SWEDISH ENVIRONMENTAL PROTECTION AGENCY

ENVIRONMENTAL QUALITY CRITERIA

Groundwater

REPORT 5051

Environmental Quality Criteria - Groundwater

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QUALITY CRITERIA

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SWEDISH ENVIRONMENTAL PROTECTION AGENCY

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We would like to express our gratitude to the above participants for their committed approach to this project.

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Foreword

Based on favourable experience with "Environmental Criteria for Lakes and Watercourses", the Swedish Environmental Protection Agency decided in 1994 to develop a more comprehensive system for evaluating a variety of ecoystems, under the heading of "ENVIRONMENTAL QUALITY CRITERIA". This development work has resulted in six separate reports on: the Forest Landscape, the Agricultural landscape, Groundwater, Lakes and Watercourses, Coasts and Seas, and Contaminated Sites.

ENVIRONMENTAL QUALITY CRITERIA provide a means of interpreting and evaluating environmental data which is scientifically based, yet easy to understand. Indicators and criteria are also being developed by many other countries and international organizations. The Swedish Environmental Protection Agency has followed those developments, and has attempted to harmonise its criteria with corresponding international approaches.

The reports generated thus far are based on current accumulated knowledge of environmental effects and their causes. But that knowledge is constantly improving, and it will be necessary to revise the reports from time to time. Such revisions and other developments may be followed on the Environmental Protection Agency's Internet web site, www.environ.se. Concise versions of the reports are available there as well.

Development of the environmental quality criteria has been carried out in co-operation with colleges and universities. Various national and regional agencies have been represented in reference groups. The project leaders at the Environmental Protection Agency have been: *Rune Andersson*, Agricultural landscapes; *Ulf von Brömssen,* Groundwater; *Kjell Johansson*, Lakes and Watercourses; *Sif Johansson,* Coasts and Seas; *Marie Larsson* and *Thomas Nilsson,* Forest Landscapes; and *Fredrika Norman,* Contaminated Sites.

Project co-ordinators have been Marie Larsson (1995-97) and Thomas Nilsson (1998). Important decisions and the establishment of project guidelines have been the responsibility of a special steering committee consisting of *Erik Fellenius* (Chairman), *Gunnar Bergvall, Taina Bäckström, Kjell Carlsson, Rune Frisén, Kjell Grip, Lars-Åke Lindahl, Lars Lindau, Anita Linell, Jan Terstad, Eva Thörnelöf* and *Eva Ölundh.*

In April of 1998, public agencies, colleges and universities, relevant organizations and other interested parties were provided the opportunity to review and comment upon preliminary drafts of the reports. That process resulted in many valuable suggestions, which have been incorporated into the final versions to the fullest extent possible. The Swedish Environmental Protection Agency is solely responsible for the contents of the reports, and wishes to express its sincere gratitude to all who participated in their production.

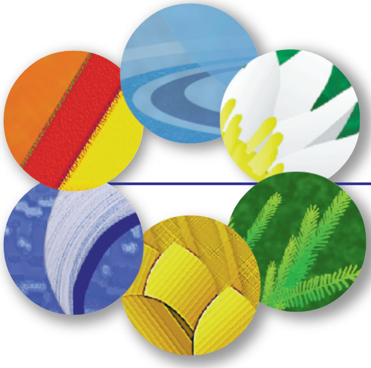
Stockholm, Sweden, December 2000
Swedish Environmental Protection Agency

Summary

This report on groundwater is one of a six-part series of reports published by the Swedish Environmental Protection Agency under the title "Environmental Quality Criteria". The other titles in the series are *the Forest Landscape, the Agricultural Landscape, Lakes and Watercourses, Coasts and Seas* and *Contaminated Sites*.

The purpose of this report is to enable local and regional authorities and others to make accurate assessments of environmental quality on the basis of available data on the state of the environment and thus obtain a better basis for environmental planning and management by objectives. Each report contains model criteria for a selection of parameters corresponding to the objectives and threats existing in the area dealt with by the report. The assessment involves two aspects: (i) an appraisal of the effects that measured conditions may have on the environment or our health; (ii) an appraisal of the extent to which the recorded state deviates from a "reference value". In most cases the reference value represents an estimate of a "natural" state. The results of both appraisals are expressed on a scale of 1–5.

The report on groundwater focuses on the main environmental threats facing groundwater. A sharp increase in air pollution during the twentieth century has greatly reduced the capacity of soil and hence groundwater to act as a buffer against acidification, lower pH and elevated concentrations of cadmium, zinc, lead and arsenic. Increased use by farmers of nitrogenous fertilisers, small-scale infiltration of effluent and deposition of airborne nitrogen on soils already saturated with the element have given rise to elevated concentrations of nitrogen in groundwater. Large-scale abstraction of groundwater changes flow direction in aquifers. This may result in saltwater intrusions and alter redox (reduction and oxidation) conditions, leading to elevated concentrations of iron and manganese and altered forms of sulphur and nitrogen compounds. These threats to groundwater are reflected in the selection of parameters appraised in this report. These are: nitrogen, chloride, metals, acidification risk, risk of pesticide presence, changes in groundwater redox and deviations from natural fluctuations in the water table. The assessment involves two aspects: (i) an appraisal of whether the recorded state of the groundwater may have any negative effects on its use for drinking purposes or negative effects on the aquatic biota; (ii) an appraisal of the extent to which the recorded state deviates from the reference value. The report on groundwater also describes methods for assessing whether or not the groundwater in an area studied is exposed to impact from a point source.



Environmental Quality Criteria

The vision of an ecologically sustainable society includes protection of human health, preservation of biodiversity, conservation of valuable natural and historical settings, an ecologically sustainable supply and efficient use of energy and other natural resources. In order to determine how well basic environmental quality objectives and more precise objectives are being met, it is necessary to continuously monitor and evaluate the state of the environment.

Environmental monitoring has been conducted for many years at both the national and regional levels. But, particularly at the regional level, assessments and evaluations of current conditions have been hindered by a lack of uniform and easily accessible data on baseline values, environmental effects, etc.

This report is one of six in a series which purpose is to fill that information gap, by enabling counties and municipalities to make comparatively reliable assessments of environmental quality. The reports can thus be used to provide a basis for environmental planning, and for the setting of local and regional environmental objectives.

The series bears the general heading of "ENVIRONMENTAL QUALITY CRITERIA", and includes the following titles: *The Forest Landscape, The Agricultural Landscape, Groundwater, Lakes and Watercourses, Coasts and Seas*, and *Contaminated Sites.* Taken together, the six reports cover most of the natural ecosystems and other types of environment found in Sweden. It should be noted, however, that coverage of wetlands, mountains and urban environments is incomplete.

Each of the reports includes assessment criteria for a selection of parameters relating to objectives and threats that are associated with the main subject of the report. The selected parameters are, for the most part, the same as those used in connection with national and regional environmental monitoring programmes; but there are also some "new" parameters that are regarded as important in the assessment of environmental quality.

Most of the parameters included in the series describe current conditions in natural environments, e.g. levels of pollution, while direct measures of human impacts, such as the magnitude of emissions, are generally not

Acidification

Eutrophication

Organic pollutants

Use of land and water

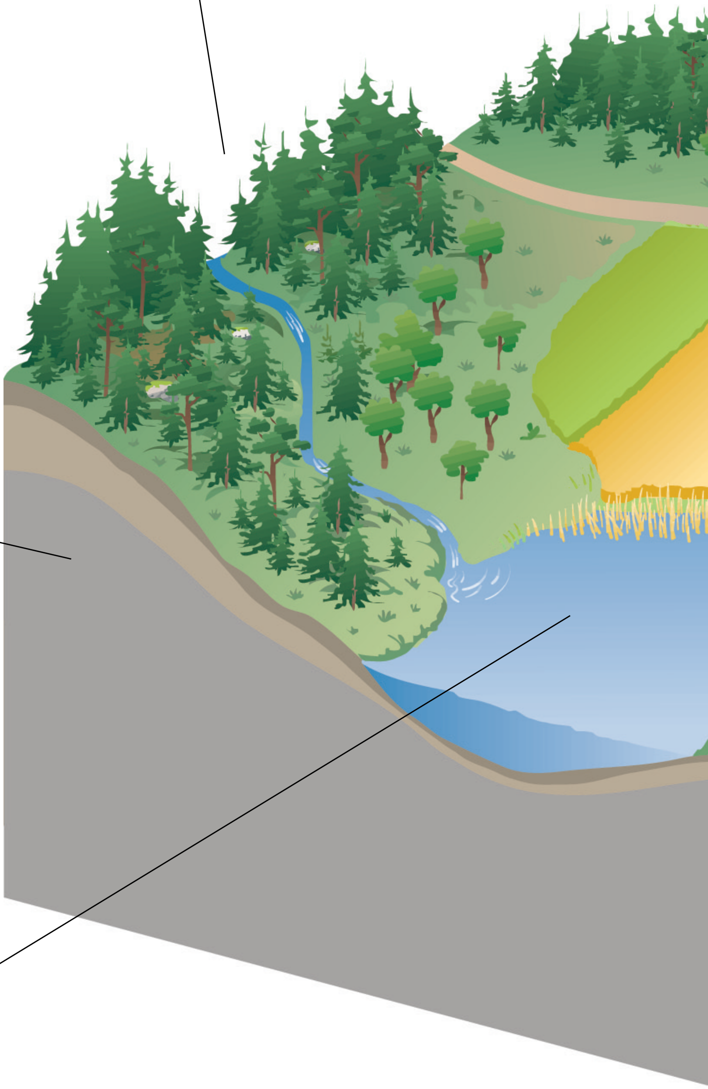
The Forest Landscape

Acidification

Leaching of nutrients

Metals

Proportion of ancient forest and deciduous forest in the landscape. Presence of dead wood and large trees



Groundwater

Acidification

Nutrients

Metals
Pesticides

Water table

Chloride

Redox

Lakes and Watercourses

Acidification

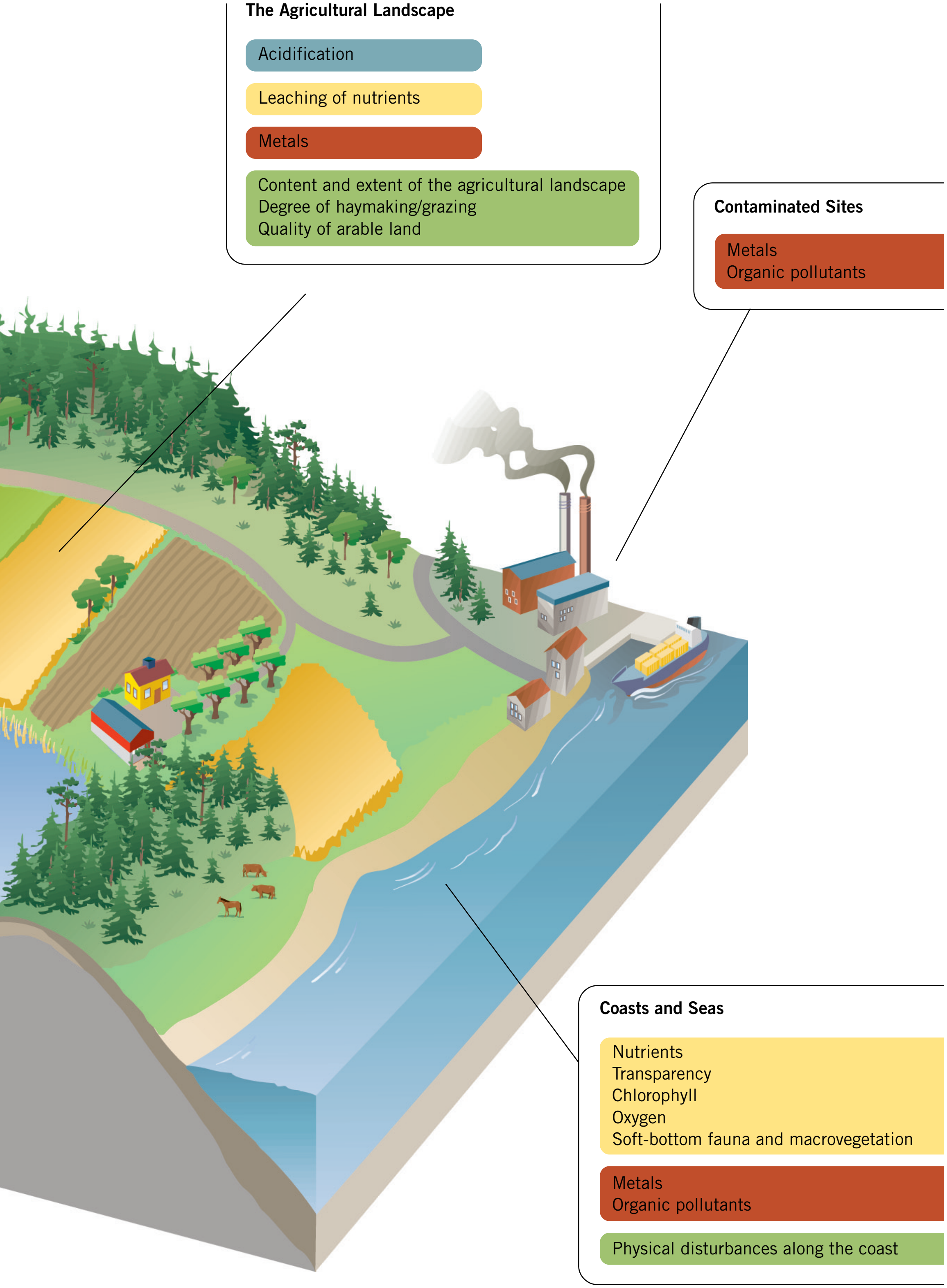
Nutrients

Metals

Presence of aquatic organisms

Light conditions

Oxygen



The Agricultural Landscape

- Acidification
- Leaching of nutrients
- Metals
- Content and extent of the agricultural landscape
  Degree of haymaking/grazing
  Quality of arable land

Contaminated Sites

- Metals
  Organic pollutants

Coasts and Seas

- Nutrients
  Transparency
  Chlorophyll
  Oxygen
  Soft-bottom fauna and macrovegetation
- Metals
  Organic pollutants
- Physical disturbances along the coast

included. In addition to a large number of chemical parameters, there are several that provide direct or indirect measures of biodiversity.

In all of the reports, assessments of environmental quality are handled in the same way for all of the parameters, and usually consist of two separate parts (see also page 13). One part focuses on the effects that observed conditions can be expected to have on environment and human health. Since knowledge of such effects is often limited, the solution in many cases has been to present a preliminary classification scale based on general knowledge about the high and low values that are known to occur in Sweden.

The second focuses on the extent to which measured values deviate from established reference values. In most cases, the reference value represents an approximation of a "natural" state, i.e. one that has been affected very little or not at all by human activities. Of course, "natural" is a concept that is not relevant to the preservation of cultural environments; in such contexts, reference values have a somewhat different meaning.

The results of both parts are expressed on a scale of 1-5, where Class 1 indicates slight deviations from reference values or no environmental effects, and Class 5 indicates very large deviations or very significant effects.

The report on Contaminated Sites with its discussion of pollutants in heavily affected areas complements the other five reports. In those cases where the parameters are dealt with in several of the reports, which is particularly the cases for metals, the report on Contaminated Sites corresponds (see further pages 13-14). However, the various parameters cannot be compared with each other in terms of risks. The following paragraphs review the extent of agreement with corresponding or similar systems used by other countries and international organizations.

INTERNATIONAL SYSTEMS FOR ENVIRONMENTAL QUALITY ASSESSMENT

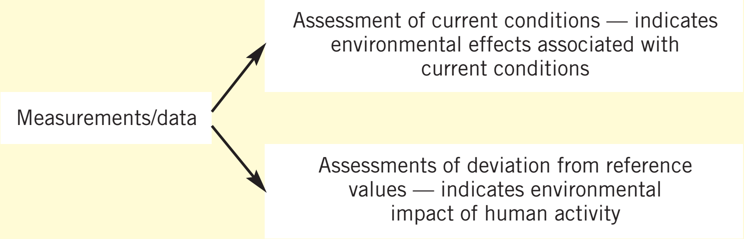
Among other countries, the assessment system that most resembles Sweden's is that of Norway. The Norwegian system includes "Classification of Environmental Quality in Fjords and Coastal Waters" and "Environmental Quality Classification of Fresh Water". A five-level scale is used to classify current conditions and usability. Classifications are in some cases based on levels of pollution, in other cases on environmental effects.

The European Union's proposal for a framework directive on water quality includes an assessment system that in many ways is similar to the Swedish Environmental Quality Criteria.

If the parameters used in the latter are regarded as forms of environmental indicators, there are many such systems in use or under development. However, the concept of environmental indicators is much broader than the parameters of Environmental Quality Criteria.

Internationally, the most widely accepted framework for environmental indicators is based on PSR-chains (Pressure-State-Response). Indicators are chosen which reflect the relationship between environmental effects, and/or there causes and measures taken. There is also a more sophisticated version, called DPSIR (Driving forces-Pressure-State-Impact-Response). Variants of the PSR/DPSIR systems are used by, among others, the OECD, the Nordic Council of Ministers, the United Nations, the World Bank, the European Union's Environmental Agency.

ASSESSMENT PROCEDURE



Assessment of current conditions

Wherever possible, the scale used in assessments of current conditions is correlated with effects on different parts of the ecosystems and their biodiversity, or on human health (”effect-related classification”). In some cases, the assessment is based only on a statistical distribution of national data (”statistical classification”).

The scale is usually divided into five classes. Where the assessment is based on effects, Class 1 indicates conditions at which there are no known negative effects on the environment and/or human health. The remaining classes indicate effects of increasing magnitude. Class 5 includes conditions leading to the most serious negative effects on the environment and/or human health. Due to wide natural variations, especially with regard to biological phenomena, the indicated effects are not always the result of human activities, in which case they can not be labelled as “negative”(see below).

Where the assessment is based only on a statistical distribution, there is no well-defined relationship between effects and class limits. It should be noted that parameters that are evaluated on the basis of different criteria cannot be compared with each other.

Reference values

Ideally, the reference value for a given parameter represents a natural state that has not been affected by any human activity. In practice, however, reference values are usually based on observations made in areas that have experienced some slight human impact. In some cases, historical data or model-based estimates are used. Given that there are wide natural variations of several of the parameters, reference values in many cases vary by region or type of ecoystem.

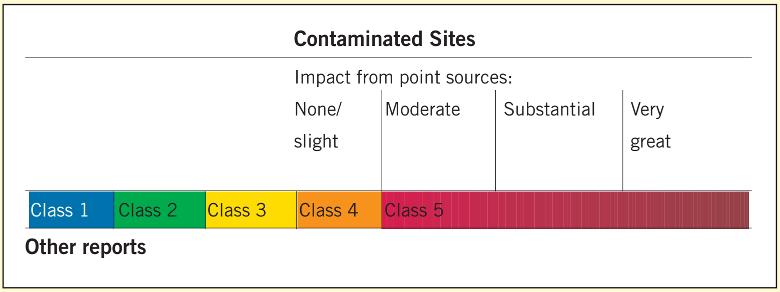
Deviations from reference values

The extent of human impact can be estimated by calculating deviations from reference values, which are usually stated as the quotient between a measured value and the corresponding reference value:

$$\text{Deviation} = \frac{\text{Measured value}}{\text{Reference value}}$$

The extent of deviation is usually classified on a five-level scale. Class 1 includes conditions with little or no deviation from the reference value, which means that effects of human activity are negligible. The remaining classes indicate increasing levels of deviation (increasing degree of impact). Class 5 usually indicates very significant impact from local sources.

Organic pollutants and metals in heavily polluted areas are dealt with in greater detail in a separate report, Contaminated Sites, which includes a further sub-division of Class 5, as follows:



Environmental Quality Criteria for Groundwater

What should be assessed?

Environmental Quality Criteria for Groundwater are a means of interpreting and assessing groundwater data. This assessment concerns the state of the groundwater, particularly in terms of human health and ecological risks, and an appraisal of whether groundwater has been affected by man's activities. The selection of parameters is based on the characteristics and functions of groundwater that should primarily be assessed.

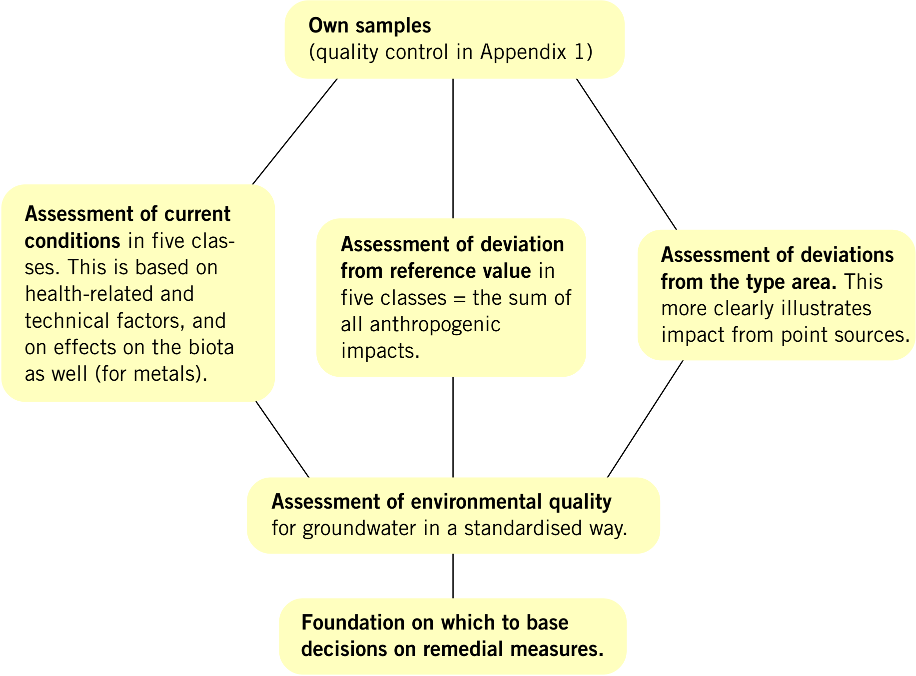


FIGURE 1. Environmental Quality Criteria for Groundwater

Groundwater is assessed:

- as drinking water from a health viewpoint
- in terms of its technical utility in drinking water distribution plants
- in terms of changes in the water table
- in terms of biological effects on the aquatic biota (metals only)

All assessments relates to aquifers. Samples may be taken from groundwater pipes, springs or wells. Samples from pipe systems should be taken as close to the well as possible (see also Appendix 1).

Environmental state and threats

The chemical composition of groundwater has changed on a large scale. The main threats are acidification and extensive leaching of nitrogen. Deposition of acidifying nitrogen and sulphur compounds result in falling alkalinity and pH, increasing the mobility of metals in the soil. Other impacts result from agriculture and forestry, the transport sector, energy generation, industry, the urban environment, quarries, mines and gravel pits. Excessive abstraction of groundwater may create a water shortage and cause changes in water quality, eg, increased salt or sulphate content. Private and municipal water supplies are sometimes contaminated in agricultural areas by nitrogen leaching out of the soil. A few studies have shown that pesticides can also enter wells via groundwater. Contamination from sewage causes microbial pollution of the groundwater and leachate from landfilled waste may have a wide range of effects on groundwater. Another threat is the large quantity of chemical products transported as hazardous goods. These goods are often transported through areas containing sensitive aquifers and catchment areas for drinking water supply.

Seven aspects are assessed

Groundwater state is assessed on the basis of seven aspects:

- alkalinity – risk of acidification
- nitrogen
- salt – chloride
- redox
- metals
- pesticides
- water table

The aspects dealt with only concern fairly extensive threats to groundwater due to human activities.

For regulations and assessment of drinking water quality, see the National Food Administration guidelines for drinking water quality and the Environmental Health Report.

For various reasons, the following aspects are not assessed in this report: radon, fluoride, phosphate, organic pollutants (except for pesticides) and pathogenic microorganisms.

Radon and *fluoride* are not included because the anthropogenic influence on the concentrations of these substances is very limited and because elevated concentrations in aquifers cannot normally be remedied using environmental protection techniques. Natural concentrations and health effects caused by these substances are presented in Appendix 9.

The occurrence of *pathogenic microorganisms* is largely of anthropogenic origin. For assessment of current conditions, see the Drinking Water Regulations issued by the National Food Administration.

Phosphate has been excluded since, being tightly fixed in soil, it usually occurs in very low concentrations in groundwater. Moreover, there is no limit value for health effects of phosphate.

As yet, we know little about *organic pollutants* in groundwater and these substances (with the exception of pesticides) have therefore been omitted from the assessment. Exclusion of these substances may be reviewed when this report is revised.

Parameters

Each aspect is described using reliable and well-established parameters. For recommended sampling and analysis methods, see the Swedish EPA Environmental Monitoring Handbook (in swedish only). In addition, Appendix 1 contains a brief description of the points in time when samples should be taken and of sampling and analytical methods. As many parameters as possible should be included in the assessment so as to obtain as complete a picture of groundwater state as possible. There is nothing to prevent use of just a few parameters, however.

Division into type areas

A set of type areas has been created to allow comparisons of similar types of groundwater. Each type area is based on a combination of nine *geological regions*, five *groundwater environments* and two *well-depth classes*; see also the chapter entitled “Division into type areas”.

Assessment of current conditions

In most cases, classification of state is based on the risk of health effects caused by consumption of drinking water. In addition, there are technical and aesthetic effects connected with use of the water as drinking water. The National Food Administration guide values and limit values (public water distribution plants) for drinking water quality are used in making these classifications. Concentrations at which effects begin to occur in aquatic biota in sensitive surface waters have been included as the basis for assessing metals. A five-point scale is used to assess water state. Class five represents the greatest effects. The class boundaries indicating effects are presented for each parameter. Other class boundaries have been set to provide the greatest possible degree of accuracy at the most frequent concentrations. Recorded levels coinciding with boundary between two classes are placed in the lower class.

Reference values

The basis for setting the reference value is described for each parameter. There are no reference values for "Alkalinity - risk of acidification", "Redox" and "Water table". In these cases only changes over time are assessed. The chapter on pesticides is presented as a risk classification of possible occurrence of pesticides in groundwater in the areas studied. Sampling and analysis of samples should be given priority where the risk is greatest.

Assessment of deviation from reference values

Assessment of deviation from the reference value is made in five classes. The boundary between class 1 and 2 constitutes the reference value. Hence, class 1 covers the natural variation for the parameter. Levels of some metals are naturally elevated above the reference value in small areas. These are described separately. The five classes encompass the national range of recorded values. The progression from class 2 to class 5 represents an increasing degree of impact. Recorded levels coinciding with the boundary between two classes are placed in the lower class.

Assessment of whether a local point source is causing an impact – deviation test

To ascertain whether the data obtained from a type area is affected by a point source, a comparison is made with the conditions in the reference population for the type area using a deviation test. This will establish whether or not the deviation is significant but will not provide any other information. This assessment thus differs from the other two types of assessment: current conditions and deviation from reference value, which are made in five classes.

The data population for a type area comprises all data in the reference database from a groundwater environment in a geological region. The data, which date from the 1980s, has been cleaned up by eliminating values caused by obvious point source influence. It reflects the regional impact of natural factors (geology and climate) and non-point source anthropogenic impact, such as land use and atmospheric deposition.

Comparisons with other reports in the series

When comparing surface water and groundwater, it is important to bear in mind that they differ quite considerably in terms of the concentrations of many substances. In particular, ancient groundwater from great depths has higher ionic strength than surface water. On the other hand, near-surface groundwater may be more acidic than almost all surface water and therefore have a high content of pH-sensitive metals like cadmium. This is one reason that the class boundaries for deviation from the reference value are higher for groundwater than for surface water.

Far less medium-depth and deep groundwater with a long turnover time enters the surface water than does near-surface groundwater with a short turn-over time. Drinking water supplied from groundwater is normally of medium depth or deep groundwater, but the main contribution of groundwater to surface water consists of near-surface groundwater. This groundwater may due to acidification contain elevated levels of metals. This contribution of metals to surface water has been considered and metals in groundwater are classified according to judgements done in the report on lakes and watercourses.

Because of the weak link between surface water flow and groundwater, it is difficult to determine the influence of groundwater on surface water chemistry. The contribution from metals has been considered, however, whereas other constituents have been deemed to have little effect. The report on lakes and watercourses classifies nitrogen based on nitrogen leaching from soil, including flow via groundwater.

As regards deviation from the reference value, metals at very high concentrations are further broken down in the report on contaminated sites.

Scale of application

This report is intended to be used primarily to assess the state of groundwater within an aquifer, municipality or county. Geological and hydrological conditions vary, both laterally and vertically, and groundwater quality, flow and level within an area therefore also vary. To make analysis of the chemical data easier, it is important to compare samples of groundwater that have envolved under similar conditions. To achieve this, each sampling point must be classified according to one of the 36 specified type areas and all groundwater conditions must be described by type area. (Where there is a large amount of data, it is suggested that the type area be divided into two well-depth classes.)

Groundwater data varies not only in time, between sampling points, but also over time. Sampling data must be representative of the type area to which it relates. The smaller the sample, the greater the likelihood of obtaining an incorrect mean figure for concentrations in the type area studied. It is generally recommended that at least 25–30 sets of sampling data be used to assess a type area, see Appendix 1. A single sample taken on a single occasion only represents itself and cannot be extrapolated to cover a larger area.

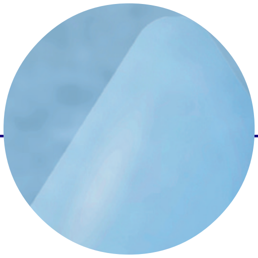
Quality assurance

All analyses should be performed at accredited laboratories.

References

Statutes of the National Food Administration 1993:35 and 1997:32.

Environmental Health Report (SOU 1996:124).



Division into type areas

A division into type areas is presented here. Account has been taken of factors, such as bedrock and soil types, having a bearing on the chemical composition of groundwater. The division into type areas makes it easier to understand various types of aquifer and is useful when comparing large quantities of data with reference materials from the same type area. Areas displaying anthropogenic impact from point sources can be identified using a deviation test.

Having examined the groundwater in a given area, one often wishes to know whether this water is similar to or, as a consequence of local impact, differs from other groundwater existing under similar conditions. A division into 36 *type areas* has been made to aid comparison of analyses. Within a given type area, reasonably unaffected water will have similar concentrations of the substances dealt with in this report. The type areas are based on a combination of *nine geological regions* and *five local groundwater* environments. Shallow and deep wells are assessed separately in *two well-depth classes* in each type area.

Table 1 shows the 36 type areas listed in Appendix 2. The appendix shows a breakdown by type area of concentrations of the substances covered in the report. There is also a breakdown according to well depth. Data has been obtained from a reference database at the Swedish Geological Survey based on nearly 30,000 wells, mainly analysed in the 1980s. These concentrations do not differ appreciably from present levels, except that sulphur levels are now lower as a result of lower sulphur deposition.

The type areas are designed to achieve a minimal spread of data within each population. The division into type areas has been based on the factors of greatest importance in terms of the chemical composition of groundwater. Clear differences between the type areas are evident in relation to alkalinity, chloride and redox conditions, among others.

For the deviation test, see the chapter entitled “Instructions for deviation test”, page 69. This method highlights areas affected by point sources and can be used to supplement comparisons with reference values. The method is well suited for use with large quantities of data.

Nine geologically distinctive regions

In order to identify different head groups of chemical composition of Swedish groundwater, a correlation analysis has been performed on different causal preconditions such as type of bedrock, type of hydrology, whether the present land surface has been under seawater or not (the highest coastline). This has resulted in a classification of the country in nine types of geological/geographical regions (see Figure 2). This classification is based primarily on bedrock type: (1) sedimentary rock (chalk, limestone, schists, sandstones) and (2) igneous rocks (granite, gneiss, granodiorite etc). A second factor is elevation in relation to the reference elevation, referred to in Sweden as "the highest coastline".

A – Sedimentary bedrock in southern Sweden

Sedimentary rock types in Skåne, and on the islands of Öland and Gotland. Easily weathered soils and rocks are typical of the region. These provide an effective buffer against acidification. High natural concentrations of sulphate may occur in the presence of certain rock types. Lies both below and above the highest coastline.

B – The highlands of southern Sweden

Areas of igneous and metamorphic rock above the highest coastline from Skåne to southern Närke. Rock and soil types are fairly resistant to weathering, which gives poor acidification buffering capacity. Western areas, in particular, are exposed to high deposition of acidifying agents.

C – The west and south coast

Areas of igneous and metamorphic rock below the highest coastline along the west coast and east coast, and also the Kalmar Sound sandstone along the coast of Småland. Here too, rock and soil types are fairly slow weathering. However, their position below the highest coastline and the presence of clays and other fine-grained soils increases resistance to acidification. High natural chloride concentrations occur in coastal areas and also derive from relict sea water in bedrock and soil strata. There is high deposition of acidifying agents.

D – Sedimentary bedrock in central Sweden

Sedimentary bedrock in Västergötland, Östergötland and Närke. The region may be compared with region A.

E – The central Swedish depression

Areas of igneous and metamorphic rock below the highest coastline around the large lakes of central Sweden. Rock and soil types fairly resistant to weathering. However, their position below the highest coastline and the presence of clays and other fine-grained soils increases resistance to acidification. High natural chloride concentrations occur in coastal areas and also derive from relict sea water in bedrock and soil strata.

F – The calcareous area of Uppland

The bedrock in Uppland is primary but soils are calcareous owing to their mineral content, which partly originates from sedimentary rocks in the Bothnian Sea. This increases resistance to acidification, as does the position below the highest coastline with the presence of clays and other fine-grained soils. High natural chloride concentrations occur in coastal areas and also derive from relict sea water in bedrock and soil strata.

G – The northern Swedish coast

Area of igneous and metamorphic rock below the highest coastline. Rock and soil types are fairly resistant to weathering. However, their position below the highest coastline with the presence of clays and other fine-grained soils increases resistance to acidification. High natural chloride concentrations occur in coastal areas and also derive from relict sea water in bedrock and soil strata.

