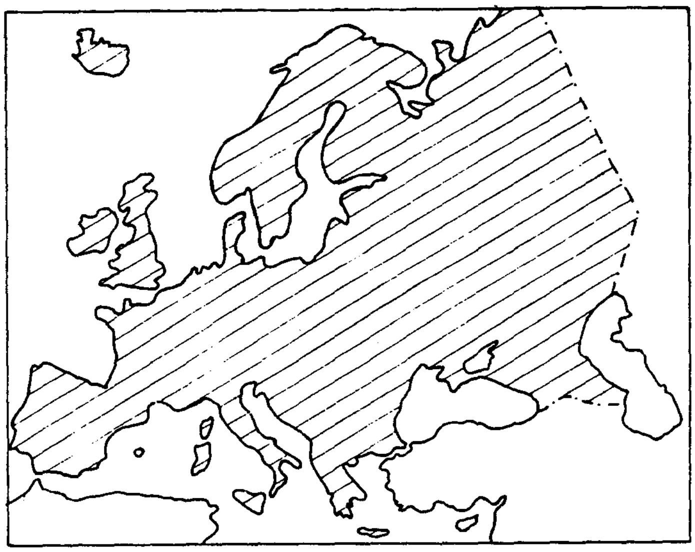
MAPPING OF SOIL AND TERRAIN VULNERABILITY TO SPECIFIED CHEMICAL COMPOUNDS IN EUROPE AT A SCALE OF 1:5 M

Proceedings of an International Workshop
held at
Wageningen, the Netherlands (20-23 March 1991)



Edited by
N.H. Batjes and E.M. Bridges

SOVEUR
Workshop organised in the framework of the
CHEMICAL TIME BOMBS PROJECT
of
VROM - IIASA - MA
by the
INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

CTB

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MAPPING OF SOIL AND TERRAIN VULNERABILITY TO SPECIFIED CHEMICAL COMPOUNDS IN EUROPE AT A SCALE OF 1:5M

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INTERNATIONAL SOIL REFERENCE AND INFORMATION CENTRE

FOREWORD

Although a practical interest in soil has occupied enquiring minds for more than two thousand years, the scientific study of soil is one of the youngest of the environmental sciences. It also tends to be the "Cinderella" of these studies which is regrettable as soils provide the vital link between the inanimate geosphere and the living biosphere. To the soil scientist, soil is a unique and fascinating ecosystem which will be damaged if abused in any way.

An awareness of the fragility of some soils was forced upon mankind by the ecological disaster of the "Dust Bowl" of the United States in the early years of the 20th century. A similar disaster occurred in the "Virgin Lands" scheme in the USSR. In these cases, physical abuse caused the soil to break down and lose its stability.

In the last quarter of the 20th century a new problem has emerged which threatens to reduce the productivity of soil and to inhibit its other biological functions. This is the problem of chemical contamination. In addition to the obviously poisonous substances, such as the toxic heavy metals and the wide range of pesticide substances, it is now clear that even some organic manures and fertilizers contain contaminants in amounts, sufficient to cause problems when added repeatedly to soil. They may also cause eutrophication in nearby natural ecosystems.

Some soils appear capable of receiving and holding chemical contaminants, and at the same time retain their biological flexibility; others are readily damaged and must be regarded as vulnerable to particular elements or compounds. Even those soils which are capable of holding chemical contaminants may in certain circumstances suddenly release them when triggered by a process such as acidification or a change from an aerobic to an anaerobic state.

It was the possibility of such catastrophic releases of contaminants which prompted VROM, IIASA and Mondiaal Alternatief to include soil vulnerability as a topic for one of a series of sponsored workshops on Chemical Time Bombs.

The conclusions and recommendations of the workshop on soil and terrain vulnerability to specified chemical compounds, which are presented in this volume, must be seen against a background of European awareness and concern for environmental protection. In particular concern is focused upon the urgent need to protect soil resources as proposed in the 6th European Ministerial Conference on the Environment, Strasbourg, 1990.

Information presented at the workshop, combined with great enthusiasm shown by the participants, and a unique opportunity for co-operation provided by the new political situation in Central and Eastern Europe favours the rapid implementation of an all-Europe initiative on Soil Vulnerability. The availability of a structured environmental data base, such as that assembled in the CORINE project for the EEC countries, provides a vehicle for management of data collected uniformly according to the SOTER approach (World Soils and Terrain Digital Data Base) developed by the International Soil Reference and Information Centre. In this way, the current enthusiasm for co-operation and awareness of the problem may be translated into practical applications and constructive measures for soil protection throughout Europe.

W.G. Sombroek,
Director ISRIC
Wageningen, July 1991

PREFACE

These proceedings contain the papers of an international workshop which was held at Wageningen, the Netherlands, to consider the feasibility and desirability of initiating a project on the mapping of soil and terrain vulnerability to specified of chemical compounds in Europe (SOVEUR) at a scale of 1:5 M. The SOVEUR workshop was part of a series of seminars organized by the Foundation for Ecodevelopment "Mondiaal Alternatief" within the operational framework of the Chemical Time Bombs (CTB) project. The CTB project was launched in January 1990 as a joint venture between the Netherlands Ministry of Housing, Physical Planning and Environment (VROM) and the International Institute for Applied Systems Analysis (IIASA) at Laxenburg, Austria, in appreciation of the need for ecologically sustainable use of chemicals. The CTB project is managed by the Foundation for Ecodevelopment "Mondiaal Alternatief".

The SOVEUR workshop, which was hosted and organized by the International Soil Reference and Information Centre (ISRIC) from 20 to 23 March 1991, was attended by thirty nine representatives from 17 European countries. Central and eastern European countries were particularly well represented. Delegates of the European Environmental Research Organization (EERO), the Food and Agricultural Organisation (FAO) and the International Society of Soil Science (ISSS) also participated in the workshop.

Following a welcome to the workshop and an introduction on the scope of the SOVEUR programme and the main issues involved, 28 papers were presented. They address a wide range of issues concerning soil pollution, soil vulnerability mapping and data availability for the various regions of Europe. These papers are published in the present proceedings.

During the editorial process, changes have been made to some papers to conform with the editorial policy without interfering with the view of the authors or the professional aspects of the documents. In case of substantial editorial changes, the edited papers were sent back to the authors for their approval. Illustrations deemed of insufficient cartographic resolution for reproduction have not been included in this document. Two speakers did not submit their papers and one speaker only submitted an extended abstract. The names of the speakers and observers of the SOVEUR workshop are listed in the Appendix.

The first Section (Chapters 1-4) reviews the problems of soil contamination and soil vulnerability in a European context. Chapter 1 provides a background on the Chemical Time Bombs project and the place of the SOVEUR workshop within this programme. The following two chapters mainly contain methodological considerations on soil vulnerability mapping with reference to experience from the Netherlands (Chapter 2) and Switzerland (Chapter 3). The fourth Chapter presents the findings of a 1:5 M mapping exercise on the sensitivity of soils and ecosystems to acidic deposition in Europe.

The second Section (Chapters 5-25) includes the national and regional presentations. Country papers for Austria, Belgium, Bulgaria, Czechoslovakia, Denmark, the eastern section of Germany, Hungary, Italy, Poland, Romania, Andalusia/Spain, Sweden, the United Kingdom, the USSR, and Yugoslavia are presented (Chapters 5-23). A discussion on computer graphics for land use mapping in Slovakia is presented in Chapter 24, and Chapter 25 is an extended abstract on geochemical mapping in Sweden.

Section 3 contains the ***executive summary*** of the SOVEUR workshop.

It is believed that the present proceedings will be of interest to all scientists and policy makers who are concerned with the problems of soil and environmental pollution either at the national, European or global level.

N.H. Batjes and E.M. Bridges (Editors)
Wageningen, July 1991

TABLE OF CONTENTS

SECTION I: SOIL VULNERABILITY IN EUROPEAN CONTEXT

1 Introduction and Framework of the Chemical Time Bombs Project

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INTRODUCTION

Europe is the continent with the longest and certainly the most intensive history of chemical pollution. Chemicals have been in use since the Iron Age, but their use has expanded considerably since the Industrial revolution. This means that contaminants deriving from industry, agriculture and domestic activities have been accumulating for a long time in sediments and soils. Some accumulated at localized sites (like waste dumps and industrial waste lands) but others are diffusely distributed. Following the idea of sustainable development from the Bruntland report, the Netherlands Ministry of Environment (VROM), in a joint venture with the International Institute of Applied Systems Analysis (IIASA), started the Chemical Time Bombs (CTB) project out of concern for the ecologically sustainable use of chemicals.

The focus of the CTB project is on the long-term problem of the delayed effects of pollution in Europe. It is concerned with pollution problems in which the effects occur much later than the start of the accumulation of potentially toxic chemicals. Particular attention is paid to the relation between environmental changes and toxification.

CHEMICAL TIME BOMBS

To achieve a clear concept and definition of "chemical time bombs", and prevent it covering every type of soil contamination, a workshop on "Chemical Time Bombs, Concepts, Definition and Examples" was organised. The following definition was prepared: *"A Chemical Time Bomb is a concept that refers to a chain of events, resulting in the delayed and sudden occurrence of harmful effects due to the mobilization of chemicals stored in soils and sediments in response to slow alterations of the environment"* (Stigliani, 1991).

This definition can be clarified using the following example, which was taken from the paper entitled "Changes in valued 'capacities' of soils and sediments as indicators of non-linear and time-delayed environmental effects" (Stigliani, 1988).

Big Moose lake in New York state is one of the few examples where accurate, simultaneous information exists for trends in pH, SO_2 emissions, and fish populations. The pH of the lake remained essentially constant over the entire period from 1760 to 1950. Then, within a period of 30 years the acidity of the lake declined by more than one pH unit. This occurred about 70 years after the beginning, and 30 years after the peak of the SO_2 emissions. The reason for this delayed acidification is the fact that a threshold was surpassed. In this case the slow variable was the gradual depletion of the buffering capacity of soils in the watershed by acidification, which resulted in a reduction of the buffering capacity of the lake's water. With increasing acidification, the fish died.

This example clearly illustrates the concept of chemical time bomb. It shows that chemicals, stored in soils, sediments and bedrocks as if in chemical "sinks", can be released into the environment

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upon a change in the ambient conditions, causing delayed environmental impacts. This may occur when:

- storage capacities are exceeded (overloading), or
- storage capacities are reduced due to changing environmental conditions, modifying the retention capacity for individual chemicals. Possible modifying factors are climate change, acidification, erosion, changes in land use.

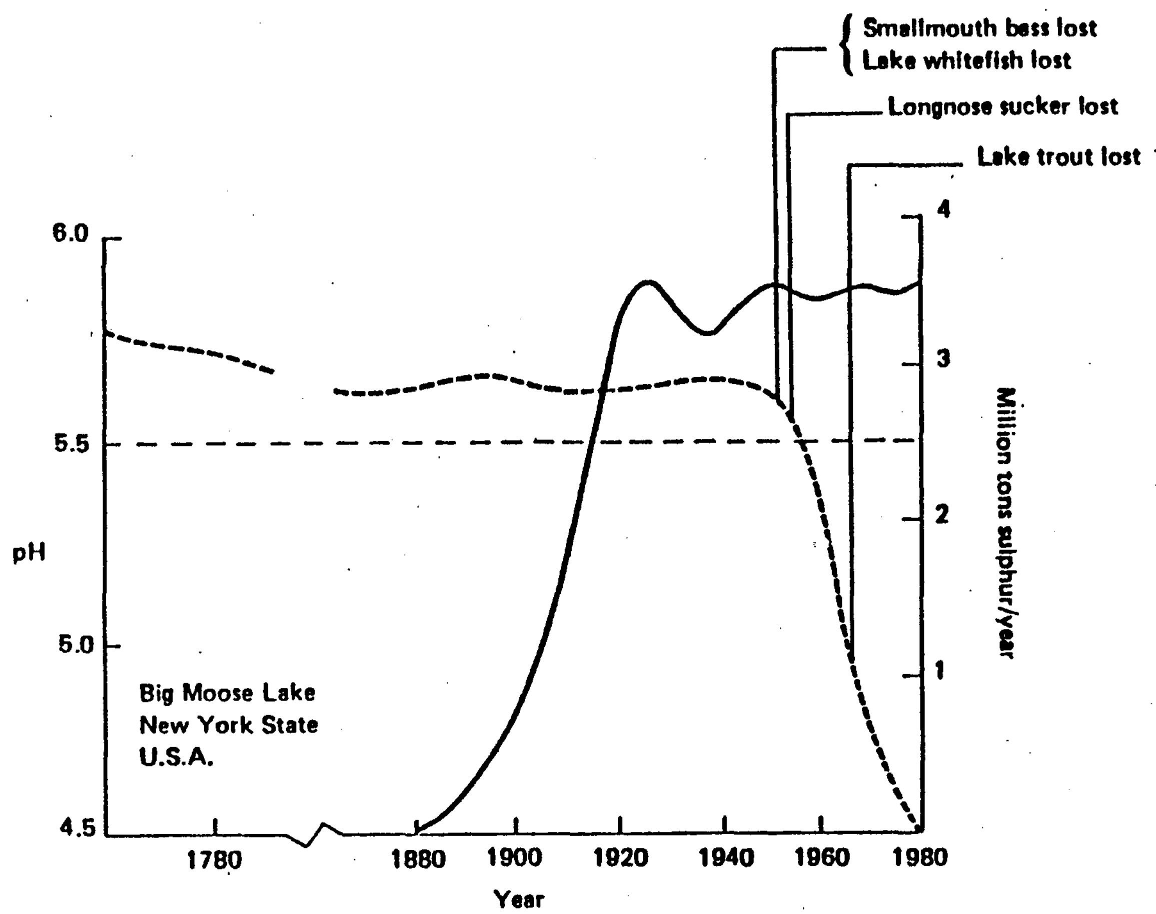

Figure 1 Trends in pH (dashed curve), emissions of SO_2 upwind from the lake (solid curve), and fish extinctions for the period from 1760 to 1980 (after Stigliani, 1988)

A reduction in storage capacities can occur, for instance, when arable fields are taken out of production. Most arable lands have been limed to improve the soils for agricultural use. After a change of land use, for instance a shift to forestry, liming practices will be stopped, and this may result in a sudden acidification of the soils. This in turn can cause sudden leakage of heavy metals; the storage capacity for heavy metals has been reduced by acidification (Fig. 2).

