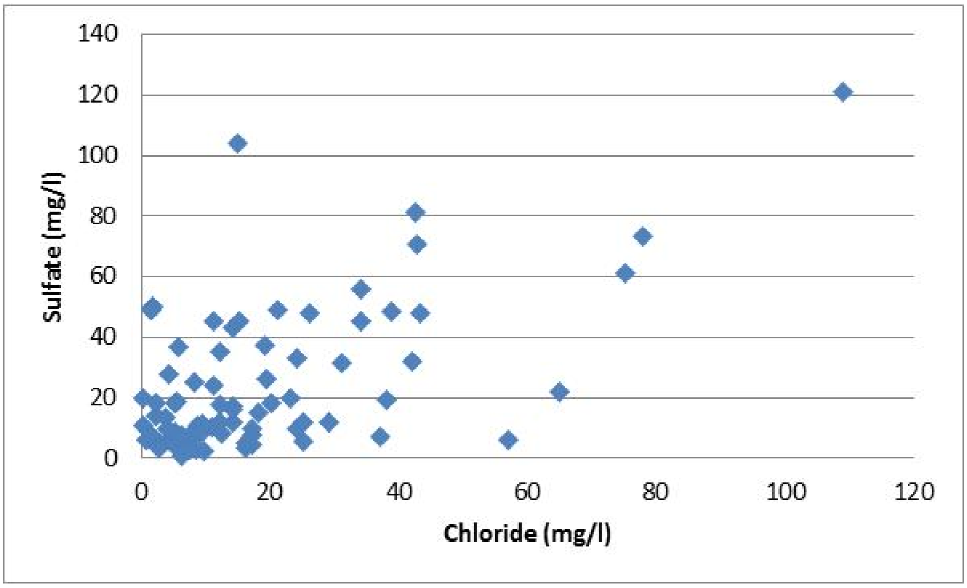

Figure 9. Chloride and sulphate concentrations of drinking water (mean values, all data).

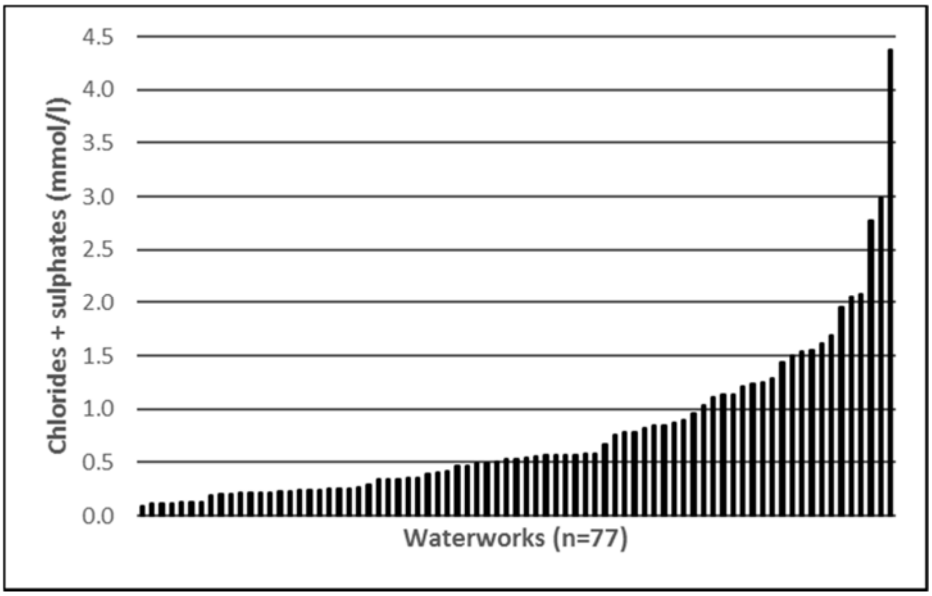

Figure 10. The sum of chlorides and sulphates in mmol/l (all data, smallest to largest).