H – Sedimentary bedrock in Dalarna and Jämtland

Sedimentary rock types in the area around lake Siljan, and in Jämtland. Easily weathered soils and rocks are typical of the region. These provide an effective buffer against acidification. High natural concentrations of sulphate occur, mainly in combination with certain rock types in Jämtland. Lies both above (Jämtland) and below (the Siljan area) the highest coastline. However, the presence of naturally high chloride concentrations is unusual, even in the Siljan area.

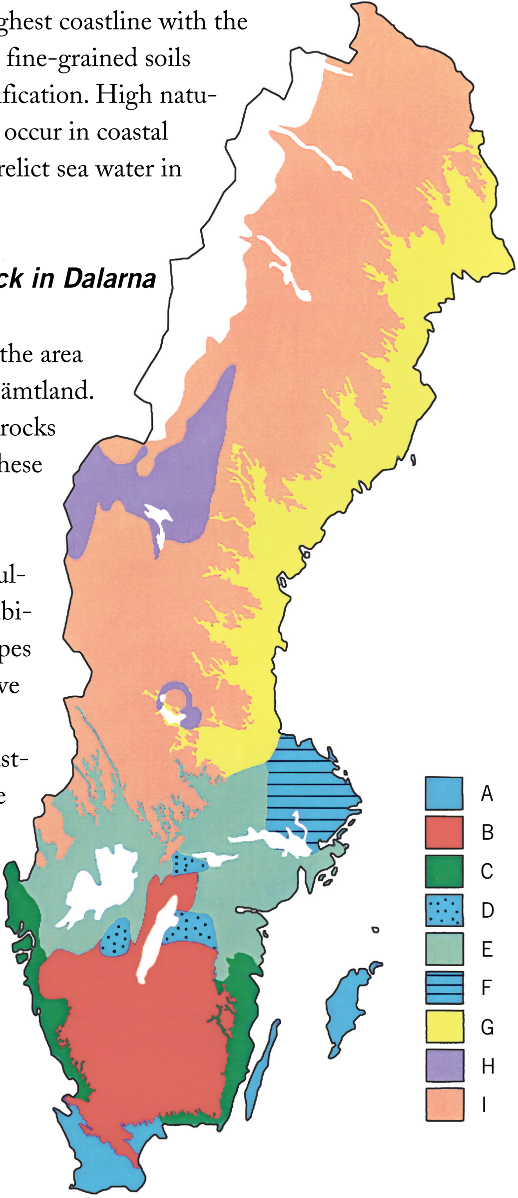


FIGURE 2. Geological regions. Note: the mountain chain is not included (mainly owing to insufficient data). Accurate classification requires specific knowledge of the bedrock occurring at depth as well as at the surface. This applies particularly to deep wells bored close to the border between two regions. Source: Swedish Geological Survey.

I – Igneous and metamorphic rock in inland northern Sweden above the highest coastline

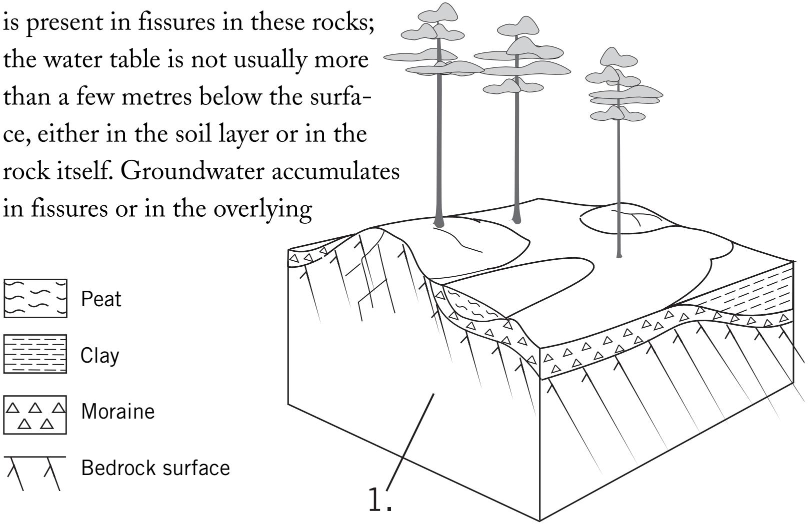
Areas of igneous and metamorphic rock above the highest coastline from Dalsland in the south-west to Treriksröset in the north. Rock and soil types are fairly resistant to weathering and therefore offer little resistance to acidification. Low deposition. However, variations in natural conditions occur within this large area. For example, western Dalarna is unusual in having particularly slow-weathering bedrock in the form of Jotnian sandstone and Dala porphyr, which provide poor buffering against acidification. Large areas of the far north are bog and peat land, which may create reducing conditions and high concentrations of iron and manganese in the groundwater (see the chapter on “Redox”).

Five groundwater environments

Precipitation infiltrating the soil surface sinks through the unsaturated zone to the saturated groundwater zone and then flows into the aquifer. The chemical composition of the groundwater is determined by the chemistry of the precipitation, the length of time the water is in contact with organic and inorganic matter in the soil, the geochemical composition of the soil and rock and the various strata sequences at the site. Ground conditions are therefore classified into five groundwater environments to cover the differing strata sequences that cause the chemical characteristics of the groundwater to vary (Bengtsson & Gustafson, 1996 and Stejmar, 1996). These groundwater environments often form a mosaic in the landscape. The five groundwater environments are presented below.

Groundwater environment 1: Igneous bedrock

This environment comprises igneous bedrock, which may outcrop or be covered by soil. The igneous metaorphic bedrock predominantly comprises gneisses and granites. Groundwater is present in fissures in these rocks; the water table is not usually more than a few metres below the surface, either in the soil layer or in the rock itself. Groundwater accumulates in fissures or in the overlying



Figures 3-7 were drawn by Karin Holmgren, Chalmers University of Technology, Gothenburg

FIGURE 3. Groundwater environment 1: Aquifers in igneous bedrock

soil strata. Groundwater environment 1 often consists of a mosaic of raised areas with thin soil interspersed with soil-filled depressions, which may be covered with a layer of peat. In the absence of anthropogenic influence, groundwater turnover is slow, with inflow in the raised areas and outflow in the low-lying areas. This results in fairly alkaline water with a low iron content. At great depths, iron concentrations are often higher owing to reducing conditions. High iron levels can also be caused by large-scale water abstraction, causing induction of groundwater formed in peat areas (see the chapter on “Redox”).

Groundwater environment 2: Sedimentary bedrock

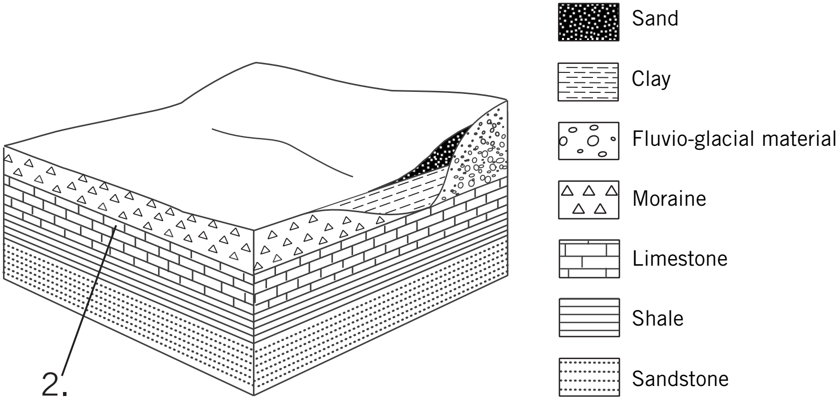


FIGURE 4. Groundwater environment 2: Aquifers in sedimentary bedrock

This environment comprises sedimentary rocks, mainly sandstones, limestone, chalk and shales. Areas of sedimentary bedrock are usually covered by massive Quaternary deposits. The rocks containing aquifers vary, but are usually sandstone or limestone. Groundwater occurs in pores in the rock and in stratification planes and fissures. Sedimentary rocks have a marked effect on groundwater quality. The frequently high lime content results in a water with high buffering capacity and a high concentration of base cations (eg, calcium and magnesium). A high sulphur content will often mean a high sulphate content and/or reducing conditions, which will result in high concentrations of iron and manganese (see the chapter on “Redox”).

Groundwater environment 3: Moraine and fluvial outwash

This environment comprises surface aquifers in moraine and sediment. The composition and thickness of the moraine varies. The water table is usually close to the surface of the moraine owing to the low hydraulic conductivity of these materials. Fluvial outwash composition may also vary a great deal; the outwash may be made up of gravel, sand or silt. The thickness varies, but is usually only 1 - 2 metres. Fluvial outwash occurs in deposits below the elevation of the highest coastline in conjunction with fluvio-glacial deposits and

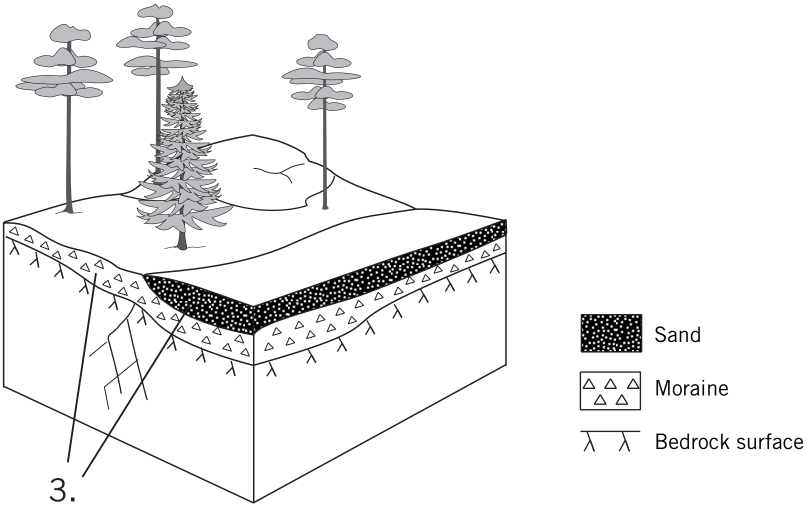


FIGURE 5. Groundwater environment 3: Surface aquifers in moraine and in fluvial outwash

moraine. The thin layers of soil and generally high porosity of the materials in this groundwater environment are conditions conducive to short retention times. As a consequence, the base cation reserve has often been leached out, which leads to water with very low total salinity. These waters are susceptible to acidification.

Groundwater environment 4: Fluvio-glacial deposits

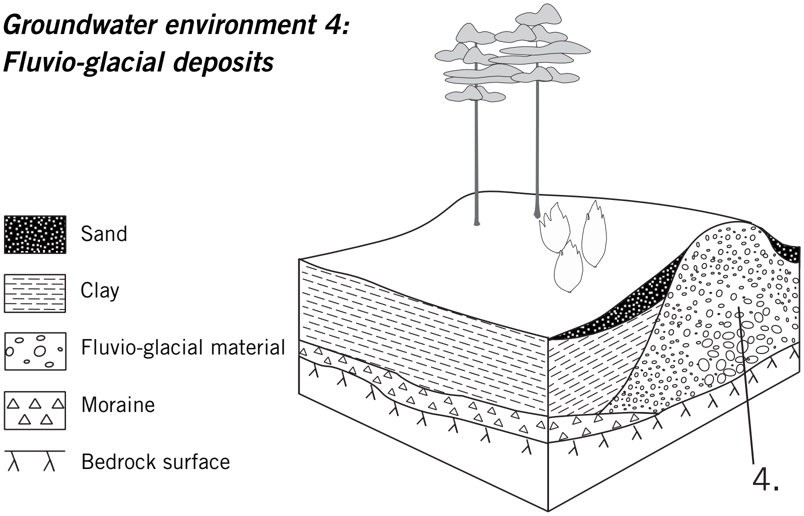


FIGURE 6. Groundwater environment 4: Surface aquifers in fluvio-glacial deposits

This environment comprises surface aquifers in fluvio-glacial deposits. These deposits are sand and gravel and occur in glacial ridges, deltas, terraces etc. Their depth varies. Environment 4 also includes sediment deposited in ice-dammed lakes and shallow wells in fluvial sediment. Coarse soils provide an effective conduit for newly-formed groundwater and the water table may therefore often be far below the surface. Fluvio-glacial deposits often form our largest aquifers. Retention times are often long, even though the water is fairly mobile. Concentrations of calcium and magnesium depend on rock type and the iron content on whether groundwater forms in a reducing environment (see the chapter on “Redox”).

Groundwater environment 5: Moraine and fluvio-glacial material beneath clay and other cohesive soils

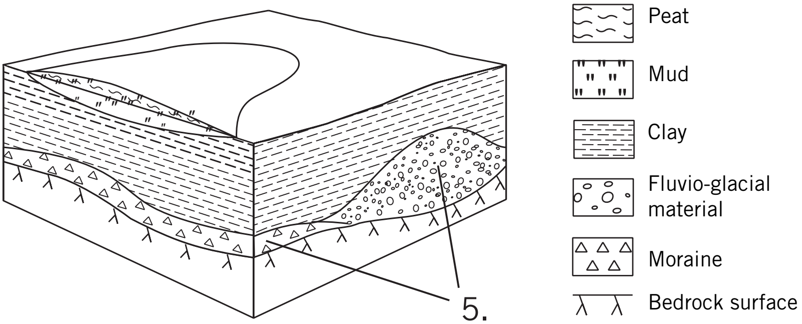


FIGURE 7. Groundwater environment 5: Confined aquifers in moraine and fluvio-glacial deposits

This environment comprises confined aquifers in moraine and fluvio-glacial material. The depth of the overlying clay (or silt) varies. The clay may be both glacial and post-glacial. Groundwater environment 5 occurs in valleys and low-lying areas. Groundwater is formed at higher elevations in the surroundings. Environment 5 also includes deep wells in fluvial sediment and wells in inter-morainic deposits. Retention times in the confined aquifers are often long and this, in combination with the present of fine sediments, often with a high lime content, tends to produce water resistant to acidification with a high concentration of base cations. Anaerobic conditions often prevail in confined aquifers, resulting in high concentrations of iron and manganese. The overlying fine sediments usually produce fertile agricultural soils. Nitrogenous fertilisers may have an impact, despite the protective layers of fine sediment.

Type areas

The combination of geological regions and groundwater environments forms various “type areas”. Hence, for example, surface aquifers in moraine or fluvial outwash in region A constitutes one type area and the same groundwater environment in region B another. Appendix 2 shows a breakdown by type area of concentrations of various substances. There is also a breakdown into two classes according to well depth. Table 1 shows the 36 type areas listed in Appendix 2. Thus, not all combinations of geological regions and groundwater environments are represented in Sweden. Type areas D1 and H1 may be explained by the fact that adjacent areas with overlying soils originating from sedimentary rocks underlain by igneous rock have been included in regions D and H.

Well depth

The length of time the water is in contact with minerals in the soil equals the time the water remains in the soil, above as well as below the water table. This contact time plays a very important role in the chemical ionic exchange between water and minerals and thus greatly influences the chemical characteristics of the water. Variations in precipitation remain in shallow aquifers with short turnover times. Shallow aquifers often contain lower concentrations of dissolved salts and lower pH

TABLE 1.

Matrix of identified type areas based on the nine geological type regions and the five local groundwater type environments. The figures follow the numbering of the type areas used in Appendix 2, Tables 1–11

Groundwater environment	**1. Igneous bedrock**	**2. Sedimentary bedrock**	**3. Moraine and fluvial deposits**	**4. Fluvioglacial outwash**	**5. Confined aquifers**
Region					
A. Sedimentary bedrock in south Sweden		A 2	A 3	A 4	A 5
B. The highlands of south Sweden	B 1		B 3	B 4	
C. The west and south coast	C 1		C 3	C 4	C 5
D. Sedimentary bedrock in central Sweden	D 1	D 2	D 3	D 4	D 5
E. The central Swedish depression	E 1		E 3	E 4	E 5
F. The calcareous area of Uppland	F 1		F 3	F 4	F 5
G. The northern Swedish coast	G 1		G 3	G 4	G 5
H. Sedimentary bedrock in Dalarna and Jämtland	H 1	H 2	H 3	H 4	H 5
I. Igneous and metamorphic rock in inland northern Sweden above the highest coastline	I 1		I 3	I 4	

than deep aquifers. All type areas have therefore been split up into two well-depth classes reflecting short and long contact time between water and minerals.

References

Bengtsson, M.-L. & Gustafson, G. (1996): Bedömning av grundvatten utgående från grundvattenmiljöer (”Assessment of groundwater on the basis of groundwater environments”). – Faculty of Geology, Chalmers University of Technology, Publ B426. Gothenburg.

Stejmar, H. (1996): Bedömning av grundvatten utifrån grundvattenmiljöer, Södermanland och Östergötland (”Assessment of groundwater on the basis of groundwater environments, Södermanland and Östergötland”). – Faculty of Geology, Chalmers University of Technology, Publ B435. Gothenburg.

Alkalinity – risk of acidification

The buffering capacity of groundwater against acidification is assessed using its alkalinity. This is considered in relation to the regional acidification load. The relationship between them is a measure of the risk of the water becoming acidified.

Introduction

All of Sweden has been subject to deposition of acidifying compounds of sulphur and nitrogen.

Traces of these acidifying agents are found in the form of sulphate, nitrate and accompanying hydrogen ions in soil and water. Sulphate is formed when sulphur dioxide is oxidised:

$$SO_2 + 0.5\ O_2 + H_2O \Rightarrow SO_4^{2-} + 2H^+ \qquad (1)$$

sulphur dioxide + oxygen + water ⇔ sulphate ion + hydrogen ion

Much of the added load of acid substances has been neutralised as sulphate has been fixed in the soil and by ionic exchange whereby hydrogen ions have replaced base cations (principally calcium and magnesium) in soil particles. The capacity of soil to neutralise acid by means of these processes is limited and, in parts of southern Sweden, has almost been exhausted. The soil has often become acidified, whereas the pH of groundwater has not fallen. However, elevated concentrations of base cations in groundwater indicate that the overlying soil is undergoing a process of acidification.

To assess long-term acidification trends, neutralisation by way of ionic exchange should be ignored; only neutralisation by decomposition (e.g. weathering) should be taken into account. Decomposition produces hydrogen carbonate ions (HCO_3^-) and base cations.

When organic matter decomposes, air in the soil loses oxygen and gains carbon dioxide. Carbon dioxide and water form carbonic acid, which dissolves minerals, such as calcium carbonate (limestone), in the soil.

$$CO_2 + H_2O \Leftrightarrow H_2CO_3 \Leftrightarrow H^+ + HCO_3^- \qquad (2)$$

carbon dioxide + water ⇔ carbonic acid ⇔ hydrogen ion + bicarbonate ion

$$H^+ + CaCO_3 \Leftrightarrow Ca^{2+} + HCO_3^- \qquad (3)$$

hydrogen ion + calcium carbonate ⇔ calcium ion + bicarbonate ion

Bicarbonate ions represent the main part of what is usually termed the “buffering capacity”, or alkalinity, of the water. Buffering neutralises hydrogen ions and reduces alkalinity, ie, reaction (2) goes in the other direction. Hence, resistance to acidification is largely determined by how easily the minerals in the bedrock and in the soils in the catchment area of a well can be broken down. In areas where soils and rocks are slow to break down (ie, without carbonate), the rate of weathering increases only marginally at lower pH levels. Weathering capacity can be measured directly in well water as the level of alkalinity.

However, the alkalinity buffering capacity of the water has been used up in areas where the soil no longer offers any protection against acidification. Alkalinity declines in these wells to a level where pH also begins to fall. Acidification of groundwater means that more aluminium and heavy metals will be dissolved in the groundwater and also increases corrosion of piping, which in turn leads to higher metal concentrations in drinking water.

pH readings are highly unreliable, particularly if taken directly in the field. Alkalinity should instead be recorded as a means of assessing the buffering capacity of groundwater against acidification. Alkalinity principally comprises HCO_3^- and is a robust parameter that does not usually change between sampling and analysis. The pH of the groundwater can be estimated on the basis of its alkalinity. Table 2 shows normal pH intervals in groundwater for the various alkalinity classes. (See Appendix 5 for more information on the choice of parameters.)

Assessment of current conditions

The capacity of the groundwater to withstand acidification is assessed. The five classes used are shown in Table 2.

TABLE 2.

EFFECT-RELATED CLASSIFICATION OF CURRENT CONDITIONS for groundwater in terms of alkalinity (HCO_3^-). The level of alkalinity is a measure of the water's ability to withstand acidification. The stated pH intervals indicate the pH levels prevailing in the aquifer (pH recorded in the field).

Class	Description/ alkalinity	Alkalinity (mg/l)	(HCO_3) (meq/l)	pH	Description
1	Very high level	≥ 180	≥ 3	>6.5	Sufficient alkalinity to maintain acceptable pH in the future
2	High level	60–180	1-3	>6.0	
3	Moderate level	30–60	0.5–1.0	5.5–7.5	Insufficient alkalinity to maintain stable and acceptable pH in areas with high deposition
4	Low level	10–30	0.2–0.5	5.0–6.0	Insufficient alkalinity for a stable and acceptable pH level
5	Very low level	<10	<0.2	<6	The level of alkalinity gives an unacceptable pH level

Out of 26,636 analyses in the Swedish Geological Survey database, 28% fell within class 1, 36% in class 2, 14% in class 3, 17% in class 4 and 5% in class 5.

Guide and limit values for drinking water issued by the National Food Administration (see also Appendix 11)

Guide value: 60 mg/l (1 meq/l) HCO_3^-
Limit value (technical reservations, acceptable): 30 mg/l (0.5 meq/l) HCO_3^-
The boundaries between classes 2–3 and 3–4 are effect-related. Other class boundaries have been selected to provide a good degree of accuracy on both sides of the guide and limit values.

If extensive corrosion of piping and resulting elevated metal concentrations are to be avoided (see also the chapter on "Metals"), the pH of the water should be higher than 6.0, which means that alkalinity should be greater than 30 mg/l (0.5 meq/l). Many Swedish wells fail to meet these standards. In some of these the groundwater is naturally acid. The natural carbonic acid in the water causes low pH in shallow wells in areas with low weathering capacity. Wells bored in rock usually have higher alkalinity (HCO_3^-) than wells bored through loose deposits.

Alkalinity – division into type areas (for regional division, see the chapter on "Division into type areas")

The risk of low alkalinity (classes 4–5) arises particularly in surface aquifers in moraine, fluvial outwash and fluvio-glacial deposits (groundwater environments 3 and 4) in areas of igneous and metamorphic rock (regions B, C, E, G and I). Wells bored in rock (groundwater environment 1) in these regions may also occasionally have low alkalinity (class 4). Very low alkalinity (class 5) is fairly uncommon in well water but does occur in very near-surface groundwater or as a result of pronounced acidification. Aquifers below clay or silt (groundwater environment 5) often display high or very high alkalinity even in areas of igneous and metamorphic rock (regions C and E). The same is true of all groundwater environments in ares with sedimentary bedrock and areas where the soil strata are calcareous (regions A, D, F and H).

TABLE 3.

Percentage distribution of current condition classes for alkalinity in the various type areas. Based on well analyses from the Swedish Geological Survey database (n=23,060)

	Groundwater environment																								
	1 Igneous bedrock					2 Sedimentary bedrock					3 Moraine and fluvial outwash					4 Fluvio-glacial deposits					5 Confined aquifers				
	Current condition class					Current condition class					Current condition class					Current condition class					Current condition class				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Region	%					%					%					%					%				
A						91	8	1	0	0	80	14	3	2	2	49	26	17	3	6	83	15	1	1	0
B	10	55	20	11	3						3	12	27	44	14	2	13	22	47	16					
C	23	59	11	5	2						10	26	23	28	14	3	12	19	53	13	20	37	20	17	7
D	72	24	4	1	0	73	24	2	1	0	22	41	19	13	5	31	25	31	10	2	18	48	27	3	3
E	43	48	5	3	1						10	31	24	25	9	5	26	27	33	9	19	35	22	20	4
F	83	16	1	0	0						52	33	12	2	1	58	21	21	0	0	80	20	0	0	0
G	19	67	10	3	1						2	14	24	41	19	2	22	23	46	7	3	20	26	42	10
H	44	51	5	0	0	71	27	1	1	0	31	38	15	15	1	23	23	31	23	0	55	38	2	5	0
I	7	62	18	12	1						2	15	20	46	16	2	11	27	52	9					

Empty spaces indicate impossible combinations of region/groundwater environment.

Reference value

It is very difficult to calculate original and exhausted alkalinity in a given body of groundwater owing to great local differences in sulphate load, mineralogy and flow patterns. Average regional figures for sulphate deposition valid for a given point in time can be derived, but when it comes to assessing a given well (or a limited number of wells), difficulties will arise, since their response to the acidification load will vary. There is therefore no reference value for "Alkalinity – risk of acidification".

Assessment of risk of acidification

The capacity of groundwater to withstand acidification is assessed in relation to the acidification load. In the past, the ratio between alkalinity and total hardness was frequently used to determine the degree of acidification impact. This model has now been abandoned. Instead, the residual capacity of the water to withstand acifidication (ie, its alkalinity) is compared with the acidification load in the form of sulphur deposition (for the reasons for this, see Appendix 5).

Regional airborne sulphur deposition (not including sea salts) is used as a measure of the acidification load. Since airborne nitrogen deposition to date has been largely absorbed by vegetation, the direct acidifying effect of nitrogen has been limited. The acidification load has therefore been derived solely from regional sulphate deposition figures. Deposition data for 1985 - 1989 has been used for the load map (Figure 8a). Sulphur deposition has been converted into a numerical value for the sulphate concentration in the precipitation infiltrating into the groundwater, using mean figures for the annual flow. For calculation purposes, annual flow is assumed to correspond to annual groundwater formation. The acidification load on a given well may be lower or higher, depending on local deposition and water turnover conditions. Deposition has been calculated for the average land use in the area. In areas exclusively covered by forest, deposition will be greater owing to high dry deposition. In south-west Sweden, which has high precipitation levels and hence a high rate of groundwater accumulation, concentrations are lower than in the south-east of the country. Wells have been affected by acid deposition to varying degrees. Apart from the amount of deposition, the degree of impact also depends on the buffering capacity of the well water, which is in turn dependent on the degree of weathering taking place in its catchment area. Sulphur deposition peaked in the 1970s, but although it has decreased, it remains far higher than natural background levels (Figure 8b).

The alkalinity of the groundwater sample is compared with the acidification load to assess the acidification impact. If the acidification load from deposition is as great or greater than the buffering capacity (calculated

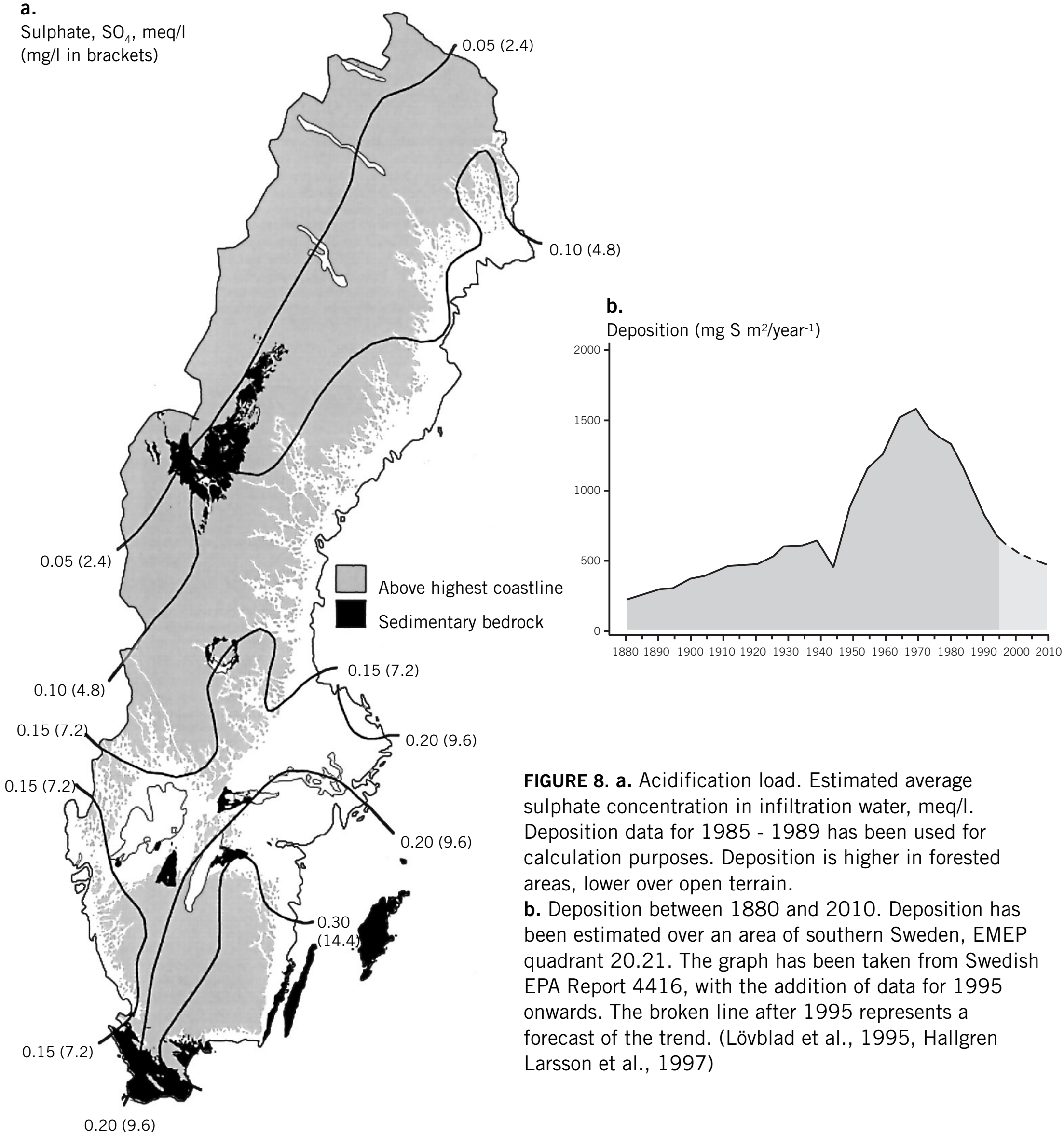


FIGURE 8. a. Acidification load. Estimated average sulphate concentration in infiltration water, meq/l. Deposition data for 1985 - 1989 has been used for calculation purposes. Deposition is higher in forested areas, lower over open terrain.
b. Deposition between 1880 and 2010. Deposition has been estimated over an area of southern Sweden, EMEP quadrant 20.21. The graph has been taken from Swedish EPA Report 4416, with the addition of data for 1995 onwards. The broken line after 1995 represents a forecast of the trend. (Lövblad et al., 1995, Hallgren Larsson et al., 1997)

from concentrations converted into meq/l), the groundwater is considered to be very heavily acidified.

The impact of acidification on groundwater is described in five classes, as shown in Table 4. Regional sulphate concentrations in infiltration water have been taken from Figure 8a.

Factors influencing the amount of alkalinity are described below.

Local deviations from sulphate concentrations given on the map (see also Appendix 5, page 117)

In many aquifers, the sulphate concentration represents the level of deposition. Minor deviations (up to a factor of 2, ie, 50–200% of the stated con-

TABLE 4.

Alkalinity of groundwater in relation to sulphate deposition (see Figure 8a)

Class	Description	Alkalinity* in the well/estimated regional sulphate concentration in the infiltration water
1	No or insignificant impact	≥10
2	Moderate impact	10–5
3	Pronounced impact	5–2
4	Strong impact	2–1
5	Very strong impact	< 1

*Concentrations in meq/l

centration) may be due to local water turnover or deposition conditions. Since sulphate deposition has varied over recent decades, the age of the groundwater is also of significance.

Sulphate concentrations in well water which are much higher than the stated sulphate concentrations in deposition may indicate oxidation of sulphides in soil or bedrock. This is a common occurrence and particularly high concentrations are often found in areas of sedimentary bedrock and areas where mud clay or other organic soils are present. Sulphide oxidation uses up alkalinity and makes the water more acid. Very low sulphate concentrations may result because the groundwater is old and unaffected by sulphur deposition or may be due to reducing conditions in the groundwater. Sulphate will then have been reduced to sulphide, which increases the alkalinity of the water. This occurs mainly in deep wells. Oxidation, which increases sulphate content, is the predominant process, however. Redox processes are described in a separate chapter.

Impact caused by agriculture and nitrogen-saturated forest soils

Nitrate nitrogen (NO_3-N) is recorded

Very low alkalinity may also be due to acidification caused by nitrogen compounds. High concentrations of nitrate usually originate from the use of fertilisers on agricultural land. In the future, deposition of oxides of nitrogen and ammonium may cause more extensive nitrogen saturation of forest soils and result in severe acidification and high concentrations of nitrate in groundwater. Nitrogen input (primarily in the form of ammonium) may cause pronounced acidification impact in alkalinity classes 4 and 5. Nitrogen leaching resulting in a concentration of 1 mg NO_3-N/l in groundwater may cause an acidification effect of up to 0.07–0.14 meq/l. This will add to the regional acidification load deriving from sulphur (as shown on the map in Figure 8a).

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Trends in sulphur deposition

Hallgren Larsson, E., Knulst, J.C., Lövblad, G., Malm, G., Sjöberg, K. & Westling, O. (1997): Luftföroreningar i södra Sverige 1985–1995 (”Air pollution in southern Sweden 1985–1995”). – Swedish Environmental Research Institute, Report B 1257.

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Deposition data

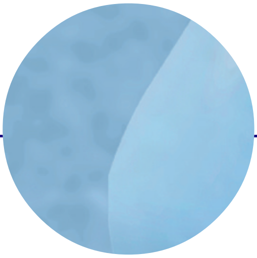
Swedish Environmental Research Institute (IVL)

Land use data

National Forest Survey

Flow data

Swedish Meteorological and Hydrological Institute (SMHI)



Nitrogen

The nitrogen content of groundwater is assessed in terms of the concentration of nitrate.