The risk of leaching and biological uptake can differ greatly between soils. This depends on the storage capacity of the soil and on the sensitivity of the storage capacity to environmental changes. The storage capacity depends mainly on soil factors and therefore can be mapped. The latter is one of the aims of the present workshop on "soil vulnerability mapping" (SOVEUR).

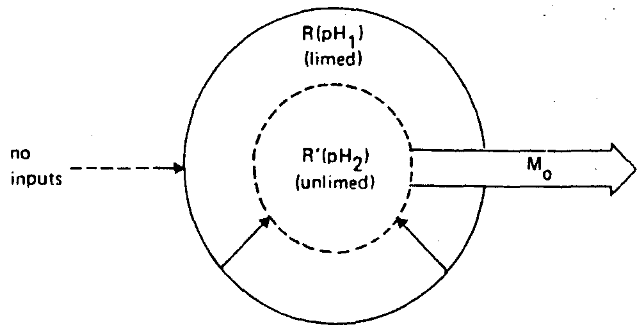

Figure 2 Schematic representation of the effect of decreasing pH on the size of the reservoir for storage of toxic materials. R (pH_1) is the storage capacity at pH_1, which is about 6.0 in limed soils. R'(pH_2) is the reduced storage capacity at pH_2, which is more acidic in absence of liming. The decrease in pH causes the release of toxic materials (M_o) from the reservoir (after Stigliani, 1988)

THE PROJECT FRAMEWORK

The CTB project started with a European workshop in June 1990 at de Bilt in the Netherlands (Smidt, 1990). Participants included scientists and policy makers. The aims of this European workshop were:
- the recognition of the existence and importance of CTBs by the scientific community,
- the identification of major areas and compounds with regard to long-term changes in environmental conditions,
- the drafting of a programme for further study and action.

During the 1990 workshop there was an agreement on the following issues:
- gradual continued accumulation of contaminants can transgress thresholds and result in sudden effects on ecosystems,
- changes in environmental conditions, such as those induced by climatic change, acid deposition or changes in land use, can cause an accelerated release of contaminants into the environment.

The final conclusion of the 1990 workshop was that CTBs were unanimously considered to be a real problem, and that it was necessary to:
- enhance the understanding of the scientific issues involved,
- convince governments and policy makers of the seriousness of the CTB problem on the basis of good examples.

The workplan which was constructed subsequent to the 1990 workshop is discussed in the next section.

WORKPLAN OF THE CHEMICAL TIME BOMBS PROJECT

Conceptual workshops

The aim of these workshops is to provide background papers for further research on the scope of the Chemical Time Bomb project. The documents derived from these workshops will provide outlines, demarcations and approaches. Out of the five scheduled conceptual workshops, two have already taken place:

a. The task force on "Chemical Time Bombs, definition, concepts and examples" the results of which have been published in an executive report by IIASA (Stigliani, 1991).
b. A task force on "Scenarios pertaining to Chemical Time Bombs" during which land use change and climate change scenarios in northwest, northeast, southeast Europe and the Mediterranean region have been discussed, together with the possible implications thereof

for Chemical Time Bombs. The results of this meeting will be published in the near future by IIASA.

c. The present international workshop on "Mapping of Soil and Terrain Vulnerability to Specified Groups of Chemical Compounds in Europe" (SOVEUR). The results of this meeting will be presented in a workshop in advance of the Second International Symposium on Environmental Geochemistry in Uppsala, September 1991.

Conceptual workshops to be held in the near future include:

d. A workshop on models and adjustment of data sets which is to develop guidelines on the kind of data needed, the tuning of data sets, and the kind of models to be used in the project.

e. A workshop on landfills and contaminated lands. The aim of this workshop is to characterize the specific long term potential chemical hazards to soils, sediments and groundwater resulting from landfills and contaminated lands in Europe, and data collection about the geographic occurrence of landfills and contaminated lands throughout Europe. The workshop will be held at Strathclyde University, Glasgow, in the United Kingdom, in August 1991.

Workshops on integrated assessment of water catchment areas

The aim of these workshops is to characterize the long term potential chemical hazards to soils, sediments and groundwater in the respective water catchment areas in Europe. It includes collection and tuning of the data sets. The workshops serve as the basis (background) for national and international projects on CTBs. Case study proposals are submitted in advance of the workshops. Subjects are: size and scope of the problem; vulnerability of soils, groundwaters and sediments to pollutants; reference areas and follow up activities of the workshops.

The long-term chemical hazards will be considered in the scope of stable and changing environmental conditions. Special emphasis will given to the possible effects of climate change and land use changes in the areas under consideration. The workshops will be attended by expert scientists and policy makers.

So far one regional workshop has taken place, and five more workshops are being planned:

a. *Danube Basin*

This workshop on "Long term environmental risks for soils, sediments and groundwater in the Danube basin" was held in Budapest in December 1990 (Csikós, 1991). Following the characterization of the long term potential chemical hazards, it may be possible to construct a background document for a large international project preparing an Environmental Masterplan for the entire Danube Basin. This project has been initiated by the RISSAC of the Hungarian Academy of Sciences. The project proposal for the Masterplan has been submitted to the PHARE programme of the European Community (EC), Brussels.

b. *Baltic basin*

This is a workshop on "Long term environmental risks for soils, sediments and groundwater in the eastern Baltic areas". It will take place in July 1991 at Tuczno, Poland.

c. *Nordic basin*

The "Long term environmental risks for soils, sediments and groundwater in the Nordic water catchment areas" will be discussed during this workshop, with emphasis on processes and vulnerability (Uppsala, September 1991).

d. *Mediterranean basin*

During this workshop on "Long term environmental risks for soils, sediments and groundwater in the Mediterranean area", special attention will be paid to the effects of erosion. The planned venue is Athens (November 1991).

e. *West European basin*

The "Long term environmental risks for soils, sediments and groundwater in the West European water catchment area (Calais - Pyrenees)" will be discussed during this workshop (venue unknown).

f. *Northwest European basin*
The "Long term environmental risks for soils, sediments and groundwater in the northwest European Basin (North of Calais)" are to be discussed during the final workshop in this series (venue unknown).

Basic paper desk studies

These desk studies are made by scientists expert on subjects which need elaboration to understand the chemical time bomb problem. The results will be used in further research on the scope of the Chemical Time Bomb project. The following desk studies are planned:

a. Adsorption and kinetics:
   - organic matter cycling
   - Fe/Mn oxides in minerals soils (Loch, 1991)
b. Erodability of soils
c. Microbial transformations of chemicals
d. Elaboration of CTB examples:
   - heavy metals
   - wastes and spoils.

The first outlines of the desk studies were submitted in November 1990 and final drafts should be ready by July 1991.

Hot spot studies and National case studies

Case studies on specific problems or areas concerning chemical time bombs will also be carried out within the framework of the CTB project. One of these studies might focus on the long term risks of chemical loads in the province of Limburg in the Netherlands. These studies are scheduled for 1991 and 1992, and work will commence as funds become available.

All European Conference

The aim of this concluding conference is to achieve international recognition of the size, scope and importance of CTBs both by scientists and governments. The conference will contain presentations and syntheses of the findings of the workshops and desk studies, executed in the scope of the project on Chemical Time Bombs. The conference will be held at Veldhoven, the Netherlands, from 2 to 5 September 1992.

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2 *Environmental Susceptibility to Chemicals: from Processes to Patterns, with Special Reference to Mapping Characteristics and Spatial Scales*

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ABSTRACT

Environmental problems concerning chemicals sometimes resemble time bombs in that they appear (explode) at unexpected moments. Similar to bombs, one may distinguish both a load and a trigger. Therefore, the concept of chemical time bombs may be used as a metaphor to understand the related environmental problems. For example, acidification has aluminium as load and acid deposition as trigger; eutrophication may have phosphorus as load and rising groundwater affecting the redox-potential as trigger. Finally, like bombs, chemicals in the environment have a target; the toxicant can remain either in the topsoil causing risks for biota, or leach to the groundwater endangering public water supply.

By means of examples concerning so-called ecodistricts of the Netherlands it will be shown that the differences in load, trigger and target are such that it is impossible to compile just one susceptibility map. Susceptibility varies with the load, trigger and target under consideration resulting in different or even contradictory patterns.

It will be argued that at the scale of 1:5 M the soil is not the most important conditional factor determining susceptibility. Instead, the ecoregion concept will be introduced. Then, after having traced the conditional parameters determining the susceptibility for well-defined environmental problems (load and trigger) and well-defined targets, some recommendations will be given on how to proceed in composing a basic map of Europe, as well as a limited number of susceptibility maps.

INTRODUCTION: THE QUESTIONS

Chemical time bombs, as defined in Stigliani (1991), are "sudden effects of chemical loads in soils and sediments, triggered by slow alterations in the environment". This definition allows a comparison with real time bombs; both a load and a trigger are needed. With only one of the two, we have no bomb. The definition also gives a clue as to the location of the load and the character of the trigger. The load is in the soil or sediment, while the trigger is a slow alteration of the environment.

Let us consider the above statements in more detail, distinguishing between different environmental problems. It will become clear that many environmental problems are caused by an overflowing of soil reservoirs rather than by actual chemical time bombs. In this text the concept of chemical time bomb, as defined by Stigliani (1991), will be used consistently, that is merely as a metaphor to permit a better understanding of the problems.

Firstly, acidification may be mentioned as an important trigger in releasing cations such as iron, aluminium and heavy metals. These are present in the soil in enormous amounts. Aluminium, for instance, is one of the dominant cations in the geosphere so that the load occurs almost globally. The trigger, however, is activated only in soils in which the rate of acidification exceeds the rate of weathering.

Where eutrophication is caused by fertilizer application, the circumstances are different. Phosphorus is fixed strongly in soils, often leading to deficiency problems in agricultural systems. It is only in areas where phosphate is applied in large amounts that the load may reach levels

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which are easily "triggered". The latter is presently the case for many sandy soils in the Netherlands. An effective trigger in releasing phosphorus is a raising groundwater table because the phosphate fixing capacity is much lower under anaerobic than under aerobic conditions.

An entirely different situation occurs for nitrogen. Large contents of nitrogen can occur in soils. Most of this nitrogen is incorporated in the organic matter. Mineralisation is an effective trigger in releasing this nitrogen. Draining of peat soils (Histosols), for instance, will enhance the rate of mineralisation.

Finally, we may look at toxic substances such as the heavy metals or organic micro-pollutants. In places, concentrations of metals may reach dangerous levels either because of a high initial content of these elements in the parent material or because of cumulative processes associated with soil formation. In parts of western Ireland, for example, the selenium concentration is inherently high in the bedrock, causing problems for cattle. Many podzols in the Netherlands have spodic horizons (B2s) in which the arsenic content exceeds the proposed "general environmental quality" standard for soils. This means that high loads of potentially toxic substances may be present in soils through natural causes. Generally, however, human activities are the main source of high concentrations of contaminants in soils, particularly organic micro-pollutants. The triggers causing the release of substances potentially toxic for biota may vary but, basically, this is irrelevant for the present discussion. It does not matter whether the contaminants will accumulate in the topsoil or disperse through the groundwater or surface water. Sooner or later these contaminants will enter in the food chain, ultimately becoming potential environmental hazards for biota.

