

Environmental Quality Criteria for Groundwater

SWEDISH ENVIRONMENTAL
PROTECTION AGENCY

Preface

The groundwater assessment criteria presented here are intended primarily to facilitate the evaluation of potability, i.e. the groundwater's suitability for drinking by humans.

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Summary

Groundwater characteristics can be influenced by a number of factors. The sharp rise in air pollution during the 20th century has impaired the ability of earth, and thereby of groundwater, to resist acidification. Another consequence has been increased levels of various metals in groundwater.

The agricultural sector's increased use of nitrate fertilisers, sewage system leaks, and the addition of nitrogen pollutants to land already saturated with nitrogen have led to increasing levels of nitrogen in groundwater. In some cases, pesticides may also find their way into groundwater.

Large-scale exploitation of groundwater can alter the characteristics of natural underground reservoirs (aquifers). This can result in the intrusion of salt water and increased levels of iron and manganese.

These threats to groundwater quality are reflected in the selection of assessment criteria presented here. Their most important function is to make it possible to interpret how various threats affect groundwater's potability, based on guidelines and threshold levels for drinking water established by the National Food Administration. Assessment criteria can also be useful in the evaluation of the extent to which metals in groundwater affect the flora and fauna of associated surface water.

The assessment criteria relate to water quality in discrete aquifers, as indicated by samples taken from drilled wells, springs and dug wells. It is important to keep in mind that the chemical and physical characteristics of groundwater vary in space and time. The interpretation of isolated samples must therefore be carried out with great caution.

In order to enable comparisons between aquifers with similar characteristics, they are classified according to type. This classification has been applied to the many thousands of well-water analyses carried out by the Geological Survey of Sweden (SGU). Using the typology, it is easier to determine whether or not an aquifer has been affected by human activity.

Further information is available in Environmental Quality Criteria – Groundwater, Report no. 5051 of the Swedish Environmental Protection Agency. The report describes the proper method for taking samples, and how to conduct independent analyses of groundwater which indicate the degree of pollution from nearby sources.

Alkalinity and Acidification in Groundwater

The assessment of groundwater's capacity to resist acidification is based on its alkalinity. The effects of pollution on groundwater can be assessed by comparing measured alkalinity with the atmospheric deposition of sulphates.

Background

All of Sweden has been exposed to acid precipitation containing compounds of sulphur and nitrogen. However, natural processes of mineral weathering protect groundwater from at least some of the air pollutants' acidifying effects. Aquifers containing minerals that readily break down have strong resistance to acidification, whereas minerals that do not readily decay result in soils with weaker resistance. Weathering processes result in the release of bicarbonate ions, and groundwater's ability to neutralise acid (i.e. its alkalinity) is largely determined by the level of bicarbonate.

In areas where acidification from air pollution has exceeded the neutralising capacity of weathering processes over a lengthy period, the alkalinity of groundwater is reduced. When the alkalinity declines to low levels, the pH will also begin to decline significantly. If groundwater becomes more acidic, concentrations of aluminium and heavy metals increase. When the water is used for drinking and other domestic purposes, those concentrations may increase further as a result of corrosion in the delivery system between water source and household tap. The risk of corrosion increases with the degree of acidity.

Assessment of current conditions

Class	Designation	Alkalinity		pH	Description
		mg/l	meq./l		
1	Very high alkalinity	> 180	> 3	> 6.5	Adequate to maintain acceptable pH level in the future
2	High alkalinity	60-80	1-3	> 6.0	
3	Moderate alkalinity	30-60	0.5-1.0	5.5-7.5	Inadequate to maintain stable, acceptable pH level in areas with heavy acid precipitation
4	Low alkalinity	10-30	0.2-0.5	5.0-6.0	Inadequate to maintain stable, acceptable pH level
5	Very low alkalinity	< 10	< 0.2	< 6.0	Unacceptable pH level under all circumstances

The National Food Administration's recommendation for drinking water is that alkalinity (i.e. the concentration of bicarbonate) should not be less than 60 mg/l (1 meq./l). In water supply systems, values under 30 mg/l (0.5 meq./l) imply a distinct risk of corrosion. Drinking water with such a low concentration of alkalinity is therefore regarded, on solid technical grounds, as potable with reservations.

Many wells in Sweden have water of such low alkalinity that it does not meet National Food Administration requirements. Such water often has a low pH value. In some cases, the water's acidity is a natural condition. Groundwater always has fairly high concentrations of carbonic acid which, in areas with low rates of mineral weathering, can lead to low-pH water in shallow wells. But water from wells drilled in bedrock usually have higher alkalinity than water from shallow dug wells.

Classification by aquifer type

The table below is based on analyses of ca. 23,000 wells included in a reference data base of the Geological Survey of Sweden (SGU). The wells are classified according to type, based on aquifer characteristics and region.

Aquifer type 1: Crystalline bedrock	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
B. South Sweden highlands	10	55	20	11	3
C. West and southeast coasts	23	59	11	5	2
D. Central Sweden sedimentary bedrock	72	24	4	1	0
E. Central Sweden lowlands	43	48	5	3	1
F. Limestone-influenced areas of Uppland region	83	16	1	0	0
G. Norrland coast	19	67	10	3	1
H. Sedimentary bedrock in Dalarna and Jämtland regions	44	51	5	0	0
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	7	62	18	12	1

Aquifer type 2: Sedimentary bedrock	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	91	8	1	0	0
D. Central Sweden sedimentary bedrock	73	24	2	1	0
H. Sedimentary bedrock in Dalarna and Jämtland regions	71	27	1	1	0

Aquifer type 3: Moraine & fluvial outwash	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	80	14	3	2	2
B. South Sweden highlands	3	12	27	44	14
C. West and southeast coasts	10	26	23	28	14
D. Central Sweden sedimentary bedrock	22	41	19	13	5
E. Central Sweden lowlands	10	31	24	25	9
F. Limestone-influenced areas of Uppland region	52	33	12	2	1
G. Norrland coast	2	14	24	41	19
H. Sedimentary bedrock in Dalarna and Jämtland regions	31	38	15	15	1
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	2	15	20	46	16

