Soil and groundwater Quality Standards

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Contents

1 Introduction

Statoil has developed and applies the Environmental Impact Factor (EIF) to assess the environmental risk of discharges. There are different methodologies to yield an EIF, each focusing on a different emission (air discharges, drilling discharges, produced water discharges and acute discharges). These are developed for offshore installations. A separate impact factor has been developed for onshore installations that discharge into the marine environment: the EIFonshore. Statoil also intends to develop an EIF for land based activities and emissions, the EIFsoil, sw, gw (EIFsoil, surface water and groundwater).

In general, for the calculation of the EIF, a comparison of the exposure concentration (Predicted Environmental Concentration (PEC)) and the environmental toxicity threshold (Predicted No Effect Concentration (PNEC)) is carried out. The PEC/PNEC ratio is an indicator of potential risk. Species Sensitivity Distributions (SSDs) can be used to translate PEC/PNEC ratios into risk measures (Smit *et al.*, 2005). However, it is not foreseen to use SSD calculations for the EIFsoil. Instead, quality standards will be derived based on established environmental soil protection policies. An overview of existing policies and related quality standards is required in order to form the Statoil policy towards soil protection for use in the EIFsoil. The goal of this study is to provide this background information for the development of the EIFsoil. Relevant quality standards are also provided separately, in an Excel spreadsheet.

The first chapter describes existing regulatory frameworks in which soil and groundwater quality standards are used. First, different types of quality standards are introduced, including their use in regulatory frameworks. The second section of this chapter describes soil protection policies. Chapter 3 provides background information for the derivation of soil and groundwater quality standards. In the final chapter, existing soil and groundwater quality standards are provided.

2 Regulatory framework

2.1 Introduction

Threshold values are generic quality standards, or Screening Values (SVs), adopted in many countries to regulate the management of contamination. Threshold values enable us to judge whether a potential charge with pollutants might cause a risk or not. All countries that have been included in this study (US, EU, Canada, the Netherlands, and Norway) address the protection of human health in the development of soil quality guidelines and/or standards (US EPA, 1996; EC, 2003; CCME, 2006; de Bruijn *et al.*, 1999; SFT, 1999). In some countries, such as Canada, human health and environmental quality standards are integrated in one value by choosing the lowest of the two. When the lowest value is affected by high uncertainty, weighted averages of the lowest and the highest values can be preferred. In the Netherlands, for example, the same weight is given to human as to ecotoxicological protection. This means that the most stringent (i.e. the lowest) value of the human toxicological and the ecotoxicological risk limits is taken as 'the' Intervention Value (seriously contaminated soil). An exception is made if the lower value is much more uncertain, in which case, the higher, but more reliable value, is taken as the overall Intervention Value (Carlon, 2007). In some other countries, such as Norway, the integration is avoided and both values are presented separately.

There are many different types of ecological soil threshold values, along with the various roles in national regulatory frameworks, for example: trigger values, reference values, target values, intervention values, clean up values and cut-off values. The diversity of terms reflects the lack of a coherent framework in Europe for the derivation and use of SVs (Carlon, 2007). As described by Bachmann *et al.* (1999), one may define threshold values as soil quality standards, given as mg/kg soil or µg/l soil eluate, regardless whether they are called screening, trigger or guideline levels, or any other name. Soil quality standards are usually expressed as the concentration of contaminants in soil (mg/kg soil-dry weight) above which certain actions are recommended or enforced.

Quality standards are often preventive and serve to describe and realise the policy objectives. Thus there is a close relation between the definition of quality standards and soil policy formulation. In other words, soil quality criteria build the link between scientific information and environmental (policy) objectives (Figure 1). On the other hand, soil quality criteria fit in or complement political strategies and concepts (Bachmann *et al.*, 1999). As shown in Figure 1, there are two types of regulatory bases used for the introduction of quality standards, legal instruments and informal instruments or guiding documents.

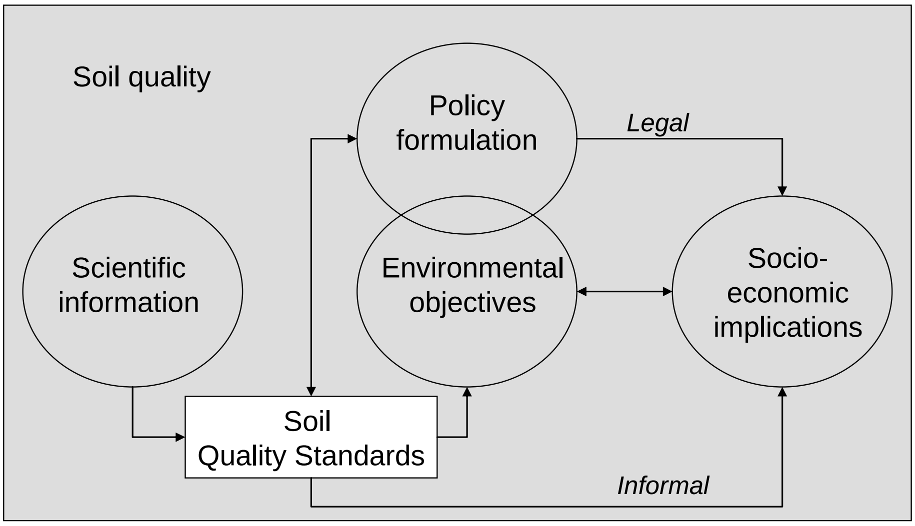

Figure 1 The use of quality standards in the regulatory framework

There are various uses of quality standards for soils, such as (Bachmann *et al.*, 1999):

- Risk assessment for contaminated soils;
- Pollution prevention policies;
- Environmental impact assessment;
- Control of remediation goals and other monitoring activities;
- Formal risk assessment procedures, in which quality standards function as a pre-requisites;
- Management of soil as a product (in the context of excavated soil being reused/recycled, one may see this soil as a “product” and not as “waste”);
- Criteria for the fertility of soil (in the sense of agriculture and the use of organic soil quality as a resource for agricultural use of soils);
- Management of salinity and acidity;
- Guiding criteria for land use.

2.2 Policy framework

Setting quality standards is strongly related to policy choices. There are two general political approaches to soil protection (Bachmann *et al.,* 1999):

- The ALARA requirement (as low as reasonably achievable) and “stand still”-strategies;
- Immission-based approach on precautionary soil levels.