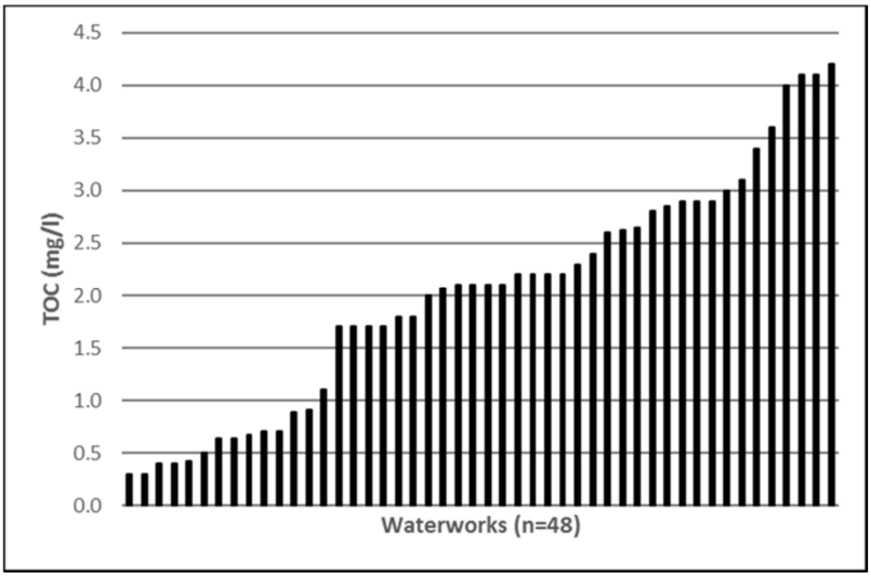

Figure 11. TOC concentration of drinking water (all data expect values given as < 2 mg/l, smallest to largest).

3.3.2 Nutrients enhancing microbiological growth

Data concerning nutrients enhancing microbiological growth were so few, that no further evaluation can be made. Phosphorus concentrations were reported in 18 cases, but in 11 of those only the level (< 2 or < 5 µg/l) was given. In other cases, the values were 2.2 – 6 µg/l, which fulfils the test water criteria in BPP-ATP method.

In BPP-ATP method TOC of test water should be < 2.0 mg/l, but according to the water quality data TOC may be higher especially in Sweden and Norway.

4 Compatibility with the test waters in existing standards

4.1 Metals testing

4.1.1 Rig test (EN 15664-1, EN 15664-2)

The data on Nordic drinking water quality was compared to the quality of test waters in the standard EN 15664-2, to estimate, whether metal alloys, tested in all three test waters, are usable also in the Nordic countries. The test water types are so called “corner waters”, known to be aggressive for certain metal alloys, and they are not meant to cover all possible drinking water qualities in Europe by chemical composition.

It should be remembered, that only few water quality parameters are included in the test water characteristics, although there are many other parameters also influencing the aggressivity of waters.

According to the data sent from Nordic waterworks the test water 1 (very hard neutral water) corresponds to some extent drinking water quality in Denmark, and is unrepresentative when compared to drinking water in Finland, Norway and Sweden, as expected.

Test water 2 with low pH (6.7-7.1) and alkalinity (0.5-1.3 mmol/l) seems to be also outside of the most typical Nordic drinking water quality data. However, it is known that especially small waterworks in Finland, using ground water as such without any treatments, deliver such soft and weakly acidic water (Ahonen et al. 2008).

Test water 3, representing soft and alkaline water (pH 8.0-8.4; alkalinity: 0.7-1.3 mmol/l), covers at least some water qualities in the data set.

In the data set minimum values for alkalinity were about 0.2 mmol/l and for hardness 0.3 mmol/l. Thus, much lower values for alkalinity exist than the minimum value in the test waters, and what is seemingly lacking in the test water types, is drinking water with alkalinity below 0.5 mmol/l. This deficiency is most likely compensated by using test waters having lower pH values, because pH is considered to be most important parameter with respect to leaching from copper alloys in this pH domain. Therefore, test waters 2 and 3 will cover the pH over a range representing a large scale of existing water qualities.

