Groundwater quality and quantity in Europe

European Environment Agency

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Preface

This report presents the first Pan-European overview of groundwater quality and quantity. It has been produced by the European Topic Centre on Inland Waters (ETC/IW) on behalf of the European Environment Agency (EEA). The project was led by the Austrian Working Group on Water with the assistance of the Water Research Centre (UK), Geological Survey of Denmark and Greenland, International Office for Water (France) and the Centro de Estudios y Experimentación de Obras Públicas (CEDEX) (Spain).

An important element of the project was the collection of data by means of a questionnaire distributed to 44 European Countries through the EEA's National Focal Points, the Phare Topic Link and other components of the Environmental Information and Obsevation Network (EIONET). Data and information provided from 37 of these countries have been used in this report. Supplementary information from literature, reports (for example, national state of the environment reports and reports produced by, for example, Eurostat and the Food and Agriculture Organization), and the World Wide Web was also used when appropriate.

This report is also the source document for information on groundwater aspects used in *Europe's Environment: The Second Assessment* published by the European Environment Agency in June 1998. This overview report is accompanied by a Technical Report which the reader should refer to for details of the data used in the study. These are also supplemented by relevant data not necessarily used in the overview report but which may, nevertheless, be of interest to the reader.

The report aims to inform and provide information for policy and decision makers at both the national and European level. For example, it will aid the European Commission's review of progress made in implementing the 5th Environmental Action Programme "Towards Sustainability", and the Groundwater Action and Water Management Programme. It will also be of value to Non-Governmental Organisations and of general interest to informed members of the public.

At the time of preparation there was no harmonised European monitoring or information network through which comparable information could be obtained. Thus this report is based on the *best available information* and has been validated, where possible, through review by the EEA's National Focal Points. It is, however, important for the reader to bear in mind the context and limitations of the information presented.

For example, background information was requested on the type of sampling sites at which quality data was measured but it was not always clear whether they represented natural background situations, high contamination areas or gave a representative

view of quality for a particular aquifer. Thus some groundwater monitoring might concentrate on areas foreseen or used as drinking water resources, or it might concentrate on industrial areas with a high contamination risk. Comparison of results from different sampling points may, therefore, lead to wrong conclusions.

The problems mentioned above are of particular importance if information is compiled and compared at the European level as in this report. Different strategies are applied in different states, and as a consequence different aspects are investigated and even data concerning the same environmental aspect may often not be comparable. It is evident from the information reported that mapping and characterisation of groundwater systems, monitoring, and adequate reporting schemes are very important actions which must be implemented at the national and regional level.

Data aggregated at the country level may, therefore, *not fully reflect the actual national status* and *level of risk* to groundwater quality and quantity within a country. Pressures on groundwater depend on the local situation and vary widely in their intensity. Hence, spatial comparisons should be made on aggregated data on groundwater areas in the future.

However in spite of these limitations, the information network of the EEA and the EIONET, has been successfully used to collect information on groundwater quality and quantity on a pan European scale. The European-wide implementation of EUROWATERNET, the EEA's information and monitoring network for inland water resources, will improve the reporting of information on the state of groundwater and the pressures placed upon it.

Executive summary

Groundwater is a major source of drinking water all over Europe, and thus the state of groundwater in terms of quality and quantity is of vital importance. Furthermore, groundwater plays an important role within the environment – for some aquatic as well as for some terrestrial ecosystems. Human interventions in the hydrological cycle may have profound effects on groundwater quantity and quality. There is a need to identify the most important interventions in order to understand the inter-relationship between the intervention and the related adverse effects on groundwater aquifers. It is also important to investigate the underlying causes, and the extent of human interventions in the hydrological cycle for establishing appropriate planning and management measures.

This Environmental Assessment Report, prepared by the European Topic Centre on Inland Waters, provides an overview of important groundwater quality and quantity issues largely in the form of maps and other geographical applications. It is the first pan-European report based on measured groundwater quality data. The report is based on important groundwater quality indicators: nitrate, pesticides, chloride, alkalinity, pH-value and electrical conductivity. Emphasis is placed on nitrate and pesticides. Quantitative aspects include groundwater over-exploitation, saltwater intrusion and wetlands endangered by groundwater over-exploitation.

Evaluations and interpretations are mainly based on the responses from 37 countries to a questionnaire distributed to 44 countries within Europe. Supplementary information was found in literature and reports (e.g. national state of the environment reports and reports prepared by various organisations) as well as on the World Wide Web.

Pressures

Different indicators have been used to assess the pressures on groundwater quality and quantity related to, in particular, nitrate, pesticides, groundwater abstraction and human interventions in the hydrological cycle.

The application of nitrogen fertilisers is seen as a pressure on groundwater quality. Commercial nitrogen fertiliser use, and usage related to agricultural area, have been increasing in most Western European countries since 1992. Before then there had been an observed downward trend. Usage is expected, however, to decrease between 1997 and 2001. In some Eastern European countries the decline in fertiliser usage reversed in 1994/95, and the usage rate for Eastern Europe is expected to increase in the future. Nitrogen fertiliser usage per unit of agricultural area is highest in the northern part of Western Europe and Cyprus, and lowest in Eastern Europe.

Pesticides also have an impact on Europe's groundwater. Approximately 800 pesticide substances are approved for use in Europe. The application of pesticides in terms of the amount of active ingredients has decreased within the last decade. This does not necessarily indicate a decrease in environmental impact as new pesticide substances are more efficient than older products. In addition, some countries have limited the use of some pesticides to specific uses, or instigated complete bans on use. In Northern and Eastern European countries the usage rate is quite low.

Human interventions in the hydrological cycle potentially can have major impacts on groundwater. The importance of such interventions to groundwater was assessed by seeking the views of national experts across Europe. This survey indicated that the most important human interventions in order of importance were:

1. abstraction for public water supply;
2. abstraction for industrial purposes;
3. abstraction for agricultural purposes;
4. land drainage;
5. land sealing.

In some regions the extent of groundwater abstraction exceeds the recharge rate (over-exploitation). In Europe, the share of groundwater needed nationally to meet the total demand for freshwater ranges from 9% up to 100%. In the majority of countries, however, total annual groundwater abstraction has been decreasing since 1990. Abstraction is one of the causes of groundwater over-exploitation, saltwater intrusion and endangered wetlands. An aquifer's vulnerability to such degradation is to a large extent determined by geography and climate.

State of Europe's groundwater resources

The quality and quantity of Europe's fresh groundwater resources are impacted by, and in some cases are at risk from, numerous human activities. The Table below summarises the information on the state of Europe's groundwater at the regional or aquifer level.

The number of groundwater regions/areas where defined percentages of sampling sites exceed the given concentrations of selected determinands.

Determinand concentration (annual mean)	Total number of regions/areas	Number of groundwater regions/areas where			
		none	>0% to <25%	≥25% to <50%	≥50%
		of the sampling sites exceed the respective determinand concentration			
Nitrate					
>50 mg NO_3/l	96	20	64	7	5
>25 mg NO_3/l	96	9	37	37	13
Chloride					
>250 mg/l	89	45	37	2	5
>100 mg/l	89	29	39	11	10
pH-value					
≤ 5.5	87	70	13	3	1
≤ 6.5	87	52	26	3	6
> 8.5	87	65	20	2	0
Alkalinity					
≤ 1 mval/l	55	26	17	7	5
≤ 4 mval/l	55	5	19	5	26
electrical conductivity					
>2000 µS/cm	79	42	33	3	1
>1000 µS/cm	79	25	32	13	9

Nitrate is a significant problem as shown by information at the country level, the regional level, and information on ‘hot spots’. In Northern Europe (Iceland, Finland, Norway and Sweden) nitrate concentrations are quite low. At the country level, the Drinking Water Directive guide level of 25 mg NO_3/l is exceeded in untreated groundwater at more than 25% of the investigated sampling sites in eight of the 17 countries providing information. In the Republic of Moldova, about 35% of the investigated sampling sites exceed the maximum admissible Drinking Water Directive concentration of 50 mg NO_3/l. At the regional level, more than a quarter of the sampling sites exceed 50 mg NO_3/l in 13% of 96 reported regions or groundwater areas, and in about 52% of the regions more than a quarter of the sampling sites exceed the guide level of 25 mg NO_3/l. There are, however, some significant differences when comparing data at the country level with data at the regional level. In general, a direct relationship between the input of nitrogen and the measured values of nitrate in groundwater could not be found at the country level.

A few countries provided information concerning trends of nitrate in groundwater. Some of the data delivered indicate statistically significant trends, with evidence of both increasing and decreasing trends in a limited number of boreholes in some countries.

Information on the occurrence of pesticides in groundwater is rather limited. Suitable analytical methods are, if available at all, very costly and analytical capacities can often be limiting factors in some countries. Many different pesticide substances have been detected in Europe’s (untreated) groundwater at levels greater than the Drinking Water Directive maximum allowable concentration of 0.1 µg/l. Significant problems with pesticides in groundwater have been reported from Austria, Cyprus, Denmark, France, Hungary, the Republic of Moldova, Norway, Romania and the Slovak Republic. The most commonly found pesticides in groundwater appear to be atrazine, simazine and lindane. However, most of the data obtained does not allow a reliable assessment of trends to be made.

Groundwater areas with serious chloride problems are located in Cyprus, Denmark, Estonia, Germany, Greece, Latvia, the Republic of Moldova, the Netherlands, Poland, Portugal, Romania, Spain, Turkey and the United Kingdom. Most of these areas are located near the coast line, and saltwater intrusion is likely to be the main cause for the high chloride content in these groundwaters.

Acidification is indicated in groundwaters with a pH of ≤ 5.5. It commonly occurs in Northern European countries, especially in Denmark, Norway, Sweden, Finland, Belgium, the Netherlands, but also in Germany, France and the Czech Republic. Alkalinity in groundwater is a indication of the potential for, or risk of, acidification. Low alkalinity in groundwater is very common in Denmark, Norway, Sweden, Finland, the Netherlands, the Czech Republic, Germany, France and the Republic of Moldova, and certain groundwater areas and regions in these countries are highly vulnerable to acidification. Nearly all investigated sampling sites in Finland and Norway, and about two thirds in Sweden, are affected by low alkalinity.

Chlorinated hydrocarbons are widely distributed in groundwater aquifers of Western European countries, whereas hydrocarbons and especially mineral oils cause severe problems in Eastern European countries. ***Hydrocarbons*** were mentioned by nine, and chlorinated hydrocarbons by 10 of the 16 countries providing information, as important groundwater pollutants. Chlorinated hydrocarbons come from old landfills, contaminated industrial sites and industrial activities. Petrochemical activities, as well as military sites, are mainly responsible for groundwater pollution by hydrocarbons, and mostly cause local problems.

The pollution of groundwater by heavy metals has been reported to be a problem in 12 countries. Contamination with heavy metals is mostly caused by leaching from dumping sites, mining activities and industrial discharges.

Groundwater over-exploitation, defined as *groundwater abstraction exceeding the recharge and leading to a lowering of the groundwater table*, is a significant problem in many European countries. Eleven countries indicated over-exploited groundwater areas, and ten others state that groundwater over-exploitation does not occur. Groundwater over-exploitation appears to be more of a problem in Eastern Europe: five out of seven PHARE countries, and three out of eight EEA countries, reported groundwater over-exploitation. In 33 cases out of the 126 specified over-exploited areas, the result is endangered wetlands, whilst in 53 cases, saltwater intrusion is the consequence. The majority of the groundwater areas have been over-exploited since the 1980s. The main causes of groundwater over-exploitation are intensive water abstractions for public and industrial supply. Mining activities, irrigation, as well as naturally occurring dry periods, also cause lowering of groundwater tables.

Saltwater intrusion results in nine of the 11 countries where over-exploitation exists. In Latvia, the Republic of Moldova and Poland (16 groundwater areas), salt water intrusion occurs because of the rise of highly mineralised water from deeper aquifers. Eight countries listed 95 areas subject to intrusion by sea water. A large proportion of the Mediterranean coastline in Spain and Turkey has been reported to be affected by saltwater intrusion. Again the main cause is groundwater over-abstraction for public water supply.

Over-abstraction is one of several factors causing the disappearance of whole lengths of rivers, and the drying out of wetlands. Countries conferred endangered status on 210 of the 420 listed wetlands of international or national importance (in 11 of 16 countries): a total of 153 wetlands are considered not to be endangered: 11 endangered by groundwater over-exploitation, and 46 endangered for other reasons. In 16 countries, no wetlands are considered to be endangered by groundwater over-exploitation. Denmark and Hungary listed six and four wetlands respectively as being threatened by groundwater over-exploitation. The UK listed one wetland as being endangered but did not provide a location map. Overall, the information obtained is probably incomplete, and hence may not reflect the actual degree of threat or risk to wetlands.

Need for Europe-wide information. Decision makers at each administrative level require information about the main environmental threats, the quality of the environment, and the consequences of further policy development. As far as groundwater is concerned, the need for information on quality and quantity, as well as on trends, is substantial.

Many of the human pressures on groundwater are on a Europe-wide scale (e.g. pressures arising from the common agricultural policy, transboundary air pollution causing acidification, etc.), and thus some problems concerning groundwater quality and quantity can only be addressed and solved at the European level. In general, the larger the geographic unit affected by the decisions, the higher will be the degree of aggregation of the information required. In addition, the larger the geographical area, the more likely it is that the data basis is patchy and heterogeneous, especially if more then one country is involved. National monitoring systems are designed to provide information according to the domestic needs of the countries. As a consequence, different countries often apply different monitoring strategies or methods.

Reliability and comparability of the data: Background information was also requested on the type of sampling sites at which quality was measured, but it was not always clear whether the sites represented natural background situations, high contamination areas, or gave a representative view of quality for a particular aquifer. Thus some groundwater monitoring might concentrate on areas foreseen or used as drinking water resources, or might concentrate on industrial areas with a high contamination risk. Comparison of results from different sampling points may, therefore, lead to wrong conclusions. Thus it is important to provide some background information, and clear definitions of the purposes of groundwater wells should be established, in order to appropriately classify and compare wells.

The problems mentioned above are of particular importance if information is compiled and compared at the European level, as in this report. Different strategies are applied in different states, and as a consequence different aspects are investigated, and even data concerning the same environmental aspect may often not be comparable. It is evident from the information reported in this report that mapping and characterisation of groundwater systems, monitoring, and adequate reporting schemes are key actions which must be implemented at the national and regional level.

Data aggregated at the country level may, therefore, not fully reflect the actual national status, and the level of risk to groundwater quality and quantity within a country. Pressures on groundwater depend on the local situation and vary widely in their intensity. Hence, spatial comparisons should be made on aggregated data on groundwater areas in the future.

Only a few time series datasets for assessing changes over time were made available. In many countries monitoring programmes are still under development. It is proposed that special representative trend monitoring sites be established where continuous observation over a long period of time could be ensured. Harmonised statistical guidelines for calculating trends should also be developed in order to guarantee comparability. The information network of the EEA, the *Environmental Information and Observation Network* (EIONET), has been successfully used to collect information on groundwater quality and quantity on a pan European scale. The Europe-wide implementation of EUROWATERNET, the EEA's information and monitoring network for inland water resources, will improve the reporting of information on the state of groundwater and the pressures placed upon it. Collection of information is often time consuming because of the (often-decentralised) administrative structures in the different countries. Different monitoring strategies, developed to meet the specific needs of the countries, make it necessary to compile the data very carefully in order to obtain reliable information.

Policy responses

There are a number of current *European Community Directives* which address the management and protection of groundwater in the European Union. These include the Groundwater Directive (80/68/EEC) and the Nitrate Directive (91/676/EEC). In addition, the Registration Directive for Plant Protection Products (91/414/EEC) controls the use of substances that may adversely affect groundwater.

As with most other directives, the impact of the Nitrate Directive will depend upon the interpretation of requirements by Member States, especially in interpretation of 'vulnerable' since this will affect the extent of the territory designated and subject to mandatory requirements. In the Netherlands for example, the whole country has been designated as a nitrate sensitive area, an action plan has been developed and a Code of Good Agricultural Practice elaborated. At the other end of the spectrum, Ireland does not intend to designate any Nitrate Vulnerable Zones. In addition, the success of the Directive will depend upon the extent to which farmers co-operate since some of the rules will be difficult to enforce. In any case, the effects of the Directive will not be clear until after its implementation in 1999.

In November 1991, the participants at a Ministerial Seminar on groundwater held at the Hague noted that existing Community legislation was inadequate to protect this essential resource against many of the threats. They recognised the need for action in order to avoid long-term deterioration of fresh water quantity and quality, and called for the establishment of an action programme, aiming at the sustainable management and protection of fresh water resources, to be implemented by the year 2000 at the national and Community level

This led to a proposal for an *Action Programme for Integrated Groundwater Protection and Management* (GAP), (COM(96) 315 final), which requires action programmes to be implemented at the national and Community level. The GAP is an important step in the development of groundwater protection in Europe, but does not have statutory requirements. The more recent proposal for a Council Directive establishing a framework for Community action in the field of water policy (COM (97) 49 final) *(Framework Water Directive)* includes some elements of the GAP in a legally binding form, but further negotiations are required between Member States before the proposal is both adopted and implemented. The strategy of water management within catchment areas and the development of action plans, will be an adequate instrument for improving groundwater protection in the future.

Of the 24 countries that provided details of their national policies on groundwater, 20 have indicated that they have national strategies or plans for the management of groundwater quality and 19 also include quantity issues. To this end, 10 countries have established special groundwater protection zones, and 14 have strategies for the restoration of polluted groundwater. A finding that appears to be consistent with other studies undertaken by the ETC/IW is the lack of national groundwater monitoring networks, with only ten countries having national networks for quality, and seven for quantity. Seven countries report to have implemented good agricultural practice (aimed at improving or safeguarding groundwater) but only five report restrictions on the use of fertiliser, or on the use of financial instruments for control of the agricultural sector. Five countries also use financial instruments, and four have licensing/authorisations for the control and management of groundwater abstractions. Thus it would appear from the available information that, although most of the respondent countries do have strategies to manage groundwater, it is not clear whether, or what, measures have been taken to safeguard groundwater resources. Many countries also need to develop monitoring and information systems which will enable them to judge the success or otherwise of their strategies and measures.

1. Introduction

1.1 Background

The European Topic Centre on Inland Waters (ETC/IW) has prepared this environmental assessment report on groundwater quality and quantity on behalf of the European Environment Agency (EEA). The report also provides the basis for the groundwater chapter of the updated review of *Europe's Environment: the Second Assessment* (EEA, 1998), and for the groundwater aspects of the *State of the Environment of the European Union* report, to be published in 1999. It will also aid the European Commission's review of the progress made in implementing the 5th Environmental Action Programme 'Towards Sustainability'.

The report provides overviews (largely in the form of maps and other geographical applications) of groundwater status, using key quality indicators such as nitrate, pesticides, chloride, pH, alkalinity and electrical conductivity. Indicators used for the evaluation of groundwater quantity issues include identification of areas with groundwater over-exploitation, saltwater intrusion, and wetlands endangered by groundwater over-exploitation. Important human interventions in the hydrological cycle are also considered. The report follows where possible the DPSIR framework for Integrated Environmental Assessment: Driving forces, Pressures, Status, Impacts and Responses. The task of preparing this report within the ETC/IW was the responsibility of the Austrian Working Group on Water (AWW). Significant contributions have been made by other partners of the ETC/IW: Water Research Centre, (UK), CEDEX (Centro de Estudios y Experimentación de Obras Públicas, Spain), GEUS (Geological Survey of Denmark and Greenland) and IOW (International Office for Water, France).

The detailed data and basic information, on which the analyses and assessments in this report are based, are given in a Technical Report (EEA, 1999).

1.2 Characteristics of groundwater in the EEA area

A brief general description of the characteristics of groundwater for most of the EEA member countries is given in Box 1.1. The information was taken from EEA Topic Report 14/1996 (*Groundwater Monitoring in Europe*) (EEA, 1997).

Box 1.1
Characteristics of groundwater in EEA member countries

Austria
The Austrian groundwater areas cover nearly one third of the national territory. Groundwater in karst areas, 15,000 km^2 in extent (18% of national territory), and groundwater in porous media, 10,000 km^2 in extent (12% of national territory), form the most important groundwater resources of Austria.
In addition, there is single productive crevice groundwater in the Central Alps, Bohemian Chain and in the borderland of the alpine region, and some larger areas with artesian and deep groundwater in Upper and Lower Austria, Burgenland, Styria and in alpine valleys.

Denmark
Danish groundwater resources are mainly situated in porous media. All regions combined have an area of 43,216 km^2 i.e. 99.9% of the national Danish territory. The resources in porous media can be divided in quaternary sand and gravel deposit areas, in Miocene sand and gravel deposit areas and in chalk deposits.

Finland
The geologic formation of Finland is a Precambrian crystalline bedrock, which is covered with thin layers of quaternary deposits. Precambrian bedrock is solid material, which allows only low water movements and small water quantity. There is no karst groundwater because of the lack of calcium minerals in the crystalline bedrock. Groundwater in porous media consists of glacifluvial aquifers (eskers and other gravel and sand formations). The other aquifers consist of small till and silt aquifers.

France
Three types of groundwater region can be distinguished. Experts estimate that 30% of these regions are situated in porous media, <10% in karst media and about 60% in other media.

Greece
The groundwater potential in Greece is around 10,300 mio m^3/year, whilst 7,400 mio m^3/year is karst groundwater. Spring water is considered as surface water and is, therefore, not included in the groundwater potential.

Iceland
Groundwater resources are situated in two main areas. In the late Quaternary hyaloclastites and basaltic lavas there are 40,000 km^2 highly permeable and deep aquifers, an area that represents 35% of the national area. The other aquifers are more superficial with low permeability, and lie in tertiary and early quaternary basaltic lavas. The extent of these aquifers is about 60,000 km^2 – about 45% of the national area.

Ireland
The total area of the Republic of Ireland is around 70,000 km^2. The geological structure of Ireland consists of Precambrian schists and quarzites, Devonian sandstone, Carboniferous limestone and some more smaller formations. The only widespread aquifers with intergranular permeability are in the quaternary deposits. Irish aquifers are relatively shallow and often small in their lateral extent. In the western parts of the country there are karst aquifers. In Ireland the total aquifer is estimated to be of the order of 18,870 km^2. It has not been possible to give a detailed breakdown by type.

Italy
It has been estimated that more than 50% of groundwater resources are in porous media, 157,244.86 km^2 in extent. Groundwater aquifers in karst media extend over 50,615.11 km^2 (i.e. 16.76% of national territory) and finally there are smaller groundwater resources in volcanic rock media with an area of 13,488.78 (i.e. 4.46% of national territory).

The Netherlands
The Netherlands is a densely populated country covering an area of 38,000 km^2. It is heavily industrialised and the agricultural use of soils is one of the most intense in the world. Because of the wide use of land there are great problems of groundwater pollution over large areas, especially sandy regions, covering about 42% of the whole country. In more than 90% the country groundwater level is less than 4 m below the surface level. Only in the central hills formed by glaciers can a deeper level be measured.

Norway
In Norway there are two main types of aquifer: bedrock without primary porosity but with secondary passages such as joints, and other fractured or Quaternary superficial deposits with primary porosity. Bedrock aquifers: with the exception of the upper Permian aeolian sandstone in Brumunddal and

some Permian volcanic rocks, all Norwegian bedrock types lack primary porosity and are non-permeable on a small scale. The presence of groundwater is restricted to joints formed by tectonic fracturing, and to a lesser extent, to open fractures and voids formed by dissolution of limestone and vein and void minerals, usually calcite. The abundance of water bearing fractures and the frequency of open joints (fissures) are strongly controlled by rock type (competency), thickness and type, and orientation of paleo stress and recent stress. These factors also control the actual fracture pattern and strongly influence topography.

Quaternary aquifers: The Quaternary deposits represent a very good aquifer in ice-margin deltas and in glacio-fluvial valley fills. Wells can produce water quantities in the order of ten to a hundred times higher than bedrock wells. Several cities, towns and other rural sites, as well as industrial enterprises use good water from aquifers in Quaternary deposits. The groundwater in fluvial aquifers in the valleys is infiltrated from rivers and is of good quality, with groundwater characteristics and stable temperature. The deposits can be regarded as large natural filters. The yield of wells in such aquifers may sometimes give about 100 l/s.

Portugal

In Portugal the main aquifer systems are in porous media and karst. The area of porous media covers 26,000 km^2 (i.e. 29.4% of national territory), karst groundwater comprises an area of 5,500 km^2 (i.e. 6.2% of national territory). The aquifer systems are located in meridional and occidental Mesocenozoic border and tiercearies basin of Tejo and Sado. The average productivity is between 10 and 30 l/s per well. Almost 40% of these aquifers have a productivity of more than 30 l/s. In general the unconfined aquifers have a higher or moderate vulnerability. Some other aquifers are located in residual soils of ancient rocks, e.g. igneous or metamorphic formations, which are important local resources. The productivity of these aquifers is less than 3 l/s and is related to the periodicity of wet and dry periods.

Spain

More than one third of Spanish territory contains groundwater aquifers. Groundwater in porous media covers an area of 79,258 km^2 (16% of the whole country), karst groundwater is spread over an area of 54,628 km^2 (11% of the whole country) and other groundwater resources can be found in an area of 38,644 km^2 (8% of the whole country).

Sweden

The main aquifers are found in glacifluvial sand and gravel deposits. They cover only a few areas of Swedish territory, although more than three-quarters of the Swedish population is supplied with drinking water from these resources. Till, another porous aquifer, covers 75% of the country. Occasionally good yields can be achieved from these deposits, but wells in this area are mainly for single household supply. Aquifers in porous sedimentary rock are found in southernmost Sweden. They are very small regions compared to the total area of Sweden. Karst groundwater is rare in Sweden. Aquifers in the Archaean bedrock area have the largest areal extent of all aquifers. They can be found all over the country. Wells drilled in these rock types seldom yield more than 1 l/s, and are mainly for private water supply for single households.

UK – England and Wales

The three most important aquifers are the Chalk, the Sherwood Sandstone and the Jurassic Limestones, which are consolidated, indurated sedimentary formations with dual porosity. The smaller aquifers have similar characteristics. They are formations in which groundwater flow has varying combinations of matrix and fractured flow components producing complex aquifers. These characteristics make representative sampling difficult. Another aspect is that smaller, but important, groundwater bodies are situated in consolidated sedimentary aquifers which are often heavily exploited.

1.3 Collection of information

A questionnaire, distributed through the EEA's EIONET/National Focal Point network, was used to obtain available information from 44 European countries including EEA member countries, and the Phare and Tacis countries. The questionnaires were distributed in December 1996 with a deadline of 3 months to respond. A record of the replies received is given in the technical report (EEA, 1999). The questionnaire was structured as follows:

1. General data on pesticide usage/sales;
2. Nitrate monitoring data;
3. Pesticide monitoring data;
4. Monitoring data on chloride, pH-value, alkalinity and electrical conductivity;
5. Other relevant sources of pollution;
6. Quantity data on inland water/groundwater;
7. Areas with groundwater over-exploitation – average long term;
8. Wetlands and wetlands endangered due to groundwater over-exploitation;
9. Most important human interventions;
10. National strategies to improve groundwater quality and quantity.

The evaluations and interpretations in this report are mainly based on this source of information. However, supplementary data were located in reviews of literature and reports (e.g. national State of the Environment reports and reports prepared by international organisations) as well as on the World Wide Web. As it is very difficult – or even impossible – to compare groundwater quality data from different types of aquifers, attention mainly focused on groundwater in porous media.

2. Driving forces

The underlying causes and origins of pressures on the environment including groundwater, the so called driving forces, are human activities that can be described in terms of the main socio-economic sectors.

Groundwater comes from rain. The average annual precipitation in Europe varies from less than 500 mm in the Spanish interior to more than 3000 mm in the western part of Britain, Ireland and Norway. Photo: Peter Warna-Moors/Geological Survey of Denmark and Greenland.

2.1 Climate and natural processes

Climatic factors (e.g. quantity, frequency and intensity of precipitation, and temperature) influence the hydrological cycle, and hence groundwater quantity and quality. Natural processes like evapotranspiration, soil moisture, natural erosion and decomposition, as well as land use, agricultural practice, and human interventions in the hydrological cycle, influence water supply on the one hand, and the input of organic and inorganic substances into the groundwater body on the other.

Climate changes (such as global warming) influenced by various factors (e.g. industrialisation, transport) will lead to land and soil degradation, changes in vegetation structure and biodiversity, more frequent floods, rising sea levels, increasing aridity, higher evapotranspiration and further changes in land use. These modifications have a direct effect on both groundwater quality and quantity.

2.2 Urbanisation

Over the last 30 years there has been a general trend towards urbanisation in Europe. The proportion of rural and agricultural population is still decreasing, whereas the proportion of urban and non-agricultural population is increasing (FAOSTAT, 1997). More than two thirds of Europe's population lives in urban areas and the rate of urbanisation is, in particular, increasing in Central and Eastern Europe, while in Western Europe the rate has stabilised.

In Western Europe, the number of households is generally growing with the average household sizes decreasing due to smaller family units. Single member households are relatively common in North-Western Europe. In Eastern Europe, household size is still increasing due to the lack of suitable housing, but there is a potential for this trend to reverse in the future (EEA, 1998). There is also a reverse process to urbanisation (though not on the same scale) where the number of households is increasing in many rural areas, with wealthier citizens purchasing second homes.

2.3 Tourism

Tourism affects, and is affected by, the environment. Over the last 30 to 40 years tourism has shown an upward trend which is expected to continue.
The coastal zones of the Mediterranean region, and often extremely sensitive mountain areas, represent important tourist destinations where water supply is rather scarce. Tourism causes very high pressures on groundwater, especially because of the additional water demand arising during the seasons when the groundwater situation may be already rather critical. In addition, waste and sewage from this sector represents another potential source of groundwater pollution.

2.4 Industry

Manufacturing and the service industries have high demands for cooling water, processing water and water for cleaning purposes. Quantities consumed strongly depend on the respective industrial sector and its activities, and can often be extremely high. In general, industrial water demand in Europe accounts for just over half of total water abstractions. It is mainly surface water, and to a lesser extent, groundwater, that is used to meet industrial water demand (ETC/IW, 1999a). The increasing concentration of industry in certain areas causes high local pressures on groundwater. Groundwater pollution occurs when used water is returned to the hydrological cycle. Mostly it is polluted with potentially toxic inorganic and organic substances (e.g. organic matter, metals, chlorinated hydrocarbons, nutrients) which enter groundwater via recharge through surface water. Also, the disposal or dumping of sludge and waste, and inadequate containment of old industrial sites, may lead to a leaching of pollutants into the groundwater. Accidents during production and transport represent an additional hazard to groundwater.

Further pollution arises from emissions to air, mainly from the combustion of fossil fuels which initiate a process known as acidification. Also the different activities themselves (e.g. mining, gravel mining and quarries) have the potential to produce significant quantitative and qualitative impacts on groundwater.

2.5 Agriculture

Agriculture is often a significant source of widespread contamination of surface and groundwaters with nitrates, although local contamination from municipal and industrial sources can also be important. Historically the primary aim of agriculture was to provide food for the farmer’s own family, followed by the supply of food and raw materials to other people.

During and after the Second World War, government control measures required modernisation and intensification of agricultural production. The Common Agricultural Policy (CAP) has been a main driving force for the increase in agricultural production in the EU over the past three decades. The intensification of agriculture, and the subsequent use of agricultural inputs (fertilisers, feed concentrates, and plant protection products), increased in response to the price support. CAP also provided incentives to consolidate farm structures which led to extensive changes in the landscape (larger fields, fewer hedges and walls), as well as pressures on semi-natural habitats (clearance of scrub and forests, ploughing of permanent pastures and draining of wet meadows and bogs). As well as intensification of farming practices, there was also specialisation of agriculture (e.g. emphasis on mono-cultures). The subsequent deterioration of the environment is one of the main concerns of the general public. Awareness of the environmental problems arising from farming practices has increased over the last decades. This, together with increased trade distortions, surplus production and unbalanced distribution of farm income, has resulted in a move towards less intensive production methods. The growth in “organic farming” is tangible evidence of this reaction. The reform of the CAP in 1992 recognised the need for “contributing to an environmentally sustainable form of agricultural production and food quality, and formalising the dual role of farmers as food producers and guardians of the countryside” (Amtsblatt der Europäischen Gemeinschaften, 93/C 138/01, 1993). However, the legacy of the intensification of the post-war years is still with us, and it is widely predicted that groundwaters will continue to be contaminated with nitrate for several decades.

3. Pressures on groundwater quality

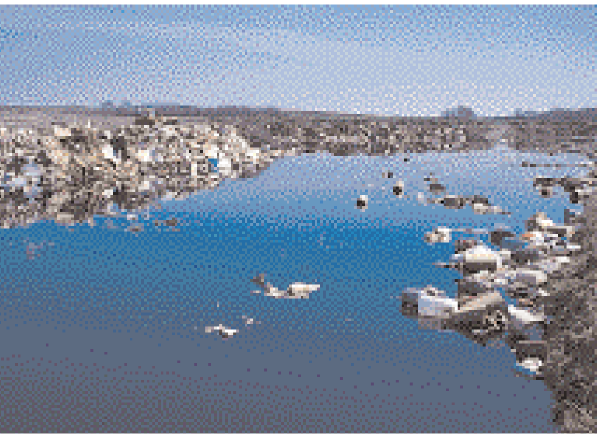
3.1 Introduction

Pressures are the "agents" which potentially stress the environment. There are three main types of pressure:

- emission of chemicals, waste and radiation to the environment;
- excessive use of environmental resources;
- land-use.

These pressures induce physical changes in the hydrological system and landscape structure, and chemical changes in the air, water and soil media.

For some countries, maps of zones of high specific pressures are available. Identifying and visualising potential contamination sources (divided into different categories), and corresponding maps of groundwater aquifers, could be a very appropriate means of estimating the probability that higher values of particular determinands could be expected in the underlying groundwater aquifer.



Leakage of contaminants from unlined landfills threatens the quality of groundwater.
Photo: Leif Schack-Nielsen/BIOFOTO

3.2 Nitrate

3.2.1 Introduction

Natural nitrate levels in groundwater are generally very low (typically less than 10 mg/l NO_3). Nitrate concentrations greater than natural levels are caused entirely by human activities, such as agriculture, industry, domestic effluents and emissions from combustion engines (Table 3.1).

Table 3.1 **Causes of nitrate pollution of groundwater**

All the activities listed here can result directly or indirectly in groundwater nitrate pollution. In the environment, several different forms of nitrogen (NO_2, NH_4, NH_3) can potentially be transformed into nitrate (NO_3).

	Agriculture	Municipal	Industrial
Diffuse sources	• Use of synthetic nitrogen fertilisers • Use of organic fertilisers (manure and slurries) The amount depends on agricultural driving forces (e.g. crop types, crop management techniques, changes of land use etc.)	• Combustion engines in vehicles • Disposal of municipal effluents by sludge spreading on fields	• Atmospheric emissions (nitric oxide and nitrite discharges) from energy production • Combustion engines in vehicles • Disposal of effluents by sludge spreading on fields
	Agriculture	**Municipal**	**Industrial**
Point and linear sources	• Accidental spills of nitrogen-rich compounds • Absence of slurry storage facilities • Leaking slurry or manure tanks	• Old and badly designed landfills • Septic tanks • Leaking sewerage systems	• Disposal of nitrogen-rich wastes using well-injection techniques • Old and badly designed landfills
	• Nitrogen-rich effluent discharge to rivers with important groundwater connections • Poorly constructed wells which allow an exchange between polluted and non-polluted aquifer layers		

Nitrate generally moves relatively slowly in soil and groundwater, and hence there is a significant time lag between the polluting activity and the detection of the pollutant in groundwater (typically between one and 20 years, depending on the situation). Thus it took some time before increasingly intensive agriculture over the last 30 years was reflected in detectable increases in groundwater nitrate concentrations. Similarly, it is predicted that current polluting activities will continue to affect nitrate concentrations for several decades. However, fissure flows can dominate in some aquifers (for example, many in the UK), and so transport can be very rapid within the saturated zone.

Pressures arise from pollution sources, which are considered as either point sources (polluting activities concentrated over a small area) or diffuse sources (polluting activities spread over a large area). Some pollution sources, such as leaking sewer pipes, can also be considered linear pollution sources.

Manure spreading on snow-covered soil may add to the pollution of groundwaters. Photo: Federal Environment Agency, Austria.

Table 3.2 gives an estimate of the different fluxes of nitrogen from these different sources. The total nitrogen flux from agriculture is higher than from other sources because of the larger surface area of agriculture in most regions.

Estimation of nitrogen fluxes towards groundwater (Source: AEAP et al. 1994) **Table 3.2**

Activity or land use	**Specific flux towards groundwater (kg N ha^{-1} $year^{-1}$)**
Municipal landfill*	600
Towns and cities**	
• Without a sewage collection system	350
• With a sewage collection system	90
Agriculture***	
• greenhouse crops	100
• vegetable crops	50
• cereals	40
• deforested areas	5

Note that the fluxes are measured in kilograms per hectare.

* *average percolation rate is assumed to be 2 l s^{-1} km^{-2} with a concentration of 1 g l^{-1} N.*

** *average flux per person is assumed to be 15 g day^{-1} N, calculated according to the currently available sewage collection system*

*** *specific leachate flux is estimated for typical synthetic (non-organic) fertilisation practices and is based on results from experimental sites. Values are intended to give a rough idea only.*

Increases in nitrate leaching and run-off to groundwater and rivers can occur where there is cultivation in areas where the soil layer is relatively thin, or has poor nutrient buffering capacity, and also where there are changes in land use and clearing of natural vegetation, which naturally have low rates of nitrate leaching.

The intensification of agricultural activities has also often resulted in significant over-fertilisation of crops to ensure maximum productivity. Some fertiliser is not taken up by the crop, and when this exceeds the soil's buffering capacity, nitrate is leached from the soil into the groundwater. In addition, it is easier to make a single application of a large amount of fertiliser rather than several smaller applications (because of labour costs or crop management techniques), but this can result in one large over-dose. It is also not easy to calculate optimal fertiliser applications because of the complex behaviour of nitrate in the environment: it is particularly difficult (and even more important) to do such calculations when economic and environmental considerations must also be taken into account.

In modern and intensive agricultural practices in some parts of Europe, the favoured crops are often those which require high fertiliser doses, and which leave the soil bare over long winter periods, such as maize, tobacco and vegetables. Vegetables require particularly high doses of fertiliser, much irrigation water and are frequently grown in light soils (often highly permeable and located in alluvial valleys). Unfortunately, this combination of factors tends to increase nitrate pollution, since much nitrogen is leached out and percolates towards the underlying shallow alluvial aquifers. This also holds true for vineyards, which due to their location on slopes and light soils, favour nitrogen run-off towards rivers or alluvial aquifers.

Irrigation can create a downward flow of water from the root zone to the groundwater, thus transporting fertiliser to the groundwater. Drainage systems, with or without irrigation systems, inevitably lead to drainage of fertilisers, which eventually reach surface and groundwater resources.

Leakage from poorly managed manure heaps is threatening groundwater quality. Photo: Bent Lauge Madsen/BIOFOTO.

Intensive agricultural rotation cycles involving frequent ploughing and extensive areas of bare soil during the winter period contribute to nitrate contamination of groundwater. During winter, high rainfall leads to high infiltration rates, and low temperatures limit denitrifying microbiological activity. On bare soil these factors inevitably lead to high rates of nitrate leaching. In Southern Europe, there is also a particularly high rate of mineralisation during spring and autumn which is made worse if the soils are left bare. Ploughing aerates the soil, providing favourable oxygen-rich conditions for nitrate formation, as well as disturbing the soil structure of the important protective upper soil horizons.

Organic fertilisers from animal husbandry may take the form of slurries or manure. If storage possibilities are limited, muck-spreading is often carried out throughout the year, including seasons (autumn and winter) when there is a high risk of leaching

3.2.2 Nitrogen fertiliser usage

The usage of nitrogen fertiliser is used here as an indicator of the pressure on groundwater. Data on nitrogen fertilisers, often with time series, are available and comparable. Data on other sources of nitrate are still insufficient. Nitrogen fertilisers can be split into commercial fertilisers and organic fertilisers (manure). In certain regions, nitrogen supply from manure is a major part of the total amount used. Estimates and regional differences were presented in the first report on Europe's Environment – The Dobris Assessment (EEA, 1995).

For Europe as a whole nitrogen fertiliser usage is stable. As demonstrated in Table 3.3 there are, however, notable differences between Eastern and Western Europe.

Actual and predicted annual nitrogen fertiliser usage in 1000 tonnes (Source: FAO, 1996). **Table 3.3**

	1994/95	1995/96	1996/97	1997/98	1998/99	99/2000	2000/01
Europe	11,768	11,940	12,200	12,210	12,230	12,260	12,290
Eastern Europe	2,058	2,250	2,380	2,510	2,650	2,800	2,950
Western Europe	9,710	9,690	9,820	9,700	9,580	9,460	9,340

towards groundwater. Often the nitrogen concentration of the organic fertiliser is not known by the farmer, which leads to additional difficulties in calculating the nitrogen balance. A sound nitrogen balance is an essential crop management technique for reducing nitrate leaching. Most countries have developed codes of good practice for this.

Increasing populations in towns (urbanisation), together with more stringent controls on sewage effluent discharges to rivers, has led to increased amounts of sewage sludge production, with increased application of sewage sludge to land as a preferred option.

(a) Eastern Europe

As a result of the economic changes in Eastern Europe, the decline in fertiliser usage has reversed, and modest recovery was recorded in 1994/95. However, recovery has not been uniform in Eastern Europe (FAO, 1996).

(b) Western Europe

Western Europe showed a modest increase in nitrogen fertiliser use in 1994/95, which constitutes a reversal of an earlier observed trend. Growth in nitrogen fertiliser usage was recorded in the major consuming countries, i.e. France, Germany and the UK. From 1997 to 2001, usage rate is expected to decrease (FAO, 1996).

(c) EU15

Figure 3.1 shows an increase in nitrogen fertiliser usage in the EU15 countries since 1992. This follows a decreasing rate between 1985 and 1992. The annual data for the usage of commercial nitrogen fertilisers by country are given in EEA (1999).