The classical policy objective in soil protection is to protect the multifunctionality of soils. The user of the land should conserve the functions for future users, in order to keep the options for actual and future land use open (Van-Camp *et al.*, 2004). Following this policy, the precautionary principle should be applied. Another policy is to differentiate between different types of land uses according to their sensitivity for pollution. This is a more short-term risk based point of view, related to the current use of the land. It has to be noted, that not taking into account future land uses and potential impacts in the long term, is in conflict with sustainability (Van-Camp *et al.*, 2004).

Different policies (for instance on water, waste, chemicals, industrial pollution prevention, nature protection, pesticides, agriculture) are contributing to soil protection. Within EU policies, quality standards are established in a few of these regulations. For example, limit ranges for concentrations of heavy metals in soil are set out in Annex I of the Sewage Sludge Directive (86/278/EC), on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture. There is no reference to the origin of these values (EC, 1986). There is no other EU regulation containing quality standards for soil (Bachmann *et al.*, 1999). Other legally established quality standards are not describing the quality of the receptor (e.g. soil) but are related to emissions. For example, the Directive on Integrated Pollution Prevention and Control (IPPC) requires all installations listed in Annex I of the Directive, to be authorised through permits containing emission limit values (EC, 1996). In 2006, the European Commission adopted a comprehensive EU strategy specifically dedicated to soil protection (EC, 2006). The framework Directive sets out common principles for protecting soils across the EU. There are no quality standards implemented in the EU soil protection strategy. The new Groundwater Directive (2006/118/EC) complements the Water Framework Directive and requires groundwater quality standards to be established by the end of 2008. The BRIDGE (Background cRiteria for the IDentification of Groundwater thrEsholds) project, within the context of the EC 6th Framework Programme, provides methodological references for the derivation of groundwater quality criteria (Griffioen *et al.*, 2006).

In most EU countries, soil quality standards are provided by special laws for contaminated sites. In some cases they are provided by soil and groundwater protection laws and in few cases by waste management laws. In the USA there is ample experience with the development of soil quality standards. However, these soil values are not used officially. Norway has calculated soil quality values that are used in the guidelines for the risk assessment of contaminated sites (SFT, 1999). Soil quality guidelines for most sensitive land use form the basis of Tier 1 risk assessment in Norway.

The variability of legal status of soil values in EU countries is high. In some countries soil quality standards have been proposed but not legally adopted, while in other cases their formulation is still under development or revision. In some countries the use of soil values is only advised and not obligatory. Within the EU, ecological technical guidelines have been legally approved only in three countries, i.e. Germany, Finland and the Netherlands (Carlon, 2007). The US and Canadian soil values are intended for general guidance only, and do not establish or affect legal rights or obligations (US EPA, 2005a; CCME, 2006).

Based on available literature (de Bruijn *et al.*, 1999; Environment Agency, 2004; US EPA, 2005a; CCME, 2006; Carlon, 2007), it can be concluded that the following authorities have considerable experience of the development of soil protection values:

- European Commission (EC);
- The Netherlands;
- Canadian Council of Ministers of the Environment (CCME);
- United States Environmental Protection Agency (US EPA).

In Chapter 3 the main derivation methods for quality standards are described, based on the approaches followed by these authorities. In addition, the Norwegian guidelines for risk assessment are included.

3 Derivation methods

3.1 Background

As already mentioned in section 2.1, derivation methods of quality standards have scientific and political bases. Derivation methods differ from country to country and the resulting numerical values vary consequently. A review on the derivation methods of soil screening values in Europe (Carlon, 2007) revealed that the differences in derivation methods between countries are primarily scientific, followed by political/regulatory and in few cases geographical and biological or socio-cultural. Political and scientific issues can often be closely linked and difficult to distinguish.

For the derivation of quality standards, most EU countries developed national risk assessment models. Some countries (Austria, Czech Republic, Lithuania, Slovak Republic, and Poland), adopted, and eventually adapted, values formulated by other countries. The most common methodological references were: EC Technical Guidance Document on risk assessment (1996 and implementations), US-EPA guidance, methods developed in The Netherlands and methods/values from the Russian federation (ex Soviet Union). Directly or indirectly, quality standards are always based on a risk based approach (Carlon, 2007).

Risk levels
Quality standards of contaminants are usually derived on the basis of the potential risk that contaminants pose to the ecosystem. The risk relates to the toxicity (an intrinsic property) of the contaminant and the exposure of the receptors of concern to the contaminant. In general three different types of values can be distinguished, based on three different risk levels:

- Negligible risk: long term objectives, e.g. target values;
- Intermediate (or warning) risk: further investigation, e.g. trigger value;
- Potentially unacceptable risk: need of remediation, e.g. cut off values.

The level of risk is usually related to the intended application of the value. The threshold value can be used for screening risk assessment (based on conservative assumptions) or site-specific risk assessment (taking full account of local circumstances). In most EU countries, "intermediate" or "potentially unacceptable" values are used to indicate the need of remediation. In the different applications of soil values it is difficult to distinguish between trigger values (triggering actions) and intervention values (enforcing actions). It seems that the last ten years, soil values more often are used as trigger values (Carlon, 2007).

The environmental protection policy of the Netherlands distinguishes between two types of standards based on the toxicological risk level (de Bruijn *et al.*, 1999):

- Maximum permissible concentration (MPC): the concentration at which no adverse effect is expected (human and ecosystem protection);
- Target value: the concentration at which the environmental effects are negligible.

In the Dutch soil protection policy only the long-term standards (target values) are considered relevant, because soil quality only changes gradually (de Bruijn, *et al.*, 1999).

Stepwise approach
All authorities follow a similar stepwise approach (Figure 2) to develop screening values (Environmental Agency, 2004). These steps are discussed in the following paragraphs.