This study shows clearly that it is not possible to define one exact Nordic water quality, and hence it is useless to try to find test water set covering all different kind of water qualities existing in the Nordic countries. Thus, the test water used should represent reasonable worst case situation related to the corrosivity of the water. The three test water types represent typical “corner waters” which are known to be aggressive to certain metal alloys. They are not meant to cover all possible drinking water compositions in Europe. Therefore, the three test waters in the standard EN 15664-2 can be estimated to cover the major drinking water compositions in the Nordic countries. For example, in Norway, test waters 2 and 3 will most likely be representative for Norwegian drinking water.

4.1.2 The 4 MS procedure

The 4MS acceptance procedure for metallic products is based on the long-term behaviour of the metal alloys (not final products), which means that the alloys must be listed on the Composition List after passing the rig tests. Requirements for the short-term behaviour should be considered too, but, according to latest report on the 4MS procedure for metallic materials, the test procedures for the product specific surface properties are in development. In the chapter 3.2.2 *Characteristics of the initial surface* is the following text: "Where the material contains lead, Pb, at levels above 1% the standardised test procedure prEN 16057 shall be carried out to ensure that the level of any metallic Pb layer left after manufacture is below set levels (to be defined!)." (Acceptance of metallic materials used for products in contact with drinking water. 4MS Common Approach. Part A- Procedure for the acceptance. 2nd Revision 07.03.2016)

The standard EN 16057 (2012) **Influence of metallic materials on water intended for human consumption. Determination of residual surface lead (Pb). Extraction method** is a process control method to determine the amount of lead on the surface of test specimens after manufacturing.

Further product tests (e.g. for the nickel release of chromium plated taps) are today not in use in any of the 4 Member States but might be proposed in the future. (Common approach 4/5 MS – Work programme and planning, 30 March 2016)

In the 4MS Common Approach for acceptance of metallic materials used for products in contacts with drinking water, rig tests (EN 15664-1) with all three test waters (EN 15664-2) are used in creating a new category and in acceptance of a reference material for a category.

The acceptance criteria are based on the parametric or indicator values for metals in the Drinking Water Directive. The acceptable concentration is 90 % of DWD value for elements originating mainly from metal products in water distribution system (e.g. copper), or 50 % for elements with other possible sources (e.g. lead). For metals outside DWD the acceptable concentrations are based on WHO documents or recommendations by toxicology experts.

Metal alloys can be accepted to use as pipes (Product group A: assumed contact area 100 %), as fittings or ancillaries (Product group B: contact area up to 10 %) or as components of fittings or other products in the group B (Product group C: contact area up to 1 %). Getting to the product group A the requirements for metal leaching must be fulfilled at the beginning of test week 16.

Acceptance of a commercial material in existing category can be based either on a comparative test against the reference material in local drinking water (suitably corrosive), or on an absolute test with the most critical test water or waters according to EN 15664-2. These most critical test waters are given for different categories in the Composition List.

For all copper alloys test water 1 has been given as the most critical test water in the 4MS Composition list. Only for the alloys CuZnPbAl and CuZnPbAlSiAs test waters 1 and 2 are mentioned. In the latest version of the 4MS procedure (Part B – 4MS Common Composition List, 27.5.2016) test water 3 has not been defined as the most critical test water for any category.

Metal alloys of the 4MS Composition List, with acceptance based on metal release results in test water 1, would correspond sufficiently to the situation in Denmark, providing that the 4 hours' stagnation time used in the rig testing is acceptable. In Denmark, the regulated stagnation time before water sampling for monitoring of metals (Cu, Sn, Zn) is 12 hours (Bekendtgørelse om vandkvalitet og tilsyn med vandforsyningsanlæg nr 802 af 01/06/2016). Water sampling method for these metals will be changed during 2017.

Recommendations to decrease aggressivity of drinking water in the Nordic countries are presented in Annex 2. Metal alloys in the 4MS Composition List are safe to use in the Nordic countries in the long term if drinking water quality fulfils the criteria in Annex 2. However, because metal surface properties differ depending on manufacturing processes, metals release during the first weeks after taken in use may result in unacceptable high metal concentrations. Because of durability aspects, it is important to use dezincification resistant brass alloys especially in Finland and Norway.