3.2.3 Nitrogen fertiliser usage related to agricultural area

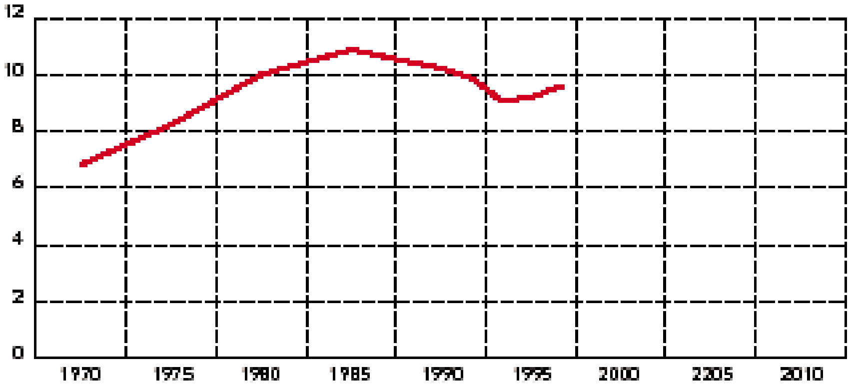
The application of synthetic nitrogen fertiliser per unit area of agricultural land (in kg/ha) gives an indication of the extent and significance of this pressure. However, nitrogen fertiliser application can vary significantly within a country as well as between countries, a factor not taken into account by country-wide indicators (Figures 3.2 and 3.3, and Map 3.1).

The usage rates of nitrate fertiliser per hectare of agricultural area are between 1.7 kg/ha (Lithuania) and 193.6 kg/ha (the Netherlands). In six countries (the Netherlands, Denmark, Belgium/Luxembourg, Norway and Germany), more than 100 kg/ha of agricultural area are used.

For most countries there has been a decreasing trend between 1990 and 1994 (Figure 3.3). However, Ireland and the United Kingdom have shown steadily increasing usage rates per hectare of agricultural land since at least the 1970s, and Cyprus from the beginning of the 1980s. Ireland and Cyprus showed high rates of increase of about 27% and 48%, respectively, between 1990 and 1994. Most Eastern European countries show very high reduction rates, with only Poland and Slovenia increasing their nitrogen fertiliser usage per agricultural land unit. The reasons for the decline in Eastern Europe are economic changes, and the collapse of the centralised economic management and distribution systems adopted during the Soviet era, particularly in the Tacis countries (ENRIN, 1996).

A more sophisticated and problem oriented indicator would be the nutrient balance for nitrogen. Surplus or deficiency of nitrogen is related to the area of fertilised agricultural land (arable land, fertilised grassland and permanent crops). The indicator of nutrient balance is more problem-oriented

Figure 3.1 **Development of commercial nitrogen fertiliser usage in EU15 (Source: FAOSTAT, 1997)**



than “use of fertilisers” because it includes inorganic fertiliser and organic manure, and refers to the nutrient output in harvested amounts (nutrient efficiency).

Eurostat (1997a) has undertaken a study that calculated soil surface nitrogen balances per unit area for 12 EU countries (there was insufficient information for the remaining 3 EU countries). The balances were based on data from the 1993 Farm Structure Survey, supplemented by other data available at a European level, and by technical coefficients supplied by the Member States.

These studies show that the surplus (difference between input and output) varies from over 200 kg N/ha/year in the Netherlands to less than 10 kg N/ha/year in Portugal (Figure 3.4). In general, there is an increasing surplus with increasing inputs, reflecting increasing potential leaching with increasing inputs. However, since the methods used to compute these balances are not the same in all countries, the data should be used cautiously. For example, alternative calculations in Germany, taking into account losses of gaseous nitrogen prior to, and during, application of animal manure, and considering the plant material remaining in fields after harvesting, estimate that the surplus would be greater, that is 110 kg/ha/yr compared to 55 kg/ha/yr in Figure 3.2.

Figure 3.2

Nitrogen balances for agricultural land in EU12 countries 1993. (Input includes fertiliser and manure. Output includes the harvest. Those countries to the right of the graph have the greatest annual surplus per hectare). (Source: Eurostat, 1997)

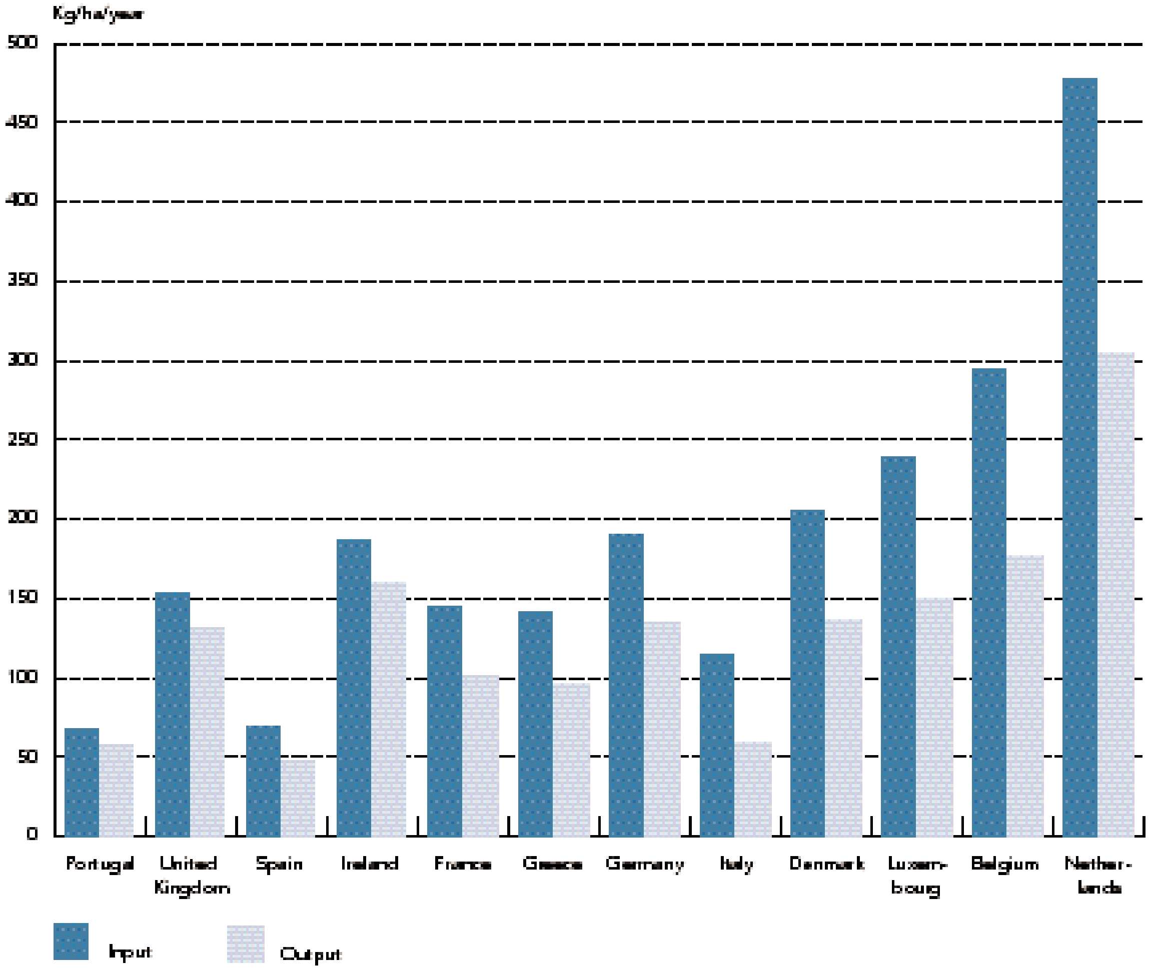
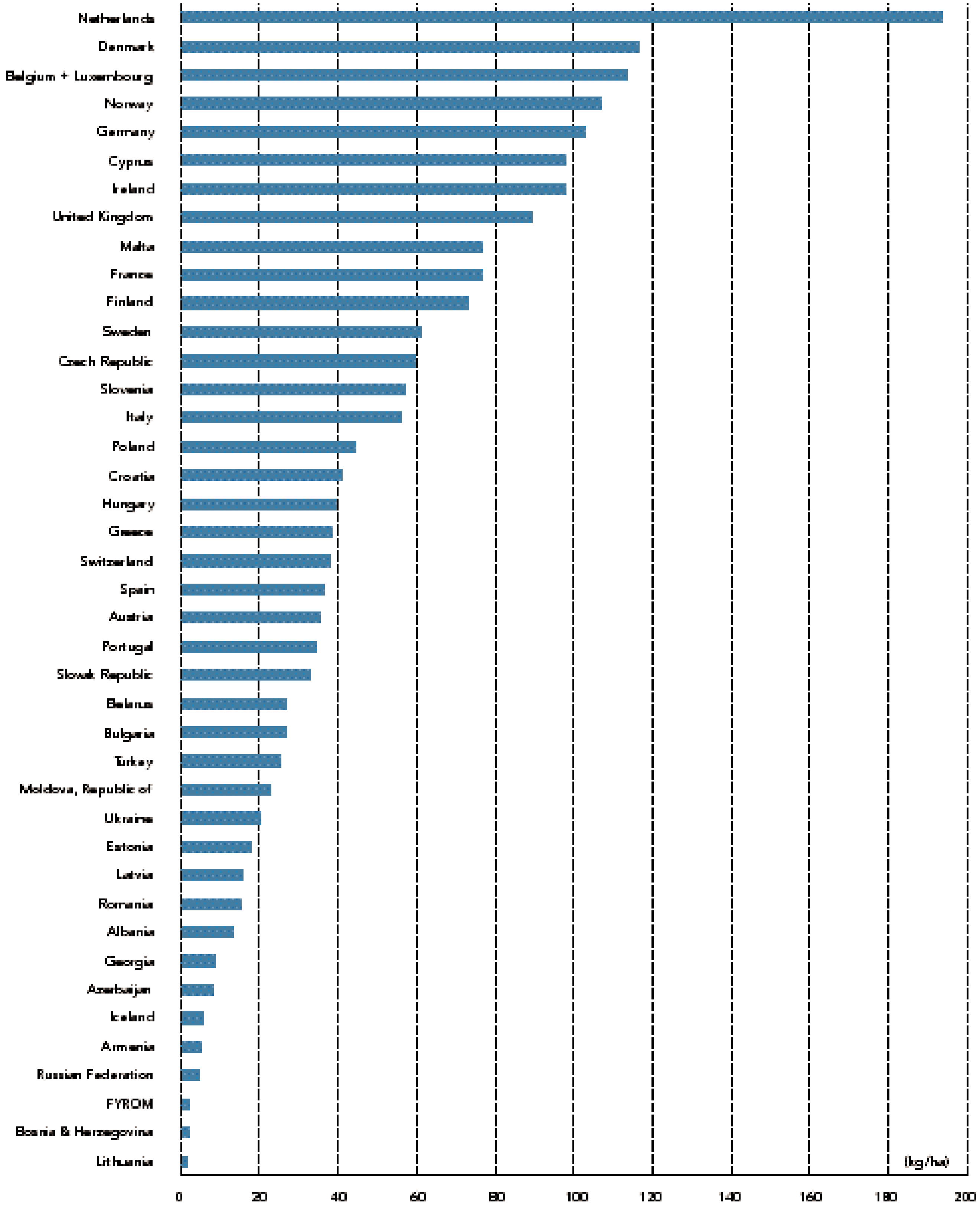
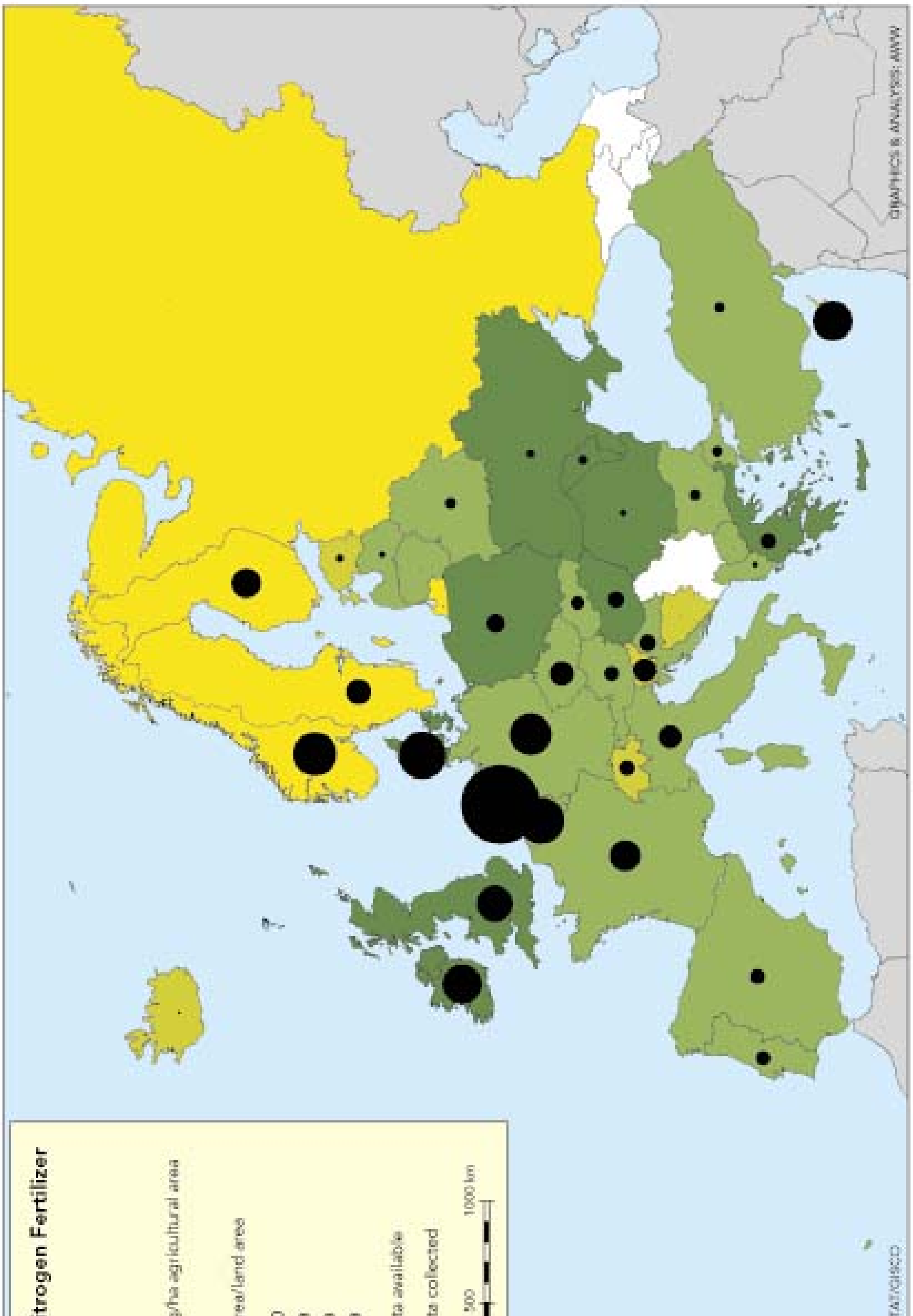


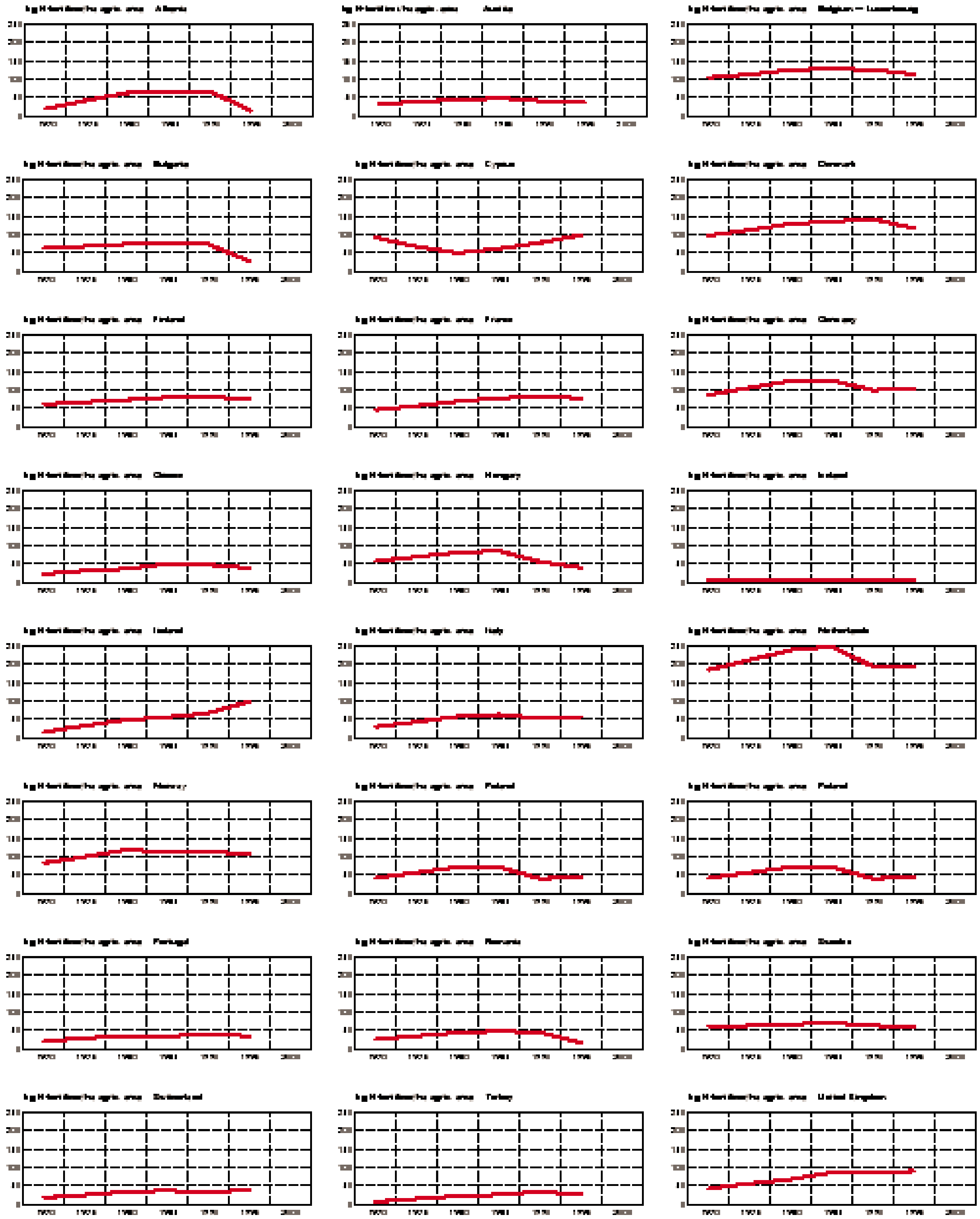
Figure 3.3 Nitrate-fertiliser usage in kg/ha agricultural area in 1994 (Source: FAO, 1996)





Map 3.1
Synthetic nitrogen fertiliser usage related to agricultural area (kg/ha) and proportion of agricultural land to land area, 1994 (FAO, 1996)

Figure 3.4 Time series of nitrate fertiliser usage 1970-1994 (Source: FAO, 1996)



3.3 Pesticides

3.3.1 General description

Pesticides are defined as any substance or mixture of substances intended for preventing, destroying or controlling any pest, including vectors of human or animal disease, unwanted species of plants or animals causing harm during or otherwise interfering with the production, processing, storage, transport, or marketing of food, agricultural commodities, wood and wood products or animal foodstuffs, or which may be administered to animals for the control of insects, arachnids or other pests in or on their bodies. The term includes substances intended for use as a plant growth regulator, defoliant, desiccant, or agent for thinning fruit or preventing the premature fall of fruit, and substances applied to crops either before or after harvest to protect the commodity from deterioration during storage and transport (FAO, 1990).

Pesticides form an integral part of modern agriculture and horticulture, helping farmers and growers to produce good quality food at reasonable prices and costs. The need to use pesticides is likely to continue for the foreseeable future, but at the same time, any undesirable side effects must be identified and, as far as possible, eliminated.

All pesticides are subject to an approval procedure under EU legislation, and often also under national legislation. The former imposes detailed conditions on the use of each product. The procedure aims to ensure that products produce no ‘unacceptable risk’ to human health or the environment. However risks are inevitable, and it is not possible to remove these entirely through the approval process. In particular, the use of pesticides has an impact on the natural environment through spray drift, leaching or run-off into water, or effects on non-target organisms.

During the process of amending the Council Directive concerning the quality of water intended for human consumption, the European Commission asked its Scientific Committee on Toxicity, Ecotoxicity and the Environment (CSTEE) for its opinion on pesticides. For example, its opinion was asked on whether the scientific knowledge presently available provides the necessary security and reliability to determine (on the basis of a precautionary approach) individual limit values. Limit values should safeguard drinking water over a lifetime’s exposure for the population, including sensitive population groups, where relevant. It was also asked as to what the correct values for individual substances should be.

The Committee’s response was:
“Referring to the parameters and data used in the WHO-guideline values for the control of drinking water, the Committee finds that they may not provide a sufficient margin of safety for the European Union. The values define upper concentration limits when each substance was studied in isolation, and the Committee wishes to stress that information on the toxicity of mixtures of individual pesticides is almost entirely lacking. For these reasons too, the Committee drew attention to the precautionary principle which should be considered when dealing with the WHO-guideline and their possible transfer to a European directive” CEC (1995).

Since groundwater is an important resource for drinking water purposes, the precautionary principle should be applied for the protection of groundwater too.

3.3.2 Constituents and ingredients

Any pesticide is a mixture of active ingredients and additives. The active ingredient refers to the biologically active part of the pesticide that kills or controls the pest(s). The additive chemicals interact with the active ingredient in order to improve the formulation and the plant uptake. They might include solvents, surfactants and carriers. Pesticides are only effective or usable after mixing or diluting, and are supplied as solid formulations (e.g. water soluble powders, wettable powders or water dispersable granules) or as liquid (e.g. emulsions or suspensions).

The most important pesticide ‘groups’ are herbicides, fungicides, and insecticides. Typical herbicides include the chemical classes of sulphonylureas, thio-carbamates, triazines, and ureas. Typical fungicides include the classes of azoles, morpholines, phenylamides and inorganic compounds. Insecticides then include the classes of carbamates, organophosphates and pyrethroids. Over recent years, there has been a change from persistent, lipophilic, and thus barely water soluble active ingredients, to the use of substances that are easily degradable.

3.3.3 Sources

Pesticides in the aquatic environment arise from diffuse, point and linear sources. They are used in agriculture, horticulture, fruit growing, viticulture, forestry, for public and private purposes, manufacturing and industrial activities. Incorrect or poor control on the use and application of pesticides can increase the impact on groundwater (and surface waters). For example, over-doses can occur, they can be applied at the wrong time or with too short a time interval between applications, or can be used when it is not really necessary.

Pesticides do occur in groundwater but the magnitude of the problem is currently not well known. Photo: Federal Ministry for Agriculture and Forestry, Austria.

For many agricultural uses, the source would generally be considered to be diffuse as pesticides are spread over relatively large areas (e.g. crop spraying). However, point sources may also arise from sheep dips, accidental spillage, improper handling during preparation, washing of equipment, inadequate storage, and illegal dumping of unused pesticides and their packaging.

In the private and the public sector, pesticides are mainly used to control insects, and to clear outdoor areas of weed vegetation, especially around railways, roads, car parks and airports. Pesticides are also applied around sports facilities, cemeteries and parks, and are included in some protective coatings for buildings and ships.

Pesticides may reach groundwater from industrial activities such as from accidents during production, storage and transport, or through the discharge of industrial effluents or leachate from dumping sites.

3.3.4 Pesticide transport into the groundwater

The concentration of pesticides in groundwater depends on many factors including:

- nature of the surface to which the pesticides is applied;
- crop and soil type;
- weather;
- nature of application;
- application rate;
- equipment used to apply and contain the pesticide;
- (bio)degradation rates in the environment;
- physical and chemical characteristics of the pesticide/formulation.

Pesticides that are sprayed reach surface waters via air and soil. Those injected into the soil are washed out and reach adjacent surface waters or deeper soil layers, and those which are directly applied to surface waters also reach groundwater aquifers through bank filtration. Atmospheric transport of evaporated, or wind-transported pesticides and their metabolites, can result in the contamination of distant ecosystems. During winter, the biodegradation of pesticides is often reduced because of low temperatures and low microbiological activity. The low oxygen content of deeper soil layers also decreases the rate of microbiological degradation.

The time a pesticide takes to reach the water table depends on the physical and chemical features of the aquifer, which can vary considerably. Typical rates of downward movement of water in the unsaturated zone of an aquifer are slow (about 1 m/yr) but features such as fissures can lead to more rapid movement (about 1 m/d).

3.3.5 Pesticide usage

The 'pressure' exerted on groundwater by pesticides can be quantified and assessed in different ways. An example of an indicator is the number of approved active ingredients in different countries. Another more detailed indicator is the total amount of pesticides and pesticide groups sold/used in relation to arable and permanent crop land. This information provides a general overview, which however does not take into account the toxicity of the used substances, and differences (application, amount) at the regional level.

The annual sale/usage data of total pesticides, herbicides, fungicides, insecticides and other pesticides for European countries, and other numerical data used in this section, are given in the technical report accompanying this monograph (EEA, 1999).

Figure 3.5 shows the number of nationally approved active ingredients, which varies from four substances in Malta to 531 substances in Spain. Figures 3.6 and Map 3.2 show the regional differences in the kind and amounts of applied pesticides in relation to arable and permanent cropland. Map 3.2 additionally shows the usage of pesticide groups in each country.

The usage of pesticides per hectare of agricultural land varies widely between countries in Europe. Between 1985 and 1991, the usage was lowest in the Nordic countries, intermediate in Eastern Europe, and highest in Southern and Western Europe (EEA, 1995). In Northern and Central European countries, herbicides are the predominant type of pesticide as measured by the amount of active ingredients, whereas in the Southern and Western countries it is insecticides and fungicides.

Herbicides are mainly used in humid areas, and in countries where intensive cultivation is automated with a low manpower requirement. Fungicides are primarily used in regions with intensive cereals, viticulture and horticulture (e.g. fruits, vegetable crops and hops). They are predominantly used in Portugal, France, Luxembourg, the Netherlands, the Republic of Moldova, Switzerland, Slovenia and Greece. Higher amounts of insecticides are used in regions with warmer climates (Mediterranean countries), especially in Albania, Greece, Turkey and Spain. In the Northern and Eastern European countries, the usage rate is quite low.

The sale of pesticides, as measured by the amount of active substance contained within the pesticide, has generally decreased over the last ten years (Figure 3.7). Figure 3.8 shows the relative usage of total pesticides since 1985 (or other reference years if 1985 data are not available) in EEA and other European countries. Eight of the 18 countries had by 1994/95 reduced total pesticide usage to at least 65% of values in the mid 1980s, a further six showed smaller decreases, and four displayed increased usage (OECD, 1995; Eurostat, 1996 and ETC/IW, 1997). For Eastern European countries, the decrease of pesticide usage is due to the economic changes, and the collapse of centralised management and distribution systems, especially in the Tacis countries.

Concurrently, new and more efficient pesticides have been developed with the same biological effect from a far smaller dose of pesticide. Therefore, the observed decrease in pesticide sales does not necessarily indicate a decrease in crop protection efficiency, and the environmental impact may have

been reduced less than the drop in sales figures suggests. Certain recently developed substances, however, are more selective on target organisms, and therefore have a lower impact on the environment in general.
The change in pesticide characteristics over recent years is also illustrated by information from the European Crop Protection Association (ECPA, 1998) on the toxicity of certain pesticide active ingredients to humans and earthworms, and on the application rates used (Figure 3.9 to 3.11).

Figure 3.9 shows the application rates (in g of active ingredient per hectare) of 144 crop protection products between 1930 and 1997. In the figure the 'first reported' date is the year of the publication of the compound in the "Pesticide Manual", and not necessarily the date of first introduction into use in different countries. The graph shows that application rates have decreased over time, confirming the reduced use figures presented earlier. Over the same period of time there has also been some decrease in the toxicity to humans of 138 crop protection products expressed as the acceptable daily intake (ADI) (Figure 3.10). The ADI is the amount of an active ingredient that can be consumed daily for the entire lifetime of an individual without causing any harm.
The ADI is calculated from the lowest "No Observed Effect Level" (NOEL) found in toxicity studies divided by a safety factor of at least 100. The NOEL is the level of active ingredient found to have no observed effects on the most sensitive species (rats, mice, dogs, rabbits, chickens, or guinea pigs) in laboratory toxicity studies. The actual safety factor applied takes into account any uncertainty in the data. Thus the more uncertain the data are, the larger the safety factor applied.

For the determination of the environmental safety of crop protection products a detailed risk assessment is necessary. As an example of this the potential hazard of 63 crop protection products to earthworms was assessed by ECPA (Figure 3.11). In this example the predicted environmental concentration (PEC) can be directly correlated with the application rate. The toxicity of the active ingredient is expressed as a toxicity exposure ratio (TER) which is the acute toxicity to earthworms (EC 50 value) over the PEC. The PEC in soil is calculated from the application rate (100%), assuming homogeneous distribution in the first 5 cm of topsoil.

Although Figures 3.9 to 3.11 illustrate a decreasing (statistically significant) trend in toxicity of some crop protection products to test species of mammals and to earthworms over the last 67 years, there is no equivalent information on the toxicity of the products to other organisms (both terrestrial and aquatic), nor on the toxicity of any degradation products arising from the pesticides.
A fuller assessment of the environmental toxicity of the products and their degradation products would include their chronic and acute toxicity to relevant and sensitive species, and their fate, behaviour and persistence in the environment. Regulatory authorities undertake such assessments when establishing environmental quality standards for such substances. It should also be borne in mind that not all active ingredients approved for use in Europe (for example, 531 in Spain) have been included in the ECPA studies (144, 138 and 63 respectively). Thus, there is no information on how representative the products tested were of the toxicity of all products used, or of actual application rates and amounts used.

Research is also carried out on the replacement of pesticides by alternative agents expected to be less harmful to the environment. Thus microbiological components, such as bacteria, fungi or viruses, are being used in pest control instead of chemical substances in many countries, particularly for pest control in greenhouses. These methods, however, are not yet used to any large extent (e.g. in Denmark less than one percent of total sales of crop protection agents are microbiological), but their use will probably increase in the future.

Number of approved active pesticide ingredients (Eurostat, 1995, ETC/IW questionnaire) **Figure 3.5**

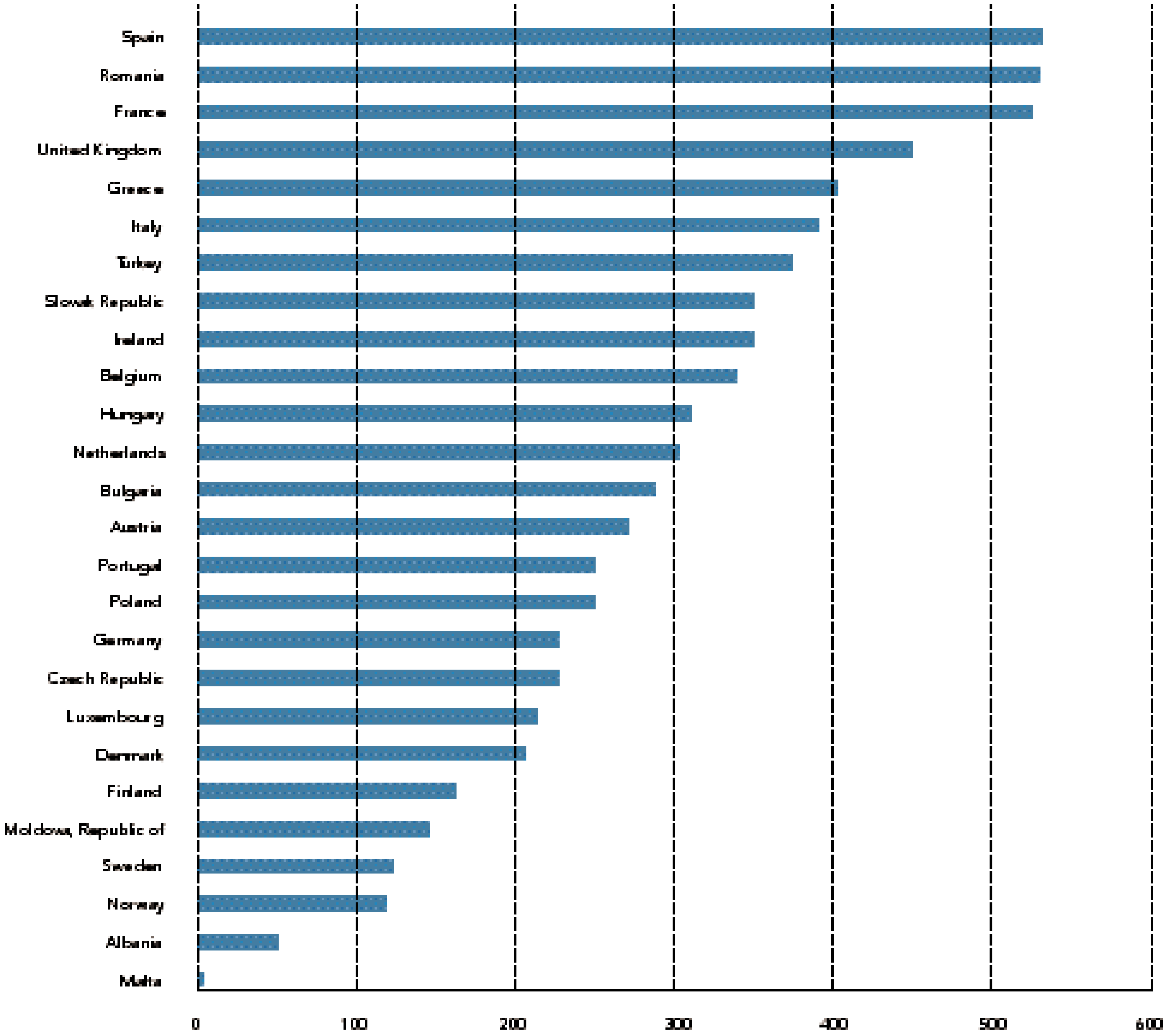


Figure 3.6 Pesticide usage (kg) per unit area (ha) of arable land and permanent cropland (FAO, Eurostat (1995), OECD and ETC/IW questionnaire

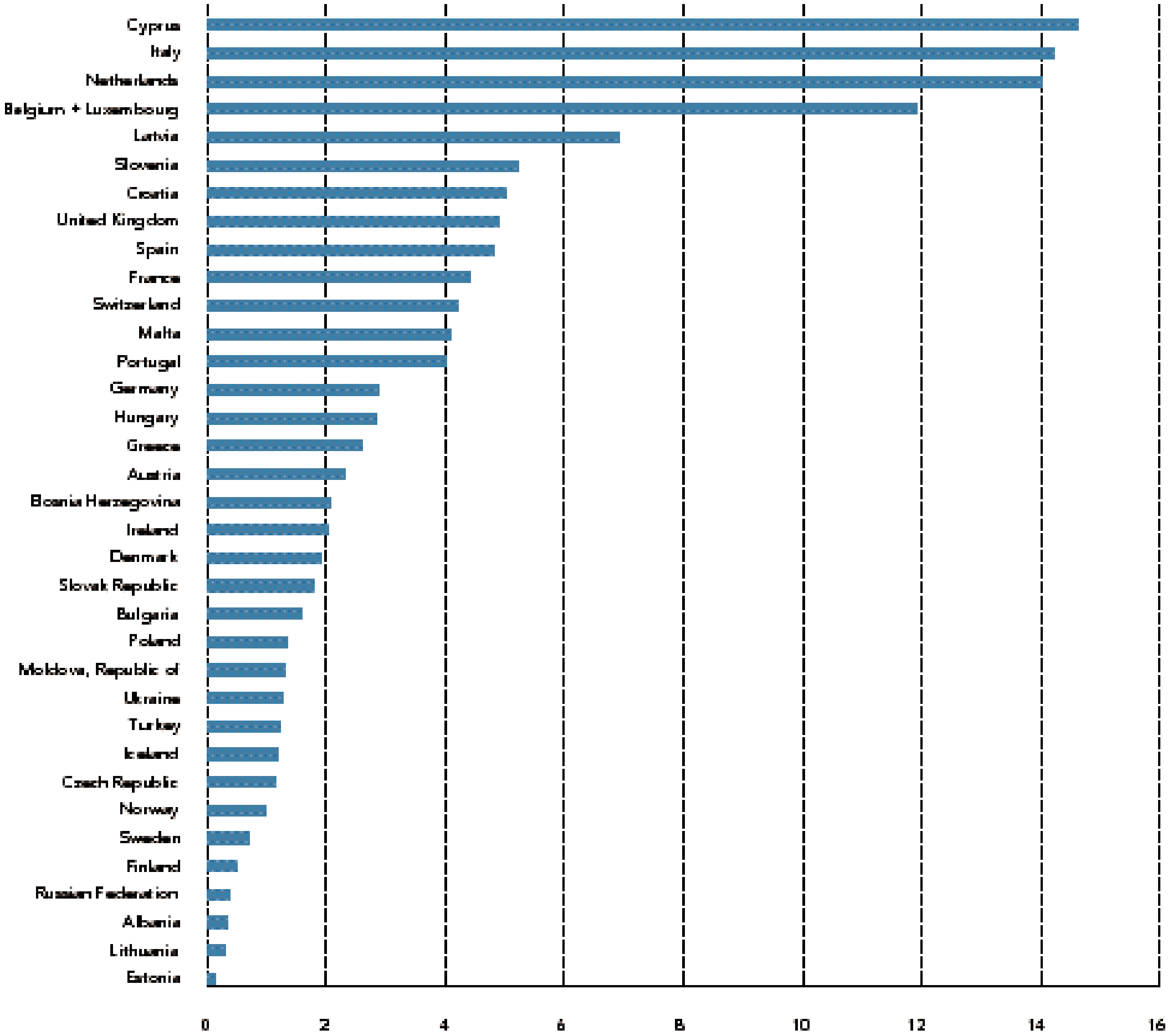
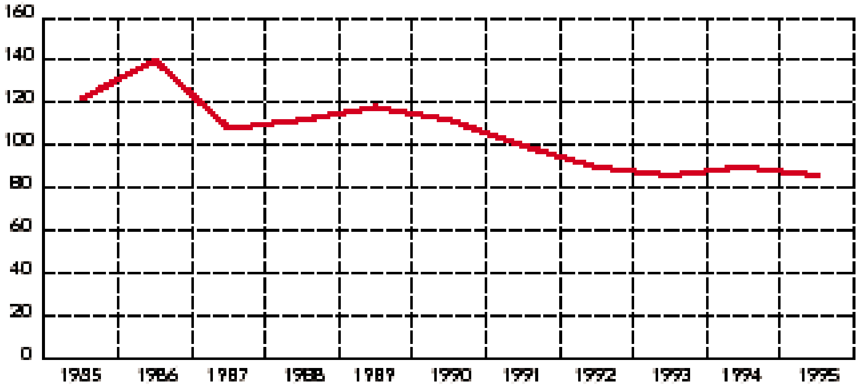
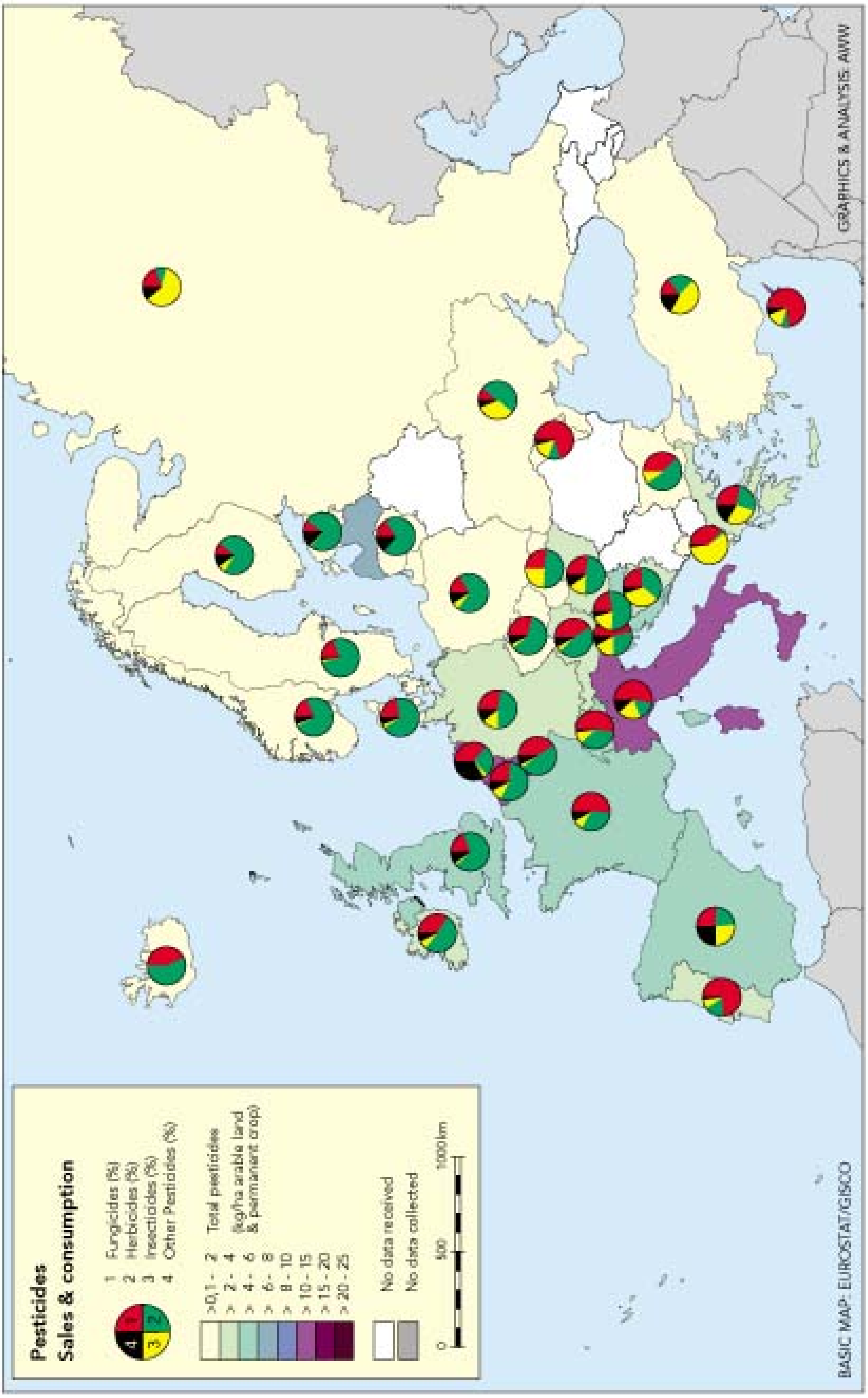


Figure 3.7 Total sales of pesticides in the EU15 countries except Belgium and Luxembourg (Index 1991 = 0) (ECPA, 1996).