The latter example shows the importance of defining the target: is it the groundwater (*sensu* public water supply) which is at risk, or a particular food chain? Or are the soil processes slowed down because of a decline in biological activity? A secondary question is: do we care? This may seem trivial, but it is important to distinguish between the facts and values. Hence, we may distinguish between susceptibility (e.g. Várallyay *et al.*, 1989) and vulnerability. The former can be determined objectively, whereas vulnerability takes into account the significance which is attributed by society (man) to a certain target (land or water unit) as to its present and future use, or for its intrinsic nature value (see Klijn, 1988 after Veelenturf *et al.*, 1987). The term susceptibility will be used in this contribution as it permits an approach from the natural sciences by considering only facts.

Firstly, the main processes resulting from acid deposition, manure spreading and the deposition of toxic substances will be treated briefly. This allows selection of the conditional parameters which will be used to decide on the mapping characteristics. Subsequently, an ecosystem approach will be introduced as a tool for analyzing the processes and selecting the characteristics which are to be mapped/considered at different spatial scales. Next, a procedure for assessing susceptibility will be proposed, with reference to examples from the Netherlands. Finally, recommendations concerning the use of a similar approach at European scale will be made.

ENVIRONMENTAL PROCESSES AND INTERACTIONS: THE SELECTION OF CONDITIONAL PARAMETERS

In this contribution, environmental problems resulting from acid deposition, manure spreading and deposition of toxic substances will be considered. These will be referred to using the general policy-terms of "acidification", "eutrophication" (for phosphorus and nitrate) and "dispersion" (for toxic substances).

Acidification

Acidification is a natural process. In many instances, the actual rate of acidification exceeds the natural "buffering" effects of weathering, erosion and sedimentation. Important buffering processes in soils are the solubilization of calcium carbonate, the weathering of silicates, the exchange of base cations, and the breakdown of clay minerals, causing the release of aluminium and iron cations into the soil solution (Ulrich, 1980; Verstraten, 1982; De Vries and Breeuwsma, 1986). The latter is considered a dangerous process because aluminium and iron cations may interfere with the growth of sensitive biota.

In addition to these buffers, which may be correlated with soil characteristics such as the $CaCO_3$ content and clay content, the groundwater or surface water may also supply cations in areas subjected to seepage or flooding. Also, denitrification can counteract the acidification in that it is a proton sink. This process is favoured by anaerobic conditions and high organic matter contents.

The preceding remarks can serve to identify the set of parameters which are relevant for assessing the susceptibility of land to acidification:
- primary $CaCO_3$ content / pH
- depth of decalcification / pH
- content of weatherable silicates
- texture (clay and silt content)
- iron (hydr)oxide content
- upward seepage of groundwater (quality and quantity)
- quality of surface water (if frequently inundated)
- groundwater level/ redox conditions
- organic matter content

Eutrophication: phosphate and nitrate

Eutrophication is a problem in the Netherlands, as a result of the enormous manure surpluses. Spreading of this manure results in the gradual saturation of the topsoil with phosphates, with subsequent losses to the surface water or groundwater. The processes and parameters determining the behaviour of phosphate and nitrate in soils are different. Phosphates are strongly fixed in soils, especially by Fe- and Al-hydroxides, some clay minerals, and organic complexes. Similarly, Ca-phosphates may be formed in calcium carbonate rich environments. Phosphate fixation is affected by the redox condition, and hence by fluctuations in the groundwater level. Thus the following parameters are considered relevant for assessing the susceptibility to phosphate saturation and through-flow to surface waters:
- content of Fe- and Al-hydroxides
- texture (clay content and mineralogy)
- primary $CaCO_3$ content / pH
- depth of decalcification
- organic matter content
- type of organic matter
- groundwater level/redox conditions

Compared with phosphorus, nitrate is very mobile in soils. It may be leached to the groundwater and subsequently be transported to zones with seepage. However, not all nitrate will be leached out of the system. Part of it may volatilize as nitrogenous gases upon denitrification under reducing circumstances. When assessing the susceptibility of land to nitrate leaching with subsequent contamination of the groundwater, the following parameters are the most relevant:
- organic matter content
- texture (permeability / aeration status)
- fluctuations in the groundwater level
- direction and rate of groundwater flow

Dispersion of toxic substances: heavy metals and organic micro-pollutants

Dispersion of toxic substances involves many different chemicals having different behaviour. Some general remarks will be made with respect to the heavy metals and organic micro-pollutants. Most heavy metals, with the exception of e.g. arsenic, are easily bonded by clay and organic matter, because they behave as cations. Hence, they may also precipitate as salts.

Most organic micro-pollutants are bonded mainly by organic matter, but the chemical properties of these compounds are very diverse. Differences in degradability are great too.

For heavy metals and organic micro-pollutants it may be relevant to determine both the susceptibility to accumulation in the topsoil and to leaching to the groundwater. The same parameters are relevant for both assessments:
- organic matter content
- texture (clay and silt content)
- content of primary $CaCO_3$/ pH
- depth of decalcification/ pH
- groundwater level (depth of unsaturated zone)
- direction and rate of groundwater flow

Summary of relevant parameters

From the preceding discussions, it may be concluded that different sets of parameters are needed for the assessment of susceptibility to different environmental problems. Some of these sets partly overlap, permitting the selection of a limited number of parameters for "multi-purpose" applications (Table 1).

Table 1 Conditioning parameters which are relevant in determining the susceptibility to processes following "acidification" (H^+), "eutrophication" (N/P), and "dispersion" of heavy metals and organic micro-pollutants (M^+/org.) in the Netherlands

	H^+	N/P	M^+/org.
PARENT MATERIAL			
Primary $CaCO_3$ content	■	■	■
Content of weatherable silicates		■	
Texture (clay, silt)	■	■	■
SOIL			
Texture (clay content, esp. Fe and Al)	■	■	■
Fe- and Al-(hydr)oxides	■	■	
Depth of decalcification	■	■	■
Organic matter content	■	■	■
Type of organic matter		■	
Groundwater level/fluctuations (redox conditions)		■	■
GROUNDWATER/ SURFACE WATER			
Groundwater level/ fluctuations	■	■	
Direction and rate of groundwater flow	■	■	■
Quality of upward seepage (cations, salinity)	■	■	■
Quality of surface water (cations, salinity)	■	■	■

From this list of parameters, relevant in assessing the susceptibility for various processes, two points become clear. Firstly, many of the considered parameters are not soil characteristics in the true sense; rather they are characteristics of the parent material, groundwater, or surface water. This may have consequences for the type of geographical data required for susceptibility mapping at a European scale; these aspects will be elaborated upon in the next two sections. Secondly, quantitative data concerning the value and spatial variability of the selected parameters are not available for large geographic areas such as countries and continents. However, we may then use established correlations between these parameters and qualitative environmental characteristics, such as bedrock or pedology. These correlations will be considered later.

ENVIRONMENT AS AN ECOSYSTEM: A SOIL-PLUS APPROACH

Since soil characteristics are not the only parameters determining environmental susceptibility it is proposed to adopt an ecosystem model (Fig. 1). It encompasses a simplification of the ecosystem which permits recognition of the different components and their possible interactions. Inherently, soils are one of the components of this ecosystem model. The model is based on hierarchy theory (Bakker *et al.*, 1981; O'Neill, 1988; Urban *et al.*, 1987; Van der Maarel and Dauvellier, 1978). It reflects a general tendency derived from hierarchies of volume, time of evolution and change, direction of fluxes of energy and matter, relative dependence of the various components resulting from these fluxes, and spatial scale.

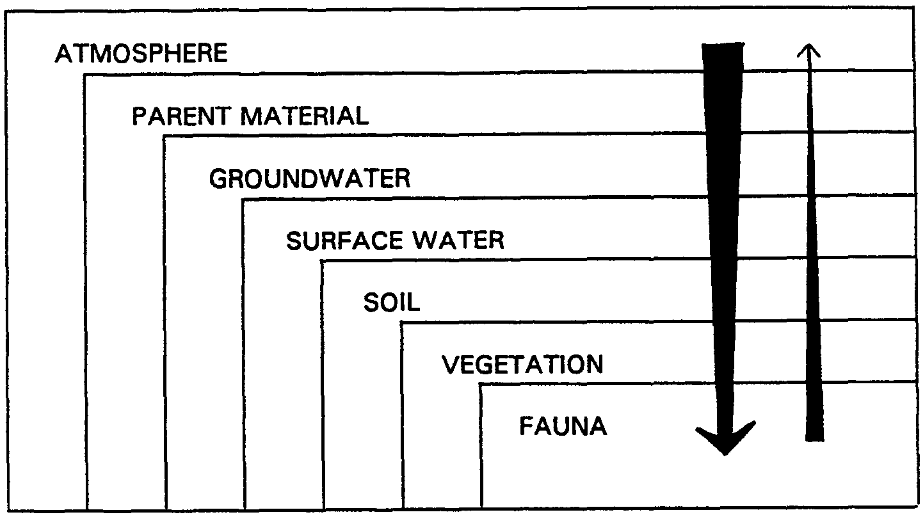

Figure 1 Hierarchical model of ecosystem, showing relative dependence of ecosystem components with main energy and matter fluxes and various hierarchies, e.g. volumetric (after Bakker et al. (1981) and Van der Maarel and Dauvellier (1978), from Klijn (1988)).

The direction of fluxes of energy and matter, as well as the relative dependence of the various components, are helpful tools in understanding environmental problems. Most environmental problems result from such fluxes of energy and matter and their relative inter-dependence. Therefore, most environmental problems can be seen as chains of responses (effects) to processes in the environment which ultimately can cause harm to the flora or fauna, including human beings. The point of attack of environmental problems may differ widely, from acidification, which primarily influences the atmospheric composition, to physical destruction of vegetation or fauna caused by land use changes (see RIVM, 1989; Klijn, 1991).

The hierarchical model of ecosystems may also be used as a guideline in choosing the mapping characteristics for integrated ecological land classification at different spatial scales. This is so because a good correlation exists between the ecosystem's components in the hierarchical model and in the spatial and temporal scales at which these determine the patterns and processes in the environment (Klijn, 1988; Klijn and Udo de Haes, 1990). These correlations were used to prepare mapping guidelines for integrated ecological land classification at the Centre of Environmental Science (CML) in Leiden. This aspect will be elaborated upon below.

MAPPING ECOSYSTEMS: SPATIAL SCALES

The linking of spatial scales and mapping characteristics is a commonly encountered difficulty when mapping soils, vegetation, parent material or groundwater systems. Often this has resulted in the elaboration of hierarchical classification systems which consider different classification criteria at different spatial scales. In the FAO-legend the "groups" are divided in main and secondary units. In Soil Taxonomy (USDA, 1977) the orders are divided into sub-orders, great groups and so on. Duchaufour (1983) introduces classes, subclasses, groups, subgroup-units, etc. All the foregoing examples are derived from soil classification. Similarly, hierarchical classification systems are commonly used in ecosystem surveys.

Different types of hierarchical classification systems have been proposed for integrated, ecological land classifications or ecosystem classifications (e.g. Bailey, 1976, 1981; Brink *et al.*, 1965; Christian and Stewart, 1968; Isachenko, 1973; Wiken and Ironside, 1977). These systems were consulted when developing the terminology proposed for use in the Netherlands and Europe, particularly the classification systems of Canada (Wiken and Ironside, *op. cit.*) and the USA (Bailey, *op. cit.*). The names begin with the prefix "eco-", to reflect the character of the classification system, and end with commonly used, scale-related geographical terms (Table 2). In some instances, commonly accepted German terms (Leser, 1976) have been used also for practical reasons. The resultant nomenclature can readily be translated into most of the European languages.

Table 2 Nomenclature for ecological land classification (hierarchical ecosystem classification) at different scale levels

	INDICATIVE MAPPING SCALE	BASIC MAPPING UNIT
ECOZONE	> 1:50,000,000	> 62,500 km²
ECOPROVINCE	1:10,000,000 - 1:50,000,000	2,500 - 62,500 km²
ECOREGION	1:2,000,000 - 1:10,000,000	100 - 2,500 km²
ECODISTRICT	1:500,000 - 1:2,000,000	625 - 10,000 ha
ECOSECTION	1:100,000 - 1:500,000	25 - 625 ha
ECOSERIES	1:25,000 - 1:100,000	1.5 - 25 ha
ECOTOPE	1:5,000 - 1:25,000	0.25 - 1.5 ha
ECO-ELEMENT	< 1:5,000	< 0.25 ha

Upon closer examination of the characteristics used for mapping the components of ecosystems at different scales, we may observe similarities. The zonal differentiation of soil groups (FAO) correlates perfectly with the vegetation zones as defined by Walter (1979). At the continental scale physiography is often reflected in the regional soil and vegetation pattern. This may be explained as follows: although the aim is to map the soils or vegetation or any other component of an ecosystem, the mapping pattern will reflect the properties of the dominant factor. In other words, the explicit mapping characteristics do not necessarily coincide with the factor which apparently causes the spatial differentiation of ecosystems and their constituents in the true sense. Consequently, it is recommended to:

- adopt an integrated ecosystems approach from the start;
- use an appropriate hierarchical approach;
- consider only mapping characteristics from the components of the ecosystem which determine the spatial pattern at the scale under consideration (Fig. 2).