Introduction

High concentrations of nitrogen compounds limit the utility of groundwater for drinking purposes owing to health risks. Natural concentrations of nitrogen compounds in groundwater are very low, since nitrogen is normally in short supply, being absorbed by vegetation. Elevated concentrations usually result from the use of farmyard manure, nitrogenous fertilisers (particularly on agricultural land) or the impact of sewage. Deposition of airborne nitrogen is high in southern Sweden. Nitrogen deposition originates from emissions of nitrogen oxides (mainly from traffic, where they are a by-product of combustion) and ammonia (almost all of which originates from livestock farming). Most airborne nitrogen has so far been absorbed by vegetation.

Nitrogen occurs mainly as nitrate in groundwater. The nitrate ion is scarcely adsorbed to soil particles and is therefore highly mobile in soil and groundwater. Elevated nitrate concentrations commonly occur in shallow wells. High levels of nitrogen may be lowered by various reduction processes, particularly in deep wells with anaerobic conditions (see the chapter on "Redox" and Appendix 6). Nitrate reduction by denitrification may occur where groundwater flows into wetlands, liberating gaseous nitrogen into the atmosphere in the process. However, elevated concentrations of nitrogen in groundwater generally mean that the amount of this element entering surface watercourses and the sea will increase.

The state of groundwater in terms of nitrogen compounds is presented here as the concentration of nitrate nitrogen (NO_3-N). Elevated concentrations of nitrite nitrogen (NO_2-N) and ammonium nitrogen (NH_4-N) may occur under reducing conditions (class 4 in Table 11 in the "Redox" chapter and Appendix 6) but concentrations are generally lower than those of nitrate. Organic nitrogen in groundwater is not usually determined.

Assessment of current conditions

Groundwater state in terms of its nitrogen content is described in five classes, as shown in Table 5.

TABLE 5.

CLASSIFICATION OF CURRENT CONDITIONS of groundwater in relation to nitrogen content, mg/l

Class	Description	NO_3-N (mg/l)	Comment
1	Very low concentration	≤ 0.5	Common concentration in forest soils
2	Low concentration	0.5–1	
3	Moderate concentration	1–5	
4	High concentration	5–10	Not uncommon in agricultural areas
5	Very high concentration	> 10	

Out of 14,221 analyses in the Swedish Geological Survey database, 74% fell within class 1, 7% in class 2, 14% in class 3, 3% in class 4 and 2% in class 5.

Guide and limit values for drinking water issued by the National Food Administration (see also Appendix 11)

Guide value: 1 mg/l NO_3-N

Limit value (technical reservations, acceptable): 5 mg/l NO_3-N and (health-related limit value, technical reservations, acceptable): 10 mg/l NO_3-N

The boundaries between classes 2–3 and 3–4 are based on the above guide and limit values. The boundary between classes 1 and 2 has been selected.

Reference value

REFERENCE VALUE: 0.5 MG NO_3-N/L

A reference value of 0.5 mg/l NO_3-N has been selected for nitrate. Sweden's natural systems are deficient in nitrogen. The natural nitrogen concentration in Swedish groundwater does not exceed 0.5 mg/l NO_3-N. The reference value has been set fairly high, which is justified by the fact that concentrations over 0.5 mg/l are reasonably certain to originate from leaching from agricultural land, from point sources or from nitrogen saturated forest soils. In addition to use of fertilisers, leaching from agricultural land mainly depends on the type of crop grown, cultivation methods, soil type and climate. Mean annual leaching from arable land south of the

Nitrogen content - division into type areas (for regional division, see the chapter on “Division into type areas”)

Nitrate concentrations are usually low in wells bored in rock, ie, groundwater environments 1 and 2 (classes 1 and 2). The main nitrate problems arise in surface aquifers in moraine, fluvial outwash and fluvio-glacial deposits (groundwater environments 3 and 4). But concentrations are also frequently high in groundwater environment 5, despite the protective layer of clay or silt. However, this environment often occurs in predominantly agricultural areas, where there is a high nitrate load.

TABLE 6.

Percentage distribution of current condition classes for nitrate in the various type areas.
Based on well analyses from the Swedish Geological Survey database (n=11,664)

	Groundwater environment																								
	1					2					3					4					5				
	Igneous bedrock					Sedimentary bedrock					Moraine and fluvial outwash					Fluvio-glacial deposits					Confined aquifers				
	Current condition class					Current condition class					Current condition class					Current condition class					Current condition class				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Region	%					%					%					%					%				
A						76	8	11	3	2	28	7	31	10	24	25	4	46	13	13	36	4	22	9	29
B	67	6	19	5	2						29	7	41	14	9	40	10	32	13	4					
C	81	8	8	2	1						65	6	17	9	3	18	12	38	19	12	60	5	26	5	3
D	84	3	9	2	2	86	2	7	2	2	43	4	35	13	4	-	-	-	-	-	-	-	-	-	-
E	80	6	11	2	1						59	13	20	7	1	67	8	19	5	1	52	11	24	8	5
F	73	8	16	2	0						36	15	43	6	0	-	-	-	-	-	18	3	58	18	3
G	89	4	6	1	0						63	6	25	2	3	59	4	37	0	0	53	13	22	10	3
H	67	7	21	5	0	73	14	10	2	2	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I	75	7	18	1	0						67	6	18	3	4	71	4	21	4	0					

Empty spaces indicate impossible combinations of region/groundwater environment
A dash indicates too few analyses (<15)

Dalälv river has been estimated at 22 kg N/ha (Johnsson & Hoffmann, 1997). Combined with estimated mean run-off of 282 mm, this represents a mean concentration of 8 mg/l NO_3-N in water flowing through the rhizosphere. Using the same calculation method, leaching from unfertilised grassland produces concentrations of between 0.7 and 2.5 mg/l. For potential nitrogen leaching from arable land, see the report on the Agricultural Landscape.

Recorded nitrogen leaching from non-nitrogen saturated forest soils shows a median figure below 0.03 mg/l NO_3-N (Hallgren et al., 1997). However, forest soils are also expected to produce a significant surplus of nitrogen entering groundwater in the future unless airborne deposition is reduced (see the report on the Forest Landscape). A rule of thumb is that if nitrogen deposition is >25 kg/ha/year, nitrogen leaching of >10 kg/ha/year can be expected. Deposition of between 10–25 kg may cause leaching of >1 kg/ha/year. At lower levels of deposition, there is little risk of more than 1 kg/ha/year leaching.

10 kg/ha/year represents a mean concentration of 3.5 mg/l and 1 kg represents 0.35 mg/l in the percolated water accumulating to form groundwater.

Assessment of deviation from reference values

Concentrations over 0.5 mg/l NO_3-N may be considered the result of some form of impact. Deviation from the reference value for nitrogen is classified as shown in Table 7.

TABLE 7.

CLASSIFICATION OF DEVIATION from reference value for nitrogen. The deviation interval is shown both as a ratio and as a concentration.

Class	Description	(multiple)	NO_3-N (mg/l)
1	No or insignificant deviation	≤ 1	≤ 0.5
2	Moderate deviation	1–4	0.5–2
3	Pronounced deviation	4–10	2–5
4	Large deviation	10–20	5–10
5	Very large deviation	> 20	> 10

Factors that may result in elevated nitrogen concentrations are described below.

Impact from agriculture, sewage and landfill sites

Phosphate (PO_4), potassium (K) and chloride (Cl) are recorded

High concentrations of nitrate are sometime accompanied by elevated concentrations of the nutrients phosphate and potassium. Since both of these are tightly fixed in soil, elevated concentrations of phosphate (>0.1 mg/l) or potassium (>10 mg/l) in agricultural areas may indicate rapid passage between the soil surface and the groundwater. Although concentrations above those indicated often derive from some kind of anthropogenic impact, higher concentrations may also have natural causes. For example, high phosphate concentrations may occur naturally in anaerobic environments (see Appendix 6). Phosphate and potassium may originate from fertilisers, sewage and landfill. Elevated chloride concentrations (see the chapter on "Salt – chloride") may also accompany high nitrate concentrations. This is common where sewage has an impact and at landfill sites for household refuse.

Knowledge of land use, location of sewage treatment plants, manure/fertiliser stores, landfill sites etc is necessary to identify the probable source(s) of elevated nitrogen concentrations in groundwater.

References

Nitrogen in arable soils

Johnsson, H. & Hoffmann, M. (1997): Kväveläckage från svensk åkermark - beräkning av normalutlakning och möjliga åtgärdar. – Swedish EPA Report 4741.

Nitrogen in forest soils

Hallgren Larsson, E., Knulst, J.C., Lövblad, G., Malm, G., Sjöberg, K. & Westling, O. (1997): Luftföroreningar i södra Sverige 1985–1995 ("Air pollution in southern Sweden 1985–1995"). – Swedish Environmental Research Institute, Report B 1257.

Lövblad, G. et al. (1992): Mapping deposition of sulphur, nitrogen and base cations in the nordic countries. – Swedish Environmental Research Institute, Report B 1055.

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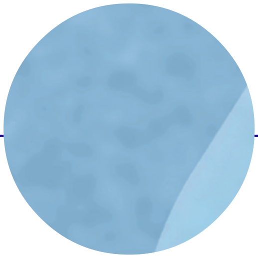


Salt – chloride

The chloride content of groundwater is assessed.

Introduction

Chloride concentrations are normally low in areas that have not been covered by the sea since the last ice age. Concentration in groundwater in areas previously covered by the sea (below the marine limit, ie, the salt-water limit) are often higher. Groundwater may be affected by relict salt water. (For the sake of simplicity, the term “highest coastline”, which coincides with the marine limit throughout most of the country, is used below.) Present sea water may also have an impact in coastal areas. Chloride concentrations are also often high in areas of sedimentary bedrock.

In urban areas the amount of salt (mainly sodium chloride) used is great compared with the quantities naturally entering the environment via the air. Elevated chloride concentrations may derive from salting of roads, sewage or landfill. The chloride ion is not adsorbed to soil particles and is therefore highly mobile in soil and groundwater. High chloride concentrations in groundwater may cause corrosion of piping and limit the utility of the water for drinking purposes owing to changes in taste.

Electrical conductivity is often measured as a simple means of monitoring a sizeable number of wells to find out whether the water in any of them has greatly elevated salt concentrations. This process can be performed in the field and provides a measure of the total quantity of ions in the water. Conductivity can be used to estimate chloride concentrations above 20 mg/l. This will not work in environments where there are high concentrations of other ions.

Chloride concentration	Electrical conductivity
< 20 mg/l	< 30 mS/m
> 50 mg/l	> 50 mS/m
> 100 mg/l	> 70 mS/m
> 300 mg/l	> 100 mS/m

A separate chloride analysis can be performed if electrical conductivity is elevated.

Assessment of current conditions

Groundwater state as regards chlorine content is described in five classes, as shown in Table 8.

TABLE 8.

EFFECT-RELATED CLASSIFICATION OF CURRENT CONDITIONS of groundwater in relation to chloride content, mg/l

Class	Description	Cl (mg/1)	Comment
1	Low concentration	≤ 20	
2	Moderate concentration	20–50	
3	Fairly high concentration	50–100	
4	High concentration	100–300	Risk of corrosion in piping
5	Very high concentration	> 300	Risk of changes in taste

Out of 22,906 analyses in the Swedish Geological Survey database, 65% fell within class 1, 23% in class 2, 6% in class 3, 4% in class 4 and 2% in class 5.

Guide and limit values for drinking water issued by the National Food Administration (see also Appendix 11)

Limit value (technical reservations, acceptable): 100 mg/l Cl and (aesthetic reservations, technical reservations, acceptable): 300 mg/l Cl

The boundaries between classes 3–4 and 4–5 are effect-related. Other class boundaries have been selected to provide greater accuracy in the intervals at which chloride concentrations will occur in many groundwater samples.

Presence of chloride – division into type areas (for regional division, see the chapter on "Division into type areas")

Chloride concentrations are often elevated in areas previously covered by the sea (regions C, D, E, F and parts of A and H) and in areas of sedimentary bedrock. Groundwater is affected by relict (or fossil) salt water. However, this does not apply to areas of sedimentary bedrock in Dalarna and Jämtland (region H), where chloride concentrations are usually low. Present sea water may also have an impact in coastal areas. But water in many wells has fairly low salinity, even below the highest coastline. In coarse soils in particular, the soil strata may be so washed out that the chloride content is equal to the concentration of airborne deposition of chloride. Approximately half of all wells have water with chloride concentrations below the reference values (5 or 20 mg/l). High concentrations (classes 4 and 5) are somewhat more common in wells bored in rock (groundwater environments 1 and 2), and in wells in valleys (groundwater environment 5).

TABLE 9.

Percentage distribution of current condition classes for chloride in the various type areas.
Based on well analyses from the Swedish Geological Survey database (n=19,669)

	Groundwater environment																								
	1 Igneous bedrock					2 Sedimentary bedrock					3 Moraine and fluvial outwash					4 Fluvio-glacial deposits					5 Confined aquifers				
	Current condition class					Current condition class					Current condition class					Current condition class					Current condition class				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Region	%					%					%					%					%				
A						21	38	17	13	11	35	51	6	6	2	57	34	3	6	0	19	51	14	13	4
B	72	24	4	0	0						74	22	3	1	0	74	23	2	1	0					
C	38	38	11	7	5						45	43	10	2	0	49	41	9	0	1	19	45	17	16	3
D	48	30	11	9	2	50	26	13	7	4	75	21	4	0	0	50	35	4	11	0	69	19	9	3	0
E	61	23	7	6	3						77	18	4	1	0	72	24	3	1	0	63	26	8	2	1
F	51	26	11	8	4						67	19	5	4	4	50	46	4	0	0	59	32	9	0	0
G	73	14	5	5	2						92	7	1	1	0	85	13	1	1	0	92	6	2	0	0
H	89	8	3	0	0	83	11	5	1	0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I	93	5	2	0	0						94	5	1	0	0	96	4	0	0	0					

Empty spaces indicate impossible combinations of region/groundwater environment
A dash indicates too few analyses (<15)

Reference value

REFERENCE VALUE
Svealand and Norrland (central and northern Sweden): 5 mg chloride/l
Götaland (southern Sweden): 20 mg chloride/l

Reference values of 5 and 20 mg/l, respectively, have been chosen for chloride. Concentrations of chloride in groundwater are normally low in areas above the highest coastline, ie, primarily in regions B and I (see the chapter on "Division into type areas"). The natural input of chloride comprises sea salts, some dissolved in precipitation (wet deposition) and some falling as particles (dry deposition). The map in Figure 9 shows the estimated concentration of atmospheric deposition of chloride in the water infiltrating to form groundwater (for method of calculating concentrations, see page 31).

The mean figure for chloride in unaffected wells in a given area should be at approximately this level. The chloride concentration in an individual well may be higher or lower owing to local variations in deposition and infiltration conditions. In almost all cases the deviation is probably less than a factor of 2, ie, 50–200 per cent of the stated concentration. In southern Sweden (Götaland) the concentration of chloride in groundwater derived from deposition may vary by up to just less than 20 mg/l. Higher concentrations may occur at exposed locations along the west coast. Deposition results in chloride concentrations below 5 mg in central and northern Sweden.

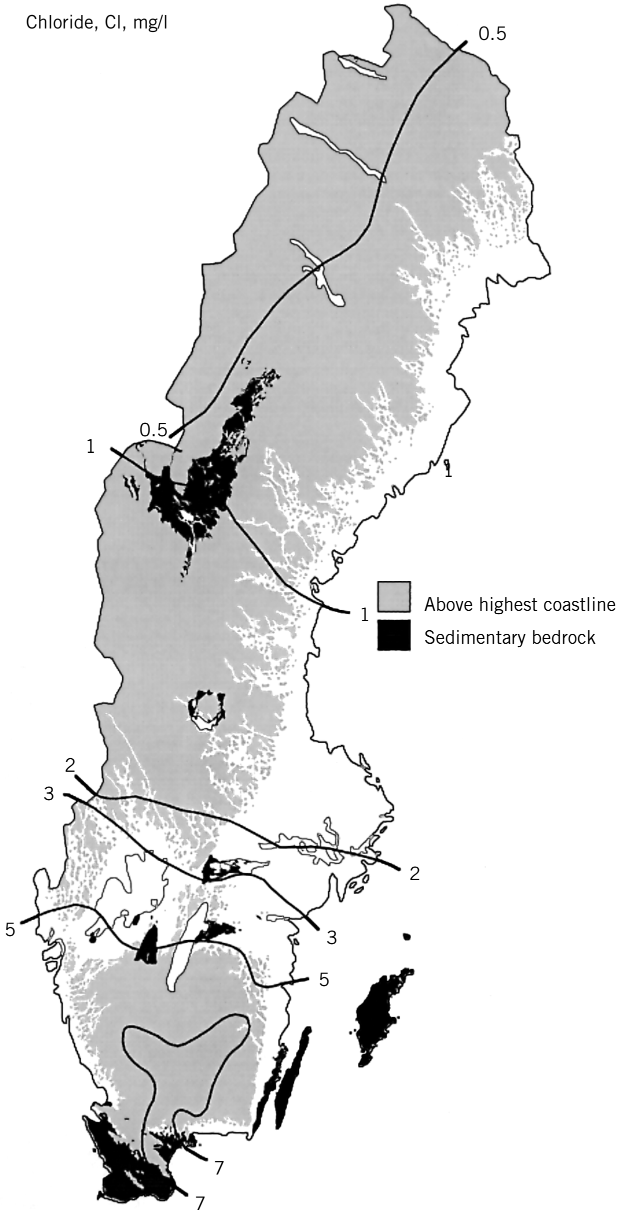


FIGURE 9. Estimated average chloride concentration in the water infiltrating to form groundwater (mg/l). Higher concentrations may occur at exposed locations on the west coast. Deposition in forested areas is much greater than over open terrain, which results in higher concentrations in the infiltrated water. The map shows areas above and below the highest coastline and areas of sedimentary bedrock. For method of calculating concentrations, see page 31.

Assessment of deviation from reference values

The impact of road salting or sewage can be proved fairly easily in areas above the highest coastline. Below the highest coastline it is often difficult to distinguish any anthropogenic chloride from natural input, since the impact of naturally occurring chloride may result in high (and also highly variable) chloride concentrations in a given area.

Intrusion of sea water may affect water quality some considerable distance from the shoreline where large amounts of water are abstracted from sand, gravel aquifers, porous sedimentary rocks or heavily fissured igneous bedrock. But salt water intrusion in other wells bored in rock (groundwater environment 1) is fairly uncommon unless the well is very close to the shoreline (<100 m). Rock-bored wells in archipelago areas are usually affected by relict sea salt rather than by salt water intrusion. Problems caused by naturally high salinity may be exacerbated if large quantities of water are abstracted and if a well is too deep in relation to the depth of the freshwater aquifer.

Deviation from the reference value for chloride is described in five classes, as shown in Table 10.

TABLE 10.

CLASSIFICATION OF DEVIATION from reference value for chloride. Note that impact may be either anthropogenic (eg, road salting) or natural (eg, relict sea salt). The deviation interval is shown both as a ratio and as a concentration.

Class	Descriptiopn	Götaland		Svealand and Norrland	
		(multiple)	Cl (mg/l)	(multiple)	Cl (mg/l)
1	No or insignificant deviation	≤ 1	≤ 20	≤ 1	≤ 5
2	Moderate deviation	1–2.5	20–50	1–10	5–50
3	Pronounced deviation	2.5–5	50–100	10–20	50–100
4	Large deviation	5–15	100–300	20-60	100–300
5	Very large deviation	> 15	> 300	> 60	> 300

Factors that may result in elevated chloride concentrations are described below. These may help to trace the cause.

Impact of salt water

The relationship between chloride, sodium, calcium and magnesium is examined. Any elevated sulphate concentrations are examined.

Not only does water in wells affected by salt water have a high chloride concentration, it may display other chemical differences as compared with water in wells not affected by salt water. These include differences in the proportions of ions of chloride, sodium, calcium, magnesium and sulphate. The sulphate content is usually higher than the deposition level in groundwater affected by salt water (see Figure 8a).

The chloride content of sea water is matched by a sodium content representing 85 per cent of the chloride content (in equivalents). Large flows and rapid passage between sea water and a well may cause the saline groundwater to display the same ratio of sodium to chloride as in sea water. This is probably unusual, however. Ion exchange usually occurs where sodium ions are replaced by those of calcium and magnesium.

Water in a well affected by relict salt water instead sometimes has a sodium content higher than its chloride content (in equivalents) and high alkalinity (>180 mg/l HCO_3).

Elevated salinity may occur in environments where salts are leached out from clays overlying the aquifer. The groundwater may have elevated concentrations of calcium and magnesium as a result of ion exchange.

Sedimentary bedrock

Sulphur content is recorded

Sedimentary bedrock, interspersed with shale, for example, exhibits naturally elevated sulphate concentrations (see the chapter on "Division into type areas", Figure 2, showing geological regions).

Salting of roads in winter

The relationship between chloride, sodium and total hardness is examined

Where road salting has had an impact, a sodium chloride ratio of 1:1 (calculated as equivalents) may be expected. However, the situation may be complicated by ion exchange in the soil, so that calcium and magnesium concentrations (total hardness) increase instead of sodium.

Sewage, landfill sites and livestock farming

Nitrogen content is recorded

Elevated chloride concentrations due to impact from sewage, landfill or livestock farming are often accompanied by elevated concentrations of nitrate and ammonium (see the chapter on "Nitrogen").

References

Lövblad, G. et al. (1992): Mapping deposition of sulphur, nitrogen and base cations in the nordic countries. – Swedish Environmental Research Institute, Report B 1055.

Lövblad, G. (1990): Luftföroreningshalter och deposition i bakgrundsluft (”Concentrations of air pollutants and deposition in background air”). – Swedish Environmental Protection Agency Report 3812, 1990:14.

Olofsson, B. (1996): Salt groundwater in Sweden – occurrence and origin. SWIM-96, Salt Water Intrusion Meeting. – Swedish Geological Survey Reports and Notices, No. 87, pp 91–100.

Deposition data

Swedish Environmental Research Institute (IVL)

Land use data

National Forest Survey

Flow data

Swedish Meteorological and Hydrological Institute (SMHI)

Redox

Redox conditions in groundwater have a great influence on the solubility of many substances and hence concentrations in the water. Redox is assessed on the basis of the relative concentrations of ion, manganese and sulphate in the water.

Introduction

The term REDOX represents a large number of chemical reactions involving electron transfer. When a substance is OXidised, it transfers electrons to another substance, which is then REDuced. Many redox reactions are extremely slow unless catalysed by bacteria. The point at which a given reaction can take place is determined by the electrical tension difference or redox potential in the water - Eh. Eh may be seen as a measure of the propulsive force for the reaction. Redox potential can be measured directly in the water, although this is difficult. Instead, it has been decided to estimate the redox potential of the water by studying the relative concentrations of iron, manganese and sulphate. They appear in aqueous solution within specific redox intervals and, taken together, give a narrower range in which the solubility conditions for all three are met. These parameters have been chosen because they normally occur in fairly high concentrations in most natural groundwater systems. These substances therefore provide a robust system of assessment.

The redox status of the water provides information about problems to be expected when water is pumped up from the well. It may show whether the water will be difficult to treat to remove dissolved iron and manganese, whether the water will emit hydrogen sulphide or methane and whether iron and manganese will be precipitated. See Appendix 6 for a more detailed description of redox potential - Eh and redox reactions in the environment.

Assessment of current conditions

Groundwater redox status is described in five classes, as shown in Table 11.

TABLE 11.

EFFECT-RELATED CLASSIFICATION OF CURRENT CONDITIONS of groundwater in relation to redox conditions, indicator parameters in mg/l

Class	Description	Fe	Mn	SO_4 southern Sweden*	SO_4 northern Sweden**	Comments
1	High redox-potential /aerobic water	< 0.1	< 0.05	> 5	> 2	Often excellent groundwater, which can normally be distributed without treatment. Good aerated means that moderate quantities of organic pollutants are rapidly broken down.
2	Moderately high redox-potential /aerobic water	< 0.1	> 0.05	> 5	> 2	It may sometimes be necessary to aerate and remove manganese by filtration
3	Low redox-potential /anaerobic water	> 0.1	> 0.05	> 5	> 2	This water may originate from great depth or may have been affected over long periods by reducing minerals containing iron. This water always requires treatment to reduce the iron content. Our commonest water quality problem in Sweden.
4	Very low redox-potential /anaerobic water	> 0.1	> 0.05	< 5	< 2	Very difficult groundwater to treat. Often tainted by hydrogen sulphide or methane odours etc. Should preferably be avoided.
5	Mixed water					Water causing severe technical difficulties. Often involves iron deposits, blockages, odour and bacterial problems.
	type 1	< 0.1	all values	< 5	< 2	
	type 2	> 0.1	< 0.05	all values	all values	

*Regions A, B, C, D, E and F

**Regions G, H and I (there are areas of sulphide soil along the coast of region G where sulphate concentrations are considerably higher)

Out of 10,054 analyses in the Swedish Geological Survey database, 28% fell within class 1, 10% in class 2, 30% in class 3, 3% in class 4 and 29% in class 5.

The first four redox classes refer to water in equilibrium. Class 5 covers two types of water that are not in equilibrium, where a balance between various ions has not been established. Type 1 refers to water with low concentrations of iron in combination with low sulphate concentrations. Type 2 relates to water with high concentrations of iron combined with low manganese concentrations. There will be obvious effects on redox conditions in mixed water in the short term. Mixed water may occur for a variety of reasons:

- stratified aquifers with differing redox conditions in the strata sequences. Water from the various strata is mixed as it flows out into a spring or enters a well from which water is pumped;
- groundwater displaying obvious signs of anthropogenic impact.

Redox – division into type areas (for regional division, see the chapter on "Division into type areas")

TABLE 12.

Percentage distribution of current condition classes for redox in the various type areas. Based on well analyses from the Swedish Geological Survey database (n=10,996)

	Groundwater environment																								
	1 Igneous bedrock					2 Sedimentary bedrock					3 Moraine and fluvial outwash					4 Fluvio-glacial deposits					5 Confined aquifers				
	Current condition class					Current condition class					Current condition class					Current condition class					Current condition class				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Region	%					%					%					%					%				
A						17	4	25	6	48	68	18	9	0	6	63	0	23	3	10	39	10	22	14	15
B	23	19	37	4	16						51	9	17	0	23	48	10	19	0	23					
C	17	16	44	1	22						40	11	21	1	27	48	9	13	0	31	26	17	29	0	29
D	10	8	41	1	40	5	1	27	3	64	59	5	18	0	18	46	8	17	8	21	-	-	-	-	-
E	14	13	33	3	37						35	5	17	2	42	44	2	17	2	35	38	9	20	2	32
F	23	10	36	1	30						57	8	14	0	21	-	-	-	-	-	87	6	6	0	0
G	18	9	43	5	25						51	2	11	0	36	46	2	19	3	30	48	2	13	1	36
H	29	8	26	11	26	38	10	24	1	26	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
I	31	12	24	8	26						48	5	11	2	34	49	3	16	1	31					

Empty spaces indicate impossible combinations of region/groundwater environment
A dash indicates too few analyses (<15)

Reference value and deviation from reference value

No reference value is available for redox. No description of deviation from reference value is therefore given.

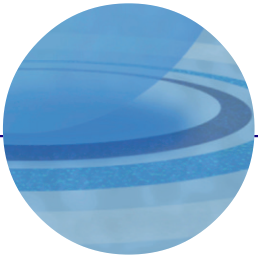
Comments

Human activities resulting in oxidation or reduction of minerals in soil or additional input of organic matter, in particular, affect redox. Water with reducing characteristics often causes problems for drinking water supply. This occurs naturally, principally in deep wells (groundwater environments 1 and 2), but also in confined aquifers (groundwater environment 5) and in association with areas of peat in other groundwater environments. Waterlogging and compaction of ground, which prevent oxygen exchange between the atmosphere and groundwater may also cause reducing conditions. An important consideration is that redox reactions often occur when water of one quality and origin is mixed with water of another. If disturbance ceases, the unstable waters will eventually assume a new chemical thermodynamic equilibrium. Access to early monitoring series will then be needed in order to analyse whether the waters were previously of a different quality. Thus, to identify anthropogenic impact, it will be necessary to have several water samples taken on different occasions and to be able to establish a change over time. Annual fluctuations in the water table themselves cause changes in redox conditions, which has a bearing on sampling (see Appendix 1, page 77).

How can changes in redox be interpreted?

A number of common causes of changes in redox conditions are given in the examples below.

- A change *from class 1 to class 2* (elevated manganese concentrations) is often a sign of shoreline infiltration. Abstraction of excessive quantities of groundwater has changed the direction of flow and induces infiltration of surface water at the shoreline, where groundwater previously seeped out.
- A change *from class 2 to class 3* or from class 3 to class 4 may have many causes, but the disturbance is stable and a new thermodynamic equilibrium has been established. One reason may be a lowering of the water table caused by pumping or drainage. A former outflow area has been transformed into an area where groundwater accumulates. Peat or other soils with a high organic content are often found here. Organic matter, which causes more reducing conditions, may also originate from clear-cut areas, leakage from sewage infiltration plants or from areas where large quantities of farmyard manure are spread. Another cause of change may be abstraction during dry periods. This may set stagnant groundwater in motion. This type of water, which has remained in an aquifer for a long time, is often anaerobic and iron-rich.
- Changes *class 1, 2 3* or *4 to class 5* indicate mixing of water of differing origin. The commonest causes of this are changes in flow direction. This may occur naturally or as a consequence of human activities. Examples of the latter are groundwater abstraction and drainage.
- Changes *from a higher to a lower class,* which lead to more oxidising conditions, may be due to discharges of nitrate. This impact may be local (most likely in igneous and metamorphic rock and moraine) or widespread (more common in sedimentary bedrock, fluvio-glacial material and in confined aquifers). A reduction in the organic pollution load on groundwater may also create better oxidising conditions.



Metals

Assessment of concentrations of cadmium, zinc, lead and arsenic

Introduction

This chapter deals with cadmium, zinc, lead and arsenic (a metalloid). They have been selected because the concentrations recorded are often the result of anthropogenic impact. Arsenic is not included in the Environmental Monitoring Handbook and very few samples have yet been taken. Our knowledge of the occurrence of arsenic has improved and a more critical view of its health effects has been adopted in recent years.

These metals are usually present in such low concentrations in minerals that their concentration in water is limited by adsorption to humus, to iron and aluminium oxides/hydroxides and to minerals in clay. Some rocks, such as schists, contain elevated concentrations, which may result in naturally high concentrations in groundwater. Mineralisation in bedrock often consists of sulphides, which may be oxidised if the water table is lowered following water abstraction. This will increase the risk of elevated metal concentrations.

Metals entering groundwater from anthropogenic sources

Elevated metal concentrations often derive from anthropogenic sources such as waste tips, mine spoil heaps and other industrial activities. The three metals cadmium, zinc and lead are in common use. They are dispersed by emissions to air and soil and reach the groundwater. Cadmium is being phased out in the manufacturing of products but has accumulated in agricultural soils and contaminated land. Zinc is much used in galvanised steel products, which often form part of ground-based constructions. Lead has accumulated in the ground as a result of exhaust emissions from vehicles running on leaded petrol and also comes from buried lead-covered cables. Lead disperses within a few centimetres of these cables. All three metals become mobile in soil where pH levels are low, lead less so than the other two.

Wood preservatives for outdoor use contain arsenic. Leakage into the ground and leaching from landfill sites threaten groundwater. Arsenic occurs as a negatively charged ion; its solubility is largely determined by redox conditions and pH (see the chapter on “Redox”).

Metals having little anthropogenic impact on groundwater

In Sweden, mercury, copper and aluminium are present in very low concentrations in drinking water and are thus not described in detail here. Regarding the anthropogenically elevated concentrations that nonetheless do occur, see the report on contaminated sites.

Occurrence and characteristics

Cadmium

Cadmium is stored in certain rocks, such as schists. In mineral form, cadmium is often found in combination with zinc. Zinc is essential to most organisms and is actively absorbed by plants as well as animals. This means that cadmium, which is chemically very similar to zinc, is also easily absorbed. Cadmium concentrations are normally less than one 100th of those of zinc and organisms are unable to distinguish between the two. People suffering from iron deficiency may absorb cadmium instead of iron (Vahter, 1994). Cadmium is toxic at low concentrations and, as far as we know, has no function in organisms. Cadmium is adsorbed to humus and minerals in clay. It is fairly weakly fixed in soil and is released at low pH when competition with hydrogen and aluminium ions increases. It has been found that the concentration of cadmium rises rapidly in water, in soil and in groundwater at pH levels below 5. Hence, acidification involves a risk of elevated cadmium concentrations.

Zinc

Zinc is essential to most organisms and certainly to man. It is more harmful to aquatic organisms, however. Moderate concentrations of zinc in groundwater are an indication of the presence of other metals, particularly cadmium. At most, cadmium concentrations reach one per cent of those of zinc. Thus, 0.5 mg Zn/l may be accompanied by 5 µg Cd/l. Cadmium occurs with zinc in zinc ores and is also present in small quantities in galvanised coatings. Steel is often coated with a surface layer of zinc, chromium or nickel. Zinc is adsorbed to humic matter. It is liberated at low pH by competition from hydrogen and aluminium ions. Acidification therefore involves a risk of elevated zinc concentrations in groundwater.

Lead

The average concentration of lead in the earth’s crust is 16 mg/kg; concentrations in soil are somewhat higher. Lead is immobile in the soil environment, since it adsorbs tightly to humus and minerals in clay. Lead is set in motion at low pH levels and elevated concentrations of dissolved organic matter. Adsorbed lead then enters the water attached to small suspended particles. Lead is non-essential to organisms. Acute lead poisoning affects haemoglobin synthesis, which leads to iron deficiency. When pregnant women are exposed to even moderate quantities of lead, the foetus may suffer mental retardation (at concentrations above 10 µg/l). Metallic lead in direct contact with water is soluble in quantities that may easily exceed the health-related limit value.