Map 3.2
Pesticide usage per arable and permanent cropland (kg/ha) and the proportion of applied pesticide groups.

Figure 3.8 Relative usage of total pesticides since the 1980's (Eurostat, OECD 1995 and ETC/IW questionnaire 1997)

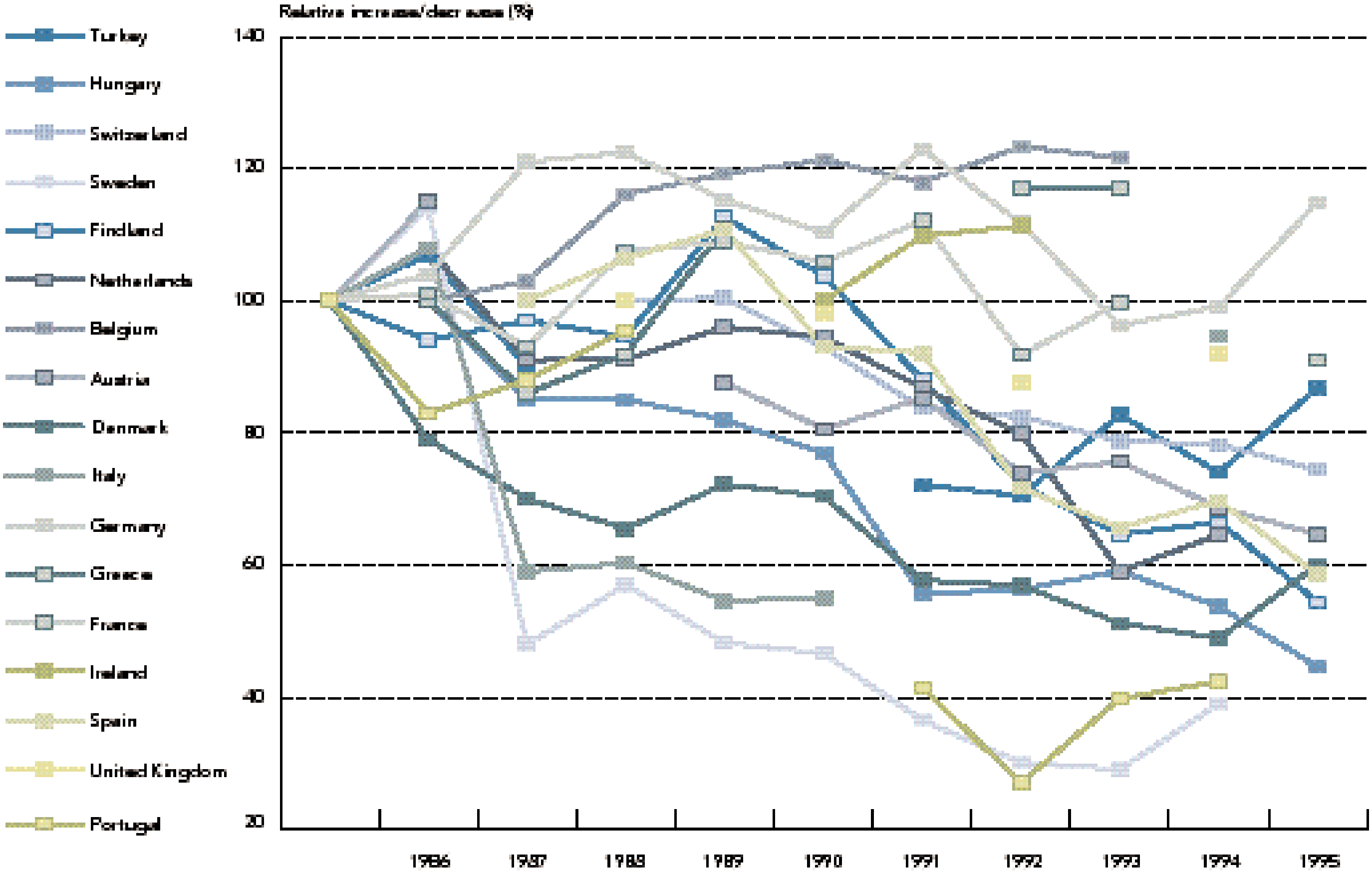
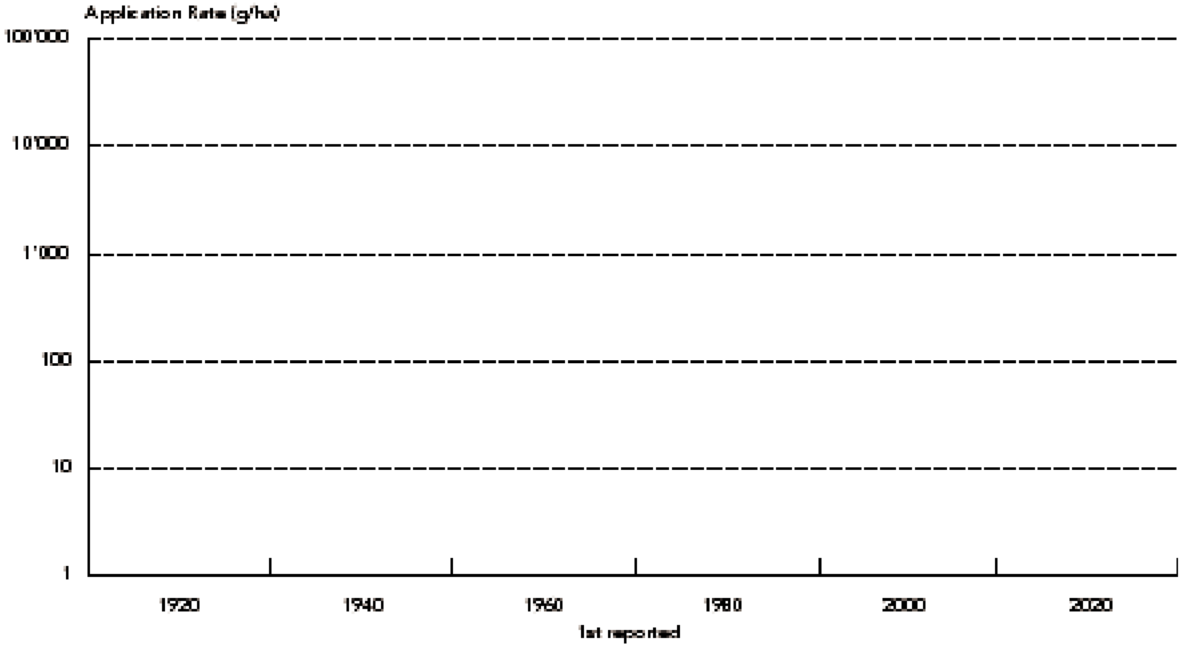
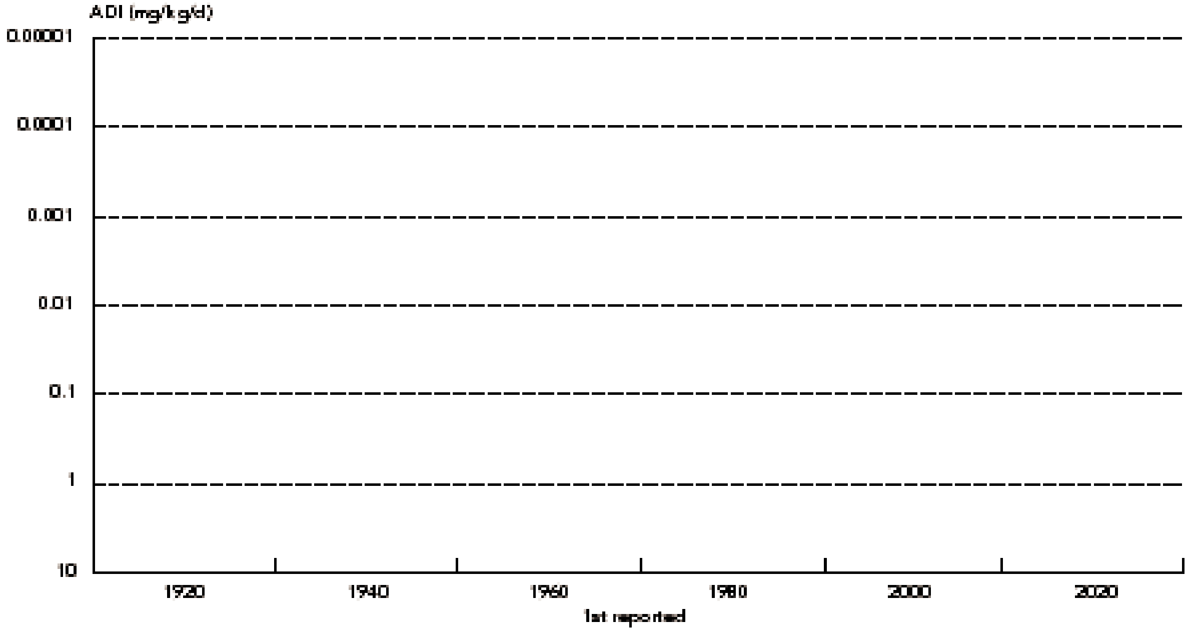


Figure 3.9 Trend of the development of application rates of crop protection products (1930-1997) (Source: ECPA, 1997)



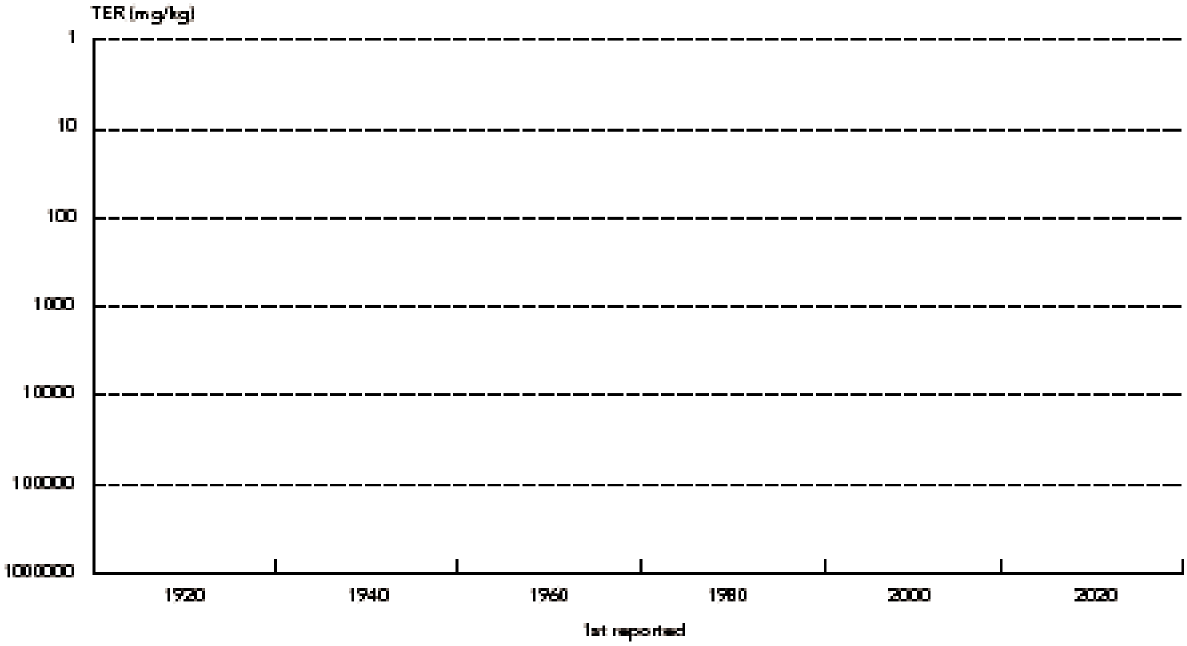
Trend of the development of Acceptable Daily Intakes (ADI) of crop protection products (1930-1997), consumer toxicity (Source: ECPA, 1997)

Figure 3.10



Trend of the development of the toxicity of crop protection products to earthworms (1930-1997) (Source: ECPA, 1997)

Figure 3.11



3.4 pH / Acidification / Alkalinity

3.4.1 pH

The causes of high pH values are mostly natural and depend on climate and geology. A high pH value is found in calcareous environments. The dominating sources are calcareous bedrock or calcareous materials incorporated into the soil. In arid areas, lime or gypsum, or both, might accumulate in the upper few centimetres of the soil when soil moisture moves upward and evaporates. Exceptionally high pH in groundwater might be a result of ion exchange processes. The lowering of the pH value is a sign of acidification.

3.4.2 Acidification

Natural acidification occurs through reactions between ubiquitous (gaseous) carbon dioxide and water (mainly in the soil, where the content of carbon dioxide might be high) to form carbonic acid. It has to be borne in mind that the (chemical) activity of carbonic acid in the water cycle does not depend on the pH-value. Carbonic acid can dissociate in two steps, releasing one proton (H^+) in each step. The activity of the two resultant ions, HCO_3^- and CO_3^{2-}, is a function of pH. However, the lower limit of pH to be expected from this process is not less than about 4.6, even in the absence of any buffering process within the aquifer. Thus, anthropogenic activities must have a significant effect on the acidification of groundwater. Industrialisation, traffic and modern intensive farming enhance natural processes by adding acidifying agents to the environment. The detrimental effect of acid deposition on forests and lakes of Northern Europe and North America is well documented, and acid deposition may also be expected to affect groundwater reservoirs. The acidification problem originates from fossil fuel combustion for electrical power production, or from car traffic as well as from waste incineration, which generate NO_X and SO_2. These substances are subsequently oxidised in the atmosphere and precipitate or deposit as diluted nitric and sulphuric acid solutions. Evapotranspiration furthermore increases the acidity of the solution that enters soil- or subsoil-systems (EEA, 1995).

Another cause of anthropogenic acidification is the excessive use of nitrogen fertiliser and manure. Oxidation of ammonia by oxygen is the main acidifying process in the soil. Also the increased content of ammonium in precipitation from ammonia released to the atmosphere from manure spreading lowers the pH of rainwater when the ammonium is oxidised. If plants consume all the nitrate produced, the proton production from the oxidation process is counterbalanced by the HCO_3^- production in the denitrification process. However, enhanced concentrations of nitrate occur in most aquifers. Hence not all nitrate is consumed, and nitrification of ammonia must be considered as an important contribution to acidifying processes.'

Oxidation of pyrites (FeS_2) is another acidifying process. Pyrites is found, at least in small quantities, in sediments with reducing conditions. Lowering of the groundwater table, caused for instance by groundwater over-exploitation, may lead to pyrites oxidation. Here one of the strongest acid-producing reactions in nature occurs, producing four protons for each molecule of FeS_2 that is oxidised.

For example, many mines contain iron minerals in their reduced form. A common feature of such mines is the presence of iron pyrites which, upon prolonged contact with water, dissolve to form sulphuric acid. This can lead to further leaching of metals that are naturally present. Thus water emerging from mines may be acidic and contain metals such as cadmium, copper and zinc. In operational mines, this acidity is often treated to reduce the impact, particularly on surface waters. However, in abandoned mines treatment may cease, and the acidic water may disperse into the surrounding aquifers and surface waters. The pH of these mine waters can be as low as 1 or 2.

3.4.3 Alkalinity

Alkalinity is a measure of the acid neutralising capacity of a system and depends on natural processes. Weathering of carbonaceous rock such as carbonates and dolomites, as well as weathering of silicate rocks produce alkalinity. Oxidation of organic matter may also contribute to the formation of alkalinity through the production of carbon dioxide.

Reasons for lowered production rates of alkalinity, and changes in the overall acidity/alkalinity balance of the top soil and groundwater, are changes in land use or changes in the production pattern of an agricultural or forest area. Changing the land use from grassland to forest, or the removal of excessive plant material (straw from farmland or bark, twigs and small branches from managed forests) removes alkaline compounds from the ecosystem and thus speeds up acidification. Liming of arable land is a man-made supplement to alkalinity.

3.5 Chloride

In most cases, an increase in salinity arises from diffuse sources. This is the case with continental aquifers where water evaporates (natural mineral deposits), and can bring about a saline intrusion. Salty water has a higher specific gravity and accumulates in deeper layers where groundwater movement is restricted. Contamination of upper groundwater horizons occurs if this water rises along geologically disturbed zones.

With regard to anthropogenic sources, chloride enters the hydrological cycle via chloride-containing liquid and solid waste (e.g. human and animal sewage, industrial effluents from the chemical, galvanic and paper industries, water softening plants, petroleum refineries, landfill leachate) and fertilisers containing chloride. In the northern and mountainous parts of Europe, groundwater contamination by chlorides often results from the storage and application of salt for de-icing streets and highways in winter.

Irrigation may also lead to an accumulation of chlorides in groundwater. Salt containing water from deep groundwater aquifers used for irrigation increases the salt content of the upper groundwater aquifers by infiltration. Irrigation of dry soils probably raises the local groundwater table, which leads to a dilution and upward movement of salts from the deeper soil to the root zone. As far as coastal aquifers are concerned, the contaminant is seawater, which causes the phenomenon referred to as marine or saltwater intrusion.

3.6 Electrical conductivity

An increase in electrical conductivity in groundwater is associated with an increase in mineralisation, and is influenced by natural geological conditions in which solution and substitution processes, as well as the contact time with rocks, determine the degree of mineralisation.

Anthropogenic inputs of calcium, magnesium, potassium, sodium, chloride, sulphate, nitrate and acidifying substances lead to an increase of the electrical conductivity in groundwater (DVWK, 1993). The main anthropogenic pressures would be similar to those described for nitrate, pH/acidification/alkalinity and chloride. Additionally, effluents from the chemical industry, and leaching of domestic and industrial dumping sites, play an important role in increasing electrical conductivity in the groundwater.

3.7 Hydrocarbons and chlorinated hydrocarbons

3.7.1 Hydrocarbons

Mineral oils are generally used as fuel for combustion engines, for heating purposes and as lubricants. Groundwater contamination by mineral oils arises mainly from public, private and industrial activities. If mineral oils reach groundwater they generally float. However, aromatic compounds can dissolve in water and are transported over long distances.

Volatile aromatic hydrocarbon contamination mostly arises through improper and careless handling, and accidents with solvents and raw materials containing aromatics in industry. The main point sources of hydrocarbons are particularly old industrial, military and railway sites. Leaching from old car dumps, industrial and municipal dumping sites, as well as illegal dumping and the use of used oil for stabilising streets, also lead to groundwater pollution. Polyaromatic hydrocarbons (PAH) resulting from the incomplete combustion of organic material are discharged into the atmosphere. The atmospheric deposition of PAH is not significant in terms of groundwater contamination as PAHs are adsorbed onto humic substances and clay minerals. However, PAHs have been detected in shallow groundwater under Stockholm.

3.7.2 Chlorinated hydrocarbons

Inadequate handling and accidents during production, transport and processing mostly cause groundwater pollution by chlorinated hydrocarbons such as tetrachloroethene, trichloroethene and 1,1,1-trichloroethane. Atmospheric inputs play a minor role. Leaching from dumping and old industrial sites are also sources of pollution.

4. Pressures on groundwater quantity

4.1 Groundwater abstraction

4.1.1 Geographical situation

The vulnerability of an aquifer to over-exploitation depends on its type, climate, and hydrological conditions, and on the uses of the water. It is clear from the data available that the most acute over-exploitation problems occur in arid or semi-arid regions where there is low groundwater recharge. Coastal areas and islands in Southern Europe are particularly vulnerable to groundwater over-exploitation.

On the Mediterranean coast, groundwater bodies are often relatively small because of the hilly topography that forms small aquifer pockets. Since water transfer between different valleys is in general not feasible, each district relies on its own resources (Margat, 1992). In these areas, irregular surface water resources and an increasing water demand from population, agriculture and tourism have led to dependence on groundwater. The proximity of the sea means that there is a real risk of saline intrusion since groundwater over-exploitation can lead to a change in the seawater/freshwater interface. It is expected that the situation in certain already stressed aquifers on the Mediterranean coast will continue to deteriorate for some years to come (e.g. Barcelona, Marseilles, Athens and the French Riviera Coast) (Margat, 1992). Islands, such as the Canary Islands, are especially vulnerable to these problems. Every year, the press in many Northern European countries reports on dried-up rivers, sometimes (but not always) caused by groundwater over-exploitation.

4.1.2 Contributory factors

Structural changes in agriculture in Europe have led to an overall increase in irrigation because of changes in crop types, and the expansion of irrigated agricultural areas. In Southern Europe, irrigation is systematic, being essential to many types of crop production (e.g. all-year vegetables and fruits). In Central and Northern Europe, irrigation can be viewed as being complementary: it can improve productivity and crop value and might be required to off-set low rainfall. Unfortunately in shallow aquifers, the irrigation season often coincides with the lowest recharge period. The cultivation of plants not adapted to the ambient conditions, together with high water demand, may lead to falling groundwater levels.

In the past, in some regions the management objective was to permanently drain large areas (often important wetlands) to facilitate agricultural or urban development (land reclamation). One way of achieving this goal was to over-pump groundwater until a lower stable water level was reached.

The expansion of the European population in the 20th century has led to a sharp increase in drinking water demand. At the same time surface water quality deteriorated because of increasing industrial and municipal effluent discharges to rivers. In general, groundwater is of naturally good quality and very little treatment (if at all) is needed to make it suitable for drinking water consumption. In addition, groundwater is often a more reliable resource than river abstractions, which may be vulnerable to seasonal rainfall variations, and may require more extensive and expensive treatment. These are the reasons why groundwater abstractions have progressively increased in many regions.

Alluvial sands and gravels are important aquifers in many parts of Europe. Photo: Peter Warna-Moors/Geological Survey of Denmark and Greenland.

In many coastal areas in Southern Europe tourism has boomed over the last few decades, creating a large additional and seasonal population which requires a lot of drinking water. Mining activities, particularly in open-pit mines (including gravel pits), can involve the pumping of significant volumes of groundwater in order to de-water the mine. Long-term de-watering on a large scale can have an important impact on the aquifer water balance. In addition, shallow mining also disturbs and alters the permeability of soil layers, often reducing recharge. Deeper mining may create potential flows by thinning certain impermeable strata and subsequent heavy pumping may connect aquifers showing a good water quality with poorer quality ones. Furthermore, mining regions are often densely populated which can lead to serious water use conflicts regarding both quantity and quality. A severe example of such a problem is the brown coal mine at Belchatów in Poland (Nawalany, 1991). This mine is reported to have caused a huge depression in groundwater levels over an area of about 910 km^2, causing significant de-watering.

In some regions, river regulation schemes have required groundwater levels to be lowered as a flood protection measure. Natural lowering of riverbeds in some areas of Europe has also caused a drop in groundwater levels (van de Ven et al., 1992).

It is not only the increasing water abstraction required to meet increasing demand which may be responsible for groundwater over-exploitation, but also changed recharge situations. If the abstracted amount remains the same, but groundwater recharge from precipitation or from surface water decreases, over-abstraction effects will arise. Several studies point out that changes in precipitation patterns, local as well as seasonal, will take place. Winter precipitation, as well as runoff from the mountains, will increase significantly, while summer runoff and lowland runoff will decrease. Activities influencing the recharge situation of groundwater aquifers are sealing and drainage of land, changes in land use and the compaction of agricultural soil from intensified agricultural production methods. The cultivation of plants with high water demands also reduces the infiltration rate of water down to the groundwater aquifer.

Changes in river flow characteristics, such as surface water abstractions, river channelisation and dredging of river channels for various purposes, may lead to decreasing groundwater recharge. Consequently, if the renewal rate of groundwater decreases, a currently sustainable groundwater abstraction will lead to groundwater over-exploitation.

4.1.3 Amount of groundwater abstraction

Groundwater sources have historically provided a local and least-cost source of drinking water for public supply and private domestic supply. Of the total water abstraction in the EU, about 18% (OECD, 1997) is taken from groundwater (12% according to EEA, 1995). Table 4.1 gives an overview of groundwater abstraction in various countries.

The relative portion of surface and groundwater varies considerably between countries, depending on the natural conditions and the characteristics of water uses in each country. In countries with extensive groundwater reservoirs (e.g. Iceland, Austria), a

Surface sealing prohibits formation of groundwater in aquifers. Photo: Peter Warna-Moors/Geological Survey of Denmark and Greenland.

major part of total abstractions comes from this source, compared with less than 10% in Belgium, the Netherlands and Finland. Table 4.2 shows the apportionment of public water supplies in Europe between the two primary sources, groundwater and surface waters.

In countries with sufficient groundwater reservoirs (Austria, Denmark, Portugal, Iceland and Switzerland) over 75% of the water for public water supply is abstracted from groundwater, between 50-75% in Belgium (Flanders), Finland, France, Germany, and Luxembourg, and less than 50% in Norway, Spain, Sweden, and the UK (Eurostat, 1997).

Share of groundwater abstraction (Sources: OECD, 1997 and EEA, 1995) **Table 4.1**

Country	Groundwater abstraction in relation to total freshwater abstractions	
	OECD, 1997 (1991/1993)	EEA, 1995 1990 [1]
Austria	34%	53%
Belgium	9%	9%
Denmark	25%	99%
Finland	10%	8%
France	16%	16%
Germany	13%	13%
Greece	26%	28%
Ireland	19%	31%
Italy	23%	
Luxembourg	46%	46%
Netherlands	13%	7%
Spain	9%	15%
Sweden	20%	20%
UK – (E & W)	19%	19%
Average EU15	18%	12%
Iceland	91%	95%
Czech Rep.	18%	
Estonia		15%
Hungary	16%	16%
Poland	16%	16%
Portugal	42%	42%
Slovenia	22%	

(1) Mostly 1990 data but also some from 1980

Groundwater abstraction by major activity based on latest year available (Eurostat, ETC/IW questionnaire)

Table 4.2 **Apportionment of public water supply between groundwaters and surface waters (Eurostat 1997, and EEA, 1999a ^)**

	Surface water	Groundwater
Austria	0.7 3	99.3
Belgium – Brussels	100 5	0
– Flanders	48.5 4	51.5
Denmark	0 5	100
Finland	44.4 4	55.6
France	43.6 3	56.4
Germany	28.0 1	72.0
Greece	50 ^	50
Ireland	50 4	50
Italy	19.7 ^	80.3
Luxembourg	31.0 5	69.0
Netherlands	31.8 5	68.2
Portugal	20.1 0	79.9
Spain	77.4*5	21.4*
Sweden	51.0 4	49.0
UK	72.6 4	27.4
Norway	87.0 3	13.0
Iceland	15.9 5	84.1
Liechtenstein	ni	
Switzerland	17.4 4	82.6
Czech Rep.	56	44

Notes:
** Other public supply water sources amounting to 1.2% of total*
^ For supplies greater than 5000 persons (EEA 1999a)
0 = 1990, 1 = 1991, 3 = 1993, 4 = 1994, 5 = 1995

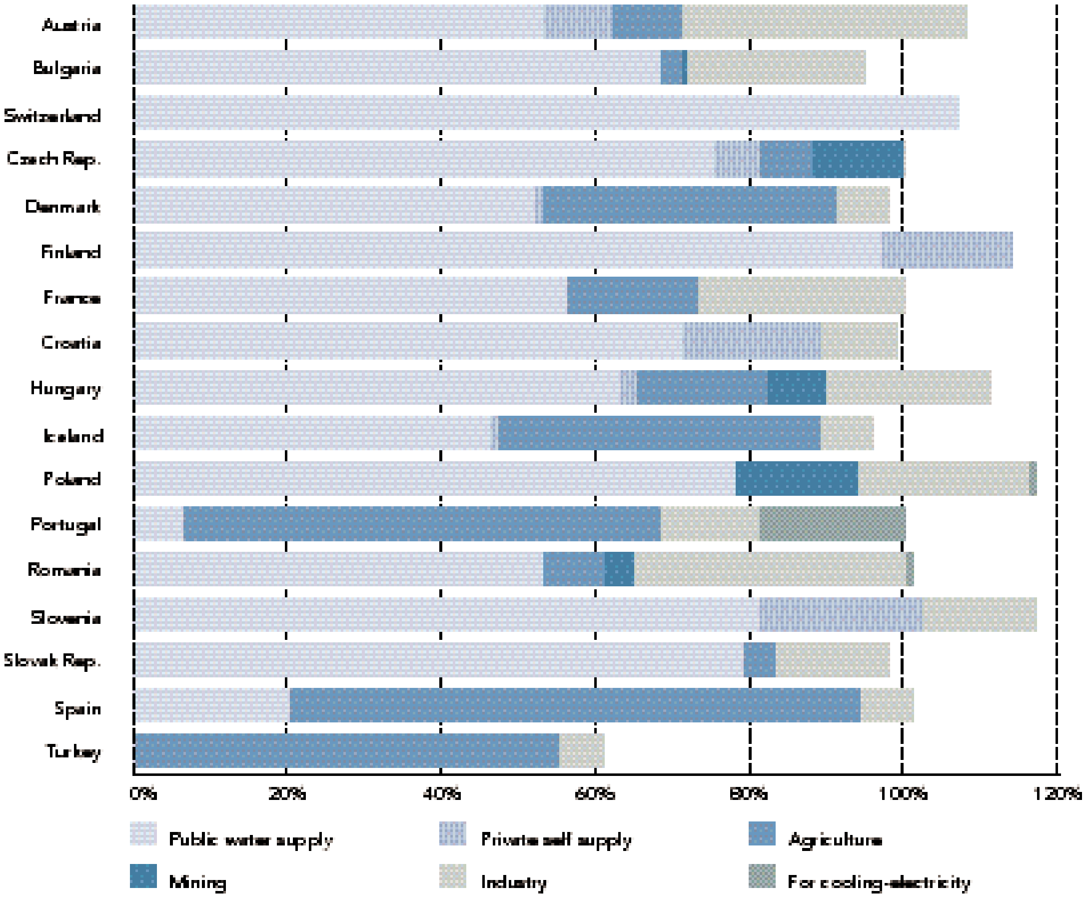
In the majority of European countries, total annual freshwater abstraction and total annual groundwater abstraction decreased between 1990 and the latest available year (mostly 1995). In fact, groundwater abstractions did not decrease to the same extent as total freshwater abstractions.

The groundwater abstraction for the major uses is illustrated in Figure 4.1 and are provided in EEA (1999). The relative values given for some countries in Figure 4.1 should be treated with some caution because of certain inconsistencies between years and sources. Note that due to a lack of data and inconsistencies in the data provided the total sum of groundwater abstraction per activity (Table 14 in EEA (1999)) does not correspond to the overall amount given in Table 13 of that report. This explains why in most of the countries groundwater abstraction by activity does not correspond to 100%. Nevertheless, it can be seen that public water supply is an important use of groundwater in many countries, for example in Austria, Bulgaria, Denmark and Finland, whereas in others such as Spain, Portugal and Turkey, agriculture is the predominant use.

4.2 Most important human interventions with related adverse effects on groundwater quantity

The nature and impact of human interventions is influenced by a number of different factors. They can be divided into hydrological characteristics and human pressures, and they vary strongly from region to region. These factors include climate, geology, Groundwater abstraction by major activity based on latest year available (Eurostat, ETC/IW questionnaire)

Figure 4.1



soil characteristics, topography, altitude, distance from the oceans, historical and current land use, water quality and population density.

For this monograph the opinions of national experts were sought on the most important human interventions with regard to adverse effects on groundwater. Experts were asked to select and rank the most important from a list of possible human interventions.

The interventions were divided into the following main categories:

1. *Decrease of groundwater quantity:*

- Groundwater abstraction/withdrawal;
- Lowering of surface water table;
- Increase of surface water run-off.

2. *Increase of groundwater quantity.*

Information was obtained from 25 countries. Experts were also requested to provide their criteria for the definition of “importance”. It is necessary to know why, and accordingly to which set of values, human interventions are considered to be important. Table 4.3 lists the country-specific definitions. However, it should be noted that the selection of the six most important aspects, as well as an evaluation of relative importance, is difficult and quite subjective. One third of the countries (seven) ranked their selections. Norway and Ireland did not report any important human interventions at the country level.

From the answers (see EEA, 1999) the following ranking of the most important human interventions in relation to groundwater was established:

1. Water abstraction for public supply;
2. Water abstraction for industrial purposes;
3. Water abstraction for agricultural purposes (especially irrigation);
4. Land drainage (especially associated with cultivation);
5. Increase of the surface water run-off by land sealing (especially by agriculture);
6. Lowering of the surface water table by river channelisation (due to drainage).

The information obtained indicates that the most common and important human interventions are those related to the category "groundwater abstraction". In some cases the number of entries for each category

Table 4.3 **Criteria for defining "importance"**

Country	Criteria for defining "importance"
Austria	1. Area impacted 2. Effect on groundwater tables
Bulgaria	Assessment related to human health and the environment
Croatia	Public water supply
Cyprus	Over-pumping
Denmark	1. Water for drinking purposes 2. Agriculture and industry 3. Other purposes
Estonia	1. Decreasing groundwater resource of deeper aquifers (water supply) 2. Decreasing the groundwater in shallow aquifers (de-watering of oil-shale mines, amelioration of cultivated land, water supply)
Hungary	Effects disturbing the balance in groundwater resources endangering drinking water supply, as well as the harmful lowering of shallow groundwater tables, depletion of wetlands.
Lithuania	Groundwater withdrawal
Romania	Modification of the physical and hydrological features of the aquifer, and changes in the groundwater dynamics
Slovak Republic	Decrease of surface streams discharges – full utilisation of groundwater sources without ecological impact
Slovenia	Extent of groundwater-level increase/decrease
Spain	Depletion of groundwater table, over-exploitation
Turkey	Over-abstraction

does not differ significantly so the ranking may have changed if more countries had provided information. The greatest difference in the selected interventions between the countries is caused by the strong interrelationship between the regional situation and human intervention on the one hand, and the different approaches for defining 'importance' on the other. Thus when considering this assessment, the criteria used to define importance should be kept in mind.

Box 4.1
Country specific remarks on human interventions

Austria
Austria is a country with abundant water resources. Nevertheless, and disregarding very local effects, the major impact on groundwater quantity was the drainage of 200,000 ha of land in the post war period in order to increase agricultural production. This drainage of land was accompanied by a straightening of water courses for better drainage and flood control. Minor impacts – according to the criteria applied – are due to the irrigation of about 76,000 hectares (1989) of land, especially in the eastern parts of Austria.

Czech Republic
Heavy machinery in agriculture and forestry, inadequate drainage of agricultural and forest lands, urbanisation (change of infiltration capacity of land), lowering of groundwater table because of river regulation (local problems).

Denmark
The most important problem is the lowering of the groundwater table from abstractions for water supply, agriculture and industry.

Finland
There is no significant over-exploitation of groundwater in Finland. Utilisation is generally less than yield.

France
Currently no assessments are available at the country level.

Hungary
- Groundwater recharge is lower drinking water abstraction in some areas, resulting in local depressions of the groundwater table over large areas of Hungary. Additional resources have been utilised (mainly the local, potentially polluted, shallow groundwater resources).
- A huge amount of groundwater pumped from shallow wells is used for irrigation.
- Pumping to decrease groundwater levels to prevent the flooding of bauxite, coal, and lignite mines has upset the groundwater balance. The greatest impact was in the Trans-Danubian Mountains where there was a 200-300 m local depression of the karst water table. Since mining ceased in 1990, the karst waters reserves have been replenishing.
- Drainage of lowlands causes decreasing water tables in the recharge areas.
- NW Hungary (Szigetköz): The river Danube has a new, artificial channel in Slovakia (Gabcikovo), built for the production of electricity. As a result, the recharge of the thick gravel aquifer from the river Danube has been disturbed. The river bed of the Danube was also dredged in many places.
- The higher transpiration of forests causes a lower infiltration rate, mainly in the recharge areas of the regional groundwater flow systems.

Iceland

Water abstraction in Iceland is mostly for public water supply and – quickly increasing – for fish farming. However, the most important human intervention in groundwater quantity is land drainage for cultivation and other land uses.

Ireland

None identified

Norway

Any problems of this sort are only at the local level – if any.

Portugal

The most important human interventions are those related to groundwater abstraction: agricultural use (76%), industrial supply (16%), public supply (8%). In some places this leads to the over-exploitation of groundwater.

Romania

The average consumption per capita, as well as the specific consumption in industry and agriculture, are higher than in other countries, because of the excessive water losses in the supply and distribution networks.

In Bucharest, for instance, the leakage losses reach 40 to 50%. In the irrigation systems water losses are 50 to 60%. The specific consumption in certain industries – such as the iron and steel industry, and the energy, chemical and textile sectors – is 1.5-2 times the consumption in more economically advanced countries.

The way in which the groundwater is used has a double negative effect:

- A high specific energy consumption, almost twice as high as necessary;
- An important imbalance of groundwater quantity.

Slovak Republic

In the Slovak Republic it would be possible to increase groundwater quantity by improving water management, mainly in Mesozoic structures.

Slovenia

In one aquifer there has been a lowering of the groundwater table by 5 m because of river channelisation and river bed gravel mining.

In another aquifer the groundwater level has increased because of river damming for a hydropower scheme.

5. Status of groundwater quality

5.1 Introduction

In this chapter, an overview of the status of Europe's groundwater is given in terms of important quality issues. Status is presented as distributions of selected quality indicators in the form of maps, figures and tables. The selected indicators are:
- nitrate;
- pesticides;
- chloride;
- alkalinity;
- pH-value;
- electrical conductivity.

Special emphasis is placed on nitrate and pesticides.

Countries were requested to submit the most recent available data at national level, together with that for at least three important groundwater areas (especially shallow groundwater bodies), with special emphasis on porous media. It should be noted that data from specific groundwater areas may not necessarily be representative of the national situation. The requested data for each determinand consisted of information on the numbers and types of sampling sites, and the frequency distributions of the annual mean values per sampling site.

It should be noted that the following sections provide a summary of the data and information provided by countries. The detailed data and information are provided in the technical report accompanying this monograph (EEA, 1999).

5.2 General remarks

5.2.1 Groundwater areas/regions

Map 5.1 shows the location of the important groundwater areas/regions for which groundwater quality data have been provided. The name and approximate area of each groundwater area/region is detailed in the technical report (EEA 1999). The level of information is very heterogeneous. Such regional areas may be administrative units (NUTS II, NUTS III regions or other units), land areas or groundwater areas, or, in some cases, even single sampling sites. Comparisons between these groundwater areas/regions are thus difficult to make.

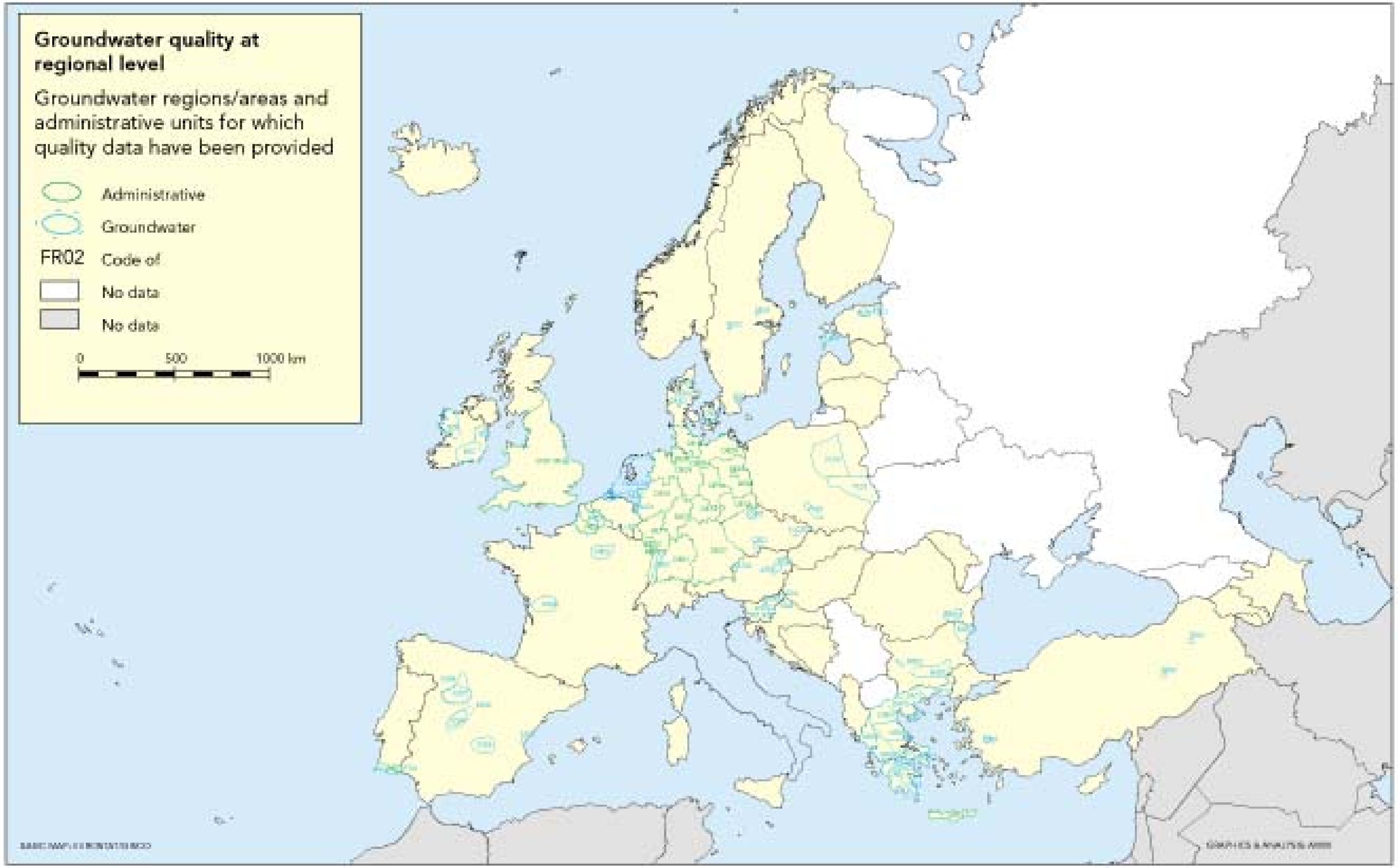
For each European country, the primary requirement would be the investigation and protection of the most important groundwater areas using certain defined criteria such as those adopted for the safeguarding of drinking water supplies.

5.2.2 Number of investigated sampling sites

In terms of the information provided by countries for this monograph, there was a fairly good correspondence between the number of sites providing information on nitrate, and the number of sampling sites in the inventory created in a previous study by the European Topic Centre on Inland Waters (EEA, 1997) (see EEA, 1999 for details).

