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ENHIS
EUROPEAN ENVIRONMENT AND HEALTH INFORMATION SYSTEM

QUALITATIVE AND QUANTITATIVE HEALTH IMPACT ASSESSMENT ON DRINKING WATER POLLUTION

How to understand and use common data on drinking water quality and health

Abstract: Water utility managers and health or water authority officers are supposed to understand the meaning of common data on drinking water quality in terms of health risks to be able to accept appropriate strategy to respond monitoring results. However, it was shown by recent study that even water professionals and public health and environmental specialist do not often understand the meaning of water monitoring data. This paper describes routine data on water quality and health and provides basic information and examples what experience or conclusion may be obtained from these data and when quantitative or only qualitative health impact assessment may be used. Principles of derivation of limit values are explained as well as possible lessons got from non-compliance or different meaning and purpose of drinking water parameters. In the case that numerical data on water quality are available the basics of quantitative health risk assessment are outlined, e.g. how to calculate safe limit value for derogation or accident cases or how to assess carcinogenic potency of drinking water.

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1. Introduction

Policy makers usually get several typical sets of data which are supposed to characterize drinking water (DW) safety or health impact of DW pollution. These data are generated periodically from national/regional/local reporting systems of various levels of completeness, preciseness, and reliability. Correct understanding and interpretation of data and the need for an appropriate strategy for responding to monitoring results are essential aspects of the risk management process and key consideration for the effective collection and use and monitoring data.

2. Routine data on water quality and health

Most usual kinds of these data includes compliance of DW monitoring results in respect to national or international standards, numerical data on DW quality in given zone or territory, and numbers of water-borne outbreaks reported.

2.1 Compliance data

Compliance (or non-compliance) of DW monitoring results in relation to the limit values set for respective parameters (indicators), usually expressed as percentage per given period. Data come from (public) water supplies which are under regular and obligatory control and publicly available. Usually synthesis results for all supplies or selection of supplies are available. Results may be presented together for all parameters (see Figure 1) or individually for each parameter, either in figure (see Figure 2) or table forms (see Table 1).

Figure 1 Example of data on drinking water quality expressed as summary data on non-compliance: % samples taken in zones failing to meet European and National standards in period of 1991-2005. Data from all public water supplies (population supplied about 58 million), United Kingdom [1]. Note: some of the standards changed with effect from 1 January 2004

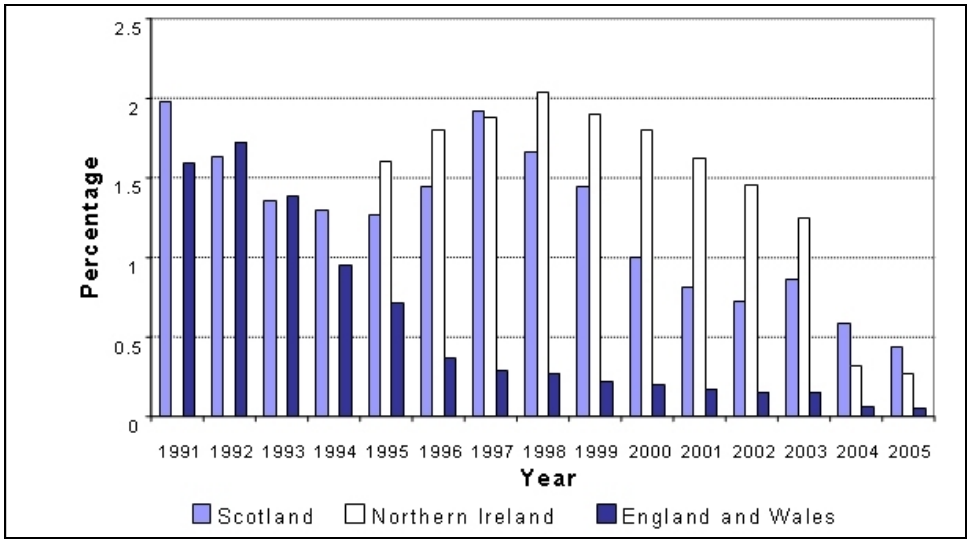


Figure 2 Example of data on drinking water quality expressed as summary data on non-compliance for selected parameters: percentage of results exceeded the limit values. Data from all public water supplies in 2006 (population supplied 9.5 million), Czech Republic

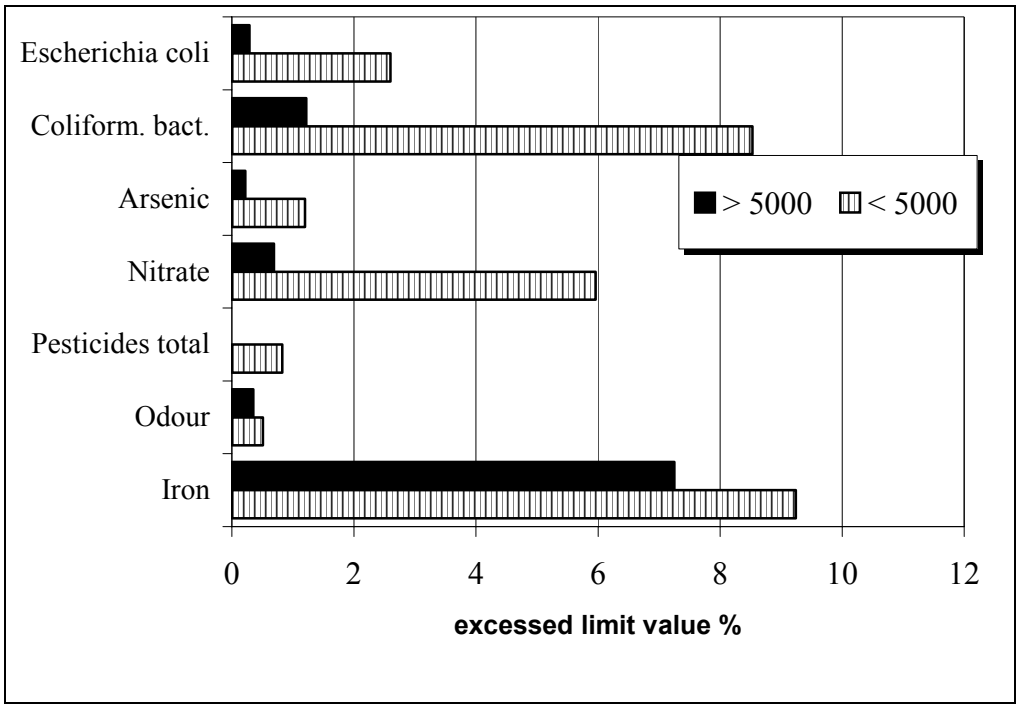


Table 1 Example of data on drinking water quality expressed as summary data on non-compliance for selected parameters: number and percentage of results exceeded the limit values (LV) + number of results under limit of quantification (LOQ). Data from all public water supplies, Czech Republic 2006

Parameter	Number of analyses	<LOQ	>LV	>LV %
Arsenic	5709	4451	55	0,96
Coliform. bact.	32679	1	1854	5,67
Escherichia coli	32326	1	546	1,69
Iron	32044	9851	2704	8,44
Nitrate	31459	1921	1214	3,86
Odour	29112	1230	129	0,44
Pesticides total	3931	0	23	0,59

2.2 Data on water quality

Data on DW quality for given period from given territory (country, region) or from selected supplies, usually expressed as mean or median concentration, minimum and maximum values found, standard deviations, quantiles, or other results of statistical analysis, and finally number of samples analysed (or collected in database) for all or some of the parameters monitored. See Table 2 for example.

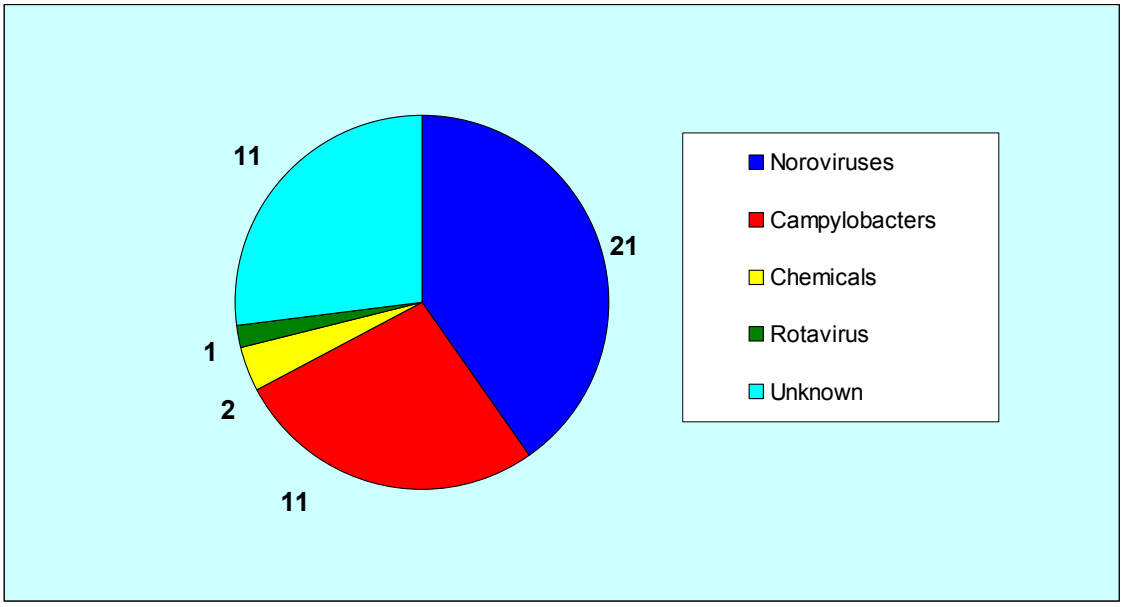
Table 2 Example of data on drinking water quality expressed as summary data on numbers/concentrations for selected parameters. Data from all public water supplies in 2006, Czech Republic

Parameter	Unit	Minim. value	Maxim. value	Average	Geometric mean	Median	Quantile		Number of analyses
							10%	90%	
Arsenic	µg/l	< 0,001	81	1,158	0,635	0,5	0,25	2,5	5709
Coliform bact.	CFU/ 100ml	0	> 700	0,942	0,000	0	0	0	32679
Escherichia coli	CFU/ 100ml	0	298	0,219	0,000	0	0	0	32326
Iron	mg/l	< 0,003	10,7	0,098	0,053	0,05	0,015	0,2	32044
Nitrate	mg/l	< 0,01	149,8	18,048	11,057	13,1	2,5	39,6	31459

2.3 Data on water-borne outbreaks

Usually expressed as number of water-borne outbreaks per year or other given period. For example see Figure 3. Beside the outbreaks, some countries are able to report also the numbers of sporadic cases of (notifiable) diseases caused/transmitted by water, but its reliability in term of completeness is questionable.