There are conditions where drinking water quality differs from the recommendations (Annex 2) so that it is more aggressive. For example, the Finnish data collected show, that in many cases the ratio of alkalinity and sum of chlorides and sulphates is below the recommended value. Drinking water with very low alkalinity probably results in higher release of metals than test water 2 with alkalinity of 0.5 – 1.3 mmol/l. Since the pH value might be even more important, test water 2 with the minimum pH of 6.7 would probably provide sufficient information on metals release in this kind of aggressive drinking water.

However, in aggressive waters with low alkalinity and low pH (although still within the Drinking Water Directive), the final evaluation of 4MS procedure for acceptance of metal alloys would need additional investigation. According to the Common Approach the acceptance of commercial alloys is based either on a comparative test against the reference material in local drinking water, or on an absolute test with the most critical test waters according to EN 15664-2. For all copper alloys test water 1, representing very hard neutral water, has been given as the most critical test water in the 4MS Composition list, and test waters 1 and 2 have been set only for two copper alloys. For evaluation of the suitability of copper alloys in the 4MS Composition List for soft and acidic waters, the test reports for specific alloys, with information on test water quality and results, should be publicly open and available also for regulators, certification bodies and other concerned parties outside the 4MS Group.

4.1.3 Nordic product acceptance test (NKB test)

In the beginning of the NKB test, the components are flushed with tap water for 1 hour. The influence of the flushing with the tap water on brass surface is not known. Variations due to the tap water quality may occur.

The synthetic drinking water used in the NKB test has pH of 6.9 – 7.1 and alkalinity of around 1 mmol/l. It resembles test water 2 in EN 15664-1. Such low pH values cannot be found in the data sets, but the alkalinity values are found.

4.2 Testing of organic materials

4.2.1 Taste and odour (EN 1420, EN 1622)

In taste and odour testing of products made of organic materials the type of the reference water will be specified in product standards or in national regulation. Reference water can be tap water or mineral bottled water, and test water is either chlorinated or non-chlorinated reference water. Therefore, test results may differ depending the water quality. This was noticed in proficiency tests (round robin) for several years ago, when reason for too high deviation of test results between different laboratories was investigated (CEN Conference on measurement of odour and flavour in drinking water 2007).

Since drinking water should be accepted by the consumer, taste and odour testing is recommended to perform with local drinking water. Origin of reference water and test water type (chlorinated or non-chlorinated) must be reported together with the results. The results will then be valid only for that type of water, and the test must be repeated with other type of water if requested.

4.2.2 Migration (EN 12873-1)

Migration tests are performed in demineralised water (conductivity < 20 µS/cm and TOC < 0.2 mg/l); therefore the results are in principle independent of the laboratory or country. However, test water may be chlorinated or non-chlorinated, and the results are valid only for the type of water used.

Since the test method is not fully specified in the standard, there are several details in the test procedure, which need clear regulatory guidance at national level and which should be reported with test results.

4.2.3 Enhancement of microbial growth (EN 16421)

The standard for determining the enhancement of microbial growth (EMG) includes three methods, the BPP-ATP (method 1), the method for biofilm volume measurement (method 2) and the mean dissolved oxygen depletion (MDOD) method (method 3). Methods are based on totally different principles which may not correlate. It should be mentioned, that a project funded by European Commission was carried out to develop the BPP-ATP method as a possible EN test method for use within Europe (van der Kooij et al 2003). BPP-ATP and MDOD methods are batch methods, not representing situation in real distribution systems. In all these 3 methods, pass-fail criteria remain a matter for individual countries.

In method 1 for biomass production potential adenosine triphosphate (ATP) concentration is used as a measure for active biomass. The ATP method measures all viable microbial cells, both aerobic and anaerobic and the result is an exact value, based on chemistry and measured with absorbance, not for example on volume of biofilm.