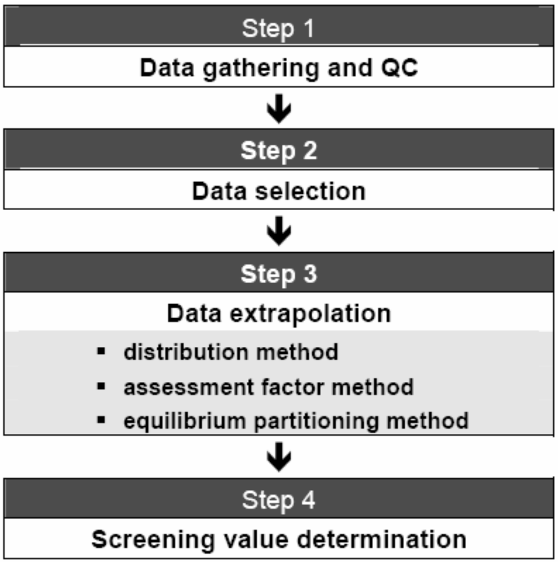

Figure 2 Step-wise approach to developing screening values (Environmental Agency, 2004).

3.2 Toxicity data

As presented in the general approach to develop screening values (Figure 2), the first step is the gathering of toxicological data. There are a number of ecological receptors that can be considered in the derivation of quality standards, as schematically presented in Figure 3:

- Microbiological processes;
- Soil fauna;
- Plants;
- Above soil ecosystem receptors, i.e. terrestrial vertebrates and invertebrates;
- Aquatic ecosystem.

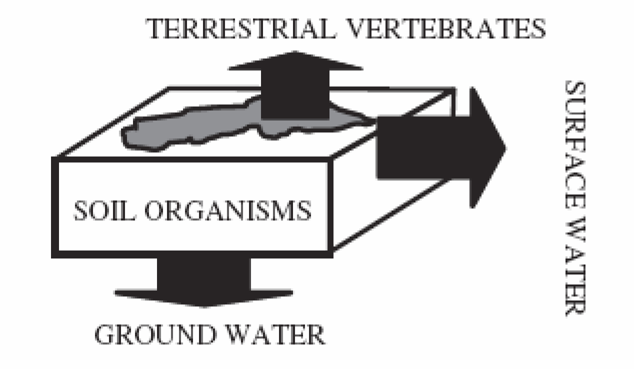

Figure 3 Ecological receptors (based on Fernández, et al., 2006).

The ecological receptors considered by most EU countries in the derivation of ecological soil values are microbiological processes, soil fauna and plants. Above soil ecosystem receptors, i.e. terrestrial vertebrates and invertebrates, are included in many EU countries, but only when secondary poisoning due to bioaccumulating contaminants can be relevant. Effects on the aquatic ecosystem are only accounted for in Belgium (Walloon region), Spain and Sweden. The choice of receptors mainly concerns a political decision, but is strongly supported by scientific knowledge (Carlon, 2007).

In regard to the ecotoxicological endpoints, effects on survival, growth, reproduction, mobility, microbial mediated processes and enzyme activities, are taken into account in nearly all EU countries, with slight variability. The reasons of variability are scientific (Carlon, 2007).

Data sources

Ecotoxicological databases developed by competent national institutions in Europe are very limited. Five countries, i.e. The Netherlands (e-tox), Spain (BaseTox developed by the Bask Government), Germany, Czech Republic and Flanders in Belgium, indicate the presence of supporting national databases. The Dutch e-tox database developed by RIVM is a common reference also for other EU countries, together with other databases developed by national or international organizations and published on internet, among which (Carlon, 2007):

- Risk Assessment Reports (RARs) published by the European Chemical Bureau of the EU Commission (www.ecb.jrc.it);
- ECOTOX developed by the United States Environmental Protection Agency, (www.epa.gov/ecotox/);
- Other United States databanks, like IRIS, RAIS, HSDB, etc.;
- Data published by the Canadian Council of Ministers of the Environment (CCME).

For the purpose of deriving soil quality values, national committees are often established, e.g. in Spain and The Netherlands, to evaluate toxicological data from various data sources.

For the same contaminant, toxicological values from different databases can easily differ by more than one order of magnitude. The selection of data sources is thus very significant for variations in soil values.

Selection of data

When sufficient toxicological data is gathered, a selection process is applied (second step in the development of screening values, see Figure 2). Each authority uses its own criteria for selecting data but generally the same reasons for selection apply (Environmental Agency, 2004):

- Data is suitable for use in preferred extrapolation methods;
- Data is suitable to meet environmental policies, and;
- A preference for species that are representative of their national ecosystems.

The European Commission in their technical guidance (EC Technical Guidance Document for risk assessment of new and existing chemicals) recommends selecting data using quality criteria based on reliability, relevance and adequacy (EC, 2003). The US EPA in the development of their ecological soil screening levels (Eco-SSLs) evaluates toxicity data based on criteria and scores the quality of data to ensure only the most appropriate data is used in the derivation of Eco-SSLs. Some other authorities use expert judgement to select (or reject) data without reporting the criteria or judgements made in selecting final data sets. The US and the Netherlands apply extensive data requirements and cite test methodologies, soil characteristics, measurement endpoints, species and contaminant details as being important parameters to select for (Environmental Agency, 2004).

When multiple toxicity data for the same toxicological endpoint is available, generally one value is derived based on the geometric mean. When data are available for more endpoints for that species, the most sensitive is taken (Carlon, 2007).

Data may also be treated so that it can meet selection criteria. For example, the most likely form of data treatment is normalising soil data. In the complex soil compartment various soil parameters (e.g. organic matter content) can influence the availability of a contaminant for uptake by organisms. This means that toxicity test results using different soil may not be directly comparable. To account for this, toxicity data can be normalised by converting results to a standard soil where data on the organic matter content of the test soil is provided. Normalisation of toxicological values to standard soil properties is commonly performed in the derivation of quality standards (Carlon, 2007). Normalisation parameters are organic carbon and, for metals only, clay content. A normalisation method applied by several EU countries is 'the empirical reference lines' developed by RIVM in The Netherlands. With this methodology, the effect concentration (EC) is recalculated for a standard soil, i.e. a soil that contains 10% organic matter and 25% of clay (Traas, 2001):
$EC_{\text{(standard soil)}} = EC_{\text{(experiment)}} * (R_{\text{(standard soil)}} / R_{\text{(experiment)}})$.

The reference values (R) for metals in soil are based on reference lines. The reference lines were derived from a regression analysis on the 90^{th} percentiles of ambient background concentrations from various, relatively unpolluted sites in The Netherlands with percentage clay and organic matter content of these soils (Traas, 2001).

