NATIONAL INSTITUTE OF PUBLIC HEALTH
AND ENVIRONMENTAL PROTECTION
BILTHOVEN
the NETHERLANDS

RIVM report nr 461501002

VULNERABILITY TO DIFFUSE POLLUTION OF EUROPEAN SOILS AND GROUNDWATER

C.R. Meinardi, A.H.W. Beusen, M.J.S. Bollen, O. Klepper

December 1994

This investigation has been performed in order and for the account of the Board of Directors of the National Institute of Public Health and Environmental Protection

MAILING LIST

1. Directie van het Rijksinstituut voor Volksgezondheid en Milieubeheer
2. Ir F. Langeweg
3. Drs L. Kohsiek
4. Drs A. van der Giessen
5. Ir G.J. Heij
6. Ir B.J. de Haan
7. Drs R. van der Velde
8. Ir A.M.A. van der Linden
9. Dr L. van Liere
10. Ir J. Knoop
11. Ir K. Kovar
12. Drs W.J. Willems

13-25 Auteurs

26. Bibliotheek RIVM
27. Hoofd Bureau Voorlichting en Public Relations
28. Bureau Projecten en Rapporten registratie

29-50 reserve exemplaren

For further information to:

51. Dr A. Carter, Soil Survey of England, Shardlow Hall, Derby DE7 2GN, UK
52. Dr S. Nortcliff, Dept. of Soil Sciences, Un. of Reading, Reading RG1 5AQ, UK
53. Dr L. Laville Timsit, BRGM, Dir. Env., b.p. 6119, 45061 Orléans Cedex 02, France
54. Dr C. Bannick, Umweltbundesamt, Mauerstr. 45-52, 10117 Berlin, Deutschland
55. Prof W. Stepniewski, Inst. of Agrophysics, ul. Doswiadczalna 4, 20-280 Lublin, Polen
56. Prof J.O. Englund, Dept. of Soil Sciences, P.O.B. 28, N 1432, Aas, Noorwegen
57. Dr S. Jelgersma, Rijks Geologische Dienst, Postbus 157, 2000 AD Haarlem
57. Drs H. Pagnier, Rijks Geologische Dienst, Postbus 126, 6400 AC Heerlen
58. Prof dr J.J. de Vries, Aardwetensch. VU, De Boelelaan 1081, 1085 HV Amsterdam
59. Prof dr ir C. van den Akker, Civiele Techniek TUD, Postbus 5048, 2600 GA Delft
60. Prof dr W. Werner, Inst. of Agric. Chemie, Un. of Bonn, Meckenheimer Allee 176, 53115 Bonn, Deutschland
61. Dr A. Tskhai, Russian Academy of Sciences, Inst. for Water and Environment IWEP, Papanintsev str. 105, Barnaul 656009, Russia
62. P. Anand Raj, Dept. of Civ. Eng., Reg. Engg. College, Warangal 506 004, A.P., India
63. Vincent Soubeyran, 1 Chemin du Turelet, 05000 GAP, La France
64. D. Augustijn, Universiteit van Twente, Postbus 217, 7500 AA Enschede
65. Milan Jarabac, U. Sportoviste 1165, 70800 Ostrava 4, Czech Republic
66. J. Heringa, Van Hall Instituut, Postbus 17, 9700 AA Groningen
67. G. Martinez, C.H.Tajo, Augustin Betaucourt 25, 28003 Madrid, Spain
68. B. van Hattum, IVM-VU, De Boelelaan 1115, 1081 HV Amsterdam
69. H. Gorka, Westfalia Sepnabos AG, Werner Habigstr. 1, D-59302, Oelde, Deutschland
70. D. Venema, Hoofdstraat 157A, 9827 PA Lettelbert
71. L. Bijlmakers, Iwaco, Postbus 8520, 3009 AM Rotterdam
72. Dr A.Tonderski, University Dept. of Water and Society, S-581 83 Linkoping, Sweden
73. Depot Nederlandse publicaties en Nederlandse bibliografie

ABSTRACT

From the Atlantic Ocean to the Ural Mountains, European soils and groundwater are threatened by diffuse pollution derived from various chemicals used in modern agriculture and by increased atmospheric deposition of pollutants. The investigated vulnerability of soils (including groundwater) to diffuse pollution depends on land cover, topsoil, net precipitation, aquifer type, groundwater recharge and age. The elaboration of the various composing elements, both for the topsoil and for groundwater, was realized by applying Geographical Information Systems (GIS). Net precipitation is estimated using meteorological data and applying the Langbein/Turc approach for the actual evapotranspiration. Irrigation techniques will not greatly change the amount of net precipitation. Net precipitation is assumed to include 5% of total precipitation, immediately discharged by runoff or by fast percolation to deeper layers. Net precipitation is discharged by groundwater recharge and surficial flow. The occurrence of surficial runoff is related to soil features. The average groundwater age follows from aquifer depth, porosity and the recharge. The vulnerability of European soils and European groundwater was estimated by establishing a ranking of the combined risks with regard to diffuse pollution. The results of the ranking and intermediate results are presented on maps.

KEYWORDS

Europe, GIS methods, groundwater, pollution, soil quality, vulnerability.

SAMENVATTING

Bodem en grondwater in Europa (van de Oeral tot de Atlantische Oceaan) worden bedreigd door diffuse vervuilingen die vooral worden veroorzaakt door de bemesting van landbouwgronden en door een toegenomen luchtverontreiniging. De kwetsbaarheid van de bodem (met inbegrip van het grondwater) voor diffuse vervuiling hangt af van het landgebruik, eigenschappen van de ondiepe bodem, het neerslagoverschot, aard van de watervoerende pakketten, aanvulling en ouderdom van het grondwater. Het overschot aan neerslag is geschat met behulp van meteorologische gegevens en de benadering van Turc-Langbein voor de actuele evapotranspiratie. Door toepassing van irrigatie zal de waarde van het neerslagoverschot niet sterk veranderen. Voor alle gebieden is aangehouden dat 5% van de neerslag onmiddellijk wordt afgevoerd door oppervlakkige afvoer of snelle percolatie in de bodem en dus niet onderhevig is aan evapotranspiratie. De aanvulling van het grondwater is gelijk aan het neerslagoverschot minus de oppervlakkige afstroming. Het voorkomen van oppervlakkige afvoer is afhankelijk gesteld van een aantal eigenschappen van de bodem (textuur, helling, landgebruik, ijsbedekking). De ouderdom van het grondwater volgt uit de waarden voor de aanvulling, de porositeit en de dikte van de desbetreffende watervoerende lagen. De kwetsbaarheid van de bodem is onderscheiden in een kwetsbaarheid van de toplaag en een kwetsbaarheid van het grondwater. In beide gevallen worden, met behulp van GIS-methodieken, waarden aan de kwetsbaarheid toegekend die volgen uit een verwerking van de gewogen bijdragen door de diverse factoren die van invloed zijn. De resultaten zijn op kaarten weergegeven.