In method 2 for biofilm volume measurement, test samples are exposed to flowing water for a certain period. Then the biofilm will be scraped from the surface and its volume will be measured. The measured biomass includes all biomass i.e. both aerobic and anaerobic microbes and products of their metabolism, but the method expects that the density of biofilm is constant. This might work in one country (such as Germany) having quite uniform water quality, but not at

European level. Biofilms contain water, microbes, extracellular polysaccharides (EPS) etc., so their density is not constant, but depends on the operational conditions and microbes forming the biofilm and producing EPS. The procedure for the removal of the biofilm is important and should not depend on the operator in the laboratory (CEN/TC164/N 2615, 2010).

The method 3 is based on the use of oxygen by aerobic micro-organisms. Therefore, it measures only aerobic microbes, not anaerobic ones.

The BPP-ATP method is estimated to be more sensitive than MDOD and biofilm volume method (CEN/TC164/N 2615, 2010).

In all the test methods test water is local tap water. There are significant differences in the chemical and microbiological quality of drinking water in Europe, and thus also in the test water quality, although the local drinking water fulfils the requirements of EU's Drinking Water Directive.

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. However, in Northern Europe (Finland, Sweden, Latvia and Norway) where there are substantial amounts of organic carbon in raw waters, the limiting nutrient is phosphorus instead of carbon (Miettinen et al. 1997, Lehtola et al. 2004).

In the BPP-ATP method "an inoculum from a surface source of water" and in the MDOD method "a lowland surface water" is added as microbial inoculum. The quality of surface water and its microbiology differ depending on the source, and so the microbes growing in the system are not known. The microbes in surface water are likely different from those in drinking water systems due to water treatment and distribution of water.

The fact that the same test might give different results, depending on the test water quality, means that tests performed in one country, are not necessarily valid in another country, even though the acceptance level will be set nationally.

Following procedure has been proposed by Finnish experts for analysis of test results. If the local drinking water is to be used for testing, the results should be normalized for example with the help of positive and negative control samples. Then the limit for acceptable contribution of materials, could be set, for example 50 %. This means that the original results are not comparable, but the outcome – how strongly microbial growth will be enhanced in that particular quality of water – will be given.

4.2.4 GC-MS identification of water leachable organic substances (EN 15768)

Typically, organic VOC compounds migrated from plastic pipes to drinking water are measured from water samples using GC-MS method equipped with either head-space or purge and trap injection method without extraction procedure, described in chapter 8.1 of the standard EN 15768, to avoid evaporation of volatile organic compounds present in the water sample.

The migration tests are performed with test water specified in EN 12873 (demineralised water) and are therefore not dependent on the drinking water quality.

4.3 Testing of cementitious materials (EN 14944-1, EN 14944-3)

Test waters in the standard EN 14944, with high alkalinity and hardness, are very much different from most Nordic drinking waters. However, they have similarities with some Danish ground waters.

It is likely, that Nordic soft, low-alkaline water is more aggressive to cementitious materials than test waters described in the standard. This should also be taken into account in the Nordic countries, when considering the suitability of cementitious products certified according to these standards.

5 Recommendations

European testing methods for materials and products in contact with drinking water are available, but there might be differences in specific test phases in the standard, and no common European acceptance criteria exist. In the possible CE marking of construction products in contact with drinking water the EN standardized test methods would be used, but the requirements and acceptance criteria must be given at national level.

The 4MS procedure is aimed to base on a common approach, the national approval schemes in these member states and mutual recognition between them. Implementing of the 4MS procedure in the Nordic countries would mean, that the country must have a notified acceptance procedure, based on the common principles of accepted materials and chemicals (Positive and Composition Lists) and use of EN standardized test methods. However, since the 4MS procedure is not a fully harmonized system, in some tests the pass-fail criteria and limit values should be set at national level.

Influence of materials and products into drinking water are tested using different types of test waters, like local tap water (chlorinated or non-chlorinated), mineral water, synthetic tap water or distilled water. In some standards test water or waters are clearly specified, but in some of them several options exist. Since test water quality has significant influence on test results, test water should be specified by regulators when using tests with several options for test water, for product approval.