Aquifer type 4: Glacial meltwater deposits	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	49	26	17	3	6
B. South Sweden highlands	2	13	22	47	16
C. West and southeast coasts	3	12	19	53	13
D. Central Sweden sedimentary bedrock	31	25	31	10	2
E. Central Sweden depression	5	26	27	33	9
F. Limestone-influenced areas of Uppland region	58	21	21	0	0
G. Norrland coast	2	22	23	46	7
H. Sedimentary bedrock in Dalarna and Jämtland regions	23	23	31	23	0
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	2	11	27	52	9

Aquifer type 5: Enclosed aquifers	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	83	15	1	1	0
C. West and southeast coasts	20	37	20	17	7
D. Central Sweden sedimentary bedrock	18	48	27	3	3
E. Central Sweden lowlands	19	35	22	20	4
F. Limestone-influenced areas of Uppland region	80	20	0	0	0
G. Norrland coast	3	20	26	42	10
H. Sedimentary bedrock in Dalarna and Jämtland regions	55	38	2	5	0

*The highest coastline is the shoreline existing at the time when the land mass was pressed down to its lowest level under the weight of the last ice age glacier.

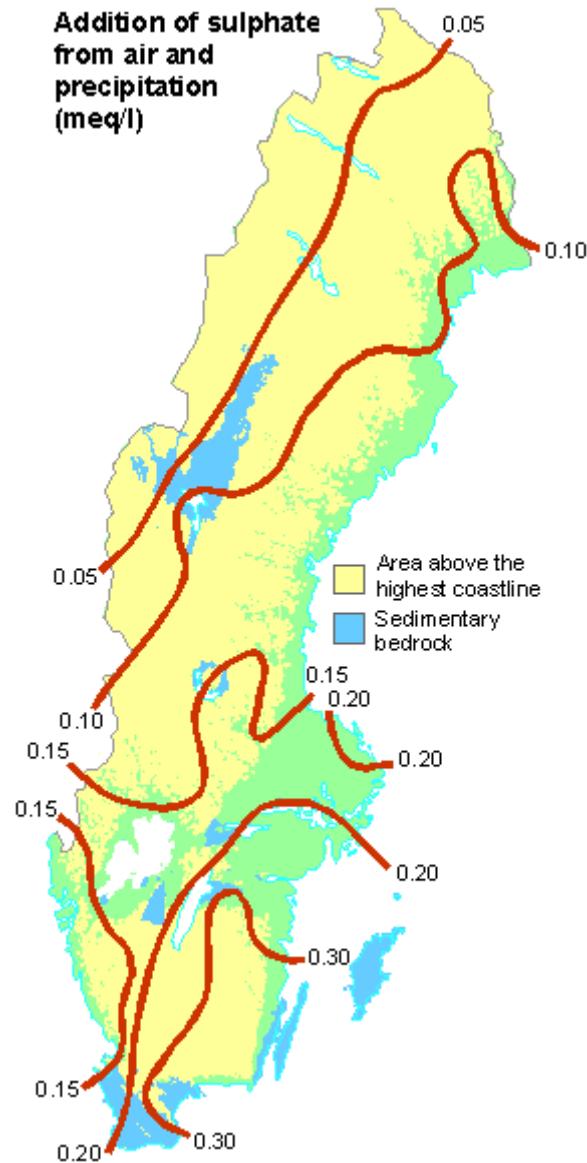
The risk of low alkalinity (classes 4 & 5) is greatest in open aquifers formed in moraines, fluvial outwash and glacial meltwater deposits (aquifer types 3 & 4), and in primeval bedrock (regions B, C, E, G & I). In exceptional cases, deep wells that are drilled in bedrock (aquifer type 1) in those regions may also have low alkalinity. Very low alkalinity is fairly unusual in well water, but can occur in groundwater very near the surface or in extreme cases of acidification.

In aquifers beneath sediments of clay or silt (type 5) concentrations of alkalinity are often high or very high, even in areas of primeval bedrock. The same is true of all aquifers in areas of sedimentary bedrock, and where surface layers contain some limestone (regions A, D, F & H).

Assessment of pollution effects

The effects of pollution on groundwater are calculated by comparing measured alkalinity with regional atmospheric deposits of sulphate resulting from human activity (i.e. "anthropogenic").

The map to the right shows the concentration (meq./l) of anthropogenic sulphate reaching the water table, based on data from different parts of the country for average annual sulphate deposition and the process of evapotranspiration which concentrates sulphate as it percolates to groundwater. There may be local deviations from the regional average for sulphate deposits and the associated infiltration to groundwater. Concentrations of sulphate in water percolating to groundwater are greater in forested areas, and less in open areas, than the average regional concentrations indicated on the map.



If both alkalinity and sulphate additions are calculated in meq./l (milliequivalents per litre), the effects on the acidity of groundwater can be directly compared. If atmospheric deposits of sulphate from precipitation have the effect of overcoming alkalinity, the groundwater is regarded as strongly affected by acidification.

Pollution effects are classified as follows:

Class	Effect	Alkalinity/sulphate infiltration* (meq./l)
1	Little or no effect	> 10
2	Moderate	10-5
3	Significant	5-2
4	Strong	2-1
5	Very strong	< 1

* Infiltration of anthropogenic sulphate is indicated on map, above.

In some cases, the measured concentrations of sulphate in groundwater deviate significantly from the levels that would result from atmospheric deposition.

If a measured sulphate concentration is much greater than the value expected from regional sulphate deposition, this could be the result of the oxidation of sulphide in soils and bedrock. Sulphide oxidation often occurs in areas of sedimentary bedrock, or in areas with clays and other types of soil containing organic matter. The process is a natural source of groundwater acidification. Intentional lowering of the water table, for example by draining forest land, can also lead to increased oxidation of sulphide.

If measured sulphate concentrations are much lower than those indicated on the map, it could be that the groundwater is so old that it has not yet been significantly affected by anthropogenic sulphur deposition. Another possible explanation is that sulphate may have been converted to sulphide through reduction (i.e. the reverse of oxidation). This occurs primarily in deep wells.