The component "parent material" has been divided into "parent material/lithology" and "relief/ geomorphology". The latter being the reflection of the first in terms of landform; it cannot be considered as a separate component because it has no volume.

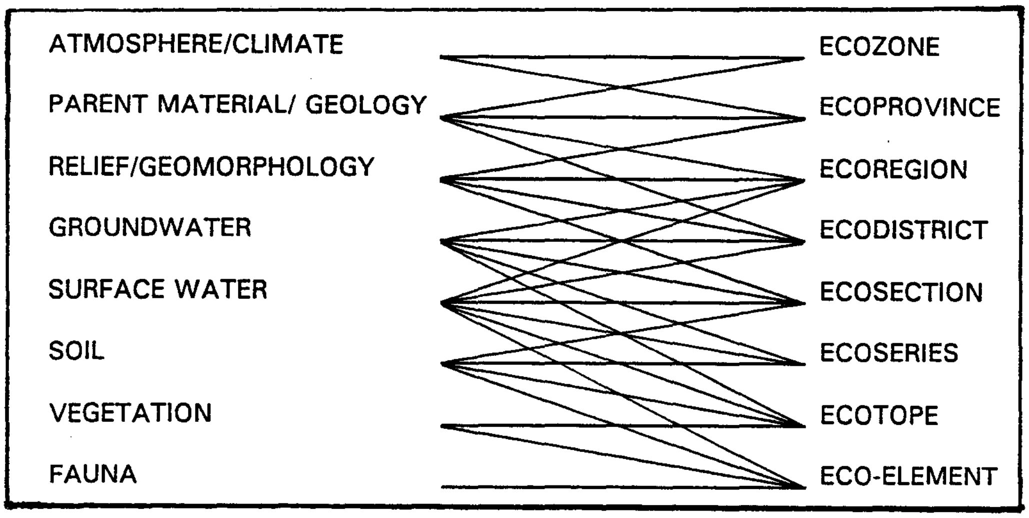

Figure 2 The relation between spatial scales and the ecosystem components which may yield the most adequate mapping characteristics

Both an ecoregion map (1:5 M) and an ecodistrict map (1:1 M) have been compiled for the Netherlands at the request of the National Institute of Public Health and Environmental Protection (RIVM). In accordance with the above guidelines on mapping characteristics, these maps are based primarily on parent material, geomorphology (relief), and geohydrology. Soils and natural vegetation are only correlated to a certain extent.

BACK TO THE PROBLEMS: CONDITIONAL PARAMETERS QUANTIFIED THROUGH CORRELATIVE COMPLEXES

The ecodistrict approach has been used to prepare different susceptibility maps for inclusion in the report "Concern for Tomorrow" (RIVM, 1989). The parameters considered relevant for assessing the susceptibility have been defined earlier in this paper. It is clear that these parameters cannot be derived directly from the ecodistrict map, because the mapping characteristics at the considered scale in fact are characteristics of a more general nature.

Fortunately, a certain degree of correlation exists between the dependent components and the mapping characteristics at this scale, i.e. parent material, geomorphology and (geo)hydrology. This is not surprising in view of the relative dependence between the various components in the model. It also due to these correlations that the value and spatial variability of the relevant parameters correlate rather well with the mapping units. In landscape ecology these correlations have resulted in the distinction and definition of the concept of "correlative complex" (Kwakernaak, 1982). The existence of correlative complexes permits a fairly accurate estimation of the value and internal spatial variability of characteristics or parameters which have not been measured separately. These estimations may be based on elaborate empirical research, existing data bases, or expert judgement. The latter method was used to assess the susceptibility of ecodistricts to different environmental processes (Klijn, 1988), however supported through existing maps on some single parameters (Van Duijvenbooden and Breeuwsma, 1987).

The preceding procedure is similar to land evaluation (FAO, 1976) in that it considers the value of the relevant parameters, buffer mechanisms, and relative importance of these mechanisms. Expert judgement was used to develop semi-quantitative rules. After some calculations, four susceptibility classes were distinguished for each process. The resulting susceptibility maps were discussed in order to match the results of the semi-quantitative interpretation with the qualitative judgement of the experts. Some examples of the resulting susceptibility maps are shown in Figures 3 to 6 (see end of paper).

Since then more sophisticated quantitative models have been developed for some of the environmental problems presently under discussion. These models permit quantified definition of the susceptibility classes which so far could only be done using relative and qualitative terms.

The examples shown in Figures 3 to 6 support the introductory statement that the load, trigger and target need to be specified clearly when assessing "environmental susceptibility"; there is no such thing as "the" susceptibility of the environment.

ECOREGION SUSCEPTIBILITY: SOME RECOMMENDATIONS

In conclusion, the main points of this contribution are summarized. They may be regarded as recommendations on how to proceed in compiling susceptibility maps at a European level:

- Chemical time bombs are merely a metaphor for some environmental problems concerning chemical substances. They should only be referred to as such.
- It is important to distinguish between susceptibility and vulnerability. The former is an objective environmental characteristic, whereas vulnerability can only be determined with respect to subjective societal values, i.e. the significance which is attributed to the respective components of the environment by man or society.
- Both the load and trigger determine the nature of the environmental problems that will be caused by a particular contaminant; the nature of the problem needs to be specified explicitly in susceptibility mapping.
- The target of the chemicals must be specified, because accumulation of chemicals in the topsoil and their leaching to the groundwater both may be dangerous. Since the patterns of susceptibility to these processes differ very much, interpretation is complicated.
- It is impossible to compile just one single susceptibility map. Therefore, it is recommended to compile one basic (ecoregion) map, with a data base on single parameters, from which several susceptibility maps for well-defined environmental processes and targets may be derived.
- Mapping of ecosystems at a scale of 1:5 M requires the selection of appropriate mapping characteristics. The latter are characteristics of the parent material, the geomorphology (relief) and associated topo-climate, and (geo)hydrology rather than soil characteristics.
- The ecoregion concept perfectly suits the purposes of SOVEUR, the "soil vulnerability mapping exercise for Europe" (Fig. 7).
- The parameters which are needed to determine susceptibility cannot be mapped at a scale of 1:5 M. However, they can be derived from ecosystem characteristics of a more general nature thanks to the existence of "correlative complexes".
- Different processes will cause different environmental problems. As stated earlier, it is therefore recommended to compile one susceptibility map for each "problem". Alternatively, tables showing the susceptibility of the respective map units for a specific "problem" can be linked to the ecoregion base map, using the map unit code as the relating item.

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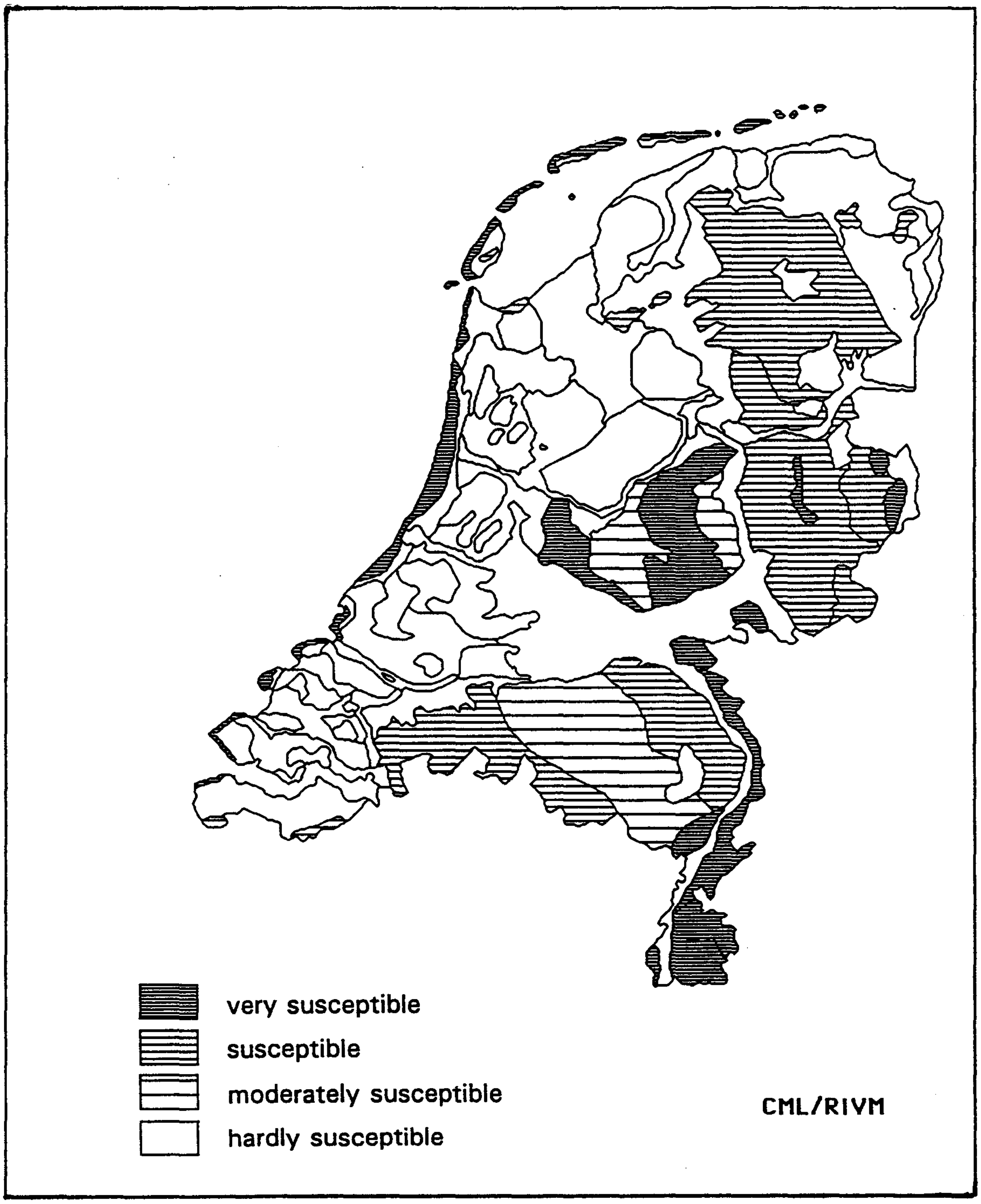

Figure 3 Eutrophication: Susceptibility of ecodistricts to leaching of nitrate to the groundwater

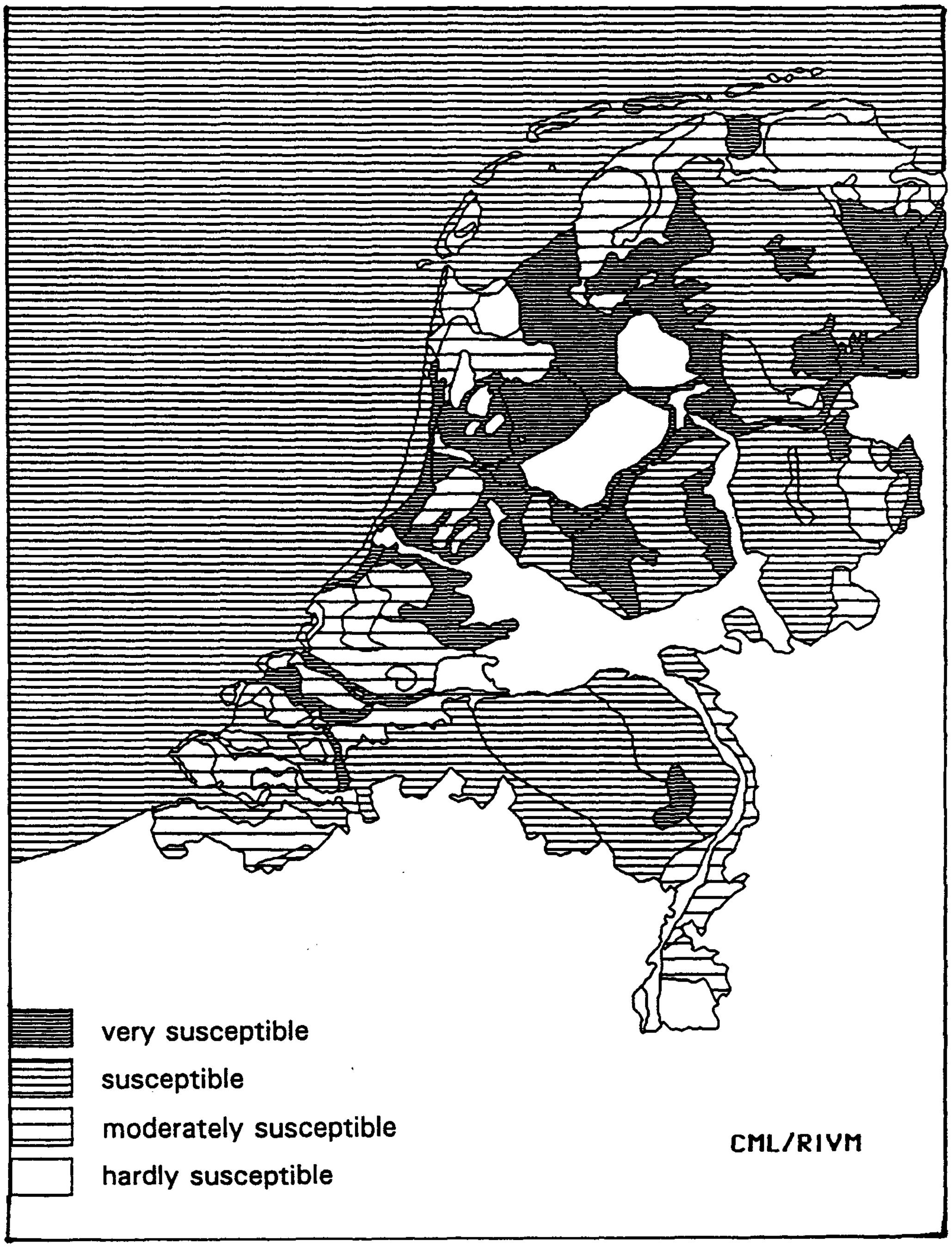

Figure 4 Eutrophication: Susceptibility of ecodistricts to saturation of soils or eutrophication of surface waters by phosphorus