In the tests for enhancement of microbial growth test water is local drinking water. The chemical and microbiological quality of drinking water is quite different in Finland and other Nordic countries when compared to Central Europe. When using local drinking water as test water in new or so far not used EN standardized test methods for products in contact with drinking water, the test methods should be validated to set national requirement levels for regulated characteristics. Tests performed in one country do not necessarily guarantee the same consumers' protection level in another country.

Test method standards do not always strictly specify the test procedures, since they may give several alternatives for example for water quality, temperature, number on test periods or use of conversion factors. According to the test method standards, the choice and procedures will be specified either in product standards or national regulation. Product standards very seldom give guidance on these points. As the test procedures mentioned have an influence on the results and requirements of the test, it is the responsibility of regulators to decide between the given alternatives. In some countries, the regulators have given approval and certification bodies authority to make these decisions. Test performance should be given in detail in test report and taken into account when comparing test results from different laboratories.

Validation of new or so far not used test methods is needed to set the limit values which would give adequate consumers' protection. Whenever correlation between the national acceptance criteria and test results from other countries are known, it is possible to consider mutual recognition.

5.1 Metallic materials

There is a wide variety in drinking water quality in the Nordic countries, and the three test waters in EN 15664 are not covering all possible compositions. However, as the test waters are known to be “corner waters”, passing the criteria for metals release in these test waters would probably provide sufficient information on metals behaviour also in the Nordic drinking waters.

Therefore, 4MS procedure for acceptance of metal alloys is applicable to use in the Nordic countries if drinking water is not aggressive according to national criteria and the brass alloys are dezincification resistant. The national criteria to decrease aggressivity of water are only recommendations (at least in Finland), but hopefully they become more binding in the future.

However, for most alloys in the 4MS Composition list the acceptance is based on UBA opinion without any public document, and the final decision of accepting a metal alloy to a certain product group is on the committee of expert. Using of rig tests according to the standard EN 15664, as part of the acceptance of metal alloys, would be possible at European level only after fully opening of the acceptance procedure for all member states. The standard EN 15664 was originally planned to have three parts, concluding third part with guidelines for data interpretation and evaluation. One alternative for more open acceptance procedure would be to start preparing the part 3 of EN 15664.

There are a lot of small water works which do not treat the water before distribution. In many cases this kind of water has low pH, hardness and alkalinity. It is questionable, whether this kind of water fulfils the Drinking Water Directive, since, according to the directive, drinking water should not be aggressive. In these cases, either water treatment should be improved to decrease aggressivity, or special guidance by water supplier or local authorities is needed for materials selection.

If short-term tests for lead release from brass components as final products will be used in the future, NKB test procedure should be improved and specified. Reproducibility of this test method may be low. Therefore, reasonable tolerances should be applied when comparing lead release results with limit value.

5.2 Organic materials

Test water for taste and odour testing of products made of organic materials should represent the local drinking water type. At least the test method should be validated with local drinking water to set the national acceptance criteria. Whenever correlation between the national acceptance criteria and test results from other countries are known, it is possible to consider mutual recognition.

For enhancement of microbial growth, there are three totally different test methods in the standard. The BPP-ATP test method has been developed already in the EU project to become an EN standard, and it is estimated to be most sensitive of the three methods, and thus recommended to use.

Even with a single test method for enhancement of microbial growth, results with the same products may be different depending on the test water quality. Mutual recognition would be applied only after knowing the correlation between test results from different countries.

The pass/fail criteria should be based on risk assessment. If we want to ensure the safety of the products with a comparable way in all the Europe, the test must be performed exactly the same way in every laboratory. This means, that the test water should be synthetic water. On the other hand, if we want to ensure the safety of the product in a local water installation, we should use the local drinking water.

The procedure according to the standard EN 15768, based on gas chromatography and mass spectrometry (GC-MS), is recommended to be carried out to reveal the presence of any chemicals in a product that are not indicated by formulation information.