Very low alkalinity can also result from the addition of nitrogen compounds, which may add to the acidifying effects of the sulphate precipitation charted on the map. Thus far, the acidifying effects of nitrogen compounds on groundwater have been slight, in comparison with the effects of sulphate compounds. But in forest areas that have been subjected to heavy deposition of nitrogen compounds over a lengthy period of time, the contribution of nitrogen to groundwater acidification is more evident. Groundwater acidification can also result from fertilisation of farmland.

Nitrogen in Groundwater

Nitrate concentrations are used to assess the amount of nitrogen in groundwater. Increased levels of nitrate are usually the result of leaching from fertiliser stores, fertilised cropland and sewage systems. Such concentrations may also occur on nitrogen-saturated forest land.

Background

Natural concentrations of nitrates in groundwater are very low, since most of the nitrogen near the ground surface is taken up by plants before it can reach the water table. For the same reason, not even today's heavy deposition of airborne nitrogen compounds has had a significant effect on groundwater nitrogen. In cases of relatively high nitrogen levels in groundwater, it is usually the result of leaching from manure, cropland fertilisers, or sewage systems.

High levels of nitrogen compounds in groundwater limit its usefulness as drinking water due to the risk of negative effects on human health. In most cases, higher levels are also associated with increased transport of nitrogen from land to watercourses and seas.

In groundwater, nitrogen is usually present in the form of nitrate (NO₃), concentrations of which are at present higher than normal in many shallow wells. Under conditions of chemical reduction (class 4 in the table below), nitrite (NO₂) and ammonia (NH₄) can also be above normal, but their concentrations are usually low in comparison with those of nitrate. Here, the level of nitrogen in groundwater is calculated by measuring the amount of nitrogen in nitrate ions (NO₃-N)

Assessment of current conditions

Class	Nitrogen levels	NO ₃ -N (mg/l)	Description
1	Very low	< 0.5	Normal level for forest land
2	Low	0.5-1	
3	Moderate	1-5	
4	High	5-10	Not uncommon on farm land
5	Very high	> 10	

The National Food Administration guidelines for drinking water recommend that nitrate nitrogen concentrations not exceed 1 mg/l. Drinking water with levels above 5 mg/l is regarded as potable, with reservations. Concentrations above 10 mg/l are regarded as potentially unhealthy and subject to strong reservations. Such water should not be given to children under one year of age.

Classification by aquifer type

The table below is based on analyses of slightly over 11,000 wells included in a reference data base of the Geological Survey of Sweden (SGU). The wells are classified according to type, based on aquifer characteristics and region.

Aquifer type 1: Crystalline bedrock	Nitrogen Class				
	1	2	3	4	5
Region	Percent				
B. South Sweden highlands	67	6	19	5	2
C. West and southeast coasts	81	8	8	2	1
D. Central Sweden sedimentary bedrock	84	3	9	2	2
E. Central Sweden lowlands	80	6	11	2	1
F. Limestone-influenced areas of Uppland region	73	8	16	2	0
G. Norrland coast	89	4	6	1	0
H. Sedimentary bedrock in Dalarna and Jämtland regions	67	7	21	5	0
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	75	7	18	1	0

Aquifer type 2: Sedimentary bedrock	Nitrogen Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	76	8	11	3	2
D. Central Sweden sedimentary bedrock	86	2	7	2	2
H. Sedimentary bedrock in Dalarna and Jämtland regions	73	14	10	2	2

Aquifer type 3: Moraine and fluvial outwash	Nitrogen Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	28	7	31	10	24
B. South Sweden highlands	29	7	41	14	9
C. West and southeast coasts	65	6	17	9	3
D. Central Sweden sedimentary bedrock	43	4	35	13	4
E. Central Sweden lowlands	59	13	20	7	1
F. Limestone-influenced areas of Uppland region	36	15	43	6	0
G. Norrland coast	63	6	25	2	3
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	67	6	18	3	4

Aquifer type 4: Glacial meltwater deposits	Nitrogen Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	25	4	46	13	13
B. South Sweden highlands	40	10	32	13	4
C. West and southeast coasts	18	12	38	19	12
D. Central Sweden sedimentary bedrock	31	25	31	10	2
E. Central Sweden lowlands	67	8	19	5	1
F. Limestone-influenced areas of Uppland region	58	21	21	0	0
G. Norrland coast	59	4	37	0	0
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	71	4	21	4	0

Aquifer type 5: Enclosed aquifers	Nitrogen Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	36	4	22	9	29
C. West and southeast coasts	60	5	26	5	3
E. Central Sweden lowlands	52	11	24	8	5
F. Limestone-influenced areas of Uppland region	18	3	58	18	3
G. Norrland coast	53	13	22	10	3

*The highest coastline is the shoreline existing at the time when the land mass was pressed down to its lowest level under the weight of the last ice age glacier.

In wells drilled in bedrock (aquifer types 1 & 2), nitrate levels are usually low (classes 1 & 2). The biggest problems with nitrates occur in open aquifers in moraine, fluvial outwash, and glacial meltwater deposits (types 3 & 4). But nitrate levels are often high in aquifer type 5, as well, despite the filtering effects of clay and silt strata. This is primarily due to the fact that aquifer type 5 is usually associated with cropland, which is heavily affected by the extra nitrogen load.

Reference values

As a reference value for nitrate nitrogen, a concentration of 0.5 mg/l has been chosen. The natural level in groundwater does not exceed that amount, and concentrations above 0.5 mg/l can be regarded as a fairly certain indication of nitrogen leaching from farmland, nitrogen-saturated forest land and point sources.

The average nitrate nitrogen concentration in water that seeps down to the water table from the surface of cropland south of the River Dalälven has been calculated to 8 mg/l, while the corresponding value for forest land that is not saturated with nitrogen is usually less than 0.03 mg/l.

Deviations from reference value

Class	Extent of deviation	Measured level/ Reference value	NO ₃ -N (mg/l)
1	None or insignificant	< 1	< 0.5
2	Moderate	1-4	0.5-2
3	Significant	4-10	2-5
4	Large	10-20	5-10
5	Very large	> 20	> 10

The figures in the table indicate the extent to which measured concentrations of nitrate nitrogen differ from the reference value, which is the natural level.