Figure 3 Example of data on health impact of drinking water quality expressed as total number of waterborne outbreaks (46) reported in specific period (1998-2005), analyzed according to the causes. Data from Finland [2]



What information, experience or conclusion may be obtained from these data?

3. Initial consideration on data quality and reliability

Before starting to evaluate any collection on data on water quality, we have to raise and (try to) answer several basic questions, which have pivotal position for subsequent evaluation and conclusions we would like to present:

- How reliable are data on water quality produced by the laboratories? Have these laboratories introduced analytical quality control system that is subject from time to time to external control? Does the system include also sampling?
- Are there monitoring plans and sampling strategies (policy)? Is a selection of monitoring sites and sampling frequency representative for all supply network monitored? Is sampling policy primarily focused on water quality on the tap, as consumed by consumers, or on water quality in distribution (pipe) network in front of the buildings supplied?
- Are there any significant imbalances in the amount of data from different water supplies, which may introduce bias[1] into the survey design? For instance, if majority of all data come from big supplies run by professionals (utility) that showed very few samples with the presence of indicator bacteria, this may be very unrepresentative of community-managed small supplies in rural areas.
- Are all data (results) obtained from routine monitoring included in the database, or any pre-selection of data, e.g. on utility level, may exist? If there is any data selection, what is its nature and purpose – may it influence a representativeness of the survey?
- What is population coverage of the survey assessed? Are all public water supplies included? Are there data on private water supplies? Then the coverage may vary according to the proportion of households connected to public water supplies – e.g. from 54.2 % in Romania to 99.9 % in the Netherlands [3]. If the survey is based on data collected from selected supplies – what is such population coverage and are selected zones representative for all supplies or not? In some cases only supply zones with population above 5000 are included, which may present quite different picture of DW quality in comparison with smaller supplies or zones.

If we are not sure about data quality, accordingly we have to be very careful in interpretation and making any conclusions. Similarly if population coverage is limited, we should clearly state what percentage or part of the population we are going to speak about and what we know or do not know about the rest.

4. Data on compliance or non-compliance

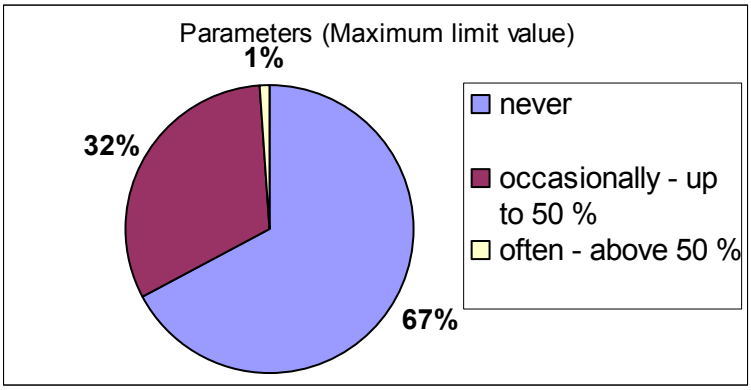
If water analysis, sampling, monitoring representativeness and data collection are reliable and all monitoring results are available, 100 % compliance rate is rather rare and sometimes even little suspicious. Even in properly operated supplies with water of high quality, occasional limit exceedances may be found which does not necessarily mean any breach of water safety, but rather sampling or analysis error or e.g. incidental bacteria occurrence – repeated analysis then usually shows acceptable results.

If summary data show low non-compliance – e.g. < 1-2 % - we should know if such quite favourable situation indicating only random exceedances is relevant to all supply zones monitored or if most zones are even better and the rate is influenced by few supply zones showing repeated or continuous non-compliance. We have to ask for more detail analysis of data and supply zones showing distribution of population according to maximum relative number of

[1] Bias is deviation of results or inferences from the truth, or processes leading to such deviation.

analyses with non-compliance of one parameter. For example: while data from the Czech Republic shows total figures for all supply zones with less than 1% non compliance for all limit values and 0.05 % non compliance for maximal limit values, from Figure 4 we know that almost 6.4 million (67 %) population were supplied with water from the distribution systems in which no exceedance of any maximum limit value was recorded in given period. In contrast, at least one of the maximum limit values was exceeded in all samples analyzed for the given parameter in 219 mostly smallest distribution systems supplying altogether more than 56,000 (0.6 %) population (Czech Republic, data from 2006 [4]).

Figure 4 Example of data on drinking water quality expressed as distribution of population (%) according to maximal relative number of analyses exceeding maximum limit value of the same parameter. Data from all public water supplies in 2006, Czech Republic



If water quality in particular supply shows 99-100% compliance, we can conclude that water is safe in agreed way (through accepted regulation). It would be highly improbable (although not entirely impossible[2]) that such water causes any health damage.

If non compliance (i.e. exceedance of limit value) is real, repeatedly found and long lasting, we can say that water does not conform to regulatory requirements, but before to conclude about possible health risk, we have to know: **Which parameter is not in compliance and how much and how often was the limit exceeded?** It is because not all parameters and not all limit values are of direct health relevance. It is necessary to consider the meaning of each parameter assessed.

4.1 Different meaning and purpose of drinking water parameters

The list of 48 parameters/indicators included in European Drinking Water Directive[3] (DWD) and additional ones included in respective national **regulations represents mixture of parameters of various nature, purpose and health relevance**. Many of them have been traditionally used just for **operational control** (e.g. pH value, oxidisability, or chlorine residual), filtration efficiency control (e.g. colony counts), corrosion control (conductivity, natural constituents of water like sulphate, chloride or hardness), or as chemical indicator for faecal pollution (e.g. ammonia or chloride, where even manifold limit exceedance of the parameter itself does not represent any health risk in very most cases). For most of the parameters any

[2] E.g. due to pathogens which presence is not indicated through current system of faecal indicators – see hereafter for explanation – or due to chemical substances which are not monitored.
[3] Council Directive 98/83/EC of 3 November 1998 on the quality of water intended for human consumption.

sudden change in concentration (e.g. from ¼ to ½ of the limit value) is more important and risky than permanent exceedance of the limit caused by geological natural conditions. Although such parameters/indicators have not direct health impact, possible non compliance and especially any abnormal change should be carefully investigated, because they may rapidly indicate presence of health risk, which (for the moment) cannot be found through other routine health related parameters used.

There are other parameters which ensure **acceptability of water** or may cause rejection of water by consumers (turbidity, taste, colour, odour, including some causes like iron or manganese), but even waters that look or smell unpleasant may be safe to drink.

Above mentioned indicator parameters are listed in the Annex I, part C, while **health related parameters** are listed in the Annex I, part A and B of the DWD.

There is a list of all DWD parameters and indicators and their meanings, health risks, and main sources of pollution in the ANNEX A. An identification of the source of pollution is important for consequent health risk assessment as it indicates about nature of contamination and possibly duration of exposure (temporary versus permanent), about stability or fluctuation the concentrations found in time and within the zone – the closer is source of pollution to consumer´s tap, the bigger fluctuation of the values measured we can expect. Regarding the parameters where non-compliance is mostly caused by the materials used in domestic plumbing system (e.g. copper or lead), it is not possible to identify what part of the population supplied from the respected supply zone may be affected by such non-compliance if we have only summary results.

There is another recent and critically evaluated list of the DWD parameters as well as other suitable parameters available and its relevance and purpose of use in separate parts of the supply system (catchments or source water control, treatment control, distribution conditions control, or consumer´s tap water quality control) in the ANNEX B. For details check the source document [5]. It is obvious from the Annex B that the parameters controlled in various parts of the supply system have different informative value.

4.2 Derivation of limit values

Two approaches to the derivation of guideline or limit values for **health-related chemicals** are used according to the type of their effect: one for "**threshold chemicals**" (see Box 1) and the other for "**non-threshold chemicals**", i.e. mostly genotoxic carcinogens (see Box 2).

Box 1: Threshold chemicals

For most kinds of toxicity, it is believed that there is a dose below which no adverse effect will occur. For chemicals that give rise to such toxic effects, a **tolerable daily intake**[4] (TDI) should be derived as follows, using the most sensitive end-point in the most relevant study, preferably involving administration in DW. The TDI is an estimate of the amount of a substance in food and DW, expressed on a body weight basis (mg/kg or μg/kg of body weight), that can be ingested over a lifetime without appreciable health risk.

As TDIs are regarded as representing a tolerable intake for a lifetime, they are not so precise that they cannot be exceeded for short periods of time. Short-term exposure to levels exceeding the TDI is not a cause for concern, provided the individual's intake averaged over longer periods of time does not appreciably exceed the level set. The large uncertainty factors generally involved in establishing a TDI (see below) serve to provide assurance that exposure exceeding the TDI for short periods is unlikely to have any deleterious effects upon health. However, consideration should be given to any potential acute effects that may occur if the TDI is substantially exceeded for short periods of time.

[4] Analogous parameter developed and used by US EPA is called Reference dose (RfD) for oral intake.

TDI = (NOAEL or LOAEL)/UF

where:
NOAEL = no-observed-adverse-effect level
LOAEL = lowest-observed-adverse-effect level
UF = uncertainty factor

The **NOAEL** (no-observed-adverse-effect level) is defined as the highest dose or concentration of a chemical in a single study, found by experiment or observation, that causes no detectable adverse health effect. Wherever possible, the NOAEL is based on long-term studies, preferably of ingestion in drinking-water. If a NOAEL is not available, a **LOAEL** (lowest-observed-adverse-effect level) may be used, which is the lowest observed dose or concentration of a substance at which there is a detectable adverse health effect. When a LOAEL is used instead of a NOAEL, an additional uncertainty factor is normally applied.

Uncertainty (or safety) factors are applied to derive the TDIs or ADIs (acceptable daily intakes) for food additives, pesticides and environmental contaminants. The reason is to cover all main sources of scientific **uncertainties:** interspecies variation (animals to humans) if animal study is used, intraspecies variation (individual variations within species), adequacy of studies or database, and nature and severity of effect. The derivation of these factors (each may get value in range of 1 to 10) requires expert judgement and careful consideration of the available scientific evidence.

The **guideline value (GV)** is then derived from the TDI as follows: **GV = (TDI x bw x P)/C**

where:
bw = body weight (default assumption for body weight of adults is 60 kg)
P = fraction of the TDI allocated to drinking-water (the values generally vary from 10% of TDI for substances for which exposure from food is probably the major source to 80% for substances for which exposure is primarily through DW)
C = daily DW consumption (default assumption for consumption by an adult is 2 litres of water per day)

For more details see the WHO Guidelines for drinking-water quality [6].