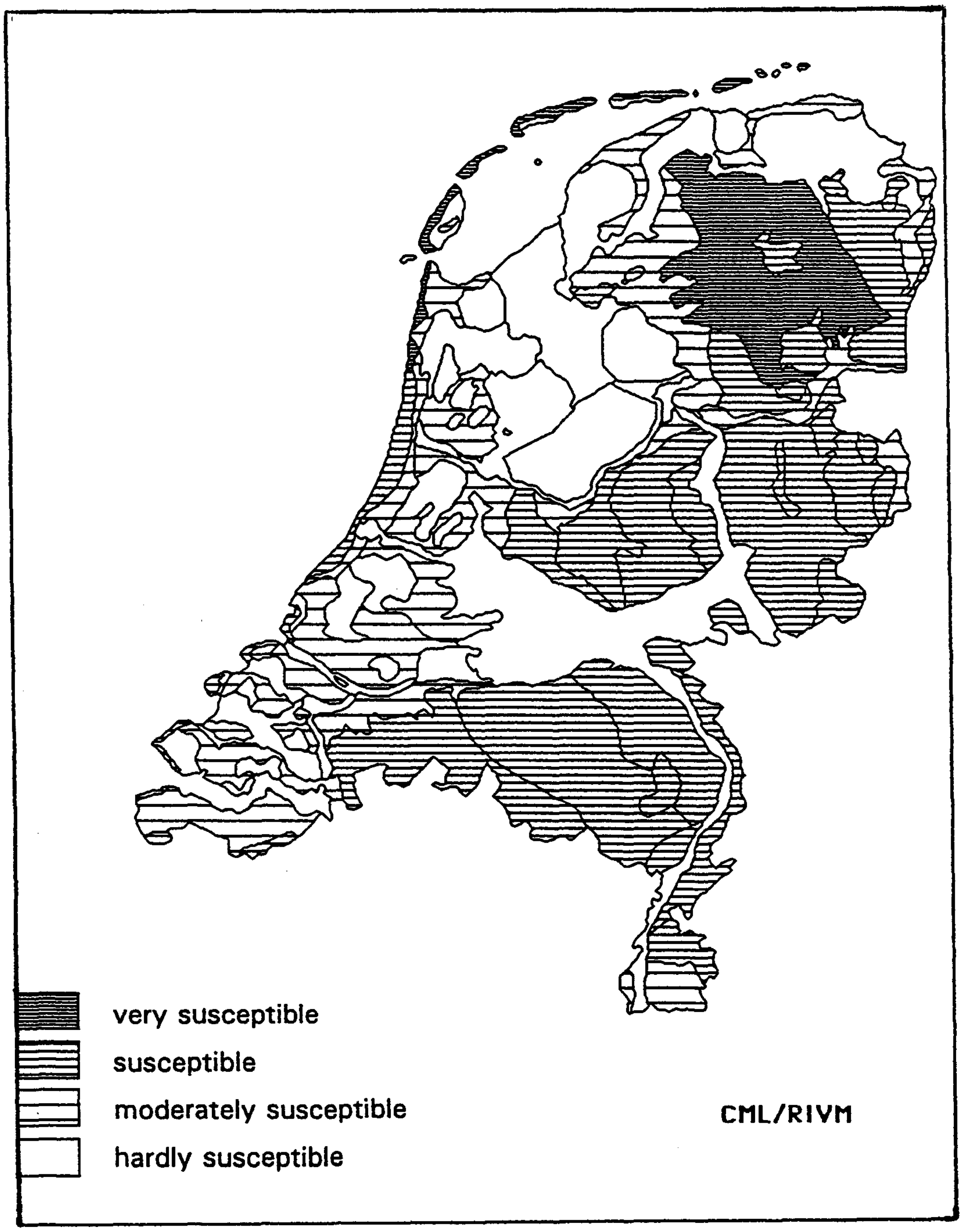

Figure 5 Dispersion: Susceptibility of ecodistricts to leaching of heavy metals to the groundwater

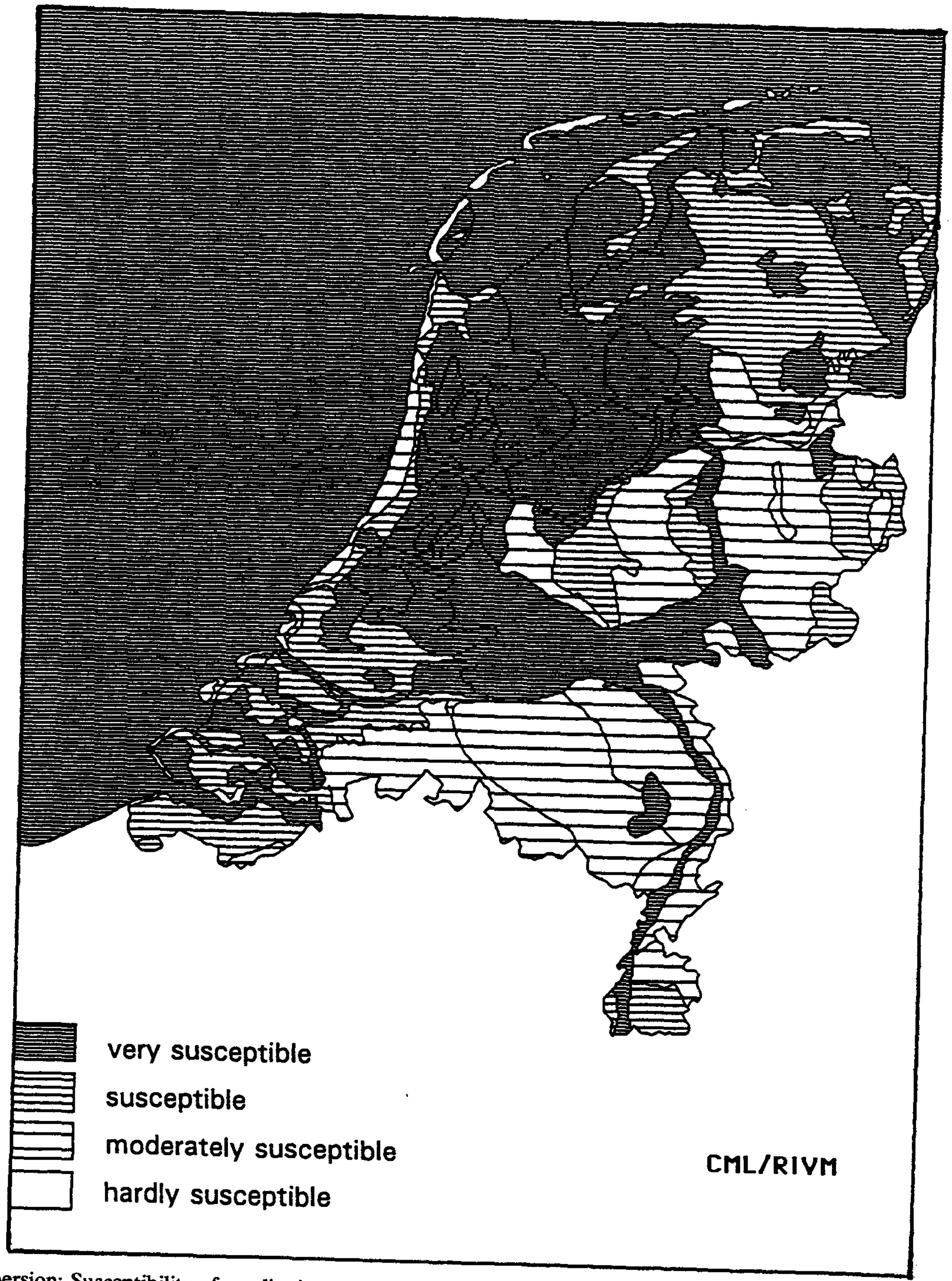

Figure 6 Dispersion: Susceptibility of ecodistricts to accumulation of heavy metals in the topsoil

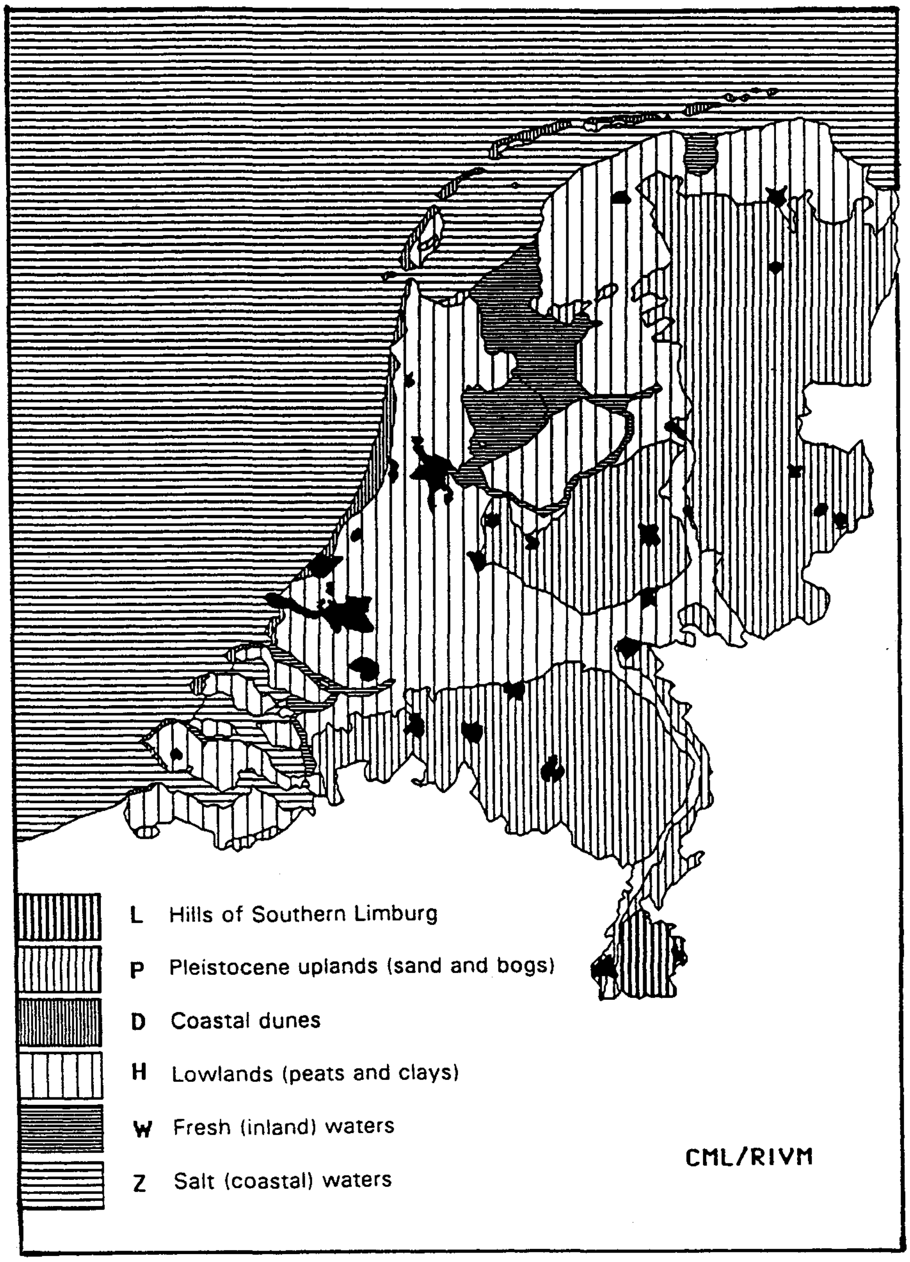

Figure 7 Ecoregions of the Netherlands, appropriate for a mapping scale of 1:5 M (after Klijn, 1988)

3 *The Soil Vulnerability Mapping Project for Europe (SOVEUR): Methodological Considerations with Reference to Conditions in Switzerland*

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ABSTRACT

Maps are only as good as their underlying concepts and the data used in their compilation. To allow qualitative statements, specifications are required. In order to meet the declared objective, namely to increase awareness for soil vulnerability to chemical compounds by a 1:5 M scale map, the following aspects of the SOVEUR mapping exercise must be specified:

a) The soil vulnerability concept must be defined in terms of agents and corresponding cause/effect relationships.
b) The geographic concepts of spatial variability and scale representation must be in agreement with the adopted functional soil vulnerability concept.
c) The available data must satisfy not only the underlying soil vulnerability concept but also the geographic concept.