TABLE OF CONTENTS

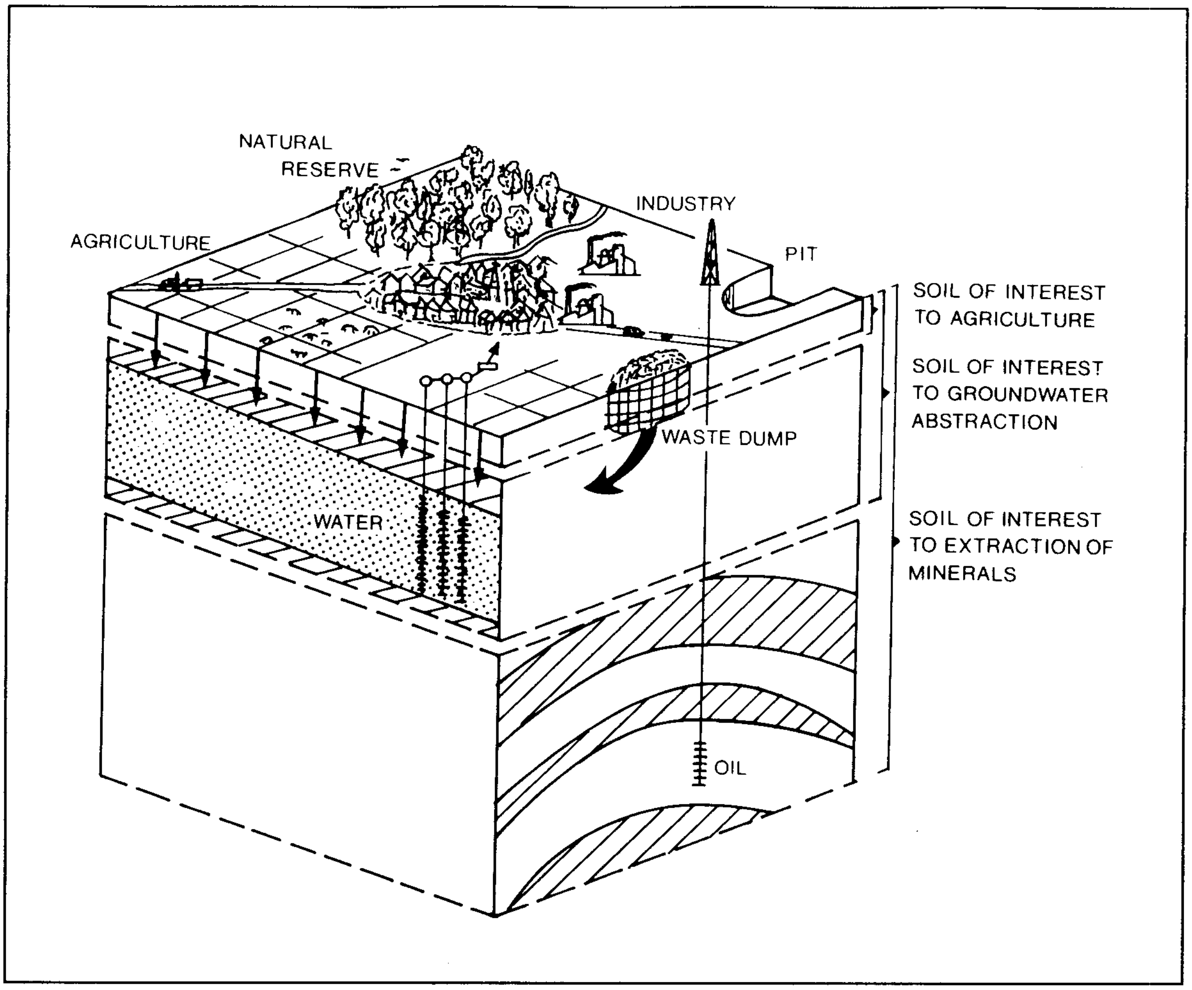

Fig.1 Economical activities with a possible environmental impact on soil quality

1. ASPECTS OF SOIL AND GROUNDWATER QUALITY

From an environmental viewpoint, it is useful to consider soil as the solid parts of the subsurface, in combination with and inseparable from the fluids, gasses and biota within the solid matrix. The soil includes the deeper strata of subsurface and groundwater forms part of it. Soil and groundwater are assailed by various sources of pollution. The effects of point sources may be serious at the affected location, but diffuse sources are a more important threat to the regional environment because of their widespread occurrence. The flow of water is the main transport mechanism bringing pollution to deeper soil layers, to the draining surface water and ultimately to the sea. Although a type of soil is present in every region of Europe, the groundwater in that soil is not exploitable everywhere, nor is it even flowing at a significant rate. The soil exerts functions (Fig.1) which are essential to human society, such as providing the foundation for constructions, food production, being a mineral reservoir and maintaining ecological conditions. Many soil functions (food production, ecological conditions) are related to the features of the topsoil. Groundwater is important, not only because it is a valuable mineral (e.g. for drinking water supply), but also because groundwater flow is transporting many pollutants. Hence, for planning purposes, it is useful to have a first insight in the vulnerability of the soil to diffuse pollution, distinguishing it in a vulnerability of the topsoil layers (affecting agricultural production and local ecological conditions) and a vulnerability of the groundwater in exploitable aquifer systems (water extraction and ecological conditions downstream). The following factors play a role in the mapping of both types of vulnerability:

a. *Definition of elementary areas.* All features of the mapped regions were averaged over basic elementary areas, or the areal distribution of the relevant features over these basic unit areas was represented.

b. *Hydrogeological mapping of the subsurface.* The available aquifers are important for the vulnerability of groundwater, however, features of the deeper soil also determine the hydrological processes at land surface and the flow of water in the topsoil.

c. *The texture of the topsoil.* The soil texture has an impact on hydrological processes, but also on (bio-)chemical changes of the entering pollutants.

d. *Land cover.* Although vulnerability is concerned with potential contamination, implying that the actual pollution is less relevant, different land use still represents a varying risk of contamination. Moreover, the type of land cover will affect the way of discharge of excess water from land surface, including groundwater recharge.

e. *Net precipitation.* Net precipitation is the amount of precipitation minus the actual evapotranspiration. In some areas the total precipitation may increase by irrigation.

f. *Groundwater recharge.* Net precipitation can be discharged directly, via surface runoff, or it may flow as groundwater in the subsurface for a certain time.

g. *Groundwater age.* Many pollutions on land surface are of a relatively recent date, implying that the percolation to saturated groundwater may not have reached yet the deeper layers of the aquifer system.

The above factors represent varying risks to a possible contamination. The objective is to combine these risks in the form of vulnerability classes for soil and for groundwater in Europe, by using Geographical Information Systems (GIS) allowing to present the final, as well as intermediate, results in the form of maps.

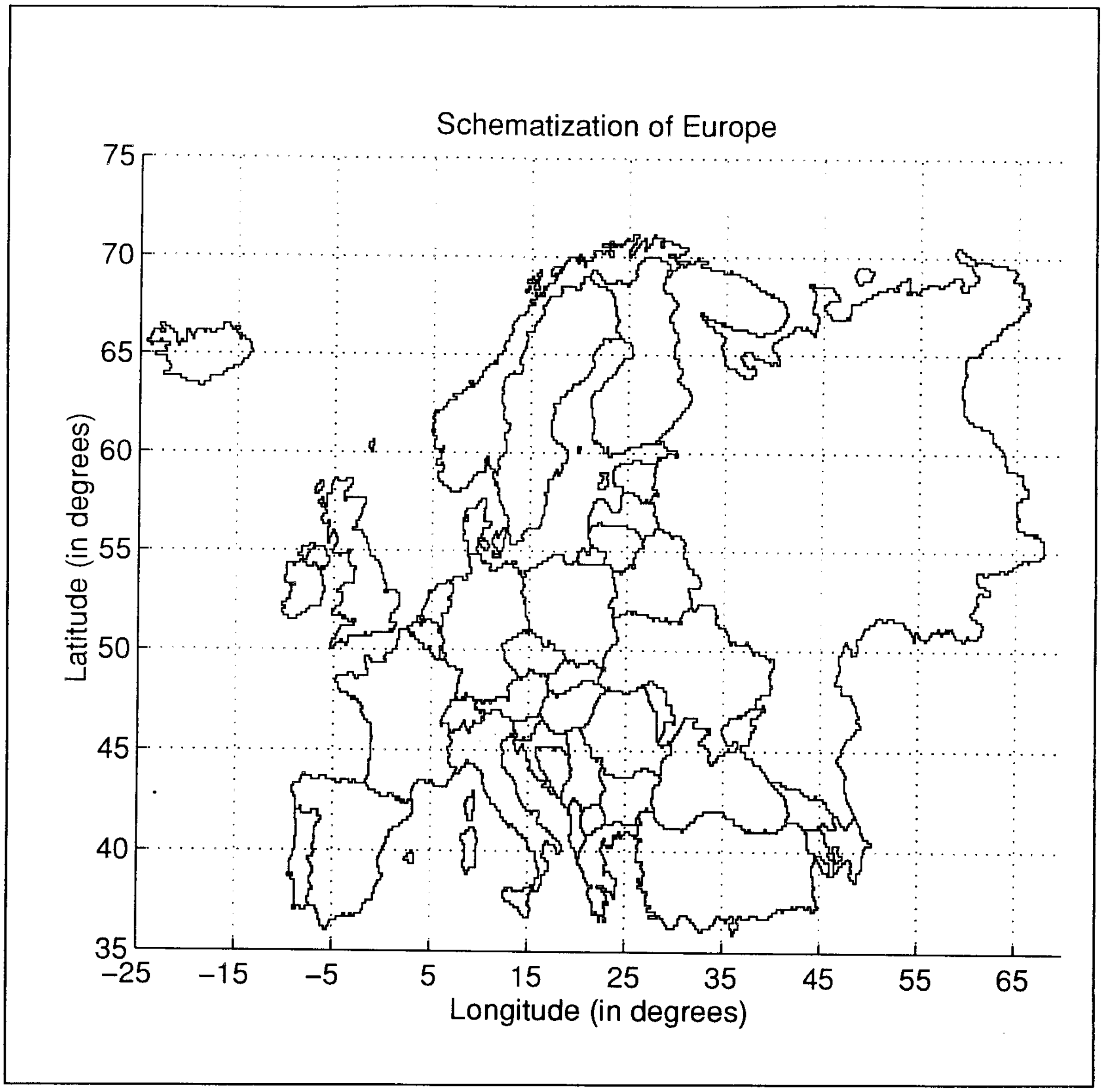

Fig.2 Division of Europe in longitudinal and latitudinal degrees

2. USE OF ELEMENTARY AREAS

The groundwater situation differs from cases with only surface water flow, insofar that contamination of surface water by a point source of pollution will be dispersed over a large part of the water body concerned in a relatively short time. Groundwater flow will mostly need many years to transport the contamination by a point source of pollution over a certain distance; the lateral dispersion will be small. Hence, the effect of a point source of pollution generally can only be observed in the near vicinity of the source and only in and near the specific groundwater stream tubes originating in the polluted area. In a natural situation a wide variety of soil and groundwater composition may be observed in subsurface, resulting from the confusing aspect that most forms of diffuse pollution at a local scale consist of a combination of point sources, each with its own impact on soil quality. As a consequence, regional considerations on soil quality and on the vulnerability of soil and groundwater to pollution should be related to diffuse sources of pollution, or to a number of point sources which may be represented by a diffuse source at the chosen scale.

The conclusion is that mapping of soil and groundwater vulnerability should be done at a predetermined scale and for predetermined elementary areas. All features of the mapped regions have to be averaged over these basic units, or the areal distribution over such unit areas should be represented. For the present purpose, the scale of mapping should be such that the whole of Europe is taken into consideration, implying that the areal representation of the various features is relatively rough. A basic condition of the elementary areas is that quality and vulnerability can be determined in sufficient detail, implying that the available data have to be adequate. The availability of data is variable for the different parts of Europe. Data of the EC member states are available in a relatively detailed form (e.g. EUROSTAT, 1991 and CORINE, 1990), whereas for the east European countries the available data are less detailed.