Concentrations of nitrate nitrogen above 0.5 mg/l may be regarded as the result of some non-natural effect. In agricultural regions, groundwater with comparatively high levels of nitrate, phosphate (> 0.1 mg/l) and potassium (> 10 mg/l) is probably in such close contact with cropland that fertilisers have a fairly direct impact on water quality. But all three substances may also find their way into the water from sewage systems and waste sites. In most cases, groundwater affected by such sources of pollution also have increased levels of chloride.

Chloride (salt) in Groundwater

The salt content of groundwater is measured by reference to the level of chloride. Increased levels of chloride may result from the effects of natural phenomena or human activities, such as the intrusion of sea water.

Background

In areas that were not covered by seawater following the retreat of the last ice age's glaciers, the chloride level of groundwater is normally low. In areas below the highest coastline (abbreviated "HK" on accompanying maps), the groundwater may have been affected by salt water remaining from the time when the land surface was part of the sea floor. In areas near the coast, groundwater may even be affected by present-day seawater. Chloride levels may also be naturally higher than average in areas of sedimentary bedrock.

In built-up areas, leaching from road salt, waste sites and sewage systems may result in elevated chloride levels. Another source is corrosion in underground pipes, which, due to the effects on taste, may also limit the usefulness of groundwater for drinking purposes.

In many wells, measuring the water's electrical conductivity for sharp rises in salt content is a quick and simple indication of the potential. Conductivity is an index of the total number of ions in water, thus high conductivity usually indicates a high level of chloride (see table).

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

Where heightened conductivity is detected, a chloride analysis can be carried out.

Assessment of current conditions

Class	Level	Chloride (mg/l)	Description
1	Low	> 20	
2	Moderate	20-50	
3	Relatively high	50-100	
4	High	100-300	Risk of pipe corrosion
5	Very high	> 300	Risk of taste effects

According to the National Food Administration, chloride levels over 100 mg/l in drinking water indicate a risk of corrosion in transport pipes. If the level exceeds 300 mg/l, there is a risk of change in the taste of the water.

Classification by aquifer type

The table below is based on analyses of some 20,000 wells included in a reference database of the Geological Survey of Sweden (SGU). The wells are classified according to aquifer type, based on aquifer characteristics and region.

Aquifer type 1: Crystalline bedrock	Salt class				
	1	2	3	4	5
Region	Percent				
B. South Sweden highlands	72	24	4	0	0
C. West and southeast coasts	38	38	11	7	5
D. Central Sweden sedimentary bedrock	48	30	11	9	2
E. Central Sweden lowlands	61	23	7	6	3
F. Limestone-influenced areas of Uppland region	51	26	11	8	4
G. Norrland coast	73	14	5	5	2
H. Sedimentary bedrock in Dalarna and Jämtland regions	89	8	3	0	0
I Pre-Cambrian bedrock in Norrland above highest coastline*	93	5	2	0	0

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Aquifer type 2: Sedimentary bedrock	Salt class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	21	38	17	13	11
D. Central Sweden sedimentary bedrock	50	26	13	7	4
H. Sedimentary bedrock in Dalarna and Jämtland regions	83	11	5	1	0

Aquifer type 3: Moraine and fluvial outwash	Salt class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	35	51	6	6	2
B. South Sweden highlands	78	22	3	1	0
C. West and southeast coasts	45	43	10	2	0
D. Central Sweden sedimentary bedrock	75	21	4	0	0
E. Central Sweden lowlands	77	18	4	1	0
F. Limestone-influenced areas of Uppland region	67	19	5	4	4
G. Norrland coast	92	7	1	1	0
I. Pre-Cambrian bedrock in Norrland, above highest coastline*	94	5	1	0	0

Aquifer type 4: Glacial meltwater deposits	Salt class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	57	34	3	6	0
B. South Sweden highlands	74	23	2	1	0
C. West and southeast coasts	49	41	9	0	1
D. Central Sweden sedimentary bedrock	50	35	4	11	0
E. Central Sweden lowlands	72	24	3	1	0
F. Limestone-influenced areas of Uppland region	50	46	4	0	0
G. Norrland coast	85	13	1	1	0
I. Pre-Cambrian bedrock in Norrland, above highest coastline*	96	4	0	0	0

Aquifer type 5: Enclosed aquifers	Salt class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	19	51	14	13	4
C. West and southeast coasts	19	45	17	16	3
D. Central Sweden sedimentary bedrock	69	19	9	3	0
E. Central Sweden lowlands	63	26	8	2	1
F. Limestone-influenced areas of Uppland region	59	32	9	0	0
G. Norrland coast	92	6	2	0	0

*The highest coastline is the shoreline at the time when the land mass was pressed down to its lowest level under the weight of the last ice age glacier.

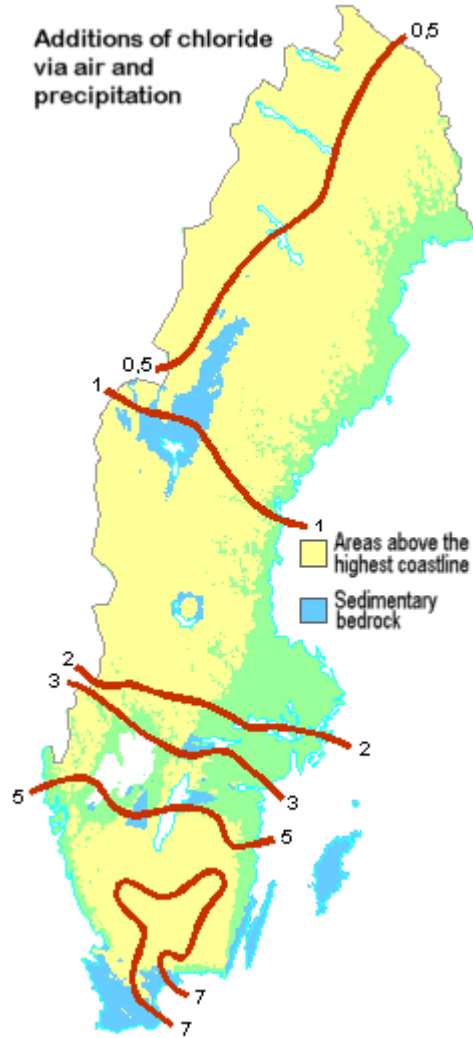
In areas that have been covered by seas in the past (regions C, D, E, F and parts of A & H), and most areas with sedimentary bedrock (regions A & D), the chloride levels of groundwater are often higher than normal. This is not the case, however, in Dalarna and Jämtland (region H). Instead, chloride levels are generally low in that region.