The discussion of methodological specifications is presented with reference to conditions in Switzerland. In conclusion, the declared objective needs a specified functional and geographic reduction of complexity by aggregation, compatible to the current state of knowledge concerning the vulnerability of soils to chemical compounds.

INTRODUCTION

The objective of the SOVEUR project is to produce a 1:5 M map of Europe, showing soil regions of similar "vulnerability to specified categories of chemical compounds" in order to increase the awareness for this particular environmental problem (ISRIC, 1991). To increase the awareness for soil vulnerability towards chemical compounds is a very delicate task, since it is not directly perceptible. An indirect way to build up awareness, is by means of plausibility which is strongly related to the propagation of the underlying conceptual framework. The present paper discusses the concept of soil vulnerability related to small scale mapping inherent to the SOVEUR project from a methodological point of view with reference to Swiss conditions.

CONCEPTUAL SPECIFICATIONS

A map does not represent the real world directly, but represents concepts about the real world (Harvey, 1969). Thus a map of soil vulnerability is only as good as its conceptual background and the data used to compile it. To allow qualitative statements, maps need specifications of both their content and their geographic representation.

Soil vulnerability concepts

Soil vulnerability as such is not a useful functional concept, it has to be specified with respect to agents, causes and effects (see Table 1) or at least assessment criteria like threshold values to become plausible and operational. The causes and effects of soil vulnerability to erosion for example, can be observed directly by the visible action of water or wind and the resulting soil loss.

Soil Vulnerability to Pollution in Europe
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This is not the case for soil vulnerability by chemical compounds which must be traced by chemical analysis.

Table 1 Agents, causes and effects of soil vulnerability to erosion and by chemical compounds

Soil vulnerability related to	Agents	Causes: external	Causes: internal	Effects: direct	Effects: indirect
erosion	water wind	* erosivity * landform * land use	* erodibility	soil loss	* reduced water holding capacity * reduced soil fertility
chemical compounds	* trace elements * heavy metals * salts * pesticides * organics * radionuclides * gases	* emission * deposition * land use	* sorption capacity	* soil cont.	* reduced soil fertility * ecotoxicity * water contamination

* Complex terms for soil vulnerability assessment. Examples: Heavy metals are specified by chemical elements as Zn and naturally occurring chemical compounds as ZnS or ZnO. Sorption capacity is specified by soil properties as pH, organic matter, amount and type of clay, oxides, redox potential and chemical compounds.

Furthermore it can be seen from Table 1 that the assessment of soil vulnerability by chemical compounds must be a very complex enterprise, since there are large numbers of chemical compounds each of which has a specific reaction to the different soil properties. To give just one example: the sorption capacity of soil is increased for most trace elements with increasing pH, with a maximum under neutral to slightly alkaline conditions. Exceptions are As, Mo, Se and some valency states of Cr which are commonly more mobile under alkaline or calcareous soil conditions (Adriano, 1986). The attributes and factors involved in soil vulnerability to chemical compounds are so numerous that the main problem is how to reduce the functional complexity in respect to the present project. It is clear, that more than one concept of soil vulnerability must exist according to the multitude of possible combinations.

The concept of soil vulnerability related to pollutants affecting soils in Switzerland can briefly be specified as follows (FOEFL, 1987). The object is to maintain the fertility of the soil. To achieve this, the government is authorized to lay down guidance or concentrations for substances which are not readily degradable. If the guide levels are exceeded, it must be assumed that the fertility of the soil can no longer be guaranteed in the long term. So far, guide levels of so-called total contents exist for 11 chemical elements (10 heavy metals and fluorine). Additionally, there are guide levels of soluble contents for 6 heavy metals and fluorine.

In the Swiss situation several qualitative statements can be made: (1) The agents are limited to 11 chemical elements. Not much can be said about chemical compounds or interactions of the elements considered. (2) The guide levels do not really explain causes of soil vulnerability. Unlike the total contents, which are of limited ecological value by themselves, the soluble contents are considered to be good indicators of amounts absorbed. (3) The effect of soil vulnerability to chemical compounds cannot be assessed by guide levels alone. The total content must be related to the natural background levels to really indicate the degree of pollution, and soil fertility after all involves more than just the load of chemical compounds.

Geographic concepts and data

All functional relationships that can be located are geographic realities and thus may be translated into geographical concepts. This is also the case for soil vulnerability by chemical compounds which is confined to properties of the soil cover. With respect to the great soil variability in space (e.g. Beckett and Webster, 1971), potential vulnerability must change accordingly. If effective soil contaminants are included into the assessment, the spatial pattern of soil vulnerability becomes still much more complex. The means to reduce geographical complexity are therefore through functional specification and by aggregation (Table 1). The degree of specification or aggregation is dependent on both, the quality and quantity of geo-referenced data as well as the method of geographic representation. Geographic representations include the map scale and discontinuous point representation or continuous cover by mapping units. Respecting further cartographic rules, it should be possible, under normal circumstances, to read maps without a magnifying glass. It is therefore recommended that the smallest mapping units should not be less than 1 cm across, unless they form a well defined pattern (Dent and Young, 1981). On a 1:5 M map, 1 cm represents 50 km in reality. Soil vulnerability is likely to vary very much over such a long distance and this makes it necessary to use compound mapping units which have a low prediction value (Dent and Young, 1981).

The readily available data sources for Switzerland which may be of use for the SOVEUR mapping project are compiled in Table 2. There are several limitations to the compatibility of the data for the present objective: (1) The data have been compiled for other purposes; (2) The implicit methodology of most atlas representations make it difficult if not impossible to make the data transferable; (3) Very small scale maps are generally compilations of information of low and variable reliability.

Unfortunately, no data are available yet of the national soil monitoring network (NABO) which would partly fit the SOVEUR mapping project (Desaules, 1986). NABO is conceived as a long term reference for Switzerland of geochemical background levels and typical loads related to air pollution, as well as the presence of 10 heavy metals and fluorine in soils. The soil samples of 102 selected observation points have been stored to allow chemical analysis of further compounds when required. A survey by Vogel *et al.* (1989), restricted mainly to the Swiss Plateau and following a similar methodology, is already published and mentioned in Table 2.

Table 2 Data related to small scale mapping of soil vulnerability by chemical compounds for Switzerland

Content	Geographic specifications					Source
	map scale	mapping units	point obser.	grid	methodology	
Soil	1:5,000,000	13[1)]			explicit, compilation	FAO-Unesco (1981)
Soil	1:1,000,000	15[1)]			explicit, compilation	ISSS (1986)
Soil	1:500,000	23			implicit	Atlas der Schweiz/7a (1984)
Soil suitability	1:300,000	43			implicit	EJPD (1974)
Soil suitability	1:200,000	141			explicit	EJPD (1980)
Soil reaction	1:800,000	6	10,000[2)]	1 km	implicit	WSL (in prep.)
Sensitivity to acid depositions	1:5,000,000	5			explicit	Chadwick *et al.* (1990)
Heavy metals (Pb,Cd,Cu, Ni,Zn)			237		explicit, survey	Vogel *et al.* (1989)
Radionuclides (Ka-40, Cs-137)			64		implicit, long term monitoring	KUeR (in prep.)

Table 2 (cont.)

Content	Geographic specifications map scale	mapping units	point obser.	grid	methodology	Source
Lithology	1:500,000	14			implicit	Atlas der Schweiz/58 (1972)
Lithology[3]	1:200,000	28			implicit	Schweiz. Geotech. Komm. (1963-1967)
Hydrogeology (permeability)	1:500,000	19			implicit	Atlas der Schweiz/16 (1967)
Geomorphology	1:500,000	22			implicit	Atlas der Schweiz/8 (1965)
Vegetation	1:500,000	18			implicit	Atlas der Schweiz/17 (1966)
Precipitation	1:800,000	11			implicit	Atlas der Schweiz/12 (1967)
Land use	1:500,000	8			implicit	Atlas der Schweiz/48 (1977)
Air pollution (SO_2,CO,NO, NO_2,O_3,dust,Pb,Cd,Zn)			8		implicit, immission and deposition	BUWAL (1989)

1) for Switzerland only; 2) under forest only; 3) also available in ARC/INFO by Bundesamt für Statistik, GEOSTAT, Bern, Switzerland.

No attempt has been made so far in Switzerland to map the results of point observations related to soil vulnerability to chemical compounds as mapping units. There are four main reasons for this: (1) The functional complexity, (2) the great spatial variability, (3) the scarcity of reliable data and (4) the legality of existing guide levels. The map scale of 1:5 M hardly makes sense for a small and complex country like Switzerland alone (Fig. 1). But since Switzerland is at least geographically part of Europe, soil vulnerability variability within mapping units covering the country should be smaller than between mapping units. The same holds for all of Europe. Furthermore it can be seen from Figure 1 that the grid resolution of the European Monitoring and Evaluation Programme (EMEP) for example, would be inadequate to represent soil related phenomena.

CONCLUSIONS

Maps are models of reality which must be empirically realistic with respect to the phenomena they are designed to represent (Harvey, 1969). Unfortunately, empiric reality of soil vulnerability by chemical compounds is not directly perceptible, but relies on plausible functional concepts. The functional concepts must be known to the broad public to raise the awareness of soil vulnerability.

Mapping involves classification into functional- as well as geographic units (Dent and Young, 1981). From the methodological point of view it is a two step procedure. The abstraction level of classification by specification and aggregation grows with decreasing scale. It follows, that the smaller the map scale, the greater is the need of an explicit methodology to simplify the information and remain realistic.

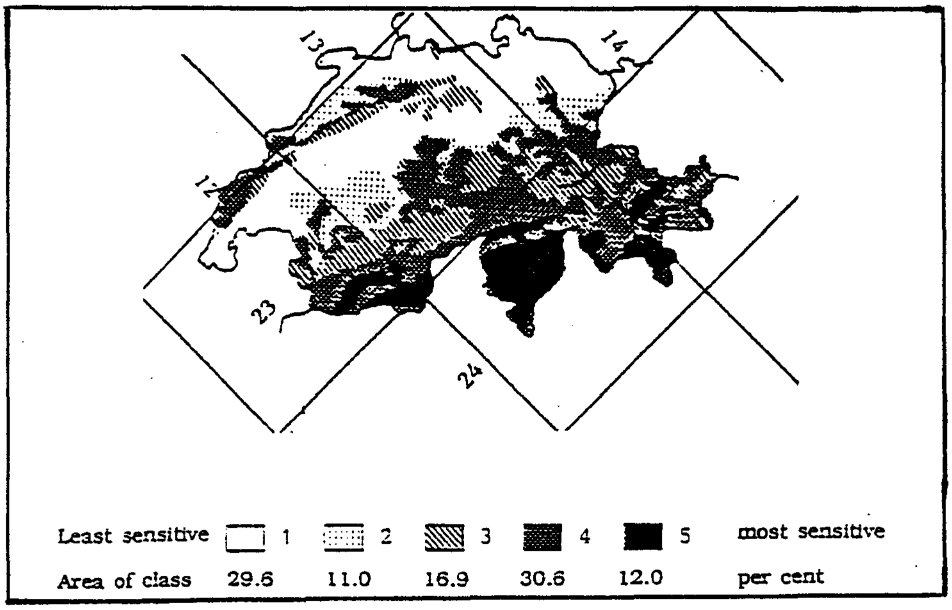

Figure 1 Relative sensitivity of ecosystems to acidic deposition in Switzerland (Source: Chadwick and Kuylenstierna, 1990). (Switzerland, area about 41,290 km^2; Scale about 1:5 M; Width of EMEP grid is 150 km).