Arsenic

Arsenic exhibits moderate acute toxicity, but ingestion via water over a long period even of quantities below the health-related limit value (50 µg/l) causes skin damage. Arsenic occurs in bedrock in combination with sulphides. It is mobilised in two main ways. Oxidation of sulphides following a lowering of the water table is one. The other results from the reduction of iron when arsenic is adsorbed to iron hydroxides. Reduction often follows a rise in the water table. The risk of dissolved arsenic in the form of trivalent or pentavalent negatively charged ions, is greatest in current conditions class 3 according to Table 11 (”Redox” chapter). Concentrations in groundwater may increase as pH rises, since adsorption to iron hydroxides is greatest in acid conditions. Adsorption declines as pH rises and arsenic is mobilised. Dissolved iron in groundwater may be an indication of an elevated concentration of arsenic. Elevated iron concentrations frequently occur in water in deep wells bored in rock and there is reason to believe that arsenic may follow a similar pattern (Idman, 1996).

Copper

Copper concentrations in groundwater are very low. The median figure in groundwater in the Swedish Geological Survey database is around 1 µg/l and the 90th percentile lies at about 5 µg/l. This means that 90 per cent of all samples in Sweden have concentrations below 5 µg/l. Elevated copper concentrations in drinking water occur as a result of corrosion of copper pipes. The National Food Administration health-related limit value is 2,000 µg/l. A study based on 900 analyses revealed a median value for copper in tap water standing overnight in pipes of 1,300 µg/l (Aastrup et al., 1995 and Figure 3, Appendix 10). Thus, copper in drinking water is a corrosion problem and is not therefore dealt with in further detail in this report.

Aluminium

Many analyses reporting aluminium concentrations in groundwater are unreliable because the samples have not undergone proper filtration. The concentration of aluminium in groundwater is directly linked to pH. Dissolved aluminium in groundwater seldom exceeds 100 µg/l at pH >5.5. When weathering of carbonate and feldspar is no longer sufficient to act as a buffer, aluminium begins to do so. The high content of aluminium in minerals in the soil provides a buffer for acid water with a pH below 5.

Accordingly, aluminium concentrations rise dramatically to 1,000–2,000 µg/l at pH levels below 5. National Food Administration guide values for aluminium in drinking water have been set from a technical viewpoint (nuisance caused by aluminium flocculation) after water treatment with aluminium sulphate and cannot be used for assessing the risk to health. Aluminium is therefore not dealt with in further detail.

Mercury

Mercury occur naturally in very low concentrations in groundwater and is therefore rarely analysed. The median figure in groundwater in the Swedish Geological Survey database is around 0.001 µg/l and the 90th percentile is just below 0.01 µg/l. The health-related limit value is 1 µg/l. Mercury has been deposited in conjunction with various kinds of industrial activity. Long-range atmospheric deposition constitutes a continual source of mercury entering soil and water, although concentrations in groundwater are nonetheless extremely low and do not pose any threat to human health. Mercury is instead carried by near-surface groundwater to lakes and watercourses. It accumulates there in various organisms in the food chain and is found in high concentrations in the muscle tissue of fish and piscivores, for example. Mercury is not assessed in this report.

Assessment of current conditions

The National Food Administration health-related limit values for drinking water represent effect limits for classification of current conditions. Zinc is an exception, since there are no health-related limit values for this metal. The National Food Administration limit value for technical utility is used instead. For all metals, the boundary between classes 2 and 3 is defined as the concentrations where effects begin to appear in aquatic biota in sensitive surface waters (see the report on lakes and watercourses). In surface waters, the risk is greatest in soft, oligotrophic, humus-poor waters and waters with low pH.

TABLE 13.

EFFECT-RELATED CURRENT CONDITION CLASSES for metals and arsenic in groundwater, µg/l

Class	Description	Cd	Zn	Pb	As
1	Very low concentration	≤ 0.05	≤ 5	≤ 0.2	≤ 1
2	Low concentration	0.05–0.1	5–20	0.2–1	1–5
3	Moderate concentration	0.1–1	20–300	1–3	5–10
4	High concentration	1–5	300–1000	3–10	10–50
5	Very high concentration	> 5	> 1000	> 10	> 50

”Effects” here means effects on the reproduction or survival at early stages of life of species or groups of species. This is often manifested as a fall in the number of individuals of a species. This may have repercussions on the assemblages of organisms in the water and structure of the ecosystem.

Guide and limit values for drinking water according to the National Food Administration (see also Appendix 11)

Cadmium (Cd): Limit value (health-related limit value, acceptable): 1 µg/l and (health-related limit value, unfit for drinking): 5 µg/l.

Zinc (Zn): Limit value (technical reservations): 300 µg/l, the survival of aquatic organisms is affected even after brief exposure (report on lakes and watercourses). Limit value (aesthetic reservations, technical reservations): 1,000 µg/l (taste and turbidity).

Lead (Pb): Limit value (health-related limit value, unfit for drinking): 10 µg/l.

Arsenic (As): Limit value (health-related limit value, acceptable): 10 µg/l (WHO specifies an effect based on the lifetime risk of cancer). Limit value (health-related limit value, unfit for drinking): 50 µg/l.

Reference values

The reference values for metals have been based on the Swedish Geological Survey water supply network data and its Environmental Monitoring Programme. These databases comprise mainly analysis data on uncontaminated groundwater, disregarding atmospheric deposition of metals. The 90th percentile in the database has been selected as a measure of groundwater unaffected by metal concentrations. This means that 90 per cent of the samples analysed have lower concentrations than the reference value.

TABLE 14.

REFERENCE VALUES for metals and arsenic in groundwater, µg/l

Metal	Reference value
Cd	0.1
Zn	100
Pb	1
As	1

The reason for choosing this percentile is that metal concentrations in water in the vast majority of wells in Sweden may be regarded as being little affected by human activities. Far fewer readings have been taken to determine arsenic concentrations than for metals. These have been taken by the Swedish Geological Survey as part of a separate arsenic monitoring programme. The 90th percentile has also been selected as the reference value for arsenic.

Locally, concentrations of cadmium and arsenic are naturally elevated owing to the geochemistry of the bedrock. Insufficient analysis data has rendered it impossible to determine regional reference values.

Assessment of deviation from reference values

The boundary between classes 1 and 2 comprises the reference value. The boundary between classes 4 and 5 has been set at the concentration at which point sources clearly influence the concentration. For classification of higher concentrations, see the report on contaminated sites. The intermediate classes (2, 3 and 4) represent a progressively increasing degree of non-point source impact.

TABLE 15.

CLASSIFICATION OF DEVIATION from reference value for concentrations of metals and arsenic. The first column for each metal shows the deviation interval in the class. The second column shows the corresponding concentration interval.

Class	Description	Cadmium (Cd)		Zink (Zn)		Lead (Pb)		Arsenic (As)	
		(multiple)	(µg/l)	(multiple)	(µg/l)	(multiple)	(µg/l)	(multiple)	(µg/l)
1	No or insignificant deviation	≤ 1	≤ 0.1	≤ 1	≤ 100	≤ 1	≤ 1	≤ 1	≤ 1
2	Moderate deviation	1–5	0.1–0.5	1–2	100–200	1–1.5	1–1.5	1–2	1–2
3	Pronounced deviation	5–20	0.5–2	2–4	200–400	1.5–2.5	1.5–2.5	2–5	2–5
4	Large deviation	20–50	2–5	4–7	400–700	2.5–5	2.5–5	5–10	5–10
5	Very large deviation	> 50	> 5	> 7	> 700	> 5	> 5	> 10	> 10

Dispersal, impact and concentration in groundwater of metals

Cadmium

Naturally high concentrations of cadmium occur in some regions of the country with sedimentary bedrock even where pH is not particularly low. Cadmium is stored here in certain rocks, such as shales. Where alum shale is a pronounced feature in the soil, this may cause elevated concentrations of cadmium in groundwater.

Cadmium enters soils via long-range dispersal and from point sources. Long-range dispersal has been in the form of atmospheric deposition (originating from, eg, engineering plants and zinc manufacture) and following use of phosphate fertilisers. Although these emissions have decreased, much cadmium remains fixed in organic matter in the soil. In particular, cadmium has accumulated in forest and agricultural soils in southern Sweden. In places, the quantity of fixed cadmium in agricultural soils has almost doubled over the last fifty years.

Examples of point sources include smelting works and nickel-cadmium battery factories. This impact may extend up to ten kilometres from the source. Fossil fuel burning may also cause locally elevated cadmium concentrations. Where concentrations exceed 5 µg/l and the groundwater is not extremely acid, there is every reason to suspect emissions from a local source. If the area is not underlain by sedimentary bedrock and the pH is over 5, concentrations above 0.5 µg/l will quite definitely indicate an anthropogenic source. A number of mechanisms may act in concert to cause elevated concentrations in the range 0.5–5 µg/l.

Zinc

The main sources of elevated zinc concentrations, even where pH is not particularly low, are ore mining spoil heaps.

Galvanised (zinc coated) materials are used for innumerable applications. Since zinc may dissolve when metals corrode, it is found in elevated concentrations in many soil environments. Landfill sites usually contain large quantities of galvanised material and it is common to find elevated zinc concentrations in leachate. Zinc is used for many other purposes, including feed for newly born piglets, and it thus immediately enters the soil. Zinc has also been used in wood preservatives and may therefore be present in soil and water in the vicinity of old impregnation plants.

Where concentrations exceed 700 µg/l in groundwater, there is reason to suspect a local pollution source. A number of mechanisms may act together to mobilise zinc and raise levels of this metal at lower concentration ranges.

Lead

The main source of lead dispersal is now its use in accumulators. Another major source is leaching from spoil heaps. Sulphide ore waste may have a lead content of about one tenth of a per cent. Leaching from this is moderate compared with that of zinc and cadmium because lead is more tightly adsorbed to the material than the other two. Lead has also been dispersed in the environment by emissions to air from smelting works, by use in batteries, in ammunition and, formerly, as a petrol additive. Lead concentrations along most roads are elevated by a multiple of 10–20. Embankments at shooting ranges may contain several per cent lead, which may then disperse into the groundwater in the absence of organic matter or other effective adsorbents.

Arsenic

Naturally high concentrations of arsenic in groundwater are found at a few locations on the Skellefteå plain in northern Sweden and in Bergslagen in central Sweden. Sulphide ores, particular those from the northern province of Västerbotten, contain high concentrations of this element, as do shales in the same area. Water from deep wells with high iron concentrations and accompanying high pH in other parts of the country may also exhibit elevated arsenic concentrations (above 10µg/l).

Arsenic is used as a wood preservative (Cu-Cr-As impregnation) and groundwater at impregnation plants often displays elevated concentrations of arsenic. Landfill sites will probably be a future source of arsenic in groundwater, when the large quantities of CCA-impregnated timber currently in use are landfilled.

If samples come from areas other than those mentioned above and the water does not fit into redox class 3 (see the chapter on "Redox", Table 11), concentrations over 10 µg/l are quite definitely caused by a point source.

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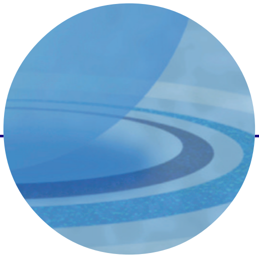

Pesticides

This chapter is arranged as a classification of risk for pesticide contamination of groundwater

Introduction

The greatest quantities of pesticides are used in the forest products industry. Other use primarily occurs in agriculture, where weedkillers predominate, followed by fungicides, insecticides and agents to combat mites. Large quantities are also used in private gardens, in market gardening, on golf courses, sports grounds, railway embankments, roadside verges and hard surfaces. Forestry accounts for a fairly small proportion of pesticide use. Agricultural pesticides are often based on organic compounds, which are scarcely soluble in water. In some circumstances, they can permeate soil and reach the groundwater. Once down in the groundwater zone, they can move on to areas “downstream” and end up in surface or well water far from the place they were used. The forest products industry uses wood preservatives containing easily soluble metal salts to treat timber against fungal attack. These are dealt with further in the chapter on “Metals”.

Model for risk classification

A procedure for classifying soil areas according to risk makes it easier to plan studies into the presence of pesticides in groundwater. Sampling and analysis can then focus on the areas with the greatest risk of pollution. This is important, since analysis of pesticides in groundwater is expensive.

- Risk classification relates both to normal dispersal and to other use of pesticides.

- Risk classification relates both to agricultural land and to land used for other purposes. Considerable quantities are used in gardens, although it is often difficult to determine the extent of this use. The approach to these areas must be decided on the merits of each case.

- Risk classification is intended to serve as a model taking account of individual factors of particular importance. These risk factors have been classified according to a five-point scale. The specific conditions are evaluated and the individual factors are then weighed up to arrive at a final risk classification.

Recommended sampling

A selection of pesticides has been made so as to focus on substances potentially able to leach out of soil, those that have been detected in groundwater and/or those that are used in large quantities. These are presented in Appendix 7. The limited number of pesticides proposed for inclusion in an initial analysis package by no means covers all those currently in use in Sweden and their metabolites (products of decomposition). The proposal should be seen as a compromise made to reduce the cost of analysis, thereby allowing analysis of a greater number of water supply sources. For some water supplies, there may be reason to include other pesticides used locally in large quantities, eg, those used in bulk in potato cultivation. It is therefore important to be aware of pesticides used locally in large quantities but not included in the list in Appendix 7. This list includes certain agents requiring specific analytical methods. Different laboratories may have differing "pesticide packages". It is important to consult the laboratory before ordering analyses. If samples repeatedly indicate the presence of pesticides or if more than one pesticide is found at the same time, it is proposed that the analysis package be expanded. It should also be borne in mind that a negative result from the analysis of a limited number of pesticides does not necessarily indicate that the water is free of pesticides.

The EC drinking water directive threshold for remedial action is 0.1 µg/l for each individual pesticide and 0.5 µg/l for total pesticides.

Risk classification

A risk assessment is made in areas where spraying takes place or has taken place. The factors considered of most importance to whether pesticides may migrate into the groundwater are listed in Tables 16 and 17. These risk factors have been classified according to a five-point scale, from a to e, where a represents the least risk and e the greatest. The letters representing the risk factors in the area to be assessed are entered in the column headed "Assessment area". When both tables have been completed, the individual risk factors can be weighed up using Table 18, which will give the relevant risk class. Sampling is recommended for areas falling within class 3.

TABLE 16.

Risk factors in connection with non-point source dispersal of pesticides.

Agricultural land and other large areas (eg, forest, golf courses, parks, churchyards, plant nurseries, commercial hard and soft fruit cultivation, railway embankments, industrial sites and other gravelled surfaces)	**Risk factors a–e**	**Assess-ment area**
1. Permeability of soil strata		
1.1 is very limited in areas with > 3 metres of clay	a	
1.2 is limited where the soil strata are fine-grained (clay, silt, fine-grained morainic soils)	c	
1.3 may be significant and lead to rapid migration (sandy soils, “light soils”, dry crust clay < 2 metres deep and thin humus-rich soils)	d	
1.4 may be significant and lead to rapid migration (gravelled surfaces with no vegetation in combination with 2.2 or 2.3)	e	
2. Humus content in top soil at a depth of 0–30 cm		
2.1 > 6% humic content	b	
2.2 2–6% humic content	c	
2.3 < 2% humic content	d	
3. pH		
3.1 Soil pH >7 (calcareous soils). Only applies to sulphonyl urea whose persistence and/or solubility increases at a pH over 7 (see Appendix 7)	d	
4. Outflow area (surface water may be sampled instead)		
4.1 permanent outflow area	a	
4.2 outflow area changing to inflow area during dry periods	b	
5. Other factors		
5.1 pesticides have not been spread in the autumn or in conjunction with watering	b	
5.2 pesticides have been spread in the autumn and/or in conjunction with watering	d	
5.3 Spraying has taken place at a well - risk of direct contamination	e	
5.4 Artificial infiltration (tank infiltration or induced infiltration at shoreline) has taken place involving surface water containing pesticides	e	

TABLE 17.

Risk factors in connection with point source dispersal of pesticides.

Point sources		Risk factors a–e	Assesment area
6.	Handling of dispersal equipment		
6.1	All filling and rinsing of sprays and other procedures involving a risk of spillage have taken place at sites specially designed for the purpose, where liquid is prevented from infiltrating the soil	b	
6.2	Filling and washing of sprays etc has taken place without any precautions on ground that is not impermeable (< 3 metres of clay)	e	

Weighing up individual risk factors gives the relevant risk class

Weighing up various risk factors provides a basis for assessing the risk of pesticides being present in the groundwater. Difficulties that may arise when making the assessment include varying conditions within the area studied or changes in land use and pesticide use from one year to another. The risk factors specified here may nonetheless help in evaluating the risk of leaching into the groundwater. Three risk classes have been formulated as regards the relative probability of pesticides being present in groundwater.

TABLE 18.

Risk classes for groundwater as regards the presence of pesticides after weighing up individual risk factors.

Class	Description	Summary of individual risk factors
1	No or insignificant risk	areas where at least 1 risk factor is present are found in group a but none in group e OR no risk factors are present in groups d and e
2	Moderate risk	areas where all risk factors are present in groups b and c OR only one risk factor is present in group d and the others in b or c
3	Significant risk	areas where at least one risk factor is present in group e OR at least two risk factors are present in group d **Sampling is recommended**

Indirect risk – dispersal of pesticides via groundwater to other areas

A list is given below of conditions of importance when evaluating risks in areas “downstream” of class 3 areas. These may be areas of land where pesticides have never been used. The far boundary of areas that may have been affected is very difficult to determine but will generally be limited by the outflow area. Beyond this, pesticides may be present in surface water instead. Although several of these conditions are difficult to assess, they should be evaluated where applicable.

- the number of years pesticides have been used or analysed in the groundwater
- the size of the areas sprayed
- geological conditions for major variations in the rate of groundwater flow within the area (see page 33 of the report on contaminated sites for help in assessing this factor)
- hydrogeological conditions appropriate for a high or a low degree of fixing, dilution and decomposition within the area.

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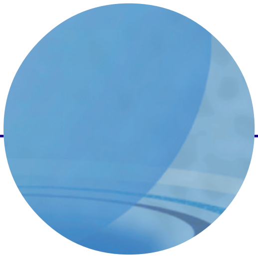

Water table

Assessment of deviation from the natural seasonal variations in the water table. The Swedish Geological Survey's monthly maps of water table status throughout the country, seasonal graphs of fluctuations in the water table and local reference series are used.

Introduction

Changes in the (pressure) level of the water table can cause problems of various kinds. Common problems caused by low levels include:

- water shortages in groundwater supplies from wells as well as from natural springs
- salt salt water intrusion in wells in coastal areas or areas where relict sea water is present
- oxidation of sulphurous soils, resulting in acidification problems
- land subsidence in certain fine grained cohesive soils
- risk of high iron and manganese concentrations due to drainage of discharge areas
- drying up of the soil surface causing biotope changes in wetland areas

Problems caused by high levels include:

- increasing risk of deterioration in water quality, e.g., in the form of high iron and manganese concentrations
- land slip and poor ultimate bearing resistance
- waterlogging and increased concentrations of organic matter in the groundwater

Human activities which may affect the water table:

- groundwater abstraction and changes in abstraction (wells)
- regulation of watercourses
- drainage and excavation below the water table (drainage resulting from underground construction, tunnels, underground cavities or deep foundations involving pumping of groundwater)
- prevention of groundwater formation (as a result of ground surfacing in urban areas and rerouting of storm water)

Methods for assessing groundwater state – level of the water table

It is difficult to use the general method of describing current conditions and deviation from reference value when assessing the state of the water table. The main reason for this is that fluctuations in the position of the water table depend on weather conditions, ie, they depend on precipitation, drought and persistent cold, as well as the hydraulic characteristics of the aquifer and the type of terrain. It is difficult to calculate a reference value in absolute figures for the position of the water table. This is particularly evident in fluvio-glacial deposits, where the position of the water table is very much dependent on the type of terrain and the depth, extent and hydraulic characteristics of the deposits. The degree of effects caused by changes of the groundwater level are not directly linked to the magnitude of the size of the changes of the groundwater level.

In spite of these difficulties, instructions are presented for:

- assessment of the natural groundwater level in various parts of the country
- assessment of whether individual water table observations lie within the natural pattern of variation.

Appendix 8 contains a brief outline of a more sophisticated method of assessing effects on the water table. However, this method requires access to reference data from earlier time series.

Assessment of the natural groundwater level

The monthly maps of water table situation produced by the Swedish Geological Survey for “small” and “large” aquifers can be used to make an overall assessment of the natural groundwater level (Figure 10). These maps date back to the mid-1980s.

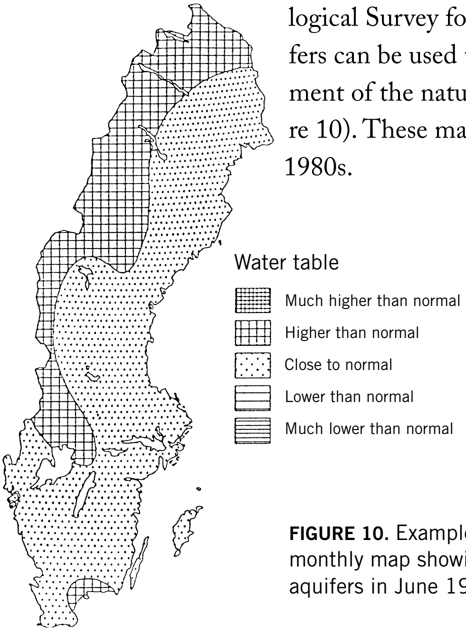

FIGURE 10. Example of Swedish Geological Survey monthly map showing water table status for small aquifers in June 1997.

Natural water table variations differ from one environment to another. In moraine, as in normal “igneous and metamorphic rock” (”small aquifers” on the monthly maps), the difference between the highest and the lowest level during the year is normally 1–3 metres, whereas the level in fluvioglacial deposits (”large aquifers” on the monthly maps) only varies by some tens of centimetres during the year (see groundwater environments 3, 1 and 4).

As regards deviation of the water table from the normal level, Table 19 shows approximate values for the class boundaries used for the monthly maps for small aquifers (see key in Figure 10). The difference is smaller in the case of large aquifers.

TABLE 19.

DEVIATION OF THE WATER TABLE from the normal level in small aquifers for the classes used on the Swedish Geological Survey monthly maps.

Class according to monthly map	Small aquifer deviation, m
Much higher than normal	> 0.5
Higher than normal	0.2–0.5
Normal	-0.2–0.2
Lower than normal	-0.5–0.2
Much lower than normal	< -0.5

The Swedish Geological Survey can also supply time series for natural water table fluctuations from some 60 areas of Sweden for more detailed evaluation. Areas where the water table is regularly monitored are marked on the map in Figure 11.

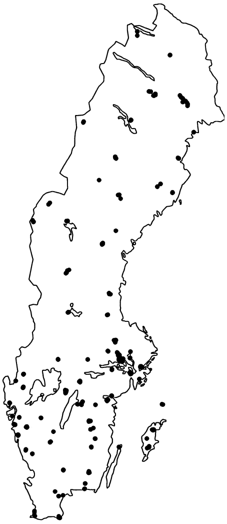

FIGURE 11. Areas where the Swedish Geological Survey has regularly monitored the water table elevation as of 1 January 1997.

Assessment of whether an individual water table observation lies within the natural pattern of variation

The water table fluctuates under natural conditions, displaying variations over a year and over several years, depending on weather conditions. The size of variations and the speed with which they occur depend on the hydraulic characteristics of the aquifer and type of terrain, etc. Graphs comparing seasonal fluctuations in the water table in metres below the surface have been produced for moraine, which is the most typical near-surface groundwater environment. These fluctuations are shown for southern Sweden and northern Sweden (see Figure 12). Northern Sweden comprises the regions of Norrland and Svealand above the highest coastline.

Southern Sweden comprises the regions of Götaland and Svealand below the highest coastline.

The graphs principally show conditions in normal morainic soils at a topographically "normal" site (ie, neither at the top of hills nor at the bottom of outflow areas such as valley floors or along the shores of lakes and banks of watercourses). The graphs for southern Sweden include some locations where water-bearing moraine is overlain by impermeable clay. This explains why the potentiometric surface (in fact shown in the graph as the water table) is sometimes at an elevation above the ground surface. The graphs are based on a selection of the monitoring series included in the Swedish Geological Survey Groundwater Network. They show (i) how the mean level in metres below the ground surface varies during the year, (ii) how the mean maximum and mean minimum at the various locations varies, and (iii) how the highest and lowest levels at all locations vary.

Various factors must be taken into consideration when comparing the observed groundwater level with these graphs since they primarily relate to groundwater environment 3, moraine. The graphs cannot be used if an observation has been made in a fluvio-glacial deposit because the conditions there are so heavily dependent on surrounding local conditions. However, the graphs may be of some help in assessing the water table position in igneous and metamorphic rock, where the fluctuation pattern often accords with morainic conditions. If the observation has been made at a pronounced topographic peak, it may be expected that the water table will be deeper than shown by the graphs. If the observation is made in an outflow area, on the other hand, the water table may be expected to be closer to the surface.

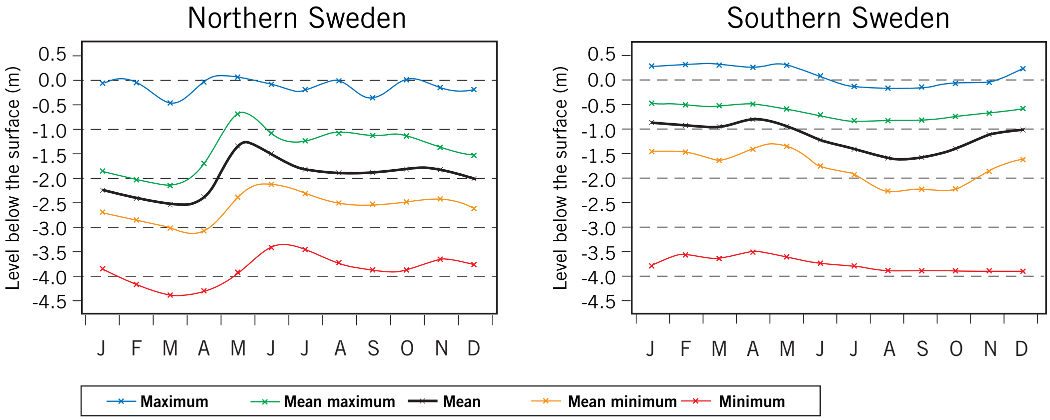

FIGURE 12. Graphs showing water table fluctuations in morainic soils in northern and southern Sweden.

The assessment must also take account of weather conditions during the period immediately preceding the observation. An observed low water table during a dry period may very well be natural, whereas a low level during a year with heavy precipitation probably has an anthropogenic explanation. Hence, during a “wet” year, it should be expected that the position of the water table will be above the mean level shown in the graphs. During a dry year it will be below that level.

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Instructions for deviation test

Variation is a normal phenomenon in the environment and occurs in all undisturbed ecosystems. This natural variation makes it more difficult to determine the degree of anthropogenic impact. The deviation test presented here makes it possible to compare the distribution of readings taken in a type area with the distribution of all readings from the same type area in the entire database. This in turn makes it possible to identify impacts originating from point sources.

Reference database

A specific reference database has been compiled of all available groundwater analyses. In total, it comprises data from nearly 30,000 wells. The analyses are mainly from the 1980s. They have been performed by municipalities, well borers, universities and government agencies and reflect groundwater composition in the 1980s, including existing human impact in the form of acid precipitation and nitrogen contamination for example. Nonetheless, they provide a valuable indication of the natural variation within a population of groundwater samples, particularly since the material has been broken down into type areas.

Concentration distributions for the 36 type areas (subdivided as shown in Table 1 on page 27) are given in Tables 1–12 in Appendix 2. In these tables, each type area is divided into two depth classes. When samples are taken in the various type areas, the distribution of concentrations may be of help for assessment purposes.

Deviation test

The great natural variation in concentrations of various substances in water occurs because an aquifer is a heterogeneous medium. This causes a dispersal of the concentrations of the various chemical constituents. The smaller the number of readings available for a given constituent in a given type area, the more difficult it is to determine how representative they are of the type area in question. A deviation test has therefore been developed to determine whether or not samples deviate significantly from the concentration distribution shown here.

The test is performed in the following stages:

(a) Group the analyses according to type area

The groundwater samples taken are grouped according to type area and well depth.

(b) Calculate a weighting index for the relevant parameter using Tables 1–12 in Appendix 2

The readings obtained are compared and classified against the concentration distributions for the corresponding type area and well-depth class in the appendix. (Tables 1 –12 include the parameters assessed in this report.)

Values ≤ 5th percentile are given a class value of 1
Values > 5th percentile and ≤ 25th percentile are given a class value of 2
Values > 25th percentile and ≤ 75th percentile are given a class value of 3
Values > 75th percentile and ≤ 95th percentile are given a class value of 4
Values > 95th percentile are given a class value of 5

The weighting index is calculated as the mean of the class values obtained. The weighting index will always lie between 1 and 5. By definition, the weighting index of the reference population is always 3.

(c) Assess the weighting index obtained

If the calculated weighting index for the parameter in question is 3, the concentration distribution is the same (or very similar to) that of the reference population. If, on the other hand, the index obtained deviates greatly from 3, there is a difference between the concentration distribution obtained and that of the reference population. If the value exceeds 3, the distribution is wider than that of the reference population. Below 3, the distribution obtained is below that of the reference population. The calculated weighting index is compared with critical values in Table 13 in Appendix 2 to determine whether it differs to a statistically significant extent. The critical values used in Appendix 2 depend on the number of samples in the population to be compared and the choice of significance level (= risk that the difference obtained is random).

If there are five samples and these give a weighting index of 4.00, this can be interpreted to mean that the population being compared is significantly higher than the reference population at a significance of 5 per cent, but not at a significance of 1 per cent. (5 per cent often suffices. This means that the risk of deviation being random is 5 per cent.) If, on the other hand, the weighting index is 2.00, one can conclude by analogy that the population being compared at the 5 per cent is lower than the reference population but not at the 1 per cent level, which, it must be remembered, requires a weighting index of less than 1.80 to be significant for five samples. If the population being compared contains more samples, significance will be attained at a progressively falling weighting index. (The more samples, the less the deviation from 3 needed to achieve significance.)

If a weighting index significantly deviates from the median of the reference population (3), a more detailed analysis should be made of the reasons for this. Could it be due to natural causes such as unusual shallowness of the wells sampled or the presence of clay containing sulphide? Or is it due to anthropogenic impact in the form of local waste tips, drainage or abstraction of excessive quantities of water from wells?

An example of the way a deviation test may be presented is given in Appendix 3.

Presentation of data

This chapter briefly describes methods of presenting findings. Uniform presentation makes it easier to compare different regions and years.

Maps

The Swedish Geological Survey has issued several series of soil maps. These are available in scales of 1:50,000 (series Aa and Ae), 1:100,000 (series Ac and Ak) and county maps at a scale of 1:100,000 (Blekinge) and 1:200,000 -1:300,000 (Värmland northwards). The new Ae series maps are as yet only available for parts of southern Sweden. In the absence of these maps, the county maps or the older Aa maps (whose quality may vary somewhat) will have to be used. A general hydrogeological map on a scale of 1:250,000 (series Ah) has been published for southern and central Sweden. In recent years the Swedish Geological Survey has started to publish municipal maps, Groundwater resource maps (series An). "General maps for groundwater protection" can also be made to order. Many maps produced by the Swedish Geological Survey and the National Land Survey are available in digital form.

Division into type areas

Current conditions and deviation from reference value are presented separately for each type area. The natural variation in concentrations is reduced if groundwater existing under similar conditions is treated separately in each case. This means that the information will be more specific to each location, which makes it more useful as a basis for action.

Presentation in map form – colour code

A uniform colour code is used for classification of current conditions and of deviation from reference value.

Class 1 - blue 🔵
Class 2 - green 🟢
Class 3 - yellow 🟡
Class 4 - orange 🟠
Class 5 - red 🔴

If the material is printed in monochrome, classes can instead be identified using numbers or be used in combination with suitable rasters.

Great caution should be exercised when extrapolating from sample points to whole areas of the map. Colouring of individual dots is preferable if little information is available about the extent of the aquifer or if monitoring points are few or exhibit great variation.

Data not meeting specified requirements

Caution should be exercised when entering data not complying with the sampling recommendations given in Appendix 1. The same applies where there are other doubt, eg, large or irregular variations in monitoring data. The map should include a footnote indicating the degree to which the data may be unreliable.

Comparison of assessments of different parameters

Note that the classification of current conditions is based on different criteria for different parameters. Thus, it is not possible simply to rank the risks of elevated concentrations, for example, in the same way in relation to different parameters belonging to the same class.

Example presentation

A detailed example presentation of data is given in Appendix 3.

Appendixes

Sampling

How samples should be taken, what time of the year they should be taken and how many should be taken. Further information is given in the Environmental Monitoring Handbook, reached via the Swedish EPA home page: www.environ.se (in Swedish only)

Introduction

Modern analytical methods have made it possible to obtain increasingly accurate figures in areas of low concentrations. Knowledge of the entire sampling chain is needed to interpret these results: the sampling location and its characteristics, sampling method, type of sampling vessel, treatment of samples, transport of samples, storage and analytical methods. If a proper comparison of findings is to be made, it is important to use the same sampling procedure and treatment, or at least to ensure that the same fraction of the water is analysed.

Purpose of sampling

The purpose of sampling always determines where, how, and sometimes also when, it is to be performed. Purposes include:

- Examination of drinking water quality
- Examination of raw water quality for drinking water production
- Surveying groundwater quality in aquifers
- Studies of changes in chemical composition of groundwater over time
- Examination of pollutants in groundwater

Sampling for drinking water quality

Samples to examine the quality of water used for drinking purposes must be taken direct from the taps used for the purpose.

An analysis often gives an indication of the chemical composition of the groundwater, although the chemical composition of the water will have changed to a varying extent on its way from the aquifer to the tap through pipes and pressure tanks. Any filters, aeration devices or chemical additives will also change the chemical composition of the original groundwater.

If analyses of water taken from household taps are used for purposes other than checking drinking water quality, it is essential to make clear the factors that may have affected the quality of the original groundwater.