In areas near the coast, there may be some effects of seawater. There are also many wells below the highest coastline with relatively low levels of chloride, especially in coarse-grained soils. High chloride levels (classes 4 & 5) are somewhat more common in wells drilled in bedrock (aquifer types 1 & 2) and wells in valley-floor sediments than in other settings.

Reference values

Reference values are derived from estimates of groundwater's original natural characteristics. The reference values that have been chosen for chloride levels are 5 mg/l for groundwater in the regions of Norrland and Svealand (north and central Sweden), and 20 mg/l in the Götaland (south Sweden) region. These levels are seldom exceeded in aquifers that only receive chloride from precipitation.

The map to the right shows the additions of chloride that groundwater receives via the atmosphere, i.e. the anticipated chloride levels in wells with pristine water. Even for such wells, however, local conditions may vary from the indicated values by up to a factor of 2. Thus, groundwater in forest areas and near coastlines may have higher levels of chloride than those indicated on the map.



Deviations from reference values

Class	Extent of deviation	Chloride (mg/l)	
		Götaland	Svealand/ Norrland
1	None or insignificant	< 20	< 5
2	Moderate	20-50	5-50
3	Significant	50-100	50-100
4	Large	100-300	100-300
5	Very large	> 300	> 300

The deviation classes indicate the extent to which measured chloride levels differ from the pristine conditions on which the reference values are based.

Note that elevated levels of chloride can stem from both natural factors such as residual salt water from former times, or human activities such as the application of road salt. In most cases, it is relatively easy to demonstrate the affects of human activities in areas above the highest coastline. But it is more difficult at lower elevations, where natural levels of chloride can be relatively high and subject to wide variations.

In coastal areas, large-scale extraction of groundwater from wells located in sand, moraines, porous sedimentary rocks and highly fractured crystalline bedrock can result in the intrusion of salt water that affects groundwater quality, even at great distances from the shoreline. In other wells drilled in bedrock (aquifer type 1), however, the intrusion of salt water is unusual in wells located more than 100 metres from the shoreline. High levels of salt in wells drilled in archipelago bedrock are more frequently an effect of residual seawater from former times than of present-day salt water intrusions. But such problems can be aggravated if a well is too deep or the amount of water removed is too great.

The effects of present-day or residual ancient salt water can sometimes be detected if, in addition to high chloride levels, the relative proportions of chloride, sodium, calcium, magnesium and sulphate deviate from the corresponding values for pristine groundwater. In cases of salt water intrusion, levels of sulphate usually exceed additions to groundwater via the atmosphere. The same is true in groundwater that has received additional chloride from sedimentary bedrock.

As a result of ion exchange in the ground, however, the proportions of ions in groundwater that has been affected by salt water may differ from their proportions in unmixed salt water. In the same way, groundwater that has been affected by road salt may have a distribution of ions that deviates from that of the salt before it is applied to the road.

Increased levels of chloride stemming from sewage systems, waste sites or animal husbandry are often associated with increased levels of nitrate and ammonia.

Redox Conditions of Groundwater

The redox conditions of groundwater affect the concentration and solubility of many substances contained in it. This, in turn, affects the water's suitability for drinking

Background

Redox is the general term for the chemical reactions involved in the transfer of electrons. When a molecule is OXidized, it gives up electrons to another molecule which is thereby REDuced – hence the term "redox". Oxygenated (aerobic) water has a higher redox potential (Eh) than water devoid of oxygen (anaerobic). Redox potential is thus an index of water's capacity to support redox reactions.

For purposes of this discussion, the redox potential of groundwater is estimated by measuring and comparing levels of iron, manganese and sulphate. Those levels are affected by redox conditions in the water and, taken together, indicate redox potential.

The redox conditions of groundwater indicate whether or not certain kinds of problem can be anticipated when water is pumped from a well. A low redox potential indicates several risks, including: the release of hydrogen sulphide and methane; precipitates of iron (Fe) and manganese (Mn); and difficulty in reducing the water's concentration of those metals in soluble form.

Assessment of current conditions

Class	Designation	Fe (mg/l)	Mn (mg/l)	Sulphate (mg/l)		Description
				S (1)	N (2)	
1	High redox potential, aerobic water	< 0.1	< 0.5	> 5	> 2	Usually excellent groundwater which in most cases can be distributed without treatment. Good aeration leads to rapid breakdown of moderate levels of organic pollutants.
2	Moderately high redox potential, aerobic water	< 0.1	> 0.05	> 5	> 2	Occasionally necessary to aerate and filter out manganese.
3	Low redox potential, anaerobic water	> 0.1	> 0.05	> 5	> 2	Water has been at great depths, or been affected by reducing iron minerals for a lengthy period of time. Always requires treatment for high levels of iron, the most common problem of groundwater quality in Sweden.
4	Very low redox potential, anaerobic water	> 0.1	> 0.05	< 5	< 2	Very difficult to treat. Often contaminated by methane, odour of hydrogen sulphide, etc. Preferably, should not be used for drinking.
5	Mixed water Type 1	< 0.1	All	< 5	< 2	Water that leads to great technical problems. Often characterised by iron precipitates, sedimentation, odours and problems with bacteria.
	Mixed water Type 2	> 0.1	< 0.05	All values	All values	

S (1) – Southern Sweden, regions A–F (see Aquifer types)

N (2) – Northern Sweden, regions G–I (Note: Along the coast of Region G, there are areas of sulphide soil, where sulphate levels are significantly higher.)