For practical reasons, elementary units are chosen, having an area of 0.16 by 0.16 degree (10 by 10 minutes). Consequently, the areas have different sizes for different parts of Europe. The more to the north, the smaller the size in kilometres of one longitudinal degree becomes, whereas the latitudinal degrees remain the same size. The set-up of the elementary grid cells, covering all European countries, can be derived from the mapping of Europe in Fig.2. All grid cells for reasons of convenience have obtained the same size in Fig.2 (hence, showing a representation slightly differing from "normal" maps).

The consequence of an approach based on elementary areas is that the vulnerability values determined are representing the average soil and groundwater conditions over the grid cells, implying that locally the vulnerability to diffuse pollution may be larger or smaller than indicated on the maps. For a more detailed representation of soil and groundwater vulnerability, the scale of mapping and the size of the elementary areas should be adapted, yet in combination with more detailed data.

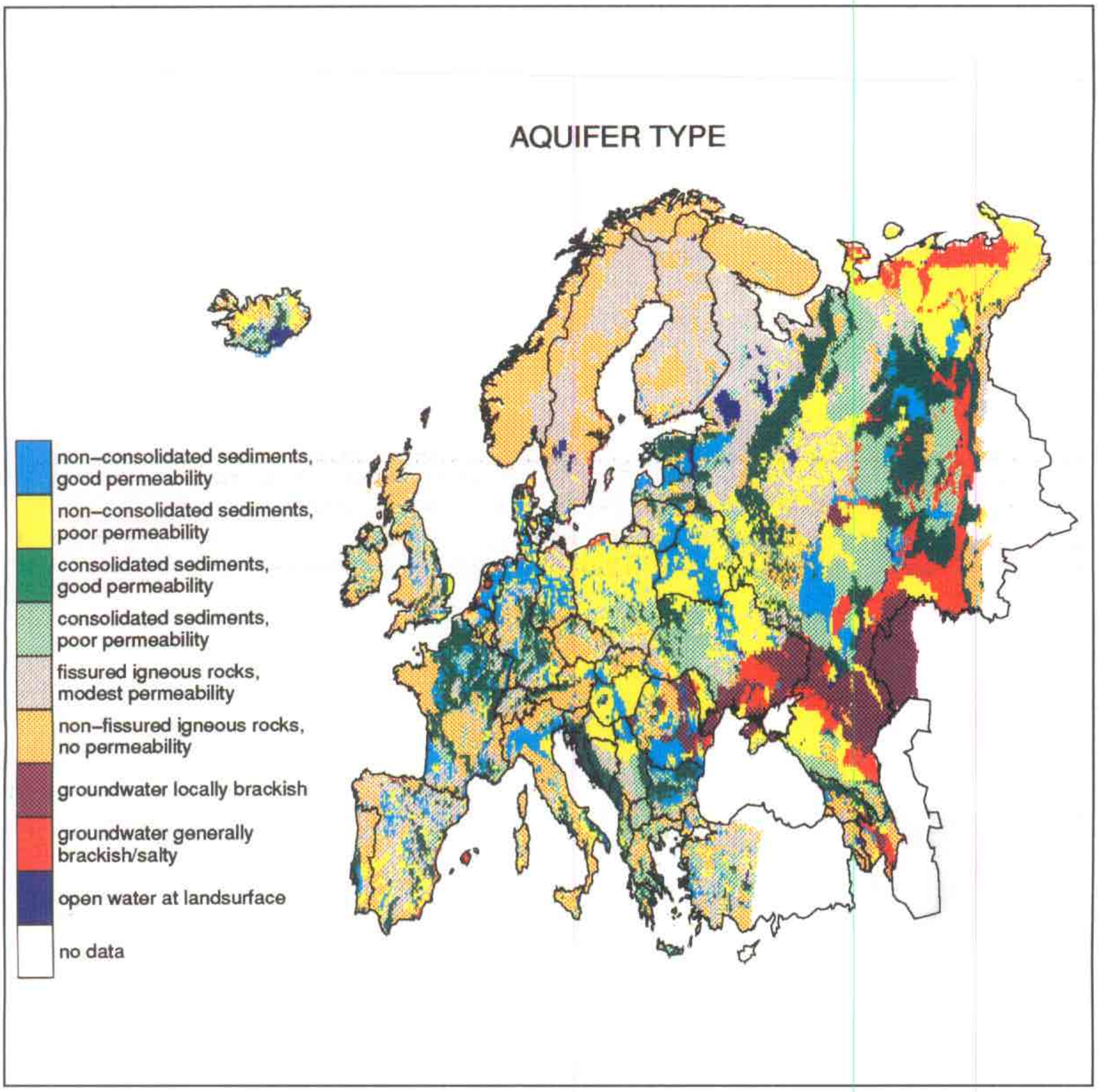

Fig.3 Hydrogeological schematization of the subsurface

3. HYDROGEOLOGICAL MAPPING OF THE SUBSURFACE

Aquifers characteristics are important with regard to the vulnerability of groundwater, but they also determine the hydrological processes at land surface and the flow of water in the topsoil. The hydrogeological mapping supporting the vulnerability classification was based on existing documentation. The Hydrogeological Map of Europe by the International Association of Hydrogeologists (IAH, various dates) does not cover the full area, the most eastern parts of European Russia, the western part of Portugal and parts of the Balkan area have not been represented yet. Hydrogeological data from the lacking areas could largely be obtained from USSR (undated), although the latter data were represented in a slightly different way. The UN publications on Groundwater in Europe (UN, 1990; UN, 1991) contain data on all European countries. The various documents at least show the surficial aquifer systems, such that the type of aquifer system could be mapped on a European scale. Eight classes were distinguished in the mapping of Fig.3, ranging from unconsolidated sedimentary rocks of good permeability to igneous and metamorphic rocks of a relatively poor permeability. The mapping also indicated areas with brackish or saline groundwater. The full classification used:

a. non-consolidated aquifers of good permeability;
b. non-consolidated aquifers of medium to poor permeability;
c. consolidated sedimentary aquifers of good permeability (prominent karst features, or sandstones with a large primary porosity);
d. consolidated sedimentary aquifers of medium to poor permeability (limited karstification, poorly developed primary porosity and limited fissuring);
e. igneous and metamorphic hardrock with well developed fissure systems;
f. igneous and metamorphic hardrock, acting as aquifuges or aquicludes, practically without permeability;
g. aquifers locally containing brackish groundwater;
h. aquifers generally containing brackish groundwater;
i. subsurface covered by surface water (lakes, rivers);

The classes g and h are representing two different situations. In coastal areas (class h), the presence of brackish groundwater will often be related to marine influences. However, in a broad zone adjacent to the Ural Mountains, the brackish groundwater most probably is caused by the presence of marine sediments of a Permian Age in subsurface. In semi-arid regions, the brackish groundwater (class g) may be caused by high evaporation rates, locally removing the water and leaving the salts in the soil (salt deserts). The areas concerned are largely situated around the Caspian Sea. No aquifer type has been indicated for the classes g and h. However, the aquifer type in many cases will consist of non-consolidated sediments, mostly of a relatively poor permeability.

The mapping does not include values for the magnitude of the various aquifer systems. Nevertheless, the presence of an aquifer system will imply a certain thickness of the layers concerned. Furthermore, the mapping only gives a regional outline of the indicated units, deviations may occur if the situation is considered on a local scale.