The density of sampling sites (the number of sites per area) differs widely from area to area and from country to country. If the density at the country level is calculated by the total number of sampling sites divided by the land area, it has to be kept in mind that groundwater areas do not necessarily cover the total land area of a country (see section Characteristics of groundwater in the EEA area). Therefore, the comparison between countries may not be valid.

Map 5.1


Groundwater quality at regional level
Groundwater regions/areas and administrative units for which quality data have been provided
Administrative
Groundwater
FR02 Code of
No data
No data
0
500
1000 km

5.2.3 *Type of sampling sites*

Groundwater sampling sites can be identified according to their main purpose as follows:

- drinking water well;
- industrial well;
- monitoring (surveillance) well;
- other types of well (irrigation, spring, unknown use).

It is important to recognise that the different types of sampling site provide different status information. The intended supply purpose of a well (with its different quality demands) determines the choice of an aquifer and the location of a well. Drinking water wells, for example, are generally located in areas where groundwater quality is high in order to minimise treatment. Thus data solely gathered from drinking water wells may deliver a biased picture of the quality situation. Monitoring wells may also have different purposes with regard to differences in philosophies and policies between countries. Thus some may be located to give representative background information on groundwater quality. In that case, they are located at sites where it is possible to capture the whole groundwater aquifer without special focus on “hot spots”. On the other hand, if monitoring is for the control of emissions, special emphasis is put on the hot spots. This kind of well would thus mainly provide data on the poorest groundwater quality, and would not necessarily represent the average groundwater situation for a whole aquifer.

5.2.4 *Quality data*

When analysing the data provided by member countries, if more than one value per sampling site and year was obtained, then data are presented as annual mean values per sampling site. Sites with just one sample a year were also included in the analysis and treated as ‘annual values’.

Exploitation of groundwater from aquifers below forests are often preferred due to better water quality than in aquifers below agricultural areas.
Photo: Peter Warna-Moors/Geological Survey of Denmark and Greenland.

Sampling sites were then classified according to their annual mean values using the threshold values and ranges given in Table 5.1. The reasons for the choice of these particular thresholds are given in the sections on each determinand.

Countries were also asked to identify problem groundwater areas. A criterion for identifying problem areas (‘hot spots’) was that the annual mean values of at least 25% of the sampling sites within a region or groundwater area exceed a certain ‘critical’ value. The critical values used are given in Table 5.2. The reasons behind the selection of these values are also given in the individual sections on each determinand.

Table 5.1 **Concentration thresholds and classes used in the assessment of the groundwater quality data**

	class 1	class 2	class 3	class 4	class 5
Nitrate [mg/l]	≤ 10	> 10 – ≤ 25	> 25 – ≤ 50	> 50	
Pesticides [µg/l]	≤ 0.1	> 0.1			
Chloride [mg/l]	≤ 25	> 25 – ≤ 50	> 50 – ≤ 100	> 100 – ≤ 250	> 250
pH-value	≤ 5.5	> 5.5 – ≤ 6.5	> 6.5 – ≤ 7.5	>7.5 – ≤ 8.5	> 8.5
El. Conductivity [µS/cm]	≤ 200	> 200 – ≤ 50	> 500 – ≤ 1000	> 1000 – ≤ 2000	> 2000
Alkalinity [mval/l]	≤ 1	> 1 – ≤ 4	> 4		

Table 5.2 **Critical values for determining problem areas**

	zone 1	zone 2
Nitrate [mg/l]	> 25 – ≤ 50	> 50
Pesticides [µg/l]	> 0.1	
Chloride [mg/l]	> 250	
pH-value	≤ 5.5	> 8.5
El. Conductivity [µS/cm]	> 2000	
Alkalinity [mval/l]	≤ 1	

5.2.5 Presentation of status

The sections on groundwater quality in terms of the selected indicators include details on:

- Definition and general description of the indicator;
- Information on data received;
- Country specific comments;
- An overview at the country level, as well as at the regional level, on the number and type of sampling sites, and including frequency distributions of the annual mean values of each site. Information is presented, where appropriate, in the form of maps, bar charts and tables;
- Maps showing problem areas ('hot spots').

It has to be recognised that there may be great differences between the frequency distribution of particular indicators at the country level and the values at the regional level. The results at the country level may, thus, not yield sufficient information on determinands that are a major threat to groundwater as problems at a regional level may be masked by the national overview.

Box 5.1
Country specific remarks on groundwater quality

Austria
The data from the Marchfeld, Südliches Wiener Becken and Mattigtal aquifers have been combined to provide a general overview of groundwater quality in Austria. The data were obtained from Austria's national monitoring network of aquifers in porous media.
The Marchfeld and the Südliches Wiener Becken (both in the east of Austria) were selected as being the two largest aquifers in Austria. The groundwater area Mattigtal was selected for its size as well as for being representative of the situation in the central, western and southern parts of Austria. The geology of Austria, the karst areas, and the distribution of sampling sites within Austria's national monitoring network are described in greater detail in the publication "Jahresbericht 1994 – Wassergüte in Österreich".
No separate data on springs (in karst areas and others) are presented. Based on the data of the Austrian national monitoring network, these waters are of good to excellent quality: all mean values of nitrate in springs in karst areas are below 10 mg/l; and no concentrations of pesticides above 0.1 µg/l were observed.

Finland
Groundwater areas are numerous (7,141 areas (excluding Ahvenanmaa) and small (average area is approximately 2 km^2). The presentation and labelling of a map illustrating the data is thus quite difficult.
Because of the size of the groundwater areas, the data (nitrate, pesticides, and other determinands) is presented for the country level only.

France
Data on quality are from the National Groundwater Quality Database (ONQES). The statistics include all the sites for which data are available in the ONQES database, and they are five-year mean concentrations for the period under consideration. The five-year average is calculated from the annual averages of a site.
The majority of the sites included in ONQES are drinking water wells as most of the data come from the public health departments. This means that most sites classified as "unknown uses" are also likely to be drinking water wells.
Pesticide data available at the national level are insufficient to provide a representative overview. Because of variations in the database in relation to site density within an aquifer and across the country, the data do not provide a representative view of groundwater quality in France.

Iceland
In Iceland there has been no monitoring of pesticides in water. Pesticides are not considered a threat due to the very limited use of these compounds in the country.

Ireland
The EPA National Monitoring Programme commenced in November 1995 and up to now only a limited amount of sampling for pesticides has been undertaken. Sampling for pesticides to date indicates that the levels are below the detection limits.
Locations of sites in the national groundwater monitoring programme are at large groundwater abstractions. Some of the drinking water, industrial and other sites which have been presented are part of the national monitoring programme.

Portugal
Data do not include the Azores and Madeira.
There is no information available on pesticides.

Sweden

Data are exclusively provided by the national groundwater monitoring network.

Since 1993, environmental monitoring has been reviewed and new programmes are being drawn up. There are programmes at both the regional and the national level, and they include groundwater resources important for the ecosystem and for drinking water purposes. The programmes are not in full operation yet. There has been no monitoring of pesticides up to now.

Cyprus

Serious problems have been detected due to over fertilisation (intensive agriculture)

Estonia

Manure water from piggeries in Linnamäe and Viiratsi cause problems.

Germany

In Baden-Württemberg there is a major threat to groundwater, especially due to maize and special crop production.

Hungary

Monitoring of groundwater quality is the duty of the Waterworks Companies taking and analysing samples from their own wells. A countrywide monitoring network is under development. The chemical data provided for this monograph were collected by the Waterwork Companies in 1993. There is a groundwater monitoring network of 600 wells but most of these are wells for public supply.

A very important problem is that the sewerage systems of some settlements are not well developed, resulting in a high nitrate content of the shallow (<20 m) groundwater in villages. However, these polluted water resources are not used for water supply.

Large-scale livestock farms have polluted shallow groundwater with nitrate and ammonia.

Latvia

During investigations carried out in the 1970s and 1980s (hydrogeological mapping etc.) no serious problems of agricultural contamination of groundwater by nitrogen compounds were found in confined aquifers.

There are two point sources of groundwater contamination: the Jonava nitrogen fertiliser factory (nitrate in groundwater) and the Kedainiai phosphorus fertiliser factory (fluorine in groundwater).

Romania

The main problems are related to intensive contamination of aquifers with organic substances, ammonia and, especially, bacteria.

The most intensive cases of multiple quality depreciation were identified in the rural village area, because of the lack of the necessary sewerage facilities. As a result, the liquid wastes directly pollute the shallow groundwater (through water closets and sewers which are not waterproof), as well as indirectly (from waste deposits, improvised garbage holes, etc.).

Leakage and seepage loss from the fertiliser or chemical industrial estates of Arad, Targu Mures, Fagaras, Victoria, Isalnita, Ramnicu Valcea, Tumu Magurele, Giurgiu, Roznov and Navodari; material stockpiles and sludge thickeners from the coal power stations of Turceni, Rovinari, Iasi and Suceava; slime thickeners from Ocna Muresului, Govora, Valea Calugareasca, Tohanul Vechi and Tulcea

There is contamination by nitrate, nitrite, ammonia, chlorides, sulphates, sulphides, cyanides, caustic soda etc. in alluvial or fissured shallow, and even deeper aquifers, and severe deterioration of groundwater quality.

There is also percolation of atmospheric contaminants close to Savinesti, Isalnita and Pitesti

5.3 Nitrate

5.3.1 General description

The element nitrogen (N) is an essential constituent of protein for animal and plant life. In the environment, nitrogen is present in various forms: as nitrogen gas (N_2), nitrate (NO_3^-), nitrite (NO_2^-), ammonium (NH_4^+) and ammonia (NH_3). The relative concentrations of each depends on redox conditions, pH and the presence and activity of denitrifying bacteria.

(a) Nitrate in the soil

In soil, most nitrogen is immobilised in organic form. However, some nitrogen is mineralised to form nitrate, the rate and extent of mineralisation depending on the temperature, calcium content, pH, the soil water content and aeration conditions. Soil type, climate and land use are also important factors. In the soil, nitrate can:

- be taken up and used by plants;
- run-off to rivers;
- be lost as N_2O or N_2 to the atmosphere (via denitrification);
- be leached into lower soil horizons and eventually infiltrated into groundwater.

In undisturbed soils such as permanent meadows, very little nitrate reaches the lower soil horizons. However, high rates of nitrate leaching to groundwater can occur in disturbed soils, such as ploughed agricultural land, especially in the case where there is excessive fertiliser use.

(b) Nitrate in groundwater

Those aquifers underlying unsaturated zones with low nitrate reduction capacity are particularly vulnerable to nitrate pollution. Alluvial and shallow aquifers are thus particularly vulnerable to nitrate pollution, whilst deep or confined aquifers are generally better protected. However, surface or near-surface outcrops of confined aquifers can nevertheless allow nitrate to migrate towards deeper strata. Poorly designed or installed wells can also allow nitrate pollution to move rapidly downwards by connecting shallow, polluted layers to deeper strata.

The rate at which nitrate moves through an aquifer is affected by the permeability and extent of fissuring in the aquifer (which controls flow, diffusion and dispersion processes) and by other physical, chemical and biological processes (e.g. adsorption, degradation, – chemical and microbiological – and hydraulic gradient). The recharge rate of an aquifer also influences the groundwater flow regime and hence the movement of nitrate. ‘Fronts’ of advancing nitrate pollution have been observed in aquifers, at rates depending upon the hydrogeological conditions (type of aquifer, flow conditions, etc.). Typical vertical progression rates observed in experimental sites are one to two m/year in sandstone and around one m/year in chalk (Roberts and Marsh, 1990). However, groundwater, and hence nitrate, can move through chalk and sandstones at velocities of tens and even hundreds of metres a day in a horizontal direction. Similarly, in karst aquifers, nitrate pollution can move extremely rapidly in the groundwater body through the extensive network of fissures.

The advance of nitrate fronts in wells can be observed by a progressive increase in nitrate concentration, which may fluctuate according to seasonal and annual hydrological conditions. Over the past 30 years steady increases in nitrate have been observed in many wells in Europe

(c) Denitrification

(i) Denitrification in the unsaturated zone

Nitrate leached from near-surface soil layers migrates slowly through the deeper soil horizons. During this time, natural denitrification and volatilisation processes may reduce nitrate concentrations, in particular from the activity of denitrifying bacteria under favourable conditions (ready supply of organic matter, anaerobic zones, presence of iron or manganese creating reducing conditions in water-logged soils). The mineral pyrites (iron sulphide) is often present in soils and tends to enhance reducing conditions.

The quality of water in shallow wells supplying individual needs is often a risk.
Photo: Johannes Grath, Austria

The most favourable zones for denitrification are found in moist areas with high loads of organic matter, such as permanent meadows and areas of natural vegetation bordering rivers. For these areas, rates of denitrification as high as 1.3 to 2.4 N kg/ha per day have been estimated (Guillemin and Roux, 1992), with the highest rates in zones close to the water table. These areas thus play an important role in protecting groundwater and surface water.

In certain cases, lakes connected to groundwater can have a local effect on groundwater nitrate concentrations. It is assumed that this happens because of the high rates of bacterial denitrification in silts or the uptake of nitrogen by algae in the lake (Guillemin and Roux, 1992).

(ii) Denitrification in aquifers

Denitrification can also occur in the saturated zones of confined aquifers, where there are suitable anaerobic conditions. It is difficult to prove that denitrification is occurring in deep aquifers, but recent studies of nitrogen mass balances, isotopes (15N), gas and bacteriological data now provide good evidence. Chemical denitrification processes are also believed to occur in aquifers, but for this relatively specific conditions are required, such as high concentrations of iron and certain trace metals (copper or silver) (Barker et al., 1995).

(d) Environmental effects

(i) Drinking water for humans

Nitrate in drinking water can present a health risk to humans and animals. Nitrate is transformed into nitrite in the digestive system, which causes methaemoglobinaemia, a condition where inactivation of haemoglobin leads to a decrease in blood oxygenation carrying capacity. Infants and unborn babies are particularly at risk because of their low gastric acidity and undeveloped enzymatic system. Pregnant women and people with cardiovascular or renal diseases are also risk groups because of their high sensitivity to this pollutant (AELB, 1988).

Experiments suggest that neither nitrate nor nitrite acts directly as a carcinogen in animals, but there is some concern about a possible increased risk of cancer in humans from the endogenous and exogenous formation of N-nitroso compounds, many of which are carcinogenic in animals. Geographical correlation or ecological epidemiological studies have provided suggestive evidence relating dietary nitrate exposure to cancer, especially gastric cancer. It must be recognised that many factors in addition to environmental nitrate exposure may be involved (WHO, 1996).

In summary, the epidemiological evidence for an association between dietary nitrate and cancer is insufficient, and the guideline value for nitrate in drinking water is established solely to prevent methaemoglobinaemia, which depends on the conversion of nitrate to nitrite. Although bottle-fed infants of less than 3 months of age are most susceptible, occasional cases have been reported in some adult populations (WHO, 1996).

(ii) Livestock

The digestive system of ruminant animals, such as goats, sheep and cows, favours the transformation of nitrate into nitrite (and consequently the transformation of haemoglobin into methaemoglobin in the blood). Other non-ruminant animals such as horses and pigs are also sensitive to high levels of nitrate. Although ingestion via food is generally a more important intake, elevated nitrate levels in drinking water can also represent a risk.

(iii) Ecological impacts

Many aquifers discharge to (or are in hydraulic continuity with) rivers emptying into coastal areas, where elevated nitrate concentrations can lead to eutrophication. If the 'filtering' ribbon of river bank scrub, forest or natural meadow is removed between a river and an intensively used agricultural plain, nitrate pollution can pass from the plain to the river through the shallow groundwater. Large quantities of nitrogen in coastal waters may lead to excessive algal growth during the summer period, which can cause severe deoxygenation leading to sudden fish kills, toxic algal blooms and a general decrease in biodiversity. Wetlands such as oligotrophic fens and shallow soft water lakes are also potentially susceptible to nutrient enrichment from nutrients in groundwater (EEA, 1999a).

5.3.2 Status of nitrate in groundwater

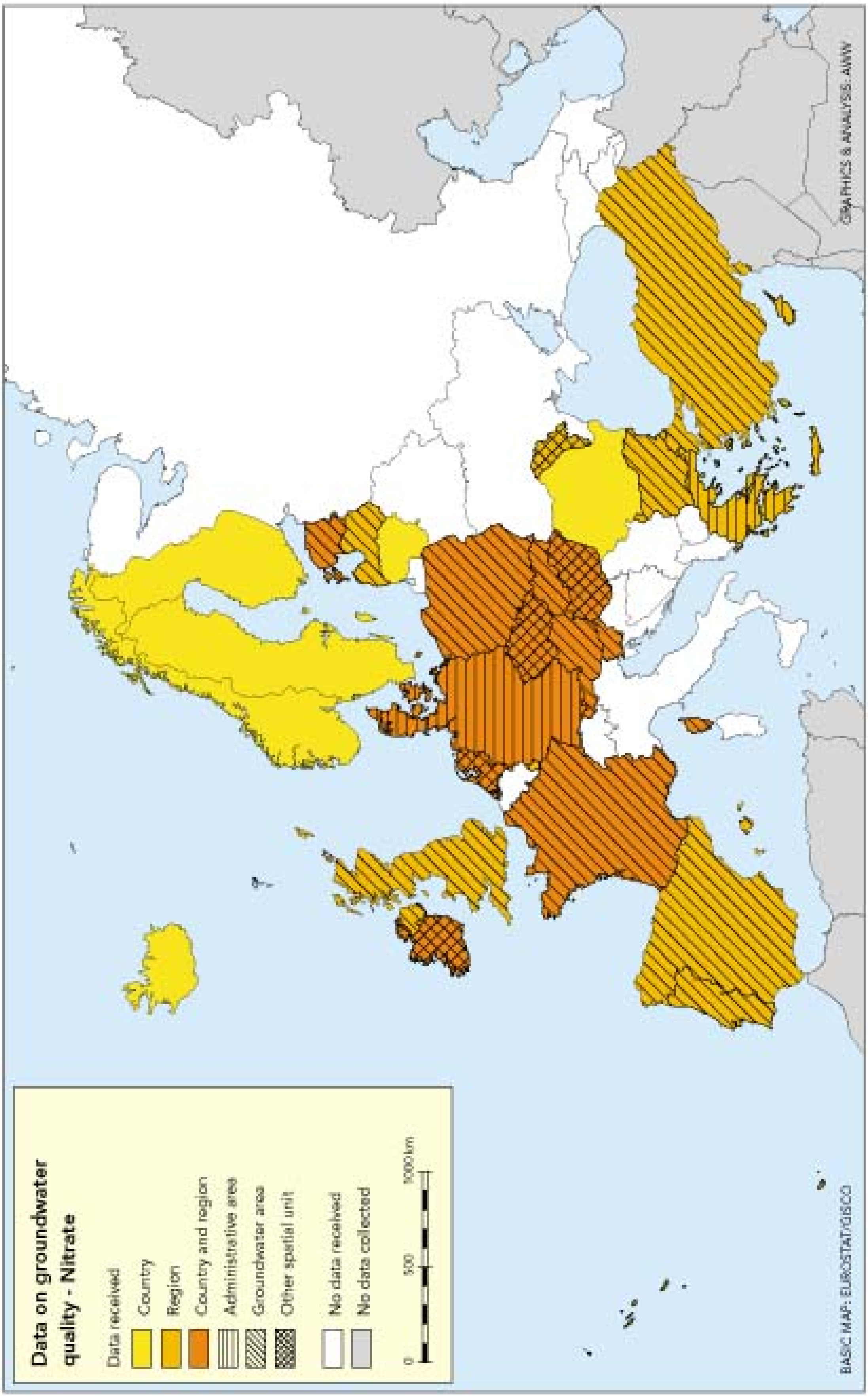
(a) Data received

Twenty eight countries provided data on nitrate: six at the country level; 12 at the country as well as the regional level; and 10 countries at the regional level only. Map 5.2 and Table 5.3 provide an overview of the information and data received on nitrate.

Nitrate – answers received (number of regions) **Table 5.3**

Country	Code	Country level	Regional level
Austria	AT	•	3
Bulgaria	BG		3
Cyprus	CY		5
Czech Rep.	CZ	•	3
Denmark	DK	•	3
Estonia	EE	•	3
Finland	FI	•	
France	FR	•	4
Germany	DE	•	16
Greece	GR		13
Hungary	HU	•	2
Iceland	IS	•	
Ireland	IE	•	3
Latvia	LV		4
Lithuania	LT	•	
Luxembourg	LU		1
Rep. of Moldova	MD		1
Netherlands	NL	•	9
Norway	NO	•	
Poland	PL	•	3
Portugal	PT		1
Romania	RO	•	
Slovak Rep.	SK	•	4
Slovenia	SI	•	6
Spain	ES		3
Sweden	SE	•	
Turkey	TR		2
UK	UK		4

Map 5.2
Nitrate – level of information received



(b) Country level

When making national comparisons it is important to consider the number and type of sampling sites (as well as the sampling frequency) on which the comparison is based. Figure 5.1, and data in the technical report (EEA, 1999), give a partial indication of the heterogeneity of the collected data in terms of the number and types of sampling sites at the country level. The number of sampling sites varies between four wells in Norway and 5805 sampling sites in France. In Finland, Hungary, Iceland and Ireland most of the sampling sites are drinking water wells.

Figure 5.2 shows the frequency distributions of nitrate in groundwater for 17 countries. Within this graph the limits of the concentration classes were set at 10, 25 and 50 mg NO_3/l. These limits were selected because the natural content of groundwater is up to 10 mg NO_3/l, and because a guide level of 25 mg NO_3/l and a maximum admissible concentration of 50 mg NO_3/l are given in the Drinking Water Directive (80/778/EEC). It should be noted that the guide level in the Directive has no recommended statistical expression (e.g. maximum, average or percentile), and the maximum allowable concentration is the concentration not to be exceeded in any individual result (sample).

In seven countries the level of 25 mg NO_3/l is exceeded at about 25% of sampling sites. In Romania, even the maximum admissible concentration of 50 mg NO_3/l is exceeded at up to 35% of all sampling sites.

A comparison of the type of sampling site with the frequency distribution of nitrate shows that in countries with a high proportion of samples taken in drinking water wells the nitrate levels are quite low.

Nitrate – types of sampling sites at the country level **Figure 5.1**

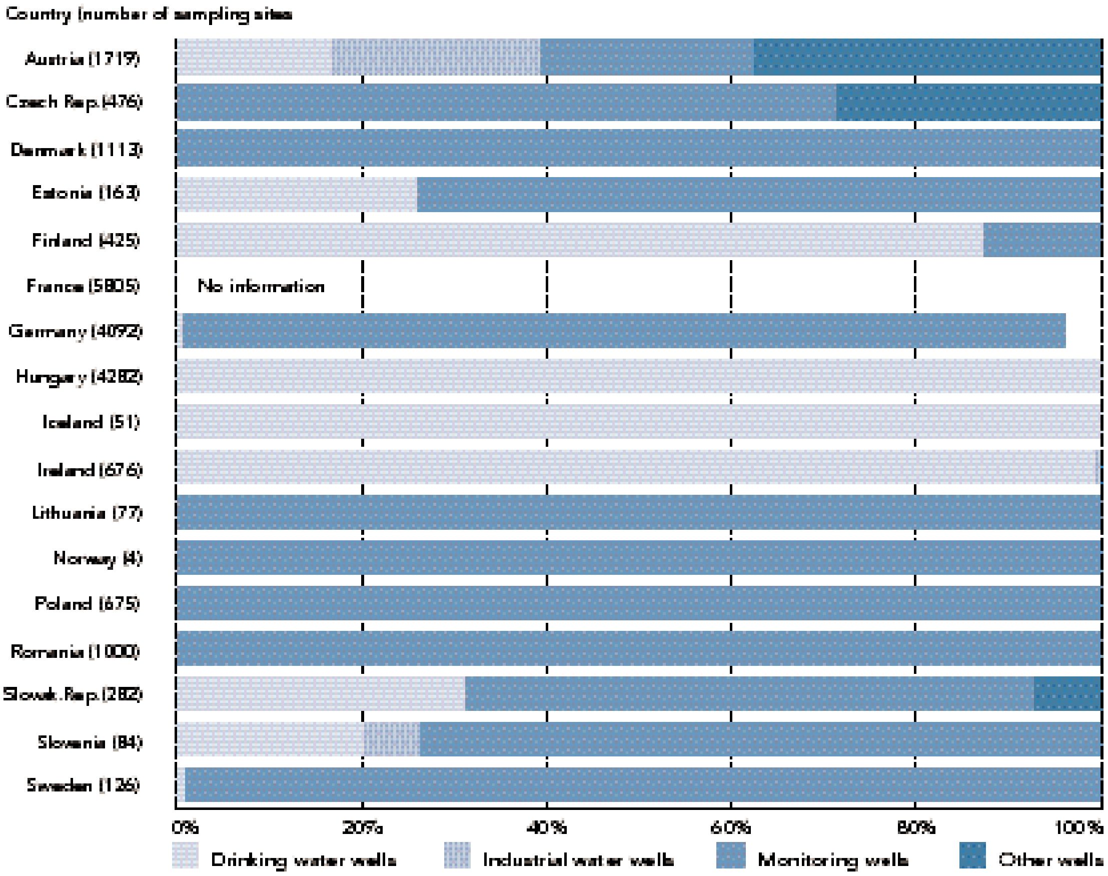
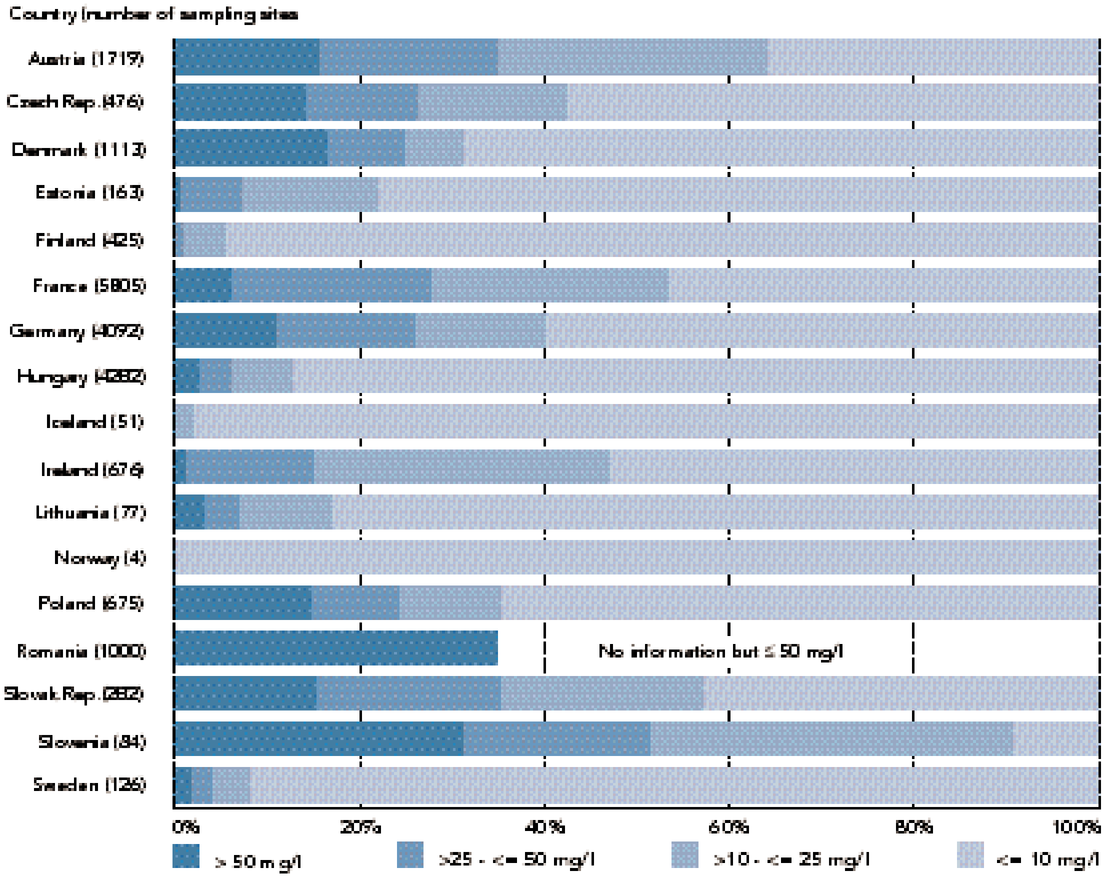


Figure 5.2 Nitrate – qroundwater quality at the country level



Map 5.3 illustrates the frequency distribution of nitrate in groundwater and is again supplemented by information from countries which delivered data at the regional level only: the number of regions and sampling sites is given at the bottom of each bar chart.

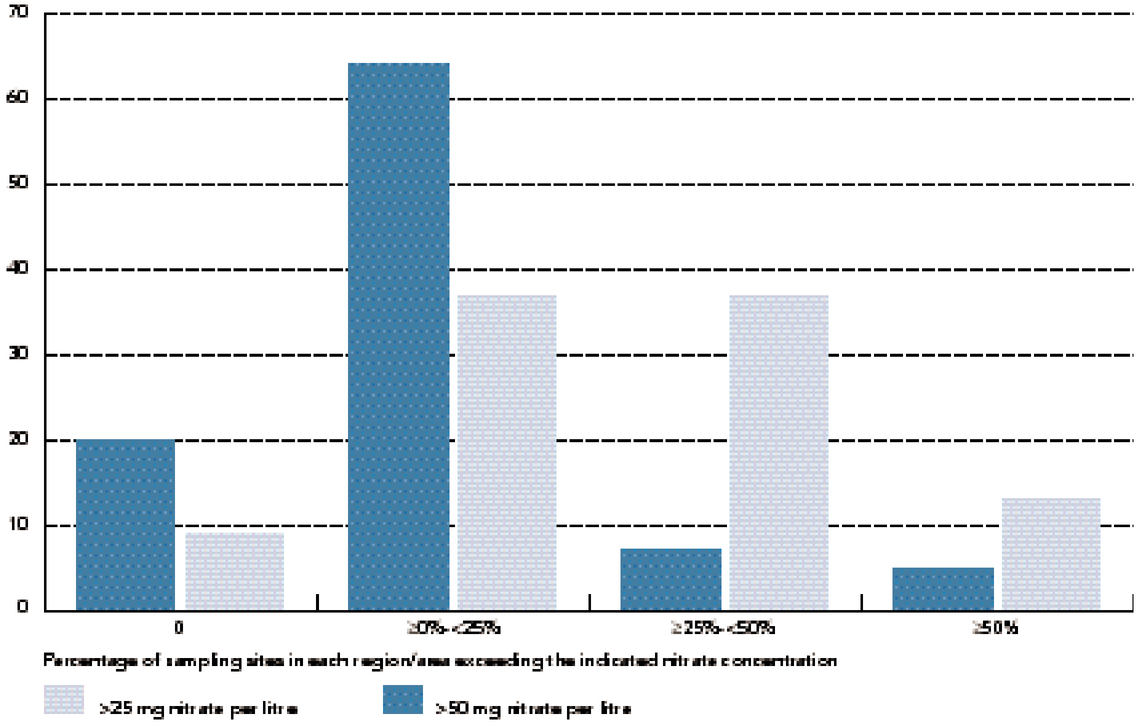
(c) Regional level

Country level data indicate that nitrate in groundwater is a significant problem. In order to identify ëhot spotsí in Europe, it is necessary to focus on the regional or provincial level. Twenty two countries delivered data on 96 regions or groundwater areas. At the regional level the number of sampling sites varies between two and 71,000 (a region in the Republic of Moldova).

In 50 regions/areas, at least a quarter of the sampling sites exceed the level of 25 mg NO_3/l, and in 13 regions/areas this level is exceeded at least half of the sampling sites (Figure 5.3). The maximum admissible concentration of 50 mg NO_3/l is exceeded at up to 67% of sampling sites in a French groundwater area, a Dutch region and a Slovenian groundwater area. In 12 regions/areas, the level of 50 mg NO_3/l is exceeded at a quarter or more of investigated sampling sites. Only 20 regions/areas out of the 96 reported had no sampling sites with annual mean values equal to or greater than 50 mg NO_3/l.

A comparison of data at the country level from Austria and France with data at the regional level, shows partially significant variations (Table 5.4). In France, for instance, the proportion of sampling sites with annual mean values of more than 50 mg NO_3/l is about 6%. At the regional level this amount varies between 0% and 67%. In Austria about 15% of the total sampling sites show annual mean values of more than 50 mg NO_3/l. At the regional level this varies between 0% and 57%.

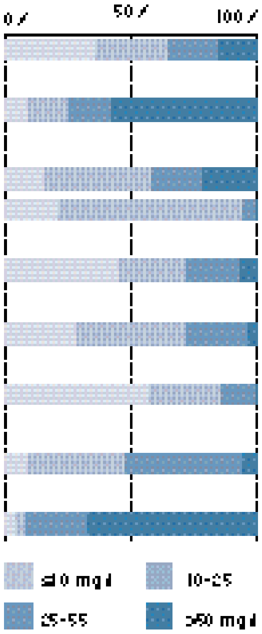
Number of regions where a nitrate level of 25 and 50 mg NO_3/l is exceeded at none, 0-25%, 25-50% and ≥ 50% of the investigated sampling sites **Figure 5.3**



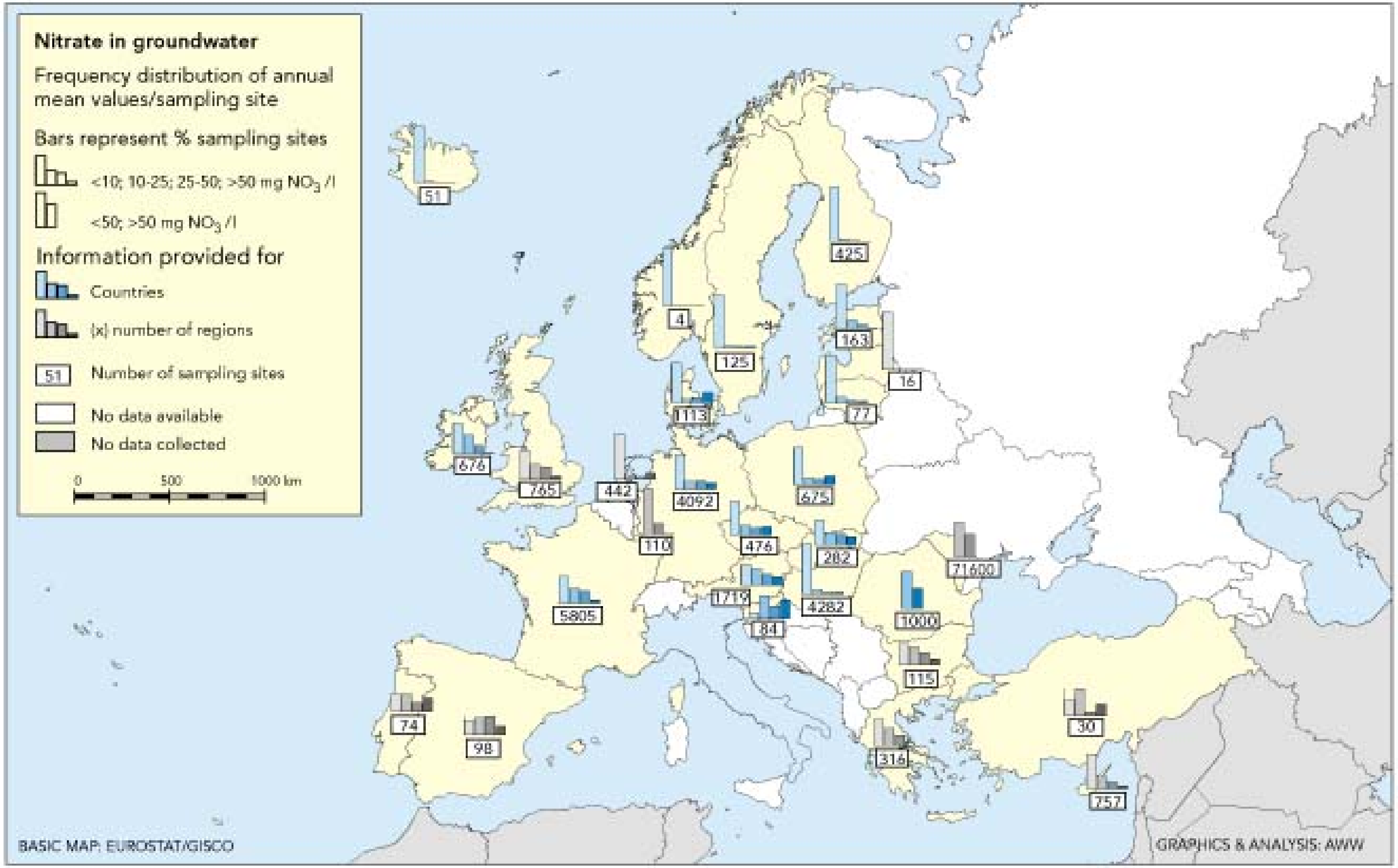
Note:
Total number of regions: 96

Nitrate – comparison between information at the country level and at the regional level **Table 5.4**

			nitrate classes in %			
			<10 mg/l	10-25	25-50	>50 mg/l
					year	
Austria		95/96	36	29	20	15
	region					
	Marchfeld	95/96	9	16	18	57
	Suedliches Wiener Becken	95/96	16	42	21	21
	Mattigtal	95/96	21	74	5	0
France		1991-95	47	26	22	6
	region					
	Nappe d´Alsace	1991-95	29	43	25	3
	Calcaires de Champigny	1991-95	57	29	14	0
	Craie du Nord et de la Picardie	1991-95	10	39	47	5
	Jurassique de Poitou-Charentes	1991-95	4	4	25	67



Map 5.3 Nitrate in groundwater. Frequency distribution of annual mean values and number of sampling sites



(d) Problem areas

Seventeen countries submitted information on nitrate problem areas (Map 5.4). Problem areas ('hot spots') were divided into two zones as follows:

- In zone 1 at least a quarter of the sampling sites within a region or groundwater area have an annual mean value exceeding 25 mg NO_3/l;
- In zone 2 at least a quarter of the sampling sites within a region or groundwater area have an annual mean value exceeding 50 mg NO_3/l.

Using the above criteria there are 'hot spots' in Austria, Denmark, France, the Netherlands and Slovenia. Belgium, Finland and Switzerland have zones where 25 mg NO_3/l and 50 mg NO_3/l are exceeded, whereas problem zones in Spain refer to levels of 20 mg NO_3/l and 50 mg NO_3/l. Greece and Portugal indicated areas where 50 mg NO_3/l is exceeded, and Romania and the Republic of Moldova have areas exceeding 45 mg NO_3/l. Hungary, Lithuania and Bulgaria did not demarcate areas but indicated monitoring wells exceeding 25 mg NO_3/l and 50 mg NO_3/l. Poland indicated monitoring wells exceeding the Polish standard of 10 mg NO_3-N/l (= 45 mg NO_3/l). In the Republic of Moldova and Poland, a large number of areas/wells exceeding 50 mg NO_3/l and 45 mg NO_3/l, respectively, can be found all over the country.

(e) Trends

Trends in groundwater quality can only be evaluated for single sampling sites if time series over a relatively long period are available. Groundwater sampling sites usually reflect the state of groundwater for a very limited area. Thus the number of sites required to obtain a balanced or representative view of the whole aquifer must take into account any local effects or differences in quality. Therefore, the illustration of trends for single sampling sites without statistical knowledge and interpretation of other relevant sites may lead to completely wrong conclusions. Only a few countries provided information concerning trends of nitrate in groundwater. The information on trends between 1990 and the mid-1990's is summarised in Table 5.5, followed by brief comments on each country.

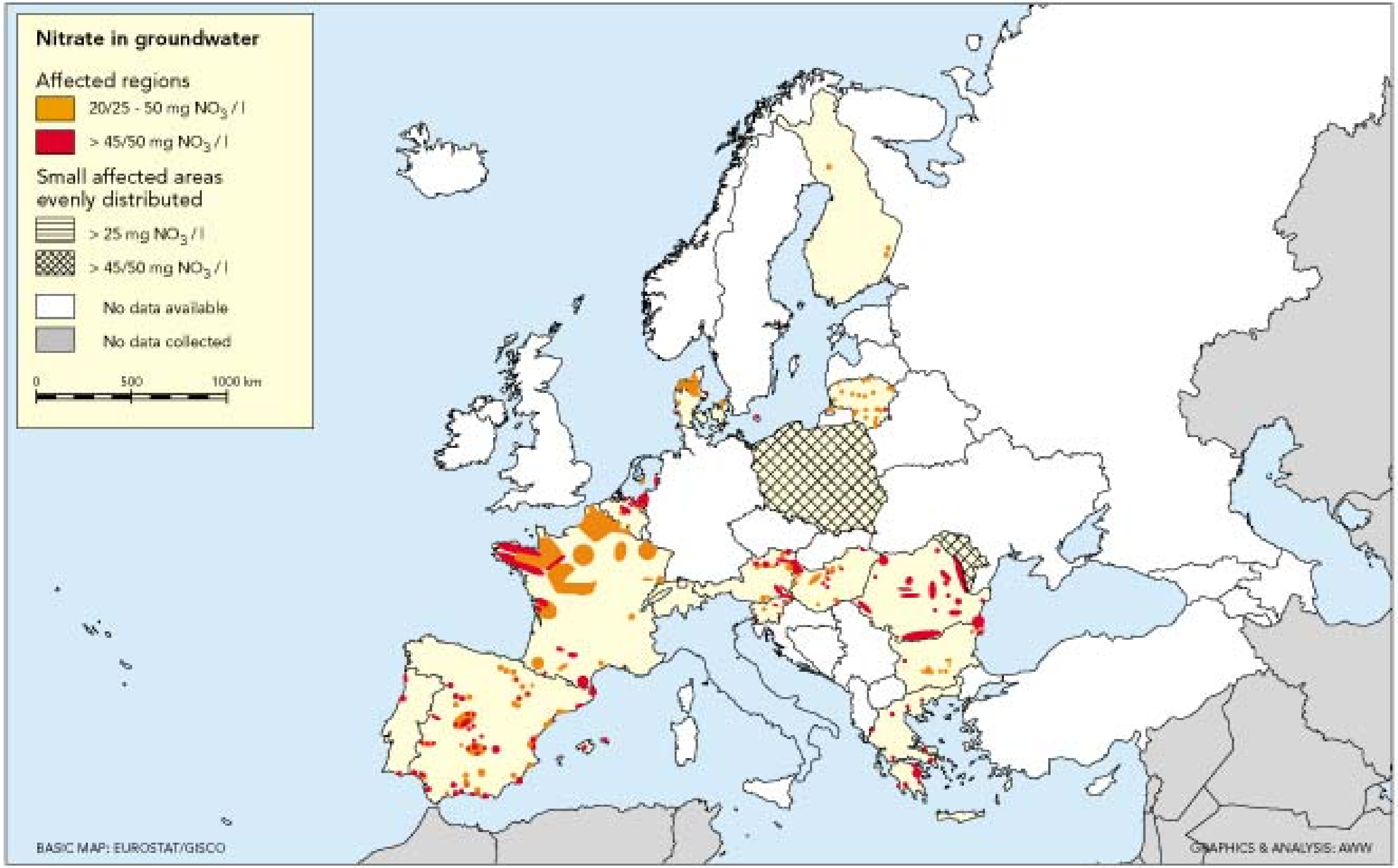
Percentage of monitoring stations with increased, unchanged or decreased nitrate concentrations (Compiled by ETC/IW from multiple sources)

Table 5.5

Country	Nitrate in groundwater, change from early 1990s to mid 1990s			
	Number of sites	Increased%	Unchanged%	Decreased%
Austria	979	13	72	15
Denmark	307	26	61	13
Finland	40	27	43	30
Germany	3741	15	70	15
United Kingdom [1]	1025	8	80	12

1 England and Wales

Map 5.4
Nitrate – problem areas



(i) Austria

In Austria, a trend analysis was carried out over the period from 1992 to 1994 for 979 sampling sites which were monitored four times a year. In general, nitrate concentrations are relatively stable. Seventy two percent of the 979 sites did not show a statistical trend, increasing trends were found at 13% and descending at 15% of the sampling sites.