In EU countries, screening values are derived for standard soils and soil type adjustments are recommended for site-specific assessment. Reasons of variability within soil type dependency of quality standards are mainly political reasons, scientific feasibility and, in principle, also variability of soil types within the country (Carlon, 2007).

3.3 Extrapolation

The third step in the derivation of screening values (Figure 2) is data extrapolation. There are three widely recognised methods used to extrapolate laboratory toxicity data to reflect field situations (Environmental Agency, 2004):

- Distribution-based methods that can include a statistical distribution or a ranked distribution and select a particular percentile or cut-off point as the screening value.
- An assessment factor method selects the lowest reported toxicity value and divides this value by an assessment (safety/uncertainty) factor.
- Equilibrium partitioning method which converts aquatic toxicity data for use in the terrestrial compartment.

Table 1 shows the general extrapolation methods used by different countries. It is indicated whether these countries also provide quality standards for (priority) substances. The Netherlands, Canada and Norway have lists of national soil quality standards available. The EC provides guidelines for the derivation of quality standards, in the form of PNEC values. For some substances, a RAR is published in which PNEC values are derived. The US also provides mainly the guidelines to derive quality standards. However, for only a few substances the quality standard is available.

Table 1 Overview of general extrapolation approaches used by main authorities

Jurisdiction	Application	Trophic level	Extrapolation approach	Values available
European Community	Screening, clean-up and risk assessment	Invertebrates, plants	Assessment factor, SSD, equilibrium partitioning	Limited
United States	Screening	Invertebrates, plants, wildlife	Assessment factor	Limited
The Netherlands	Screening, clean-up	Invertebrates, plants, wildlife	Assessment factor, SSD, QSAR, equilibrium partitioning	Yes
Canada	Screening, clean-up	Microbes, invertebrates, plants, wildlife	Assessment factor	Yes
Norway	Risk assessment	Microorganisms, plants, animals	Assessment factor, SSD	Yes

Sensitivity distribution
For the derivation of soil quality standards within the EU, usually Species Sensitivity Distributions (SSD) are applied, if sufficient ecotoxicological data are available[1]. A cut-off percentage p is chosen (to protect 100-p percent of species) and the desired 'safe' concentration (HCp) is calculated. The 5th percentile (i.e. p=5) of a chronic toxicity distribution (HC5) is chosen by the Netherlands and the EC TGD to be protective for most species in a community, but the value of p is a policy decision, not a scientific one (Environmental Agency, 2004).

Assessment factors
If insufficient ecotoxicological data are available, assessment factors are applied. Most international authorities use an assessment factor approach to derive screening values and may even apply additional assessment factors to values derived using other extrapolation methods when there is large uncertainty in the data (Environmental Agency, 2004). In Spain and Canada, for example, assessment factors are considered as first approach and are preferred above the SSD statistical extrapolation. Within Europe, the application of assessment factors usually refers to the values recommended by the EC Technical Guidance Document (EC, 2003). Canada prefers the weight of evidence approach (see below) which also includes the application of uncertainty factors (UF). If there is insufficient data available, the Lowest Observed Effect Concentration Method or the Median Effects Method is used (CCME, 2006).

The modified EPA method uses assessment factors and is internationally accepted. The lowest assessment factor 10 is applied on the lowest NOEC (No Observed Effect Concentration) value for chronic toxicity. The highest factor 1000 is applied on the lowest L(E)C50 value for acute toxicity (de Bruijn *et al.*, 1999). This methodology is used in the Netherlands for the derivation of quality standards for some substances.

Weight of evidence
This method uses a percentile of the effects data set, or combined effects and no effects data set, to estimate a concentration in the environment expected to cause no adverse biological effects, as with the SSD method. There are two approaches to the Weight of Evidence Method for ecological soil contact guidelines (CCME, 2006). The preferred approach is to compile effective concentration (EC) data for a certain percentile (such as 25% (EC25) or 50% (EC50)). If, however, insufficient EC data are available and these values cannot be derived from

[1] The minimum species requirements when using the SSD method are at least 10 NOECs (preferably more than 15) for different species covering at least 8 taxonomic groups (Smit *et al.,* 2007).

the dose-response curves, then the combined set of "effects" and "no observed effects" data are used instead. An uncertainty factor between 1 and 5 can be applied, depending on the available data.

Equilibrium partitioning method

When no, or insufficient, ecotoxicological data on terrestrial species are available, representative NOEC values can be extrapolated from observed effects on aquatic organisms. For this purpose, the equilibrium partitioning method is applied (EC, 2003). Most EU countries, with exception of Denmark, have adopted this method. Using this approach means converting aquatic data to the soil environment by using the soil/water partition coefficient. It is assumed that bioavailability and toxicity of chemicals to soil organisms is only determined by the concentration of a contaminant in the soil pore water. As some organisms take up contaminants from the solid phase, the total uptake for some substances may be underestimated (Environmental Agency, 2004). To overcome the potential for underestimation when considering lipophilic compounds (log Kow > 5), the EC TGD recommends an additional factor of 10 to be applied to the final PEC/PNEC ratio. When only considering effect concentrations, it is reasonable to assume that the PNECsoil will be divided by a factor of 10 (Environmental Agency, 2004).

Bioconcentration and bioaccumulation

Bioconcentration in soil organisms and plants is always considered in the derivation of quality standards by EU countries (Carlon, 2007). Secondary poisoning is usually estimated for only few substances that are likely to bioaccumulate, e.g. some heavy metals and organic chemicals with logKow >5, (e.g. Walloon, Finland, The Netherlands, UK).

Some authorities also use physico-chemical information as an early screen for predicting the likelihood of a contaminant moving through food chains. For example, the Dutch authorities suggest contaminants with a log Kow greater than 3 and molecular weight less than 700 are likely to accumulate in terrestrial biota and flag these contaminants as likely to cause harm to higher organisms early in the risk assessment process (Environmental Agency, 2004). US EPA Region IV suggests that for those contaminants that biomagnify, soil values can be determined by back-calculations from acceptable levels in prey items through two trophic levels to the soil (US EPA, 2003a).

Background concentration

Different definitions of background concentration exist, e.g. focused on contaminants that have a "natural" origin ("natural" background) or concentrations that are found in large areas, including man-influenced agricultural land. Moreover, different statistics can be used to derive background representative values, e.g. the mean value or a specific percentile.