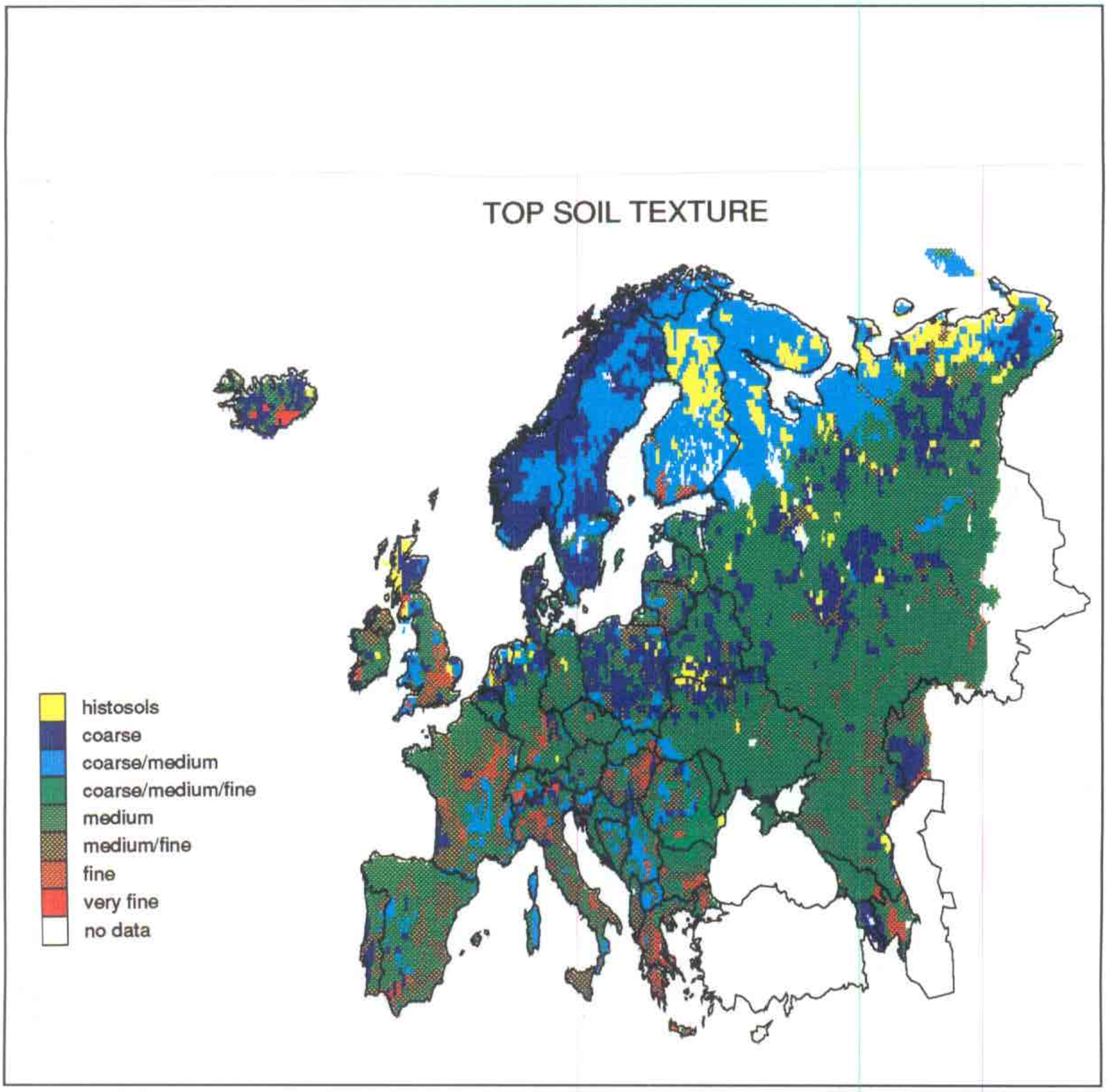

Fig.4 Texture of the topsoil

4. FEATURES OF THE TOPSOIL

The grain sizes in the top layers are important for two reasons. The soil texture has influence on hydrological processes; the coarser the topsoil, the better the water may flow through it. Furthermore, the silt and the organic material in the topsoil may (bio-) chemically change the entering pollutants. The major units of the FAO Soil Map of the World (FAO-UNESCO, 1981) were digitized, including about 60 main soil types and a number of additional properties, like texture and groundwater depth. The FAO Soil Map gives a texture classification, where 3 major classes are distinguished, depending on grain size (indicating "coarse", "medium" and "fine"), roughly corresponding to the units sandy soils, loamy soils and clayey soils. Additionally, situations with a combination of texture classes are given. A next distinction on the map is the presence of organic material. The FAO Soil Map indicates histosols, mainly consisting of various forms of peat in the topsoil layers. Another interesting class are the stony soils, indicated by lithosols in various forms.

The soil map of the CORINE (1991) data-base, based on FAO Soil map units, including a more detailed classification with regard to texture, was used for the EC member states. The various classes were based on soil triangles; it was assumed that the distribution of particle sizes will be equal to the values of the point in the middle of the area in the triangle representing the class concerned. The following classes were distinguished:

"coarse"	consists of 80% sand; 10% silt and 10% clay;
"medium"	consists of 40% sand; 40% silt and 20% clay;
"medium fine"	consists of 10% sand; 70% silt and 20% clay;
"fine"	consists of 25% sand; 25% silt and 50% clay;
"very fine"	consists of 10% sand; 10% silt and 80% clay;

Two intermediate classes, representing a combination of the major classes coarse/medium and coarse/medium/fine, were used. It is assumed that they consist of equal portions of the included texture classes. Also the various "histosols", which were indicated on the maps were used for the present purpose.

Groundwater depth is only in a rudimentary form indicated on the FAO Soil map. The indication "phreatic phase" marks soils with a groundwater table less than 3 to 5 m below land surface. In soils indicated with the adjective "gley", the water content of shallow layers (less than 2 m below surface) is near saturation during parts of the year, implying a shallow groundwater level in many cases.

The FAO Soil map of Europe also gives the slope of land surface, divided in three classes:
Slope smaller than 8%: flat land;
Slope between 8 and 30%: undulating land;
Slope more than 30%: mountainous areas;
The EC Soil map from the CORINE data-base, when using the same units, gives more detail because also combinations are indicated.

The topsoil texture units, which were schematized for the present exercise, are indicated in Fig.4, but also other elements of the FAO Soil Map were used, such as groundwater depth and slope classes.

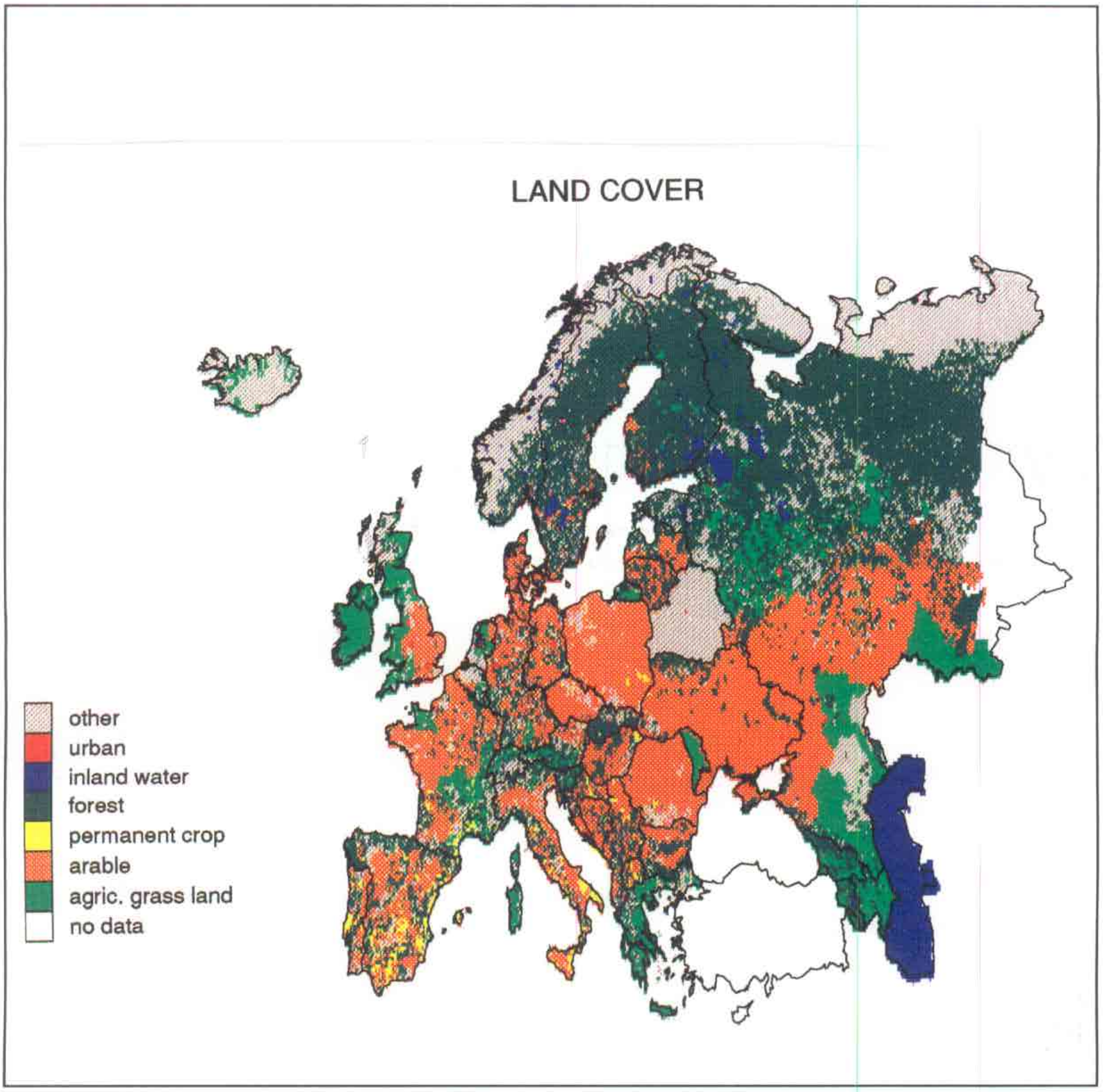

Fig.5 Dominant land cover units

5. LAND COVER AND LAND USE

Land cover and land use affect the soil and groundwater vulnerability in a number of ways. Although the actual situation of soil pollution is less relevant for vulnerability mapping, only indicating the sensitivity to contamination, yet the areas with a high degree of human activity will run a higher risk of soil and groundwater contamination. Furthermore, land use may also imply that the soil is worked. Large volumes of soil may be removed from one place to another especially in urban areas, but also the tillage of arable land will affect the soil composition. The type of land cover will have its effect on the various flows of water over and through the soil, as it is for example expressed by the relation between type of vegetation and the actual evapotranspiration. Land cover features may also partly determine the magnitude of the surficially discharged water. The flow of water over paved area in an urban environment is the most striking example.

A geo-referenced land use data base has been created at RIVM (Van de Velde et al., 1994), within the framework of environmental monitoring and forecasting on a European scale. The set-up of the data base included an inventory among 30 countries concerning the availability of land use data, either derived from satellite imagery or from maps. A distinction was made with regard to nomenclature between land cover, referring to the attributes of land surface and adjacent strata and land use, referring to the purpose for which the land cover is exploited. Land cover data were categorized in 7 major classes:

1. arable land;
2. permanent pasture used for intensive grazing;
3. permanent crops;
4. forest;
5. urban area;
6. areas covered by inland waters;
7. others;

A sub-division included the categories:
Coniferous and mixed forest and broadleaf forest (combined in the major category "forest"); extensive agriculture and natural areas (extensive grass land, waste lands, rough areas) and glaciers (combined in the major category "others"). But also the other major categories are far from homogeneous. Urban areas will contain gardens, parks etc., partly having the features of agricultural lands. Arable land will also be covered by farm yards, villages and roads, having an "urban area" impact on soil and groundwater composition.