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4 *The Sensitivity of Soil and Ecosystems to Acidic Depositions*

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ABSTRACT

Acidification damage, caused by sulphur and nitrogen compounds, derives from the long term increase in base cation leaching from the soil as a result of the input of mobile anions in deposition. This may alter soil water chemistry to a point where deleterious effects occur in terrestrial and aquatic ecosystems. SEIY has mapped the relative sensitivity to acidic depositions based on the base cation rate of production and capacity in the soil modified by land use, and this map shows the sensitivity of aquatic and terrestrial ecosystems to certain changes in structure and/or function. Surrogates for the four main factors affecting base cation status of soils (soil type; rock type; land use; rainfall) have been digitised from 1:5 M to 1:2.5 M maps available for the whole of Europe. The factors have been combined using weights which reflect their importance in determining sensitivity and this gives rise to five classes of relative sensitivity. On the basis of a comparison between critical loads for acidic deposition at specific sites quoted in the literature, and the sensitivity class for that area, targets have been applied to each sensitivity class.

PURPOSE OF THE MAP

Sulphur and nitrogen emissions from the combustion of fossil fuels and from industrial processes are subject to long range transboundary dispersion. It is not possible for countries to reduce their deposition solely by domestic abatement and it is therefore necessary to have coordinated abatement strategies in the entire European region. International protocols to reduce emissions of sulphur at present rely on across the board uniform percentage reductions, such as the "30 per cent club" (ENDS, 1985), but there is a growing awareness that such reduction plans are not cost-effective and may not be the best approach to reducing depositions in Europe. The sensitivity of ecosystems upon which depositions fall varies across Europe and abatement is more expensive in some countries than in others. It is necessary to target emission reductions according to the sensitivity of ecosystems on to which the depositions fall and to meet these reductions most cost-effectively. The relative sensitivity map to acidic depositions has been produced in order to map the spatial variation of sensitivity in Europe to acidic depositions which may form the basis of target deposition values for coordinated abatement strategy models. One such model is the Coordinated Abatement Strategy Model (CASM) developed at the SEIY which contains estimates of emissions and then employs the transfer coefficients from the atmospheric transfer model devised by EMEP to give depositions in Europe. The depositions may then be compared to the sensitivity map and abatement strategies investigated. The development of country marginal cost curves allows aspects of cost-effectiveness to be included in the optimised model runs.

CONSTRUCTION OF THE MAP

The map of relative sensitivity to acidic depositions has been constructed by combining the main factors influencing sensitivity. A small number of categories are distinguished from each factor, which are mapped and combined using weights which reflect the importance of the factors in determining ecosystem response.

The main factors determining ecosystem response are determined by considering the processes involved in acidification. Sulphate and nitrate ions deposited on the soil may leach from the soil

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together with base cations, leading to soil acidification, or acid cations (H^+ and Al^{3+}) leading to surface water acidification. Base saturation decreases as a result and the soil may shift to lower buffer ranges where pH will be lower (Ulrich, 1983). If the soil is in the cation exchange buffer range further acidification may push the soil into the aluminium buffer range where major buffering is by the weathering of clay minerals causing aluminium to be released into soil solution (Ulrich, 1983). Aluminium has been shown to cause root damage in experiments and in the field (Meiwes *et al.*, 1986). Decreases in surface water pH and increases in aluminium concentrations lead to changes in species composition and decreases in abundance of aquatic organisms (Hultberg, 1983). The variables whose response is of interest are mainly the biotic features of ecosystems and this assessment does not attempt to map the sensitivity of soil to changes in soil chemistry.

The main factors considered to affect ecosystem sensitivity are the capacity to buffer; the rate of buffering; the effect of water flux and the modification of sensitivity by land use. The sensitivity of both aquatic and terrestrial ecosystems depends on the current amount of base cations in the soil, which represents the capacity to buffer acidic inputs and the rate of production of base cations. The rate of weathering is determined by the proportion of different minerals in the soil as well as factors such as texture, temperature and soil moisture (Sverdrup *et al.*, 1990). Detailed information on the rate of production or capacity of base cations in soils is difficult to obtain for an area as large as Europe and it is therefore necessary to use surrogate variables which approximate to these.

Soil type has been digitised in order to map the capacity of sites to buffer acidic depositions. Soil type is a variable which integrates the influence of a number of factors, including the type of parent material, climate, and the influence of vegetation. These factors give rise to typical pH, cation exchange capacities (CEC) and base saturation (V) which together give an indication of the capacity of the soil to buffer acidic depositions (Table 1). Soil type chemical and physical attributes have been compiled as shown in Tables 1 and 2 in order to assign soil types to one of two categories. Category I soil types (Table 2) are considered to be typical of high sensitivity sites, due to low pH and base cation content. It is considered that these soil types have low capacity to buffer acidic depositions and the soil may be likely to move to the aluminium buffer range where deleterious effects may occur to biota. Category II soil types are assumed to have a higher capacity to buffer acidic depositions (Table 1).

A number of factors cause the development of soils and so soil type may not accurately represent soil mineralogy and in this assessment of sensitivity the weathering rate is represented by rock type which is assumed to reflect the mineralogy of the parent material. Table 3 shows a review of the relative weathering rates for different rock types based on the chemical and mineralogical composition of rocks, catchment studies and laboratory analyses. Two categories of rock type were distinguished of which Category I comprises the rock types considered to have low weathering rates and is designed to represent the rock types in Group A in Table 3. Other rock types (groups B-D) were assigned to category II which have higher weathering rates. Due to the availability of mapped information for the whole region it was necessary to use bedrock lithology rather than surficial geology.

The amount of rainfall will alter the rate and capacity of sites to buffer the acidic depositions. As the amount of rainfall increases, base cation leaching increases (Cresser *et al.*, 1986) thus decreasing amounts of base cations in the soil able to buffer the acidic inputs. In areas of high rainfall the organic layer builds up and this will affect the capacity to buffer acidic depositions since the mineral content of these organic layers is low and base saturation tends to be low (Cresser and Edwards, 1987). The thick organic layer is not able to buffer the relatively high proportion of precipitation reaching surface waters as run-off and therefore surface water sensitivity in high rainfall areas is greater due to the increased frequency of low pH episodic events. The average annual rainfall is used to represent water flux and areas receiving more than 1200 mm per annum are considered to have higher sensitivity than areas receiving less than this amount.

Table 1 Typical characteristics of Category II soils

Soil type	pH	CEC (meq/100g)	V (%)	Sand (%)	Ca content (meq/100g)
Eutric Cambisol	6.0		85	8	30
Gleyic Cambisol	6.5	18	90	45	
Calcic Cambisol	7.7	25	98	15	16
Vertic Cambisol	7.7	20			20100
Humic Cambisol	6.0		38	40	
Haplic Chernozem	7.5			40	31
Calcic Chernozem	8.2	50		20	
Luvic Chernozem	6.8		87	5	28
Eutric Podzoluvisol	5.3		75	12	7
Gleyic Podzoluvisol	5.6			40	5
Dystric Gleysol	5.1		25	30	
Eutric Gleysol	7.4		30		15
Mollic Gleysol	7.0				80
Calcaric Phaeozem	8.1	60	100	50	18
Gleyic Phaeozem	7.7		98	14	26
Haplic Phaeozem	6.8		90	25	20
Luvic Phaeozem	6.0	20	50	5	17
Calcaric Fluvisol	8.0		20	20	
Eutric Fluvisol	5.0-6.2		82	5-30	
Dystric Fluvisol	5.5		40	80	1.5
Calcic Kastanozem	8.2			4	18
Luvic Kastanozem	7.2			5	23
Chromic Luvisol	6.2	40	60	3-60	3-15
Calcic Luvisol	7.7	20	94	40	10
Orthic Luvisol	6.4	11	70	5	6
Vertic Luvisol	6.4	20	80	20	12
Ferric Luvisol	5.5	17	38	7	2
Gleyic Luvisol	6.7	15	87	10	13
Orthic Greyzem	5.9		100	5	25
Eutric Histosol	6.5	182	70	20	40
Cambic Arenosol	6.5		90	80	4
Luvic Arenosol	6.3		60	75	70
Gleyic Solonetz	6.5		50	20	0.2
Orthic Solonetz	7.6			5	12
Humic Andosol	4.9		7	35	1
Ochric Andosol	5.3		27	20	9
Vitric Andosol	5.8		25	40	7
Chromic Vertisol	7.6		100	27	15
Pellic Vertisol	7.9	57	93	5	20-30
Eutric Planosol	6.0	25	50	20	
Calcic Xerosol	7.7			20	
Orthic Solonchak	8.4			25	
Gleyic solonchak	8.3	20	90	2	7
Eutric Regosol	7.0	3	90	75	2
Calcaric Regosol	7.5			95	
Dystric Regosol	5.0	2	40	97	1

Source: FAO-Unesco (1981), EEC (1985).

Table 2 Typical characteristics of Category I soils

Soil type	pH	CEC (meq/100g)	V (%)	Sand (%)	Ca content (meq/100g)
Rankers	4.1	23	6	45	0.98
Acid Lithosols		depends on type			
Dystric Cambisols	4.5	33	6	30	
Dystric Podzoluvisols	4.2	14	13	60	
Orthic Acrisols		no values			
Gleyic Podzols	4.2		10	75	
Humic Podzols	4.2			94	0.11
Leptic Podzols	3.8			50	
Orthic Podzols	4.5		8	80	1.0
Placic Podzols	4.5		7	55	
Dystric Histosols	3.8		7	peat	4.0

Source: FAO-Unesco (1981) and EEC (1985).

Table 3 The acid neutralizing ability of rock types

Group	Acid neutralizing ability	Rock type
A	none - low	granite, syenite, granite-gneisses, quartz sandstones (and their metamorphic equivalents) and other siliceous (acidic) rocks, grits, orthoquartz, decalcified sand-stones, some quaternary sands/drifts
B	low - medium	shales, conglomerates, high grade metamorphic felsic to intermediate igneous, calcsilicate gneisses with no free carbonates, metasediments free of carbonates
C	medium - high	slightly calcareous rocks, low-grade intermediate to volcanic ultramafic, glassy volcanic, basic and ultrabasic rocks, calcareous sandstones, most drift and beach deposits, mudstones
D	"infinite"	highly fossiliferous sediment (or metamorphic equivalent), limestones, dolostones

Source: Norton (1980); Kinniburgh and Edmunds (1986); Lucas and Cowell (1984).

The buffering ability of sites determined by the capacity and rate factors discussed will be modified by the current vegetation and management practices. Different plant species create different types of leaf litter with differing effects on the site to buffer acidic inputs. Coniferous tree species tend to produce an acidic mor type of humus which will not buffer the depositions as efficiently as the mull type of humus produced by deciduous species (Mikola, 1985). Heathland vegetation also produces a mor type of humus but sites with this type of vegetation will not be as sensitive as those with coniferous forest due to other effects of coniferous forest on the sensitivity to acidic depositions. Conifer trees effectively scavenge particles from the air, the so-called filter effect, and so the deposition of acidic substances is greater (Hultberg, 1985). Coniferous forests alter hydrological features of sites to a greater extent than heathland vegetation and this affects the acidification of streams in forested catchments (Miller, 1985). Site management is also of significance in the ability of sites to buffer acidic depositions and the addition of lime to arable land causes these sites to have a lower sensitivity than they would otherwise have. Land use has been used to include the effect of vegetation and management and four categories have been distinguished: arable and rich pasture; deciduous forest; heathland and relatively unmanaged land; coniferous forest. Of these, coniferous forest areas will be most sensitive.

Some factors are more important in determining the sensitivity of sites than others and this is reflected by applying different weights to the factors which indicate the relative influence of the different factors in buffering acidic inputs. These are shown in Table 4. The rate of weathering is considered to be of greater significance than the capacity of sites to buffer since in the long term the weathering rate is the ultimate sink for protons. The high weight applied to land use reflects the great difference between the modification of sensitivity by arable land and coniferous forest.

Table 4 Division of site factors into categories and associated weights for use in combination

Factor	Weight		Category	Weighting
Rock type	2	I	siliceous, slow weathering rocks	1
		II	faster weathering rocks	0
Soil type	1	I	major acid buffering < pH 4.5	1
		II	major acid buffering > pH 4.5	0
Land use	3	I	coniferous forest	1
		II	rough grazing	2/3
		III	deciduous forest	1/3
		IV	arable land	0
Rainfall	1	I	>1200 mm (annual average)	1
		II	<1200 mm (annual average)	0

Using the weights applied to categories from Table 4 eight sensitivity classes result and in consideration of the way in which the map is used these have been further combined to give five classes of relative sensitivity according to Table 5 which are shown on the map (Figure 1).

Table 5 The combination of sensitivity classes

Original Sensitivity Class	0	1	2,3	4,5	6,7
Combined Sensitivity Class	1	2	3	4	5

SOURCES OF INFORMATION

The categories of the factors shown in Table 4 were digitised from maps and subsequently combined using a Geographical Information System. It was intended that the assessment of sensitivity in Europe be mapped as consistently across the region as possible and the maps digitised covered the whole or large parts of the region. The sources of information are summarised in Table 6.