Redox classes 1–4 in the above table relate to water in chemical balance. Class 5 relates to two types of water that are not in balance: Type 1 has low levels of both iron and sulphate; Type 2 has a high level of iron in combination with a low level of manganese.

Groundwater that has not yet developed a balance between various types of ion is in most cases a recently formed mixture of water with different origins and characteristics. The well or spring in question may, for example, be receiving infusions of water from various depths with differing redox conditions, or from sources that have been affected by human activity.

Classification by aquifer type

The table below is based on analyses of some 11,000 wells included in a reference data base of the Geological Survey of Sweden (SGU). The wells are classified according to type, based on aquifer characteristics and region.

Aquifer type 1: Crystalline bedrock	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
B. South Sweden highlands	23	19	37	4	16
C. West and southeast coasts	17	16	44	1	22
D. Central Sweden sedimentary bedrock	10	8	41	1	40
E. Central Sweden depression	14	13	33	3	37
F. Limestone-influenced areas of Uppland region	23	10	36	1	30
G. Norrland coast	18	9	43	5	25
H. Sedimentary bedrock in Dalarna and Jämtland regions	29	8	26	11	26
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	31	12	24	8	26

Aquifer type 2: Sedimentary bedrock	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	17	4	25	6	48
D. Central Sweden sedimentary bedrock	5	1	27	3	64
H. Sedimentary bedrock in Dalarna and Jämtland regions	38	10	24	1	26

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Aquifer type 3: Moraine & fluvial outwash	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	68	18	9	0	6
B. South Sweden highlands	51	9	17	0	23
C. West and southeast coasts	40	11	21	1	27
D. Central Sweden sedimentary bedrock	59	5	18	0	18
E. Central Sweden depression	35	5	17	2	42
F. Limestone-influenced areas of Uppland region	57	8	14	0	21
G. Norrland coast	51	2	11	0	26
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	48	5	11	2	34

Aquifer type 4: Glacial meltwater deposits	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	63	0	23	3	10
B. South Sweden highlands	48	10	19	0	23
C. West and southeast coasts	48	9	13	0	31
D. Central Sweden sedimentary bedrock	46	8	17	8	21
E. Central Sweden depression	44	2	17	2	35
F. Limestone-influenced areas of Uppland region	50	46	4	0	0
G. Norrland coast	46	2	19	3	30
I. Pre-Cambrian bedrock in Norrland, in areas above highest coastline*	49	3	16	1	31

Aquifer type 5: Enclosed aquifers	Alkalinity Class				
	1	2	3	4	5
Region	Percent				
A. South Sweden sedimentary bedrock	39	10	22	14	15
C. West and southeast coasts	26	17	29	0	29
E. Central Sweden depression	38	9	20	2	32
F. Limestone-influenced areas of Uppland region	87	6	6	0	0
G. Norrland coast	48	2	13	1	36

*The highest coastline is the shoreline existing at the time when the land mass was pressed down to its lowest level under the weight of the last ice age glacier.

Comments

Groundwater with low redox potential may not be suitable for drinking. Such water is most often found naturally in deep wells (aquifer types 1 & 2), but also in enclosed groundwater reservoirs (aquifer type 5). In areas near peat bogs, redox potential may also be low in other types of aquifers.

If repeated measurements indicate that the redox potential of a well has changed, the cause could be some sort of human impact. It is usually a question of activities that have affected groundwater currents or the local atmosphere. Examples include pavement of the land surface and waterlogging, both of which hinder the transfer of oxygen from the atmosphere and thereby lower the redox potential of the groundwater.

A shift from redox class 1 to class 2 (i.e. an increased level of manganese) often indicates infiltration from a shoreline. Along shorelines where groundwater has previously discharged, excessive removal of groundwater may have changed the direction of currents, with the result that surface water has begun to penetrate down into underlying strata.

Shifts from class 2 to 3, or from 3 to 4, may occur when a run-off area has begun to retain groundwater – for example, through the lowering of the water table by pumping or draining. Especially in peat bogs and other areas that are rich in organic material, such intrusions may lower the groundwater's redox potential, since additions of organic matter increase the absorption of the water's oxygen.

Additions of organic material may also have their sources in clear-cut forest areas, leaking sewage treatment facilities, or heavily fertilised cropland. Another possible cause of changes in redox potential is water extraction during periods of drought. On such occasions, stagnant groundwater may be pumped to the surface; this is water that has lain deep in the earth for a long time, with the result that iron levels are high but oxygen levels are very low or non-existent.

Shifts from classes 1–4 to class 5 indicate a mixture of water from a variety of sources. This usually results from changes in groundwater currents, either from natural causes or human activities such as draining and extraction of groundwater.

A shift from a higher to a lower class, i.e. in the direction of greater oxidation, may be due to additions of nitrate. But the same result may be produced by reductions in the contamination of groundwater by organic material.

Metals in Groundwater

Levels of cadmium, lead, zinc and arsenic in groundwater are often related to pollution or other human activities. Cadmium, lead and arsenic are dangerous to human health even in fairly low concentrations.

Background

Environmental assessment in this context is concerned with groundwater concentrations of cadmium, zinc, lead and arsenic, the levels of which are often increased by the effects of human activity.

Metals are spread via the atmosphere from smelters and other metal industrial plants. Significant increases in groundwater concentrations of metals from such sources may occur within a local radius of ca. ten kilometres; but their distribution through the atmosphere extends over far greater areas. Large quantities of lead have also been released into the atmosphere through the use of leaded petrol. Such releases have declined in recent years, but the greater portion of airborne lead pollution from previous years is still present in the surface layers of earth.

Metals have also entered land and water by more direct routes. In some areas, the use of cadmium-contaminated phosphate fertiliser has led to a doubling of cadmium levels in cropland during the past fifty years. Since zinc is often used for anti-corrosion purposes, it may enter the soil via galvanised steel products embedded in the ground.