(ii) Denmark

Over the last 8 to 10 years some restrictions have been imposed on farming. Table 5.5 shows that nitrate increased at 26% of the sites, remained unchanged at 61% and decreased at 13%.

(iii) UK

In England and Wales, trends have been calculated over the period 1945 to 1996 for 1244 boreholes located in nine aquifers (Table 5.6). [Note: UK trends in Table 5.5 cover a more recent period]. About seven aquifers show increasing average nitrate trends between 0.3 and 2.0 mg/l/year and two aquifers show decreasing trends of -0.1 mg/l/year. In one of the nine aquifers the percentage of boreholes with decreasing nitrate concentrations exceeds the percentage of boreholes with increasing nitrate concentrations.

Table 5.6

Percentage of boreholes with significant nitrate trends over the period 1945 – 1996 in England and Wales

Aquifer name	% Increasing	% Same	% Decreasing	Number of Boreholes	Average Nitrate Trend (mg/l/year)
Upper Greensand	100	0	0	1	2.0
Great Oolite	50	50	0	2	-0.1
Chalk and Upper Greensand	25	75	0	8	1.2
Inferior Oolite	22	44	33	9	0.8
Jurassic Limestone	27	73	0	15	0.6
Lower Greensand	40	51	9	35	-0.1
Permo Triassic Sandstone	66	29	6	126	0.4
Chalk	40	51	9	209	0.5
Unknown type	38	52	10	824	0.3
Overall	**41**	**50**	**10**	**1229**	**0.4**

Table 5.7

Nitrate concentrations (mg NO_3/l) in Finnish private groundwater wells in 1958 and 1990

Year	Number of samples	5 percentile	25 percentile	Median	75 percentile	95 percentile	maximum
1958 (a)	2593	0	1	5	17	60	198
1990 (a)	1415	<0.1	0.5	4.6	15	43	233
1996 (b)	1426			1.0			62

(a) (Heinonen P. 1998, Wäre, 1961 and Korkka-Niemi et al., 1993) and in raw water samples of Finnish groundwater supply areas in 1996

(b) Kujala-Räty et al. 1998)

(iv) Finland

Finland provided a map with 40 locations for which trends have been assessed. At 17 sites (42.5%) there was no trend observed, 11 sites (27.5%) showed an increasing trend and 12 (30%) sites showed a descending trend.

Additional information from private groundwater wells in Finland (Heinonen 1998) is presented in Table 5.7(a) and compares nitrate concentrations in 1958 with those in 1990. Even though the median values for the two years are similar, some of the percentile concentrations suggest that concentrations in 1990 were generally lower than those in 1958. However, the maximum found in 1990 was higher than that in 1958. The private wells serve approximately 310,000 households (approximately 12% of the population). Groundwater is also supplied to around 2.5 million people in Finland via water works and as Table 5.7(b) clearly shows, the nitrate concentrations in these boreholes are much lower than in the samples taken from the private wells.

(v) Germany

A comprehensive report on nitrate in groundwater in Germany (LAWA, 1995) presents trend investigations in various types of aquifers. In several provinces an increasing trend (0.5 to 1 mg/l NO_3 per year) from the mid fifties and the beginning of the sixties was observed at water supply wells. At the end of the eighties no further increase was detected. Since then concentrations have remained the same and at some sampling sites a descending trend has been observed. It is generally assumed that annual nitrate concentrations in groundwater will further increase.

(vi) Spain

Spain provided nitrate data for three groundwater regions (Figure 5.4). Time series span 1991/92 to 1995. The number of sampling sites providing data in each year is given below the reference year (in brackets).

Other countries did not provide sufficient trend information.

(f) Conclusions

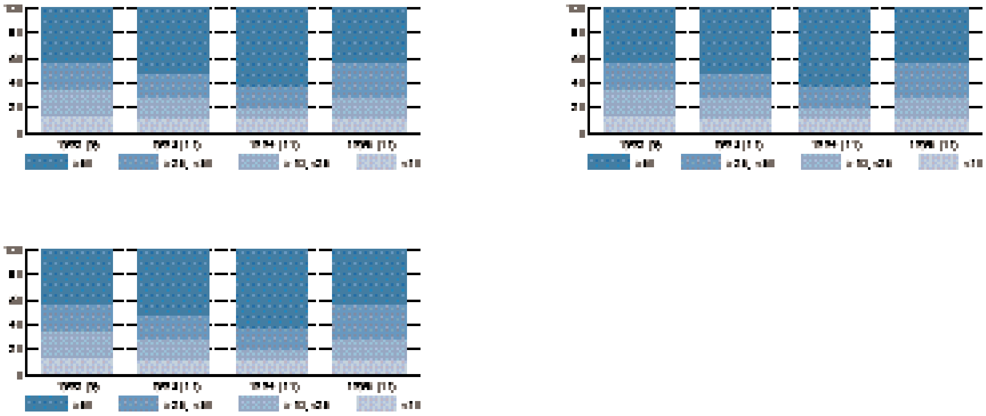
Nitrate in groundwater is still a significant problem in some parts of Europe as information at the country and regional level, and on ‘hot spots’ shows. Information gathered at the country level indicates that in about seven of 17 countries the guide level of 25 mg NO_3 /l is exceeded at more than a quarter of the sampling sites. In the Republic of Moldova about 35% of the sampling sites exceed the maximum admissible concentration of 50 mg NO_3 /l.

At the regional level only in 9% (9) of 96 reported regions or groundwater areas do all annual mean values of all sampling sites fall below the guide level of 25 mg NO_3 /l (Figure 5.3). In 21% (20) of the regions the maximum admissible concentration of 50 mg NO_3 /l is not exceeded. In 13% (12) of the reported regions more than a quarter of the sampling sites exceed 50 mg NO_3 /l and in about 52% (50) of the regions more than a quarter of the sampling sites exceed the nitrate guide level of 25 mg NO_3 /l.

Partly significant differences are evident when comparing data at the country level with data at the regional level. More detailed and comparable information can be found by collecting data at the regional or provincial level.

Nitrate time series of three Spanish groundwater areas (number of sites in brackets, concentrations in mg NO_3/l

Figure 5.4



Six countries provided information concerning trends of nitrate in groundwater. Some data show statistically significant decreasing as well as increasing trends.

The comparison of synthetic nitrogen fertiliser usage (Figure 3.3) with nitrate in groundwater at the country level does not show a direct relationship. However, synthetic nitrogen fertiliser usage is not the only pressure exerting an influence on the nitrate content of groundwater, but it nevertheless should give an estimate of the nitrogen load of the environment.

Furthermore, there are a lot of factors influencing the input of nitrogen (also organic fertilisers, sewage, etc.), its transfer and the measured values of nitrogen in groundwater. The gathering of groundwater data and the philosophy of sampling (especially the location and the types of sampling sites) play a major role as well as the time lag between the input and the measured content of nitrate in groundwater.

5.4 Pesticides

5.4.1 Criteria for assessing quality data

Pesticides by their nature are designed to kill unwanted organisms. Most act by interfering with biochemical and physiological processes which are common to a wide range of organisms. This results in them being potentially harmful to non-target organisms and, therefore, can be serious pollutants even in low concentrations. The widespread use of pesticides inevitably leads to a mixture of pesticides being present in surface water and groundwater. There may also be degradation products and isomers of the pesticides present. Some of these chemicals may react synergistically or at least additively.

Standards for the use and regulation of pesticides are set internationally (see Section 7.2 and below) and nationally. The derivation of standards would consider a number of factors including the pesticides chemical and physical properties to predict the major fate and behaviour pathways in the environment which may influence the eventual concentrations occurring in water, sediments or biota. An assessment of fate in the environment would consider the substance's degradation properties and it's form (complexed or dissolved). This would then identify the persistence of the substance and its main sink (e.g. does it adsorb to sediment or does it volatilise). Pharmacokinetics, toxicology and bioaccumulation information is also used to assess the effects on aquatic life and mammals (including humans).

The European Commission's Directive on Drinking Water (80/778/EEC) establishes maximum allowable concentrations (in any single result/sample) for pesticides in water for human consumption of 0.1 µg/l for individual substances and for total pesticides of 0.5 µg/l. These have become statutory limits in many European countries. The World Health Organisation (WHO) has also considered and proposed limits for many pesticides in drinking water. In some cases WHO proposed limits are higher than the limit set by the Directive, e.g. chlordane 0.2 µg/l, but some are lower, e.g. heptachlor and aldrin/dieldrin all at 0.03 µg/l. For the purpose of this report, the EC limits of 0.1 µg/l and 0.5 µg/l are used when assessing the significance of quality data. Even though groundwater is a prime source of drinking water this assessment does not imply that these levels of pesticides are necessarily reaching the consumers of drinking water as treatment may take place before supply, and not all the groundwater monitored will necessarily be used for drinking. In surface waters, and also in groundwaters connected to surface waters, other limits that protect aquatic organisms both short and long term would also be relevant.

There are examples of priority lists of pesticides used for regulation and information within Europe. Examples are given in Table 5.8. The list includes the UK Red List, the PAN (Pesticides Action Network) Dirty Dozen, the WHO Hazard Class 1a and 1b, the List I (Black list) and the List II (Grey list) of most harmful chemicals quoted in the EC Dangerous Substances Directive (76/464/EEC), and Annex 1A of the North Sea Agreement. There are also two major internationally recognised classifications of potential carcinogens which include pesticides. One is from the IARC (International Agency for Research on Cancer) and the other from the US Environmental Protection Agency. The use of some of these pesticides is now banned at international level and/or in specific countries.

5.4.2 Status of pesticides in groundwater

Table 5.9 and Map 5.5 give overviews of the active substances that have been detected in groundwater in at least two countries out of Austria, Denmark, France, Germany, Greece, Italy, Netherlands, Sweden and United Kingdom (Source: INFU, 1995).

In addition, the number of EU countries where the active substance is approved for use is given. It should be noted that to some extent the substances detected will depend on which ones are monitored for, and the extent to which groundwaters are monitored in any particular country.

Table 5.8

Overview of pesticides and other dangerous organic substances listed in Council Directive 76/464/EEC and other priority lists

	North Sea Conference Annex 1A	PAN Dirty Dozen 1995	UK Red List	List I or candidate List I,[1]
1,2-Dichloroethane		•	•	
2,4,5-T		•		
Aldicarb		•		
Aldrin*		•	•	•
Atrazine	•		•	•
Azinophos-ethyl	•			•
Azinophos-methyl	•		•	•
Camphechlor (Toxaphene)**		•		
Chlordane**		•		•
Chlordimeform	•			
DBCP		•		
DDT** (DDD, DDE)	•	•	•	•
Dieldrin**		•	•	•
Dichlorvos	•		•	•
Dioxins	•			
Drins	•			•
EDB**		•		
Endosulfan	•		•	•
Endrin*		•	•	•
Fenitrothion	•		•	•
Fenthion	•			•
HCH/BHC**	•	•		•
Heptachlor**		•		•
Hexachlorobenzene	•		•	•
Hexachlorbutadiene	•		•	•
Lindane		•	•	•
Malathion	•		•	•
Paraquat		•		
Parathion	•	•		•
Parathion-methyl	•	•		•
Pentachlorophenol	•	•	•	•
Polychlorinated biphenyls		•	•	
Simazine	•		•	•
Trichlorobenzene	•	•		
Trifluralin	•		•	•

(Source: Annex 1A: specified by the North Sea agreement; UK Red List, Carter A.D., Heather A.I.J., 1995; Dirty Dozen 1995 Chart specified by PAN North America, 1995, Panna, 1997).

Note: inorganic substances are not included in this table

[1] *Directive 76/464: This is not an exhaustive list of the substances mentioned in this document*

• *listed in the document;*

* *severely restricted in the European Community*

** *banned in the European Community*

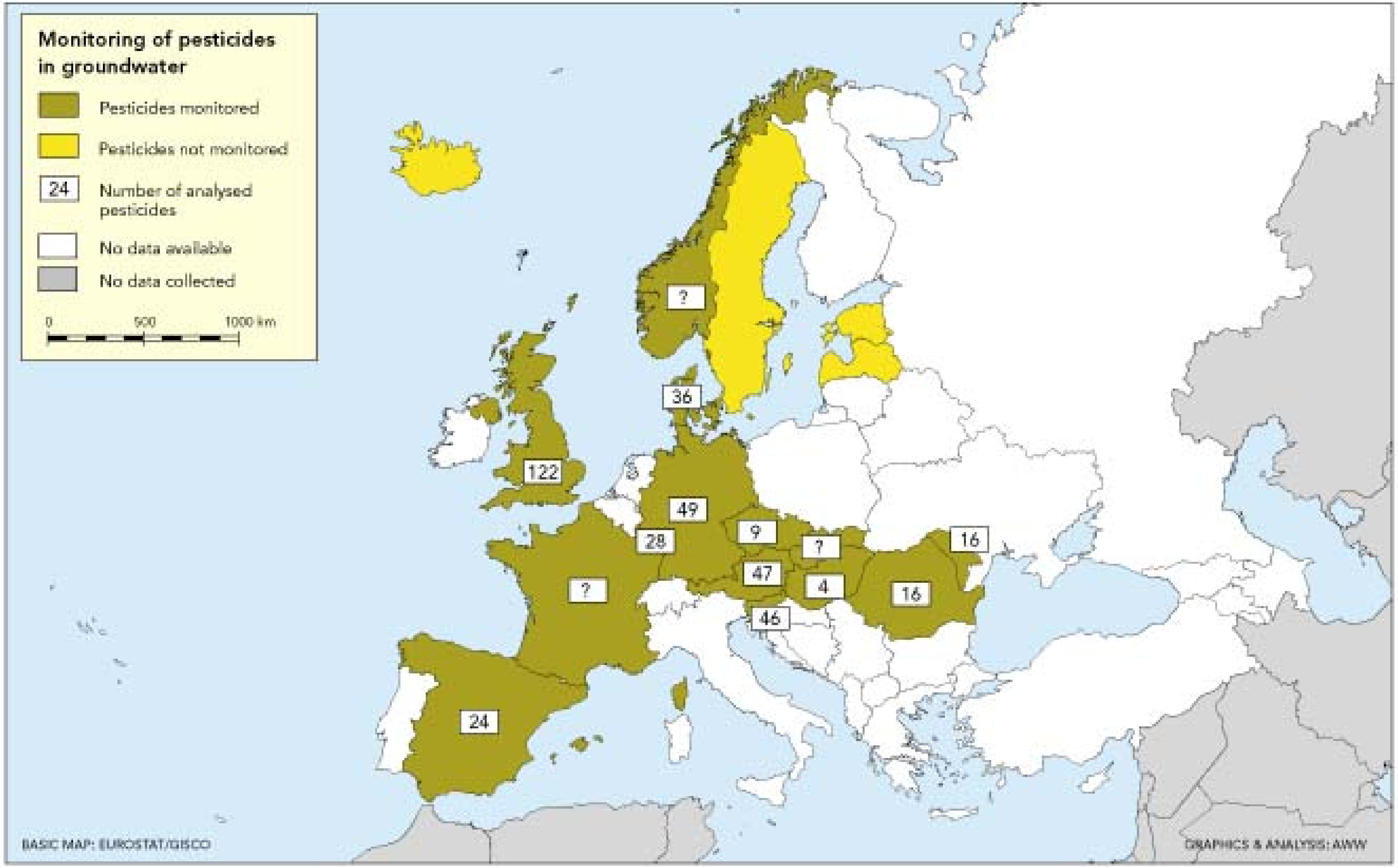
Table 5.9 **Number of EU countries where the pesticides are approved, monitored and detected (INFU, 1995)**

Pesticide	number of countries	
Common name (active ingredient)	approved (out of 15)	detected/ monitored (out of 9)
Herbicides		
Atrazine	10	7/7
Simazine	13	7/7
MCPP	13	7/7
2,4-D	14	6/6
Diuron	13	5/5
MCPA	15	5/6
Dichlorprop (2,4-DP)	10	5
Chlortoluron	12	4/4
Isoproturon	14	4/4
Linuron	14	4/4
Bentazone	15	4/4
Propazine	0	4/5
Alachlor	5	4/5
Metolachlor	10	4/5
Prometryne	11	4/6
Atrazine-Desethyl	*	3/3
Atrazine-Desisopropyl	*	3/3
MCPB	5	3/3
Bromacil	10	3/3
Metobromuron	11	3/3
2,4,5-T	2	3/4
Carbetamide	10	2/2
Bromoxynil	14	2/2
Dicamba	15	2/2
Ioxynil	15	2/2
Cyanazine	12	2/3
Pendimethalin	14	2/3
Terbuthylazine	14	2/3
Methabenzthiazuron	15	2/3
Terbutryn	12	2/4
Atrazine-Desethyldesisopropyl	*	2/2
Dinoseb		2/2
Sebutylazine		2/2
TCA	6	2/2
Hexazinon	8	2/2
Metoxuron	10	2/2
Insecticides		
Dimethoate	15	6/6
Hexachlorocyclohexene		5/5
Aldrin		4/4
Lindane	12	4/6
DNOC	6	2/2
Terbufos	9	2/2
DDT		2/3
Vinclozolin		2/3
Fenitrothion	11	2/4
Malathion	12	2/5
Parathion	8	2/6
Fungicides		
Carbendazim	14	2/2
Chlorothalonil	14	2/2
Iprodione	15	2/2
Hexachlorobenzene		2/5
Other		
1,2-Dichloropropane	3	2/2
Dikegulac	6	2/2
1,3-Dichloropropene	9	2/2
Aldicarb	11	2/2

** metabolite*

Approved: Number of EU 15 countries where each active substance is on the market. (Status on 14 Oct. 1996 for authorisations of active substances on the market 23 July 1993.

Detected/monitored: Number of countries where the active substance was detected and monitored in groundwater



Map 5.5
Countries where pesticides in groundwater are monitored and not monitored and the total number of monitored pesticide substances

Table 5.10 Information received on pesticides

Country	Code	Country level	Regional level
Austria	AT	•	3
Czech Rep.	CZ	•	3
Denmark	DK	•	3
France	FR		2
Germany	DE	•	2
Hungary	HU	•	
Luxembourg	LU		1
Rep. of Moldova	MD		2
Norway	NO	•	
Romania	RO	•	
Slovak Rep.	SK	•	1
Slovenia	SI	•	6
Spain	ES		3
United Kingdom [1]	UK		4

1 England and Wales

5.4.3 Data received

Fourteen countries provided data on pesticides. Three delivered data at the country level, six at the country as well as at the regional level, and five countries delivered data at the regional level only. Table 5.10 gives an overview of level of information obtained. Pesticides are not monitored in groundwater in Estonia, Iceland, Latvia and Sweden. They are mentioned as not being a problem in Malta and Portugal. Cyprus reported serious problems with pesticides.

5.4.4 Analysed pesticide substances

Information on the analysed active ingredients is given in Map 5.5, and a list of analysed pesticide substances in those countries submitting information (Table 5.10) can be found in the technical report (EEA 1999). The number of active pesticide substances analysed varies between four (Hungary) and 122 (UK). The most frequently analysed substances are aldrin, atrazine, dieldrin, lindane, heptachlor and simazine.

5.4.5 Monitoring situation

The number of pesticide substances monitored in any particular sampling well ranges between one (Slovak Republic and the UK) and 142 (Germany) in those countries and groundwater areas/regions where information was provided. Not all of the pesticides are monitored at each sampling site within an area. Within the same area the sampling frequency may also vary, but is mainly between 1 and 4 times per year. Also it should be noted that the maximum number of analysed pesticide substances in a country (section 5.4.4) does not necessarily match with the maximum number of pesticides monitored, indicating that some countries may not have provided a complete list of the former. The mean number of pesticides monitored in a groundwater area/region was calculated and weighted according to the number of sampling sites. It was found that, where calculation was possible, that the mean number of pesticides monitored ranged between 2 and 34 .

Countries were requested to give frequency distributions for the five most important (in terms of exceeding standards, for example) pesticide substances. Fourteen countries reported a total of 39 different pesticides as being important. Table 5.11 gives an overview of the selected pesticides at the country level, and the percentage of sampling sites where mean annual pesticide concentrations exceed 0.1 µg/l. The figures in brackets are the total number of sampling sites.

The pesticide substances most frequently mentioned as being important are atrazine, simazine and lindane. Atrazine, desethylatrazine and simazine appear to be the most polluting pesticide substances when considering the countrywide representativeness of the received information (by considering the number of sampling sites).

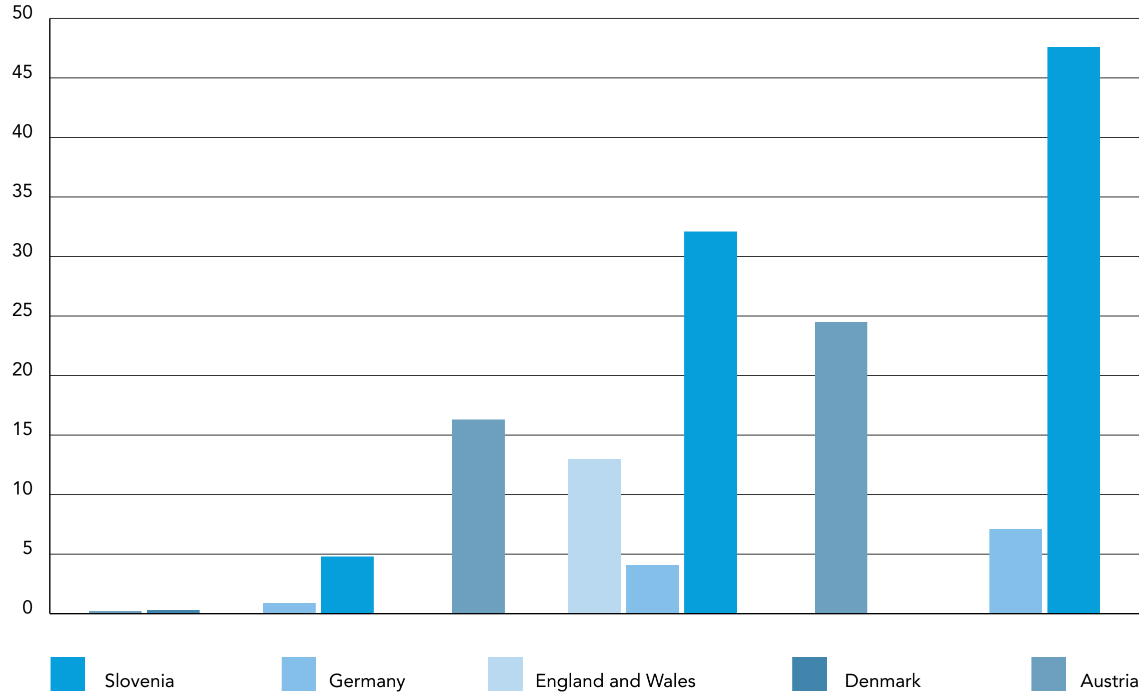
Table 5.11

Most important pesticide substances. Percentage of sampling sites with pesticide concentrations >0.1 µg/l. Total number of sampling sites in brackets.

	EEA18								PHARE					TACIS	
	AT	DK	FR	DE	ES	LU	NO	UK	CZ	HU	RO	SK	SI	MD	sum
Atrazine	16.3 (1666)	0 (625)	•	4.1 (11690)		•		•		15.5 (174)			32.1 (84)		8
Simazine	0.2 (1248)	0.3 (625)	•	0.9 (11630)		•				6.8 (177)			4.8 (84)		7
Lindane			•	•	•				0 (215)			25 (8)			5
Atrazine-Desethyl	24.5 (1666)			7.1 (11690)									47.6 (84)		3
Heptachlor			•		•							0 (12)			3
Metolachlor	1.1 (1248)					•							4.8 (84)		3
Bentazone						•	80 (5)								2
DDT									0 (215)			0 (12)			2
Dichlorprop		0.6 (623)					83.3 (6)								2
MCPA							100 (2)			4.8 (168)					2
Methoxychlor									0 (206)			8.3 (12)			2
2,4-D										3.6 (168)					1
AtrazineDesisopropyl	1.3 (1666)														1
Bromacil				3.5 (6650)											1
DDE,DDD,DDT														•	1
DDD (p,p'), DDT (p, p')					•										1
Chlortoluron								•							1
Dichlorbenzamid		13.7 (102)													1
Dieldrin		•													1
Diuron								•							1
Endosulfan I					•										1
Endosulfan sulphate					•										1
GCCG-a,b														•	1
HCH, a, b, d					•										1
Hexachlorobenzene												0 (10)			1
Hexazinon				•											1
Isoproturon								•							1
Linuron								•							1
Mecoprop (MCPP)		0.2 (625)													1
Metalaxyl														•	1
Metazachlor						•									1
Parathion-methyl					•										1
Pentachlorophenol									0 (207)						1
Phosphamid														•	1
Phozalon														•	1
Prometryn													2.4 (84)		1
Propazine			0.6 (10890)												1
sum(HCH)											•				1
sum(HCH+DDT)											•				1

• data available at the regional level only

Figure 5.5 **Percentage of sampling sites with pesticide concentrations >0.1 µg/l for simazine, atrazine and desethylatrazine and the total number of sampling sites in each country**



Note:
No data for desethylatrazine in Denmark
No data for simazine and desethylatrazine in UK (England and Wales)

Figure 5.5 compares the percentage of sampling sites exceeding 0.1 µg/l for the triazines (simazine, atrazine and desethylatrazine) between certain countries where these pesticide substances are monitored. The figures on top of the bars are the total numbers of investigated sampling sites.

As for nitrate the comparison of national data is difficult because of the great differences in the monitored pesticide substances, the different monitoring frequencies, the wide ranges in the number of sampling sites per area and the different types of sampling well. Regional information showed that the national data do not provide a very representative overview of the actual situation within the country because of the great differences between the monitored groundwater areas. For example, in Slovenia about 47.6% of the investigated sampling sites at the country level exceed 0.1 µg/l for desethylatrazine. At the regional level this percentage varies between 0% and 93.3%. About 30% of total sampling sites at the country level show annual mean atrazine values of more than 0.1 µg/l. At the regional level this percentage varies between 0% and 73.3%. In Austria, the number of sampling sites showing annual mean values of atrazine higher than 0.1 µg/l varies between 5.3% and 28.6%.

Most of the data obtained do not allow a reliable assessment of trends to be undertaken. However, a recent study of groundwater monitoring data from six European countries (Austria, Denmark, France, Germany, Switzerland and the UK) indicates that at some of the sampling sites in some countries (Austria, France, Switzerland) there has been a statistically significant decrease in the concentration of atrazine and its metabolites (Fielding et al., 1998). There were also a smaller number of sites where concentrations were increasing. The reasons for the decrease were reported to be restrictions on its use ranging from more cautious application to an outright ban, improved application or introduction of integrated pest management.

5.4.6 Conclusions

Significant problems with regard to certain pesticide substances exceeding standards have been reported from Austria, Cyprus, Denmark, France, Hungary, Republic of Moldova, Norway, Romania and the Slovak Republic.

The pesticide substances most frequently mentioned as being important are atrazine, simazine and lindane. Considering the countrywide representativeness of the information received (by the number of sampling sites), atrazine, desethylatrazine and simazine are probably the most polluting pesticide substances. There is some evidence that levels of some pesticides, in particular atrazine, have recently been declining as a result of the control or banning of use.

Representative comparisons can only be made at the regional level by considering the pesticide substances monitored, and the different types of sampling sites.

5.5 Chloride

5.5.1 General description

Chloride is present in considerable amounts in almost all natural waters. It is one of the most constant components of water and its concentration in water hardly changes when physico-chemical and biochemical processes take place. Chlorides generally take the form of salts, sodium chloride (NaCl), potassium chloride (KCl) or calcium chloride ($CaCl_2$). The largest amounts of natural chlorides are in the oceans.

Chloride (Cl^-) concentrations in groundwater range from 10 to 100 mg/l, unless the wells are contaminated by saltwater intrusion where the sodium chloride (NaCl) content can be as high as 25%. The chloride content in municipal effluent generally ranges between 20 to 50 mg/l above the water supply concentration, which can bring about a gradual increase in the salinity of rivers, springs and aquifers.

There is no health-based guideline value proposed for chloride in drinking water. However, chloride concentrations in excess of about 250 mg/l can give rise to detectable taste in water (WHO, 1993). The Drinking Water Directive (80/778/EEC) gives a guideline concentration for chlorides of 25 mg/l, and indicates that concentrations greater than 200 mg/l may give rise to unpleasant organo-leptic effects on those who consume such water. The Surface Water Directive (75/440/EEC) has a guideline chloride concentration levels for all water treatment categories of 200 mg/l of chloride.

5.5.2 Environmental effects

Restrictions on chloride in drinking water are based on palatability requirements rather than on health. Groundwater containing chloride at relatively high concentrations may be harmful to people suffering from heart diseases. Once chloride reaches groundwater it can remain as a contaminant for long periods (Rail, 1989). Conventional methods of water treatment do not eliminate chloride ions. The amount of chloride that is ingested on a daily basis via the consumption of drinking water is only a very small proportion of the total amount ingested per day.

Chloride has a toxic effect on plants. High salinity seriously interferes with plant growth because of a rise in the osmotic potential of the water. In addition, the presence of sodium leads to a destruction of soil structures.

Table 5.12 Information received on chloride

Country	Code	Country level	Regional level
Austria	AT	•	3
Bulgaria	BG		3
Cyprus	CY		3
Czech Rep.	CZ	•	3
Denmark	DK	•	3
Estonia	EE	•	3
Finland	FI	•	
France	FR	•	4
Germany	DE		6
Greece	GR		13
Hungary	HU	•	2
Iceland	IS	•	
Ireland	IE	•	3
Latvia	LV		4
Lithuania	LT	•	1
Luxembourg	LU		1
Rep. of Moldova	MD		1
Netherlands	NL		9
Norway	NO	•	
Poland	PL	•	3
Portugal	PT		1
Romania	RO		1
Slovak Rep.	SK	•	4
Slovenia	SI	•	6
Spain	ES		3
Sweden	SE	•	3
Turkey	TR		3
United Kingdom	UK		4

5.5.3 Status of chloride in groundwater

(a) Data received

Twenty eight countries provided data on chloride: four at the country level, 11 at the country and the regional level, and 13 countries at the regional level only (Table 5.12).

(b) Country level

Figure 5.6 illustrates the number of sampling sites and their distribution according to type. In most of the countries providing information, monitoring wells are the predominant type of sampling site. The number of sampling sites varies between four wells (Norway) and 4,659 wells in France. Figure 5.7 shows the frequency distribution of chloride in groundwater in the 15 countries providing country wide information. In this bar chart the concentrations of 25, 50, 100 and 250 mg Cl/l were used to classify the sampling sites. These concentrations relate to the guideline value of 25 mg/l in the Drinking Water Directive, the upper limit of the natural range of chlorides, 100 mg/l, and the taste threshold value of chloride in water of about 250 mg/l (WHO, 1993).

The guideline value of 25 mg/l is not exceeded by the four sampling sites in Norway. In six countries the sampling sites do not exceed 250 mg/l, and in four (Lithuania, Norway, Slovenia and Sweden) all sampling sites show chloride values lower than 100 mg/l. Nine countries (Austria, Czech Republic, Denmark, Estonia, France, Hungary, Iceland, Poland, and the Slovak Republic) have sampling sites where the annual mean value of 250 mg Cl/l is exceeded. In eight countries, the level of 250 mg/l is exceeded at up to 3% of the sampling sites. In Estonia about 20% of the sampling sites even exceed 100 mg Cl/l, and 10% exceed 250 mg/l.

Figure 5.6

Chloride – types of sampling sites at the country level

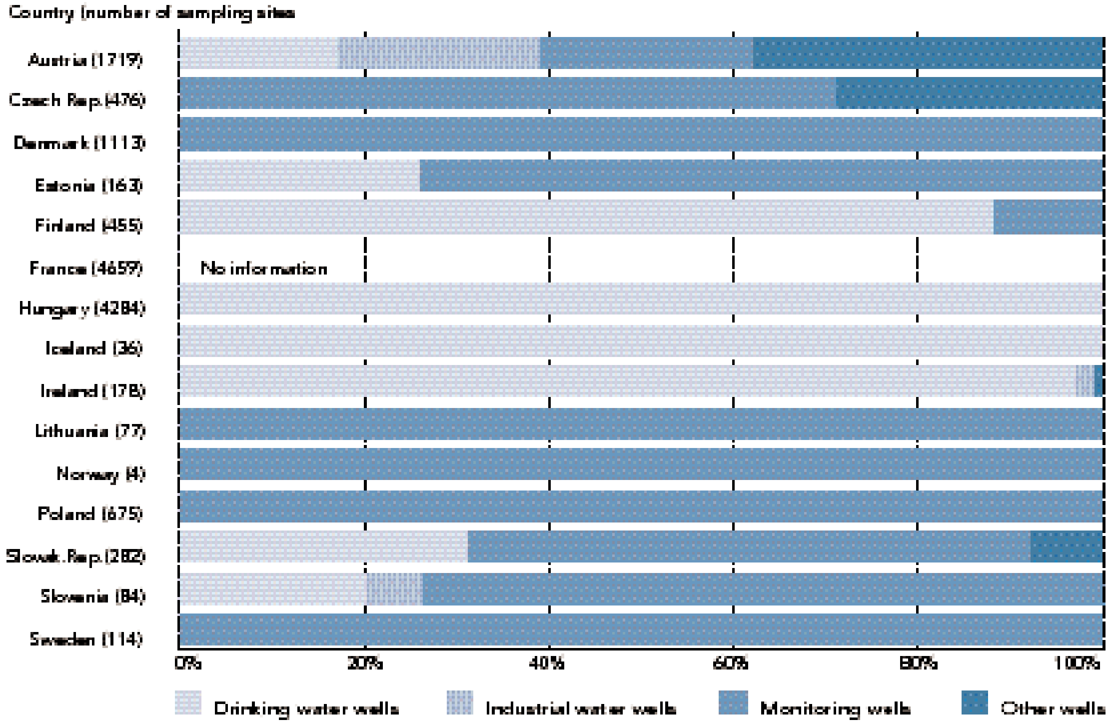
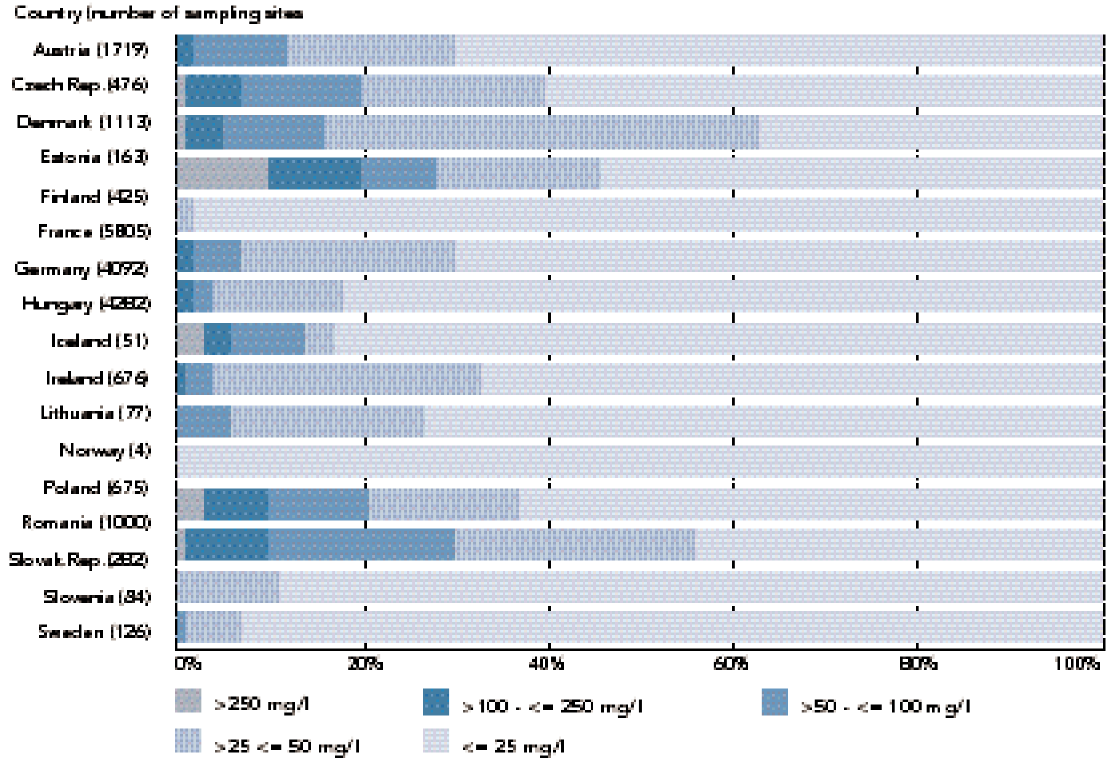
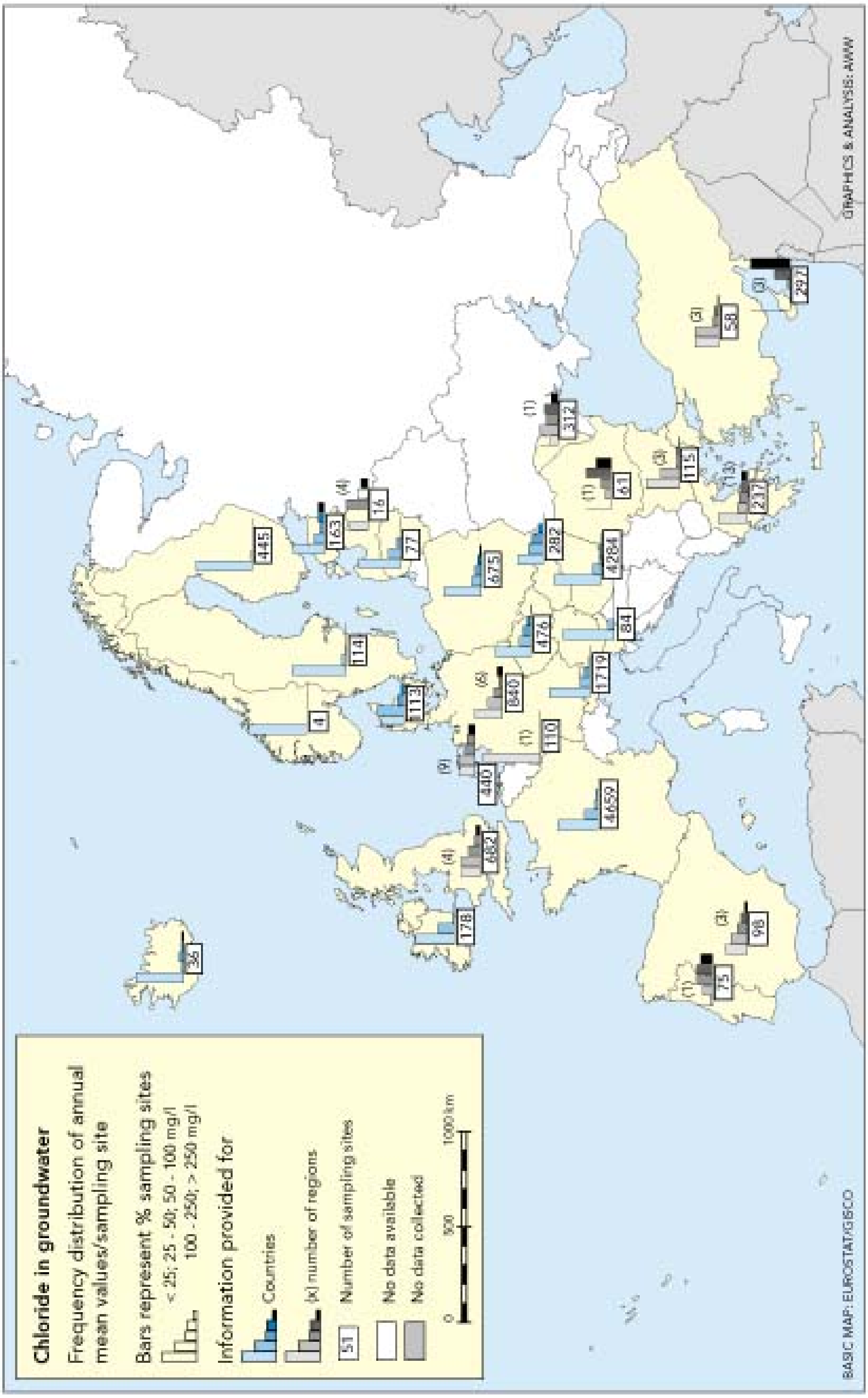


Figure 5.7

Chloride – groundwater quality at the country level



Map 5.6
Chloride in groundwater. Frequency distribution of annual mean values and number of sampling sites



Map 5.6 illustrates the frequency distribution of chloride in groundwater, and is again supplemented by aggregated regional information from countries where only data at the regional level were provided. This map shows that chloride in groundwater seems to be very problematic in Cyprus, and in some areas of Romania, the Netherlands, Portugal, Latvia and Greece.