Sampling to ascertain groundwater quality

Groundwater is seldom readily accessible at ground level. It usually has to be brought to the surface in some way. Excavated and bored wells can be used to sample soil water and water in the bedrock. The most clearly defined samples are obtained using tubes inserted into the ground.

Well samples

Well water is a mixture of groundwater seeping into the well at various levels. Sampling in wells therefore provides an integrated picture of the groundwater present.

Wells bored in rock

Water samples from borehole wells should be taken at as early a stage as possible in the water distribution system, preferably before the pressure tank. To get a fresh groundwater sample, old water that has been standing in the well and the distribution system should be turned over by flushing this water away before sampling.

Excavated wells

The volume present is first replaced. It is best to take the sample straight from the well. This can be done using a container or pump made of inert material. Otherwise, the procedure is the same as for wells bored in rock.

Samples from groundwater sampling tubes

More detailed surveys of the chemical composition of groundwater will require use of a sampling tube designed for the purpose. By inserting the tube filter down to the required level, it is possible to take samples from a well-defined part of the aquifer.

The water present in the sampling tube is replaced before sampling. If interest is focused on the chemical composition of the layer in which groundwater flows, eg, fluvio-glacial deposits, the water volume can be replaced several times over before samples are taken. If, however, the primary concern is to monitor changes in groundwater chemistry over time at a given point, the volume present should not be replaced more than one and a half times, so that the water in the immediate vicinity of the slit is forced into the tube.

The material of which the sampling tubes are made should be chosen to take account of the chemical variables to be analysed. In particular, the choice of materials is limited by the chemical substances naturally occurring in very low concentrations in the groundwater, such as heavy metals and organic pollutants. Inert, colourless acrylic or polythene plastics are preferable for heavy metals, whereas stainless metal tubes are best for sampling organic pollutants.

Sampling of springs

Samples of this kind need not come into contact with any foreign materials which could contaminate them, which is a good thing. The water flows continually and need not be replaced prior to sampling. Spring water is mixed and provides an integrated picture of the quality of the groundwater present. Chemical composition may vary considerably during the year.

Sampling equipment

Sampling equipment must always be made of inert materials, which is particularly important if samples are to be analysed for heavy metals. Sampling equipment must be stored so that it is not contaminated (internally or externally) between sampling occasions.

It must be possible to flush out tubes with metal-free deionised water between sampling occasions. After each batch of samples has been taken the tubes should be placed in a bath of weak acid before being flushed out with metal-free deionised water, in order to allow any metals adsorbed to the plastic to leach out.

Simple sampling equipment can easily be used to take samples from near-surface groundwater (6 - 9 m deep). By evacuating the air from a collection vessel using a normal suction pump, it is possible to create sufficient pressure to extract groundwater from a depth of around 7 m. This technique is often used nowadays. However, it is now possible to buy peristaltic pumps and systems allowing on-line filtration (see below) and field analysis in flow cells in a closed system. This has the advantage that sample water does not come into contact with air, thus preventing oxidation of some chemical elements and changes the chemical composition of the water.

Some kind of container or submersible pump must be used where groundwater is too deep to be removed by suction. The essential thing is to ensure that the pump does not contaminate the samples. Several “environmental sampling” pumps are now available on the market.

Wells bored in rock already have pumps fitted, as do most excavated wells. However, in the latter case, the water should ideally be sampled straight from the well using a sampling device made of inert materials.

Filtration

Water pumped up from a pipe contains a greater or lesser quantity of mineral particles. It is therefore necessary to filter samples before preserving them using acid.

Dissolved metals are usually defined as the fraction passing through a membrane with a pore diameter of 0.40–0.45 µm. Colloids, hydroxides and small clay particles can also pass through, however. It is therefore better to term the analysed fraction “filtrable” instead of “dissolved”. Filtration equipment should be made of teflon, polythene, polypropylene, plexiglass or polycarbonate, which will withstand cleaning by leaching in an acid bath.

Filtration using plastic syringes is one practical way of taking groundwater samples, firstly because the filtrate goes straight into the specimen bottle and secondly because the equipment is light and takes up little room. Filtration of anaerobic water should take place in an anaerobic environment in a closed system (see above). Otherwise, there is a risk of filters clogging when iron is oxidised, which would also cause the retention of heavy metals as flocculants with the iron hydroxide.

Filters should be cleaned using 0.05M HNO_3 and be rinsed in the cleanest possible deionised or distilled water.

Sampling

Replacement of water

Sampling always commences with replacement of the water to be sampled (see above). This also applies when examining drinking water quality. In that case, the water is allowed to flow evenly out of the cold water tap until it reaches an even temperature.

Every time new samples are taken and collected in a vessel the vessel should first be properly rinsed with the water to be sampled before it is transferred into different specimen bottles.

Sampling of water for analysis of anions, nutrients, conductivity and pesticides (see Tables 1 and 2)

Water analysed for anions, nutrients, alkalinity and conductivity can be collected in the same bottle (a 250 ml polythene bottle with an airtight cap). Smaller quantities can be taken when sampling for individual parameters. It is important to fill the bottle to the top and to ensure that no air bubbles are trapped under the cap. Samples should be kept in cool, dark conditions during transport to the laboratory. Alkalinity, the various nutrients and conductivity are analysed or measured within 24 hours. The list in Appendix 7, page 127 should be followed when sampling for pesticides. Different laboratories will need to use different combinations of analysis packages to cover the list. Information on requirements for vessels, volumes etc will be supplied by the laboratory used. This must have GLP status or be accredited and must take part in annual test comparisons.

Sampling of water for analysis of metals (see Tables 1 and 2)

Samples to be analysed for metals must be filtered before being preserved. Plastic gloves should be worn when samples are taken. The filtration procedure is as follows.

Rinse the filtration syringe with water from the collection vessel. Refill the syringe. If a loose membrane filter is used, this should be secured in the filter holder by plastic clips and be rinsed in situ with distilled or deionised metal-free water. If disposable filter holders are used, these should be adjusted when fitted on the syringe. The first 10 ml of water passing through the filter should be discarded. The same applies if filtration is performed on-line.

Polythene bottles, cleaned in acid, to be used for metal analysis samples, are stored in double plastic bags. The remainder of the water in the syringe is filtered down into the bottle. When the filter is changed, the filter holder is rinsed thoroughly several times over using metal-free water. The first 10 ml of water passing through the new filter are also discarded.

Samples for metal analyses are preserved using a 0.5 ml conc. HNO_3 super-pure quality per 100 ml of sample. This should be done as soon as possible under the cleanest possible conditions. If samples are preserved at a laboratory, this should be done in a sterile room. The outer plastic bag is removed outside the clean room. Acid is added using a pipette with polypropylene tips, washed in acid solution.

Determination in the field and storage of samples

Conductivity is determined in the field when water samples are taken, so as to minimise changes. These are best performed using a flow cell, which prevents contact between the sample and the atmosphere. Sample bottles are kept in a dark cold store (+4℃) until analysis begins.

TABLE 1.

The seven aspects are assessed using the following parameters.

Parameter	Name of, variable (variable code)	Sampling vessel	Required volume	Preservation, treatment of samples	Analytical method
Alkalinity	Alkalinity, (Alk)	Polythene	100 ml	Samples kept in cool, dark conditions. Analysis within 24 hours	ALK_NP54DA[1] SS 028139 mod or ALK_NTG DA
Arsenic		Polythene bottles	See footnote 2	Filtration by membrane filter (0.45 µm), preservation using 0.5 ml conc. HNO_3 per 100 ml sample. After this kept in cold store (+ 4°C)	AS_DG DA AS_DSA DA ICP-MS in accordance with instrument manuals[2]

Pesticides

The list in Appendix 7, page 127 should be followed when sampling for pesticides. Different laboratories will need to use different combinations of analysis packages to cover the list. Information on requirements for vessels, volumes etc will supplied by the laboratory used. This must have GLP status or be accredited and must take part in annual test comparisons.

TABLE 1 Contd.

Parameter	Name of variable (variable code)	Sampling vessel	Required volume	Preservation, treatment of samples	Analytical method
Lead	Lead, filtr. (Pb-dissolved)	See arsenic	See arsenic	See arsenic	PB_DG DA SS 028152,-83 O -84 mod. ICP-MS according to instrument manuals
Water table	Water table (Level)	–	–	–	WL_DA
Iron	Iron (Fe-dissolved)	See arsenic	See arsenic	See arsenic Anaerobic water is filtered in a closed system.	FE_DF DA FE_DG DA SS 028152 DIN 38406 Teil 22 ICP-MS according to instrument manuals
Cadmium	Cadmium, filtr. (Cd-dissolved)	See arsenic	See arsenic	See arsenic	CD-DG DA SS 028152,-83 o-84 ICP-MS according to instrument manuals
Chloride	Chloride, (Cl)	Polythene	Approx. 20 ml	See alkalinity	Cl_NIC DA Fritz et al 1982 SS 028136
Conductivity	Conductivity- (CondF) (KondL)	Polythene	Approx. 50 ml	Field determination during water sampling. Best performed using flow cell.	CTY_25F DA SS 0028123 CTY_25L DA SS 028123 mod
Manganese	Manganese, (Mn)	See arsenic	See arsenic	See arsenic	MN_DF DA MN_DG DA SS 028157 DIN 38406 Teil 22 ICP-MS according to instrument manuals
Nitrate nitrogen	Nitrate nitrogen (NO_3-N)	Polythene	Approx. 50 ml	See alkalinity	NO23N_DA DA SS 028132-M
Sulphate	Sulphate sulphur (SO_4-S)	Polythene	Approx. 100 ml	See alkalinity	SO4S_NIC DA or SO4S_NA DA Fritz et al., 1982
Zinc	Zinc, filtr. (Zn-dissolved)	See arsenic	See arsenic	See arsenic	ZN-DG DA SS 028152,-83 o-84 mod. ICP-MS according to instrument manuals

TABLE 2.

Additional substances have been proposed to aid understanding the causes of elevated concentrations of the above parameters.

Parameter	Name of variable (variable code)	Sampling vessel	Required volume	Preservation, treatment of samples	Analytical method
Phosphorus	Total phosphorus, (Tot-P)	Polythene	Approx. 50 ml	Samples kept in cool dark conditions Analysis within 24 hours	PTOT_NA DA SS 028127-M Schuster HH 1965
Potassium	Potassium (K)	Polythene	See arsenic		K_DF DA SS 028160 DIN 38406 Teil 22
Sodium	Sodium, (Na)	Polythene	See arsenic		NA_DF DA SS 028160 DIN 38406 Teil 22
Calcium	Calcium, (Ca)	Polythene	See arsenic		CA_DF DA SS 028161 DIN 38406 Teil 22
Magnesium	Magnesium, (Mg)	Polythene	See arsenic		MF_DF DA SS 028161 DIN 38406 Teil 22
Total hardness	Expressed as Calcium, (Ca)	Polythene	50 ml		SS-028121 - 2[3]

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[1] DA states that the codes conform to the “Nordic Code Center – code list DA”

[2] Na, K, Ca, Mg ICP-MS according to instrument manuals. Aggregate sample volume approx. 20 ml. As, Pb, Fe, Mn, Cd, Zn ICP-MS according to instrument manuals. Sample volume approx. 20 ml.

[3] Calculated as Ca+Mg but expressed as mg Ca/l (NB - summarise on equivalent basis)

Temporal variations in groundwater chemistry

Variation within and between years

The chemical composition of groundwater varies both in space and time. Various analyses have shown that spatial factors such as the variable resistance to weathering of bedrock and soils, type of groundwater and depth below the surface have the greatest influence. However, groundwater chemistry at a given location varies over time as a result of climatological fluctuations, changes in the composition of precipitation, land use etc.

Temporal variations can be split into variations over several years and those occurring during a single year. One type of variation over a period of several years is referred to as trends. Analyses of variations in groundwater chemistry over time from the early 1980s to the mid-1990s show that statistically significant trends do sometimes occur. For example, sulphate concentrations fell in the 1980s following a decrease in sulphur deposition. This trend is fairly widespread across the country. There are also more statistically scattered trends for other parameters.

In total, chemical constituents in groundwater at a given monitoring location typically show variability, as expressed in terms of variation coefficients (mean/standard deviation), ranging from 5–30 per cent, although higher variation coefficients do occur, particularly in water with a low ion content. (In comparison, typical variation coefficients for water from different type areas are in the order of 50–100 per cent, lower in areas of sedimentary bedrock and higher in coarse soils derived from igneous and metamorphic rock). For alkalinity, hardness and pH, for example, the variation coefficient usually falls with rising concentrations, which often occurs in relation to increasing age of groundwater, increasing depth below the surface, falling resistance to weathering of rock and soil and the presence of confined aquifers under clays and other impermeable soils. Variations in the concentrations of other constituents, such as sulphate, are less, or not at all, dependent on depth.

Examples of climatological factors influencing the chemical composition of groundwater are:

- snow melt or heavy, persistent precipitation, resulting in low-ion near-surface groundwater, particularly in coarse soils resistant to weathering
- a drop in the water table following a long drought, which may cause oxidation of sulphides, leading to rising sulphate concentrations and falling pH
- a rising water table after a dry period, which may cause iron and manganese compounds precipitated in the surface layer to dissolve in the groundwater

Variation in concentrations within groundwater environments

Using its groundwater chemistry database, the Swedish Geological Survey has studied how the 90 per cent confidence interval for conductivity varies with sample size. (This means that there is a 90 per cent likelihood that the true mean lies within the limits of the confidence interval.) Conductivity was chosen because it represents the total concentration of dissolved substances in the groundwater. Figure 1 shows that the 90 per cent confidence interval is approximately 1 to 2 times the mean when 10 samples are taken, but is only one third as great when 90 samples are taken. As may be seen from the graph, the variation in concentration is greatest in groundwater environment 1 (GWE1 - wells in igneous and metamorphic rock) and lowest in groundwater environment 2 (wells bored in sedimentary rocks). Excavated wells fall between the two.

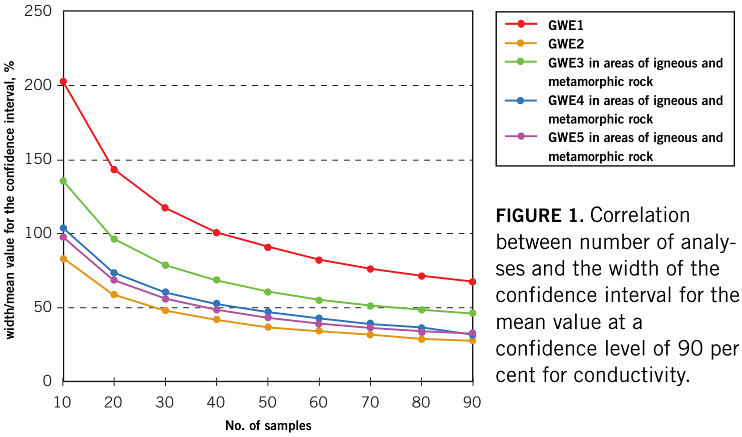


FIGURE 1. Correlation between number of analyses and the width of the confidence interval for the mean value at a confidence level of 90 per cent for conductivity.

Figure 1 shows that a fairly large number of wells must be sampled to estimate the mean with sufficient reliability. When samples are taken within a limited area, such as a municipality, the variation may be expected to be lower than the graph shows, since it is based on figures from all of Sweden within each environment as shown in the key.

General recommendations - quality control

The following general recommendations for sampling of groundwater may be given in relation to seasonal/temporal variations.

- Avoid sampling immediately after snow melt or heavy and lengthy precipitation. This applies particularly to near-surface groundwater. (This does not apply to analysis for pesticides; samples may certainly be taken after snow melt or heavy rain.)
- In order to gain a general picture of variation over a single year at a given location, samples can be taken after snow melt, when the aquifer is replenished (March - June) and after summer depletion (August/September).
- Spatial variation should primarily be taken into account when sampling. It is better to take twice as many individual samples at different locations in the type area studied that to take two samples at half as many locations. Individual samples should be taken in late summer or early autumn.
- It is difficult to specify the precise number of samples, but Figure 1 shows that efforts should be made to ensure access to at least 30 samples per type area and preferably also 30 samples per well-depth class. (When assessing environment 1, a limited number of samples carries a greater risk of incorrect assessment than when assessing environment 2).

Tables

A reference database is presented here, compiled from nearly 30,000 wells. Most of the analyses were collected in the 1980s. Concentration distributions for 35 type areas, each divided into two well-depth classes, are shown in table form.

Explanation of the concentration distributions shown in Tables 1–12

A combination of two letters and one number is given in Tables 1–12 under the heading "Type area – Depth". The first letter indicates the region in which the area is located. The figure indicates the relevant groundwater environment and the second letter stands for the well-depth class. ("Division into type areas" is presented in the chapter of the same name.)

For instance, G3d is the reference database for all deep wells (d) in surface aquifers in moraine and fluvial outwash (3) from the coast of Norrland (northern Sweden) (G).

The distribution into shallow and deep wells:

Groundwater environment-depth	Explanation
1g	Igneous bedrock, < 65 m
1d	Igneous bedrock, > 65 m
2g	Sedimentary bedrock, < 65 m
2d	Sedimentary bedrock, > 65 m
3g	Surface aquifers in moraine and fluvial outwash, < 4 m
3d	Surface aquifers in moraine and fluvial outwash, > 4 m
4g	Surface aquifers in fluvio-glacial deposits, < 4 m
4d	Surface aquifers in fluvio-glacial deposits, > 4 m
5g	Confined aquifers in moraine and fluvio-glacial deposits, < 4 m
5d	Confined aquifers in moraine and fluvio-glacial deposits, > 4 m

Other codes used in Tables 1–12:

Code	Explanation
N	Number of analyses in the reference database
P5, P95	5th/95th percentile of the data
Q1, Q3	1st/3rd quartile, ie, 25/75 per cent of the data
Median	The median figure, ie, the figure in the middle of the data

Table 13: "Critical values for weighting index" is presented in the chapter entitled "Instructions for deviation test".

Parameters in the tables

Redox

The deviation test is suitable for the constituents in Tables 1–10 in this appendix.

The method cannot be used for the distribution of redox classes shown in Table 11, since that table differs from the others. The redox classes are those presented in the chapter on “Redox”, Table 11 (although the fifth class, for mixed water, is not included). If a high redox class occurs at low percentile or quartile values, this means that anaerobic water is common in that environment. For example, it may be seen that at least 25 per cent of wells monitored in environment type A2d (deep wells in sedimentary rocks in region A - Skåne and elsewhere) belong to class 4 (anaerobic water, where sulphate has been reduced and hydrogen sulphide may occur), and only 5–25 per cent of wells belong to class 1, with high redox potential and low concentrations of iron and manganese. On the other hand, Table 11 shows that at least 75 per cent of wells monitored in environment type G3g (shallow wells in moraine or outwash in region G – coast of Norrland, northern Sweden) belong to class 1 and that class 4 only occurs in fewer than 5 per cent of wells.

Arsenic (As) and Cadmium (Cd)

The tables for arsenic and cadmium are only divided into wells bored in soil or rock. The number of analyses is insufficient to allow a further distribution. Nor is there sufficient data to perform deviation tests.

PHLAB and total hardness (as calcium, Ca)

The tables showing distributions of the values for PHLAB and concentrations for total hardness have been included even though they are not used as parameters in the Groundwater report.

TABLE 1

PHLAB

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	358	6.9	7.3	7.6	7.9	8.2
A2d	165	6.8	7.3	7.6	7.9	8.5
A3g	31	5.8	7.3	7.6	7.8	8.0
A3d	43	6.1	7.0	7.4	7.6	7.8
A4g	14	5.9	6.8	7.5	7.8	7.9
A4d	16	6.3	7.1	7.5	7.7	8.0
A5g	30	6.8	7.2	7.4	7.6	7.9
A5d	61	7.0	7.3	7.5	7.8	8.0
B1g	1126	5.5	6.3	6.8	7.3	7.9
B1d	912	5.9	6.7	7.2	7.6	8.1
B3g	970	5.4	5.8	6.1	6.5	7.2
B3d	1088	5.5	5.9	6.2	6.5	7.3
B4g	215	5.4	5.8	6.1	6.5	7.3
B4d	256	5.4	5.9	6.2	6.6	7.7
C1g	720	5.8	6.7	7.2	7.7	8.2
C1d	762	6.2	7.0	7.5	7.9	8.6
C3g	372	5.2	5.9	6.3	6.8	7.6
C3d	246	5.5	6.1	6.5	7.0	8.1
C4g	102	5.3	5.9	6.2	6.5	7.1
C4d	100	5.6	6.0	6.3	6.7	7.4
C5g	187	5.3	6.2	6.8	7.3	7.9
C5d	153	6.0	6.6	7.1	7.6	8.4
D1g	144	6.4	7.2	7.4	7.7	8.1
D1d	148	7.0	7.3	7.6	7.9	8.2
D2g	193	6.9	7.3	7.5	7.8	8.1
D2d	138	7.2	7.6	7.7	8.1	8.6
D3g	59	5.7	6.3	6.7	7.1	7.7
D3d	58	5.6	6.4	6.9	7.3	7.6
D4g	24	5.7	6.8	7.2	7.6	7.9
D4d	21	6.3	6.4	6.6	6.9	8.0
D5g	10	6.0	6.3	6.5	7.4	7.6
D5d	11	6.3	6.3	6.9	7.5	7.9
E1g	2392	5.9	6.8	7.3	7.7	8.2
E1d	2408	6.4	7.3	7.7	8.0	8.5
E3g	957	5.4	5.9	6.3	6.8	7.5
E3d	511	5.6	6.2	6.5	6.9	7.6
E4g	183	5.5	5.9	6.3	6.8	7.6
E4d	177	5.5	6.2	6.6	7.1	7.7
E5g	576	5.7	6.2	6.6	7.1	7.6
E5d	372	6.0	6.5	6.9	7.4	7.9

TABLE 1 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	851	6.7	7.2	7.5	7.9	8.4
F1d	994	6.9	7.4	7.8	8.1	8.5
F3g	38	6.0	6.6	7.0	7.2	7.7
F3d	40	6.0	6.8	7.1	7.4	8.0
F4g	5	6.3	6.9	7.3	7.4	7.8
F4d	18	6.3	6.8	7.4	7.6	7.8
F5g	28	6.0	6.9	7.1	7.5	7.7
F5d	20	6.6	7.0	7.3	7.4	7.9
G1g	869	6.2	6.9	7.5	7.9	8.4
G1d	772	6.7	7.5	7.9	8.2	8.7
G3g	786	5.5	6.0	6.3	6.6	7.2
G3d	414	5.8	6.2	6.4	6.8	7.4
G4g	83	5.8	6.1	6.4	6.9	7.5
G4d	91	5.7	6.3	6.7	7.2	8.2
G5g	261	5.7	6.2	6.5	6.8	7.5
G5d	95	5.9	6.2	6.5	6.9	7.5
H1g	60	6.4	7.3	7.7	8.0	8.4
H1d	19	6.6	7.5	7.7	8.2	9.0
H2g	53	6.9	7.3	7.8	8.0	8.3
H2d	30	7.1	7.6	8.0	8.3	9.3
H3g	74	5.9	6.3	6.9	7.2	7.5
H3d	35	6.1	6.5	6.8	7.3	7.5
H4g	14	6.0	6.1	6.4	7.2	7.8
H4d	9	5.9	6.4	7.0	7.2	7.7
H5g	26	6.4	6.7	7.1	7.3	7.3
H5d	27	6.2	6.6	7.1	7.3	7.6
I1g	672	5.9	6.7	7.2	7.7	8.2
I1d	340	6.1	7.0	7.5	7.9	8.3
I3g	631	5.5	5.9	6.2	6.6	7.3
I3d	285	5.6	6.1	6.4	6.7	7.4
I4g	79	5.6	6.0	6.3	6.7	7.6
I4d	59	5.9	6.1	6.5	6.9	7.9

TABLE 2

ALKALINITY – HCO_3, mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	356	127	245	306	370	505
A2d	163	162	300	397	461	641
A3g	31	18	180	240	337	492
A3d	43	34	110	180	260	311
A4g	14	9	100	175	217	250
A4d	16	5	158	220	283	360
A5g	30	99	213	295	382	505
A5d	61	230	320	400	502	677
B1g	1065	9	35	70	110	200
B1d	896	21	58	92	130	217
B3g	956	3	12	22	39	110
B3d	1085	6	15	27	46	140
B4g	215	3	12	20	37	81
B4d	254	5	13	23	43	150
C1g	660	12	63	120	165	260
C1d	699	33	92	131	180	259
C3g	342	2	13	30	63	215
C3d	243	7	23	42	94	232
C4g	98	4	14	19	28	82
C4d	99	7	14	21	49	117
C5g	157	5	22	70	145	287
C5d	132	14	52	114	183	280
D1g	144	42	160	220	300	388
D1d	147	91	180	236	280	390
D2g	184	113	190	250	294	383
D2d	137	76	163	207	259	359
D3g	60	12	42	76	142	272
D3d	58	9	46	101	156	300
D4g	25	12	34	131	229	350
D4d	20	31	36	57	169	322
D5g	10	20	40	65	192	268
D5d	11	25	52	135	240	390
E1g	2217	25	102	158	210	310
E1d	2356	55	130	171	220	312
E3g	898	5	16	34	73	201
E3d	487	9	25	52	98	217
E4g	170	5	14	26	50	146
E4d	169	9	23	44	89	195
E5g	542	13	32	64	133	270
E5d	368	22	64	128	205	330

TABLE 2 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	855	100	195	251	310	383
F1d	994	131	205	255	309	388
F3g	40	32	77	141	257	323
F3d	41	25	96	179	283	306
F4g	5	35	43	65	81	251
F4d	19	36	105	253	272	340
F5g	29	30	178	240	301	365
F5d	20	90	249	291	325	375
G1g	868	25	68	106	153	243
G1d	771	46	95	138	175	268
G3g	761	3	10	18	34	87
G3d	412	10	22	39	64	134
G4g	76	7	15	23	37	102
G4d	91	10	20	32	71	140
G5g	242	6	16	31	59	148
G5d	93	15	26	49	89	230
H1g	60	48	110	164	219	315
H1d	19	38	112	187	230	336
H2g	53	69	175	265	320	506
H2d	30	122	171	215	291	413
H3g	74	12	28	69	141	342
H3d	35	28	98	153	244	361
H4g	14	18	38	57	76	236
H4d	9	16	22	50	98	257
H5g	26	31	86	165	232	367
H5d	27	38	110	226	348	434
I1g	663	15	41	80	119	193
I1d	337	20	64	98	130	200
I3g	626	4	11	19	37	92
I3d	283	8	17	31	60	130
I4g	80	8	12	19	30	70
I4d	59	9	19	31	46	140

TABLE 3

TOTAL HARDNESS AS CALCIUM (Ca), mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	352	14	68	109	135	196
A2d	165	12	62	119	142	208
A3g	31	21	75	110	163	241
A3d	43	35	73	89	122	205
A4g	13	12	54	93	110	122
A4d	16	30	69	97	129	168
A5g	30	47	95	136	250	376
A5d	61	49	102	158	274	396
B1g	989	11	24	33	48	84
B1d	855	14	27	38	52	85
B3g	898	7	14	22	32	63
B3d	1006	10	17	25	36	80
B4g	204	7	14	21	30	51
B4d	236	11	16	23	34	70
C1g	519	8	21	34	55	97
C1d	623	5	18	31	48	89
C3g	240	10	19	28	41	78
C3d	183	14	25	34	50	82
C4g	79	11	17	28	36	92
C4d	82	10	19	29	38	53
C5g	96	7	18	31	48	107
C5d	67	13	25	43	76	100
D1g	145	17	52	82	120	160
D1d	148	23	53	73	110	170
D2g	197	16	51	83	112	163
D2d	139	8	25	63	100	179
D3g	60	13	26	44	72	116
D3d	58	9	27	44	74	129
D4g	25	15	24	46	89	141
D4d	20	19	29	61	71	141
D5g	10	15	22	46	79	137
D5d	11	20	29	49	92	173
E1g	2057	15	32	47	66	114
E1d	2289	12	29	44	63	110
E3g	720	4	11	20	35	77
E3d	417	9	19	30	49	94
E4g	142	4	10	17	33	64
E4d	149	8	17	26	47	85
E5g	466	8	18	31	54	90
E5d	298	16	35	54	83	128

TABLE 3 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	852	18	40	65	91	139
F1d	988	14	32	52	79	137
F3g	40	20	38	57	94	126
F3d	41	16	35	72	95	221
F4g	5	1	18	24	25	60
F4d	19	5	32	94	102	216
F5g	29	22	75	91	106	139
F5d	20	37	88	103	122	146
G1g	810	8	20	31	45	83
G1d	750	8	20	30	47	97
G3g	736	4	6	10	18	39
G3d	382	6	12	19	28	54
G4g	67	3	7	15	24	53
G4d	82	6	9	18	36	69
G5g	250	5	9	17	30	64
G5d	88	6	13	23	33	89
H1g	58	20	39	67	80	127
H1d	19	1	32	53	66	127
H2g	47	6	50	98	129	154
H2d	29	3	35	56	86	164
H3g	71	6	14	29	43	71
H3d	32	18	33	50	61	129
H4g	8	15	25	35	57	100
H4d	3	35	35	35	43	43
H5g	23	14	32	43	57	100
H5d	19	29	43	56	100	143
I1g	522	7	17	28	41	62
I1d	307	7	22	32	42	67
I3g	536	3	5	9	17	38
I3d	202	4	9	14	23	49
I4g	70	3	6	10	18	32
I4d	38	6	8	12	21	39

TABLE 4

SULPHATE – SO_4, mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	307	1	14	35	61	130
A2d	159	1	2	15	47	110
A3g	31	16	20	34	58	100
A3d	42	15	25	40	56	96
A4g	14	12	25	40	55	110
A4d	16	4	14	32	82	200
A5g	30	23	35	47	62	94
A5d	61	1	15	48	78	140
B1g	754	6	13	18	26	47
B1d	595	5	11	17	27	52
B3g	866	9	13	17	23	35
B3d	1025	9	14	19	25	38
B4g	206	8	12	17	24	36
B4d	233	9	14	18	24	48
C1g	309	8	15	23	37	77
C1d	340	8	14	22	35	76
C3g	245	8	15	21	32	59
C3d	181	10	23	33	50	85
C4g	81	10	17	24	32	68
C4d	80	14	22	28	36	56
C5g	57	8	13	19	31	71
C5d	69	3	18	26	50	83
D1g	84	10	24	45	70	116
D1d	48	8	23	47	66	276
D2g	150	3	17	34	60	117
D2d	104	2	3	10	29	92
D3g	60	10	16	22	35	54
D3d	58	10	15	20	31	60
D4g	23	8	14	25	41	90
D4d	20	3	12	17	27	74
D5g	10	13	23	30	40	81
D5d	10	11	19	22	44	45
E1g	1143	4	11	19	30	70
E1d	1089	4	13	21	35	70
E3g	741	3	9	14	20	39
E3d	420	6	12	18	27	52
E4g	142	5	9	14	20	34
E4d	146	5	11	17	30	63
E5g	429	6	13	19	29	65
E5d	282	9	19	28	43	73

TABLE 4 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	495	9	20	30	44	83
F1d	510	9	19	31	47	80
F3g	40	9	21	31	39	53
F3d	38	8	16	24	43	192
F4g	5	6	14	32	44	80
F4d	17	9	24	38	132	239
F5g	29	14	19	29	41	58
F5d	20	10	16	23	30	66
G1g	805	1	6	13	23	53
G1d	718	1	6	13	26	65
G3g	739	2	4	7	12	24
G3d	408	2	6	10	15	28
G4g	74	1	3	6	14	24
G4d	89	2	6	11	18	42
G5g	235	3	5	8	14	33
G5d	94	3	6	10	16	48
H1g	59	2	8	13	22	51
H1d	17	0	6	10	13	95
H2g	47	3	12	23	41	94
H2d	28	1	2	10	19	46
H3g	74	3	6	10	16	36
H3d	33	8	12	21	32	65
H4g	8	2	7	11	33	66
H4d	3	2	2	6	48	48
H5g	26	6	7	12	20	47
H5d	27	9	13	22	27	40
I1g	593	1	3	7	11	24
I1d	289	1	3	7	12	26
I3g	597	1	3	5	9	17
I3d	265	1	4	7	10	23
I4g	75	1	3	5	8	15
I4d	54	1	3	5	9	18

TABLE 5

CHLORIDE – Cl, mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	358	12	20	32	72	470
A2d	165	13	26	46	182	483
A3g	31	7	12	21	39	130
A3d	43	5	12	21	32	76
A4g	14	5	11	15	24	31
A4d	16	7	13	24	39	204
A5g	30	10	22	27	37	349
A5d	61	16	27	41	74	257
B1g	910	5	9	14	21	47
B1d	813	5	9	13	21	48
B3g	790	3	7	11	19	46
B3d	971	4	9	13	21	46
B4g	202	3	8	12	20	39
B4d	230	3	8	13	20	33
C1g	498	7	15	25	49	270
C1d	608	8	15	26	48	410
C3g	194	6	12	21	34	75
C3d	169	8	15	24	43	193
C4g	69	5	14	23	34	68
C4d	78	8	13	18	25	58
C5g	76	11	20	29	50	127
C5d	49	16	28	41	98	220
D1g	144	3	11	20	41	116
D1d	147	3	10	25	62	270
D2g	199	7	12	19	38	165
D2d	139	6	12	22	71	610
D3g	54	4	8	14	21	35
D3d	50	3	8	11	19	65
D4g	23	4	11	18	33	50
D4d	20	10	14	22	70	118
D5g	10	8	12	17	34	157
D5d	11	1	7	10	19	88
E1g	1963	3	7	14	29	150
E1d	2266	3	8	16	36	220
E3g	594	1	4	9	16	47
E3d	380	2	6	11	22	61
E4g	129	1	5	9	19	57
E4d	137	3	8	14	25	49
E5g	393	2	6	11	22	64
E5d	271	4	9	17	32	89