The list of the DWD parameters with parametric (limit) values, TDIs or corresponding level of cancer risk is provided in the ANNEX C.

Box 2: Non-threshold chemicals

In the case of compounds considered to be genotoxic carcinogens, guideline values are normally determined using a mathematical model. Although several models exist, the linearized multistage model was generally adopted. Guideline values are presented as the concentrations in DW associated with an estimated upper-bound excess lifetime cancer risk of defined level. For example, the WHO Guidelines for drinking water quality present the guideline values based on the cancer risk of 10^{-5} (or one additional cancer per 100 000 of the population ingesting DW containing the substance at the guideline value for 70 years). The parametric values of non-threshold chemicals included in the DWD are mostly based on the cancer risk of 10^{-6}, i.e. one order more strict values. However, all these values must be regarded as rough estimates of cancer risk.

For more details on model assumptions and calculation see the WHO Guidelines for drinking-water quality [6].

4.3 Evaluation of non-compliance with chemical health-related parameter limit values

Even the breach of the limit value of chemical health-related parameter does not necessarily pose any health risk, because:

- the limits are usually set with considerable margin of safety – see for the principles of setting the limit values of health related parameters (e.g. for tetrachloroethene and trichloroethene with limit value 10 μg/l, the safe concentration for temporal exposure is 200 μg/l for infants and 1000 μg/l for adults);
- the limit is based on organoleptic basis: e.g. some volatile organic compounds like the xylenes have the limit value based on taste and odour about one order more strict than health-based limit;
- the limit value is set by political decision: for example this is the case of most pesticides for which the DWD sets uniform limit value 0,1 μg/l, which is expression of political decision that the pesticides should not be present in DW (even in low, toxicologically safe concentration).

As from simple information on non-compliance we are not able to estimate the extent of exceedance (and the dose received), we have to identify the group of parameters where even little exceedance of the limit may cause harm effect (mostly for sensitive subpopulations) and when we can indicate health risks from any non-compliance.
These parameters are:

- nitrate and nitrite which may cause infant methaemoglobinaemia (acute effect);
- copper which may cause gastrointestinal problems at some sensitive children or adults (acute effect);
- sulphates in presence of high magnesium contents which may cause diarrhoea at some consumers not adapted to the source (acute effect);
- lead which may cause subencephalopathic neurological and behavioural effects if foetus, infant or very young children with developing neurological system are exposed (chronic effect);
- fluoride which may cause dental fluorosis (mottled teeth) at some children (chronic effect);
- arsenic ? (there are significant uncertainties regarding the risk assessment for arsenic carcinogenity whether even low concentrations about the limit value represent risk or not).

In theory, in case of accident and gross contamination we could expect acute health problems from most chemical substances – even of relatively low toxicity, but these situations are very rare.

4.4 Evaluation of non-compliance of microbiological parameters

Evaluation of microbiological parameters seems to be more difficult and one have to understand the system used at the first (see Box 3 for the principle of current microbiological quality monitoring).

Box 3: Microbiological quality of drinking water

Principles of current microbiological quality monitoring

There are a wide variety of micro-organisms that may be found in water. These include those that are pathogenic and those that are not pathogenic. Some of the non-pathogenic micro-organisms may lead to other problems in water supplies such as taste and odour, which may be of particular importance to users of the supply as an indicator of safety and may influence their selection of water for consumption. However, the principal concern for microbiological quality is the potential contamination by pathogens. Pathogens tend to be classified according to their group or family and include bacteria, helminths, protozoa and viruses.

Although it is known that pathogens cause disease, the routine monitoring of pathogens is generally not undertaken for several reasons. For many pathogens there is a lack of analytical tools available and where these do exist they are often expensive and difficult to perform. Individual pathogens cannot be guaranteed to be present in all untreated or unprotected waters as this depends on whether the faeces (or other materials e.g. medical wastes) from an infected person or animal are present in the water. Therefore failure to observe a particular pathogen cannot be taken to imply an absence of other pathogens. Furthermore, it is desirable to have a means of detecting contamination before there is a significant public health risk in order to ensure actions can be taken to prevent a major outbreak of disease.

As a result of the issues raised above and because most water-borne pathogens are derived from faeces, it is usual practice to use **indicator organisms, usually bacteria**, for the analysis of microbiological quality of DW. There are a number of indicator micro-organisms that may be used in drinking water quality monitoring programmes. The organisms listed in the DWD are: *Escherichia coli (E. coli),* enterococci, *Clostridium perfringens*, and coliform bacteria.

Critique of the indicator-based approach

The principal current indicators used do have serious limitations. The relationship between pathogens and indicator bacteria is not simple, the range of pathogenic organisms is large, and their nature is broad and many do not bear many similarities with the indicator organisms. The weaknesses of current indicators in predicting health risks has been noted as there is evidence of infection by waterborne pathogens when indicators are not present in water. It has been suggested that whilst the current suite of indicators of microbiological quality have provided a useful tool in prevention of epidemics, they provide far less information about endemic disease, particularly where the disease agents are viruses. The data from these studies suggests that the current indicator bacteria are not adequate alone to predict pathogen presence.

The limitations in the use of the current indicators indicate weakness in the application and interpretation of the results of analysis rather than the imperfections of the system itself. The original development of standards for water quality based on indicator bacteria in the early 20th Century were designed to verify treatment system performance (in particular slow sand filtration and disinfection). The bacterial indicators were only one mechanism of verification of water quality and were supported by sanitary surveys of water supplies and monitoring of treatment plant operation. However, over time, the basis of legally enforceable measures of water quality has increasingly focused of numerical limit values for faecal indicator bacteria.

Support for continued use of the indicators

There are strong arguments that can be made for continued use of indicator bacteria as the principal method for monitoring the microbiological quality and thus, indirectly, the likelihood of pathogen presence in DW supplies. A recent review of microbial indicators concluded that the use of the standard indicators has done much to improve health and their abandonment due to recognized weaknesses is unjustified and likely to be counter-productive to health.

Adapted from Howard et al. (2003)

The interpretation of the results of indicator bacteria analysis in the context of standards illustrates profound misconceptions of the meaning of the absence, presence and numbers of faecal indicator bacteria. Many people in water and health sectors still equate an absence of faecal indicator bacteria with an absence of pathogens. As noted in the box this may not be true given the evidence of water-borne infections resulting from DW meeting current standards. Furthermore, many professionals also seem to equate the presence of faecal indicator bacteria with confirmation of the presence of pathogens. However, it may also not be true – in reality it merely implies that the risk of pathogen presence has increased, as there is evidence of recent faecal contamination. Any attempt to translate the findings of monitoring that describe a risk (which is an inherently probabilistic approach) into a certainty, means the principal flaw in the use of indicator bacteria. Such an approach inherently contains some degree of potential for false positive and false negative results in relation to pathogen presence [7].

Moreover, one also has to take into account two other important facts: what does it mean in reality the absence of faecal indicator bacteria in terms of "zero" results (e.g. 0 CFU/100 ml) and the relativity of any result in microbiological analysis of water relating to the method used. If we consider confidence intervals (e.g. 95% CI), then the results of coliforms 0 CFU means 0.0 – 3.7 CFU, 1 CFU means 0.1 – 5.6, 2 CFU means 0.2 – 7.2, etc. [8]; or the results 1 CFU means < 1 – 6 CFU, 2 CFU means < 1 – 7 CFU, 3 CFU means < 1 – 9 CFU etc. [9]. As bacteria are not homogenously distributed in water, but usually clustered, there may be the large variability in bacterial densities across a drinking water supply. For example coliform densities in some regions of the drinking water supply where coliforms are not detected in 100-ml volumes may vary by as much as 10^8-fold. The 0/100-ml samples may therefore provide a false sense of security if the operator does not know how close each zero sample was to registering a coliform or how many of the 0/100-ml samples were close to registering coliforms [10].

If we consider the nature of microbiological analysis, we know that we do not look for absolute number of bacteria of selected groups of bacteria in water, but just for certain part of it which is strictly defined by the standard method agreed. If we use little modified method or even another method – in terms different cultivation medium, way of inoculation, incubation temperature or time – we should get totally different results from the same water sample. Not speaking about another key role of the sampling method.

What should be the lessons learned?

a) Any figures in microbiological analysis of water are relative and defined by the method used.
b) Any result – either positive or negative finding of indicator bacteria – does not provide absolute information on the presence or absence of health risk; it just expresses the probability of the risk: the relative numbers of faecal indicators in a water supply are more important than simple presence, as increasing numbers of indicator bacteria implies that the risk of pathogen presence increases.
c) Key assessment action may be done only on the level of the single zone, taking account the results of other parameters (do other results, either microbiological or chemical, support non-compliance finding?) and information from sanitary survey or local investigation of water supply.

d) If indicator bacteria are isolated and other results or complementary information from sanitary survey (accident source pollution, treatment failure, pipe break, etc.) confirm the result, the proper investigation of the cause of non-compliance should be done to select the most appropriate remedial action.

5. Numerical data on water quality

5.1 Microbiological parameters

Not even real data on microbial water quality in terms of numbers of CFU found in routine monitoring allow to assess health risk precisely – see above for comments on evaluation of non-compliance of bacterial faecal indicators. The assessment will be in any case qualitative: lower or decreasing versus higher or increasing risk of infection.

Although there have been already developed the methods for quantitative health impact assessment (HIA) related to biological pollution of drinking water, the information available and needed for the calculation is still very limited. So far, the lack of available exposure-response functions for each potential pathogen in water and especially the lack of data on real occurrence of pathogens in water supplies hinders scientific progress on HIA development and its routine use in practice. Basic principles and more details of quantitative microbial risk assessment (QMRA) can be found in special literature [6] or websites [11].

5.2 Chemical parameters

If numerical or concentration data on each health related parameter are available, various kinds of quantitative health risk assessments are possible. Some examples follow.

5.2.1 Health risk assessment from non-compliance

In case of non-compliance of threshold chemicals we can calculate average daily dose (ADD) consumed and through comparison with tolerable daily intake (see Box 1) to assess whether one can expect health risk or not (and for what age-specific population[5]). In case of non-compliance of non-threshold chemicals we can calculate lifetime average daily dose (LADD) consumed and with help of cancer slope factor[6] we can assess whether level of cancer risk[7] is still acceptable or not. These assessments should be made obligatory before any derogation[8] is granted to ensure that such derogation does not constitute a potential danger to human health. Some countries established and published maximum acceptable values of chemical parameters listed in the DWD for the purpose of derogation, for example Germany [12]. The method of calculation of ADD and health risk is shown in Box 4.

[5] Based on usual body weight of each age group.