The average background concentration can be differently considered in the derivation of negligible risk values:

- as reference value;
- added to the estimated negligible risk concentrations;
- as reference concentration if it exceeds the estimated negligible risk concentration.

The use of the above approaches not only differs between countries (or policies) but can also differ between substances: naturally occurring substances and new chemicals. Negligible risk values for metals and metalloids are usually related to national background concentrations. It has to be noted that for heavy metals the average background is usually much higher (one order of magnitude or more) than the estimated negligible risk concentration. When the estimated risk based concentration is lower than the average background concentration, often the background concentration is taken as quality standard (Carlon, 2007).

The use of background concentration in the derivation of quality standards varies between EU countries. It is also a highly sensitive factor on the derivation of quality values. In the Netherlands the 'added risk approach' is applied for metals and other naturally occurring substances. With the added risk approach the "natural" background concentration in soils is added to the risk-based concentration (de Bruin *et al.*, 1999).

According to the viewpoint of several EU countries, any soil protection policy should be aware of the difference between existing contamination resulting from historic activities and new contamination, resulting from ongoing deposition of pollutants on soils from land application of waste, soil related products or by atmospheric deposition (Bachmann *et al.*, 1999).

US EPA Region IV disallows the use of area or regional background levels and prefers to develop screening level concentrations based on data showing associations with ecological effects (US EPA, 2003a).

Harmonisation procedure

The Netherlands further accounts for the harmonisation of water and soil quality standards with standards for air. For example, emission of benzene to surface water results in an equilibrium concentration in air higher than the quality standard in air. In that case, the harmonisation procedure is applied (de Bruijn *et al.*, 1999). This method adjusts for the equilibrium of benzene between water and air by using a factor 10. If the soil value is based on the surface water value (because of a lack of soil toxicity data) this adjustment factor is implemented for soil as well.

Safety factor for combined toxicity

The Netherlands has derived two toxicological risk limits: the Maximum Permissible Concentration (MPC) and the Negligible Concentration (NC). The NC is the lower risk threshold for a substance and is in principle set at 1/100 of the MPC. This reduction makes an allowance for the combined toxicity when many pollutants occur together in the environment (De Bruijn, *et al.*, 1999). The NC is set as a policy objective (target value) in the Netherlands (CIW, 2000).

Soil type

In general, soil quality standards are derived for standard soil conditions and apply for a wide range of soil types (Carlon, 2007). Other approaches are: to provide quality standards as a function of soil characteristics (such as pH, clay and organic matter content); to provide different quality standards depending on soil type or depth class; or to set limitations for soil properties for which the generic guidelines are applicable. Canada for example, distinguishes for some organic substances between values for coarse and fine soil and surface and subsoil (CCME, 2007).

Land use

The soil values can be generic or land-use specific, such as nature conservation, residential, industrial, agricultural and public green. Some countries, like Sweden, only distinguish between sensitive and less sensitive land uses. Negligible risk values are generally not related to the land use. On the contrary, for intermediate (warning) risk and the potentially unacceptable risk, different values for two soil-uses, i.e. residential and industrial, are commonly considered. The most common classification is agricultural, natural, recreational, residential and industrial land use (Carlon, 2007). The general approach to include land use in the derivation of environmental quality standards, is that less sensitive land uses are prescribed a lower percentage of protected species along the SSD. In Canada, however, the land-use category determines the receptor-pathway combination (CCME, 2006). The derivation of the Canadian soil quality standards is summarized in the text box below.

The Canadian guidelines development process
The Canadian guidelines are developed to protect human and key ecological receptors that sustain normal activities for four land use categories: agricultural, residential/parkland, commercial, and industrial. The environmental soil quality guideline (SQG_E) is determined by evaluating direct soil contact for plants and soil invertebrates, nutrient and energy cycling processes, ingestion of contaminated food and soil by wildlife, and the transport of contaminants through groundwater to potential livestock watering sources and surface water bodies inhabited by freshwater life. The lowest of the soil concentrations deemed protective of each of these pathway-receptor combinations becomes the SQG_E. The level of protection required for each pathway is dependent on the land use scenario; some of the receptor-pathway combinations are not evaluated for all land uses or contaminant types. Similarly, the human health soil quality guideline (SQG_{HH}) is determined by evaluating direct soil exposure (soil ingestion, dermal contact, and particulate inhalation), transport of contaminants through groundwater to potential potable water sources, intrusion of contaminant vapours into buildings, and human consumption of contaminated food. The lowest of the soil concentrations deemed protective of each of these potential exposure pathways becomes the SQG_{HH}. The specific exposure scenario is dependent on the land use; some of the exposure pathways are not evaluated for all land uses or contaminant types. The lowest of the SQG_E and SQG_{HH} becomes the final soil quality guideline (SQG_F) for each land use scenario. The SQG_F is also checked against non-toxicity considerations and typical background soil concentrations (CCME, 2006).

3.4 Groundwater

Groundwater resources can be protected by setting (separate) groundwater quality standards or by implementing the soil-groundwater leaching pathway in the soil quality standards. Figure 4 shows the general approaches used by different countries to protect groundwater resources. Canada for example, provides guidelines to derive soil quality standards which also protect aquatic organisms, wildlife and livestock from contaminated groundwater (CCME, 2006). Within the EU, the soil-groundwater leaching pathway is considered in several countries, while the protection of surface water is usually not included, with the exception of Spain (for natural land use) and Sweden (Carlon, 2007). In most countries, the groundwater protection refers to human drinking-water use. Usually, there is no link to the soil quality standards. However, in some countries the leaching potential is estimated and compared with groundwater quality criteria (or drinking-water criteria). If the groundwater criteria are exceeded, the soil value is adjusted to reduce the potential leaching to acceptable levels. A different approach is used by the Netherlands: the Dutch groundwater quality standards are based on quality standards for surface water (de Bruijn *et al.*, 1999).