(c) Regional level

In six regions/areas out of the 89 for which information was obtained, the drinking water guideline value of 25 mg/l was not exceeded (Map 5.6 and Figure 5.8). The percentage of sampling sites within a region/area showing chloride values of more than 250 mg/l varied between 0% and 100%. In 44 of the 89 regions, at least one sampling site exceeded the annual mean concentration of 250 mg/l. In seven regions, the level of 250 mg/l was exceeded at a quarter or more of the investigated sampling sites, and in five regions this value was exceeded by at least half of the wells.

(d) Problem areas

Seven countries provided information on chloride problem areas where at least a quarter of the sampling sites exceed an annual mean value of 250 mg/l. In four countries (Austria, France, Hungary and Lithuania), there are no problem areas, Latvia reported one zone, Denmark five, and Romania six 'hot spots'.

(e) Conclusions

Chloride is a significant problem in some groundwater areas in Cyprus, Denmark, Estonia, Germany, Greece, Latvia, Republic of Moldova, the Netherlands, Poland, Portugal, Romania, Spain, Turkey and the United Kingdom. Most of these areas are located near the coast, and saltwater intrusion is probably the main cause of the high chloride content.

Number of regions where a chloride level of 100 and 250 mg/l is exceeded at none, 0-25, 25-50 and ≥50% of the sampling sites for which information is available **Figure 5.8**

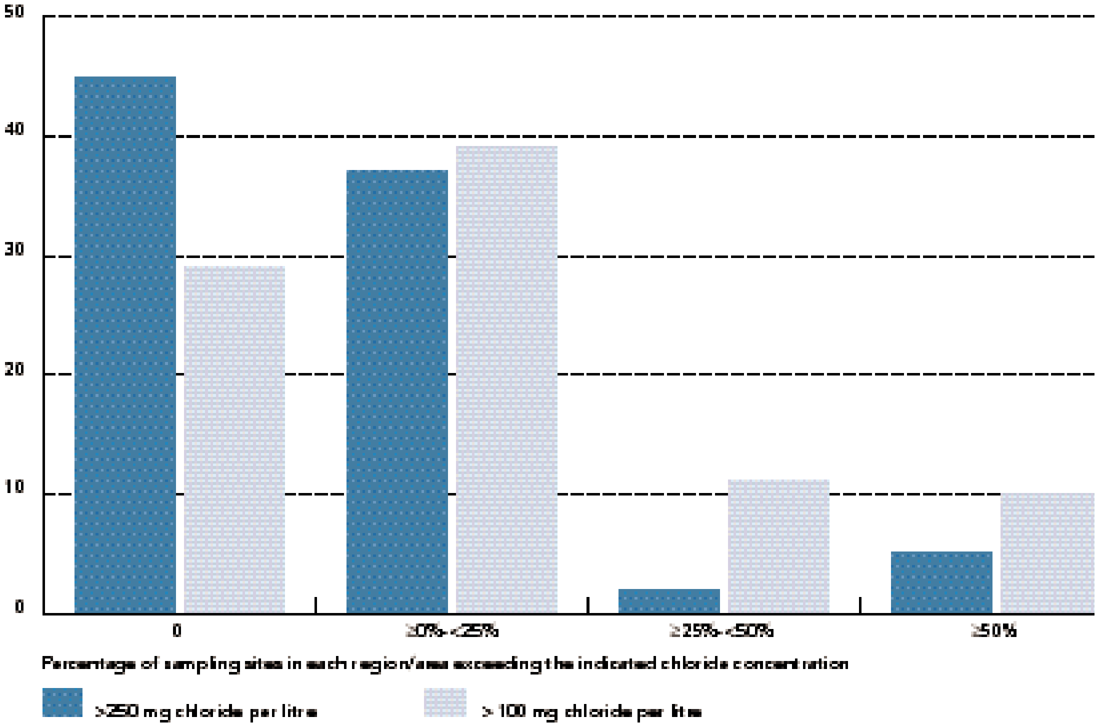


Table 5.13 **Information received on pH: (number of regions/groundwater areas)**

Country	Code	Country level	Regional level
Austria	AT	•	3
Bulgaria	BG		3
Czech Rep.	CZ	•	3
Denmark	DK	•	3
Estonia	EE	•	3
Finland	FI	•	
France	FR	•	4
Germany	DE		7
Greece	GR		13
Hungary	HU	•	2
Iceland	IS	•	
Ireland	IE	•	3
Latvia	LV		4
Lithuania	LT	•	
Luxembourg	LU		1
Rep. of Moldova	MD		1
Netherlands	NL		9
Norway	NO	•	
Poland	PL	•	3
Portugal	PT		1
Romania	RO		1
Slovak Rep.	SK	•	4
Slovenia	SI	•	6
Spain	ES		3
Sweden	SE	•	3
Turkey	TR		3
United Kingdom	UK		4

5.6 pH

5.6.1 General description

The pH-value of unimpacted groundwater is generally in the range of 6 to about 8.5. Polluted river water generally has a pH of between 6.5 and 8.5. Unpolluted rain water has a pH of 5.6, and a lowering of the pH in natural ecosystems below this level has been termed acidification. pH is an important regulator of chemical and biological processes in natural water.

5.6.2 Environmental effects

The pH of groundwater for public supply is important because of its effect on taste, the efficiency of chlorination, corrosion (of building materials) and industrial processes. pH is an important factor affecting chemical weathering and soil leaching processes, and further influences the concentration of trace elements in groundwater. It can make groundwater unsuitable for irrigation and can have adverse effects on aquatic flora and fauna. In particular, a pH below 6.0 makes groundwater potentially corrosive to concrete, and it also favours the formation of carbonic acid from bicarbonates.

5.6.3 Status of pH in groundwater

(a) Data received

Twenty seven countries provided data on pH: four at the country level, 11 at the country and regional level, and 12 at the regional level only (Table 5.13).

(b) Country level

Figure 5.9 shows the number and types of sampling sites at the country level. The number of sampling sites varies between four wells in Norway and 5,541 sampling sites in France. In most of the countries monitoring (surveillance) wells are the overwhelming majority of sampling sites. In Finland, Hungary, Iceland and Ireland most of the sampling sites are drinking water wells.

Figure 5.10 shows the frequency distribution of pH in groundwater of 15 countries. pH value thresholds of 5.5, 6.5, 7.5 and 8.5 were used in the map to illustrate the data. These concentrations equate to approximately natural pH-value between 6.5 and 8.5, with a pH-value lower than 5.5 representing acidification. Map 5.7 illustrates the frequency distribution of pH-value in groundwater, and is again supplemented by information from those countries that delivered data at the regional level only.

In the Czech Republic, Denmark, Finland, France, Norway and Sweden, more than 18% of the investigated sampling sites show pH-values ≤ 6.5. In nine countries (Austria, Czech Republic, Denmark, Finland, France, Ireland, Norway, Slovak Republic and Sweden) sampling sites with pH-values ≤ 5.5 have been detected. In Norway, 100% of the sampling sites (4 wells) showed annual mean pH-values ≤ 5.5. In eight countries (Austria, Czech Republic, Estonia, France, Hungary, Iceland, Lithuania and Poland), a pH-value of 8.5 is exceeded in some wells. In Iceland more than 25% of the sampling sites (37 wells) show pH-values of more than 8.5.

pH – types of sampling sites **Figure 5.9**

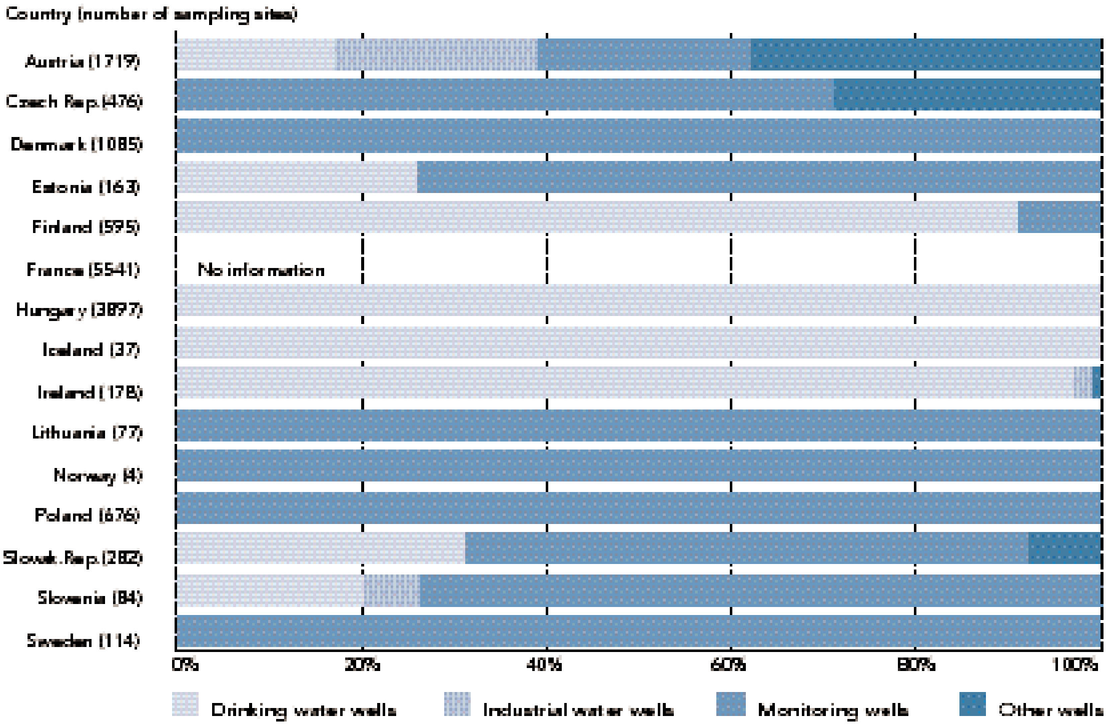


Figure 5.10 pH – groundwater quality at the country level

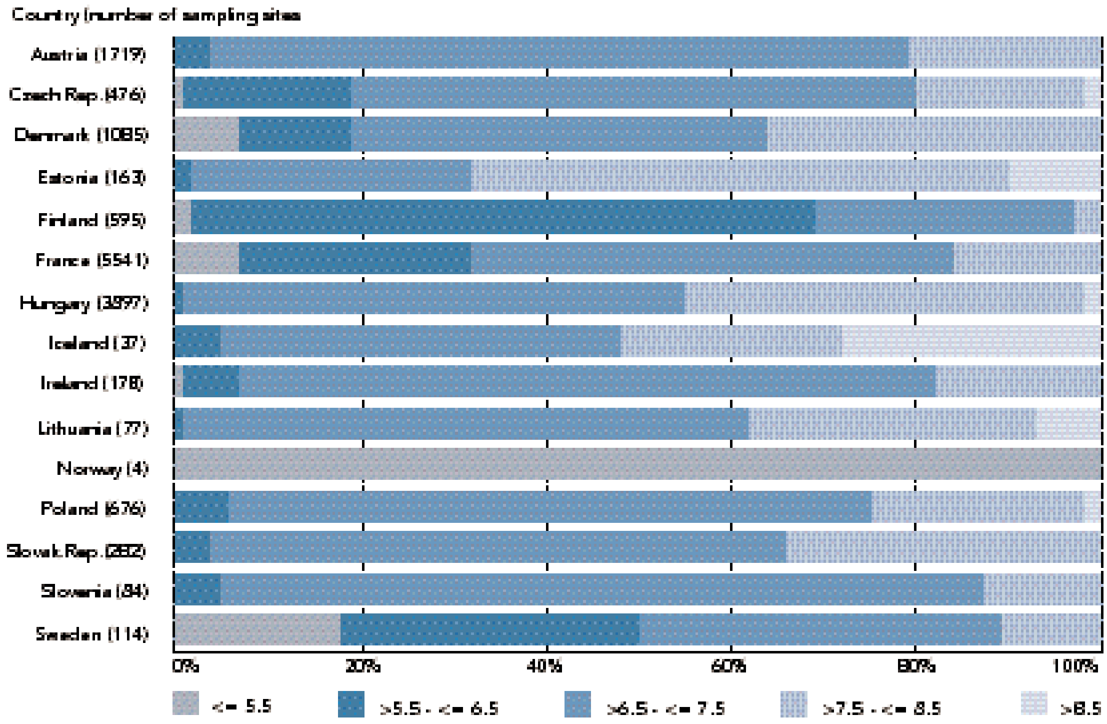
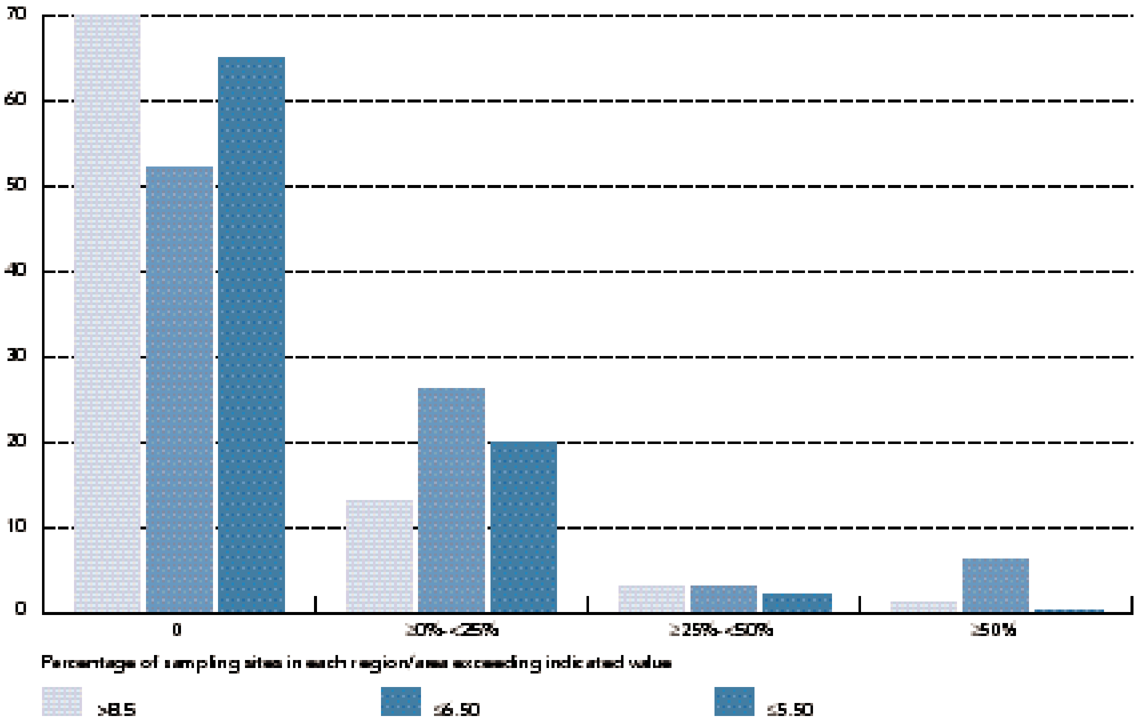
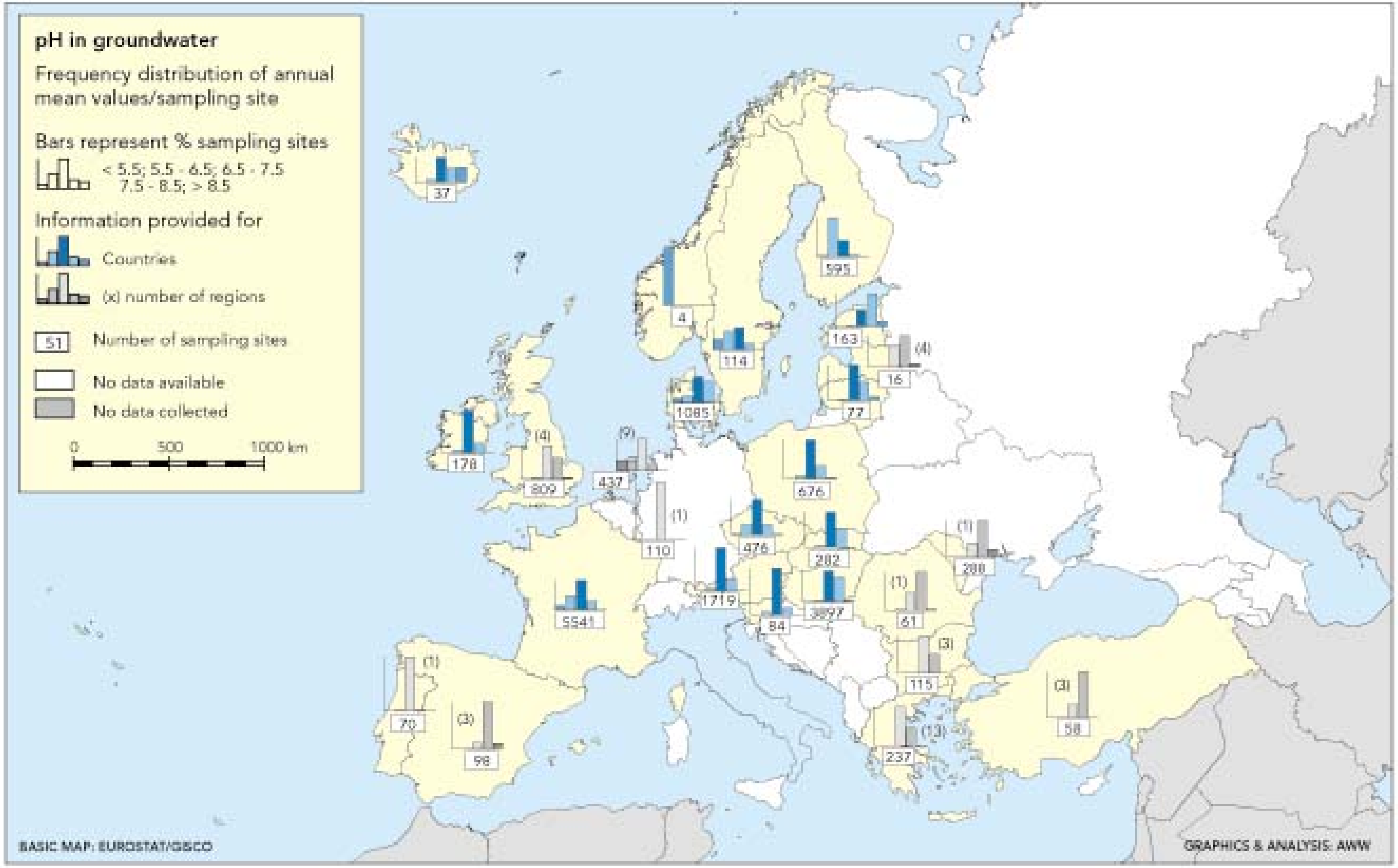


Figure 5.11 Number of regions where pH-values of ≤ 5.5, ≤ 6.5, and > 8.5 are exceeded at 0%, 0-25, 25-50 and ≥ 50% of the investigated sampling sites





Map 5.7
pH in groundwater.
Frequency distribution of annual mean values and number of sampling sites

(c) Regional level

At the regional level the most acidified regions/areas are found in the Czech Republic, Denmark, Germany and the Netherlands. In nine regions/areas, at least a quarter of the sampling sites have an annual mean pH-value of ≤ 6.5, and in six regions (within the Czech Republic, Denmark, Germany and the Netherlands) at least a half of the sites have this value. In four regions/areas (within Denmark and the Netherlands), the annual mean pH-value at at least a quarter of the sampling sites is ≤ 5.5. In one region in the Netherlands, more than half of the sampling sites show pH-values ≤ 5.5. In one groundwater area in Latvia, the pH-value of 8.5 is exceeded at up to 33% of sampling sites.

(d) Problem areas

Nine countries provided information on groundwater areas with pH problems. These were divided into two categories as follows:

- Category 1: at least a quarter of the sampling sites within a region or groundwater area have an annual mean value below 5.5.
- Category 2: at least a quarter of the sampling sites within a region or groundwater area have an annual mean value exceeding 8.5.

No such problem areas were reported for Austria, Hungary and Lithuania. Belgium (21 areas), Denmark (2), Greece (1), Finland (7) and France (2) reported category 1 areas, and only Republic of Moldova has areas in category 2.

e) Conclusions

Acidification of groundwater commonly occurs in northern countries, especially in Denmark, Norway, Sweden, Finland, the Netherlands, and also in Germany, France and the Czech Republic. Acidification is characterised by a pH lower than, or equal to, 5.5, and within this survey the pH data correspond very well with the alkalinity data. In about 5% of the regions/areas, at least a quarter of the sampling sites have a pH ≤ 5.5 (Figure 5.11).

5.7 Alkalinity

5.7.1 General description of alkalinity

Alkalinity can be defined as a measure of the Acid Neutralising Capacity (ANC) of a water body. It is thus a capacity parameter, in contrast to pH, which is a parameter of intensity. Common determinands for alkalinity are carbonates, bicarbonates, phosphates and hydroxides. Alkalinity is generally associated with a relatively high pH-value, hardness and excessive amounts of dissolved solids.

(a) Environmental effects of alkalinity

Alkalinity acts as a buffering component, tending to keep the pH of the groundwater within certain limits. It prevents sudden changes of pH, which can cause the death of aquatic organisms, and it thus counteracts acidification.

5.7.2 Status of alkalinity in groundwater

(a) Data received

Nineteen countries provided data on alkalinity: three countries at the country level, eight at the country and regional level, and eight countries at the regional level only (Table 5.14).

(b) Country level

Figure 5.12 shows the number and types of sampling sites at the country level. In most countries monitoring (surveillance) wells are the majority type of sampling site. In Finland and Hungary most of the sampling sites are drinking water wells. Figure 5.13 shows the frequency distribution of alkalinity in groundwater of 11 countries. For this graph, concentration thresholds of 1 and 4 mval/l were used. These concentrations were selected based on the experience and suggestions of the Geological Survey of Denmark and Greenland (GEUS): less than 1 mval/l is considered as low alkalinity, 1 to 4 mval/l, medium alkalinity, and greater than 4 mval/l, high alkalinity. Map 5.8 shows the frequency distribution of alkalinity in groundwater, and is supplemented with information from countries that delivered data at the regional level only.

Low alkalinity groundwater is very common in Norway, Sweden, the Czech Republic, Finland and France. In Finland and Norway more than 90% of the sampling sites show annual mean alkalinity values of ≤1 mval/l, while about 65% of the sampling sites in Sweden, about 40% of the sampling sites in France, and about 20% in the Czech Republic and Denmark show low alkalinity. Low alkalinity in groundwater is also found in some areas of the Netherlands and Germany.

Information received on alkalinity **Table 5.14**

Country	Code	Country level	Regional level
Austria	AT	•	3
Bulgaria	BG		3
Czech Rep.	CZ	•	3
Denmark	DK	•	3
Finland	FI	•	
France	FR	•	4
Germany	DE		5
Hungary	HU	•	2
Latvia	LV		4
Lithuania	LT	•	
Rep. of Moldova	MD		1
Netherlands	NL		9
Norway	NO	•	
Poland	PL	•	3
Romania	RO		1
Slovak Rep.	SK	•	4
Sweden	SE	•	3
Turkey	TR		3
UK	UK		4

Figure 5.12 Alkalinity – types of sampling sites

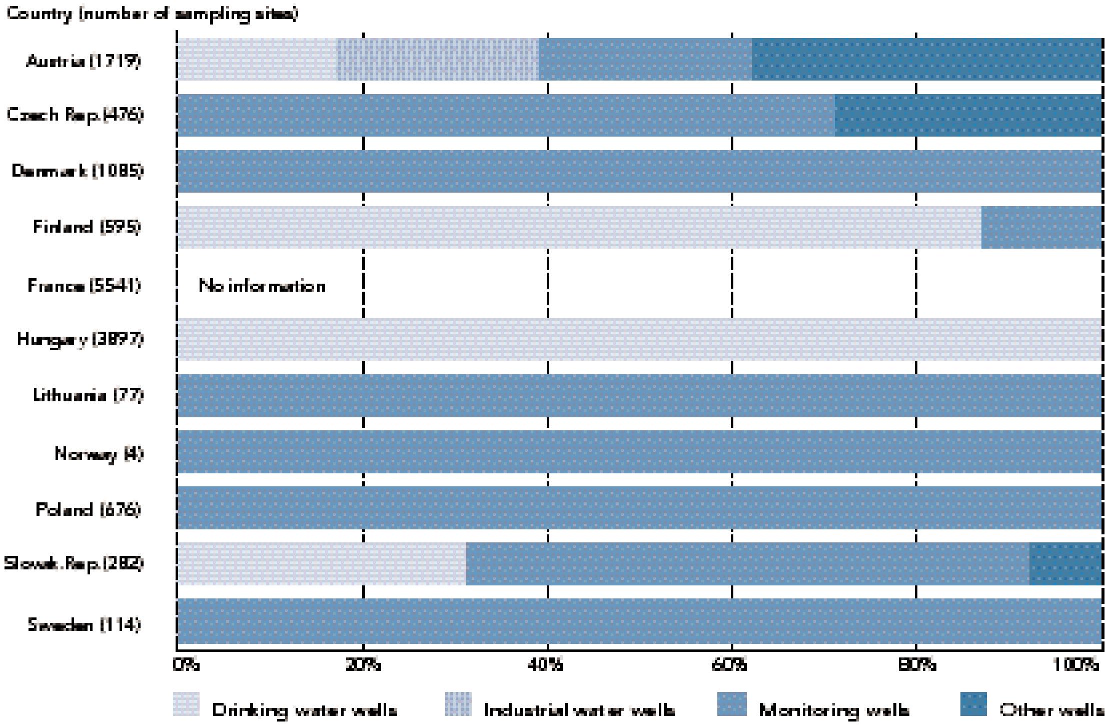
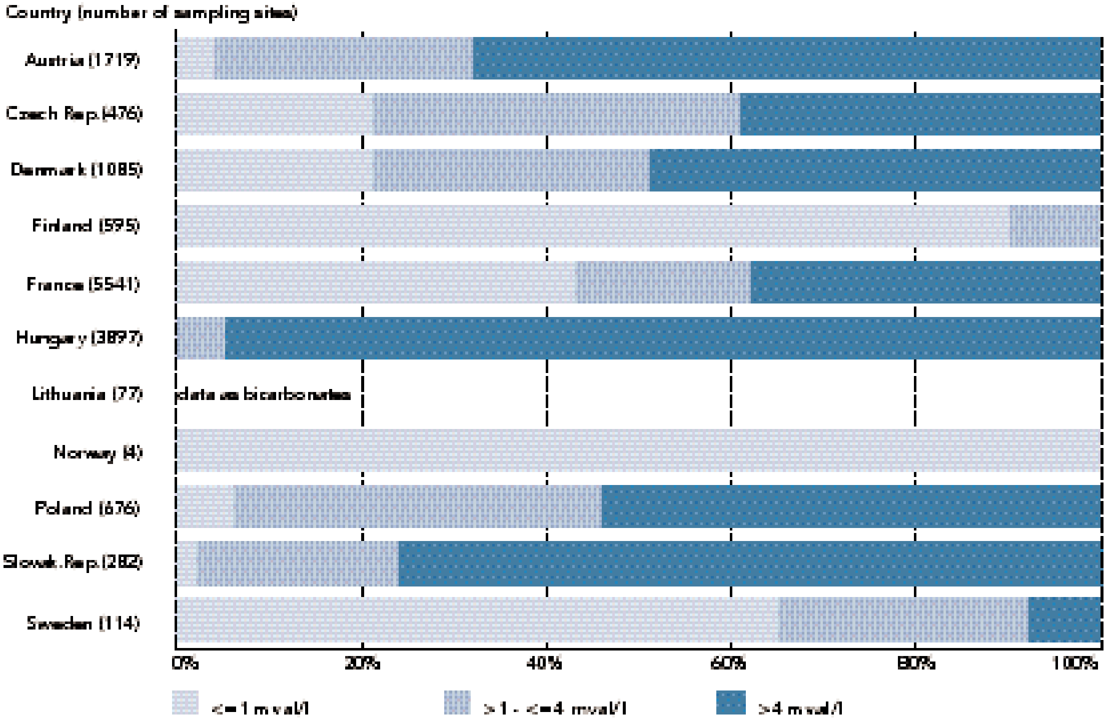
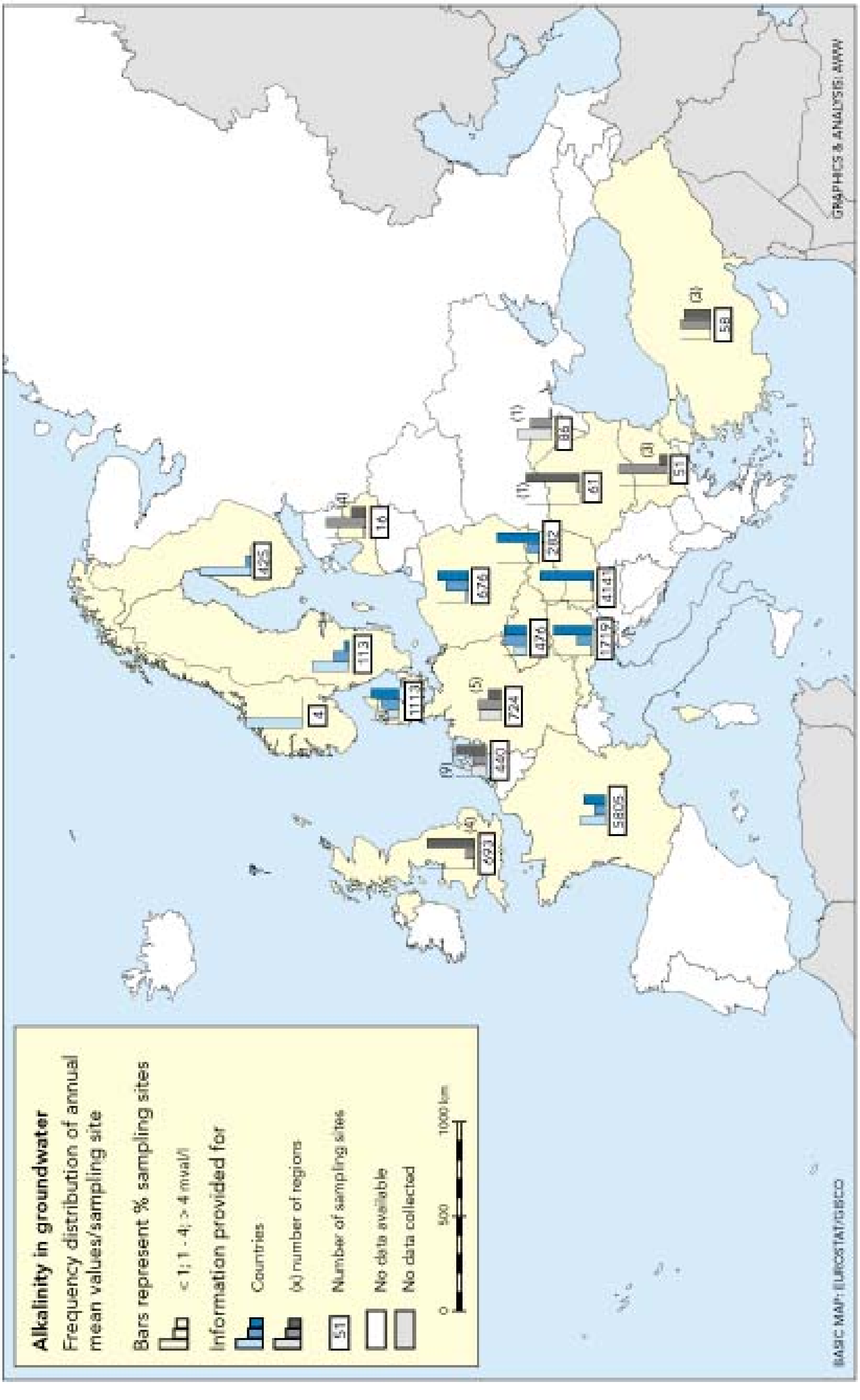


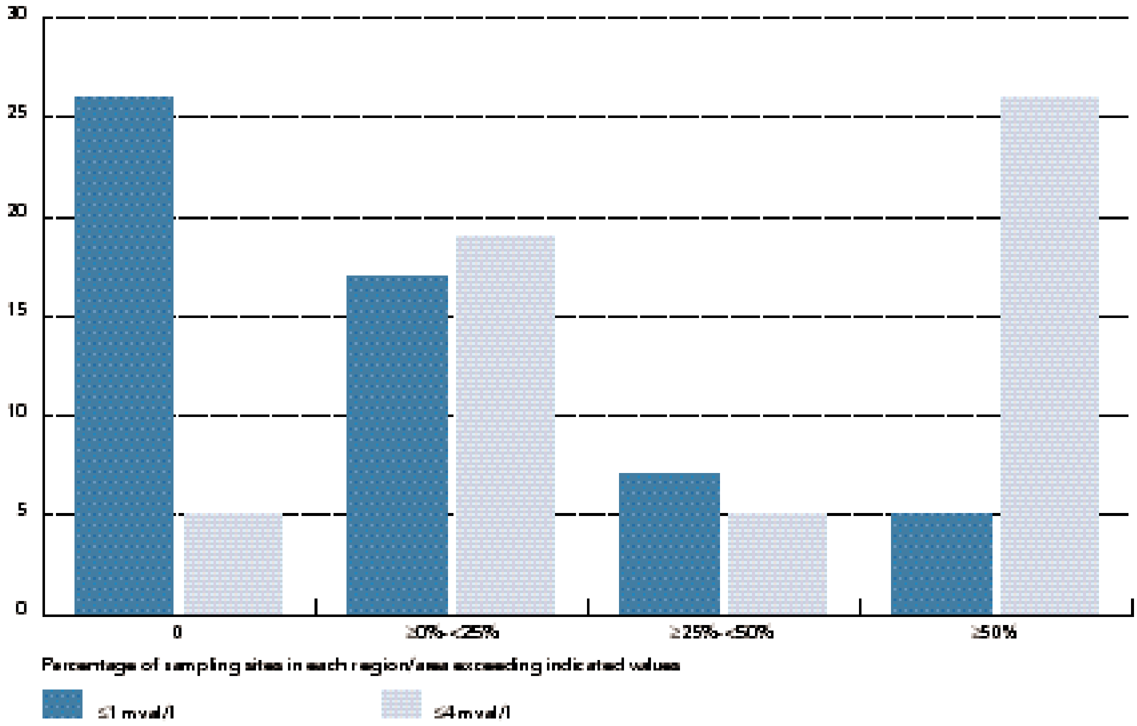
Figure 5.13 Alkalinity – groundwater quality at the country level





Map 5.8
Alkalinity in groundwater. Frequency distribution of annual mean values and number of sampling sites

Figure 5.14 Number of regions where the alkalinity content is < 1 and < 4 mval/l, at 0%, 0-25, 25-50 and ≥ 50% of the investigated sampling sites



(c) Regional level
Alkalinity data aggregated at the country level indicate that acidification of groundwater is a significant problem in certain countries, particularly in Denmark, Norway, Sweden, Finland, the Netherlands, the Czech Republic, Germany, France and the Republic of Moldova, where certain groundwater areas and regions are highly vulnerable to acidification. A summary of regional information on alkalinity is given in Figure 5.14.

(d) Problem areas
Six countries provided information on problem groundwater areas with regard to alkalinity. Problem areas were defined as where at least a quarter of the sampling sites have an annual mean alkalinity of ≤1 mval/l. There are no such areas in Austria and France, whilst in Denmark there is one large zone and Finland indicated 366 such groundwater areas. In addition, the Republic of Moldova indicated sampling sites where alkalinity is low (≤1 mval/l). Most of Sweden is a 'problem area', with the exception of small areas with calcareous bedrock or soils.

(e) Conclusions
Low alkalinity in groundwater is common, particularly in Denmark, Norway, Sweden, Finland, the Netherlands, the Czech Republic, Germany, France and the Republic of Moldova, and certain groundwater areas and regions are highly vulnerable to acidification. In Finland nearly all sampling sites, and in Sweden about two thirds of the sampling sites, are affected by low alkalinity.

5.8 Electrical conductivity

5.8.1 General description

Electrical conductivity is a measure of the degree of mineralisation of groundwater, and is an indicator of water quality. It is an indirect measure of salinity, and this, in turn, is an indicator of the presence of several salts, such as chlorides, sulphates, nitrates, carbonates and bicarbonates, generally associated with the cations K^+, Na^+, Ca^{2+}, Mg^{2+}, etc. Salts are essential for keeping the water-electrolyte balance in organisms. However, an excess of salts could be a source of serious damage to human health. Electrical conductivity of groundwater is determined by natural geological conditions and anthropogenic pollution.

The Drinking Water Directive contains a conductivity guideline value of 400 µS/cm at 20°C, whereas the Surface Water Directive refers to a conductivity of 1,000 µS/cm for all water treatment categories.

5.8.2 Environmental effects

Electrical conductivity is another indicator of groundwater contamination from point and diffuse sources. For a description of possible environmental effects refer to the sections on ‘nitrate’, ‘chlorides’, ‘pH’ and ‘acidification and alkalinity’.

Information received on electrical conductivity **Table 5.15**

Country	Code	Country level	Regional level
Austria	AT	•	3
Bulgaria	BG		3
Czech Rep.	CZ	•	3
Denmark	DK	•	3
Finland	FI	•	
France	FR	•	4
Germany	DE		5
Greece	GR		13
Hungary	HU	•	2
Iceland	IS	•	
Ireland	IE	•	3
Latvia	LV		4
Luxembourg	LU		1
Netherlands	NL		9
Norway	NO	•	
Poland	PL	•	3
Portugal	PT		1
Romania	RO		1
Slovak Rep.	SK	•	4
Slovenia	SI	•	6
Spain	ES		3
Sweden	SE	•	3
Turkey	TR		3
UK	UK		3

5.8.3 Data received

Twenty four countries provided data on electrical conductivity: three at the country level, 10 at the country as well as at the regional level, and 11 at the regional level only (Table 5.15).

5.8.4 Country level

Figure 5.15 shows the number and types of sampling sites at the country level. In most of the countries, monitoring (surveillance) wells are the majority type of sampling site. In Finland, Hungary, Iceland and Ireland most of the sampling sites are drinking water wells. Figure 5.16 shows the frequency distribution of electrical conductivity in the groundwater of 13 countries. For this monograph conductivities of 200, 500, 1000 and 2000 µS/cm were used for comparing the information. Map 5.9 illustrates the frequency distribution of electrical conductivity in groundwater, and is supplemented by information from countries which delivered data at the regional level only.

In eight countries the annual mean value of 1000 µS/cm is exceeded at up to 18% of the sampling sites. In six countries (Austria, Czech Republic, France, Hungary, Poland and the Slovak Republic) the level of 2500 µS/cm is exceeded at up to 1% of sampling sites. Relatively high electrical conductivity is also problematic in some areas of the Netherlands, Latvia, Greece, Portugal and Romania.