[6] Cancer slope factor is practical expression of exposure (dose) - response function for carcinogenic substances in the low-dose region. When low-dose linearity cannot be assumed, the slope factor is the slope of the straight line from 0 dose (and 0 excess risk) to the dose at 1 % excess risk. An upper bound on this slope is usually used instead of the slope itself. The units of the slope factor are usually expressed as 1/(mg/kg-day).

[7] Individual lifetime cancer risk.

[8] Temporary agreement with non-compliance of chemical parameter – see Article 9 (Derogations) of the Drinking Water Directive (98/83/EC).

Box 4: Method of calculation of quantitative health risk assessment from non-compliance

The first step is to assess the exposure, which is calculated as so called **average daily dose (ADD)** for non-cancer risk or threshold chemicals, usually averaged for one year of exposure, but shorter period is also possible, or so called **lifetime average daily dose (LADD)** for cancer risk or non-threshold chemicals; as follows:

ADD (LADD) = CW x IR x EF x ED/ BW x AT
where:
CW = chemical concentration in water (mg/l)
IR = ingestion rate (litres/day)
EF = exposure frequency (days/year)
ED = exposure duration (years)
BW = body weight (kg)
AT = averaging time (period over which exposure is averaged – days); when assessing toxic effect then AT = ED x 365; when assessing carcinogenic effect, we average dose for whole assumed life time (70 years) or AT = 70 x 365, then we get LADD (lifetime average daily dose)

If chemical substance assessed is volatile and one can assume not only exposure from ingestion, but from inhalation, too (e.g. when water is used for bathing or showering), ADD from inhalation exposure may be calculated and than added to oral ADD. To be precise, also ADD from food may be calculated or estimated (if known) to receive total exposure.

The second step or assessment of probability of the risk of toxic effect of given substance (non-cancer risk) is calculated by mean of so called hazard quotient (HQ):

HQ = ADD/TDI

If HQ value is less than 1, we do not expect any risk of toxic effect.

Level of risk from the exposure to carcinogenic substance(s) is determined as so called **individual lifetime cancer risk (ILCR)**, which is calculated through formula:

ILCR = LADD x CSF
where
LADD see above
CSF = cancer slope factor (factors for individual substances may be found in various databases e.g. IRIS – see http://www.epa.gov/iris/)

From the ILCR we can calculate **annual population cancer risk (APCR)** that expresses annual risk of cancer cases occurrence in specific exposed population, or average number of additional cases of cancer (caused by DW exposure) per year:
APCR = ILCR x number of people exposed / 70 (years).

Acceptable level of cancer risk is defined by political decision on national (regional, EU...) level.

As an example of such approach we can use the case study producing estimates for Health Risk Assessment (HRA) and Environmental Burden of Disease (EBD) due to higher arsenic content in DW which was conducted in one French region (Puy de Dôme).The study was developed within the project "Implementing Environment and Health Information System in Europe" (ENHIS). Both carcinogenic (skin cancer) and toxic effect (vascular complication) from As exposure were evaluated.
The results for HRA showed that, for lifetime exposure under *normal* (mean) exposure patterns, there would be an increase of 11.8 skin cancers per 100,000 in the exposed general

population over 70 years. For an *extreme* (P95) water ingestion, this number would be 29 cases per 100,000 in general population. According to the percentages of children (10 251 children in total) exposed to the different arsenic concentration ranges in the study area, a total increase of 0.4 cases (4.3 cases per 100,000) above the number of expected skin cancers for children would be predicted for a normal daily intake. When an *extreme* DW intake (1.06 L/day for this age group) was considered, the increase would be up to one child (12.1 cases per 100,000) in the same period.
Regarding chronic toxic hazard, the HQ values exceeded 1 and indicated potential occurrence of skin diseases and vascular complications in general population and adult age groups (>15 years old) for arsenic concentrations higher than 30 µg/l and *normal* DW intake. In the case of children (body weight 30.2 kg), HQ >1 were obtained even under lower arsenic concentrations (> 20 µg/l), suggesting that negative health effects for smaller children could be relevant and more significant than for adults. Risk for developing negative health effects for children and adults could be especially important under the worst-case scenario (*extreme* ingestion rate). The toxicity thresholds in this case was exceeded (HQ > 1) when population consumed water with an arsenic concentration higher than 11 µg/l.
Regarding another approach to health impact assessment – Environmental Burden of Disease – the DALYs (Disability Adjusted Life Years[9]) were calculated. The number of DALYs attributable to skin cancer related to arsenic oral exposure under *normal* ingestion rate (IR) in Puy de Dôme population was of 2.2 and 594 DALYS for morbidity or mortality, respectively. Results were more than double for both health outcomes when *extreme* IR was considered.
For details on exposure assumptions and calculation methods see original text [13].

Generally there is a rule that smaller unit of analysis we are going to evaluate (e.g. one water supply zone), usually more detail information is available and the better health impact or health risk assessment can be done!

5.2.2 Assessment of importance of threshold chemicals exposure from drinking water

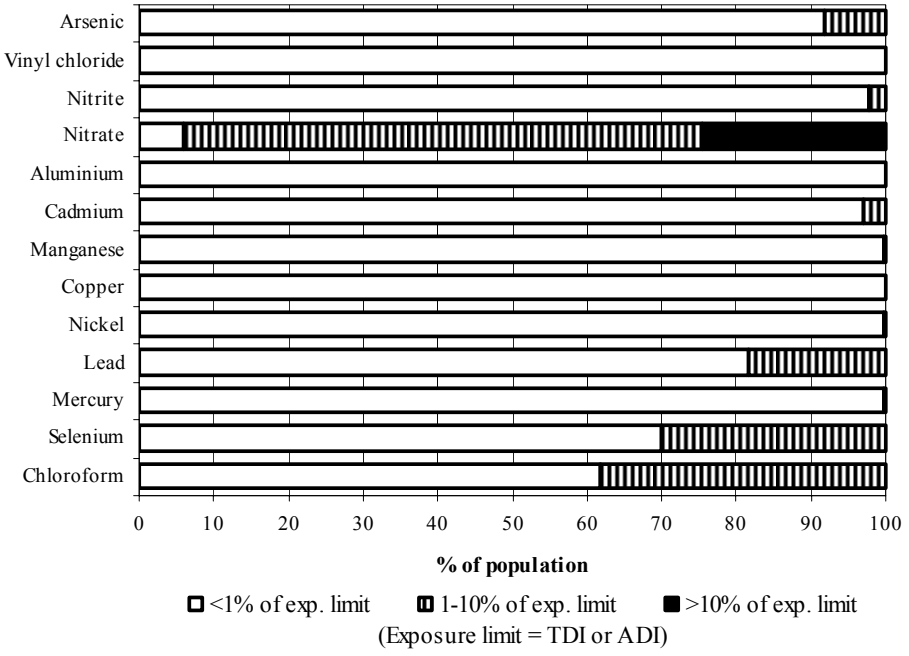
In case of compliance of health related parameters (threshold chemicals) we can assess, how important is drinking water as a source of exposure for some chemical pollutant: through calculation of average daily dose we can identify the share (%) how DW can contribute to tolerable daily intake of respective chemical substance. Comparing this contribution with other routes of exposure (air or food), we can identify priority for risk management measures, if needed.
Method of calculations: If we want to evaluate the situation in population supplied from one water supply zone, we calculate average daily dose (ADD) for respective chemical – see above – and from the formula **(ADD/TDI) ∗ 100** we know how intake from DW consumption draws off tolerable daily intake (TDI). If we want to evaluate the situation in whole population supplied from public water supply, we have to calculate at first the share for every water supply zone, to combine this figure with number of inhabitants supplied from the zone, and finally to sum up all these data from all zones to get country-wide overview. See example in Table 3 and Figure 5.

[9] For details see website of the International Burden of Disease Network (www.ibdn.net).

Table 3 Exposure of population to selected contaminants from drinking water ingestion expressed as % of exposure limit (TDI or ADI) according to the size of supply (population more or less than 5000). Data from all public water supplies in 2006, Czech Republic. Daily water consumption of 1 litre considered; both median and quantile 90 concentrations used for calculation

	% exposure limit (TDI)			
Size of the zone (population)	**more than 5000 persons**		**less than 5000 persons**	
Parameter	**median**	**quantile 90**	**median**	**quantile 90**
Arsenic	<1	<1	<1	<1
Vinyl chloride	<1	<1	<1	<1
Nitrite	<1	<1	<1	<1
Nitrates	6,07	8,24	6,62	8,21
Aluminium	<1	<1	<1	<1
Cadmium	<1	<1	<1	<1
Manganese	<1	<1	<1	<1
Copper	<1	<1	<1	<1
Nickel	<1	<1	<1	<1
Lead	<1	<1	<1	<1
Mercury	<1	<1	<1	<1
Selenium	<1	<1	<1	<1
Chloroform	1,10	1,71	<1	<1

Figure 5 Distribution of population exposure to selected contaminants from drinking water expressed as % of exposure limit (TDI or ADI). Data from all public water supplies in 2006, Czech Republic. Daily water consumption of 1 litre considered; median concentrations used for calculation



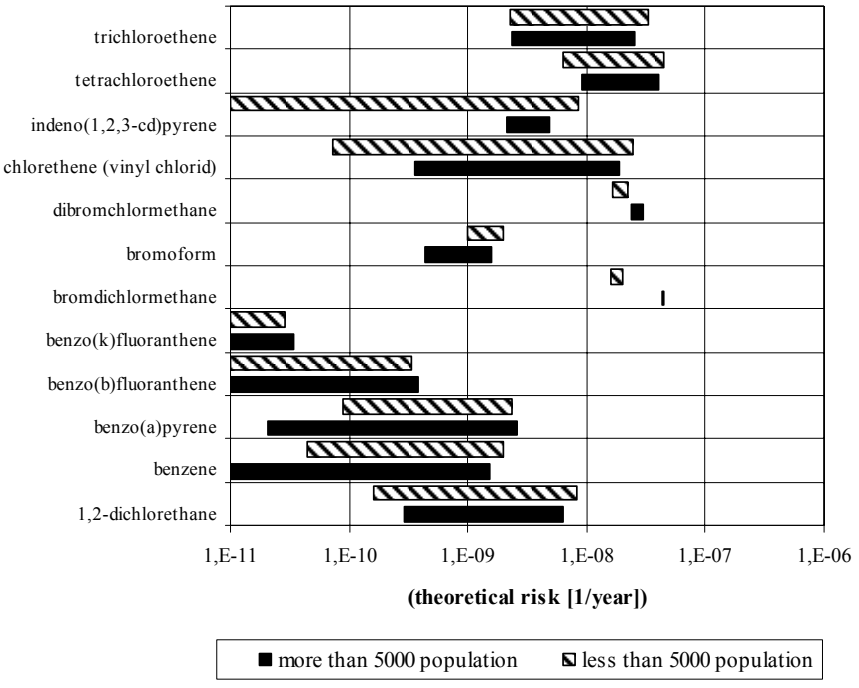
5.2.3 Assessment of carcinogenic potency of drinking water

In case of compliance of non-threshold chemicals we can calculate individual lifetime cancer risk (caused by the presence of these chemicals in DW) and consequently population cancer risk if data on water quality and the size of population supplied are matched together. If we have already lifetime average daily dose calculated, we can also compare intake from DW with intakes from food or air (if known) to know what is the main exposure route for non threshold chemical. Method of calculations is provided in Box 5. The example is given in Figure 6 – the calculation revealed that any excess cancer risk from 12 substances considered did not reach the level in order of 10^{-7} (1,E-07), which means that DW intake might theoretically result in an annual excess cancer risk of about 2 x 10^{-7}, i.e. 2 excess cancer cases per 10 million population.