Data were recovered from various sources and represented in a grid of 10 by 10 minutes, implying three different steps (three inter-related data bases):

1. Pan European land use vector data base;
2. Pan-European land use statistical data base;
3. 10-Minutes Pan-european land use data base for each cell;

A major requirement in the procedure was that the created data set should correspond to basic data sources like EUROSTAT, FAO-Agrostat and national data bases. Contents of the 10-minutes land use data base are represented in Fig.5, showing the dominant type of land cover, if compared to the other classes. The indicated type may only cover a minor part of grid cells with a mixed land use. However, the representation of Fig.5 will not affect the results of further elaborations based on the type of land cover if the underlying distribution is used, which was the case in the present study.

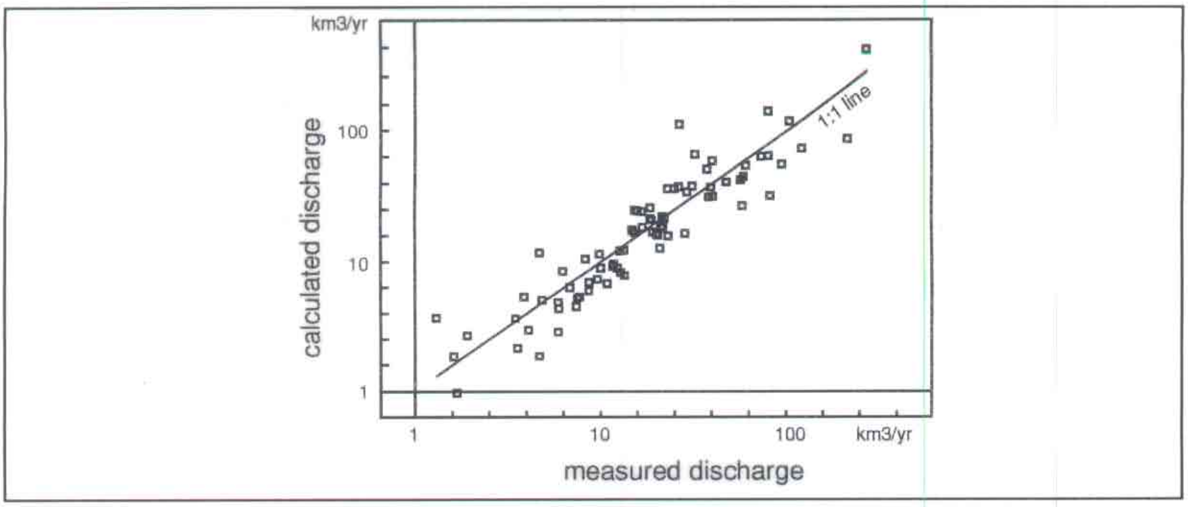

Fig.6 The comparison of calculated and measured river discharge

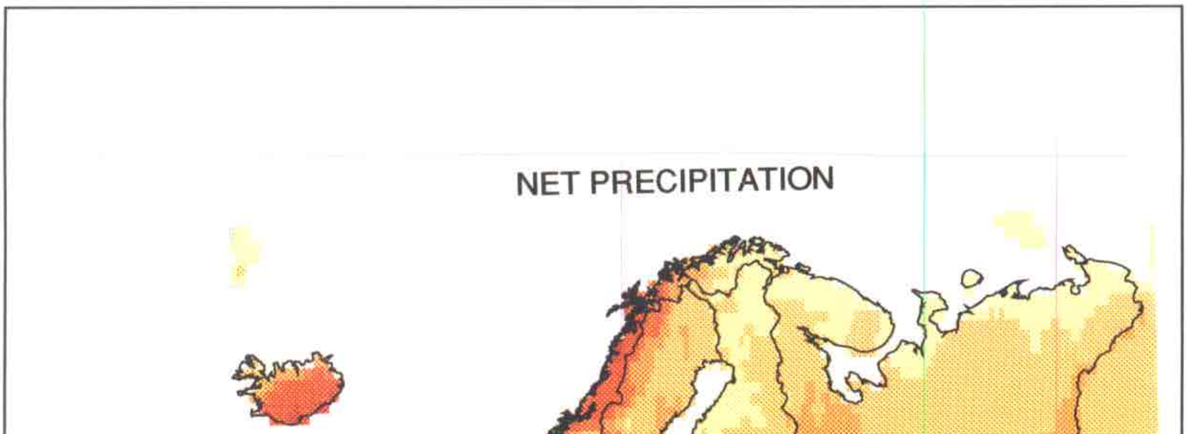

Fig.7 Net precipitation

6. PRECIPITATION, EVAPOTRANSPIRATION AND NET PRECIPITATION

Data on meteorological observations were derived from Leemans and Cramer (1991). The precipitation data were elaborated to obtain average yearly values (P). Estimates of the potential yearly evapotranspiration E_{pot} can be based, according to Penman, on temperature and cloudiness (radiation). An even more simple estimate has been proposed by Langbein: $\mathbf{E_{pot} = 325+21*t+0.9*t^2}$, with
E_{pot}=yearly potential evapotranspiration ($mm.a^{-1}$) and t=average yearly temperature (°C). Two methods were used to derive average values for the yearly actual evapotranspiration. Leemans and Van den Born (1994) propose to elaborate on topsoil features in order to obtain estimates of evaporation in periods without rainfall. The other method was the empirical relation between potential and actual evapotranspiration, E_{act} , derived by Turc:
$\mathbf{E_{act}= P/sqrt(0.9+P^2/E^2_{pot})}$
where E_{act} , P and E_{pot} (all in $mm.a^{-1}$) are long-year averages.
The difference between the values of precipitation and actual evapotranspiration is the average net precipitation (PN). The method is valid for the determination of long-year averages of the actual evapotranspiration in areas with a mixed vegetation. The grid cells have a relatively large area, implying that the method can be used. The yearly net precipitation in river catchment areas should correspond to the measured discharges. The general good agreement between annual net precipitation and river discharge does not imply that the Turc-Langbein approach will always and everywhere lead to good results. The measured discharges are deviating from the estimates especially for (semi)-arid areas.

Other areas where the approach might yield less accurate values are the permafrost areas in the north and the highest parts of mountainous terrains. A possible deviation has less severe consequences for permafrost and mountainous areas, as the actual evaporation in those areas will only represent a minor fraction of the local precipitation. For semi-arid regions the ratio between precipitation and evapotranspiration is small ($P/E_{pot} < 0.5$, according to Simmers (1990), implying low values for net precipitation. However, it may be assumed that always a certain amount of precipitation is removed by immediate runoff or by fast percolation through cracks (indirect groundwater recharge). For all regions of Europe, it is taken that 5% of precipitation will be discharged without being affected by evapotranspiration. This assumption will only marginally affect the net precipitation in non-arid areas, but it will lead to a significant increase in net precipitation of semi-arid regions. The comparison between calculated and measured discharge of European rivers under the 5% assumption is shown in Fig.6, showing good agreement. The conclusion is that the approach can be used to assess the average net precipitation over Europe.

Leemans and Cramer (1991) provided monthly values of precipitation and temperature. The Turc-Langbein approach was applied to 95% of the annual precipitation, the other 5% immediately contributing to net precipitation. Net precipitation is the amount of water having to be discharged by surficial runoff and by groundwater flow. Hence, this volume of water is the maximum amount being potentially available for recharge. Irrigation techniques will not greatly change the amount of net precipitation as the extra inflow of water is largely compensated by an increased actual evapotranspiration in the relatively small areas concerned. Calculated values of net precipitation are represented in Fig.7.