Figure 5.15 Electrical conductivity – types of sampling sites

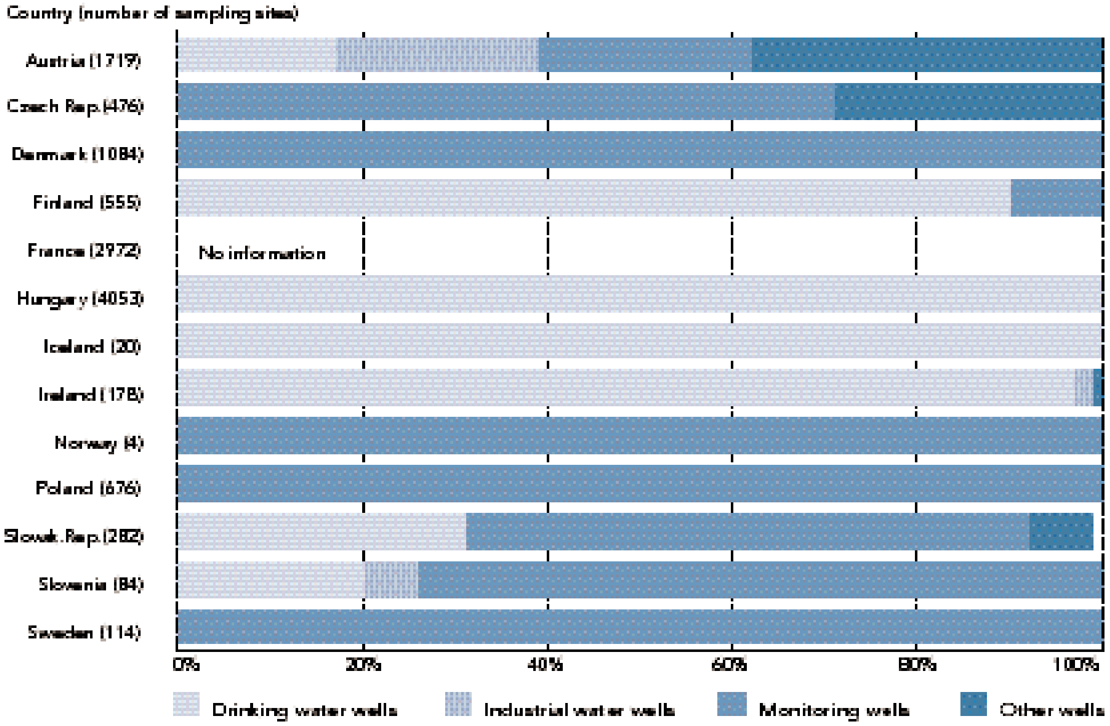
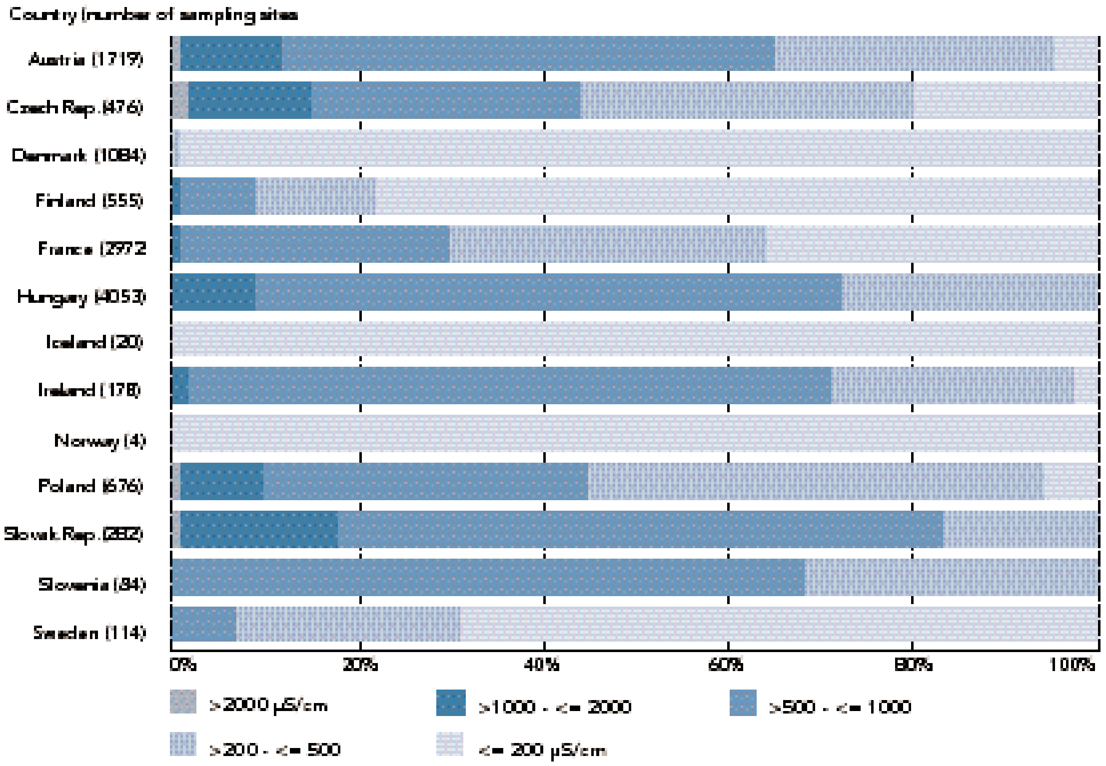
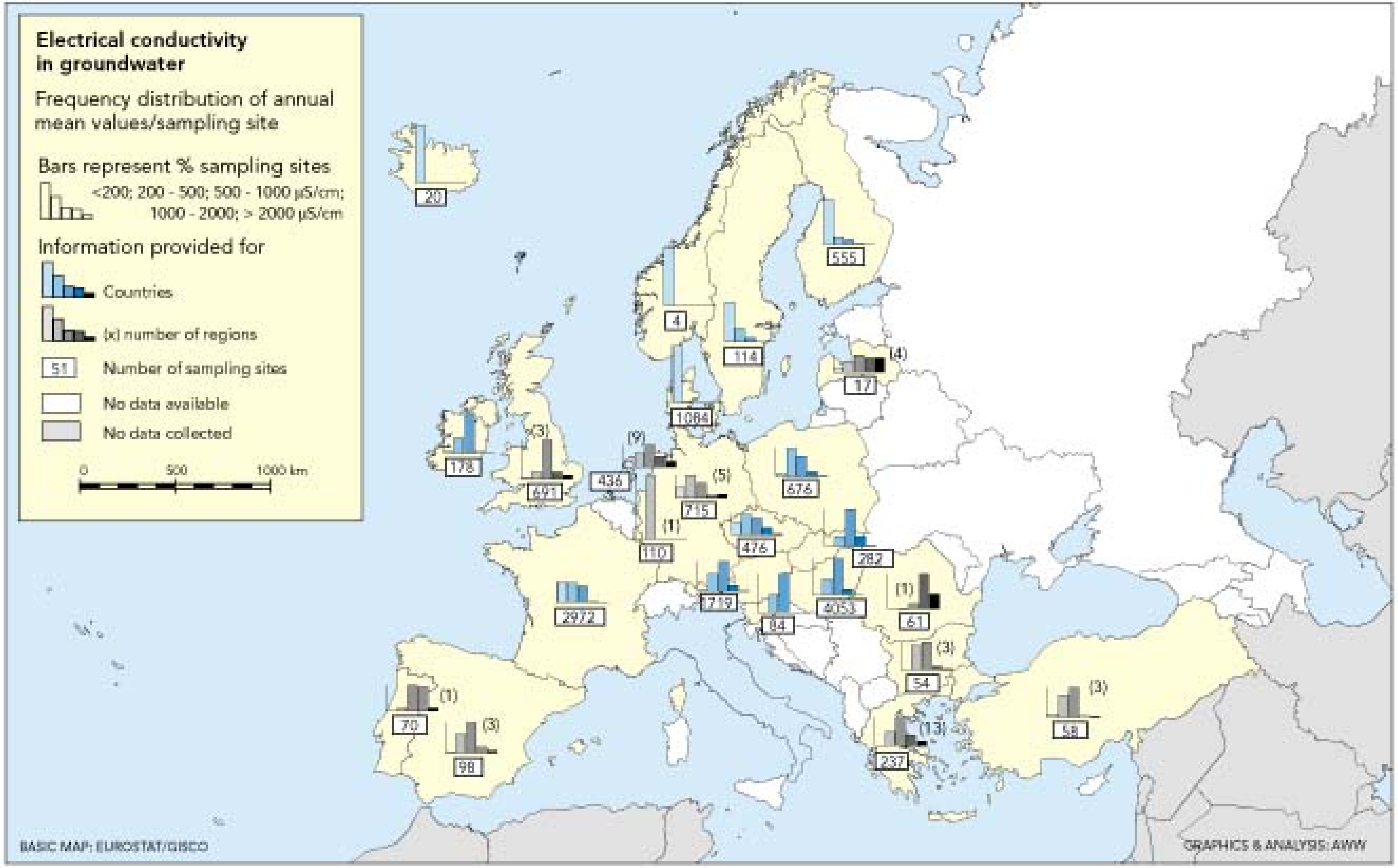


Figure 5.16 Electrical conductivity – groundwater quality at the country level





Map 5.9
Electrical conductivity in groundwater. Frequency distribution of annual mean values and number of sampling sites

5.8.5 Regional level

Twenty one countries delivered data on 79 regions or groundwater areas: a summary of information is given in Figure 5.17.

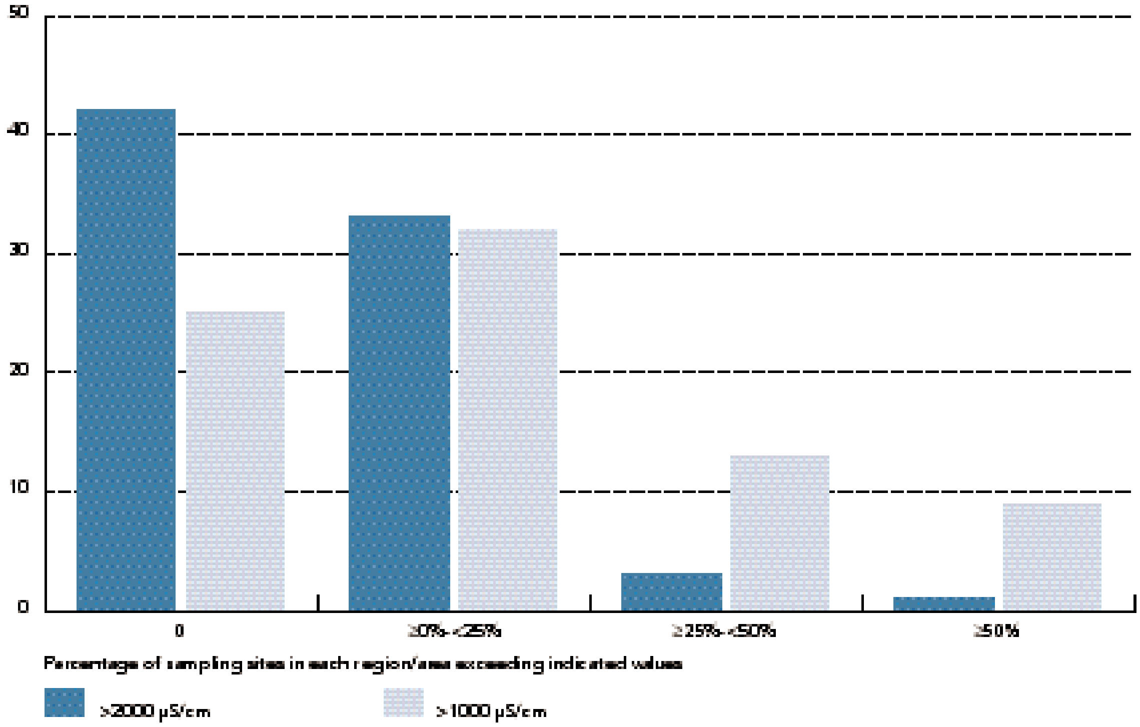
5.8.6 Problem areas

Five countries provided information on areas with electrical conductivity problems, which are defined as zones where at least 25% of the sampling sites exceed 2000 µS/cm. There are no such regions in Austria and France, Denmark reported one ëhot spotí area, and Greece marked 16 problem areas on a map. Hungary indicated seven monitoring wells exceeding 2000 µS/cm.

5.8.7 Conclusions

High values of electrical conductivity have been detected in certain areas of the Netherlands, Hungary, Latvia, Greece, Portugal, Spain and Romania. In about 5% of the 79 reported areas/regions, at least a quarter of the sampling sites exceed an electrical conductivity of 2000 µS/cm (Figure 5.17). In one region of Latvia, all two sampling sites show electrical conductivity values of more than 2000 µS/cm.

Figure 5.16 Number of regions where the electrical conductivity of 1000 and 2000 µS/cm is exceeded at 0%, 0-25, 25-50 and ≥ 50% of the investigated sampling sites



5.9 Other sources of contamination

Countries were asked to give information on other substances that cause problems in their groundwater. Sixteen countries provided such information (Table 5.16). In two countries (Iceland and Ireland), no other groundwater contaminants were reported. Finland, the Czech Republic, Latvia and Poland did not specify particular determinands, but indicated sources of groundwater contamination.

Eleven countries reported contamination with hydrocarbons or chlorinated hydrocarbons. Chlorinated hydrocarbons are widely distributed in groundwater aquifers of Western European countries, whereas hydrocarbons, and especially mineral oils, cause severe problems in Eastern European countries.

For example, in Austria, a nation wide survey of porous aquifers in 1994/95 indicated that one out of four sampling sites had tetrachloroethene concentrations above 0.1 µg/l, and at about one out of 10 sites, concentrations of trichloroethene, 1,1,1-trichloroethane and chloroform were above 0.1 µg/l. A few sample sites with higher concentrations (several µg/l) can still be found, especially at sites around larger towns with industrial areas. In France, there are many isolated cases of high chlorinated solvent levels, where an obvious cause can be found (industrial). Two serious incidents which occurred recently have been reported in the east of France: chloronitrobenzene in Mulhouse (1986) and tetrachloroethylene in Strasbourg (1990) which both affected public supply wells. However, widespread low levels are now being detected across, for

Other sources of groundwater contamination **Table 5.16**

Country/	**EEA18**							**PHARE**							**T**	**R**
Pollutant	**AT**	**DK**	**ES**	**FR**	**DE**	**SE**	**UK**	**BG**	**EE**	**HU**	**LT**	**RO**	**SK**	**SI**	**MD**	**CY**
Heavy metals		•	•	•		•	•	•	•	•		•	•	•	•	
Chlorinated hydrocarbons	•	•	•	•	•		•			•		•	•	•		
Hydrocarbons				•	•		•		•	•	•	•	•		•	
Sulphate				•			•		•						•	•
Metals		•								•						
Phosphate												•				
Bacteria				•								•				

T=Tacis, R=Others

example, the Rhône-Méditerranée-Corse basin (particularly chloroform) or in the Nievre region (especially tetrachloroethylene). In the Landes (Southwest France) where there is major wood industry, various insecticide products have been detected in groundwater. Further examples are found in Baden-Württemberg (Germany), where volatile chlorinated hydrocarbons, especially tetrachloroethene and trichloroethene, have been detected in groundwater in highly industrialised and urbanised areas. Chlorinated hydrocarbons have also been reported in Hungary (around waste disposal sites, landfills and military sites), the Slovak Republic (for example, from the chemical industry and military waste dumps) and Latvia (around Riga).

Contamination of groundwater by hydrocarbons is often associated with spillages and leaks of oil from tanks, pipelines, garages and along transport routes. Such contamination is reported in Estonia, were the groundwater under some military airfields is heavily contaminated with fuel. In Romania, oil products are found in groundwater around pipelines, refineries and storage areas, and in the Republic of Moldova, around old military sites.

Groundwater pollution by heavy metals has been reported to be a serious problem in 12 of the 22 countries (Denmark, France, Spain, Sweden, UK, Bulgaria, Estonia, Hungary, Romania, the Slovak Republic, Slovenia and the Republic of Moldova). Heavy metal contamination is mostly caused by leaching from dumping sites, mining activities and industrial discharges.

Romania reported extensive groundwater pollution from bacteria. This also seems to be a widespread problem in France, arising mostly from slurry spreading in agriculture, and particularly causing problems in fissured rocks which do not have any bacterial filtering capacity.

6. Status of groundwater quantity

6.1 Groundwater abstraction and over-exploitation

6.1.1 General description

Groundwater over-exploitation is generally considered to be groundwater abstraction which leads to adverse effects (physical, economic, ecological or social) in the short or long term. However, the understanding of adverse effects is very subjective, and for this reason the term 'over-exploitation' has never been formally defined. Water companies, water authorities and environmentalists may in fact have different perceptions of adverse effects, as listed in Table 6.1 (Custodio, 1991).

6.1.2 How to assess over-exploitation of an aquifer

(a) Aquifer water balance

For many aquifers it is difficult to determine whether there really is an over-exploitation problem. Over-exploitation is often thought of as being the relatively straightforward situation where abstraction volumes (water taken out of the aquifer) exceed the estimated long term recharge (water infiltrating back into the aquifer). Even in this situation it is often not that easy to determine the balance because of the uncertainty involved in estimating long-term recharge. Recharge may in fact evolve as a function of the level of exploitation: for instance recharge to aquifers from rivers can depend on the groundwater level. However, the situation is often more complicated. Undesirable effects from groundwater over-exploitation may occur long before total abstraction volumes approach the long term recharge. These undesirable effects may be due to seasonal or medium term shortfalls in recharge (such as an extended drought), but they may also occur under normal recharge conditions.

In evaluating over-exploitation it is essential to consider the resource management objectives, possible negative impacts, the type of aquifer and the timescales involved. For instance, in Europe, groundwater is considered to be a renewable resource, and the management objective is sustainability. However, in some arid regions, a valid management objective can be to exploit groundwater deliberately, which can thus be considered a non-renewable resource like metallic ores or fossil fuels.

(b) Geological timescales

Timescales are a particularly important factor in aquifer evaluation. Over-exploitation encompasses long-term resource problems as well as shorter term problems, such as periodically dried-up river beds (caused by a combination of unusually low annual recharge and seasonally high water demand).

Adverse effects of groundwater exploitation from different perspectives **Table 6.1**

Water suppliers	Water regulators	Environmental impacts
• future supply problems, for example restrictions on future abstraction volumes • water quality problems in the abstracted water • increased abstraction costs due to deeper wells (drilling and pumping costs)	• difficulty in guaranteeing minimum river flow levels, creating problems for various users (navigation, power stations, fishing, etc.) • conflicts in water supply between different users • long-term and widespread water quality problems in the aquifers • risk of ground subsidence	• unsustainable use of resources • negative impacts on wetland areas because of decreasing water levels affecting vegetation • indirect impacts on wetland ecosystem (for example bird habitats) • decreased spring and river flows affecting river ecosystems

A widespread misconception is that continuously falling groundwater levels mean that the aquifer is invariably over-exploited. Groundwater bodies behave in a 'transient' manner (slow and delayed groundwater flow), sometimes extended over very long periods of time. In large aquifers with relatively low permeability, the transient stage may last for hundreds or thousands of years. In this case, it is possible for groundwater levels to fall for many years whilst the aquifer adjusts to a new water balance, and then very slowly levels out.

6.1.3 Environmental effects

(a) Groundwater quality

Continuous groundwater over-exploitation can cause isolated or widespread groundwater quality problems. Groundwater abstractions cause a draw-down in groundwater level which can influence the movement of water with different quality within an aquifer. Significant draw- downs can cause significant quality changes, including:

- rising of mineral-rich water from deeper aquifers in supply wells;
- displacement of the freshwater/saltwater interface, horizontally and/or vertically, causing active saltwater intrusion;
- in confined aquifers a draw-down can cause the emergence of the roof of the aquifer, leading to a change of redox conditions (from anaerobic to aerobic), and consequently to a change in water chemistry;
- draw-down can cause pollution because of potential increased connections of polluted groundwater (typically in shallow layers) with previously unpolluted groundwater;
- induced/increased recharge with surface water that may be contaminated.

The following example is a historical case of groundwater over-exploitation dating from the last century which caused quality problems that persist today. Parts of the London basin aquifer in the United Kingdom were de-watered because of over-abstraction from 1820 to 1940 (Kimblin et al., 1991). At some sites this caused deterioration in groundwater quality because of pyrites (iron sulphide) oxidation in some of the de-watered zones. The oxidation can cause operational difficulties for abstractions because of the high iron and sulphate content.

(b) River-aquifer interactions

Many aquifers exert a strong influence on river flows, as well as on chemical processes occurring in river banks (in particular, denitrification). In summer, many rivers are dependent on the groundwater base flow contribution to provide a minimum flow. Lower groundwater levels because of over-exploitation may, therefore, endanger river-dependent ecological and economic functions (including surface water abstractions, dilution of effluents, navigation and hydropower). Many groundwater fed streams have a high amenity value, and research shows that low flows can be related to habitat availability for aquatic flora and fauna.

Factors such as climate variability and the possible change in the frequency of extreme events could be critical in determining the severity of this problem in the future, particularly in regions where there is a fine balance between available resources and demand.

In southern and eastern Britain there have been a number of significant droughts in the last twenty years. The latest drought period in 1989-1992 was notable for the reduction in the length of river network in headwater streams, accentuated in areas where groundwater abstractions resulted in severe depletion of low flows (BGS, 1995).

(c) Wetlands

Pressures on wetlands are primarily caused by natural episodes, and by human activities such as land management practices (e.g. drainage), vigorous farming practices, physical changes of stream courses, groundwater abstractions, over-exploitation, excessive urbanisation and pollution from agriculture and industry. More than half of Europe's wetlands have disappeared in recent years. It has been estimated that about 25% of Europe's wetlands are potentially endangered today.

Wetlands and their condition depend on the occurrence of water, and how the different components in the hydrological cycle interact. One key parameter is the precipitation rate, a factor dependant on climate. Recently the greenhouse effect has been recognised as a factor that may stress the global climate and may change precipitation in the future. A possible consequence will be a higher amount of precipitation in some areas and less amounts in others. This may cause the drowning of some wetlands and the drying up of others.

Groundwater conditions in freshwater wetland areas are influenced by surface water conditions with respect to physical relationships and chemical compounds. The construction of dams (e.g. for hydropower purposes) effects streams and wetlands since some areas will then have higher water levels and may be drowned. In these areas the groundwater inflow compensates for the anthropogenic changes.

The regulation of surface water (e.g. for flood control) leads to the draining of adjoining areas, and prevents regular and necessary inundation of the wetlands with surface water. Wetlands are highly dependent on shallow groundwater tables. Drainage lowers the groundwater level, and removes the water in the saturated zone, and thus creates new possibilities for the growth of crops in the wetland area. The changed drainage pattern of an area because of stream regulation affects the groundwater conditions. The groundwater flow directions can also change and affect the surface water inflow to the wetland.

Groundwater over-exploitation has several adverse effects. Drying out of small water bodies is one example. Photo: Erik Thomsen/BIOFOTO

Groundwater abstraction in areas near wetlands can be a very severe problem, especially where over-exploitation is caused by a large demand, be it from populations in large cities, industry, water requirements for the irrigation of crops or for livestock breeding. Groundwater pumping normally lowers the groundwater table and then produces a new, deeper unsaturated zone. This change especially does great damage to wetland ecosystems which are very sensitive to even minor changes in water level.

Wetlands can be directly polluted by agriculture, industry, traffic and also through the flow of water from groundwater to surface water in the riparian areas.

(d) Ground subsidence

In certain areas over-exploitation can cause ground subsidence. The risk in karst limestone areas can be particularly serious because of the sudden formation of sinkholes ('catastrophic subsidence'), caused by the following factors (Lamoreaux, 1991):

- lowered groundwater levels lead to loss of buoyant support for the upper unconsolidated layers (called the overburden);
- infiltration (induced recharge) through these layers leads to the erosion and flushing out of sediment weakened due to repeated wetting and drying cycles;
- heavy construction, traffic or explosives can trigger the downward movement of soil layers;
- removal of vegetation or trees opens up preferential flow paths;
- impoundment of water saturates the overburden and leads to collapse.

Although catastrophic subsidence is rare in Europe, heavy draw-down has been identified as the cause of ground subsidence or soil sagging phenomena in some parts of Europe, notably along the Veneto and Emilia-Romagna coasts, the Po delta and in particular in Venice, Bologne and Ravenna in Italy (Barrocu, 1992).

6.1.4 Extent of groundwater over-exploitation

Groundwater over-exploitation in this monograph is defined as 'groundwater abstraction exceeding the recharge and leading to a lowering of the groundwater table'. Countries were asked to give:

- a list of over-exploited groundwater areas;
- the approximate area in km^2;
- a short description of the main causes of groundwater over-exploitation;
- the year over-exploitation was first detected; and,
- if over-exploitation leads to saltwater intrusion and/or endangered wetlands.

A complete list of the gathered information is given in the technical report associated with this monograph (EEA, 1999).

Table 6.2 presents a summary of the collected information. Eleven out of 37 countries that responded enumerated over-exploited groundwater areas. In ten countries groundwater over-exploitation does not occur. Groundwater over-exploitation seems to be a major problem in Eastern European countries. Five out of seven Phare countries, and only three countries from eight EEA countries, reported groundwater over-exploitation. Out of the 126 named groundwater areas, there are 33 cases where groundwater over-exploitation endangers wetlands, and 53 cases where saltwater intrusion is the consequence. One case of over-exploitation goes back to 1900 (Estonia) but the majority of the groundwater areas have become over-exploited since the eighties.

The main reported cause of groundwater over-exploitation is water abstraction for public and industrial supply. Mining activities, irrigation and dry periods can also cause decreasing groundwater tables. Map 6.1 gives an overview of the information received on over-exploited groundwater areas and locations of saltwater intrusion.

6.2 Saltwater intrusion

6.2.1 General description

The problem of saltwater intrusion into pumped wells has been widely recognised in many aquifers situated in or near coastal regions. In general, fresh groundwater is discharged into the sea. If the demand for groundwater exceeds renewal rates, the seaward flow of groundwater decreases or is reversed. Seawater then advances inland within the aquifer leading to seawater intrusion.

Because of its high salt content, about 2% of seawater mixed with freshwater makes the water unusable in terms of drinking water standards. A small amount of intrusion, therefore, can jeopardise the use of an aquifer for water supply. Once contaminated with seawater, a fresh groundwater aquifer can remain contaminated for long

Over-exploited groundwater areas **Table 6.2**

Code	Country	Impacted groundwater area [km²]	Groundwater over-exploitation	Over-exploited groundwater area [km²]	Number of over-exploited areas	Over-exploitation leading to		Map
						Saltwater intrusion	endangered wetlands	
Summary			11•, 10 X		126	53	33	
AM	Armenia	1,807	X	—	—	—	—	
AT	Austria	12,500	X	—	—	—	—	
HR	Croatia	29,970	X	—	—	—	—	
CY	Cyprus	3,500	•	1,250	7	6	1	•
CZ	Czech Republic		X	—	—	—	—	
DK	Denmark	35,000	•	1,115	14	10	5	•
EE	Estonia	26,500	•	25,000	3	1	0	•
FI	Finland	5,933	X	—	—	—	—	
HU	Hungary	80,000	•	16,800	4	0	2	•
IS	Iceland		X	—	—	—	—	
IE	Ireland	18,865	X	—	—	—	—	
LV	Latvia	64,700	•	7,600	3	1	3	
LU	Luxembourg	600	X	—	—	—	—	
MD	Republic of Moldova	31,100	•		17	14	0	•
NO	Norway		X	—	—	—	—	
PL	Poland	163,440	•	5,537	18	3	13	•
PT	Portugal	20,000	•	135	3	3	0	•
RO	Romania	18,350	•	1,050	3	0	0	•
SI	Slovenia		X	—	—	—	—	
ES	Spain	174,745	•		45	11	3	
TR	Turkey	131,810	•	17,100	9	4	6	

• = yes
X = no
— = consequently not possible

periods. The normal movement of groundwater precludes any rapid displacement of seawater by freshwater. Abandonment of the groundwater resource may be a necessity and treatment is often very expensive. (Rail, 1989).

The main contributor to saltwater intrusion in coastal aquifers is overpumping, by which groundwater levels are lowered and freshwater flow to the ocean reduced. If the pumping of groundwater reverses the gradient, the freshwater flow ceases and seawater then moves into the entire aquifer. In flat coastal areas drainage channels can also cause saltwater intrusion because of a lowering of the groundwater table, and an associated decrease in underground freshwater flow.

On islands, freshwater aquifers form a lens overlying seawater. Consequently, if a well is substantially pumped, the underlying seawater rises and contaminates the freshwater aquifer. Wells can also serve as a means of vertical access to fresh groundwater aquifers lying above or below saline zones (Rail, 1989).

6.2.2 Environmental effects

See section 5.5 on the 'Environmental effects of chloride'.

Concentration of tourism on the coast may boost the need for water with over-exploitation of groundwater and instrusion of salt water into aquifers Marbella, Costa del Sol, Spain. Photo: John Nielsen/BIOFOTO

6.2.3 Extent of saltwater intrusion

Twenty one countries out of 37 countries answering the questionnaire provided information on groundwater over-exploitation. In nine of the 11 countries where over-exploitation is reported to exist, saltwater intrusion is the consequence. In three countries (16 groundwater areas) salt water intrusion occurs from the rise of highly mineralised water from deeper aquifers. In the Republic of Moldova, saltwater intrusion is only from highly mineralised water from deep aquifers.

Ninety five areas of salt water intrusion from the sea have been identified in eight out of 32 European countries with coastlines (28 of which received the questionnaire). Along the Mediterranean coastline, saltwater intrusion has been found in Italy, Spain and Turkey. In Slovenia and Croatia, groundwater over-exploitation does not exist. Other Mediterranean countries did not provide information.

The main cause of saltwater intrusion is over-abstraction for public water supply. Industrial water supply, water abstraction for irrigation purposes and mining activities are also important.

Some more detailed information on the number of groundwater areas concerned can be found in Table 6.3 and are illustrated in Map 6.1. A list of groundwater areas, their size and the cause of groundwater over-exploitation leading to saltwater intrusion can be found in the technical report (EEA, 1999).

Summary of information received on saltwater intrusion **Table 6.3**

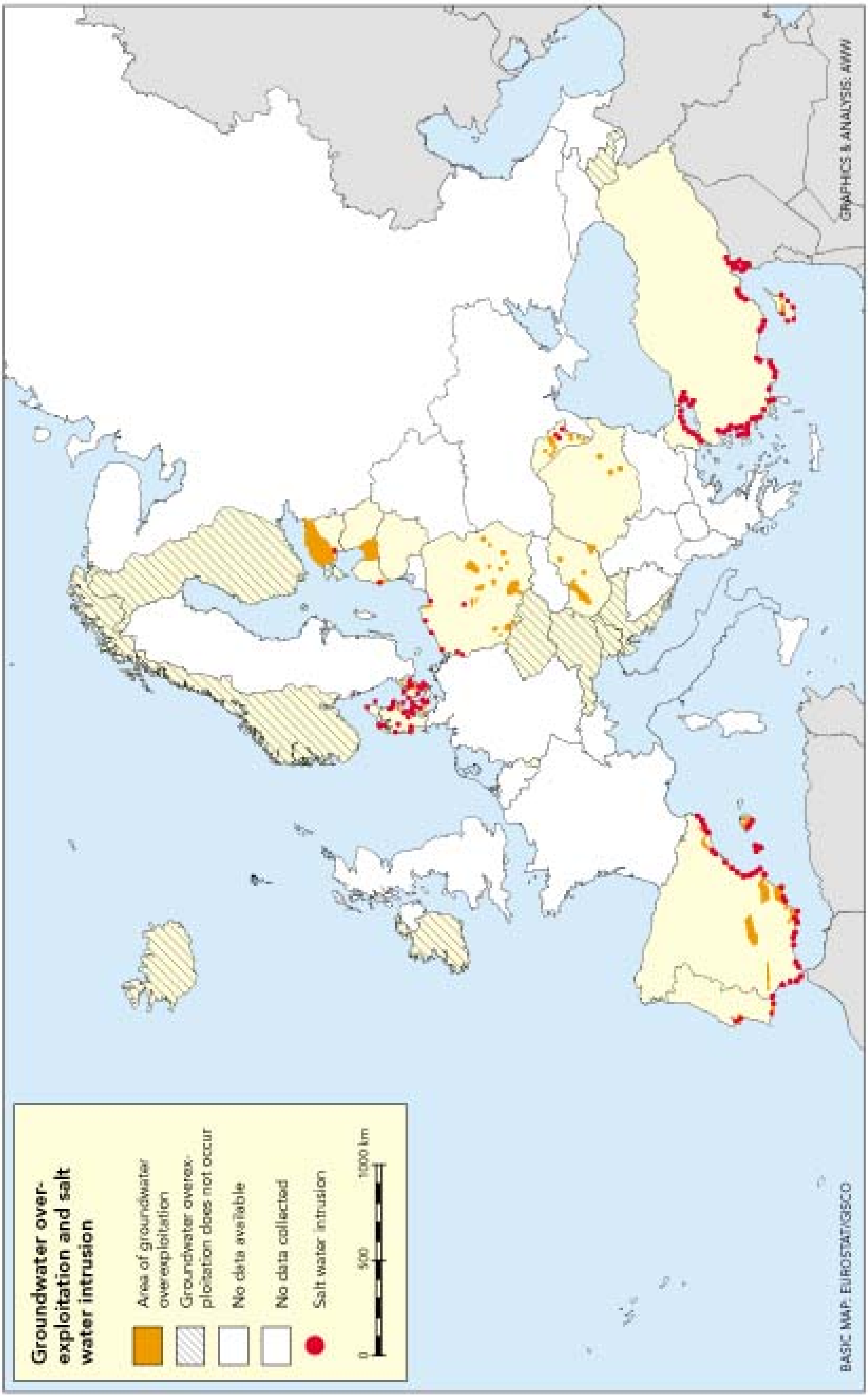
Code	Country	Over-exploitation	Saltwater-intrusion	Coastline	Saltwater intrusion from		Map
					seawater	a deep aquifer	
Summary		**11•, 10 X**	**9**	**32•, 12 X**	**95**	**16**	
AL	Albania			•			
AM	Armenia	X	—	X	—	—	
AT	Austria	X	—	X	—	—	
AZ	Azerbaijan			X	—		
BY	Belarus			X	—		
BE	Belgium			•			
BA	Bosnia & Herzegovina			•			
BG	Bulgaria			•			
HR	Croatia	X	—	•	—	—	
CY	Cyprus	•	•	•	6		•
CZ	Czech Republic	X	—	X	—	—	
DK	Denmark	•	•	•	31		•
EE	Estonia	•	•	•	1		•
FI	Finland	X	—	•	—	—	
FR	France			•			
MK	FYROM			X	—		
GE	Georgia			•			
DE	Germany			•			
GR	Greece			•			
HU	Hungary	•	X	X	—	—	
IS	Iceland	X	—	•	—	—	
IE	Ireland	X	—	•	—	—	
IT	Italy			•			
LV	Latvia	•	•	•	1	1	•
LI	Liechtenstein			X	—		
LT	Lithuania			•			
LU	Luxembourg	X	—	X	—	—	
MT	Malta			•			
MD	Republic of Moldova	•	•	X	—	14	•
NL	Netherlands			•			
NO	Norway	X	—	•	—	—	
PL	Poland	•	•	•	6	1	•
PT	Portugal	•	•	•	3		•
RO	Romania	•	X	•	—	—	•
RU	Russian Federation			•			
YU	Serbia Montenegro			•			
SK	Slovak Republic			X	—		
SI	Slovenia	X	—	—	—		
ES	Spain	•	•	•	47		•
SE	Sweden			•			
CH	Switzerland	X	—				
TR	Turkey	•	•	•			•
UA	Ukraine			•			
UK	United Kingdom			•			

•= yes

X = no

— = consequently not possible

Map 6.1
Over-exploited groundwater areas and locations with saltwater intrusion



6.3 Wetlands endangered by groundwater over-exploitation

6.3.1 General descriptions

The Ramsar Convention describes wetlands as areas of marsh, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water depth which at low tide do not exceed six metres. With regard to groundwater problems, it is particularly wetlands located near rivers, lakes and estuaries that are of concern, but under certain conditions offshore wetlands e.g. marsh areas, may also be affected by groundwater abstraction. Wetlands near rivers are located in the riparian areas along the river banks and in connected shallow lakes. In lakes, wetlands are often located along the shore, and bogs and fens can also form. In estuaries, wetlands occur as marshes.

Wetlands are of fundamental importance and value as ecosystems for animals and plants, and as recreational areas for humans. They regulate water levels as well as providing habitats for a large variety of plants and animals, in particular for migratory birds. In this respect the Ramsar Convention, and other international agreements such as the Mediterranean MedWet, are initiatives for the protection of these areas.

The influence of groundwater on wetlands is manifold. The interaction between groundwater and surface water is one important issue. Freshwater wetlands are typically groundwater discharge areas fed by shallow and deep groundwater seepage. These areas often exist along stream channels as riparian corridors. Apart from the physical connection between groundwater and river water, the water chemistry may also be affected by this connection.

With the exception of perched wetlands (wetlands located over a clay band for example), most wetlands are at the approximate level of the groundwater table, and correspond to aquifer discharge zones (water flows out of the aquifer into the wetland). When groundwater levels drop, the situation reverses and the wetland becomes an aquifer recharge zone (water flows into the aquifer, draining the wetland).

Groundwater over-exploitation has several adverse effects. Drying out of fen habitants containing vulnerable species (eg. Orchis mascula) is one example. Photo: Niels Westergaard Knudsen/BIOFOTO

6.3.2 Environmental effects

Wetland habitats are highly vulnerable to changes in hydrological and chemical conditions. Changing groundwater quality and quantity does have significant effects on ecology, and on animal and plant habitats. Nitrate transformation and reduction capacity in the riparian zone are well known, and it is thought that important pesticide degradation and adsorption can take place in wetlands that are recharged by shallow groundwater. Low flows may cause pollution from nitrate and phosphorus at concentrations favouring the growth of toxic blue-green algae. De-oxygenation and eutrophication may result causing loss of fish and invertebrates.

In peatbogs, iron may be found in sulphide minerals, for example, as pyrites (FeS_2).
In these areas, a lowering of the groundwater table produces a deeper unsaturated zone followed by oxidation of the pyrites deposits. This causes the production of ferric irons (as oxides, ochre) and sulphate, and often leads to acidification. If pumping is stopped, the groundwater table will rise and trigger a remobilisation of the metallic components and phosphorous.

6.3.3 Extent of endangered wetlands

Over-abstraction of groundwater from wetlands is one of several causes of the disappearance of whole lengths of rivers and the drying out of wetlands. Countries were asked to provide a list of Ramsar sites, and other important wetlands larger than 40 ha where national Red List 'highly endangered' species and species 'threatened by extinction' occur. Furthermore their status (endangered or non-endangered) was requested with their approximate area, and information about the factors causing the threat.

Fourteen countries (out of 37 receiving questionnaires) reported wetlands of importance, and 11 of them gave information on their endangered status. Ten countries attached maps where wetlands were marked. Out of the 420 named wetlands, information on endangered status was given for 210:

- 153 wetlands are not endangered,
- 11 wetlands are endangered by groundwater over-exploitation, and
- 46 are endangered for other reasons.

In 16 countries there are no wetlands endangered by groundwater over-exploitation. Denmark and Hungary named six and four wetlands respectively, as being threatened by groundwater over-exploitation. The UK named one wetland as being endangered but did not deliver a map. Map 6.2 and Table 6.4 gives an overview of wetlands endangered by groundwater over-exploitation. The information obtained however may be very incomplete and may not reflect the actual degree of the threat. [Note that endangered wetlands without details of location are not plotted in Map 6.2.]

Wetlands endangered from groundwater over-exploitation **Table 6.4**

Code	Country	Answers	Over-exploitation	Wetlands	Not endangered	Endangered by		Map	Year
						over-exploitation	other reason		
Summary					**153**	**11**	**46**		
AL	Albania	•		11			2		1997
AM	Armenia		X			—			
AT	Austria	•	X	9	9	—		•	1997
BG	Bulgaria	•		6	4	0	2	•	1996
HR	Croatia	•	X			—			
CY	Cyprus		•						
CZ	Czech Republic	•	X			—			
DK	Denmark	•	•	16	9	6	1	•	1995
EE	Estonia	•	•	10	10	0	0	•	1997
FI	Finland		X			—			
FR	France	•		~ 100				•	
HU	Hungary	•	•	20	0	4	20	•	1995
IS	Iceland		X			—			
IE	Ireland		X			—			
IT	Italy			45					1991
LV	Latvia		•						
LU	Luxembourg		X			—			
MD	Republic of Moldova		•						
NO	Norway	•	X			—			
PL	Poland	•	•	27	14	0	13	•	1995
PT	Portugal		•						
RO	Romania	•	•	1	0	0	1	•	1996
SK	Slovak Republic	•		7	0	0	7		1995
SI	Slovenia		X			—			
ES	Spain		•						
CH	Switzerland	•		8	8	0	0	•	
TR	Turkey	•		56				•	1993
UK	United Kingdom	•		104	103	1	0		1997

• = yes

X = no

— = consequently not possible

Map 6.2
Wetlands endangered from groundwater over-exploitation

7. Policy measures and instruments

7.1 Introduction

Over the last ten years, there has been increasing concern at the European level over groundwater resources and pollution problems. For example, the participants at the Ministerial Seminar on groundwater held at The Hague on 26/27 November 1991 recognised that:

- groundwater is a natural resource with both ecological and economic value, which is of vital importance for sustaining life, health, agriculture and the integrity of ecosystems;
- groundwater resources are limited and should therefore be managed and protected on a sustainable basis;
- it is essential to protect groundwater resources against over-exploitation and adverse changes in hydrological systems resulting from human activities and pollution.

Among others they noted the following threats to groundwater resources:

- over-exploitation;
- deterioration caused by saltwater intrusion;
- pollution by fertilisers and pesticides;
- pollution from industry, old industrial sites, waste, sewage sludge disposal;
- accidental pollution.

The participants at the Ministerial Seminar noted that existing Community legislation is inadequate to protect this essential resource against many of the above threats. They agreed, among other things, that in order to ensure sustainable management, both corrective and preventive measures should be put in place which would:

- preserve the quality of uncontaminated groundwater;
- prevent further deterioration;
- restore contaminated groundwater to a quality required for drinking water purposes (taking into account local conditions);
- prevent long-term over-exploitation and groundwater pollution.

The objective of sustainability should be implemented through an Integrated Approach which means that:

- surface water and groundwater should be managed as a whole, paying equal attention to both quality and quantity aspects;
- all interaction with soil and atmosphere should be duly taken into account;
- water management policies should be integrated within the wider environmental framework as well as with other policies dealing with human activities such as agriculture, industry, energy, transport and tourism.

This led to a draft proposal for an Action Programme for Integrated Groundwater Protection and Management (GAP), (COM(96) 315 final) which requires that an action programme be implemented at national and Community level. Many of the recommendations in the GAP are now found in a legally binding form in the more recent European Commission proposal for a Framework Water Directive (COM(97) 49 final). Certain revisions in the Common Agricultural Policy (CAP) are also aimed at reducing agricultural pollution. The most significant policy measures implemented by the European Union are EC Directives.

7.2 European Union policy

More than 15 years ago, the European Commission issued a directive directly related to groundwater management. The Council Directive (80/68/EEC) concerns the protection of groundwater against pollution caused by certain dangerous substances (including nitrogen compounds). In the Directive, however, the definition of the actual strategies for protecting groundwater resources from defined pollutants was left to Member States. Although the Directive can be considered to have had an early influence on national groundwater policies and has made a significant contribution to protecting groundwater from many point sources, its implementation and application in some Member States has been slow, particularly with regard to diffuse sources of pollution.

Other European directives that may also have direct or indirect effects on groundwater quality and quantity are:

- The Nitrate Directive (91/676/EEC), which seeks to reduce or prevent the pollution of water from the application and storage of inorganic fertiliser and manure on farmland. Member States are required to identify Nitrate Vulnerable Zones, and design and implement action programmes for their protection.
- The Urban Waste Water Treatment Directive (91/271/EEC), which sets minimum standards for the collection, treatment and discharge of urban wastewater (sewage and industrial effluents).
- The Drinking Water Directive (80/778/EEC), which concerns standards for water intended for human consumption.
- The Directive on the Conservation of Habitats (92/43/EEC).
- The Registration Directive for Plant Protection Products (91/414/EEC), which sets standards for the admission of pesticide products and stimulates that active ingredients being submitted for approval in the various Member States should be tested on the basis of ‘uniform principles’.
- The Integrated Pollution, Prevention and Control (IPPC) Directive (96/61/EEC), which identifies installations for which integrated permits covering emissions to air, water and soil, and contains emission values based on Best Available Technology (BAT), must be issued by the competent authorities.

A proposal for an EU Action Programme for Integrated Groundwater Protection and Management, commonly known as the Groundwater Action Programme (GAP) (COM(96) 315 final) was adopted by the Commission in August 1996. This proposal is aimed at maintaining the quality and quantity of unpolluted groundwater while facilitating the restoration, where appropriate, of polluted groundwater and inhibiting its further contamination. Each Member State will be required to draw up a detailed action programme.

The Commission issued a proposal for a Council Directive establishing a Framework for Community action in the field of water policy (COM(97) 49 final) in February 1997. The proposal, which aims to protect inland surface waters, estuaries, coastal waters and groundwater, establishes a framework for the whole of EU water policy. The GAP was originally intended to lead to a revision of the Groundwater Directive but the Commission concluded that provisions for the protection of groundwater should be included in the Framework Directive. Many of the recommendations in the GAP are therefore also found in a legally binding form in the Framework proposal. However, many other aspects of the GAP cannot be implemented through the Framework Directive but relate to other policy areas and measures which have a less formal nature.

7.2.1 Fifth European Environmental Action Programme

Five successive EU European Environmental Action Programmes have included the protection of groundwater quality as a major issue. The fifth and current programme indicates the following general targets:

- to maintain the overall quality of life;
- to maintain continuing access to natural resources;
- to avoid lasting environmental damage;
- to consider the Brundtland Report in which sustainable development is characterised as a development which meets the needs of the present without compromising the ability of future generations to meet their own needs.