TABLE 5 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	853	4	9	17	38	230
F1d	991	5	10	21	53	346
F3g	40	3	6	11	20	138
F3d	40	2	8	16	36	390
F4g	5	4	9	18	33	36
F4d	19	4	10	22	30	74
F5g	28	5	8	12	23	59
F5d	20	2	8	13	29	229
G1g	789	1	3	7	17	113
G1d	741	1	3	9	27	207
G3g	695	1	1	2	5	30
G3d	357	1	2	5	9	30
G4g	65	1	1	4	10	28
G4d	76	1	3	8	18	35
G5g	230	1	1	3	9	30
G5d	71	1	2	5	12	45
H1g	48	1	3	7	11	35
H1d	17	2	4	5	12	86
H2g	42	2	3	7	11	52
H2d	25	1	3	5	12	47
H3g	11	0	1	2	3	20
H3d	4	5	6	8	28	47
H4g	4	2	2	3	4	4
H4d	2	1	1	1	1	1
H5g	2	4	4	15	26	26
I1g	493	1	2	3	7	24
I1d	296	1	2	4	8	23
I3g	463	1	1	2	5	20
I3d	162	1	1	3	8	27
I4g	63	1	1	2	6	17
I4d	33	1	2	4	6	25

TABLE 6

NITRATE NITROGENE – NO_3-N, mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	337	0.0	0.1	0.2	0.6	6.1
A2d	152	0.0	0.1	0.2	0.4	4.5
A3g	16	0.0	0.2	1.8	9.1	27.3
A3d	23	0.0	0.9	2.5	13.2	22.7
A4g	10	0.2	1.1	2.3	5.0	36.4
A4d	14	0.0	0.1	2.6	6.6	11.6
A5g	13	0.3	3.6	11.8	15.9	29.5
A5d	26	0.0	0.1	0.4	2.0	19.3
B1g	519	0.1	0.2	0.2	1.5	6.7
B1d	600	0.0	0.2	0.2	0.9	6.8
B3g	124	0.0	0.1	1.3	4.0	11.6
B3d	97	0.1	0.7	2.7	6.4	17.5
B4g	42	0.1	0.1	0.7	2.7	6.8
B4d	53	0.1	0.2	1.1	5.0	13.0
C1g	405	0.0	0.1	0.2	0.5	4.3
C1d	569	0.0	0.1	0.2	0.2	2.0
C3g	55	0.0	0.0	0.5	4.1	10.5
C3d	28	0.1	0.2	0.6	3.4	7.0
C4g	37	0.1	0.7	1.7	3.7	10.2
C4d	35	0.1	1.2	3.3	10.0	14.8
C5g	63	0.0	0.0	0.0	0.5	3.9
C5d	14	0.0	0.1	0.2	1.6	3.4
D1g	113	0.0	0.1	0.2	0.4	5.2
D1d	138	0.0	0.1	0.2	0.2	1.8
D2g	163	0.0	0.0	0.1	0.2	4.9
D2d	133	0.0	0.0	0.0	0.2	3.4
D3g	12	0.1	0.3	1.5	5.2	13.4
D3d	4	0.0	0.3	1.7	5.9	9.1
D4g	13	0.0	0.0	0.1	1.2	9.1
D4d	1	0.0	0.0	0.0	0.0	0.0
D5g	1	3.6	3.6	3.6	3.6	3.6
D5d	3	0.7	0.7	1.5	5.7	5.7
E1g	1518	0.0	0.1	0.2	0.4	3.4
E1d	1920	0.0	0.2	0.2	0.2	2.5
E3g	127	0.0	0.0	0.2	0.8	4.8
E3d	54	0.0	0.2	0.8	4.5	10.4
E4g	49	0.0	0.1	0.2	0.6	4.2
E4d	51	0.0	0.1	0.2	1.8	6.6
E5g	112	0.0	0.0	0.3	1.6	10.0
E5d	70	0.0	0.2	0.7	3.0	9.3

TABLE 6 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	786	0.0	0.2	0.2	0.7	4.3
F1d	963	0.1	0.2	0.2	0.5	3.4
F3g	22	0.1	0.2	1.6	3.2	4.3
F3d	18	0.0	0.3	2.3	4.5	7.3
F4d	10	0.0	0.2	0.8	3.6	8.0
F5g	15	0.0	1.0	1.6	2.5	18.6
F5d	14	0.0	1.7	2.7	6.1	7.0
G1g	494	0.0	0.2	0.2	0.2	2.5
G1d	570	0.1	0.2	0.2	0.2	0.9
G3g	102	0.1	0.2	0.5	1.6	4.3
G3d	23	0.0	0.2	0.2	1.7	5.9
G4g	31	0.0	0.2	0.5	2.0	4.1
G4d	19	0.1	0.2	0.2	1.8	3.9
G5g	44	0.1	0.5	0.7	2.6	6.8
G5d	13	0.2	0.2	0.2	0.4	1.7
H1g	44	0.0	0.2	0.2	1.0	3.4
H1d	16	0.0	0.2	0.2	0.7	6.4
H2g	36	0.0	0.0	0.2	0.8	5.9
H2d	23	0.0	0.2	0.2	0.2	1.0
H3g	9	0.0	0.1	0.2	0.2	1.0
H3d	3	2.0	2.0	3.6	5.9	5.9
H4g	2	0.0	0.0	0.1	0.1	0.1
H4d	1	0.5	0.5	0.5	0.5	0.5
H5g	1	0.2	0.2	0.2	0.2	0.2
I1g	313	0.0	0.2	0.2	0.7	2.8
I1d	229	0.0	0.2	0.2	0.5	2.7
I3g	156	0.0	0.1	0.1	0.9	8.2
I3d	43	0.0	0.1	0.4	1.8	5.9
I4g	29	0.0	0.1	0.3	1.0	3.2
I4d	20	0.0	0.2	0.2	0.5	5.2

TABLE 7

IRON – Fe,mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	338	0.02	0.07	0.34	1.40	7.00
A2d	153	0.02	0.12	0.78	2.10	11.00
A3g	23	0.03	0.03	0.05	0.25	1.01
A3d	30	0.03	0.03	0.03	0.36	3.40
A4g	14	0.01	0.03	0.03	0.04	0.63
A4d	16	0.03	0.06	0.37	1.69	6.00
A5g	13	0.03	0.03	0.03	0.03	0.58
A5d	26	0.03	0.03	0.23	3.50	7.00
B1g	767	0.03	0.05	0.15	0.67	4.70
B1d	717	0.03	0.05	0.16	0.43	2.70
B3g	604	0.02	0.03	0.06	0.20	1.10
B3d	587	0.03	0.03	0.07	0.18	1.00
B4g	129	0.03	0.03	0.07	0.20	2.70
B4d	150	0.03	0.03	0.08	0.29	1.60
C1g	490	0.03	0.08	0.22	0.70	3.40
C1d	610	0.03	0.06	0.18	0.44	1.80
C3g	212	0.00	0.04	0.10	0.34	2.20
C3d	142	0.02	0.05	0.12	0.35	1.20
C4g	75	0.01	0.03	0.09	0.20	1.30
C4d	65	0.01	0.03	0.10	0.30	0.76
C5g	85	0.00	0.07	0.20	1.00	3.50
C5d	30	0.03	0.06	0.11	0.55	2.80
D1g	121	0.03	0.12	0.39	1.00	3.70
D1d	141	0.05	0.12	0.30	0.70	2.10
D2g	190	0.05	0.24	0.48	1.00	3.40
D2d	138	0.05	0.13	0.26	0.54	1.59
D3g	20	0.01	0.03	0.03	0.07	0.98
D3d	15	0.03	0.03	0.07	0.25	2.50
D4g	15	0.00	0.03	0.05	0.33	1.30
D4d	9	0.05	0.05	0.19	0.25	1.30
D5g	4	0.03	0.06	0.85	6.45	11.30
D5d	4	0.03	0.03	0.09	0.68	1.20
E1g	1602	0.02	0.07	0.21	0.62	3.00
E1d	1950	0.03	0.06	0.17	0.45	2.10
E3g	437	0.02	0.05	0.11	0.35	1.82
E3d	175	0.02	0.05	0.13	0.40	2.70
E4g	98	0.01	0.03	0.09	0.31	3.10
E4d	82	0.03	0.05	0.18	0.55	6.50
E5g	180	0.00	0.03	0.12	0.38	2.75
E5d	89	0.00	0.03	0.10	0.44	1.59

TABLE 7 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	808	0.03	0.06	0.18	0.45	1.60
F1d	975	0.03	0.05	0.13	0.29	1.00
F3g	27	0.01	0.02	0.03	0.11	0.27
F3d	23	0.01	0.03	0.08	0.18	3.50
F4d	10	0.01	0.01	0.07	0.48	1.00
F5g	25	0.01	0.02	0.03	0.09	0.94
F5d	16	0.01	0.02	0.03	0.07	0.45
G1g	594	0.03	0.10	0.30	0.90	4.50
G1d	630	0.03	0.07	0.21	0.53	2.60
G3g	353	0.01	0.03	0.08	0.35	2.30
G3d	174	0.01	0.05	0.15	0.40	3.35
G4g	40	0.02	0.03	0.19	1.93	9.46
G4d	47	0.00	0.03	0.07	0.60	4.40
G5g	127	0.01	0.03	0.11	0.34	2.70
G5d	35	0.03	0.05	0.13	0.70	5.00
H1g	51	0.01	0.06	0.24	0.70	2.20
H1d	18	0.03	0.03	0.11	0.35	1.70
H2g	42	0.01	0.02	0.05	0.13	1.10
H2d	29	0.03	0.07	0.20	0.36	4.50
H3g	11	0.02	0.03	0.03	0.04	0.16
H3d	5	0.03	0.03	0.03	1.40	4.54
H4g	4	0.03	0.03	0.03	0.05	0.05
H4d	2	0.29	0.29	0.40	0.50	0.50
H5g	2	0.03	0.03	0.06	0.09	0.09
H5d	1	0.03	0.03	0.03	0.03	0.03
I1g	435	0.02	0.03	0.11	0.42	4.90
I1d	253	0.03	0.03	0.11	0.26	1.60
I3g	443	0.02	0.03	0.07	0.24	1.70
I3d	157	0.03	0.03	0.09	0.20	1.10
I4g	56	0.03	0.03	0.06	0.30	2.80
I4d	36	0.03	0.03	0.10	0.79	3.00

TABLE 8

MANGANESE – Mn, mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	338	0.01	0.02	0.03	0.10	0.40
A2d	152	0.01	0.03	0.05	0.10	0.30
A3g	23	0.01	0.01	0.03	0.06	0.10
A3d	30	0.01	0.01	0.03	0.06	0.21
A4g	14	0.01	0.01	0.03	0.03	0.15
A4d	16	0.01	0.03	0.04	0.17	0.22
A5g	13	0.01	0.01	0.01	0.02	0.12
A5d	26	0.01	0.07	0.11	0.20	0.42
B1g	754	0.01	0.03	0.11	0.33	1.00
B1d	706	0.01	0.03	0.13	0.31	1.00
B3g	605	0.01	0.02	0.03	0.06	0.33
B3d	585	0.01	0.03	0.03	0.06	0.31
B4g	129	0.00	0.02	0.03	0.07	0.23
B4d	150	0.01	0.02	0.03	0.06	0.51
C1g	474	0.01	0.05	0.14	0.30	0.70
C1d	602	0.01	0.03	0.10	0.24	0.68
C3g	198	0.00	0.02	0.03	0.08	0.46
C3d	138	0.01	0.03	0.04	0.15	0.52
C4g	74	0.01	0.01	0.03	0.05	0.45
C4d	63	0.01	0.01	0.03	0.06	0.20
C5g	80	0.00	0.02	0.07	0.15	0.46
C5d	27	0.01	0.03	0.07	0.20	0.66
D1g	119	0.01	0.03	0.12	0.30	0.81
D1d	139	0.02	0.06	0.13	0.29	0.73
D2g	175	0.02	0.02	0.04	0.10	0.48
D2d	136	0.02	0.02	0.03	0.06	0.28
D3g	20	0.00	0.01	0.01	0.03	0.47
D3d	16	0.01	0.03	0.03	0.03	0.19
D4g	16	0.00	0.01	0.02	0.06	0.22
D4d	9	0.03	0.03	0.06	0.10	1.00
D5g	4	0.01	0.02	0.03	0.31	0.60
D5d	4	0.00	0.00	0.01	0.04	0.06
E1g	1576	0.01	0.03	0.15	0.36	0.83
E1d	1951	0.01	0.03	0.08	0.23	0.68
E3g	372	0.00	0.01	0.03	0.07	0.45
E3d	163	0.01	0.03	0.03	0.10	0.48
E4g	90	0.01	0.01	0.02	0.04	0.29
E4d	79	0.01	0.01	0.03	0.07	0.59
E5g	176	0.00	0.01	0.03	0.10	0.42
E5d	86	0.00	0.01	0.06	0.20	0.44

TABLE 8 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	808	0.01	0.03	0.07	0.16	0.34
F1d	975	0.02	0.03	0.06	0.12	0.31
F3g	27	0.01	0.01	0.01	0.03	0.15
F3d	23	0.01	0.01	0.03	0.12	0.31
F4d	10	0.01	0.01	0.02	0.03	0.05
F5g	25	0.01	0.01	0.01	0.03	0.45
F5d	16	0.01	0.01	0.01	0.02	0.20
G1g	587	0.01	0.03	0.08	0.20	0.54
G1d	626	0.01	0.03	0.07	0.16	0.44
G3g	325	0.00	0.01	0.02	0.03	0.20
G3d	167	0.01	0.01	0.03	0.05	0.38
G4g	37	0.00	0.01	0.03	0.10	0.30
G4d	43	0.00	0.02	0.03	0.10	0.29
G5g	121	0.00	0.01	0.02	0.07	0.27
G5d	31	0.01	0.01	0.03	0.09	0.37
H1g	51	0.00	0.03	0.06	0.23	0.50
H1d	18	0.01	0.03	0.03	0.09	0.37
H2g	42	0.00	0.01	0.02	0.07	0.60
H2d	29	0.01	0.03	0.03	0.08	1.40
H3g	11	0.00	0.01	0.01	0.01	0.02
H3d	5	0.01	0.01	0.03	0.36	0.95
H4g	4	0.01	0.01	0.02	0.02	0.03
H4d	2	0.03	0.03	0.03	0.03	0.03
H5g	2	0.01	0.01	0.02	0.03	0.03
H5d	1	0.03	0.03	0.03	0.03	0.03
I1g	390	0.00	0.03	0.05	0.21	0.70
I1d	239	0.01	0.03	0.07	0.18	0.60
I3g	362	0.01	0.01	0.03	0.05	0.27
I3d	104	0.01	0.01	0.03	0.04	0.30
I4g	48	0.01	0.01	0.03	0.05	0.64
I4d	30	0.01	0.02	0.03	0.05	0.30

TABLE 9

LEAD – Pb, mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	50	0.0002	0.0002	0.0002	0.0002	0.0005
A2d	33	0.0002	0.0002	0.0002	0.0002	0.0003
A3g	6	0.0002	0.0002	0.0002	0.0002	0.0002
A3d	19	0.0002	0.0002	0.0002	0.0003	0.0010
A4g	4	0.0002	0.0002	0.0002	0.0003	0.0004
A4d	8	0.0002	0.0002	0.0002	0.0002	0.0002
A5g	12	0.0002	0.0002	0.0002	0.0005	0.0039
A5d	23	0.0002	0.0002	0.0002	0.0002	0.0002
B1g	124	0.0001	0.0001	0.0001	0.0002	0.0006
B1d	112	0.0001	0.0001	0.0001	0.0002	0.0007
B3g	100	0.0001	0.0001	0.0001	0.0004	0.0015
B3d	67	0.0001	0.0001	0.0002	0.0004	0.0015
B4g	30	0.0001	0.0001	0.0001	0.0001	0.0006
B4d	33	0.0001	0.0001	0.0001	0.0003	0.0017
C1g	21	0.0001	0.0001	0.0001	0.0003	0.0005
C1d	32	0.0001	0.0001	0.0001	0.0002	0.0007
C3g	9	0.0001	0.0001	0.0002	0.0006	0.0013
C3d	8	0.0001	0.0002	0.0004	0.0008	0.0027
C4g	6	0.0001	0.0001	0.0004	0.0010	0.0028
C4d	5	0.0003	0.0003	0.0008	0.0010	0.0011
C5g	6	0.0001	0.0001	0.0001	0.0001	0.0002
C5d	3	0.0001	0.0001	0.0001	0.0001	0.0001
D1g	14	0.0001	0.0001	0.0004	0.0022	0.0026
D1d	4	0.0001	0.0001	0.0001	0.0004	0.0007
D2g	7	0.0001	0.0001	0.0001	0.0017	0.0034
D2d	1	0.0001	0.0001	0.0001	0.0001	0.0001
D3g	10	0.0001	0.0001	0.0001	0.0001	0.0010
D3d	3	0.0001	0.0001	0.0001	0.0001	0.0001
D4g	8	0.0001	0.0001	0.0001	0.0006	0.0028
D4d	1	0.0013	0.0013	0.0013	0.0013	0.0013
D5g	1	0.0001	0.0001	0.0001	0.0001	0.0001
D5d	2	0.0001	0.0001	0.0001	0.0001	0.0001
E1g	121	0.0000	0.0000	0.0001	0.0002	0.0008
E1d	132	0.0000	0.0000	0.0001	0.0002	0.0013
E3g	48	0.0000	0.0000	0.0001	0.0004	0.0009
E3d	15	0.0000	0.0001	0.0001	0.0003	0.0017
E4g	26	0.0000	0.0001	0.0001	0.0002	0.0007
E4d	15	0.0000	0.0000	0.0001	0.0002	0.0013
E5g	42	0.0000	0.0000	0.0001	0.0001	0.0007
E5d	24	0.0000	0.0001	0.0001	0.0001	0.0140

TABLE 9 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	3	0.0001	0.0001	0.0006	0.0028	0.0028
F1d	9	0.0001	0.0002	0.0003	0.0006	0.0009
F3g	1	0.0008	0.0008	0.0008	0.0008	0.0008
F3d	2	0.0002	0.0002	0.0007	0.0013	0.0013
F4d	3	0.0003	0.0003	0.0008	0.0017	0.0017
F5d	3	0.0009	0.0009	0.0015	0.0017	0.0017
G1g	49	0.0000	0.0001	0.0001	0.0003	0.0012
G1d	33	0.0000	0.0001	0.0001	0.0001	0.0002
G3g	23	0.0000	0.0001	0.0001	0.0001	0.0001
G3d	7	0.0000	0.0001	0.0002	0.0003	0.0006
G4g	10	0.0000	0.0000	0.0001	0.0001	0.0015
G5g	11	0.0000	0.0000	0.0001	0.0001	0.0005
G5d	5	0.0000	0.0000	0.0001	0.0001	0.0001
H1g	10	0.0003	0.0003	0.0003	0.0009	0.0021
H1d	2	0.0000	0.0000	0.0000	0.0000	0.0000
H2g	29	0.0003	0.0003	0.0003	0.0003	0.0024
H2d	2	0.0000	0.0000	0.0000	0.0000	0.0000
H3g	6	0.0000	0.0000	0.0001	0.0006	0.0007
H3d	2	0.0000	0.0000	0.0000	0.0000	0.0000
H4g	1	0.0000	0.0000	0.0000	0.0000	0.0000
H5g	1	0.0000	0.0000	0.0000	0.0000	0.0000
I1g	102	0.0000	0.0000	0.0002	0.0004	0.0016
I1d	52	0.0000	0.0000	0.0000	0.0001	0.0007
I3g	84	0.0000	0.0000	0.0000	0.0001	0.0007
I3d	26	0.0000	0.0000	0.0000	0.0005	0.0012
I4g	10	0.0000	0.0000	0.0000	0.0003	0.0007
I4d	9	0.0000	0.0000	0.0000	0.0003	0.0008

TABLE 10

ZINC – Zn, mg/l

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	113	0.0080	0.0120	0.0510	0.1200	0.4200
A2d	57	0.0070	0.0120	0.0450	0.1500	0.9500
A3g	6	0.0090	0.0360	0.0795	0.0880	0.1500
A3d	18	0.0270	0.0380	0.0770	0.2500	0.4700
A4g	4	0.0200	0.0210	0.0275	0.0330	0.0330
A4d	8	0.0025	0.0025	0.0025	0.0390	0.0420
A5g	10	0.0025	0.0220	0.0485	0.0610	3.7000
A5d	22	0.0190	0.0290	0.0405	0.0840	0.1100
B1g	127	0.0090	0.0250	0.0850	0.1900	0.9900
B1d	111	0.0025	0.0210	0.0530	0.1400	0.8000
B3g	107	0.0025	0.0170	0.0450	0.1360	0.8000
B3d	65	0.0100	0.0200	0.0400	0.1400	0.7200
B4g	35	0.0025	0.0120	0.0420	0.1300	1.2000
B4d	31	0.0025	0.0160	0.0300	0.1500	0.5800
C1g	31	0.0025	0.0100	0.1100	0.2700	1.4500
C1d	46	0.0090	0.0110	0.0585	0.2100	0.3800
C3g	33	0.0100	0.0100	0.0430	0.0720	1.8000
C3d	9	0.0100	0.0400	0.0910	0.1000	1.2000
C4g	15	0.0060	0.0100	0.0200	0.0940	0.1120
C4d	5	0.0090	0.0130	0.7000	0.7000	0.7290
C5g	14	0.0025	0.0210	0.0365	0.1300	0.6900
C5d	8	0.0100	0.0120	0.0260	0.1600	0.2500
D1g	15	0.0078	0.0085	0.0210	0.1500	0.4210
D1d	5	0.0088	0.0160	0.0240	0.1610	0.5200
D2g	23	0.0014	0.0900	0.2200	0.5200	0.7500
D2d	3	0.0280	0.0280	0.1500	0.6000	0.6000
D3g	11	0.0005	0.0050	0.0200	0.0870	0.7400
D3d	5	0.0060	0.0150	0.0200	0.0290	0.4900
D4g	7	0.0010	0.0015	0.0027	0.0160	0.0200
D4d	1	0.0140	0.0140	0.0140	0.0140	0.0140
D5g	1	0.0180	0.0180	0.0180	0.0180	0.0180
D5d	2	0.0850	0.0850	0.1525	0.2200	0.2200
E1g	140	0.0000	0.0003	0.0110	0.0605	0.4550
E1d	167	0.0000	0.0000	0.0100	0.0600	0.1850
E3g	66	0.0000	0.0000	0.0052	0.0340	0.4600
E3d	25	0.0000	0.0100	0.0130	0.1100	0.6600
E4g	29	0.0000	0.0053	0.0084	0.0110	0.0200
E4d	25	0.0000	0.0025	0.0100	0.0600	0.3800
E5g	46	0.0000	0.0000	0.0034	0.0130	0.0990
E5d	37	0.0000	0.0100	0.0300	0.0700	0.3550

TABLE 10 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	74	0.0100	0.0200	0.0380	0.1400	0.3900
F1d	44	0.0100	0.0195	0.0300	0.1300	0.6000
F3g	20	0.0018	0.0080	0.0195	0.1320	0.6500
F3d	11	0.0030	0.0210	0.0640	0.1900	1.8000
F4d	5	0.0200	0.0200	0.0370	0.1100	0.2100
F5g	13	0.0020	0.0060	0.0130	0.0550	0.2300
F5d	11	0.0530	0.0690	0.1200	0.5200	3.2000
G1g	78	0.0000	0.0010	0.0175	0.0740	0.3000
G1d	45	0.0000	0.0010	0.0110	0.0250	0.2300
G3g	190	0.0020	0.0120	0.0325	0.1500	0.8900
G3d	44	0.0060	0.0190	0.0405	0.1660	3.5000
G4g	23	0.0000	0.0110	0.0500	0.1100	1.1100
G4d	10	0.0010	0.0150	0.0250	0.0380	0.2400
G5g	66	0.0005	0.0100	0.0250	0.0900	1.0500
G5d	12	0.0000	0.0080	0.0280	0.1950	4.7500
H1g	10	0.0000	0.0000	0.0390	0.0600	0.3800
H1d	2	0.0000	0.0000	0.0000	0.0000	0.0000
H2g	28	0.0000	0.0010	0.0140	0.0435	0.2310
H2d	2	0.0000	0.0000	0.0000	0.0000	0.0000
H3g	4	0.0000	0.0000	0.0000	0.0005	0.0010
H3d	2	0.0000	0.0000	0.0000	0.0000	0.0000
H4g	1	0.0000	0.0000	0.0000	0.0000	0.0000
H5g	1	0.0000	0.0000	0.0000	0.0000	0.0000
I1g	99	0.0000	0.0000	0.0040	0.0400	0.3000
I1d	44	0.0000	0.0000	0.0000	0.0039	0.1200
I3g	105	0.0000	0.0000	0.0010	0.0180	0.1300
I3d	31	0.0000	0.0000	0.0025	0.0300	0.6600
I4g	9	0.0000	0.0000	0.0000	0.0005	0.0033
I4d	9	0.0000	0.0000	0.0000	0.0085	0.0380

TABLE 11

REDOX CLASS

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
A2g	357	1.0	1.0	3.0	3.0	4.0
A2d	164	1.0	2.0	3.0	4.0	4.0
A3g	31	1.0	1.0	1.0	2.0	3.0
A3d	43	1.0	1.0	1.0	3.0	3.0
A4g	14	1.0	1.0	1.0	1.0	3.0
A4d	16	1.0	1.0	3.0	3.0	4.0
A5g	30	1.0	1.0	1.0	1.0	2.0
A5d	61	1.0	1.0	1.0	3.0	4.0
B1g	1122	1.0	1.0	2.0	3.0	4.0
B1d	909	1.0	1.0	2.0	3.0	4.0
B3g	972	1.0	1.0	1.0	2.0	3.0
B3d	1089	1.0	1.0	1.0	2.0	3.0
B4g	214	1.0	1.0	1.0	3.0	3.0
B4d	254	1.0	1.0	1.0	2.0	3.0
C1g	720	1.0	1.0	2.0	3.0	4.0
C1d	764	1.0	1.0	2.0	3.5	4.0
C3g	374	1.0	1.0	1.0	3.0	4.0
C3d	246	1.0	1.0	1.0	3.0	3.0
C4g	102	1.0	1.0	1.0	3.0	3.0
C4d	100	1.0	1.0	1.0	3.0	3.0
C5g	187	1.0	1.0	1.0	3.0	4.0
C5d	153	1.0	1.0	1.0	1.0	3.0
D1g	144	1.0	2.0	3.0	4.0	4.0
D1d	148	1.0	2.0	4.0	4.0	4.0
D2g	200	1.0	3.0	3.0	4.0	4.0
D2d	134	1.0	3.0	3.0	4.0	4.0
D3g	60	1.0	1.0	1.0	1.0	3.0
D3d	58	1.0	1.0	1.0	1.0	3.0
D4g	25	1.0	1.0	1.0	2.0	4.0
D4d	20	1.0	1.0	1.0	2.5	3.5
D5g	10	1.0	1.0	1.0	1.0	3.0
D5d	11	1.0	1.0	1.0	1.0	4.0
E1g	2391	1.0	1.0	2.0	4.0	4.0
E1d	2405	1.0	1.0	2.0	4.0	4.0
E3g	953	1.0	1.0	1.0	1.0	4.0
E3d	511	1.0	1.0	1.0	1.0	3.0
E4g	184	1.0	1.0	1.0	1.0	4.0
E4d	176	1.0	1.0	1.0	3.0	4.0
E5g	576	1.0	1.0	1.0	1.0	4.0
E5d	371	1.0	1.0	1.0	1.0	3.0

TABLE 11 Contd.

TYPE AREA – DEPTH	N	P5	Q1	MEDIAN	Q3	P95
F1g	853	1.0	1.0	3.0	4.0	4.0
F1d	992	1.0	1.0	3.0	4.0	4.0
F3g	40	1.0	1.0	1.0	1.0	3.0
F3d	41	1.0	1.0	1.0	2.0	3.0
F4g	5	1.0	1.0	1.0	1.0	1.0
F4d	19	1.0	1.0	1.0	1.0	4.0
F5g	29	1.0	1.0	1.0	2.0	3.0
F5d	20	1.0	1.0	1.0	1.0	2.5
G1g	857	1.0	1.0	2.0	3.0	4.0
G1d	759	1.0	1.0	3.0	3.0	4.0
G3g	778	1.0	1.0	1.0	1.0	4.0
G3d	413	1.0	1.0	1.0	1.0	3.0
G4g	83	1.0	1.0	1.0	3.0	4.0
G4d	90	1.0	1.0	1.0	1.0	3.0
G5g	258	1.0	1.0	1.0	2.0	4.0
G5d	94	1.0	1.0	1.0	1.0	4.0
H1g	60	1.0	1.0	3.0	3.0	4.0
H1d	19	1.0	1.0	2.0	3.0	4.0
H2g	52	1.0	1.0	1.0	3.0	4.0
H2d	30	1.0	2.0	3.0	4.0	4.0
H3g	74	1.0	1.0	1.0	1.0	1.0
H3d	35	1.0	1.0	1.0	1.0	3.0
H4g	14	1.0	1.0	1.0	1.0	1.0
H4d	9	1.0	1.0	1.0	1.0	4.0
H5g	26	1.0	1.0	1.0	1.0	1.0
H5d	27	1.0	1.0	1.0	1.0	1.0
I1g	664	1.0	1.0	1.0	3.0	4.0
I1d	329	1.0	1.0	2.0	3.0	4.0
I3g	625	1.0	1.0	1.0	3.0	4.0
I3d	282	1.0	1.0	1.0	1.0	4.0
I4g	78	1.0	1.0	1.0	3.0	4.0
I4d	57	1.0	1.0	1.0	3.0	4.0

TABLE 12

ARSENIC – As and CADMIUM – Cd, mg/l.

Variable	Well type	N	P5	Q1	Median	Q3	P95
As	all	280	0.0002	0.0002	0.0002	0.0005	0.0114
As	soil	111	0.0002	0.0002	0.0002	0.0004	0.0021
As	rock	162	0.0002	0.0002	0.0003	0.0006	0.0181
Cd	all	2072	0.00002	0.00003	0.00003	0.00010	0.00033
Cd	soil	1017	0.00002	0.00003	0.00006	0.00014	0.00039
Cd	rock	993	0.00000	0.00003	0.00003	0.00006	0.00028

Note: Not all samples have been classified according to whether they come from wells in soil or rock, respectively. The total figure given for soil and rock wells is therefore less than the total for all wells.

TABLE 13

CRITICAL VALUES FOR WEIGHTING INDEX

Number of samples	Lower than reference population Level of significance		Higher than reference population Level of significance	
	1%	5%	5%	1%
1	-	1.00	5.00	-
2	1.00	1.50	4.50	5.00
3	1.33	1.67	4.33	4.67
4	1.75	2.00	4.00	4.25
5	1.80	2.18	3.82	4.20
6	2.00	2.22	3.78	4.00
7	2.12	2.29	3.69	3.89
8	2.17	2.37	3.63	3.86
9	2.20	2.40	3.60	3.82
10	2.22	2.44	3.56	3.78
12	2.30	2.50	3.50	3.67
14	2.36	2.55	3.47	3.64
16	2.42	2.57	3.44	3.58
18	2.45	2.61	3.41	3.56
20	2.50	2.63	3.38	3.50
24	2.54	2.65	3.35	3.46
28	2.57	2.68	3.32	3.43
32	2.59	2.71	3.29	3.41
36	2.64	2.73	3.27	3.36
40	2.65	2.75	3.25	3.35
45	2.67	2.76	3.24	3.33
50	2.68	2.78	3.22	3.32

Example presentation of data

An example of presentation of current condition, the ratio of alkalinity to sulphate deposition and deviation from the reference population. The deviation test is used for the latter.

A municipality in central Sweden wishes to study alkalinity – risk of acidification in shallow (<4 m) wells in moraine and deep (>4 m) excavated wells under cohesive soils. The municipality has sampled 10 wells in each environment.

One of the main aims is to ascertain whether alkalinity in municipal wells deviates from other areas of the country where conditions are comparable, ie, in the same type areas. A deviation test is therefore made to see whether municipal alkalinity data deviates from reference population alkalinity data.

To do this, it will first be necessary to identify the reference populations. According to the regional classification of Sweden (see Figure 2, page 22), the municipality is in region E. Shallow wells in moraine belong to groundwater environment 3 as described on page 24 and deep wells under cohesive soils to groundwater environment 5. The analysis figures obtained are therefore classified as type area-depth E3g (shallow wells in moraine or fluvial outwash) and type area-depth E5d (deep wells under cohesive soils), respectively, in Table 2 on page 90.

The table shows type area populations divided according to percentiles. Municipal analysis figures are compared, one at a time, with the type area table. Classification, which is a way of showing how the municipal figure compares with the distribution of concentrations in the type area population, is made in the way described in the chapter on “Instructions for deviation test”. Note that class value 1 is used for the lowest relative values and class value 5 for the highest, regardless of whether low values are “good” or “bad”.

Weighting indixes are now computed as the mean of all individual class values obtained. In our example, the municipality has only taken ten samples in each type area and well-depth class and these gave weighting indixes of 2.20 and 2.80, respectively. The significance of the weighting index obtained depends on the number of samples and the chosen level of significance as shown in Table 13 on page 110. According to the table, alkalinity values for wells in moraine are significantly lower than those of the reference group at a significance level of 1 per cent (critical value 2.22).

The inference is that the alkalinity of shallow wells in moraine in the municipality (assuming that those sampled are representative of this kind of well in the municipality) is significantly higher than is generally the case in wells of this kind in the central Swedish depression. The calculated risk that the observed difference is due to random factors is just less than 1 per cent.

On the other hand, the weighting index for deep wells under cohesive soils

TABLE 1.