Box 5: Method of calculation of quantitative health risk assessment of carcinogenic potency of drinking water

The procedure of calculation of individual lifetime cancer risk (ILCR) and annual population cancer risk (APCR) for respective water supply zone is provided in Box 4. If we want to calculate excess cancer risk for region or country, we have to calculate at first the ILCR and APCR (for respective chemical) for every supply zone. Then we add up all single APCRs calculated to get the value for whole region or country and finally we divide the figure received by number of people supplied in all evaluated zones to get weighted average of the ILCR. By summing the ILCRs from all considered carcinogens we get receive the summary information on cancer potency of drinking water distributed throughout the region(s) considered.

Figure 6 Theoretical excess of relative cancer risks from chronic exposure to selected organic contaminants (carcinogens) associated with drinking water intake (R_{min} – R_{max}) for big and small water supply zones. Data from all public water supplies in 2006, Czech Republic. Daily water consumption of 1 litre considered; two methods of calculation used to get mean values of chemical concentration in water as most results were under limit of quantification (LOQ): minimum R_{min} – values under LOQ replaced by zero; maximum R_{max} – values under LOQ replaced by the LOQ value



5.2.4 Assessment of safe temporary limit in case of accident or emergency

Knowledge on tolerable daily intake and the method how to calculate limit value allows to set not only safe limit value for derogation (up to 3 or 6 or 9 years), but also to set even less strict "emergency" limit value[10] for a number of parameters, which may be applied only temporarily (e.g. for 10 days or 30 days) in emergency cases without compromising consumer´s health. Some countries developed such guidelines for local authorities or water suppliers to be able quickly respond in case of accidents or emergency water supply. See Box 6 for example.

Box 6: Health advisories developed by the US EPA

The Health Advisory (HA) Program of the Office of Water (U.S. Environmental Protection Agency) provides informal technical guidance to Federal, State and local officials responsible for protecting health when emergency spills or DW contamination situations occur. HA value is defined as the concentration of chemical in drinking water that is not expected to cause any adverse non-carcinogenic effects for specified exposure time. Under this program, first initiated in 1985, HA values are developed for 1-day and 10-day (both for 10-kg child) and lifetime exposures based on data describing non-cancer endpoints of toxicity. For substances that are known or probable human carcinogens, lifetime HAs are not recommended. In these situations, the HA document provides an estimate of the DW concentration that is equivalent to a 10^{-4} – 10^{-6} cancer risk. Up to now the HAs for more than 160 chemicals has been developed. A tabular summary of HA values can be accessed through the US EPA web site: http://www.epa.gov/waterscience/criteria/drinking/dwstandards.html [14].
Example for illustration: while parametric (limit) value for acrylamide is 0.1 μg/l, safe ten-day HA for child is up to 300 μg/l. Or ten-day HA for cadmium is 40 μg/l in comparison with standard limit value of 5 μg/l.

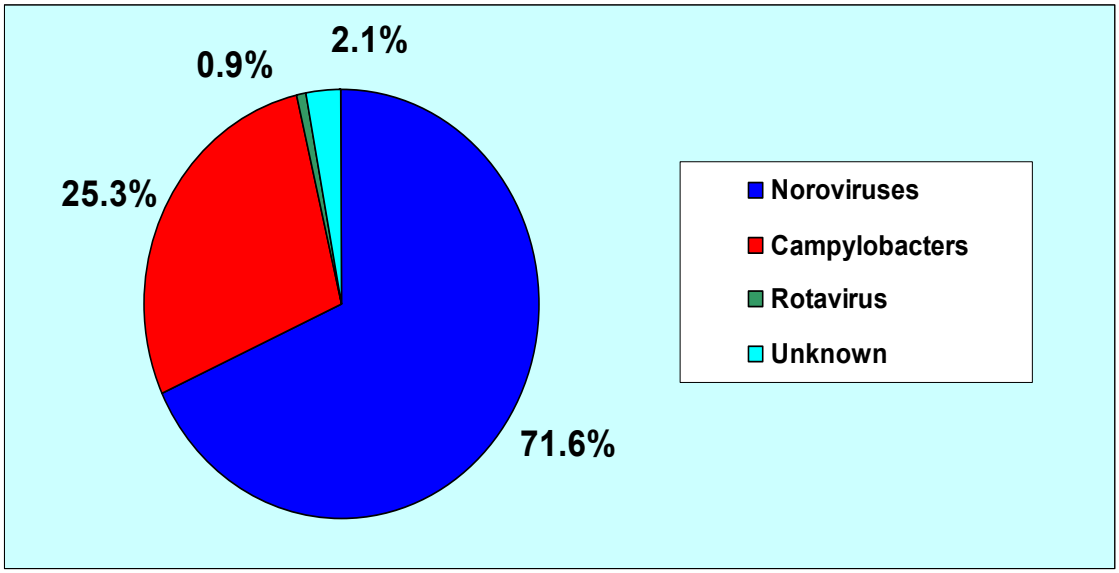
6. Number of water-borne outbreaks

Number of outbreaks of water-borne diseases is important and the only direct information on health impact of drinking water quality which is usually available. Occurrence of the outbreaks of water-borne diseases is currently still not limited to developing countries only, but affluent nations are affected as well [15]. Although some countries include under such outbreaks also diseases caused by chemical agents in drinking water (e.g. USA [16] or Finland [2]), very most countries use national surveillance notification system and report only outbreaks of infectious diseases. Beside data on total number of outbreaks (see Figure 3), various additional data processing may be available, e.g. number of cases (see Figure 7).

However, before we start to evaluate the figures on reported outbreaks or even to compare data from several countries, at first we have to understand the reporting mechanism (its scope, efficiency and reliability) on which the figures are based. The reason is that the numbers of outbreaks reported may rarely represent the true picture, showing usually an underestimation of the real occurrence. Also the differences in reported numbers among countries do not reflect real situation in drinking water quality and its health effect, but rather efficiency of surveillance system. Paradoxically, high numbers of outbreaks are sometimes reported from the countries with high level quality of drinking water supply, just because of high efficiency of surveillance systems. However, even in these countries many reported outbreaks of water-borne diseases may be hidden under the outbreaks of food-borne or unidentified origin.

[10] Less strict safety factor may be applied. Issues of taste and odour have to be considered.

Figure 7 Total number of cases (15,850) from waterborne outbreaks reported in specific period (1998-2005), analyzed according to the causes. Data from Finland [2]



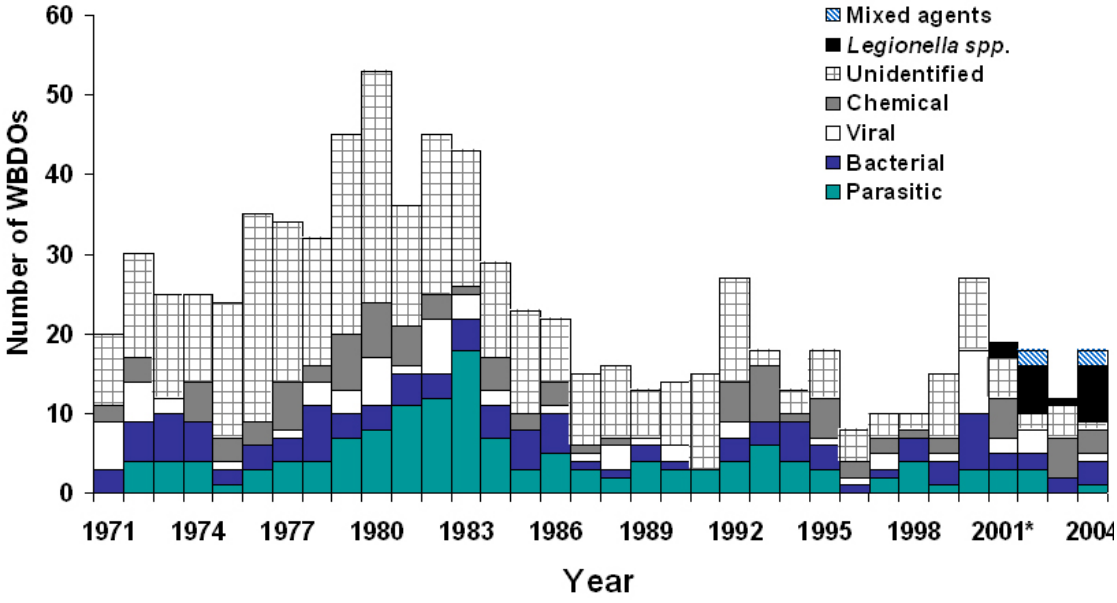
Beside differences in national reporting systems, generally there is a complex chain of events which might affect whether an infected person appears as a reported case (and whether number of related cases appears as a reported outbreak) and which should be understood in basic: if individual is infected, but illness does not occur or the ill person does not seek medical care or appropriate clinical test is not ordered by physician or laboratory is not proficient or the test result is not reported etc., then the case escapes reporting system [17]. Also, if any outbreak is caused by disease which does not belong under notification, it my happen that the outbreak is not reported. For example, the outbreaks of skin warts caused by *Moluscum contagiosum* among children visiting swimming pools are quite common and the dermatologists are well familiar with this disease and its cause and the way of transmission, but it does not appear in any statistics as it does not belong to the set of notifiable diseases.

For all reasons given above, any comparison between countries must be assessed and presented very carefully. Much more important seems to be two other outcomes:

a) Assessment of trend in single country which uses same reporting system over the years. It may show progress in more reliable way. For example see Figure 8.
b) Identification of the causes of any water-borne outbreak (origin and transmission route of disease, kind of failure in water supply) through proper outbreak investigation aiming:
   ⇒ to prevent spread of the disease,
   ⇒ to avoid secondary cases,
   ⇒ to prevent recurrence from the same source,
   ⇒ to get the lesson which may prevent failure at other water sources,
   ⇒ to obtain and preserve accurate records of the event.