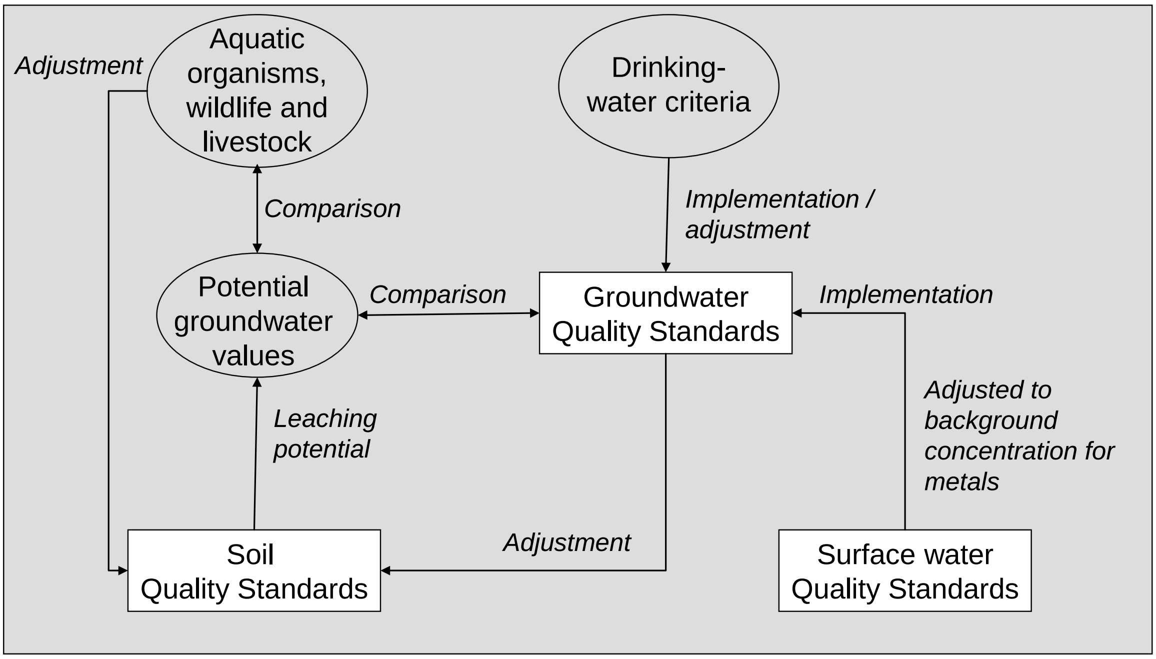

Figure 4 Different approaches to derive groundwater quality standards

In 2006, the EC has adopted the European Groundwater Directive. It requires establishment of groundwater quality standards by the end of 2008. The following guidelines are laid down in Annex IIA of the EC Directive on the protection of groundwater against pollution and deterioration (2006/118/EC):

1. The determination of quality standards should be based on:
   - the extent of interactions between groundwater and associated aquatic and dependent terrestrial ecosystems;
   - the interference with actual or potential legitimate uses or functions of groundwater;
   - all pollutants which characterise bodies of groundwater as being at risk, taking into account the minimum list set out in part B of Annex II;
   - hydro-geological characteristics including information on background levels and water balance;
2. The determination of quality standards should also take account of the origins of the pollutants, their possible natural occurrence, their toxicology and dispersion tendency, their persistence and their bioaccumulation potential;
3. Wherever elevated background levels of substances or ions or their indicators occur due to natural hydro-geological reasons, these background levels in the relevant body of groundwater shall be taken into account when establishing quality standards;
4. The determination of quality standards should be supported by a control mechanism for the data collected, based on an evaluation of data quality, analytical considerations, and background levels for substances which may occur both naturally and as a result of human activities.

4 Quality Standards

A list of substances, of which soil and groundwater quality standards are required for the development of the EIFsoil, sw, gw, has been provided by Statoil. The list consists of substances that are potentially released from land based activities, i.e. oil and/or gas production. For these substances, available soil quality standards are provided in paragraph 4.1 and available groundwater quality standards are provided in paragraph 4.2.

4.1 Soil

In Table 2, for pollutants resulting from land based oil and gas development (as indicated by Statoil), the available quality standards and their national, legislative context are presented. The quality standards of the following countries are included:

- The Netherlands (De Bruijn *et al.*, 1999)
  The soil quality standards of the Netherlands are presented as target values. These values are based on ecosystem protection and are in principle set at 1/100 of the MPC (to account for combined toxicity). The MPC is based on human and ecosystem protection. If insufficient ecotoxicological data for the terrestrial environment is available, the quality standard is based on aquatic data (as noted in the table).
- Canada (CCME, 2007)
  The Canadian soil quality guidelines (SQG) are developed to protect human and key ecological receptors that sustain normal activities for four land use categories: agricultural, residential/parkland, commercial, and industrial. The values included in Table 2 are the lowest of the human and ecological standards of all categories and soil types.
- US
  On a national level, the US also only provides guidelines (US EPA, 2005a), with exception of a few metals (e.g. Cadmium, Copper, Lead and Nickel), of which Ecological Soil Screening Levels (Eco-SSL) are derived (US EPA, 2005b&c; 2007a&b). US EPA Region IV has published Ecological Screening Levels (ESL) for many substances (US EPA, 2003b). These are used in the screening of ecological risk at sites in the state Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin. Within the US, human soil screening levels are derived separately. As the US EPA provides only guidelines no human health related SSLs are included in this report.
- Norway (SFT, 1999)
  The Norwegian soil quality guidelines provide both human health and environmental quality standards. The lowest of the two represents the ideal soil quality guideline which is included in Table 2.
- EU
  The European Commission provides only guidelines and no quality standards (EC, 2003). However, for some substances, the European Chemicals Bureau (ECB) has derived PNECs to be used as a threshold value in risk assessment.