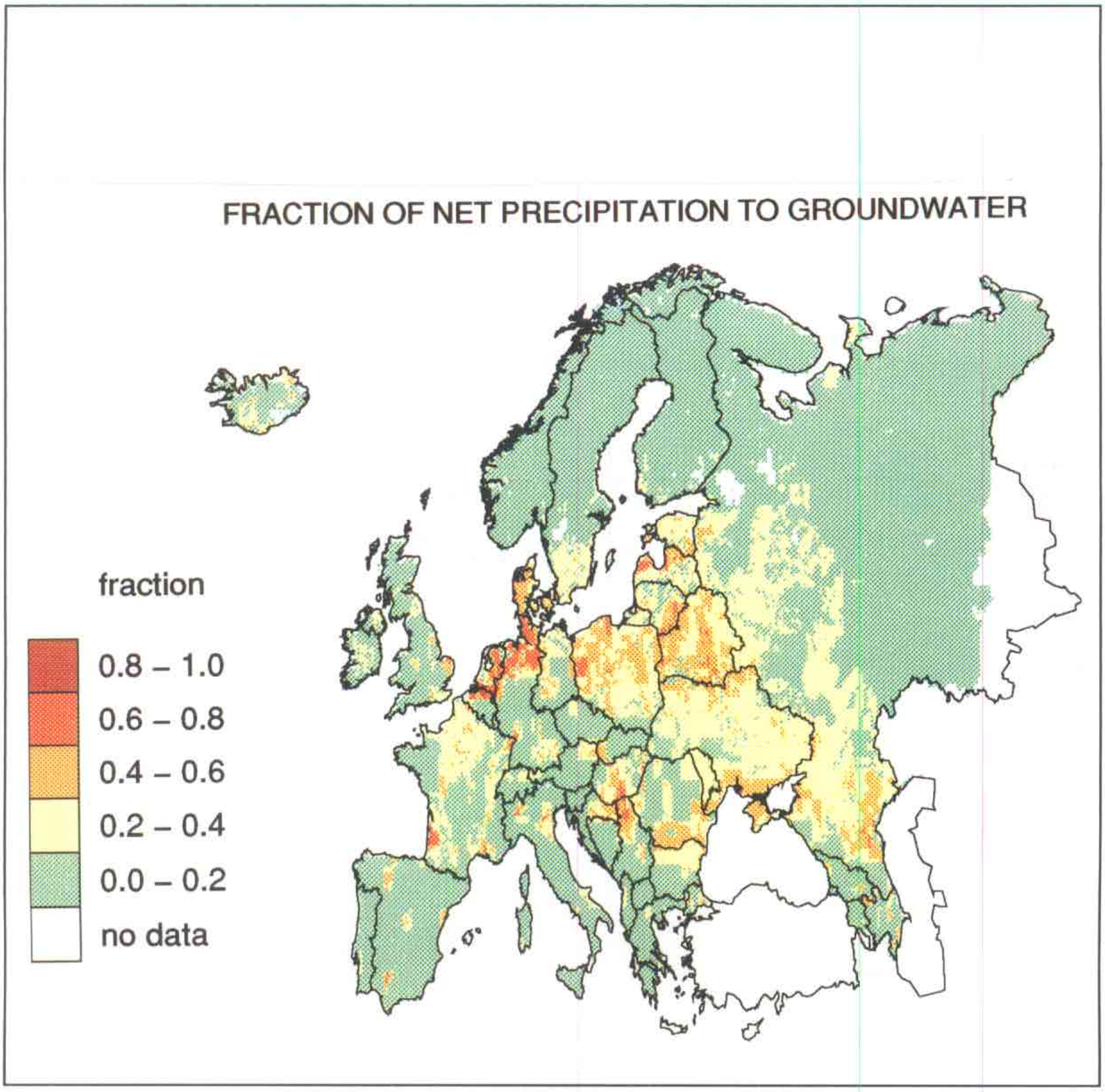

Fig.8 Groundwater recharge as a percentage of net precipitation

7. SURFICIAL RUNOFF; GROUNDWATER RECHARGE AND GROUNDWATER AGE

The magnitude of the average groundwater recharge was estimated by elaborating the average annual water balance:

GR = PN - SR , with:

GR = average groundwater recharge (and subsequent transport), in mm.a^{-1};

PN = average annual net precipitation, in mm.a^{-1};

SR = average surficial runoff, not reaching the groundwater, in mm.a^{-1};

No well-established methods are available to estimate values of regional surficial runoff. It has been assumed that the occurrence of surficial runoff components depends on aquifer type (possibility of groundwater recharge), on texture of the topsoil (sand versus clay), on slope (flat versus steep), on land use (urban areas versus open land), on temperature (presence of frozen soils during part of the year) and on groundwater levels (marshy areas versus hills). The ratio between surface runoff and net precipitation was estimated for each of these features. The total amount of groundwater recharge for a given area was derived from a multiplication of the estimated percentages of net precipation which were supposed to contribute to groundwater recharge. The remainder has to be surficially discharged. The amount of surface runoff will be a portion of net precipitation and thereby of total rainfall. Under European circumstances, the actual evapotranspiration will predominate in summer periods, whereas surface runoff will largely occur in the winter months. Both discharge components will hardly interfere with regard to the available amount of water: Surficial discharge will form part of winter precipitation, only slightly affected by evaporation. The summer rainfall is mainly discharged by groundwater flow after evapotranspiration.

The aquifer type is assumed to result in the following division of runoff (SR= surficial runoff; GR= groundwater recharge):

unconsolidated sedimentary aquifer; good permeability	SR = 5% ; GR = 95%
unconsolidated sedimentary aquifer: poor permeability	SR = 20% ; GR = 80%
consolidated sedimentary aquifer; good permeability	SR = 30% ; GR = 70%
consolidated sedimentary aquifer: poor permeability	SR = 50% ; GR = 50%
igneous and metamorfous hardrock; good permeability	SR = 60% ; GR = 40%
igneous and metamorfous hardrock: poor permeability	SR = 90% ; GR = 10%
incidentally brackish groundwater	SR = 20% ; GR = 80%
generally brackish or saline groundwater	SR = 20% ; GR = 80%
surface water cover	SR =100% ; GR = 0%

The topsoil texture results in:

coarse	SR= 5%; GR= 95%;
medium	SR= 25%; GR= 75%;
medium fine	SR = 50%; GR= 50%;
fine	SR = 75%; GR= 25%;
very fine	SR = 95%; GR= 5%;
histosols	SR = 90%; GR= 10%;

The slope of land surface yields:

0-8%	SR= 5% ; GR= 95%
0-30%	SR= 25%; GR= 75%
8-30%	SR= 75%; GR= 25%
0-8% (incl. >30%);	SR= 40%; GR= 60%
0-8% (8-30%; >30%)	SR= 60%; GR= 40%
8-30% (incl. >30%)	SR= 80%; GR= 20%
>30%	SR= 95%; GR= 5%

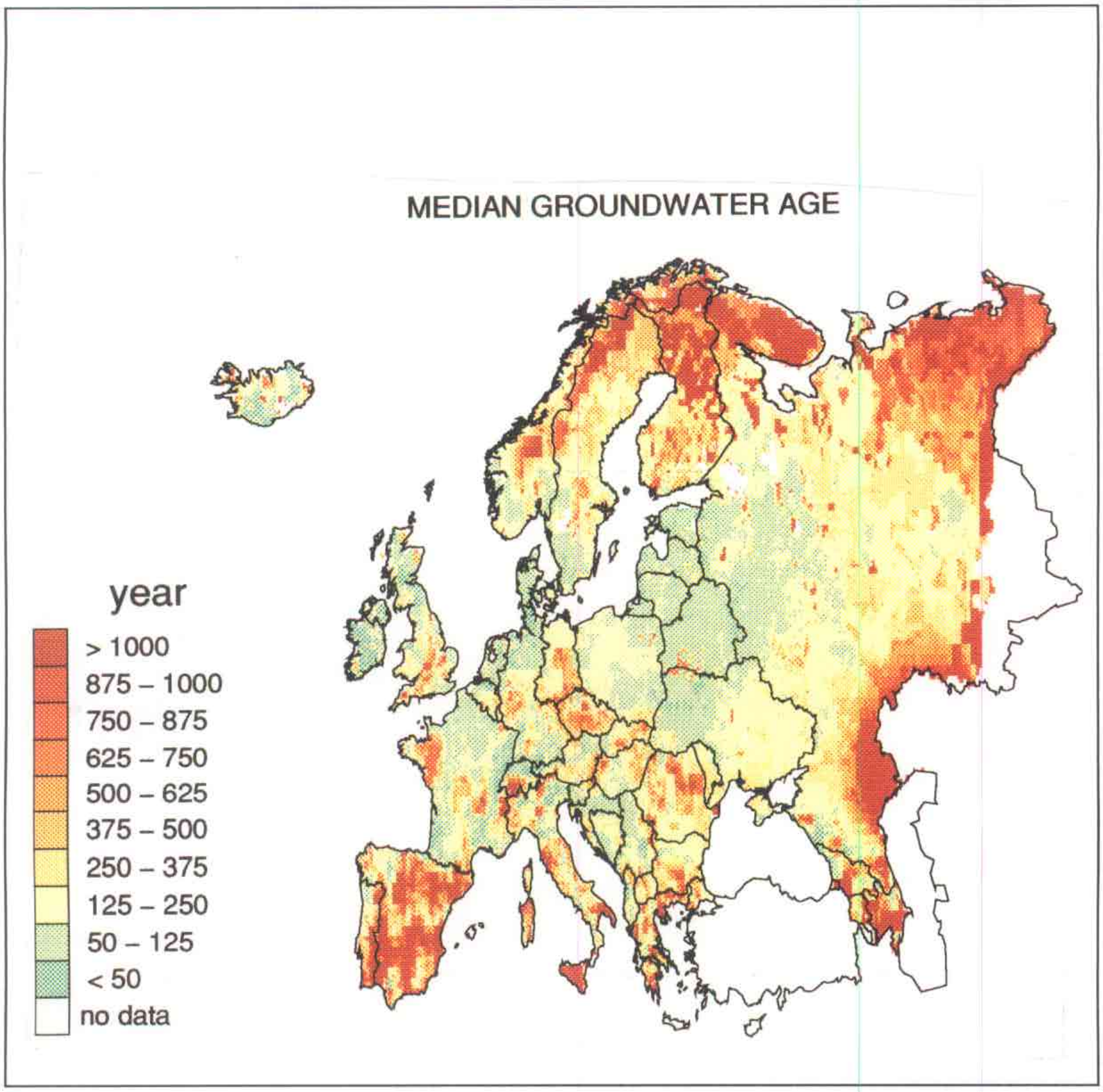

Fig.9 Median values of the groundwater age

Land use will also affect the occurrence of surface runoff, it has been assumed that for:

forest :	SR= 0%;	GR= 100%
permanent crops, others:	SR= 5%;	GR= 95%
agricultural use:	SR= 10%;	GR= 90%
urban area:	SR= 60%;	GR= 40%
inland waters	SR= 100%;	GR= 0%

Fluctuations in the seasonal air temperature have effect on the occurrence of surface runoff in the sense that a cold climate can lead to a frozen subsoil in the winter period and the presence of a snow cover. A considerable surface runoff of snowmelt and precipitation may occur in the spring period. The following subdivision was applied:

$T_{jan.}$	> 0°C	SR= 0% ; GR= 100%
$T_{jan.}$	0 to -4°C	SR= 10% ; GR= 90%
$T_{jan.}$	-4 to -8°C	SR= 25% ; GR= 75%
$T_{jan.}$	-8 to -12°C	SR= 50% ; GR= 50%
$T_{jan.}$	-12 to -16°C	SR= 75% ; GR= 25%
$T_{jan.}$	< -16°C	SR= 90% ; GR= 10%

The ratio SR/PN and also the ratio GR/PN were derived for any of the above factors in a given area (grid cell). The portion of groundwater recharge follows from the accumulation of the effects by multiplying all the individual factors. The resulting value is the recharge as a percentage of net precipitation (Fig.8). The percentage of surficial runoff is the complement of this value to the total of 100% net precipitation.