Examples of analysis results and classification of them in relation to current conditions, ratio of alkalinity to sulphate deposition and deviation from type area/reference population

Shallow wells in moraine

sample, No.	alkalinity mg/l	alkalinity mekv/l	current condition class	alkalinity/ reg. sulphate	alkalinity/ reg. sulphate, class	deviation from type area, class
1	2	0.03	5	0.16	5	1
2	10	0.16	5	0.82	5	2
3	25	0.41	4	2.05	3	3
4	7	0.11	5	0.57	5	2
5	57	0.93	3	4.67	3	3
6	30	0.49	4	2.46	3	3
7	15	0.25	4	1.23	4	2
8	9	0.15	5	0.74	5	2
9	4	0.07	5	0.33	5	1
10	25	0.41	4	2.05	3	3
					weighting index	2.20
						significance

Deep wells under cohesive soils

sample, No.	alkalinity mg/l	alkalinity mekv/l	current condition class	alkalinity/ reg. sulphate	alkalinity/ reg. sulphate, class	deviation from type area, class
1	40	0.66	3	3.28	3	2
2	90	1.48	2	7.38	2	3
3	175	2.87	2	14.34	1	3
4	225	3.69	1	18.44	1	4
5	138	2.26	2	11.31	1	3
6	89	1.46	2	7.30	2	3
7	23	0.38	4	1.89	4	2
8	59	0.97	3	4.84	3	2
9	103	1.69	2	8.44	2	3
10	74	1.21	2	6.07	2	3
					weighting index	2.80
						no significance

shows that significance is not attained, either at a level of 1 per cent (critical value 2.22), or at a level of 5 per cent (critical value 2.40). This means that there is no marked difference between water in the municipal wells and in the type area in terms of alkalinity.

If the number of samples in the municipal population increases, significance is attained at a progressively falling weighting index. (The more samples, the less deviation from 3 needed to achieve significance).

Analysis results and classification in relation to current conditions (using Table 2 on page 29), the ratio of alkalinity to sulphate deposition (using Table 4 on page 33) and deviation from type area/reference population (as described in the chapter on "Instructions for deviation test") are shown in Table 1.

In this example, the regional sulphate concentration in deposition (can be taken from Figure 8a, page 32) is 0.20 meq/l SO_4.

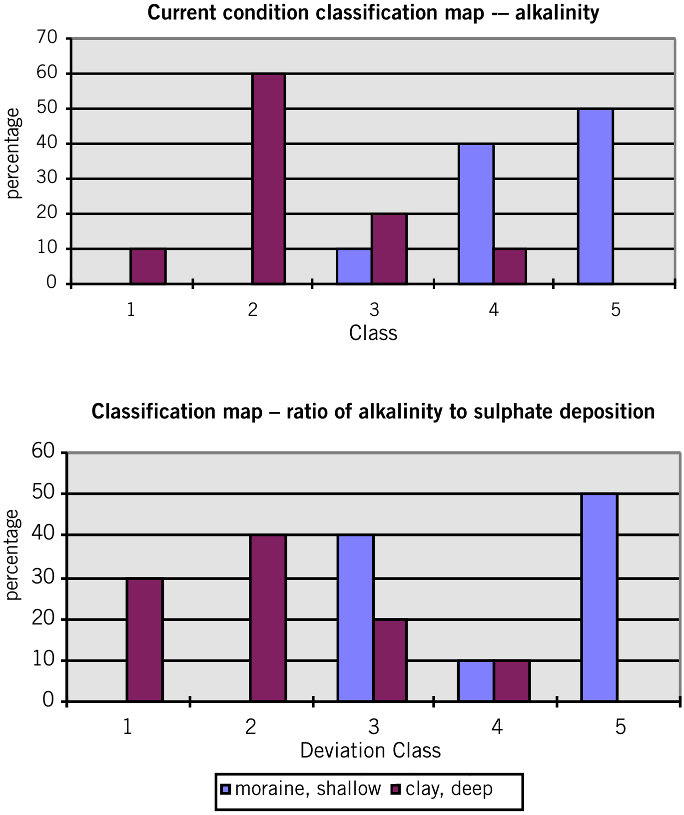


FIGURE 1. Example of classification of current conditions in relation to alkalinity and classification of the ratio of alkalinity to sulphate deposition for shallow wells in moraine or outwash sediment and for deep wells under cohesive soils.

In summary, the result of sampling and the findings is as follows.
Shallow wells in moraine:

- alkalinity is insufficient to unacceptable for all wells in terms of their resistance to withstand acidification
- the wells are moderately to very severely affected by acid deposition
- the wells surveyed have significantly lower alkalinity than corresponding wells in the reference population

Deep wells under cohesive soils:

- the ability to withstand acidification was adequate in most wells surveyed, although inadequate in some
- no - moderate impact of acid deposition in the majority of wells; one well was considered to be severely affected
- the wells surveyed do not differ significantly from the reference wells with regard to the impact of acid deposition

Computerised version

A computerised version of Environmental Quality Criteria for Groundwater is described here.

A computerised version of Environmental quality criteria for groundwater has been developed, which, when completed, will provide the user with additional support in using the methods described in this report. The computerised version will be able at the Swedish Geological Survey's web site: www.sgu.se.

It will not only show "current conditions" and "deviation from reference values" as described in this report; but it will also contain other information highlighting ambiguities and special cases to be considered when making an assessment. The maps showing the location of wells, colour coding for the various current condition classes and the classes for deviation from reference value serve as a complement. These maps make it easier to see the correlation between elevated concentrations and local emission sources (see Figure 1).

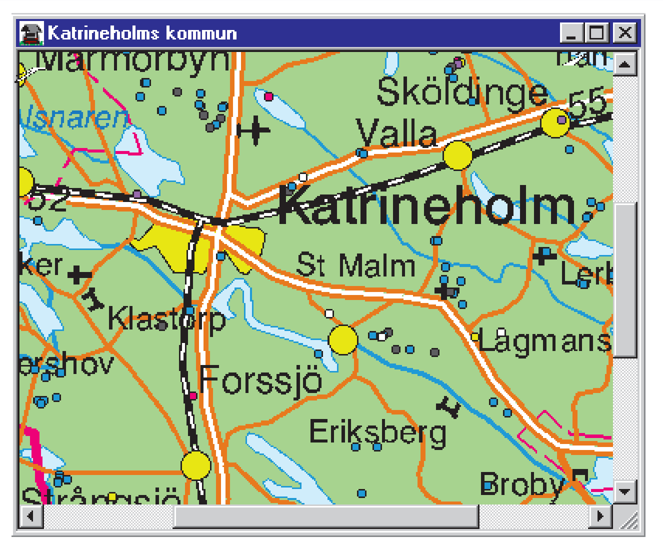
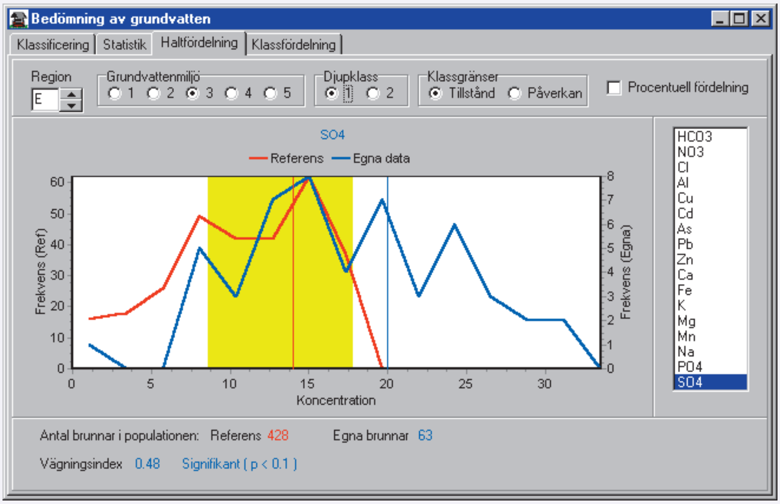


FIGURE 1. Map showing part of the municipality of Katrineholm with chloride concentration in wells classified according to deviation from the reference value. The wells are shown as small circles, colour coded according to class. Proximity to roads may be one factor explaining the presence of wells severely affected by salt from road salting.

Another additional feature of the computerised version is the possibility of sorting, grouping and printing diagrams showing the groundwater status of a group of wells. Perhaps the greatest advantage of the computerised version is that the variation of concentrations in a group of wells can be dealt with. This variation can be used to compare the status of a well or group of wells with other wells from the same type area. The basis for these comparisons is a structured reference population, which comprises analyses from about 30,000 wells in the Swedish Geological Survey database from the 1980s. This may be seen as complementing the basic classification of deviations, which is performed without dividing the wells into type areas. Figure 2 showing the conditions in the Katrineholm region, the concentration range of sulphate input from airborne deposition is marked as a yellow band.



Bedömning av grundvatten

Region E

Grundvattenmiljö ○ 1 ○ 2 ● 3 ○ 4 ○ 5

Djupklass ● 1 ○ 2

Klassgränser ● Tillstånd ○ Påverkan

☐ Procentuell fördelning

Antal brunnar i populationen: Referens 428 Egna brunnar 63

Vägningsindex 0.48 Signifikant ($p < 0.1$)

FIGURE 2. Comparisons of the sulphate concentration in wells in groundwater environment 3 in the municipality of Katrineholm with those in the reference population (taken from the Swedish Geological Survey database of groundwater analyses from the same region and same groundwater environment). Diagrams of this type make it easier to identify local emission sources in individual wells or groups of wells. The average input of sulphate from airborne deposition is marked as a yellow band. The left side of the band shows deposition on open terrain and the right side that on coniferous forest. The calculations have been made on a municipal basis. This demonstrates that both in Katrineholm and in the type area as a whole there is a fairly large number of wells with a sulphate content one and half times higher than that due to atmospheric deposition. In most cases this indicates sulphate originating from the bedrock.

The graphic overview provided by a map and the ability to study the distribution of concentrations in one's own data compared with the reference population makes it easier to identify local emission sources.

Alkalinity – risk of acidification

This appendix presents the choice of parameters used to describe acidification status.

Introduction

It is difficult to determine the exact natural state of groundwater in terms of alkalinity or pH.

The ratio of alkalinity to total hardness or the "acid ratio" has often been used in the past to determine the degree of acidification impact. The reason is that natural weathering by carbonic acid (see equation 2 on page 28) theoretically gives the same quantity of base cations (of which calcium and magnesium are the largest part = total hardness) as alkalinity. Weathering under the strongly acidic conditions existing after deposition of acidifying compounds instead produces twice as many base cations as the quantity of alkalinity. Instead of a 1:1 relationship between alkalinity and base cations, a 1:2 relationship occurs. (Bicarbonate ions make up the main part of what is normally termed the "buffering capacity" or alkalinity of the water.)

An attempt to estimate the margin of error when using alkalinity/total hardness to describe acidification impact

The ratio and the difference may be distorted by factors other than acidification.

The most important are:

1. Ion exchange caused by chloride or nitrate
2. Oxidation of sulphur in the soil
3. The fact that the acid ratio is not proportional to the acidification impact. This ratio may instead be expected to be greater at the beginning of an acidification process owing to greater availability of exchangeable calcium and magnesium ions
4. Deposition of calcium and magnesium and weathering of sodium
5. Other factors

The reasons become clear if we take the ionic balance into account, ie, the fact that the number of negatively charged ions (anions) is always equal to the number of positively charged ions (cations) in the water. This means that all changes that increase or reduce the concentration of anions are coupled with equally great changes in the concentration of cations. The concentration of base cations may then change as a result of ion exchange, whereby different positive ions can exchange places on soil particles. As with acidifying input in the form of sulphate, a nitrate compound from agriculture or sewage, for example, may result in increased concentrations of cations (mainly calcium and magnesium). The same thing happens when roads are salted: sodium in the road salt undergoes a partial process of ion exchange with calcium and magnesium. Impact of this kind will have the same effect on the acidification ratio as acidification, ie, it will increase hardness without increasing alkalinity (see Figure 1). Moreover, it is not clear what happens to the ratio when the store of exchangeable base cations is depleted, or when deposition of acidifying compounds decreases and/or changes from mainly sulphur deposition to nitrogen deposition.

Ion exchange caused by chloride or nitrate

Figure 1 shows that acid ratio falls as concentrations of chloride and nitrate rise.

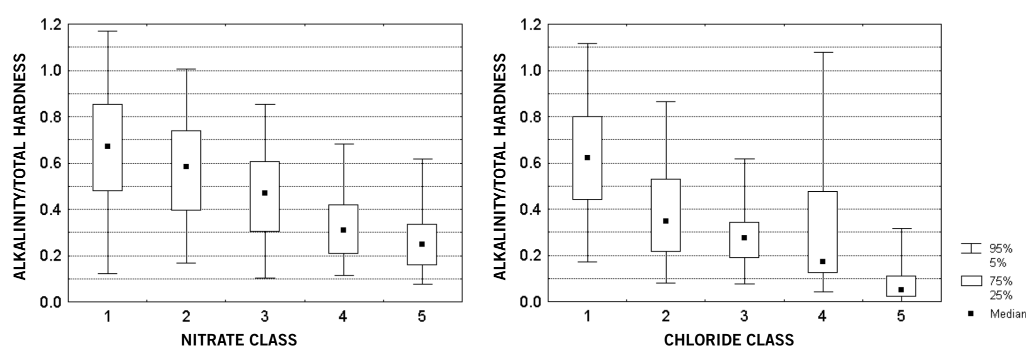


FIGURE 1. Impact of elevated concentrations of nitrate and chloride, respectively, on the acid ratio. For class boundaries for these two substances, see Tables 5 and 8 in the chapters "Nitrogen" and "Salt - chloride". All wells (Alkalinity <1 meq/l)

Oxidation of sulphur in the soil

The recorded concentration of sulphate in the well water could conceivably be used to correct for the impact of chloride and nitrate when assessing acidification impact.

In areas of igneous and metamorphic rock above the highest coastline, the concentration of sulphate in groundwater largely corresponds to the input from wet and dry deposition. Natural input is limited here, mainly comprising sea salts. The remainder is sulphur from anthropogenic sources such as combustion.

In areas below the highest coastline and areas of sedimentary bedrock, many wells are severely affected by sulphate input, either of marine origin or from oxidation of sulphur in the soil or bedrock. This should not be included if the intention is to assess the acidification impact of sulphur deposition. Inputs from these sources vary greatly from well to well and probably also vary considerably over time in many wells.

It should be noted that input from soil is not only substantial in areas with clay soils, sulphide soil etc. Organically fixed sulphur or other reduced sulphur capable of being released during dry periods or as a result of drainage is common in areas below the highest coastline. This produces higher concentrations along the coasts and in the Mälar valley region. Sulphur

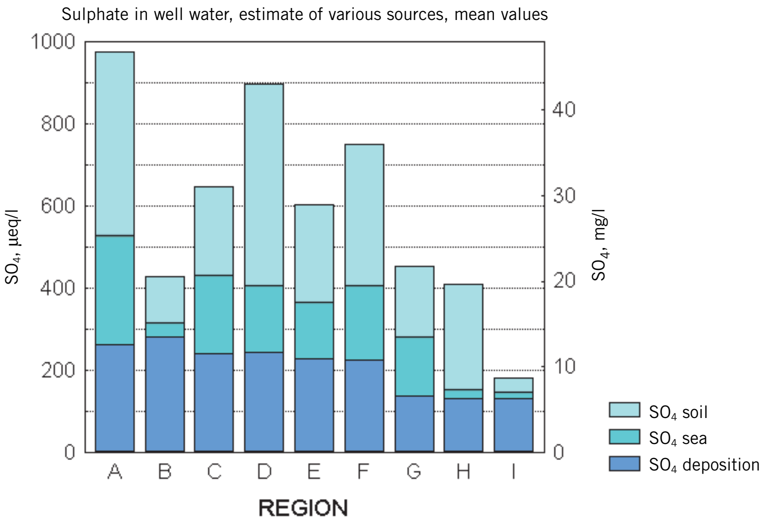


FIGURE 2. Input from various potential sources of sulphate in well water (all well types). Mean values.

Figure 2 shows the estimated average input from the various sources for each region. Sulphate from the sea has been estimated from the chloride concentration. This may overestimate the figure at the expense of the quantity of oxidised sulphate if the well is affected by chloride from non-marine sources, eg, road salting or sewage. This error is probably a fairly minor one, which may be seen from the relatively small proportion of estimated marine sulphate in the regions above the highest coastline (B and I), ie, the southern Swedish highlands and areas of igneous and metamorphic rock in inland northern Sweden.

In the regions above the highest coastline (B and I) and in region H (sedimentary areas of Dalarna and Jämtland in central Sweden, most of which are above the highest coastline), the estimated proportion of marine sulphate is low. In region H the input from sulphur released from soil and bedrock is considerable, which is also true of other sedimentary areas. The proportion of marine sulphate is fairly large in areas below the highest coastline. In order to split up the various sulphur inputs in the same way as in Figure 2, it is necessary to know the sulphate concentration in the infiltrated water from the individual well. This is difficult, since the concentration varies depending on land use and other factors.

concentrations are also higher in areas of sulphide mineralisation than in surrounding areas.

Input of marine sulphate is accompanied by base cations and is not acidifying, unlike deposition of sulphate from combustion processes etc and oxidation of sulphur in soil.

The fact that the acid ratio is not proportional to the acidification impact but may instead be expected to be greater at the beginning of an acidification process owing to greater availability of exchangeable calcium and magnesium ions

Much of the shift in the acid ratio at the beginning of an acidification process results from the increase in total hardness when calcium and magnesium are displaced from soil particles by hydrogen (and aluminium) ions. This displacement can be expected to lessen even where the acidification load is constant because the store of exchangeable base cations is depleted. In areas experiencing a peak of acidification impact, eg, Sweden, it is not certain which direction the ratio will take. It is difficult to say how much uncertainty will be introduced by using the acid ratio because many other factors are involved, eg, the original size of the cations in storage and the size of the acidification load compared with weathering. The objection to using the ratio because of this doubt is a matter of principle. It would be unfortunate if a constant acidification load were to be viewed as a declining load.

Airborn deposition of calcium and magnesium and sodium from weathering

Another factor hindering the use of the ratio of alkalinity to total hardness is that in naturally very ion-weak groundwaters a significant proportion of calcium and magnesium in groundwater may derive directly from deposition. A further factor is that in very shallow groundwater, sodium by weathering is fairly significant. Since these two factors tend to cancel each other out, the effect on the ratio is less, however. But there may be a great impact on individual wells owing to differing deposition or mineralogy. It should be stressed that it is essential to classify this group of wells correctly, since they are the water sources most sensitive to acidification.

Other factors

The arguments above principally take account of factors causing displacement of calcium and magnesium. There are many other possibilities, however. If the soil is acid, input of salt, for example, may produce a direct increase in the quantity of hydrogen ions in the water phase, which may possibly be involved in ion exchange or cause weathering further down in the soil. Absorption of nutrients by plants often causes soil acidification.

These processes, which are at least partly influenced by nitrogen availability, have a great impact on the soil in a given area and hence also on the groundwater. These and many other factors affect the acid ratio and, it might be mentioned, also the actual acidification impact on the groundwater. This has not been dealt with here, however.

General comments on use of the acid ratio and the assessment method proposed here

As may be seen from the above, the acid ratio is heavily influenced by a number of factors. It is difficult to ascertain what part of acidification impact derives from deposition and what is due to other causes in a given case. The inclusion of total hardness and alkalinity in the ratio might be said to ensure that a large proportion of the chemical constituents of the water are covered.

A new concept has been developed for use in this Groundwater report as a way of circumventing the difficulties of using the ratio of alkalinity to total hardness. The new method is to compare the residual buffering capacity of the water against acidification (its alkalinity) with the load in the form of sulphur deposition.

The problem of the influence of other types of impact lessens using this approach. The assessment is rough but comparatively transparent. The alkalinity of well water is compared directly with the acidification load. Since the alkalinity of the water results from a number of processes, the alkalinity created by weathering has been partially used to neutralise acid deposition, biological acidification and other soil processes such as oxidation of sulphur. Extensive ion exchange renders it impossible to estimate how great alkalinity would have been without the acid deposition. The extent to which the alkalinity of the water has already been affected by acidification is not calculated. Hence, it is the amount of alkalinity that is compared with the amount of the acid deposition. Acceptance of this will make assessment easier.

It has been found that even if all wells have been affected by acid deposition, the alkalinity of water in most of them is so high compared with the deposition that the acidification impact on the water is negligible. The wells that have been severely affected by acid deposition can also be definitely identified.

Redox

A more detailed description of the terms redox potential and redox reactions in the environment is given here.

One way of measuring the energy level at which a given reaction can take place is to measure the electrical tension difference between an aqueous solution containing the substances of interest and a standardised hydrogen gas electrode. The tension difference can be seen as a measure of the driving force for the reaction. This is termed redox potential - Eh. These reactions are often reversible and, depending on whether the redox potential is above or below the equilibrium, either the oxidising or the reducing form will be stable. They form reaction pairs. Hence, for example, nitrate is stable at Eh exceeding 0.6 volts, whereas the stable form of nitrogen below this figure is nitrogen gas. Lower Eh values mean more reducing conditions. The extremes for an aqueous solution are observed when oxygen is liberated, which occurs at an Eh of approximately 0.75 volts and when hydrogen is liberated at an Eh of approximately -0.4 volts. The point of equilibrium is also influenced by pH and temperature. If both forms of a reaction pair occur simultaneously, this is a sign that the Eh of the aqueous solution is in equilibrium and will remain so until one of the substances in the reaction pair has been consumed. The system is said to be "redox buffered". Knowledge of the redox-sensitive substances present in the solution can thus be used to determine the interval within which the redox potential must lie. Figure 1 shows a diagram of redox intervals which various redox-sensitive compounds and ions of nitrogen, sulphur, manganese, iron, as well as methane may occur in solution. Intervals within which the substance does not occur in solution are shaded grey. These intervals apply to all waters in chemical equilibrium.

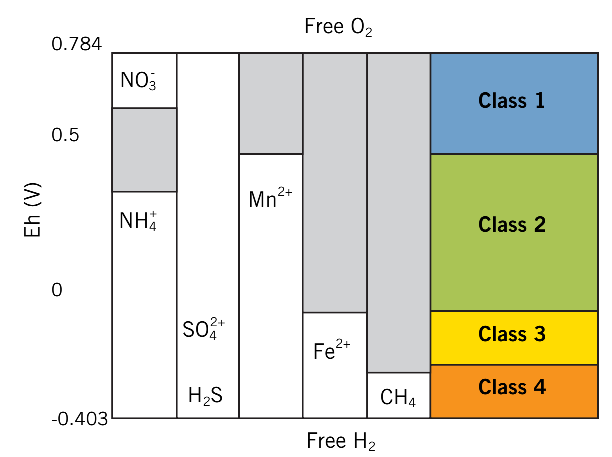


FIGURE 1. The chart shows the forms in which certain redox-sensitive substances occur in the current condition classes in relation to redox, as presented in the chapter on this, page 48. Manganese and iron are insoluble in the grey area. The two compounds of nitrogen are present simultaneously in solution in the grey area. Class 5 signifies combinations of substances in solution which only occur in water that has not reached chemical equilibrium. The class therefore cannot be included in this chart. The conditions shown apply at a pH of 7. Lower pH normally means that the boundaries will move upwards somewhat.

Groundwater quality and redox reactions

Waters which are strongly reducing are called anaerobic since they are characterised by a lack of oxygen. It is difficult to use them for drinking purposes. One problem, for example, is iron, which, at low redox potential, is reduced to free iron ions (having been relatively insoluble iron hydroxide at a higher redox potential). Manganese is another substance whose solubility is sensitive to redox conditions in the water. Both often cause quality problems where groundwater is used for water supply purposes. Other examples are compounds of sulphur and nitrogen, see below. Water in the ground is always in contact with minerals in rocks or soils. New substances can therefore always be dissolved in the water when redox potential changes.

Bacteria and redox reactions

Bacteria are often involved in redox reactions. Many of these reactions are extremely slow unless catalysed and speeded up by bacteria. Various species and groups of species specialise in specific conversions of substances.

Depending on the availability and combination of different substances in the water, whose capacity to be oxidised by bacteria varies, redox conditions may shift towards oxidation or reduction.

Nitrogen, phosphate and redox reactions

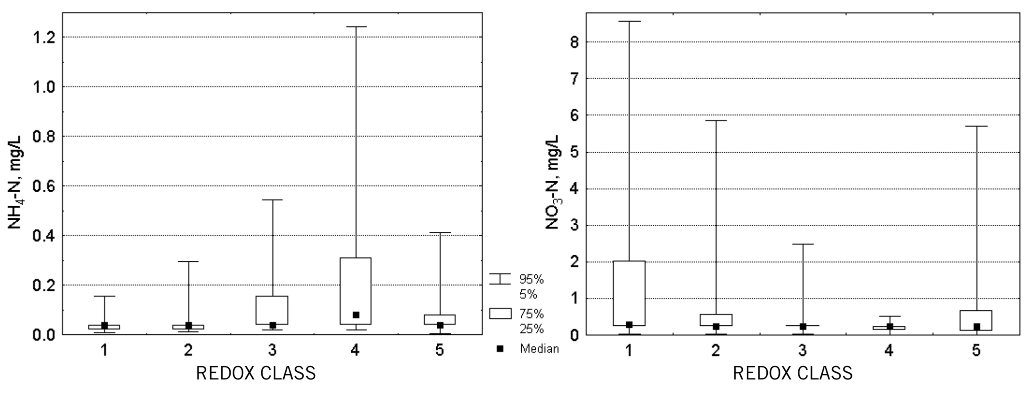


FIGURE 2. The correlation between ammonium and nitrate concentrations and redox conditions. The diagram also shows that concentrations of ammonium are much lower than those of nitrate. Note that class 5 represents mixed water. All well types.

Nitrate (NO_3) occurs mainly under oxidising conditions and ammonium (NH_4) mainly under reducing conditions, see Figure 2. They form a reaction pair.

Reducing conditions occur mainly in fairly deep wells, see Table 11. It is difficult, however, to know whether nitrate concentrations in these anaerobic environments are lower because nitrate has been eliminated by reduction or for other reasons. N concentrations in deep wells may be assumed to be less affected by local pollution sources, e.g., sewage or livestock farming, then water in wells in groundwater environments 3 and 4. Wells may also be protected by thick layers of clay (groundwater environment 5). Moreover, their inflow areas are often not as local as the source of groundwater accumulating in aquifers in groundwater environments 3 and 4. However, it is likely that reduction processes act to keep nitrate concentrations low in many wells bored in rock. The comparatively high nitrate concentrations (see Table 1) nonetheless present in groundwater environments 2 and 5 (sedimentary bedrock areas and clay valleys/plains) may be due to the fact that intensive farming often takes place in these areas, which are also often fairly densely populated. The soil in these areas obviously has insufficient capacity to eliminate nitrate by reduction. As mentioned in the chapter on “Redox”, a large influx of nitrate may also raise the redox potential.

Hence, the nitrate concentration in the well can be seen as a function of at least three factors: nitrogen input, groundwater environment and redox conditions.

TABLE 1.

Percentage distribution of well analyses from Swedish Geological Survey data into nitrate classes for each groundwater environment at vary degrees of oxygen deficiency (note that class 5 represents mixed water). For a division into nitrate and redox classes, see Tables 5 and 11 (n = 7,721)

	Groundwater environment																								
	1					2					3					4					5				
	Igneous bedrock					Sedimentary bedrock					Moraine and fluvial outwash					Fluvio-glacial deposits					Confined aquifers				
	Nitrate-class					Nitrate-class					Nitrate-class					Nitrate-class					Nitrate-class				
	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5	1	2	3	4	5
Redox	%					%					%					%					%				
1	67	8	19	4	1	48	10	23	10	8	44	11	33	8	5	39	12	33	11	5	26	7	38	16	12
2	77	7	13	2	1	56	7	22	4	11	50	6	23	8	12	33	0	33	8	25	56	12	24	3	6
3	87	3	7	1	1	87	6	5	1	1	63	8	20	4	4	77	1	16	3	3	68	5	17	3	7
4	96	2	2	0	0	98	2	0	0	0	85	8	8	0	0	83	0	17	0	0	92	8	0	0	0
5	74	6	15	3	1	86	4	8	1	1	59	5	22	12	2	47	8	28	15	1	50	9	28	8	5

The phosphate concentration is also dependent on redox conditions, see Figure 3. The concentration is usually low in the groundwater but may rise under reducing conditions. The diagram shows that elevated phosphate concentrations essentially only occur in combination with severely anaerobic conditions (redox class 4). Wells with high iron concentrations may have elevated phosphate concentrations without this constituting contamination.

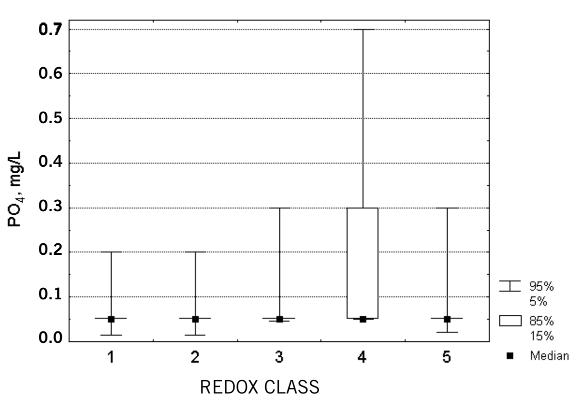


FIGURE 3. The correlation between phosphate concentration and redox conditions, see Table 11. Note that class 5 represents mixed water. All well types.

Pesticides

A brief summary of studies of the occurrence of pesticides in groundwater is given below. This is followed by a section describing the behaviour of pesticides in soil and factors that increase the risk of leaching into groundwater. The appendix concludes with a list of substances in an analysis package.

Some studies into the occurrence of pesticides in groundwater

Few surveys designed to detect the presence of pesticides in groundwater have yet been made. Those performed to date have usually been confined to locations where groundwater contamination has been suspected.

For the period 1987–1996 there are 394 analyses of groundwater from private wells in Malmöhus, Kristianstad and Gotland counties. Pesticides were found in 43 per cent of the samples; a total of 21 substances were identified. Targeted sampling explains the high proportion of contaminated samples.

In some cases, samples from public water supply sources have also revealed low concentrations of pesticide residues. These surveys were performed at various locations throughout Sweden by the National Food Administration. However, the concentrations are so low that the Administration does not consider them to pose a threat to health. The most commonly found substances are used as weedkillers on uncultivated land.

The National Food Administration drinking water regulations stipulate that drinking water from public water supplies must contain no demonstrable concentrations of pesticides.

The EC Drinking Water Directive sets a limit of 0.1 µg/l for each pesticide and 0.5 µg/l for total pesticides. Remedial action must be taken at these levels.

Conditions governing pesticide mobility in soil

The characteristics of organic pesticides vary greatly. Important characteristics that play a key role in their mobility in soil are their solubility in water, adsorption to organic matter and rate of decomposition, microbial as well as hydrolytic. Apart from the chemical structure of these compounds, there are a number of soil characteristics that affect their behaviour in soil. Hence, the main factors are the content of organic matter, pH (for certain groups of pesticides), soil type and conditions for microbial activity. Local climate conditions are an additional consideration.

Adsorption

Adsorption is greater in a fine-grained material than in a coarse one. This is because there is a much greater surface area available for adsorption in fine-grained soils. Organic matter also has a great capacity to adsorb pollutants. Factors affecting adsorption are the concentration of pesticide and the pH of the soil. Some pesticides become much more soluble in water at higher pH levels.

Persistens

Pesticides are primarily broken down with the help of micro-organisms. Aerated soil strata and a high content of organic matter are two factors creating high microbial activity. Most pesticides are broken down fairly quickly under these conditions. In fine-grained material, pesticides may diffuse into the soil aggregate and avoid microbial decomposition for varying lengths of time. Even where the input of a given pesticide ceases, a proportion of the quantity previously fixed in the soil can once again be dissolved. The same thing occurs when organic matter is broken down. Decomposition is very slow below the water table, particularly if there is little oxygen, which is usually the case. Regulations governing the rate at which pesticides decompose were tightened in the 1990s, since some of the agents previously in use were found to be highly stable in groundwater. In some places, pesticides have been found in groundwater more than 10 years after their use was banned. The National Chemicals Inspectorate examines all pesticides in terms of the risk they pose to health and the environment before approving their use.

Transport via groundwater

Once they have reached the groundwater, pesticides may be dispersed very irregularly. One reason for this is the presence of different soil strata with varying capacity to convey the water in the saturated zone. Water samples taken in different parts of an area or at different depths may thus reveal sizeable differences in concentration. A proven concentration of a pesticide therefore only shows the concentration at the place and depth where the sample was taken. It must therefore be decided how representative the concentration is of a larger area. Groundwater movements mean that a risk assessment must take account of the fact that any pesticides may in time end up downstream from the areas where they were used.

Factors increasing the risk of pesticide presence in groundwater:

- use of pesticides on gravelled surfaces such as courtyards, farmyards, industrial sites and road and railway embankments
- large areas sprayed with pesticides and high-intensity dispersal
- use of pesticides with a long half-life and high mobility

- pesticides spread in the autumn or in conjunction with watering
- filling and cleaning of dispersal equipment carried out on well-drained ground
- well-drained soils and soils interlaced with cracks, root channels and worm holes
- soil with a low content of organic matter or low clay content
- soil where the water table is permanently or intermittently high
- soils with a high pH, which increases solubility in water and the half-life of certain groups of pesticides
- areas with total and intermittently high levels of groundwater formation
- artificial groundwater formation by means of basin infiltration or induced infiltration along shorelines where the surface water contains pesticides

References

EC Groundwater and Drinking Water Directives: Dir. 80/68/EEC and Dir. 80/778/EEC.

Hessel, K., Kreuger, J., Ulén, B. (1997): Survey of pesticide residues in surface water, groundwater and rainwater in Sweden 1985–1995. Findings from monitoring and targeted sampling. Ekohydrologi 42, Swedish Geological Survey, Department of Water Management, Uppsala.

National Food Administration drinking water regulations. SLV FS 1993:35.

Substances proposed for inclusion in an analysis package:

Pesticides and metabolites (products of decomposition) (italics):

Laboratories not capable of analysing all compounds in a package may need to divide them up according to what is technically possible. The list will be updated when it is necessary to add or remove substances.