Table 2 Soil quality standards (based on De Bruijn et al. *(1999); SFT (1999); CCME (2007); EC (2004); US EPA (2003b; 2005b&c; 2007a&b))*

Contaminants	**Standard**	**Value (mg/kg)**	**Country**	**Derivation**	**Framework**
Benzene	Target value	0.01	The Netherlands	QSAR, sensitivity distribution (based on aquatic data), equilibrium method, harmonization & safety factor 100.	Risk assessment and policy objective
	SQG	0.0068*	Canada	Weight of evidence, UF	Risk assessment
	ESL	0.255	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
	Ecotox related soil quality guideline	0.002	Norway	Lowest NOEC aquatic data, safety factor 50 and equilibrium method.	Risk assessment
Toluene	Target value	0.01	The Netherlands	Modified EPA method (lowest NOEC factor 10) & safety factor 100	Risk assessment and policy objective
	SQG	0.08*	Canada	Weight of evidence, UF	Risk assessment
	ESL	5.45	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
	Health related soil quality guideline	0.4	Norway	Based on total human exposure for most sensitive land use	Risk assessment
Ethylbenzene	Target value	0.03	The Netherlands	QSAR, sensitivity distribution (based on aquatic data), equilibrium method & safety factor 100	Risk assessment and policy objective
	SQG	0.018*	Canada	Weight of evidence, UF	Risk assessment
	ESL	5.16	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
	Health related soil quality guideline	0.5	Norway	Based on total human exposure for most sensitive land use	Risk assessment

Contaminants	Standard	Value (mg/kg)	Country	Derivation	Framework
Xylene	Ecotox related soil quality guideline	0.03	Norway	Lowest NOEC aquatic data, safety factor 100 and equilibrium method.	Risk assessment
	Target value	0.1	The Netherlands	QSAR, sensitivity distribution (based on aquatic data), equilibrium method & safety factor 100	Risk assessment and policy objective
	SQG	2.4*	Canada	Weight of evidence, UF	Risk assessment
	ESL	10	US EPA Region IV	Based on potential direct toxicity to plants	Risk assessment
Phenol	Target value	0.05	The Netherlands	Not based on ecotoxicological risk thresholds	Risk assessment and policy objective
	SQG	3.8*	Canada	Weight of evidence, UF	Risk assessment
	ESL	120	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
Naphtalene	Ecotox related soil quality guideline	0.8	Norway	Lowest NOEC, safety factor 10	Risk assessment
	Target value	0.001	The Netherlands	Modified EPA method on aquatic data (lowest LC50, factor 100), equilibrium method & safety factor 100	Risk assessment and policy objective
	SQG	0.1*	Canada	Weight of evidence, UF	Risk assessment
	ESL	0.0994	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
Phenanthrene	Target value	0.005	The Netherlands	Modified EPA method on aquatic data (lowest LC50, factor 100), equilibrium method & safety factor 100	Risk assessment and policy objective
	ESL	45.7	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment

Contaminants	Standard	Value (mg/kg)	Country	Derivation	Framework
Benzo[a]pyrene	Health related soil quality guideline	0.01	Norway	Based on total human exposure for most sensitive land use	Risk assessment
	Target value	0.003	The Netherlands	Modified EPA method (lowest NOEC, factor 10) & safety factor 100	Risk assessment and policy objective
	SQG	0.1*	Canada	Weight of evidence, UF	Risk assessment
	ESL	1.52	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
Cyclohexane	PNEC	0.147	EC	Equilibrium method	Risk assessment
Glycol (ethylene glycol)	SQG	960*	Canada	Weight of evidence, UF	Risk assessment
MDEA	n.a.				
Cu	Ecotox related soil quality guideline	100	Norway	Lowest NOEC, safety factor 1 and adjustment factor 10 **	Risk assessment
	Target value	36	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach	Risk assessment and policy objective
	Eco-SSL	28*	US	Based on geometric mean of avian toxicological values and uptake	Risk assessment
	SQG	63*	Canada	Weight of evidence, UF	Risk assessment
	ESL	5.4	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
Ni	Health related soil quality guideline	50.9	Norway	Based on total human exposure for most sensitive land use	Risk assessment
	Target value	35	The Netherlands	Modified EPA method (lowest NOEC factor 10), safety factor 100 & added risk approach	Risk assessment and policy objective
	SQG	50*	Canada	Weight of evidence, UF	Risk assessment

Contaminants	Standard	Value (mg/kg)	Country	Derivation	Framework
Ni	Eco-SSL	38*	US	Based on geometric mean of ecotoxicological values	Risk assessment
	ESL	13.6	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
Cd	Health related soil quality guideline	3.5	Norway	Based on total human exposure for most sensitive land use	Risk assessment
	Target value	0.8	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach	Risk assessment and policy objective
	Eco-SSL	0.36*	US	Based on geometric mean of mammalian toxicological values and uptake	Risk assessment
	SQG	1.4*	Canada	Weight of evidence, UF	Risk assessment
	ESL	0.00222	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
Zn	Ecotox related soil quality guideline	100	Norway	Lowest NOEC, safety factor 1 and adjustment factor 10 **	Risk assessment
	Target value	140	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach	Risk assessment and policy objective
	SQG	200*	Canada	Weight of evidence, UF	Risk assessment
	ESL	6.62	US EPA Region IV	Based on potential direct toxicity to soil invertebrates	Risk assessment
Pb	Health related soil quality guideline	60.5	Norway	Based on total human exposure for most sensitive land use	Risk assessment
	Target value	85	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach	Risk assessment and policy objective

Contaminants	**Standard**	**Value (mg/kg)**	**Country**	**Derivation**	**Framework**
Pb	SQG	70*	Canada	Weight of evidence, UF	Risk assessment
	Eco-SSL	11*	US	Based on geometric mean of avian toxicological values and uptake values	Risk assessment
	ESL	0.0537	US EPA Region IV	Based on potential direct toxicity to soil invertebrates and plants	Risk assessment
Hg (inorganic)	Health related soil quality guideline	0.8	Norway	Based on total human exposure for most sensitive land use	Risk assessment
	Target value	0.3	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach	Risk assessment and policy objective
	SQG	6.6*	Canada	Weight of evidence, UF	Risk assessment
	ESL	0.1	US EPA Region IV	Based on potential direct toxicity to soil invertebrates	Risk assessment
Chloride	n.a.				
Sulphate	n.a.				

n.a. : not available

* : the SQG is based on land use and soil type and the Eco-SSL is based on different receptors. Only the lowest value is presented in this table

** : for metals the PNEC value is adjusted with a factor 10 to derive the soil quality guideline

4.2 Groundwater

In Table 3 groundwater quality standards are presented for pollutants resulting from land based oil and gas development (as indicated by Statoil), Since the US, Canada and Norway do not provide groundwater quality standards, the only values found were those provided by the Netherlands. In addition, standard values for drinking water are included in the table, as provided by the WHO, Canada and the EU. It has to be noted that the drinking water standard values are considerably higher than the environmental target values. The Dutch target value represents negligible risk and is in principle set at 1/100 of the maximum permissible risk. The Dutch standards are based on the quality standards for surface water. Because of the lack of toxicity data for groundwater organisms, it is assumed that the standards for surface water also provide a good estimate of toxicity for groundwater organisms. Most values are derived by applying sensitivity distribution.