Both arsenic and zinc are included in many wood preservatives, and can be spread via waste spill at impregnating facilities or via the wood products themselves. Waste sites are another source of zinc and arsenic, which may leach out from discarded materials that include those metals. Still greater quantities of polluting metals may leach from dumps of mining waste.

Naturally high levels of cadmium and arsenic can occur in areas where the bedrock contains high concentrations of metals; this applies to many types of shale and slate. Lowering the water table, for example by pumping out water, may lead to increases in the amounts of naturally-occurring metals that enter the groundwater. This is because metals in bedrock are often bound in sulphide minerals. The addition of oxygen results in oxidation of the sulphide compounds and the release of their metallic components. In some cases, however, arsenic may also be released as the result of a rise in the water table. It is with redox class 3 that the risk of water-soluble arsenic is greatest.

The solubility of cadmium and zinc increases significantly with a decline in pH value, which means that acidification can lead to increased levels of those metals in groundwater. Normally, lead is very tightly bound to humus and clay, but it may dissolve more readily if the pH value declines. In the case of arsenic, the reverse usually applies: Solubility increases concurrently with rising pH values.

Zinc is an element that is essential to life for most organisms, and humans can tolerate high concentrations. Aquatic organisms, on the other hand, are much more sensitive to zinc. Increased levels in groundwater indicate that concentrations of other metals may be above normal. This is especially true of cadmium, which is often present concurrently with zinc. In most cases, cadmium levels are, at most, one percent higher than those of zinc; but cadmium can be harmful even at such low concentrations.

Lead is another heavy metal which is toxic at low concentrations. If pregnant women are exposed to lead concentrations above medically-established threshold levels, there is an increased risk of birth defects. The toxicity of arsenic is comparatively moderate, but over longer periods of time it may produce changes in skin tissue, even at levels below medically-established thresholds.

Assessment of current conditions

Class	Level	Cadmium µg/l	Zinc µg/l	Lead µg/l	Arsenic µg/l
1	Very low	< 0.05	< 5	< 0.2	< 1
2	Low	0.05-0.1	5-20	0.2-1	1-5
3	Moderate	0.1-1	20-300	1-3	5-10
4	High	1-5	300-1000	3-10	10-50
5	Very high	> 5	> 1000	> 10	> 50

In several cases, the limits for the above five classes correspond with those of the National Food Administration's threshold levels (see table below). For all metals, the boundary between class 2 and class 3 is defined as the level at which effects on organisms in lakes and watercourses begin to occur (see Environmental Quality Criteria for Lakes and Watercourses).

Threshold levels for concentrations of metals in drinking water

Type of threshold level	Cadmium µg/l	Zinc µg/l	Lead µg/l	Arsenic µg/l
Warning based on technical grounds; survival of aquatic organisms is affected even with brief exposure		> 300		
Warning based on technical and aesthetic grounds; risk of taste changes and turbidity		> 1000		
Medically-established threshold; use with caution	> 1			> 10
Medically-established; unsuitable for drinking	> 5		> 10	> 50

Source: National Food Administration

Reference values

Reference values have been set so high that uncontaminated groundwater has low concentrations of metals in the majority of cases. Such water may, however, include pollutants that have travelled lengthy distances through the atmosphere.

Metal	Reference value µg/l
Cadmium	0.1
Zinc	100
Lead	1
Arsenic	1

Deviations from reference values

Class	Extent of deviation	Cadmium µg/l	Zinc µg/l	Lead µg/l	Arsenic µg/l
1	None or insignificant	< 0.1	< 100	< 1	< 1
2	Moderate	0.1-0.5	100-200	1-1.5	1-2
3	Significant	0.5-2	200-400	1.5-2.5	2-5
4	Large	2-5	400-700	2.5-5	5-10
5	Very large	> 5	> 700	> 5	> 10

The five classes indicate the extent to which measured levels of metals in groundwater deviate from the reference values, which are relatively unaffected by non-natural causes.

The upper limit of class 1, separating it from class 2, is the same as the reference value. The values of class 5 indicate the strong possibility of a local source of contamination. But in isolated cases, there may be another cause of the unusually high levels, for example: Class 5 levels of cadmium may occur naturally in extremely acid water (pH < 5); likewise, high arsenic levels occur naturally at a number of locations in the regions of Bergslagen and Skellefteå, as well as other parts of the country in certain deep-drilled wells with high levels of iron (redox class 3) and high pH values.

Pesticides in Groundwater

The spread of pesticides on farmland and other types of land involves a risk that such chemicals may find their way into the groundwater. The following section presents a basic procedure for the assessment of that risk, taking into consideration soil characteristics, application methods, etc.

Background

Large quantities of toxic chemicals are used in agriculture. The greater portion consists of pesticides for the control of weeds; but also widely applied are pesticides against moulds, insects and mites. In addition, there is a fairly extensive use of such chemicals in private gardens and commercial nurseries, as well as on golf courses, sporting arenas, the verges of roads and railways, and paved surfaces. The forest industry, on the other hand, accounts for only a small portion of the total amount of pesticides used in Sweden.

The pest-control chemicals used in agriculture are often based on organic compounds with limited solubility in water. Under certain conditions, they can move down from the soil surface to the groundwater. Once there, they can be further transported via underground currents, to wells and surface water located far from the place of application.

Chemical analysis of pesticides in water is expensive, and it is therefore necessary to concentrate sampling in areas with the highest risk of contamination. In order to assist in the setting of those priorities, a classification of the risks associated with various factors is outlined below. The classification applies to both farmland and other areas; it is also suitable for the evaluation of risks associated with both normal and exceptional levels of application.

According to European Community directives on drinking water, measures to deal with contamination must be taken if the concentration of any single pesticide exceeds 0.1 µg/l, or if the concentration of all such chemicals taken together exceeds 0.5 µg/l.

Classification of risks

The following classification of risk factors applies to areas in which pest-control chemicals are currently being used, or previously have been. The table lists those factors determined to have the greatest significance for the transport of pesticides into groundwater. The risks have been classified on a scale from 'a' to 'e', where 'a' represents the least, and 'e' the greatest risk.