Many interesting and useful examples were published and can be found in the literature, e.g. [15].

Figure 8 Number of waterborne disease and outbreaks (WBDOs) associated with drinking water (n=803), by year and etiologic agent. Data from the United States, 1971–2004 [18]



* Beginning in 2003, mixed agents of more than 1 etiologic agent type were included in the surveillance system. However, the first observation is a previously unreported outbreak in 2002.

† Beginning in 2001, Legionnaires' disease was added to the surveillance system, and *Legionella* species were classified separately in this figure.

7. Data on supplies not under (regular) monitoring?

The DWD applies to water supplies serving more than 50 people or producing more than 10 m^3/day, though no reporting is required if the number of people served is less than 5000 or the amount of water produced is less than 1000 m^3/day. At the same time at least one in ten Europeans (40 to 50 million people) receives their daily DW from small (serving 50 to 5000 persons) and very small (serving less than 50 persons) supplies, including private wells. There is an urgent lack of reliable information on the number of such supplies and the exact number of people served by such supplies, because many countries have little information on such numbers within their territory.

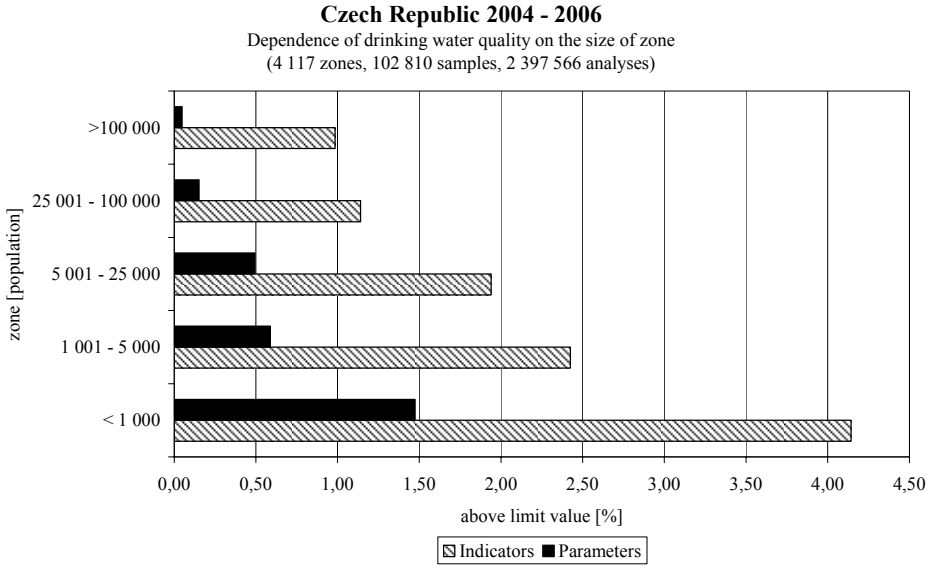
As mentioned above, water supplies serving less than 50 persons or providing less than 10 m^3/day can be exempted from the provisions of the DWD and about half of the EU countries have indeed done so and very small supplies are not covered by national legislation (exemption does not apply to water supplies that are used to supply water to the public or as part of a commercial activity).

In most countries there is no systematic monitoring of DW or systematic data collection from very small supplies and thus reliable information on water quality is missing. Monitoring does not include private wells which are left to the owner initiative. Based on occasional analyses or regional pilot studies it is estimated that microbiological contamination is by far the major

problem with water from such sources. Other frequent water quality problems here are iron, manganese, nitrate, arsenic, pesticides, organoleptic parameters or radon [19].

Although any very small water supply may have water of excellent quality and some of them really do, generally it is known that more problems with DW quality occur just in (very) small supplies than in bigger supplies. It is mostly because of less or no source protection, no or unreliable treatment and operation by non-professionals in case of smaller supplies. An illustration of differences in water quality between small and big supplies is shown in Figure 9.

Figure 9 Dependence of drinking water quality (% non compliance) on the size of supply zone. Data from all public water supplies in 2004-2006, Czech Republic



8. Conclusions

The interpretation of data and the need for an appropriate strategy for responding to monitoring results are essential aspects of the risk management process and important considerations for the effective use and collection of monitoring data. Risk management decisions based on DW quality data often carry significant health, social and economic consequences. Hence the reliability and meaning of data from monitoring programs must be clearly understood by all involved in their analysis and interpretation, as well as in the design of monitoring programs. However, it was shown by recent study [20] that even water professionals and public health and environmental specialist do not often understand the meaning of DW monitoring data.

In an environmental health context, it is arguably preferable to avoid false negative decisions over false positive decisions. Obviously failing to take appropriate action when it is required may, at worst, lead to an outbreak of waterborne disease resulting in illness and potentially death. However, it must also be recognized that chronic false positive decisions carry their own significant costs. False alarms and repeatedly taking action when none is required will serve to undermine public confidence, waste resources, and risk complacency developing in the long term, leading to harm if the public does not respond to a subsequent real event [20].

At least for all these reasons the policy makers, public health managers, and water and health professionals involved should strive after continuous education and training in this field. Beside there has to be continuous effort to collect data so far missing for correct health impact assessment [13] including both better collection of routine data already available and stimulating additional monitoring or research in areas where data is still missing.

Further information: www.ENHIS.org
(Summary information sheet and
HIA Guidelines and examples on drinking water pollution)

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ANNEX A

Meaning, health risks and main sources of pollution of parameters included in the Council Directive on the quality of water intended for human consumption (98/83/EC)

Microbiological parameters

Parameter	Meaning of parameter / health risks / main sources of pollution or changes
Escherichia coli (E. coli)	Health-related parameter. Currently the best indicator of faecal pollution. Because of its sensitivity to environmental factors it indicates recent pollution Source: waste waters from animal farms and human settlements; faeces of warm-blooded animals.
Enterococci	Health-related parameter. Indicator of faecal pollution. More resistant to environmental factors than *E.coli.* Source: see *E.coli*; rarely some species can grow also in soil and plant vegetation not polluted by faeces.

Microbiological indicator parameters

Parameter	Meaning of parameter / health risks / main sources of pollution or changes
Clostridium perfringens (including spores)	Parameter for process control. It forms very resistant spores which were proposed as indicator of filtration efficiency and indicator of viruses and protozoa presence in treated water. Its spores can survive in environment much longer than pathogens do and therefore may serve as indicator of older or intermittent faecal pollution. Source: faeces and waste waters. C.p. is normal part of intestinal bacterial flora of warm-blooded animals and humans.
Colony count at 22°C	Parameter for process control. Monitoring of efficiency of water filtration and disinfection. Monitoring of general conditions or changes in distribution network. May cause problems with aesthetic quality of water. Source: These are ubiquitous bacteria which can grow in water under suitable conditions. The count is influenced by: colony count in water leaving treatment, water stagnation time in network including higher water temperature, slow velocity flow, sort and residual of disinfection substance, presence of biofilms, corrosion products or sediments in distribution network, quality of pipe materials, water stability (presence of nutrients like C,P,N).
Coliform bacteria	Parameter for process control. Although some toxin producing pathogenic species may rarely occur among coliform bacteria, these are currently understood mostly as indicator of water treatment and disinfection efficiency, secondary contamination or high nutrient content in treated water, not as reliable faecal indicator. Source: These are not harmful saprophytic bacteria living in intestine, but also in not contaminated soil.

Chemical parameters

Parameter	Meaning of parameter / health risks / main sources of pollution or changes
Acrylamide	Health-related parameter. Toxic effects on nervous system, blood formation and reproductive function. Probable human carcinogen. Intake from food is several times higher then from water. Source: Polyacrylamide coagulants used in water treatment (content of acrylamide monomer in coagulant is about 0.05 %). Polyacrylamides are also used as grouting agent in the construction of reservoirs or as part of reverse osmosis membranes.
Antimony	Health-related parameter. Biochemical changes in blood. Source: Naturally occurring due to geological structures. Part of alloys and flame retardants; waste waters from oil refineries.
Arsenic	Health-related parameter. Vascular and skin diseases. Higher risk for several kinds of cancer. Source: Mostly naturally occurring due to geological structures. Rarely in waste waters from glass and electrical industries.
Benzene	Health-related parameter. Anaemia, damage of blood formation, cancer risk. Source: Industrial waste waters, leachates of gasoline from underground tanks, leachates from toxic landfills.
Benzo(a)pyrene	Health-related parameter. Carcinogenic effect. Source: Bitumen coatings of steel and cast iron mains. Atmospheric depositions (product of combustion).
Boron	Health-related parameter. Damage of reproductive functions and faetus development. Source: Naturally occurring due to geological structures. Waste waters from manufacturing of glass, soaps, detergents, and flame retardants. Communal waste waters (detergent use).
Bromate	Health-related parameter. Mutagenic substance suspected from carcinogenic effect, kidney damage. Source: Mostly formed as disinfection by-product (ozonation) if bromide ions in raw water are present. May be present in sodium hypochlorite as pollutant. Waste waters from textile industry (cloth dyeing).
Cadmium	Health-related parameter. Kidney damage. Source: Waste waters from metal and chemical industries, leachates from landfills of batteries and old paints. Diffused pollution from fertilizers in agriculture in the past.
Chromium	Health-related parameter. Hexavalent chromium is genotoxic agent suspected from carcinogenic effect (proved if inhaled). Allergic dermatitis (skin rush). Source: Waste waters from industries (chemical, metal, glass, leather manufacturing). Partial leaching from metal materials (steel, chromium-plated brass).
Copper	Health-related parameter. Acute effect: vomiting, nausea and other gastrointestinal symptoms. Chronic effect: liver and kidney damage. Source: Corrosion of copper pipes of other copper containing products in contact with drinking water; rarely naturally occurring due to geological conditions.