2,4-D	
Atrazine	formerly a constituent of Totex and other agents
Desethylatrazine	*Atrazine metabolite*
Desiopropylatrazine	*Atrazine metabolite*
Benatzon	
BAM 2,6-Dichlorobenzamide	Dichlorobenzonitrile metabolite; Dichlorbenzonitrile was formerly a constituent of Totex and other agents
2-Imidazolidinethione (ETU)[1]	
3-Pyridinecarboxylic acid[4]	
Clopyralid	
Cyanazine	
Dimethoate	
Ethofumesate	
Fenoxaprop-P[2]	
Glycine[3]	
Isoproturon	
Kvinmerac[2]	
Propanoic acid	
MCPA	
Mekoprop-P	
Metamitron	
Metazachlor	
Metribuzin	
Simazine	
Sulfonylureor[5]	
Terbuthylazine	

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[1] ETU may be present in small quantities as an impurity and may form in the spray tank when agents containing mankozeb, maneb and zineb are used. ETU should be analysed in areas of intensive potato cultivation where these pesticides have been used and where mankozeb is still widely used.

[2] New substance or increased application. Considered mobile. Use assumed to be increasing. Needs to be monitored.

[3] Very widely used universal pesticide. Fairly pronounced tendency to fix in soil. Not yet found in groundwater in Sweden.

[4] Not used in agriculture but on road and railway embankments. Can be included if effects originating in these embankments are suspected.

[5] Sulphonyl urea variants, commonly known as low-dose pesticides. Since solubility in water and half-life increase with rising pH, analysis of the sulphonyl urea variants regularly used in areas where the soil pH is greater than 7 is recommended. Consult the laboratory used.

Water table

A description is given below of how to perform an analysis of a time series for water table variation at a location. This variation can then be compared with a reasonably long reference series from a location in a similar geological environment.

As mentioned earlier, the approach outlined in the water table chapter is only suitable in certain clearly defined situations. A time series for fluctuations in the water table at the location in question before and after anthropogenic disturbance is normally required in order to determine whether the water table has in fact been affected by anthropogenic factors. The monitoring series should begin at least six months prior to the disturbance and continue for the same length of time afterwards. Readings should be taken at least every 14 days.

This monitoring series can then be compared with a reasonably long reference series from a location in an area of similar geology and climate. These series can often be obtained from the Swedish Geological Survey.

The two series can then be analysed using various methods, eg,

- Plotting of the two figures on the same graph (water table against observation period). Since the two locations have similar geology and climate, there should be fairly close co-variation between them under natural unaffected conditions. If the co-variation is replaced by a changed pattern for the local water table simultaneously with the occurrence of human disturbance, this indicates that the disturbance is the cause of the change.
- Specific methods for studying water table changes have been developed, e.g., at Chalmers University of Technology, Gothenburg. Among others, Chester Svensson (Svensson 1984, Svensson & Sällfors 1985) has developed a method that makes it possible to forecast the highest or lowest groundwater level at a given point. A fairly short series of monitoring data (at least three months) from the observation site is needed. This is compared with a relatively long reference time series. An observation which is below the estimated minimum figure or above the estimated maximum figure after the disturbance may then be considered to have an anthropogenic cause.
- Other statistical methods can be used to determine whether two time series co-vary or not. One of these is the "double-mass method" (Svensson 1988), which is based on plotting progressively accumulated

data from one monitoring series against corresponding data from another. The result is a line with a certain gradient. If an event occurs which affects one of the data series, the gradient on the graph will change.

- Another method that may be used is to study the co-variation in the form of the correlation coefficient before and after a disturbance in the surroundings suspected of affecting the water table.
- In some cases, water table fluctuations can also be simulated using climatological data and one of the existing hydraulic models, eg, the HBV or SOIL model. However, this presupposes that the models can first be calibrated against an unaffected time series that is long enough to reflect normal fluctuations in climate.

A common feature of the above methods is that they should be applied by specialists in the field. User-friendly computer software has been developed in recent years. Whether or not these methods can be used depends on the availability of a fairly short series of monitoring data from the site in question, both before and after the disturbance, and also a reasonably long series of reference data (preferably more than 10 years) from a similar groundwater environment and climatological region.

References

Olofsson, B. (1991): Effects on groundwater by tunnelling in hard crystalline rocks – analysis of groundwater level data from the Bolmen tunnel, S. Sweden, 1969–1987. – Report from the Department of Soil and Water Resources, Royal Institute of Technology, TRITA KUT 91:1062.

Svensson, C. (1984): Analys och användning av grundvattennivåobservationer (”Analysis and use of groundwater level observations”). – Diss. Chalmers University of Technology, Department of Geology, Publ A49. Gothenburg, 126–131.

Svensson, C. & Sällfors, G. (1985): Beräkning av dimensionerande grundvattentryck. 1. Göteborgsregionen (”Modelling size-determinant groundwater pressure. 1. Gothenburg region”). – Chalmers University of Technology, Geohydrological research group, Notice 78. Gothenburg.

Svensson, C. (1988): Analysis av påverkade grundvattennivåer (”Analysis of affected ground water levels”). – Chalmers University of Technology, Geohydrological research group, Notice 84. Gothenburg.

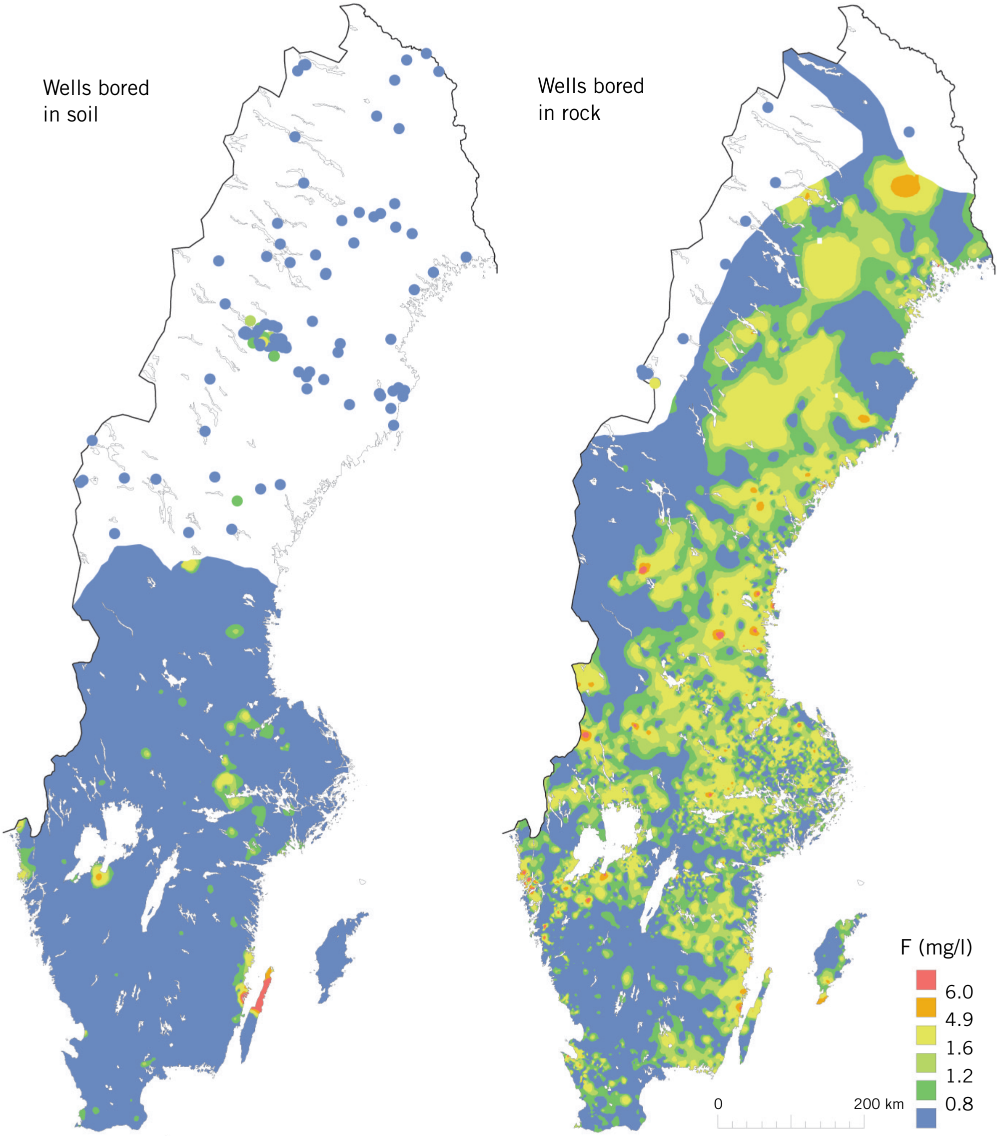
Fluoride and radon

Fluoride

Variation in fluoride concentrations is almost entirely due to natural factors. The highest concentrations are found in some wells bored in igneous and metamorphic rock and sandstone. Examples of this kind of environment are water with long retention times in bedrock comprising young granites and pegmatites. Concentrations in wells bored in soil are generally low. Anthropogenic impact is found in only a very few places. Examples are found in the vicinity of smelting works, where fluorspar or minerals containing fluoride have been used and at glassworks. The Drinking Water Regulations issued by the National Food Administration (SLV FS 1993:35) classify water with a fluoride concentration above 6 mg F/l as unfit for consumption, since it poses a risk of bone damage (osteofluorosis). This water should not be used for drinking purposes or in connection with foodstuffs. A limit value for health purposes for water from public and private sources has been set at 1.3 mg/l, since higher levels may cause stains on the teeth of young children (dental fluorosis).

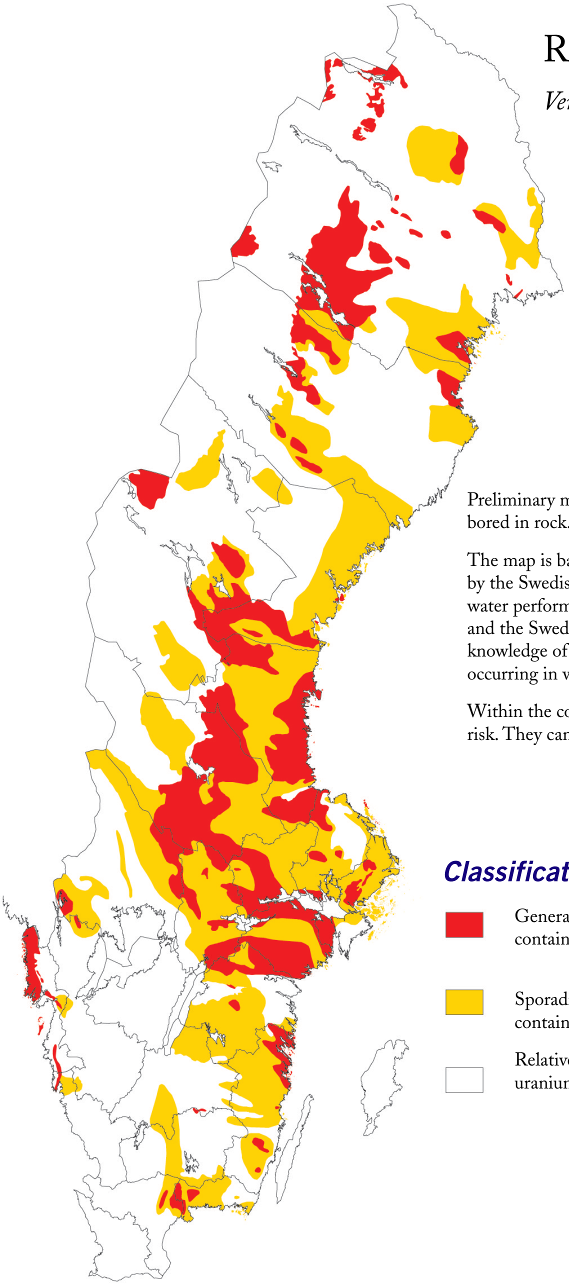
Radon

Radon occurs naturally in groundwater, mainly in that from wells bored in rock in areas of uranium-rich bedrock. Examples are uranium-rich syenites, vulcanites and pegmatites. Water with a radon concentration exceeding 1,000 Bq/l is classified as unfit for consumption in the statutes of the National Food Administration (SLV FS 1997:32). This water should not be used for drinking purposes or in connection with foodstuffs. A limit value for health purposes for water from public and private sources has been set at 100 Bq/l, since higher levels may pose a threat to the health of young children.



F (mg/l)	% of wells in soil (1,322 in total)	% of wells in rock (9,225 in total)
< 0.8	92	46
0.8–1.6	6	29
> 1.6	2	25
> 6.0	0.1	0.6
median	0.2 mg/l	0.8 mg/l

FIGURE 1. Fluoride concentrations in groundwater in wells bored in soil and wells bored in rock. The maps have been taken from Aastrup, M., Berntell, A., Bertills, U., Johnson, J. & Thunholm, B. (1995): Groundwater chemistry in Sweden – Swedish EPA Report 4416.



RADON IN WATER

Version 3. Revised June 1998.

Preliminary map of risk areas for radon in water from wells bored in rock.

The map is based on an aerial radiometric survey performed by the Swedish Geological Survey, monitoring of radon in water performed jointly by the Swedish Geological Survey and the Swedish Radiation Protection Institute, and current knowledge of bedrock where there is a particular risk of radon occurring in water.

Within the coloured areas there are also areas with low radon risk. They cannot be separately identified at this scale.

Classification

🟥 General risk of radon in water. Bedrock which fairly often contains uranium-rich granites, pegmatites and aplites.

🟨 Sporadic risk of radon in water. Bedrock which, in places, contains uranium-rich granites, pegmatites and aplites.

⬜ Relatively low risk of radon in water. Bedrock with a low uranium content.

FIGURE 2. Preliminary map of risk areas for radon in water from wells bored in rock. The map has been taken from Radon i vatten. Swedish Radiation Protection Institute information 98:03. Published in collaboration with the National Board of Housing, Building and Planning, the National Food Administration, the National Board of Health and Welfare and the Swedish Geological Survey.

Metal concentrations

The following charts show concentration ranges for some selected substances, pH-dependent metals and an illustration of the way corrosion affects metal concentrations.

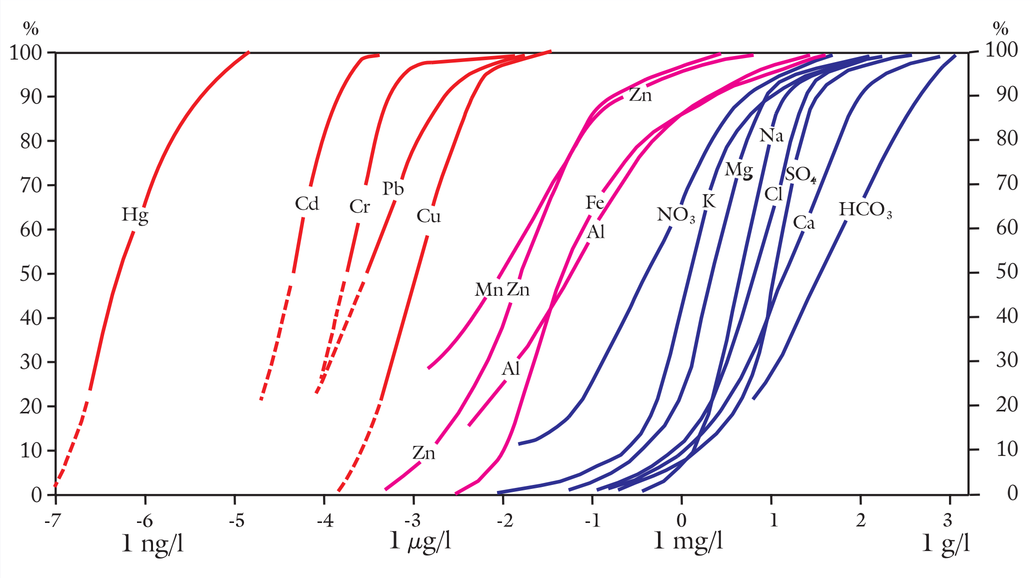


FIGURE 1. Concentration ranges for some heavy metals in groundwater before it has been affected by foreign matter. Comparisons with other chemical constituents (blue lines). Data from sites included in the Swedish Geological Survey's groundwater network and groundwater monitoring under the National Environmental Monitoring Programme. The graph has been taken from Aastrup, M., Berntell, A., Bertills, U., Johnson, J. & Thunholm, B. (1995): Groundwater chemistry in Sweden – Swedish EPA Report 4416.

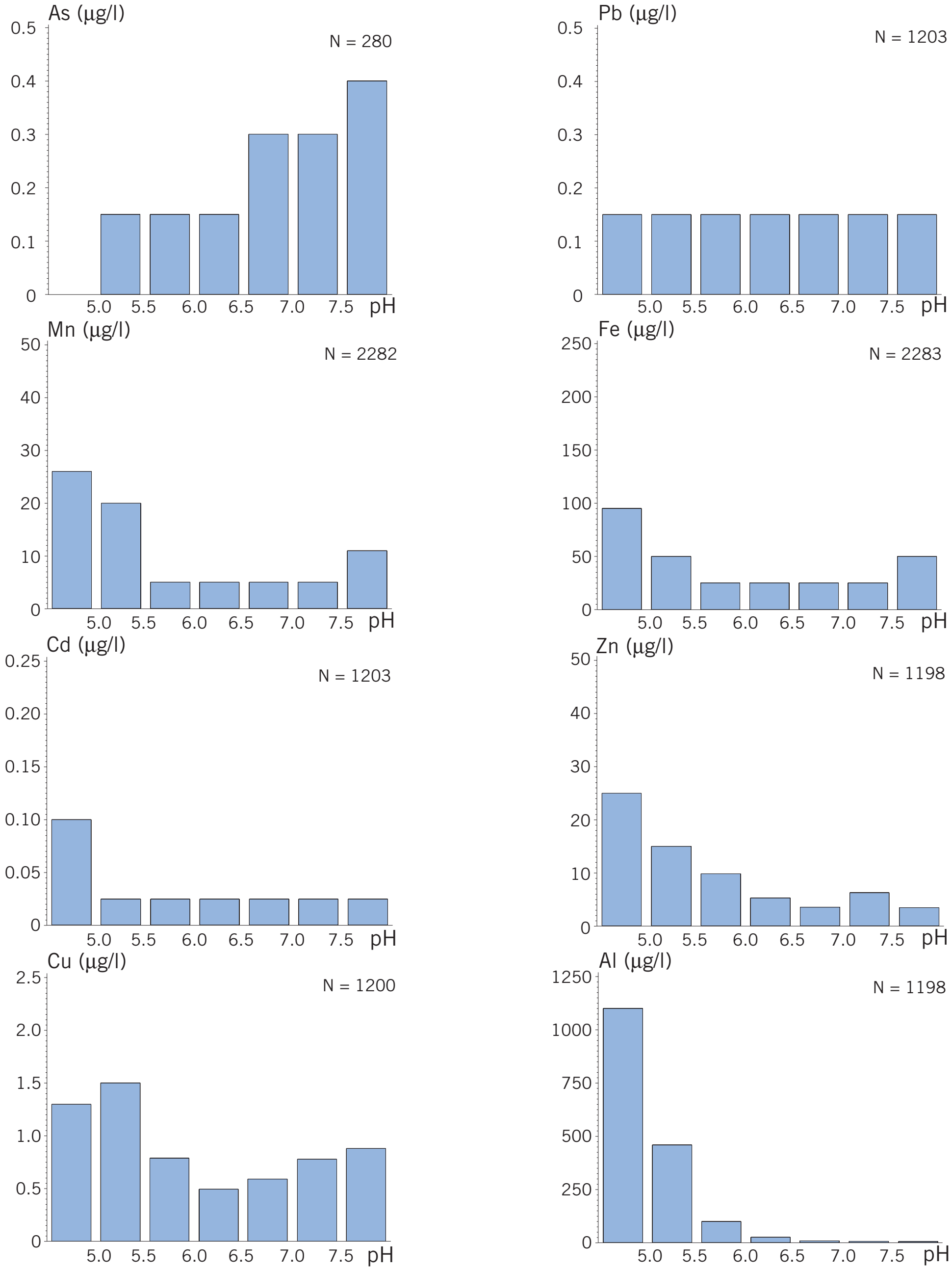


FIGURE 2. Median concentrations for various pH intervals. The median concentration of lead (Pb) does not exceed the analysis limit within any pH interval. Data from the Swedish Geological Survey's groundwater monitoring network and groundwater monitoring under the National Environmental Monitoring Programme. The charts have been taken from Aastrup, M., Berntell, A., Bertills, U., Johnson, J. & Thunholm, B. (1995): Groundwater chemistry in Sweden – Swedish Environmental Protection Agency Report 4416.

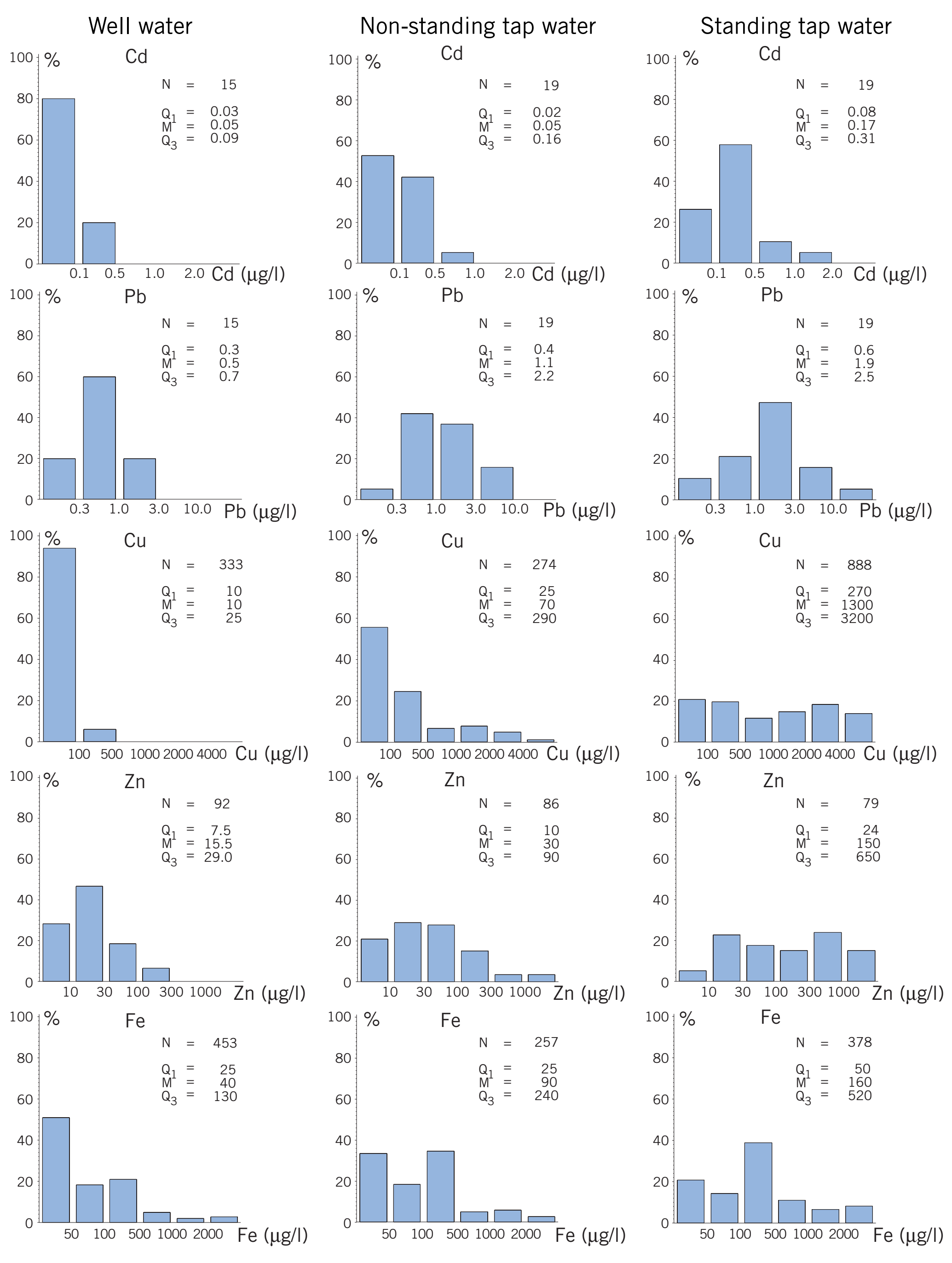


FIGURE 3. Metal concentrations rise as the water makes its way from well to tap as a result of corrosion of pipes, joints and pressure tanks. Very high concentrations may occur in water left standing in pipes. The charts show distributions of metals in well water, non-standing tap water and standing tap water. Data on cadmium (Cd) and lead (Pb) has been obtained from the project entitled "Tungmetallerna arsenik, bly och cadmium in brunns- och grundvatten" (The heavy metals arsenic, lead and cadmium in well and groundwater") and data on copper (Cu), zinc (Zn) and iron (Fe) from the acid well archives. The charts have been taken from Aastrup, M., Berntell, A., Bertills, U., Johnson, J. & Thunholm, B. (1995): Groundwate chemistry in Sweden – Swedish Environmental Protection Agency Report 4416.

National Food Administration guide and limit values for drinking water quality

National Food Administration guide and limit values for drinking water quality for the parameters included in this report.

Substances and unit	Guide value[1]	Limit value (h, a, t)[2]			Comments in the National Food Administration drinking water regulations (1993:35)
		Acceptable[3]		Unfit[4]	
		Public	Private		
Alkalinity (HCO$_3$) mg/l	60				Concentrations over 60 reduce the risk of corrosion in pipes etc.
		< 30 (t)			Risk of corrosion increases.
Arsenic (As) µg/l		10 (h)	10 (h)		May indicate impact from pollution source. However, in wells bored in rock the cause is usually natural (sulphide minerals).
				50 (h)	Possible risk of chronic health effects from long-term consumption. The water should not be used for drinking or in connection with foodstuffs.
Pesticides		Reg. conc. (h)	Reg. conc. (h)	Decided in each case	May be caused by leakage from treated crops, arable land etc or careless pesticide handling. The National Food Administration considers that pesticides should not present in detectable concentrations in drinking water. Further investigations should be made to confirm the presence of pesticides and trace their source. Verified presence of pesticides should be reported to the National Food Administration for assessment of health risks. They will confirm whether there is reason to limit use of the water for drinking purposes or in food.
Lead (Pb) µg/l				10 (h)	The reason is usually corrosion of materials containing lead in old properties, although the presence of lead may also indicate impact from industrial discharges, rubbish tips or the like. There is a risk of chronic health effects from long-term consumption, particularly among young children. The water should not be used for drinking or in connection with foodstuffs.
Iron (Fe) mg/l	0.05	0.1 (t)			Risk of sludge formation in the distribution system.
		0.2 (a,t)	0.5 (a,t)		Causes flocculation, discolouration and changes in taste. Risk of damage to textiles when used for washing and risk of pipe blockages. Nuisance may sometime occur at lower or higher levels than the limit value.

		1.0 (a,t)	1.0 (a,t)		Nuisance as above. Samples of standing water must be taken where it is suspected that pipes or equipment may be affecting water quality.
Cadmium (Cd) µg/l		1 (h)	1 (h)		The cause is usually corrosion of materials containing cadmium in old systems but cadmium in groundwater may also be an indication of acidification.
				5 (h)	Risk of chronic health effects from long-term consumption. The water should not be used for drinking or in connection with foodstuffs.
Chloride (Cl) mg/l		100 (t)	100 (t)		Indicates impact from relict salt water (formed during the ice age) or sea water. May accelerate corrosion.
		300 (a,t)	300 (a,t)		Risk of changes in taste.
Manganese (Mn) mg/l	0,02 (Public)	0.05 (a,t)	0.30 (a,t)		Manganese flocculates in water pipes, causing accretions which discolour the water (black) when dislodged. Risk of damage to textiles when used for washing.
Nitrate nitrogen (NO_3-N)	1	5 (t)	5 (t)		Indicates impact from sewage, fertiliser use and other sources of pollution.
mg/l		10 (h,t)	10 (h,t)		The following comment should always be made in the report: “This water should not be given to children under one year old, owing to the risk of methaemoglobinaemia (impaired absorption of oxygen by the blood)”.
Sulphate (SO_4)		100 (t)	100 (t)		May accelerate corrosion.
mg/l		200 (h,a,t)	200 (h,a,t)		Risk of changes in taste. May cause temporary diarrhoea in sensitive children.
Zinc (Zn) µg/l		300 (t)	300 (t)		Presence normally a result of corrosion of galvanised pipes.
		1000 (a,t)	1000 (a,t)		Risk of changes in taste and cloudiness. Samples of standing water must be taken where it is suspected that pipes or equipment may be affecting water quality.

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[1] Guide values should be seen as quality objectives; levels exceeding the guide value do not require comment and a demand for remedy. Where the guide value is the minimum concentration, this is pointed out in the comments.

[2] Unless otherwise stated, this assessment applies where a concentration is equal to, or higher than, the stated limit value. (h) = health reservations, (a) = aesthetic reservations, (t) = technical reservations.

[3] When water is considered to be acceptable, this means that the composition of the water is not entirely satisfactory but it is not considered to pose a risk to health. It cannot therefore be classified as unfit for drinking. This water can be consumed without restriction. However, for health reasons, elevated concentrations of nitrate may restrict use of the water by children.

[4] The limit value for unfitness in terms of chemicals and characteristics is always the same for public drinking water sources as for private.

Conversion table

mg/l	mg/l	meq/l	mmol/l
1 mg Na^+/l		0.043 meq/l	0.043 mmol/l
1 mg K^+/l		0.026 meq/l	0.026 mmol/l
1 mg Mg^{2+}/l		0.082 meq/l	0.041 mmol/l
1 mg Ca^{2+}/l		0.050 meq/l	0.025 mmol/l
1 mg NH_4^+-N/l	1.3 mg NH_4^+/l	0.071 meq/l	0.071 mmol/l
1 mg NO_3^--N/l	4.4 mg NO_3^-/l	0.071 meq/l	0.071 mmol/l
1 mg Cl^-/l		0.028 meq/l	0.028 mmol/l
1 mg HCO_3^-/l		0.016 meq/l	0.016 mmol/l
1 mg SO_4^{2-}-S/l	3.0 mg SO_4^{2-}/l	0.062 meq/l	0.031 mmol/l
1 mg PO_4^{2-}-P/l	3.1 mg PO_4^{2-}/l	0.065 meq/l	0.032 mmol/l

Glossary

Adsorption Binding of ions to particles of soil with electrically charged surfaces or binding of non-water soluble substances onto particle surfaces lacking an electrical charge

Anions Negatively charged ions. Most non-metals form anions

Aquifer Geological formation sufficiently permeable to allow groundwater to be abstracted in usable quantities

Base cations The replaceable ions Ca^{2+}, Mg^{2+}, K^+ och Na^+

Cations Positively charged ions. Metals usually form positively charged ions, although hydrogen and nitrogen are also capable of doing so

Chemical equilibrium A chemical reaction is in equilibrium when it has run its full course

Clay A soil in which the fraction having a grain size of less than 20 mm contains more than 15 per cent by weight of clay (<0.002 mm)

Cohesive soil A type of soil bound together by the power of attraction between molecules. Clay and mud are examples

Confined aquifer Aquifer overlain by a stratum impermeable or semi-impermeable to water. The groundwater is under pressure sufficient to raise the potentiometric surface ("water table" in popular parlance) higher than the upper surface of the aquifer and even above the water table in overlying surface aquifers

Geological strata sequence The order in which soil or rock strata have been laid down

Gravel Sediment in which the gravel fraction (2–60 mm) is the characteristic constituent and where the fraction having a grain size of less than 20 mm contains less than 15 per cent by weight of clay

Hydrolysis Distribution of a substance by reaction and accumulation of water

Infiltration Penetration by water of the ground surface in soil or rock

Inflow area Area of land where groundwater is formed by infiltrated precipitation or inflowing surface water

Ion exchange Exchange of ions between particle surfaces and a liquid

Metalloid Semi-metals (Ge, As, Sn, Sb, Te): elements possessing characteristics half way between those of metals and those of non-metals

Milliequivalent/l (meg/l) A measure of the concentration of ions, millimole charges per litre. Equivalent: the quantity of a substances, which in a given chemical reaction, is equivalent to a mole (SI unit of amount of substance) of a given other substance

Moraine Unsorted sediment transported and deposited by an ice sheet or glacier

Surface aquifer Aquifer in which the water table is in contact with the atmosphere, ie, not overlain by a stratum impermeable or semi-impermeable to water

Outflow area Area of land where the groundwater pressure is directed upwards

Percolation The passage of water (mainly vertically) from the soil surface through the unsaturated soil zone to the groundwater

Porosity The relationship between the volume of cavities and total volume

Pressure tank Pressurising equipment for water supply network for individual buildings or groups of buildings

Sand Sediment in which the sand-size fraction (0.06 - 2 mm) is the characteristic constituent and where the fraction having a grain size of less than 20 mm contains less than 15 per cent by weight of clay

Significant deviation Deviation that cannot be explained by coincidence alone

Silt Sediment in which the silt-size fraction (0.002–0.06 mm) is the characteristic constituent and where the fraction having a grain size of less than 20 mm contains less than 15 per cent by weight of clay

Surface water Lakes and watercourses

Tap water Water taken from a tap connected to a water supply network

Weathering Disintegration and transformation of rock and soil by chemical and mechanical processes

REPORT 5051

Environmental Quality Criteria

Groundwater

GROUNDWATER IS NOT as well protected as one might imagine. It is affected by pollutants in the ground, by acidification and eutrophication. A rise or fall in the water table can cause harmful effects. Groundwater quality can be interpreted and evaluated using the model criteria in this report.

The report is one of a series of six reports published by the Swedish Environmental Protection Agency under the heading ENVIRONMENTAL QUALITY CRITERIA. The reports are intended to be used by local and regional authorities, as well as other agencies, but also contain useful information for anyone with responsibility for, and an interest in, good environmental quality.

Reports available in English are:

	Report No.
• Lakes and Watercourses	5050
• Coasts and Seas	5052
• Contaminated Sites	5053

Abridged versions in English of all the six reports are available on the Agency's home page: www.environ.se (under the headline legislation/guidelines).

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