Risk factors associated with the application of pesticides to agricultural land and other large areas*

Surface layer porosity	
Very limited (areas with > 3 m clay)	a
Limited (fine-grained strata of clay, silt, fine moraine soils, etc.)	c
Potentially high in the event of fast-flowing water (sandy and "light" soils, thin humus, and cracked clay < 2 m)	d
Potentially high in the event of fast-flowing water (gravel surfaces lacking vegetation in combination with humus levels of > 6%)	e
Humus levels in cropland of 0–30 cm depth	
> 6%	b
2-6%	c
< 2%	d
Acidity/alkalinity (pH value)	
Soils with pH > 7 (lime-rich soils). Refers only to applications of sulphonyl urea, whose persistence and/or solubility increases at pH > 7	d
Direction of flow	
Constant outflow from aquifer	a
Outflow from aquifer except under drought conditions, when water flows in	b
Other factors	
No application of pesticides during autumn or in connection with irrigation	b
Pesticides applied during autumn and/or in connection with irrigation	d
Spraying in the vicinity of wells – risk of direct contamination	e
Artificial infiltration by surface water containing pesticides	e

* Examples include forest land, golf courses, parks, churchyards, plant nurseries, fruit and berry farms, road and railway verges, industrial areas and gravel surfaces.

Risk factors associated with the spread of pesticides from a point source*

Use of equipment	
Filling and rinsing of sprayers, or other procedures involving a risk of spillage, are restricted to areas specially prepared for such purposes, so that liquids are hindered from entering the underlying soil layers	b
Filling and rinsing of sprayers, etc., are performed without measures to protect soil layers (< 3 m clay)	e

The following classification of various risks that groundwater in a given area will be contaminated by pesticides, is based on a summary of individual risk factors.

Class	Degree of risk	Summary of risk factors
1	None or insignificant	At least one risk factor is present in category 'a', but none in 'e'; or, no risk factor present in categories 'd' or 'e'
2	Moderate	All risk factors are present in categories 'b' and 'c'; or, only one factor present in category 'd', and the rest in 'b' or 'c'
3	Significant	At least one risk factor is present in category 'e'; or, at least two factors present in category 'd'

If a specific area has been placed in class 3 due to the risk of pesticides in groundwater, there is an associated risk that such chemicals may have spread into adjoining areas, including land on which they have never been used. In general, the total area of potentially contaminated groundwater does not extend beyond the aquifer's outflow boundary. Outside those limits, pesticides may instead be present in surface water.

Water Table

The height of the water table is subject to large natural variations, but in some places it is also influenced by human activities. The following discussion is intended to provide some guidance on how to distinguish between the two sources of variation.

Background

The water table may be altered by several types of human impact. This includes not only the removal of water, but also the regulation of watercourses and underground constructions such as tunnels. In urban areas, the formation of groundwater reserves may be hindered by the removal of surface water, and by paving the ground with asphalt, etc.

Lowering the water table may have a variety of consequences, including: depletion of the water supply; the intrusion of salt water into wells situated near coastlines or in areas with residual salt water from earlier times; acidification through oxidation of sulphur in areas where that element is abundant; ground-settling; draining of wetlands and associated changes to ecosystems; and elevated levels of iron and manganese in groundwater.

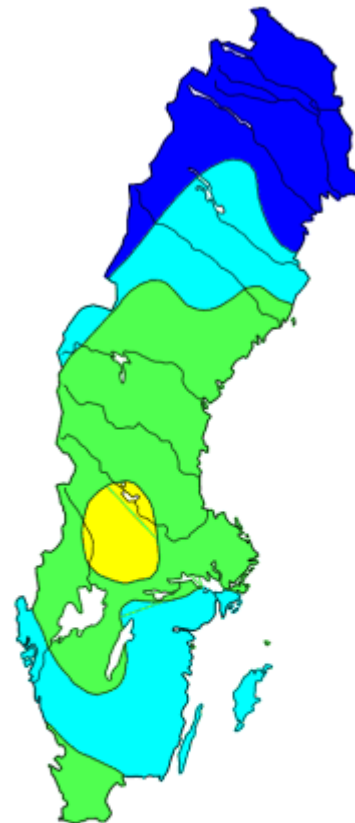
Raising the water table may result in higher levels of iron and manganese, increased risk of landslides, the saturation of previously dry land, and increased levels of organic matter in groundwater.

Assessment of current conditions

Due to the varying characteristics of earth layers and bedrock, the natural level of groundwater varies significantly from place to place in Sweden. There are also constant changes over time. This means that it is difficult to determine from isolated measurements whether or not the water table has been influenced by human activity.

Despite such difficulties, there are two sources of information that can assist in the cautious interpretation of isolated measurements. One is the Geological Survey of Sweden's (SGU) monthly chart of natural water table levels in different parts of the country. The example shown here is for June 1998.

There are two different types of chart - one for smaller aquifers (e.g. in moraines or bedrock), and the other type for larger aquifers (primarily in glacial melt-water deposits). In smaller aquifers, the water table's natural variation is usually 1–3 metres per year, while the level in larger aquifers usually changes by no more than a few decimetres. Each chart also indicates deviations from the annual average.



Water Table Levels



Water table level (SGU monthly survey)	Deviation from annual average (metres)
Far above normal	> 0.5
Above normal	0.2 – 0.5
Normal range	-0.2 – 0.2
Below normal	-0.5 – -0.2
Far below normal	< -0.5

This classification is used with SGU water table charts for smaller aquifers.

Further sources of information are the following diagrams showing natural water table variations during the course of a year. The diagram for "Northern Sweden" covers approximately two-thirds of the country's length. The one for "Southern Sweden" refers to the remaining third.

The curves of the diagram trace the average variation of water table levels in moraine aquifers at "normal topographical elevations". At higher elevations, the water table is usually lower than indicated by the curves; near lakes and on valley floors, it is usually higher than indicated. Variations in bedrock aquifers often correspond quite closely with those of moraine aquifers. However, the diagrams may not be used to interpret water table measurements of aquifers in glacial meltwater deposits.