Cyanide	Health-related parameter. Toxic effects on the thyroid and nervous system. Source: Waste waters from industry (metal, plastic, chemical, etc.).
1,2-dichloroethane	Health-related parameter. Possible human carcinogen; toxic effect on liver, kidney, immune and central nervous systems. Source: Waste waters from chemical industry (intermediate in the production of vinyl chloride and other chemicals and to a lesser extent as a solvent).
Epichlorohydrine	Health-related parameter. Local irritation, changes in central nervous system, suspected from carcinogenic effect. Source: Leaching from epoxy-resin coatings of pipes and from some ion-exchangers used in water treatment.
Fluoride	Health-related parameter. Teeth mottling (dental fluorosis), bone damage (skeletal fluorosis). Source: Mostly naturally occurring due to geological structures; rarely from phosphate fertilizers and aluminium industry. Intentionally dosed in treated water for control of caries in some countries.
Lead	Health-related parameter. Reduction of cognitive development and intellectual performance in children. Disturbation of calcium metabolism. Hypertension, kidney damage and anaemia in adults Source: Lead pipes of service connections and plumbing. Brass and bronze parts (valves, fittings) in pipe network. Old types of PVC pipes (lead stabilizers). Lead solders. Organolead antiknock compounds in petrol.
Mercury	Health-related parameter. Kidney damage (inorganic mercury) or central nervous system damage (organic mercury). Source: Waste waters from industry (e.g. electrolytic production of chlorine, electric devices industry, ore mills) and dental units (components of amalgam). Mercury pesticides (for seed treatment) were used in the past.
Nickel	Health-related parameter. Possible carcinogens (proved carcinogens if inhaled), possible effect on reproductive functions; worsening of allergy in individuals who are sensitive to nickel. Source: Leaching from nickel/chromium plated taps, fittings, various valves or some steels. Boiling kettles and pots from pseudo stainless steel may be important source of nickel for consumers.
Nitrate	Health-related parameter. Nitrate is reduced to nitrite in the stomach. Nitrite reacts in blood with haemoglobin to form methaemoglobin – methaemoglobinaemia or “blue-baby” syndrome may occur in very young infants (risk of asphyxia or inner suffocation). Nitrite in GIT also reacts with secondary amines in food to form nitrosamines, which are suspected carcinogens. Source: Human and animal faeces, waste waters from human settlements and animal farms. Inorganic fertilizers in agriculture.
Nitrite	Health-related parameter. See nitrate. Source: See nitrate. Nitrite may be formed from nitrate in water under anoxic conditions.
Pesticides	Health-related parameter. Because of various chemical nature of these (very different group of) substances, there are both substances with very high and very low toxicity among them. Health effects are miscellaneous, too (liver or kidney damage, disruption of hormonal

	and reproductive systems, carcinogenic effect, disorder of blood formation etc.). Source: Large and chemically very various group of substances used to pests or weeds control. Main areas of use: agriculture, forestry, railways, golf courses, etc.
Polycyclic aromatic hydrocarbons	Health-related parameter. Miscellaneous group of substances of various toxic potency, some of them are suspected from carcinogenic effect. Source: Bitumen coatings of steel and cast iron mains. Atmospheric depositions (product of combustion).
Selenium	Health-related parameter. In certain dose essential for human health. Higher intake may cause damage of hair, nails, liver functions or cardiovascular system. Source: Mostly naturally occurring due to geological structures; rarely from waste waters from oil refineries.
Tetrachlorethene and Trichlorethene	Health-related parameter. Liver damage, suspected from carcinogenic effect. They can cause objectionable odour of water. Source: Component of solvents (dry cleaning) and degreasing agents (metal industry, machinery) – waste waters from such business and industrial premises.
Trihalogenmethanes total	Health-related parameter. Toxic influence on liver, kidney and central nervous system. Suspected from carcinogenic effect and disorder of reproductive functions. Source: Group of most common disinfection (chlorinated) by-products.
Vinyl chloride	Health-related parameter. Carcinogenic effect. Source: Leaching from PVC materials (pipes, linings) or formed under anoxic conditions in groundwater polluted by tetrachlorethene and trichlorethene.

Chemical indicator parameters

Parameter	Meaning of parameter / health risks / main sources of pollution or changes
Aluminium	Parameter for process control + aesthetic parameter. May cause problems with aesthetic quality (colour) of water, but no acute toxicity in concentrations usually found in drinking water. Long term use of low doses discussed for possible neurotoxic effect, but not yet proved. Source: Mostly residuum of Al-based coagulants used for water treatment, but in some areas present in raw water (leaching from soil and geological structures).
Ammonium	Parameter for process control. Traditional, but not always reliable indicator of faecal pollution. Not toxic in concentration found in water, but it may compromise disinfection efficiency, support nitrite formation in pipe network or cause water taste and odour problems. Source: Rarely naturally occurring due to geological structures; mostly from waste waters from human settlements and animal farms. Another source is disinfection of water by chloramines and new cementitious lining of water pipes.
Chloride	Parameter for process control (corrosivity) and aesthetic parameter

	(objectionable taste). Possible health effects may be thought only within high total dissolved solids contents. Source: Natural component of water, but contents may be increased also due to deicing of roads and waste waters or due to contamination during water treatment (ion-exchangers in chloride cycle or direct dosing of chloride salts as MgCl for water stabilizing).
Colour	Compromised acceptability for consumers. Source: high contents of natural organic matter or metals (namely iron) of natural origin or pipe corrosion.
Conductivity	Parameter for process control. Indirect indicator of total dissolved solids (TDS). TDS are in basic determined by natural mineral water composition. Sudden change may indicate serious change in water quality. It may influence aggressivity and taste of water. High TDS is considered as risk factor for various kinds of lithiasis (nephro-, uro-, chole-) and arthritis. Very low TDS water supports excretion and losses of some essential elements; may disturb salt-water metabolism of the body and lead to some diseases relating to calcium and magnesium deficiency.
pH	Parameter for process control (it influences many steps in water treatment, including efficiency of disinfection), suitable on-line measured indicator for sudden changes in water quality. pH value may be naturally low in soft (low-mineral) water or water with higher CO2 contents or artificially low due to contamination by acid (e.g. disorder of dosing of some acidic chemicals for water treatment). pH value may be high in water in contact with new cement lining or due to disorder of dosing of some alkaline chemicals for water treatment.
Iron	Parameter for process control and aesthetic parameter (objectionable taste and colour; staining of laundry and plumbing fixtures). Source: natural (geological) origin or pipe corrosion.
Manganese	Parameter for process control and aesthetic parameter (objectionable taste and colour). High exposure is suspected from degenerative effects in central nervous system. Source: natural (geological) origin. Component of some chemicals used for water treatment (kalium permanganate).
Odour	Compromised acceptability for consumers. Source: various organic and inorganic compounds; chlorine, metabolite products of bacteria, cyanobacteria and algae.
Oxidisability	Parameter for process control – non-specific indicator of total content of organic substances indicating contents of natural organic matter or organic pollution. See TOC.
Sulphate	Parameter for process control (corrosivity) and aesthetic parameter (objectionable taste). High concentration together with magnesium may cause laxative effect (diarrhoea). Source: Natural (geological) origin, natural component of water.
Sodium	Aesthetic parameter. It may cause objectionable taste of water. Increase of blood pressure in children. Source: Deicing of roads; waste waters from some industries. Contamination during water treatment (ion-exchangers in sodium cycle; chemicals containing sodium for disinfection or pH adjustment).
Taste	Compromised acceptability for consumers. Source: various organic and inorganic compounds; chlorine, metabolite

	products of bacteria, cyanobacteria and algae.
Total organic carbon (TOC)	Parameter for process control – non-specific indicator of total content of organic substances. There is (possibly) no direct health impact, however, higher TOC content may compromise disinfection efficiency and water colour and support microbial regrowth in distribution network. Source: natural organic matter (humic acids etc.), communal waste waters.
Turbidity	Parameter for process control and aesthetic parameter. Compromised acceptability for consumers and disinfection efficiency; support of microbial growth. Easy and on-line measured indicator of sudden changes in water quality. Source: non-dissolved substances with origin in raw water (dust or soil particles, planctonic and other microscopic organisms) or in distribution network (corrosion products or disturbed sediments).

Radioactivity

Parameter	Meaning of parameter / health risks / main sources of pollution or changes
Tritium	Health-related parameter. Potential health effects: cancer, damage of genetic material, effects on foetuses. Source: nuclear power plants (heavy water-moderated reactors), nuclear fusion industry, nuclear reprocessing, watch industry.
Total indicative dose	Indicator of annual exposure or committed effective dose from one year´s consumption of drinking water (from the possible total radioactive – both naturally occurring and artificial – contamination of drinking water). It is calculated usually from screening monitoring for gross alpha and/or beta activity or from the results of specific analysis of individual radionuclides if screening activity levels are exceeded. Radiation-induced stochastic health effects which include cancer and hereditary effects (genetic malformation) are not expected if committed effective dose is below 0.1 mSv/year. Radioactive constituents of drinking water result by far from naturally occurring radioactive species, in particular radium-226/228; to a lesser extent from technological processes involving naturally occurring radioactive materials (e.g. mining), rarely from radionuclides discharged from nuclear fuel cycle facilities or manufactured radionuclides.

ANNEX B

Extended list of suitable parameters available and its relevance and purpose of use in separate parts of the supply system. Adapted from TECHNEAU document Monitoring and control of drinking water quality. Selection of key-parameters [5]

Parameter	Catchment	Source water SW	Source water GW	Treatment [1]	Finished water	Distribution ingress [2]	Distribution time related[3]	Customer's tap
Microbiological parameters								
E. coli	A,B	A,B	A,B	A,B,C	A,B	A,B		A,B
Enterococci	B	B		B,C	B	B		B
Clostridium perfringens	B	B		B,C	B			B
Total coliforms	B	B	B	B,C	B	B	B,C	B
Colony count/HPC				B,C	B	B	B,C	B
Enteric viruses	A	A						
Giardia/Cryptosporidium	A	A		A,C				
Campylobacter	A	A						
Legionella								A
Pseudomonas aeruginosa							A,C	A
Aeromonas							C	
F-specific RNA phages				C				
Aerobic spore-forming bacteria				C				
Biofilm formation							C	
Total cell counts				C	C	C	C	C
Cultivation-free viability analysis				C	C	C	C	C
Chemical parameters								
antimony					A,B			A,B
arsenic			A,B		A,B			A,B
benzene					A,B			
benzo(a)pyrene					A,B			A,B
boron	A,B	A,B			A,B			
bromate				A,B, C,F	A,B			
cadmium								A,B
copper								A,B
chromium					A,B			A,B
cyanides		A,B			A,B			
1,2-dichloroethane					A,B			
fluoride			A,B		A,B			
lead								A,B
mercury					A,B			
nickel								A,B
nitrite				A,B,C	A,B,C			A,B
nitrate			A,B		A,B			
PAHs					A,B			A,B