5.3 Cementitious materials

Since Nordic soft, low-alkaline water is considered to be more aggressive to cementitious materials than test waters specified in the standard, cementitious products tested and certified according to these standards do not probably give adequate protection level in several regions in the Nordic countries. If the influence of cementitious products on drinking water will be assessed according to EN 14944, a low alkaline test water should also be included.

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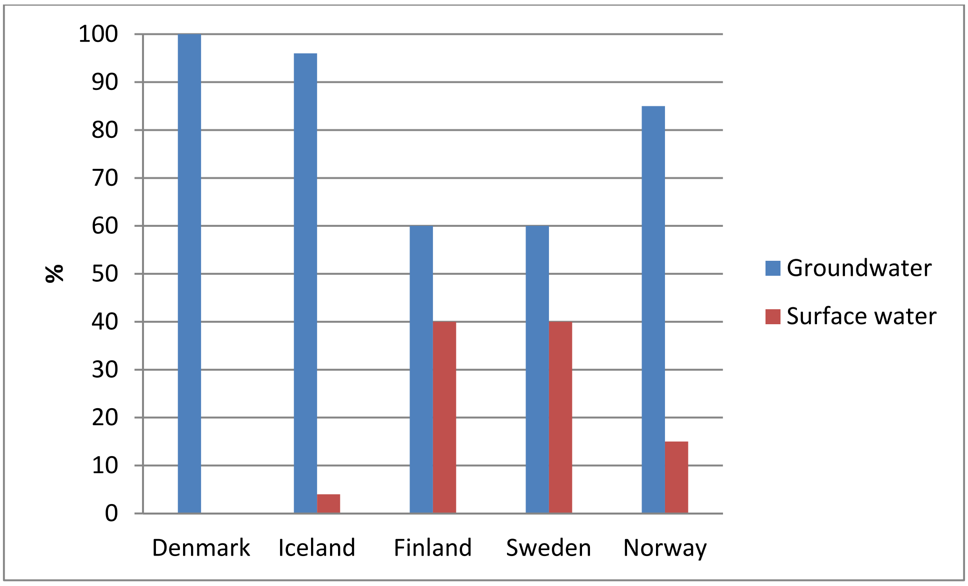
ANNEX 1

Water Supply in the Nordic countries

Ref: Gunnarsdóttir et al. 2016

Raw water type



Regulated water supplies in the Nordic countries

	Inhabitants				
	>5000	501-5000	51-500	<50	All regulated
Denmark	260	1078	993	250-300	2600
Finland	154	300*	400*	350-650	1200-1500
Iceland	9	39	138	610	796
Norway	146	422	906	1800*	3300
Sweden	250	450	1050	2700*	4450
SUM	819	2290	3490*	5900*	12500*
Presentage	7%	18%	28%	47%	100%

*estimate

ANNEX 2

Recommendations to decrease aggressivity of drinking water

Parameter	Denmark[1)]	Finland[2)]	Norway[3)]	Sweden[4)]
pH	7.5-8.5	>7.5	8.0-9.0	7.5-9.0
Alkalinity (mmol/l)	>1.6 (HCO_3^- >100 mg/l)	>0.6	0.6-1.0	>1 (HCO_3^- >60 mg/l)
Calcium (mg/l)	<200	>10	15-25	20-60
Hardness (mmol/l)	0.9-5.3 (5-30 °dH)			
Free CO_2	2 mg/l		as low as possible	
Total chloride	As low as possible	<25 mg/l		<100 mg/l
Sulphate		<150 mg/l		
Conductivity (µS/cm)		<2500		
$\frac{Alkalinity\ (\frac{mmol}{l})}{\text{Sulphate (mg/l)/48 + Chloride (mg/l)/35.5}}$		≥1.5		
Oxygen (mg/l)		>2		

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3) Mattilsynet: Veiledning til Drikkevannforskriften (Mars 2011), p. 32.

4) Livsmedelsverket: Vägledning till Livsmedelsverkets föreskrifter (SLVFS 2001:30) on dricksvatten (2014), p. 57, Bilaga 2.