Table 3 Groundwater quality standards (based on CIW (2000); WHO (2006); Health Canada (2007) and EC (1998))

Contaminants	Standard	Value (µg/l)	Country	Derivation	Framework
Benzene	Target value	0.2	The Netherlands	QSAR, sensitivity distribution & safety factor 100 (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	10	Global	Based on human health	Risk management
	MAC for drinking water	5	Canada	Based on human health	Risk management
	Quality standard for drinking water	1	EC	Based on human health	Policy objective
Toluene	Target value	7	The Netherlands	QSAR, sensitivity distribution & safety factor 100 (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	700	Global	Based on human health	Risk management
	AO for drinking water	≤ 24	Canada	Based on odour threshold levels	Risk management
Ethylbenzene	Target value	4	The Netherlands	QSAR, sensitivity distribution & safety factor 100 (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	300	Global	Based on human health	Risk management
	AO for drinking water	≤ 2.4	Canada	Based on odour threshold levels	Risk management
Xylene	Target value	0.2	The Netherlands	QSAR, sensitivity distribution & safety factor 100 (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	500	Global	Based on human health	Risk management
	AO for drinking water	≤ 300	Canada	Based on taste and odour threshold levels	Risk management
Phenol	Target value	0.2	The Netherlands	Not based on ecotoxicological risk thresholds	Risk assessment and policy objective
Naphthalene	Target value	0.01	The Netherlands	Modified EPA method (lowest LC50, factor 100) & safety factor 100 (aquatic data).	Risk assessment and policy objective
Phenanthrene	Target value	0.003	The Netherlands	Modified EPA method (lowest LC50, factor 100) & safety factor 100 (aquatic data)	Risk assessment and policy objective

Contaminants	Standard	Value (µg/l)	Country	Derivation	Framework
Benzo[a]pyrene	Target value	0.0005	The Netherlands	Modified EPA method (lowest LC50, factor 1000) & safety factor 100 (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	0.7	Global	Based on human health	Risk management
	MAC for drinking water	0.01	Canada	Based on human health	Risk management
	Quality standard for drinking water	0.01	EC	Based on human health	Policy objective
Cyclohexane	n.a.				
Glycol	n.a.				
MDEA	n.a.				
Cu	Target value	1.3 – 15 *	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	2000	Global	Based on human health	Risk management
	AO for drinking water	≤ 1000	Canada	Based on taste threshold levels	Risk management
	Quality standard for drinking water	2000	EC	Based on human health	Policy objective
Ni	Target value	2.1 – 15 *	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	70	Global	Based on human health	Risk management
	Quality standard for drinking water	20	EC	Based on human health	Policy objective
Cd	Target value	0.06 – 0.4 *	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	3	Global	Based on human health	Risk management
	MAC for drinking water	5	Canada	Based on human health	Risk management
	Quality standard for drinking water	5	EC	Based on human health	Policy objective

Contaminants	Standard	Value (µg/l)	Country	Derivation	Framework
Zn	Target value	24 – 65 *	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach (aquatic data)	Risk assessment and policy objective
	AO for drinking water	≤ 5000	Canada	Based on taste threshold levels	Risk management
Pb	Target value	1.7 – 15 *	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	10	Global	Based on human health	Risk management
	MAC for drinking water	10	Canada	Based on human health	Risk management
	Quality standard for drinking water	10	EC	Based on human health	Policy objective
Hg (inorganic)	Target value	0.01 – 0.05 *	The Netherlands	Sensitivity distribution (HC5), safety factor 100 & added risk approach (aquatic data)	Risk assessment and policy objective
	Guideline value for drinking water	6	Global	Based on human health	Risk management
	MAC for drinking water	1	Canada	Based on human health	Risk management
	Quality standard for drinking water	1	EC	Based on human health	Policy objective
Chloride	Target value	100** (mg Cl/l)	The Netherlands	Unknown	Risk assessment and policy objective
	Guideline value for drinking water	5 (mg Cl/l)	Global	Based on human health	Risk management
	AO for drinking water	≤ 250 (mg Cl/l)	Canada	Based on taste and corrosive threshold levels	Risk management
	Quality standard for drinking water	250 (mg Cl/l)	EC	Based on human health	Policy objective
Sulphate	Target value	150** (mg SO_4/l)	The Netherlands	Unknown	Risk assessment and policy objective
	AO for drinking water	≤ 500 (mg SO_4/l)	Canada	Based on taste threshold levels	Risk management
	Quality standard for drinking water	250 (mg SO_4/l)	EC	Based on human health	Policy objective

n.a. : not available.
MAC : Maximum Acceptable Concentration
AO : Aesthetic Objective (this value is also protective for human health)

* : lowest value represents the quality standard for deep groundwater (>10 m), highest value represents undeep groundwater (<10 m). The difference is based on background concentration (added risk approach).

** : in areas with marine influence higher values occur naturally.

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6 Authentication

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This report has been professionally prepared by Wageningen IMARES. The scientific validity of this report has been internally tested and verified by another researcher and evaluated by the Scientific Team at Wageningen IMARES.

Approved: Dr. R.H. Jongbloed
Senior Scientist

Signature:

Date: 16 February 2008

Approved: Drs. J.H.M. Schobben
Head of Department

Signature:

Date: 21 February 2008

7 Quality assurance

IMARES utilises an ISO 9001:2000 certified quality management system (certificate number: 08602-2004-AQ-ROT-RvA). This certificate is valid until 15 December 2009. The organisation has been certified since 27 February 2001. The certification was issued by DNV Certification B.V. The last certification inspection was held the 16-22 of May 2007. Furthermore, the chemical laboratory of the Environmental Division has NEN-AND-ISO/IEC 17025:2000 accreditation for test laboratories with number L097. This accreditation is valid until 27 March 2009 and was first issued on 27 March 1997. Accreditation was granted by the Council for Accreditation, with the last inspection being held on the 12th of June 2007.