Parameter	**Catchment**	**Source water SW**	**Source water GW**	**Treatment [1]**	**Finished water**	**Distribution ingress [2]**	**Distribution time related[3]**	**Customer's tap**
pesticides	A,B,F	A,B,F	A,B		A,B			
selenium			A,B		A,B			
tetra- & trichloroethene					A,B			
disinfection byproducts[4]				A,B, C,F	A,B			A,B
radioactivity			A,B					
EDCs	A,F	A,F			F			
genotoxicity	A	A		A,F	A			
acute toxicity	A,E	A,E			A	A		A
algae toxins	A,E,F	A,E,F			A,F			
pharmaceuticals	F	F			A			
industrial chemicals	A,F	A,F						
organic micropollutants[5]				A, (B), C,D				A,C,D, (B)
pH				B,C	B,C		C	
chloride				B,C	C			
alkalinity				C	C			
saturation index				C				
sodium				B,C				
conductivity				B,C				
calcium				C,D				
magnesium				C,D				
sulphate				B,C				
aluminum				B,C			C	
ammonium		B	B	B,C				
iron			B,D	C,D				
manganese			B,D	C,D				
taste				B,C,D	B,D			B,D
odour				B,C,D	B,D			B,D
colour				B,C,D	B,C,D			B,D
turbidity		B,E		B,C	B,C	B,D	C	B,D
AOC/BDOC				C	C			
DOC/TOC		B,E	B	B,C				
UV absorption		E		C	C	C		
particle counts				C	C			
oxygen				C				
inhibitors				C [6]				
Process parameters								
head loss				C				
filter velocity				C				
residence time								
ozone dose, contact time (Ct)				C				
ozone concentration				C				
residual ozone				C				
UV dose				C				

Parameter	Catchment	Source water SW	Source water GW	Treatment [1]	Finished water	Distribution ingress [2]	Distribution time related[3]	Customer's tap
oxidant dose				C				
residual oxidant conc.				C				
disinfectant dose				C				
residual disinfectant conc.				C	A	A	C	D
inhibitors					C			
sediments (e.g. iron oxides)							C	
flow rate				C				
transmembrane pressure				C				
pressure drop				C,E				
particle size distribution				C,E				
membrane (bio)fouling				C				

Notes:

[1] Various parameters are suitable/preferable for different treatment steps. For details see original document.

[2] Monitoring of quality changes (ingress of pollutants) during distribution.

[3] Monitoring of time related changes in water quality due to residence time in the distribution network.

[4] Disinfection by-products: chlorination by-products, ozonation by-products, UV/AOP by-products.

[5] General group, consisting of e.g. pharmaceuticals, industrial pollutants etc.

[6] If dosed.

Selection criteria:

A. **Health-related parameter**
B. **Parameter listed in EU Drinking Water Directive (98/83/EC)**
C. **Parameter for process control**
D. **Aesthetic parameter**
E. **Early-warning parameter**
F. **Emerging water quality parameter.**

Abbreviations:

SW = surface water
GW = ground water
HPC = heterotrophic plate count
EDC = endocrine disrupting compounds
AOC/BDOC = assimilable organic carbon/ biodegradable dissolved organic carbon
DOC/TOC = dissolved organic carbon/ total organic carbon
AOP = advanced oxidation process

ANNEX C

Parametric values, exposure limits (total daily intake = TDI) and associated cancer risk of parameters included in the Council Directive 98/83/EC

Microbiological parameters

Parameter	Parametric value	Unit
Escherichia coli (E. coli)	0	CFU/100 ml
Enterococci	0	CFU/100 ml

Microbiological indicator parameters

Parameter	Parametric value	Unit	Notes
Clostridium perfringens (including spores)	0	CFU/100 ml	Note 1
Colony count at 22°C	No abnormal change		
Coliform bacteria	0	CFU/100 ml	

Note 1: This parameter need not be measured unless the water originates from or is influenced by surface water. In the event of non-compliance with this parametric value, the Member State concerned must investigate the supply to ensure that there is no potential danger to human health arising from the presence of pathogenic microorganism, e.g. cryptosporidium. Member States must include the results of all such investigations in the reports they must submit under Article 13(2).

Chemical parameters

Parameter	Parametric value	Unit	Notes	TDI (mg/kg/day)	Cancer risk
Acrylamide	0.10	µg/l	Note 1		Value 0.10 µg/l corresponds to cancer risk $5x\ 10^{-6}$
Antimony	5.0	µg/l		0,006	
Arsenic	10	µg/l			Value 10 µg/l corresponds to (skin cancer) risk $6x\ 10^{-4}$
Benzene	1.0	µg/l			Value 1.0 µg/l corresponds to cancer risk 10^{-6}
Benzo(a)pyrene	0.010	µg/l			Value 0.010 µg/l corresponds to cancer risk close to 10^{-6}; (WHO: value 0,7 µg/l corresponds to the risk 10^{-5})
Boron	1.0	mg/l		0,16	
Bromate	10	µg/l	Note 2		Value 10 µg/l corresponds to cancer risk $5x\ 10^{-5}$
Cadmium	5.0	µg/l		0,007	
Chromium	50	µg/l		0,003 (RfD_o for Cr-VI)	
Copper	2.0	mg/l	Note 3	0,04 (RfD_o)	
Cyanide	50	µg/l		0,012	
1,2-dichloroethane	3.0	µg/l			Value 3.0 µg/l corresponds to cancer risk 10^{-6}
Epichlorohydrine	0.10	µg/l	Note 1	0,00014	

Fluoride	1.5	mg/l		0,06 (RfD_o)	
Lead	10	µg/l	Notes 3, 4	0,0035	
Mercury	1.0	µg/l		0,00049	
Nickel	20	µg/l	Note 3	0,005	
Nitrate	50	mg/l	Note 5	3,7	
Nitrite	0.50	mg/l	Note 5	0,07	
Pesticides	0.10	µg/l	Notes 6, 7		
Pesticides total	0.50	µg/l	Notes 6, 8		
Polycyclic aromatic hydrocarbons	0.10	µg/l	Note 9		
Selenium	10	µg/l		0,005 (RfD_o)	
Tetrachlorethene and Trichlorethene	10	µg/l	Sum of TCE and PCE	0,00146 (TCE); 0,014 (PCE)	
Trihalogenmethanes total	100	µg/l	Note 10		
Vinyl chloride	0.50	µg/l	Note 1		Value 0.05 µg/l corresponds to cancer risk about 2x 10^{-5}

Note 1: The parametric values refers to the residual monomer concentration in the water as calculated according to specifications of the maximum release from the corresponding polymer in contact with the water.

Note 2: Where possible, without compromising disinfection, Member States should strive for a lower value.
For the water referred to in Article 6(1) a), b) and d), the value must be met, at the latest, 10 calendar years after the entry into force of the Directive. The parametric value for bromate from five years after the entry into force of this Directive until 10 years after its entry into force is 25 µg/l

Note 3: The value applies to a sample of water intended for human consumption obtained by an adequate sampling method at the tap and taken so as to be representative of a weekly average value ingested by consumers. Where appropriate the sampling and monitoring methods must be applied in a harmonised fashion to be drawn up in accordance with Article 7(4). Member States must take account of the occurrence of peaks levels that may cause adverse effect on human health.

Note 4: For water referred to in Article 6(1)a), b) and d), the value must be met, at the latest, 15 calendar years after the entry into force of this Directive. The parametric value for lead from five years after the entry into force of this Directive until 15 years after its entry into force is 25 µg/l.
Member States must ensure that all appropriate measures are taken to reduce the concentration of lead in water intended for human consumption as much as possible during the period needed to achieve compliance with the parametric value.
When implementing the measures to achieve compliance with that value Member States must progressively give priority where lead concentrations in water intended for human consumption are highest.

Note 5: Member States must ensure that the condition that [nitrate]/50 + [nitrite]/3 $\geq$ 1, the square brackets signifying the concentrations in mg/l for nitrate (NO_3) and nitrite (NO_2), is complied with and that the value of 0,10 mg/l for nitrites is complied with ex water treatment works.

Note 6: „Pesticides“ means: organic insecticides, organic herbicides, organic fungicides, organic nematocides, organic acaricides, organic algicides, organic rodenticides, organic slimicides, related products (*inter alia*, growth regulators) and their relevant metabolites, degradation and reaction products. Only those pesticides which are likely to be present in a given supply need be monitored.

Note 7: The parametric value applies to each individual pesticide. In the case of aldrin, dieldrin, heptachlor and heptachlor epoxide the parametric value is 0,030 µg/l.

Note 8: „Pesticides - total“ means the sum of all individual pesticides detected and quantified in the monitoring procedure.

Note 9: Sum of concentrations of specified compounds. The specified compounds are: benzo(b)fluoranthene, benzo(k)fluoranthene, benzo(ghi)perylene, indenol(1,2,3-cd)pyrene.

Note 10: Sum of concentrations of specified compounds. The specified compounds are: chloroform, bromoform, dibromochloromethane, bromodichloromethane. Where possible, without compromising disinfection, Member States should strive for a lower value.
For the water referred to in Article 6(1)a), b) and d), the value must be met at latest, 10 calendar years after the entry into force of this Directive. The parametric value for total THMs from five years after the entry into force of this Directive until 10 years after its entry into force is 150 µg/l.
Member States must ensure that all appropriate measures are taken to reduce the concentration of THMs in water intended for human consumption as much as possible during the period needed to achieve compliance with the parametric value. When implementing the measures to achieve compliance with that value Member States must progressively give priority where THMs concentrations in water intended for human consumption are highest.

Chemical indicator parameters

Parameter	Parametric value	Unit	Notes
Aluminium	200	µg/l	
Ammonium	0.50	mg/l	
Chloride	250	mg/l	Note 1
Colour	Acceptable to consumers and no abnormal change		
Conductivity	2 500	µS/cm at 20°C	Note 1
pH	≥ 6,5 and ≤ 9,5	units pH	Notes 1, 2
Iron	200	µg/l	
Manganese	50	µg/l	
Odour	Acceptable to consumers and no abnormal change		
Oxidisability	5.0	mg O_2/l	Note 3
Sulphate	250	mg/l	Note 1
Sodium	200	mg/l	
Taste	Acceptable to consumers and no abnormal change		
Total organic carbon (TOC)	No abnormal change		Note 4
Turbidity	Acceptable to consumers and no abnormal change		Note 5

Radioactivity

Parameter	Parametric value	Unit	Notes
Tritium	100	Bq/l	
Total indicative dose	0.10	mSv/year	

Note 1: The water should not be aggressive.

Note 2: For still water put into bottles or containers, the minimum value may be reduced to 4,5 pH units. For water put into bottles or containers which is naturally rich in or artificially enriched with carbon dioxide, the minimum value may be lower.

Note 3: This parameter need not be measured if the parameter TOC is analysed.

Note 4: This parameter need not be measured for supplies of less than 10 000 m^3 a day.

Note 5: In the case of surface water treatment, Member States should strive for a parametric value not exceeding 1,0 NTU (nephelometric turbidity units) in the water ex treatment works.