Surficial runoff is the general denominator of rather different flows of water. In permafrost areas it can consist of the flow of water underneath glaciers, but also of melt water in spring. In areas with a rocky soil it consists of the fast overland flow to small streams. In mountainous areas with a thin soil cover, the interflow of water through shallow layers to drainage means is a surficial flow. In areas where a tile drainage has been installed, the drain discharge is one of the surficial flow components. The type of flow is important for the water composition. In the present case, where soil and groundwater vulnerability to pollution are concerned, it is assumed that surficial flow will have been in close contact with the soil and that surficially discharged water will have obtained the same composition as water percolating through the topsoil layers.

The groundwater age in aquifers (Meinardi, 1994) obeys the equation: $\mathbf{t=pD/I*ln(D/(D-z))}$, with t= age (a), p= porosity, D= aquifer thickness (m), z= depth (m) and I= groundwater recharge ($m.a^{-1}$). The mean groundwater age is T= pD/I (year) and the median age is 0.7*T (year). The porosity was chosen to be p=0.3 for unconsolidated aquifers; p=0.2 for consolidated aquifers of good permeability and p=0.1 for consolidated, but poorly permeable aquifers. The depth was assumed to be everywhere D=50 m, taking into account that the upper sedimentary aquifers will not often exceed this depth and that openings in fissured rock tend to close at a depth of less than 100 m (UNESCO, 1987). Hence, the groundwater age is proportional to the reciprocal value of the downward velocity (I/p) of the groundwater flow on top of the aquifer. GIS methods provided the median values of groundwater age in Europe (Fig.9).

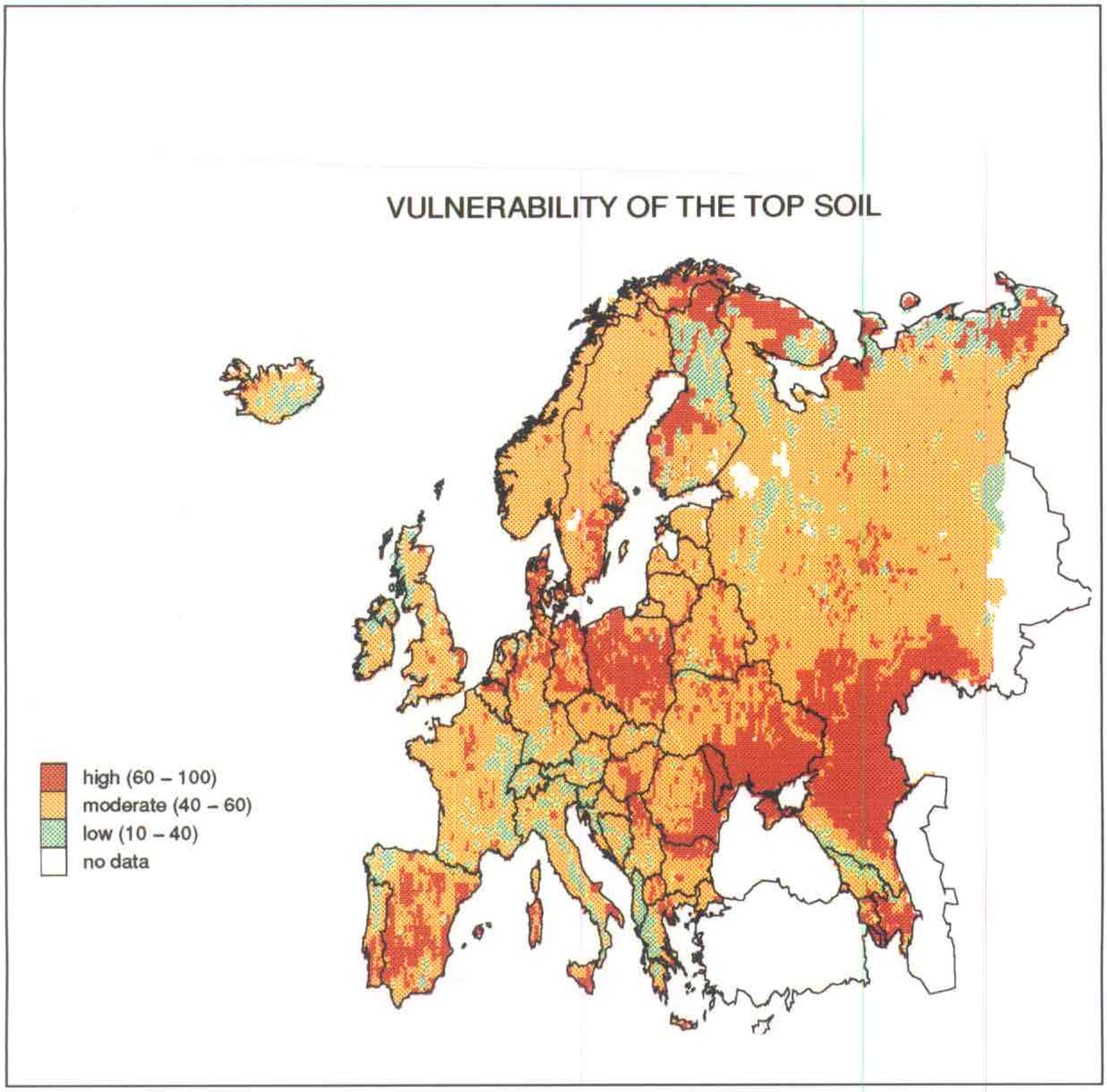

Fig.10 Vulnerability of the topsoil

8. VULNERABILITY OF THE TOPSOIL TO DIFFUSE POLLUTION

The following factors were considered to affect the vulnerability of the topsoil:

a. Land cover. The risk of contamination varies with different forms of land use.

b. Net precipitation. Water quantities and the velocity of flow determine the dilution and the flushing of contaminants.

c. Topsoil features. The intensity of bio-chemical changes depends on the type of soil. Four classes are distinguished:
  - c1. peat and other organic sediments: full degradation of many contaminants;
  - c2. clay and clayey sediments: strong degradation of many contaminants;
  - c3. loam and silty sands: moderate degradation of many contaminants;
  - c4. sand and most hardrock: no significant degradation of most contaminants.

The vulnerability of the topsoil can be expressed by $V = W_a * R_a + W_b * R_b + W_c * R_c$, with W_a, W_b and W_c representing weight factors and R_a, R_b and R_c representing the specific risk of contamination of the topsoil, respectively related to land cover, net precipitation (PN) and topsoil texture. The following values were assigned:

a. Land cover: $W_a = 2$;		*b. Net precipitation:* $W_b = 4$;	
urban area	$R_a = 10$	PN > 500 $mm.a^{-1}$	$R_b = 1$
arable land	$R_a = 6$	PN 400 to 500 $mm.a^{-1}$	$R_b = 2$
agricultural pastures	$R_a = 5$	PN 300 to 400 $mm.a^{-1}$	$R_b = 3$
permanent crops	$R_a = 4$	PN 200 to 300 $mm.a^{-1}$	$R_b = 4$
others	$R_a = 2$	PN 100 to 200 $mm.a^{-1}$	$R_b = 6$
forested areas	$R_a = 1$	PN 50 to 100 $mm.a^{-1}$	$R_b = 8$
inland water	$R_a = 1$	PN < 50 $mm.a^{-1}$	$R_b = 10$

c. Topsoil features	$W_c = 4$
coarse	$R_c = 10$
coarse/medium	$R_c = 9$
coarse/medium/fine	$R_c = 8$
medium	$R_c = 7$
medium fine	$R_c = 6$
fine	$R_c = 4$
very fine	$R_c = 2$
histosols	$R_c = 1$

Hence, all features representing risks with regard to pollution were given a value. For the sake of consistency, the values were chosen such that for every class of risks, the range is from zero to ten, respectively indicating cases without much risk and situations with the maximum risk of pollution. The vulnerability of the topsoil (V) thus has a range varying between a minimum value of 10 (only slightly vulnerable) and a maximum value of 100 (very vulnerable). The vulnerability of the topsoil (Fig.10) was determined by GIS methods, once the basic data had been assigned to all grid cells.