A series of targets have been set, some of which should be achieved by the year 2000, others which must be realised in the shorter term and still more which constitute longer-term objectives. In the Fifth Environmental Action Programme, the long term objectives for the sustainable use of groundwater are as follows:

- the maintenance of uncontaminated groundwater;
- the prevention of further contamination of polluted groundwater;
- the restoration of contaminated groundwater to a quality suitable for drinking water purposes.

The above targets should be achieved by extensification, reduced application of chemicals (especially pesticides and fertilisers), reduction of nitrate loads, organic farming, consumer information and economic and fiscal incentives.

7.2.2 Common Agricultural Policy (CAP)

The Common Agricultural Policy (CAP) was launched in 1962 with the principal aim of ensuring sufficient food production in Europe. The CAP can therefore be identified as a main driving force behind the intensification of agriculture, through efforts to increase agricultural areas and increase productivity.

The CAP reform in 1992 included, amongst others, a number of agri-environmental measures which receive European financial aid. These include:

- conversion of arable land to grassland;
- reducing the density of livestock on land;
- long-term set-aside of land (20 years);
- environmentally sound production techniques and the harmonisation of green labelling standards;
- reduction of nitrogen fertilisers and pesticides;
- afforestation.

In theory, the CAP should therefore result in an overall decrease in the leaching of nitrate and pesticides towards groundwater. However, there are several drawbacks which mean that the CAP can not be considered an effective environmental policy for reducing nitrate and pesticide pollution in groundwater. Firstly, it should not be forgotten that the policy's primary aim is economic: the environment is a secondary factor. Secondly, the application of agri-environmental measures does not necessarily have any relation to the local soil and hydrological conditions and may therefore be mis-targeted. Some commentators also consider that the voluntary nature of compliance with agri-environmental measures render them less effective, and they are often too temporary to result in significant positive impacts. Finally, the CAP has been criticised for being inefficient in terms of environmental protection due to its cost.

Cleaning up of contaminated sites to prevent further grounwater pollution is a costly exercise.
Photo: Peter Warna-Moors/Geological Survey of Denmark and Greenland.

7.2.3 Control of nitrate

The European Commission has established standards for drinking water and water used in food and drink manufacturing (Directive 80/778/EEC relating to the quality of water intended for human consumption). For nitrate, it specifies a maximum allowable concentration (MAC) of 50 mg/l NO_3 and a guideline value of 25 mg/l NO_3. As groundwater is the most important source of drinking water in many countries (Section 4.1.4), elevated nitrate concentrations in groundwater can therefore cause significant problems for local and regional supply.

(a) General principles

In Europe the preferred option for controlling nitrate in groundwater is through policies which aim to prevent pollution at its source. As well as ensuring that unpolluted groundwater bodies will not be seriously impacted in the future, the aim is to reduce pollution in already polluted aquifers. Because of the long time-lag between nitrate pollution and the natural cleaning of an aquifer, policies need to be applied and sustained over long periods of time, even if there are no immediate results.

To ensure efficient policies, fundamental research and detailed local studies are required in order to understand nitrate's behaviour in groundwater and predict its future evolution under different scenarios. Technological developments and economic systems are also necessary so that best practice can be identified and become economically viable. Finally, comparable and reliable monitoring information plays a crucial role in ensuring that policies are correctly and effectively targeted.

For Eastern European countries, the economic environment is perhaps the most important factor in developing groundwater policies (Nawalany 1991). The tough rules of the free market may hinder the often costly technological and management improvements required to reduce groundwater pollution. This is another reason why harmonisation of environmental standards is a particularly important issue in these countries.

(b) International policies

Many international agreements are directly or indirectly concerned with nitrate pollution in groundwater. At the United Nation's Conference on Environment and Development in Rio de Janeiro in 1992, an agreement known as Agenda 21 set out a comprehensive programme of national strategies and action plans which are designed to promote environmentally sustainable development. Other conventions including one or more EEA countries as contracting parties, such as the Paris (1974), Helsinki (1974/1992), North-East Atlantic (OSPAR 1992) and Protection and Use of Transboundary Water Courses and International Lakes (1992) conventions include recommendations to reduce land-based sources of pollution, including nitrogen.

(c) Nitrate Directive

The Nitrate Directive (91/676/EEC) is intended to protect all types of water bodies (surface and groundwater) against nitrate from agricultural pollution sources. The Directive has four main requirements.

1. Designation of vulnerable zones (Article 3). Member States are required to identify those areas of their territory in which the nitrate concentration of surface or groundwater already exceeds 50 mg/l NO_3, or is likely to exceed this figure.

2. Establishment of action programmes in the designated vulnerable zones (Article 5), in which a number of measures must be specified, notably a maximum limit of 170 kg N/ha/year of animal effluents in the medium term.
3. Definition of codes of good agricultural practice for the whole territory (Article 4) and, as necessary, the setting up of information and training programmes for farmers. The codes must address a number of specified issues, including the conditions of fertiliser applications and animal effluent storage.
4. Monitoring and reporting of nitrate concentrations in surface water and phreatic groundwater bodies on a regular basis (Article 6).

The original timescale for the implementation of the Directive was December 1993 for the designation of vulnerable zones, with two consecutive four year programmes operating over 1996 to 1999 and 2000 to 2003. Whilst most Member States already had national or local codes of good practice in place, the setting up of vulnerable zones and their action programmes specific to the directive has been problematic (and hence delayed) in some countries, mainly for political and technical reasons (see section 'e' for more details).

The Nitrate Directive has been criticised by some commentators on several counts. Some consider that the directive is unbalanced since it defines specific limits on animal effluents, but not synthetic fertilisers. In some countries, the limits on animal effluent applications and lack of land for muck-spreading appear to be leading to an increase in effluent exportation across frontiers. The limit itself has also been criticised for not making sufficient allowance for local soil and hydrological conditions.

Finally and perhaps most importantly for its practical application and general acceptance, the Nitrate Directive is criticised for addressing nitrate pollution solely from agricultural pollution sources. Municipal sources of nitrogen pollution are in fact treated in the completely separate Urban Waste Water Treatment Directive. This means that it can be difficult to co-ordinate the two directives in local catchment management plans: ideally, priority actions in each catchment should be based on the estimated responsibility of each type of pollution source in the catchment. In addition, the balance between the two directives, particularly when introduced in a step-wise fashion in certain regions, can appear economically and unjust to farmers, undermining goodwill for carrying out codes of good practice.

Reducing the use of artificial nitrogen fertilisers by agriculture can reduce the problem of nitrate contamination of groundwater. Photo: Klaus Bentzen/BIOFOTO *(d) Codes of good agricultural practice*

Codes of good agricultural practice have been developed in many countries and generally comprise the following types of recommendations:

- fixing the mineralised soil nitrogen during the winter period when leaching is more intense, by introducing cover crops (crops planted to cover the bare soil during the winter);
- use of straw fertilisation during the winter period, when the carbon-rich organic substances in the straw tend to immobilise the soluble soil nitrogen;
- use of synthetic nitrification inhibitors, the result of on-going active research and development;
- using catch crops (a crop with a high intake of nitrogen), either during the winter or as a rotation crop;
- timing fertilisers to avoid applications during high risk leaching periods such as autumn and winter;
- optimal timing of the harvesting season;
- fractionating fertiliser applications, so that spreading occurs when the plant requires the nutrients;
- optimising nutrient supply by carrying out a forecast of nutrient balance for the site and the crop, based, if possible, on field measurements (such as the remaining nitrogen soil content at the end of winter) and assuming certain weather conditions;
- elimination or reduction in the use of raw animal effluent or other organic fertilisers (sludge etc.);
- water-tight and adequately-sized storage facilities for liquid and solid organic fertilisers;
- limits on irrigation during high risk periods;
- appropriate methods and timing of tillage (ploughing);
- adaptation of crop rotation methods.

(e) Water protection zones

As described above, the Nitrate Directive requires the designation of Nitrate Vulnerable Zones in EU countries. However, most European countries have already designated (or are currently establishing) other types of water protection zones, generally around drinking water abstraction points, with the main aim being protection from diffuse pollution. These may consist of areas immediately surrounding the abstraction point where all potentially polluting activities are banned (the land is often bought by the water company) and additional zones with graded restrictions (generally based on pollutant travel times).

A study of water protection zones in five north European countries indicated that the role of these zones as part of the national approach varies widely (Cartwright et al. 1991). In terms of nitrate pollution control, agricultural restrictions are sometimes enforced on legally designated water protection zones, using limits on manure and synthetic fertiliser applications (and timing of applications), stocking density and the use of catch crops. Uniform agricultural restrictions have political and administrative advantages but do not necessarily protect groundwater adequately and local factors such as soil type, denitrification, mineralisation and crop requirements should be considered. Ideally, restrictions should be based on actual soil nitrate concentrations. However, the cost of adequate sampling can prove prohibitive, which is why predictive models relating nitrate leaching to land use are often used.

One of the first European regions to establish extensive and strict water protection zones and define strict limits on fertiliser applications was Baden-Württemberg in Germany (SchALVO, 1987). In defining good agricultural practice, the regulations state, amongst other things, that fertiliser applications should be controlled in water protection zones, in particular so as to ensure that the soil nitrate concentration after harvesting does not exceed 45 kg NO_3-N/ha. This regulatory instrument was considered the most efficient option by the Baden-Württemberg authorities, but the method and specified values have been considered controversial by some commentators (Laigle et al., 1990).

In many cases, it is too early to determine the overall effectiveness of these water protection schemes. Nevertheless, some of the most effective policies so far appear to have been voluntary and have worked because of the close co-operation between farmers, water companies and agricultural agencies. The most promising approaches are often considered to be: integrated management schemes to match nutrient inputs to outputs, the use of cover and catch crops, and adjustments in the rate and timing of nutrient additions to match crop requirements. In addition, the conversion of arable land to grassland has resulted in relatively rapid reductions in groundwater nitrate concentrations in shallow aquifers (Cartwright, 1991).

However, there are some disadvantages in imposing agricultural restrictions solely in water protection zones. Aquifers that may be used for drinking water in the future are not necessarily protected, since the zones generally occur around existing abstraction points. The zones may be perceived as being contrary to the polluter pays principle, since it is the water companies (and therefore the water consumer) who usually provides the compensation to the farmer. Finally, the effectiveness of the zones can be limited because of compromises over size and shape.

As with most other directives, the impact of the Nitrate Directive will depend upon the interpretation of requirements by Member States, especially in interpretation of 'vulnerable' since this will affect the extent of the territory designated and subject to mandatory requirements (Table 7.1). Five Member States have designated the whole of their territory according to Article 3(5). This means that they are exempt from the obligation to identify specific vulnerable zones if they establish and apply action programmes throughout their national territory. The UK and Sweden have designated 69 and 5 NVZs respectively, and at the other end of the spectrum, Ireland does not intend to designate any NVZs. In addition, the success of the Directive will depend upon the extent to which farmers co-operate since some of the rules will be difficult to enforce. In any case, the effects of the directive will not be clear until after itsimplementation is finalised in 1999.

A recent report on the implementation of the Directive so far (CEC, 1997) concluded that the status of its implementation in most Member States is unsatisfactory. This late implementation makes it impossible to assess the effectiveness or otherwise of the Directive. Although some Member States have made progress, many are already behind the implementation timetable. So far only five countries, Austria, Germany, Denmark, Luxembourg, and Sweden, have submitted Action Programmes, required by December 1995, to the Commission.

The Commission also considered a directive on phosphorus emissions but has decided that at the present time this is not necessary.

Table 7.1

Designation [2] of Vulnerable Zones (as of 30/7/97)

Country	Area covered
Austria	Whole territory [3]
Denmark	Whole territory [3]
France	46% of agricultural land [1]
Germany	Whole territory [3]
Greece	4 potential zones
Ireland	No zones [1]
Luxembourg	Whole territory [3]
Netherlands	Whole territory [3]
Sweden	5 vulnerable zones [1]
UK	69 vulnerable zones [1]

Notes:

[1] Currently being considered by the Commission

[2] Designation was required by December 1993

[3] According to Article 3(5)

7.2.4 Pesticides

(a) Drinking Water standards

Currently there are no standards specifying pesticide limits in groundwater. Standards only apply to water which will be used for drinking water purposes. The EU Drinking Water Directive (80/778/EEC) limits exposure through drinking water for all single pesticide substances to 0.1 µg/l and to 0.5 µg/l for the total pesticide content. The aim of the Drinking Water Directive is to guarantee pesticide free drinking water. These limits reflect the precautionary approach towards groundwater protection. At the time these limits were established, they corresponded to the detection limits of most pesticides

The WHO recommends guideline values for approximately 60 pesticides, based on an assessment of potential risks. WHO 'Guidelines for drinking-water quality' however, must be applied according to local or national environmental, economic and cultural conditions. These guidelines define upper limits of concentrations which are derived from isolated investigations of individual substances. There is no information available as regards the toxicity of a combination of pesticides. It was decided that these guidelines would possibly not constitute a sufficient security factor for the EU. The precautionary principle should rather be taken into consideration (CEC,1995).

(b) Registration Directive

Due to the necessity of developing a single European regulatory system, the Registration Directive (91/414/EEC) has been implemented through the Plant Protection Product Regulations (1995) as the legal basis for pesticide registration. This Directive sets standards for the admission (for use) of pesticide products and stipulates that active ingredients being submitted for approval in the various Member States should be tested on the basis of "uniform principles". The structure of the Directive is:

- scientific and technical knowledge is the basis for decision making;
- risk management is a part of the evaluation process;
- there is an obligation to ensure that there are real benefits from use.

The Directive aims to harmonise registration across the EU and to prioritise risks to health, groundwater and the environment over the improvement of plant protection. It is a further EU requirement that for all new products, analytical methods with detection limits of at least 0.1 µg/l in water must be developed.

(c) Environmental Action Programme

The fifth European Environmental Action Programme targets a reduction of pesticide use for areas under agricultural production. Furthermore, farmers should be trained in methods of integrated pest control. Subsidies have been proposed for a renunciation of pesticides. Only the size of the extended agricultural area can be chosen by the farmer but not the degree of extensification per area, which would probably be more effective.

(d) Groundwater Action Programme (GAP)

At the Member State level, the GAP requires appropriate monitoring, the drawing up and implementation of codes of good agricultural and forestry practice and the use of economic instruments as incentives for good housekeeping, rational use or even renunciation of use of pesticides. The GAP also sees the Registration Directive as a basis for the further development of codes of good agricultural practice and as an important element in the establishment of reduction programmes. A reassessment of active substances and other products are required on a 10-year basis. A more detailed provision on the distribution and sales of pesticides as well as restrictions on their use and the substitution of the most dangerous plant products is also foreseen.

(e) Framework Water Directive

The Commission issued a proposal for a Framework Water Directive (COM(97) 49) in February 1997. The proposal aims to protect inland surface waters, estuaries, coastal waters and groundwater, and establishes a framework for the whole of EU water policy. Its overall objective is to achieve good water quality and it requires Member Sates to identify and analyse pressures on and the status of River Basins. Furthermore, the directive necessitates the preparation of action programmes designed to achieve good surface water and groundwater status, including quality and quantity standards. An economic analysis of different water uses within the River Basin must also be carried out. Article 12 stipulates that the price of water should reflect the economic costs and, where necessary, the environmental and resource depletion costs as well as the costs of providing the necessary services.

(f) Integrated pest management

Integrated Pest Management (IPM) is the careful integration of a number of available pest control techniques that discourage the development of pest populations and maintain pesticides and other interventions at levels that are economically justified and safe for human health and the environment. IPM emphasises the growth of a healthy crop with the least possible disruption of agro-ecosystems, thereby encouraging natural pest control mechanisms (FAO, 1996)

IPM uses non-contaminating, self-renewing and environmentally benign processes which are ecologically sustainable. The use of durable crops resistant to pests, natural enemies, appropriate cultivation methods and the capabilities of crops to compensate for pest damage contribute to a reduction of pesticide use. At first, the nature and extent of infestation has to be determined, pests have to be identified and the infestation pressure has to be quantified. If certain limits are exceeded, the use of pesticides will be tolerated.

7.2.5 Groundwater over-exploitation

Despite the existence of many European policy statements concerning groundwater management, there is, at present, no European legal framework or EC Directive concerning groundwater over-exploitation. However, the future Framework Water Directive is likely to include a number of measures intended to improve groundwater management, as a part of integrated water resources management.

7.3 National and regional political strategies

7.3.1 General comments

Over recent years, national and regional efforts have been made to develop appropriate strategies for the protection of groundwater resources. In many countries these efforts have resulted in the creation or adoption of legal frameworks. In others, frameworks are being prepared. In most countries a mixture of three types of policy is used, often at the national and regional levels:

- legislation (e.g. to reduce point or diffuse sources of pollution or to establish protection zones);
- financial aid (e.g. to encourage the adoption of alternative crops or agricultural techniques);
- general or targeted education programmes, establishment of codes of good practice and provision of advisory and information services.

Optimising the mix of these different types of policies and correctly targeting the different sources of pollution is a complex issue. Additionally, national/regional authorities must try to balance benefits and cost. Often several types of groundwater pollution must be considered at the same time.

For this report countries were asked to give brief descriptions of political strategies and instruments used to manage groundwater quality and quantity presently and over the next 5 years.

The main aim in many countries is to improve knowledge of their groundwater resources by defining and mapping out groundwater aquifers, improving groundwater monitoring systems and setting up databases on groundwater quality and quantity.

Another important objective is the reduction of the impact of pollutants in groundwater by controlling 'pressures'. Common legislative instruments include the establishment of protection zones, licensing systems, the restoration of contaminated land, environmental impact assessment with regard to groundwater and close co-operation with other policies (agriculture, sewage, industry). The establishment of codes of good practice is also a widely used instrument for reducing impacts. In some national strategies the restoration of polluted aquifers and the prevention of further pollution are highlighted as being very important targets for the future.

Regarding groundwater quantity, the main legislative instruments are a licensing policy, the definition of upper limits for abstraction, and education programmes on good house keeping.

Some PHARE countries emphasised the need to develop their strategies and legal frameworks in close co-operation with European Community policy measures.

7.3.2 Summary

At national and local level, European countries have developed different approaches to the protection of groundwater resources. Table 7.2 summarises the measures taken based on the information gathered from 24 countries for this report. This of course does not mean that these or other different measures are not used in any particular country.

Of the 24 countries, 20 have indicated that they have national strategies or plans for the management of groundwater quality, and 19 also include quantity issues. To this end, ten have established special groundwater protection zones, and 14 have strategies for the restoration of polluted groundwater. A finding which appears to be consistent with other studies undertaken by the ETC/IW is the lack of national groundwater monitoring networks. Only ten countries have national networks for quality and seven for quantity. Seven countries report to have implemented good agricultural practice (aimed at improving or safeguarding groundwater) but only five report restrictions on the use of fertiliser or the use of financial instruments for the control of the agricultural sector. Five countries also use financial instruments and four have licensing/authorisations for the control and management of groundwater abstractions.

Thus it would appear from the available information that although most of the respondent countries do have strategies to manage groundwater, it is not clear whether, or what, measures have been taken to safeguard groundwater resources. Many countries also need to develop monitoring and information systems which will enable them to judge the success or otherwise of their strategies and measures.

Table 7.2

Stategies adopted or to be implemented for the protection of groundwater quality and quantity in EEA, PHARE, TACIS and other countries

Countries Approach	AT	CH	CY	CZ	DE	DK	EE	ES	FI	FR	HR	HU	IE	IS	LT	MD	NO	PL	PT	RO	SK	SL	TU	UK
QUALITY																								
National or Local Plans/Strategies	•			•	•	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•	•	•
Restoration polluted groundwater	•							•	•	•	•	•	•		•	•		•		•	•	•		•
Restoration contaminated land					•	•		•	•	•		•												•
Prevention/Maintenance	•		•		•	•		•	•			•				•			•				•	
Special Protection Zones				•	•	•	•			•		•			•	•		•						•
Monitoring quality systems	•	•	•			•		•		•		•	•		•	•		•	•			•		
Set up database/mapping								•	•	•		•	•		•			•	•					•
POINT SURFACE WATER DISCHARGES																								
Licensing System	•						•			•		•												•
Industry – BAT			•	•	•					•										•		•	•	•
UWWT treatment	•			•	•					•		•								•			•	•
AGRICULTURE																								
Good agricultural practice	•				•	•				•					•							•		•
Nitrate restrictions						•				•		•							•					
Fertiliser restrictions				•	•	•				•										•				
Financial instruments	•					•				•														
QUANTITY																								
National or Local Plans/Strategies	•			•	•	•	•	•	•	•	•	•	•	•	•			•	•	•	•	•		•
Water management system					•		•	•		•	•	•				•		•		•		•		•
Rehabilitation/Protection resources	•		•	•	•	•		•	•			•			•	•				•	•	•	•	•
Monitoring quantity system	•	•				•		•		•		•		•					•					•
Set up database/mapping	•							•	•	•		•	•				•		•					
EFFICIENCY of USE																								
Decrease water exploitation			•									•			•								•	•
Water supply companies	•				•		•																	•
Industry-BAT					•		•																	•
Household	•				•		•																	•
Agriculture				•		•	•																•	•
Abstraction authorisation/licensing	•						•			•		•												•
Financial instruments	•					•	•			•														•

• Strategies adopted or being prepared

Countries:

AT	*Austria*
FI	*Finland*
PT	*Portugal*
CH	*Switzerland*
EE	*Estonia*
RO	*Romania*
CY	*Cyprus*
HU	*Hungary*
SK	*Slovak Republic*
CZ	*Czech Republic*
IE	*Ireland*
SL	*Slovenia*
DE	*Germany*
IS	*Iceland*
TU	*Turkey*
DK	*Denmark*
LT	*Lithuania*
UK	*United Kingdom*
ES	*Spain*
MD	*Republic of Moldova*
EE	*Estonia*
NO	*Norway*
FR	*France*
PL	*Poland*

8. Conclusions

Main conclusions

1. Europe's groundwater is at risk from various pressures arising from human activities. The major threats are from the use of agricultural chemicals (e.g. fertilisers and pesticides), more localised contamination (e.g. from industrial sites, landfills and poor storage facilities) and over-abstraction for drinking water and other uses. These pressures have led to a degradation of the quality and decrease in the quantity, of water in many groundwater bodies and aquifers.

2. At the time of preparation of this report there was no harmonised European groundwater monitoring or information network through which comparable information could be obtained. Thus this monograph is based on the best available information obtained through the information network of the EEA, the Environmental Information and Observation Network (EIONET). The information has been validated, where possible, through review by the EEA's National Focal Points. There are, however, some limitations to the information presented. For example, data aggregated at the country level may not fully represent the actual national status, and the level of risk to groundwater quality and quantity within a country.

3. Therefore, the implementation of EUROWATERNET, the EEA's information and monitoring network for inland water resources, across Europe is essential as it will improve the quality, comparability, scope and reporting of information thereby giving a representative overview of the state and trends of Europe's groundwater and the pressures placed upon it.

Pressures on groundwater

4. Nitrate arising from the use of nitrogen fertilisers can contaminate groundwater. The use of nitrogen fertiliser in agriculture has been increasing in some Western European countries since 1992. Before then there had been a downward trend. However, usage is expected to decrease between 1997 and 2001. In some Eastern European countries the previously observed decline in fertiliser usage was reversed in 1994/95, and usage rate for Eastern Europe is expected to increase in the future.

5. Pesticides also contaminate Europe's groundwater. Approximately 800 pesticide substances are approved for use in Europe, and many could potentially reach groundwater. The application of pesticides in terms of the amount of active ingredients has decreased within the last decade. This does not necessarily indicate a decrease in environmental impact as new pesticide substances are more efficient than older products. In addition, some countries have limited the use of some pesticides to specific uses, or instigated complete bans on use. In Northern and Eastern European countries the usage rate is relatively low.

6. Abstraction of groundwater can lead to over-exploitation, intrusion of saltwater into aquifers and to damage to dependent wetlands. Groundwater abstraction for various purposes was found to be the most important human intervention in the hydrological cycle. In European countries the share of groundwater needed for meeting the total demand for freshwater ranges from 9% to 99%. In some regions the extent of groundwater abstraction exceeds the recharge rate (over-exploitation). However, in most countries total annual groundwater abstraction has been decreasing since 1990.

State of groundwater

7. There are no statutory EU guideline values or standards for groundwater. Therefore, for this report the guideline values and maximum allowable concentrations (MACs) laid down in the Council Directive relating to the quality of water intended for human consumption (80/778/EEC) (Drinking Water Directive) were used as a measure of the degree of groundwater contamination. These guidelines and MACs are of direct relevance as groundwater is an important source of drinking water in many European countries. It is evident that the limits and guideline values for drinking water are often exceeded for several determinands in untreated (thus before human consumption) groundwater. This is particularly the case for nitrate and pesticides. Hence potentially costly treatment or mixing with less contaminated water is often needed prior to supply of groundwater for drinking water.

8. Nitrate is a significant problem in some areas of Europe. For example, at the national level in 8 countries (Austria, Czech Republic, France, Germany, the Republic of Moldova, Romania, Slovak Republic and Slovenia) of the 17 for which information is available, at least 25% of the sampled wells had concentrations in untreated water exceeding the Drinking Water Directive guide level of 25 mg NO_3/l. In the Republic of Moldova about 35% of the sampled wells had concentrations exceeding the MAC of 50 mg NO_3/l.

9. At the regional level more than a quarter of the sampling wells exceeded 50 mg NO_3 /l in 13% of 96 reported regions or groundwater areas, and in about 52% of the regions more than a quarter of the sampling sites exceeded the guide level of 25 mg NO_3 /l. There were, however, some significant differences when comparing data at the country level with data at the regional level. In general, a direct relationship between the input of nitrogen and the measured values of nitrate in groundwater could not be found at the country level.

10. In Northern Europe (Iceland, Finland, Norway and Sweden) nitrate concentrations in groundwater are relatively low.

11. Relatively few data were available on the trends of nitrate concentrations in groundwater. Those that yielded statistically significant trends showed both increasing and decreasing trends in some boreholes in some countries.

12. Many different pesticide substances have been detected in Europe's (untreated) groundwater at levels greater than the Drinking Water Directive's MAC of 0.1 µg/l for individual pesticides. Significant problems have been reported from Austria, Cyprus, Denmark, France, Hungary, Republic of Moldova, Norway, Romania and the Slovak Republic. The most commonly found pesticides in groundwater are atrazine, simazine and lindane. Most of the data obtained did not allow a reliable assessment of trends to be made. However, a recent study covering six European countries indicated that in some boreholes in three of the countries (Austria, France and Switzerland), there had been a statistically significant decrease in the concentration of atrazine and its metabolites, perhaps in relation to controls on its use. There were also a smaller number of boreholes where concentrations were increasing.

13. Groundwater areas with serious chloride problems (concentration >100 mg Cl/l) are located in Cyprus, Denmark, Estonia, Germany, Greece, Latvia, Republic of Moldova, the Netherlands, Poland, Portugal, Romania, Spain, Turkey and the United Kingdom. Most of these areas are located near the coast line, and saltwater intrusion is likely to be the main cause for the high chloride content in these groundwaters.

14. Acidification of groundwater commonly occurs in Northern European countries, especially in Denmark, Norway, Sweden, Finland, Belgium, the Netherlands, but also in Germany, France and the Czech Republic.

15. Chlorinated hydrocarbons are widely distributed in groundwater aquifers of Western European countries, whereas hydrocarbons, and especially mineral oils, cause severe problems in Eastern European countries. Chlorinated hydrocarbons come from old landfills, contaminated industrial sites and industrial activities. The production, storage and use of petrochemicals, particularly on military sites, are mainly responsible for groundwater pollution by hydrocarbons, and mostly cause local problems.

16. The pollution of groundwater by heavy metals has been reported to be a problem in 12 countries. Contamination with heavy metals is mostly caused by leaching from dumping sites, mining activities and industrial discharges.

17. Groundwater over-exploitation, leading to a lowering of the groundwater table, is a significant problem in many European countries. Eleven countries reported over-exploited groundwater areas, and 10 others stated that groundwater over-exploitation does not occur. The effect of over-exploitation in 33 of the 126 identified cases is damage to wetlands, and in 53 cases saltwater intrusion is the consequence. The majority of the groundwater areas have been over-exploited since the 1980s. The main causes of groundwater over-exploitation are water abstractions for public and industrial supply. Mining activities, irrigation, as well as naturally occurring dry periods, also cause lowering of groundwater tables.

18. Saltwater intrusion is the consequence in nine of the 11 countries where over-exploitation exists. In Latvia, the Republic of Moldova and Poland (16 groundwater areas), salt water intrusion occurs because of the rise of highly mineralised water from deeper aquifers. Eight countries listed 95 areas subject to intrusion by sea water. A large proportion of the Mediterranean coastline in Spain and Turkey has been reported to be affected by saltwater intrusion. Again the main cause is groundwater over-abstraction for public water supply.

19. Over-abstraction is one of several factors causing the disappearance of whole lengths of rivers, and the drying out of wetlands. Of the 57 internationally or nationally important wetlands (in eight countries) considered to be endangered, 11 are endangered by groundwater over-exploitation. These occurred in Denmark (6), Hungary (4) and the UK (1). Wetlands are considered not to be endangered by groundwater over-exploitation in 16 countries. Overall the information obtained was incomplete, and hence may not reflect the actual degree of threat or risk to wetlands.

Comparability of information

20. Background information was requested on the type of sampling well at which quality data was measured, but it was not always clear whether the wells represented natural background situations, high contamination areas or gave a representative view of quality for a particular aquifer. Thus, national groundwater monitoring may concentrate on areas foreseen or used as drinking water resources, or it might concentrate on industrial areas with a high contamination risk. Comparison of results from different sampling points may, therefore, lead to wrong conclusions. Hence, it is important to provide some background information on monitoring objectives, with clear definitions of the type of sampling well. This will allow an appropriate classification and comparison of wells. This is particularly important if information is compiled and compared at the European level as in this report.

21. It is evident from the information reported in this report that mapping and characterisation of groundwater systems, monitoring and adequate reporting schemes are very important actions which have to be implemented at the national and regional level.

Responses – policies and measures for the management of groundwater

22. Of the 24 countries that provided details of their national policies on groundwater, 20 have indicated that they have national strategies or plans for the management of groundwater quality, 19 also include quantity issues. To this end 10 countries have established special groundwater protection zones and 14 have strategies for the restoration of polluted groundwater. A finding that appears to be consistent with other work undertaken by the EEA is the lack of national groundwater monitoring networks, with only 10 countries with national networks for quality, and seven for quantity. Seven countries report to have implemented good agricultural practice (aimed at improving or safeguarding groundwater) but only five report restrictions on the use of fertiliser, or the use of financial instruments for control of the agricultural sector. Five countries also use financial instruments, and four have licensing/authorisations for the control and management of groundwater abstractions.

23. Thus it would appear from the available information that, though most of the respondent countries do have strategies to manage groundwater, it is not clear whether, or what, measures have been taken to safeguard groundwater resources. Many countries also need to develop monitoring and information systems which will enable them to judge the success or otherwise of their strategies and measures.

24. The draft EU Groundwater Action Programme (GAP) contains several very constructive approaches, and it would be helpful to pursue further the spirit of this programme and to integrate the proposed actions into legally binding instruments (Directives or Regulations) of the European Union. Many of the requirements of the GAP will appear in a legally binding form in the proposed Water Framework Directive once adopted.

25. The adoption and implementation of the Water Framework Directive should help the establishment of a better database on both groundwater quality and quantity. This is necessary for reliable assessments of the state of groundwater resources and their development over time. Once adopted, the Directive would establish a EU-wide objective to achieve good qualitative and quantitative groundwater status achieved through action programmes developed and implemented at the river basin level.

The way forward

26. Data aggregated at the country level may not fully reflect the actual national status and level of risk to groundwater quality and quantity within a country. Pressures on groundwater depend on the local situation and vary widely in their intensity. Hence, in the future, spatial comparisons should be made on aggregated data of groundwater areas.

27. Only a few time series datasets for assessing changes over time were available. In many countries monitoring programmes are still under development. It is recommended that special representative trend monitoring sites are established where continuous observation over a long period of time could be ensured. Harmonised statistical guidelines for calculating trends should also be developed in order to guarantee comparability and reliability.

28. The integration of water management policies into other policies dealing with human activities is an absolute necessity, and should be developed by the Commission as well as by the Member States. The achievement of this integration would be consistent with the objectives of the Fifth European Environmental Action Programme.

9. References

AEAP *et al.* (1994). *Azote et agriculture de A à Z. Agence de l'eau Artois-Picardie. Chambre d'agriculture du Nord, du Pas-de-Calais, de la Somme et de l'Aisne.* Douai: Agence de l'eau Artois-Picardie.

AELB (1988). *Azote et phosphore. Origine, effets, élimination.* Orléans: Agence de l'eau Loire Bretagne. pp 174.

Amtsblatt der Europäischen Gemeinschaften (1993). *Entschließung des Rates und der im Rat vereinigten Vertreter der Regierungen der Mitgliedstaaten vom 1. Februar 1993 über ein Gemeinschaftsprogramm für Umweltpolitik und Maßnahmen im Hinblick auf eine dauerhafte und umweltgerechte Entwicklung* (93/C 138/01).

Barker, J.A., Kinniburgh, D.G. and Macdonald, D.M.J. (1993). *Groundwater modelling and modelling methodology.* R&D Project Record 295/20/A. National Rivers Authority. Bristol. pp 258.

Barrocu, G. (1992). *Problèmes de gestion des eaux de surface et souterraines en Italie.* Hydrogéologie 4.

BGS (1995). *Groundwater in the UK. A strategic study. Groundwater issues.* Report prepared by the British Geological Survey. FR/GF 2.

Carter A.D. and Heather A.I.J. (1995). *Pesticides in Groundwater.* pp. 112-123. In "Pesticides – Developments, Impacts and Controls". (Eds.) G. Best and D. Ruthven The Royal Society of Chemistry. Cambridge.

Cartwright, N.G. (1990). *The control of nitrate and pesticides in groundwaters in seven EC Member States.* WRc plc for the National Rivers Authority. Marlow Foundation for Water Research. pp 99.

Cartwright, N.G., Rees, Y.J. and Derick, M. (1991). *Water protection zones to reduce nitrate in groundwater. Their role and effectiveness in five North European countries.* pp 90. WRc plc for the National Rivers Authority. Marlow: Foundation for Water Research.

Commission of the European Communities (CEC) (1995). *Proposal for a Council Directive concerning the quality of water intended for human consumption.* COM(94) 612 fin. Brussels.

Commission of the European Communities (CEC) (1997). *The implementation of Council Directive 91/676/EEC concerning the Protection of Waters against Pollution caused by Nitrates from Agricultural Sources.* Report of the Commission to the Council and European Parliament. COM(97) 473 final.

Custodio, E. (1991). *Characterisation of aquifer over-exploitation: comments on hydrogeological and hydrochemical aspects: the situation in Spain.* XXIII I.A.H Congress 'Aquifer over-exploitation'. Canary Islands, Spain, April 1991.

DVWK (1993). *Stoffeintrag und Grundwasserbewirtschaftung.* Heft 104. Paul Parey.

European Crop Protection Association (ECPA) (1998). Information provided to ETC/IW.

EEA (1995). *Environment in the European Union 1995: Report for the Review of the Fifth Environmental Action Programme.* (Ed.) K. Wieringa. European Environment Agency, Copenhagen.

EEA (1995). *Europe's Environment: The Dobris Assessment.* (Eds.) D. Stanners and P. Bourdeau. European Environment Agency, Copenhagen.

EEA (1998). *Europe's Environment: The Second Assessment.* European Environment Agency, Copenhagen.

EEA (1999). *Groundwater Quality and Quantity in Europe: Data and Basic Information.* Technical report. European Environment Agency, Copenhagen. (in print)

EEA (1999a). *Sustainable Water Use in Europe: Part 1: Sectoral use of water.* Topic Report 1. European Environment Agency. Copenhagen. (in print).

ETC/IW (European Topic Centre on Inland Waters) (1997). *Groundwater quality and quantity.* Questionnaire returns from EEA National Focal Points.

ETC/IW (European Topic Centre on Inland Waters) (1998). *The Reporting Directive: Report on the returns for 1993 to 1995.* ETC/IW Draft Report to DGXI.

EUROSTAT (1995). *Europe's Environment: Statistical Compendium for the Dobris Assessment.* Environment Series 8A. Brussels, Luxembourg.

EUROSTAT (1996). *Umwelt 1996/1: Überblick über die Pestiziddaten der Europäischen Union.* Brussels, Luxembourg.

EUROSTAT (1997). *Water abstractions in Europe.* Internal working document, Water/97/5.

EUROSTAT (1997a). *Soil Surface Nitrogen Balances in EU Countries.* Internal working document, Agrienv/97/4.

FAO (1990). *International Code of Conduct on the Distribution and Use of Pesticides* (Amended version), Rome.

FAO (1996). *Current World Fertiliser Situation and Outlook 1994/95 + 2000/2001.* World Wide Web, http://www.fao.org/waicent/faoinfo/agricult/agl/agin/cwfso94.htm.

FAOSTAT (1997). World Wide Web, http://apps.fao.org/.

Fielding, M., Mole, N., Horth, H., Gendebien, A. and Van Dijk, P. (1998). *Pesticides in Groundwater: Phase II.* WRc Report No. CO 4395.

Guillemin, G. and Roux, J.C. (Eds). (1992). *Pollution des eaux souterraines en France.* Manuels & méthodes 23. Orléans: Editions du BRGM. pp 264.

Heinonen, P. (1998). *Lyhyt katsaus maatalouden vaikutuksista vesistöjen tilaan ja pohjavesien laatuun* (In Finnish with a short abstract in English: A short assessment of the effects of agriculture on the state of water courses and the quality of groundwaters in Finland). Vesitalous 39: 28-32.

INFU, Institut für Umweltschutz Universität Dortmund (1995). *Economic Efficiency Calculations in Conjunction with the Drinking Water Directive* (Directive 80/778/EEC), Part III: The Parameter for Pesticides and related Products.

Kimblin, R.T., Bierens de Haan, S., Parker, A. and Rae, J.E. (1991). *Geochemical consequences of over-abstraction in the London Basin aquifer, S.E. England.* XXIII I.A.H Congress 'Aquifer over-exploitation', Canary Islands, Spain, April 1991.

Korkka-Niemi, K., Sipilä, A., Hatva, T., Hiisvirta, L., Lahti, K. & Alfthan, G. (1993). *Valtakunnallinen kaivovesitutkimus. Talousveden laatu ja siihen vaikuttavat tekijät.* Vesi- ja ympäristöhallinnon julkaisuja-sarja A 146 (Sosiaali- ja terveysministeriön selvityksiä 2/93). pp. 225.

Kujala-Räty, K., Hiisivirta, L., Kaukonen, M., Liponkoski, M & Sipilä, A. (1998). *Talousveden laatu Suomessa 1996. Helsinki, sosiaali- ja terveysministeriö, maa- ja metsätalousministeriö, ympäristöministeriö.* Suomen ympäristökeskus. Suomen ympäristö, luonto ja luonnonvarat 181. pp. 135. Abstract in English "The Quality of Drinking Water in Finland".

Laigle, D., Kugler, J., Kobus H. and Zilliox, L. (1990). *Contamination des eaux souterraines par les nitrates. Recherches et applications dans le cadre de la coopération franco-allemande.* Hydrogéologie, 1: 51-60.

Lamoreaux, P.E. (1991). *Environmental effects to over-exploitation in a karst terrain.* XXIII I.A.H Congress 'Aquifer over-exploitation'. Canary Islands, Spain, April 1991.

Länderarbeitsgemeinschaft Wasser LAWA (Hrsg) (1995). *Bericht zur Grundwasserbeschaffenheit Nitrat.*

Lehr, J.H. (1991). *Perceived aquifer over-exploitation is, in reality, mismanagement – commonly correctable by artificial recharge and well field design.* XXIII I.A.H Congress 'Aquifer over-exploitation'. Canary Islands, Spain, April 1991.

Lloyd, J.W. (1991). *Protective and corrective measures with respect to the over-exploitation of groundwater.* XXIII I.A.H Congress 'Aquifer over-exploitation'. Canary Islands, Spain, April 1991.

Margat, J. (1992). *L'eau dans le bassin Méditerranéen. Situation et prospective.* Les Fascicules du Plan Bleu 6. Paris.

Nawalany, M. (1991). *Groundwater pollution problems in Poland.* European Water Pollution Control, 3.

Organisation for Economic Co-operation and Development (OECD) (1995). OECD *Environmental Data, Données OCDE sur L'Environnement.* Compendium 1995. OECD, Paris.

Organisation for Economic Co-operation and Development (OECD) (1997). *OECD Environmental Data Compendium 1997* (DRAFT), OECD, Paris.

PANNA (1997). *Demise of the Dirty Dozen 1995 Chart.* Pesticide Action Network North America. URL: http://www.igc.acp.org/panna/DD.html.

Rail, C.D. (1989). *Groundwater Contamination. Sources, Control and Preventive Measures.* Technimic Publishing Co. Lancester, Basel.

Roberts G. and Marsh T.J. (1990). *Les tendances à l'augmentation des concentrations de nitrates dans les eaux en relation avec les pratiques agricoles des pays d'Europe occidentale: la situation en Grande-Bretagne.* Les Cahiers du Murs 19-20. 1er/2ème trimestres.

SchALVO (1987). *Verordnung des Ministeriums für Umwelt über Schutzbestimmungen in Wasser- und Quellenschutzgebieten und die Gewährung von Ausgleichsleistungen (Schutzgebiets- und Ausgleichs- Verordnung-*SchALVO) vom 27 November 1987. Gesetzblatt für Baden-Württemberg 22.

Van de Ven, F.H.M., Kohsiek, L., da Silva Costa, J. and Fried, J.J. (1992). *EC action programme for sustainable use of groundwater.* European Water Pollution Control 4. vol. 2.

Wäre, M. (1961). *Analyysitulokset Suomen maalaiskunnissa syys-lokakuussa 1958 käytetystä talousvedestä ja vedenottopaikat. Maataloushallituksen insinööriosasto. Maa- ja vesiteknillinen tutkimustoimisto.* Tiedotus 3, 5 s.+ taulukot ja karttaliitteet.

WHO (1993). *Guidelines for drinking-water quality.* Volume 1: Recommendations. WHO, Geneva

WHO (1996). *Guidelines for drinking-water quality.* Volume 2: Health criteria and other supporting information. WHO, Geneva.