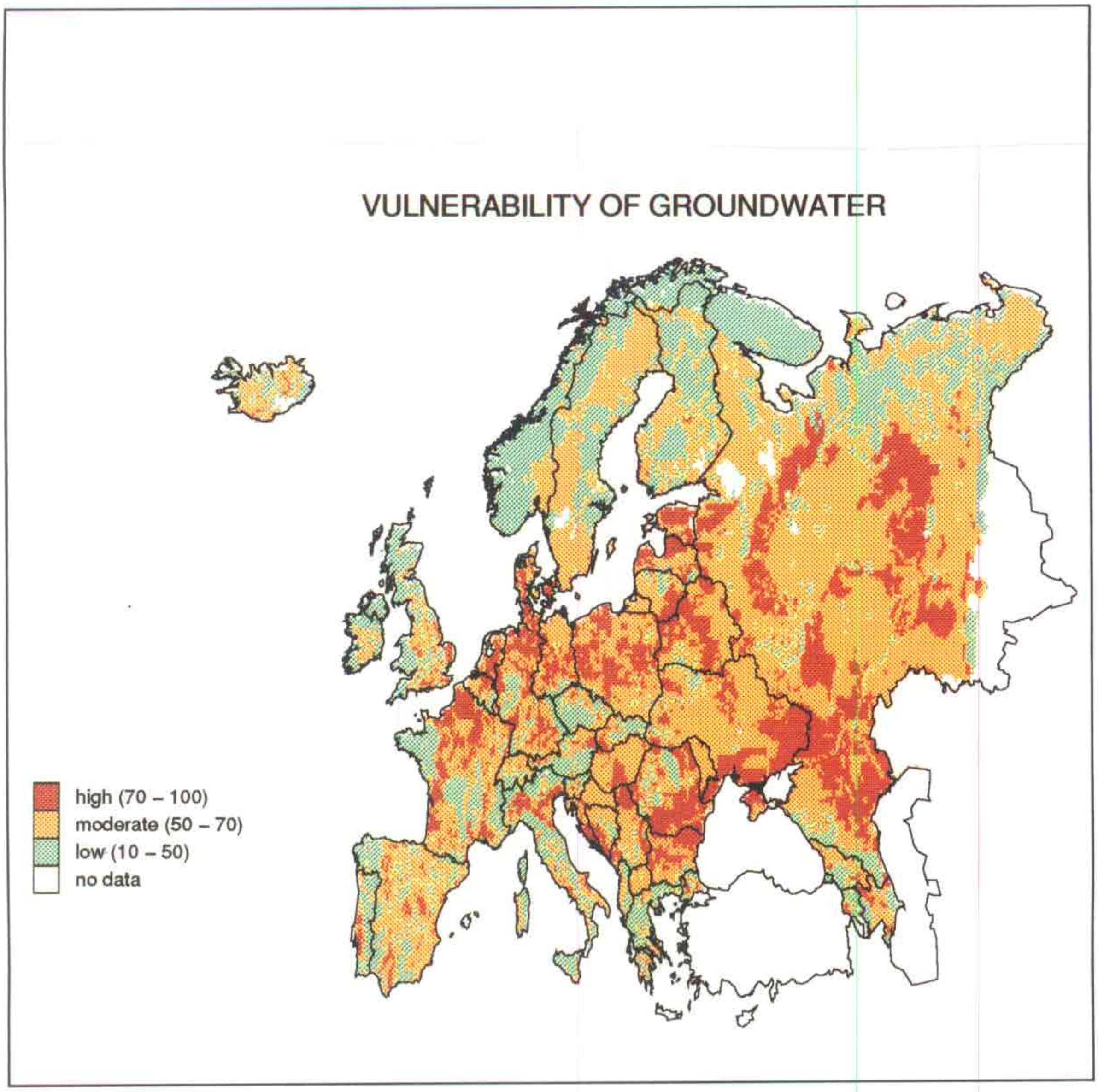

Fig.11 Groundwater vulnerability

9. THE GROUNDWATER VULNERABILITY TO DIFFUSE POLLUTION

The vulnerability of the flowing groundwater to a possible pollution depends on:

d. Leaching of contaminants from the topsoil, being indicated by the already determined vulnerability (V) of the topsoil;
e. Thickness of the unsaturated zone, including related features;
f. Groundwater flow in a vertical direction, expressed by the median value of groundwater age, this flow determining the transport of contaminants;
g. Aquifer characterization, determining the (chemical) changes of contaminants;

The vulnerability of groundwater can be expressed by $R= W_d{*}R_d+W_e{*}R_e+W_f{*}R_f+W_g{*}R_g$, the factors W representing weight factors belonging to the specific risks indicated by the R factors. The vulnerability of groundwater in exploitable aquifers can be determined if the appropriate values are assigned to the mentioned factors.
The following scheme has been applied:

d. Vulnerability (V) of topsoil $W_d = 3$

vulnerability	$10 < V < 40$	$R_d = 1$
	$40 < V < 70$	$R_d = 5$
	$70 < V < 100$	$R_d = 10$

e. Unsaturated zone $W_e = 1$;

gleyic features	$R_e = 1$
phreatic phase;	$R_e = 5$
all other areas	$R_e =10$

f. Aquifer type: $W_f = 4$;

unconsol. sedimentary aquifer; good permeability	$R_f=10$
unconsol. sedimentary aquifer: poor permeability	$R_f= 6$
consol. sedimentary aquifer; good permeability	$R_f= 8$
consol. sedimentary aquifer: poor permeability	$R_f= 3$
igneous, metamorfous hardrock; good permeability	$R_f= 5$
igneous, metamorfous hardrock: poor permeability	$R_f= 1$
incidentally brackish groundwater	$R_f= 9$
generally brackish or saline groundwater	$R_f= 7$
surface water cover	$R_f= 1$

g. Groundwater age $W_g = 2$

median age	
< 50 yr	$R_g=10$
50-125 yr	$R_g= 9$
125-250 yr	$R_g= 8$
250-375 yr	$R_g= 7$
375-500 yr	$R_g= 6$
500-625 yr	$R_g= 5$
625-750 yr	$R_g= 4$
750-875 yr	$R_g= 3$
875-1000 yr	$R_g= 2$
> 1000 yr	$R_g= 1$

The vulnerability (V) of the topsoil was determined as described before. All other data were derived from existing maps and data bases, implying that specific risk values could be assigned to the grid cells. Subsequently, the algorithme to determine the values of the combined risks was applied in a GIS elaboration, resulting in a map representing the total ranking for the elementary areas. The range of the groundwater vulnerability is running from R=10 (only slightly vulnerable) to R=100 (maximum vulnerability). The map of values of the groundwater vulnerability is represented in Fig.11.

10. DISCUSSION AND CONCLUSIONS

The two types of vulnerability summarize the situation of the topsoil and of groundwater in relatively large areas, thus ignoring much of the local detail. Nevertheless, the method can easily be adapted to smaller regions if necessary. However, a further detailing will only be possible if also the basic data are available in a sufficiently detailed form.

In the present case, the emphasis is on a possible contamination by diffuse pollution, having its origin at land surface and transported to the soil by water movement. The first step is the discharge of net precipitation carrying contaminants over and through the topsoil. Part of it recharges the underlying groundwater. Groundwater with the accompanying contaminants will flow through aquifer systems, finally reaching its natural drainage system and becoming surface water flowing to the sea. In some cases, part of the groundwater is pumped by a well field, supplying water, either to private consumers, or to a community water supply system using it as drinking water. Soil and water have to fulfil various quality requirements during the subsequent steps.

When moving on its transport route, each contaminant may be liable to specific changes, depending on the soil conditions encountered. For the vulnerability mapping as reported, it was assumed that the different elements of diffuse pollution all behave in the same way. Only the general features of soil and groundwater vulnerability have been indicated in the preceding chapters. However, an adaptation of the method to attain a more specific representation of the vulnerability to any selected type of pollution (for example with pesticides) can be realized in a relatively simple way.

From a hydrological point of view, the diffuse loading of land surface with contaminants may additionally have other adverse effects than only soil pollution. Discharge of net precipitation, transporting contaminants, can also take the form of surficial flow not entering the groundwater, yet affecting the ecological quality of the area concerned. These effects fall beyond the scope of the present study. Nevertheless, the basic data represented here are also of interest to an elaboration of surface water contamination, caused by an inflow of pollutants derived from diffuse sources on land surface. (Klepper et al., 1994).

Given the above restrictions, it is possible to compose an overview of the vulnerability of European soils and groundwater. The most vulnerable soils and groundwater are found in various regions of Europe (the Netherlands, Denmark, northern Germany, Poland and a large zone north of the Black Sea). Agricultural areas on sandy soils, underlaid by permeable and unconsolidated aquifers run the highest risk of groundwater pollution.

11. REFERENCES

CORINE (1991). Examples of the use of the results of the programme 1985-1990. Directorate-General Env. Civil Protection, Nuclear Safety, CEC, Brussels.

EUROSTAT (1991). Statistical data on EC member states (on tape), Statistical office of the European Communities, Luxembourg.

FAO-UNESCO (1981). Soil map of the world, Volume V Europe, UNESO, Paris.

IAH (various years), International Hydrogeological Map of Europe (various sheets), UNESCO, Paris.

Klepper O, Beusen A.H.W, Meinardi C.R. (1994). Modelling the flow of nitrogen and phosphorus in Europe, from loads to coastal seas. Report no. 461501004, RIVM, Bilthoven.

Leemans R. and W.P. Cramer (1991). The IIASA database for mean monthly values of temperature, precipitation and cloudiness on a global terrestrial grid. Report RR-91-18, IIASA, Laxenburg.

Leemans R. and G.J. van den Born (1994). Determining the potential distribution of vegetation, crops and agricultural production, Water, Air and Soil Pollution, 76

Meinardi C.R. (1994). Groundwater recharge and travel times in the sandy regions of the Netherlands, Ph.D thesis VU Amsterdam. Report no. 715501004, RIVM, Bilthoven

Simmers I. (1990). Aridity, groundwater recharge and water resources management. In: *IAH, GROUNDWATER RECHARGE, A guide to understanding and estimating natural recharge, IAH International Contributions to Hydrogeology, Vol.8.*

UNESCO (1987). Les eaux souterraines des roches dures du socle, Etudes et rapports d'hydrologie no. 33, UNESCO, Paris.

UNITED NATIONS (1990). Groundwater in eastern and northern Europe, Natural Resources/ Water Series No. 24, UN, New York.

UNITED NATIONS (1991). Groundwater in western and central Europe, Natural Resources/ Water Series No. 27, UN, New York.

USSR (undated). Groundwater Runoff Map of Central and Eastern Europe, All Union Institute of Hydrogeology and Engineering Geology, Moscow.

Velde R.J. van de, M. Verspuy, W. Faber, V. van Katwijk, H.J. Scholten, T. Thewessen, M. Zandbergen (1994). The Preparation of a European Land-use Database. Report no. 712401001, RIVM, Bilthoven.