Table 6 Maps used for the production of the sensitivity map

BEDROCK TYPE	
Map:	International Geological Map of Europe and the Mediterranean Region
Scale:	1:5 M
Author:	Unesco (1971)
Comments:	Igneous and metamorphic rocks are mapped by type but sedimentary rocks mapped by age. Siliceous igneous and metamorphic rocks were digitised together with Precambrian and Lower Palaeozoic to approximate to slow weathering sedimentary rocks. Covers entire European region.
SOIL TYPE	
Map:	Soil Map of the World, Volume V, Europe.
Scale:	1:5 M
Author:	FAO-Unesco (1981)
Comments:	Large volume of information accompanies maps describing soil type characteristics. Entire European region covered. Soil types digitised from this map.
Map:	Soil Map of the European Communities
Scale:	1:1 M
Author:	European Community (1985)
Comments:	Only covers European Community countries. Not digitised but used for information.
LAND USE	
Map:	Land Use Map of Europe
Scale:	1:2.5 M
Author:	FAO-Cartographia (1980)
Comments:	Does not cover USSR and only includes part of western Turkey. Most countries digitised from this map.
Map:	Types of Agriculture Map of Europe
Scale:	1:2.5 M
Author:	Kostrowicki (1984)
Comments:	Covers Europe and includes USSR but not Turkey. Non-agricultural areas not specified. USSR digitised from this map.
Map:	Weltforstatlas
Scale:	various
Author:	Weltforstatlas (1975)
Comments:	Used to identify areas and type of forest in the USSR; forest areas in Turkey digitised from this map.
RAINFALL	
Map:	Climatic Atlas of Europe I. Maps of Mean Temperature and Precipitation
Scale:	1:5 M and 1:10 M
Author:	WMO-Unesco-Cartographia (1970)
Comments:	Data are an average of the 1931-1960 period. Mean annual rainfall digitised.

USE OF THE MAP

The relative sensitivity map is compared to deposition estimates of sulphur and nitrogen compounds to identify areas of potential risk. This comparison is carried out by assigning target deposition values to the sensitivity classes which represent a threshold to damage. The targets have been assigned by referring to the now extensive literature on *critical loads* which have been worked out for various ecosystems referring to the damage caused by acidifying depositions.

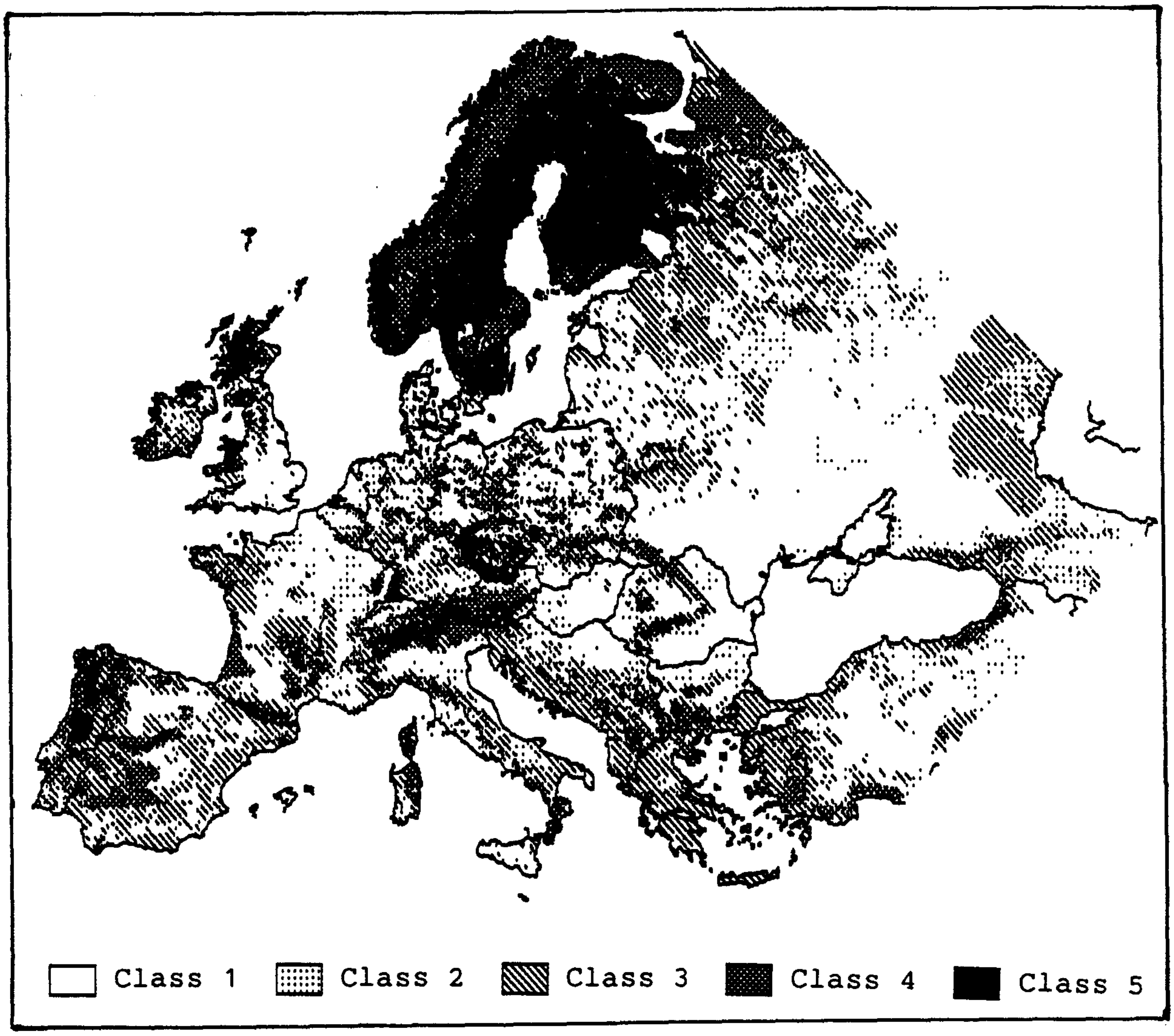

Figure 1 The relative sensitivity of ecosystems in Europe to acidic depositions

Critical loads have been defined as: "A quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge" (Nilsson and Grennfelt, 1988).

Critical loads have been calculated for specific sites and ecosystems in many countries in Europe using empirical approaches, by steady-state and process oriented models of ecosystem response to acidic depositions (Sverdrup *et al.*, 1990). Target deposition values have been applied to the sensitivity classes (Table 7) at the level of critical loads by comparing the critical load value derived by the various approaches to the sensitivity predicted for the area in which the site lies.

By overlaying the depositions for a given year over the targets applied to the sensitivity classes it is possible to display the areas where the deposition exceeds targets. The excess of depositions over targets may be demonstrated in three ways:

1. where targets are exceeded (by any amount);
2. the amount by which targets are exceeded;
3. the excess over targets in relation to the targets.

Table 7 Target deposition levels applied to the relative sensitivity classes

Relative sensitivity class	Targets (keq H^+ km^{-2} yr^{-1})*
1	>160
2	160
3	80
4	40
5	20

* keq H^+ km^{-2} yr^{-1} = 100 x keq H^+ ha^{-1} yr^{-1} = 0.1 x mol_c ha^{-1} yr^{-1}

Using the areas where targets are exceeded by any amount shows where some deleterious effect on ecosystem structure or function would be expected to occur. The amount by which targets are exceeded gives an indication of the deposition reduction which is required to bring deposition below critical loads. Figure 2 shows the estimated 1984 sulphur deposition, and Figure 3 shows the number of times by which the 1984 sulphur deposition exceeds targets. This relates exceedence to the critical load value set for the area and implies an unstipulated dose-damage relationship. Within a dose-response framework it would be assumed that the amount of damage caused to ecosystems once the threshold for damage has been exceeded would be related to the sensitivity of the ecosystem, which is proportional to the target.

The sensitivity map, with targets applied, may be used to compare the merits of different abatement strategies by comparing the distribution, total amount and area of the target (critical load) exceedence and may also be used to drive certain targeted strategies whereby priority is given to reducing emissions giving rise to exceedences. Some of the strategies currently being investigated within the SEIY CASM model are:

1. Uniform Percentage Reductions (UPR) - such as the "30 per cent club";
2. Emissions Minimisation - whereby the same amount of money spent on UPR is spent cost-effectively (abating first in the cheaper countries) to give the minimum emissions;
3. Exceedence Minimisation - a targeted approach whereby the total depositions in excess of targets is minimised, most cost-effectively;
4. Area Minimisation - a targeted approach whereby the total area of exceedence is minimised, most cost-effectively;
5. Damage Minimisation - a targeted approach which minimises the total exceedence weighted by the sensitivity of ecosystem area over which they occur, effectively minimising the total damage since the dose-response curve will be steeper in more sensitive sites. Also carried out most cost-effectively.

In order to carry out the optimised model runs for the targeted approaches it is necessary to chose single target values for the grid units on which the transport and deposition is based (the EMEP grid which is 150 x 150 km). The target assigned to this grid could be based on the maximum sensitivity (lowest target) occurring anywhere in the grid; occurring in greater than 5 per cent of the grid; the mode sensitivity or the median. These will have different effects on the abatement strategies which may be investigated.

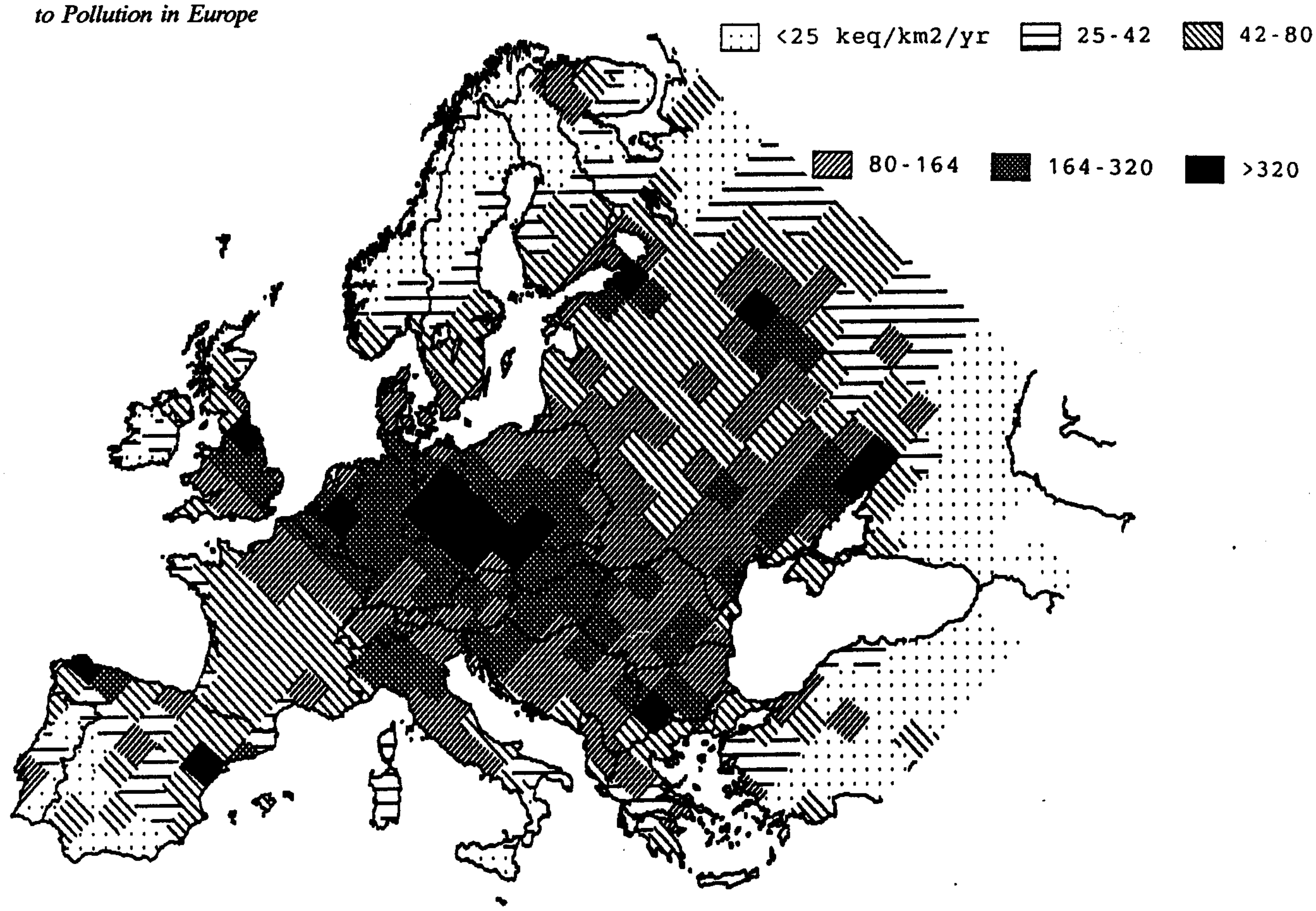

Figure 2 The sulphur deposition in 1984 estimated from SEIY emission estimates and EMEP 1984 transfer coefficients

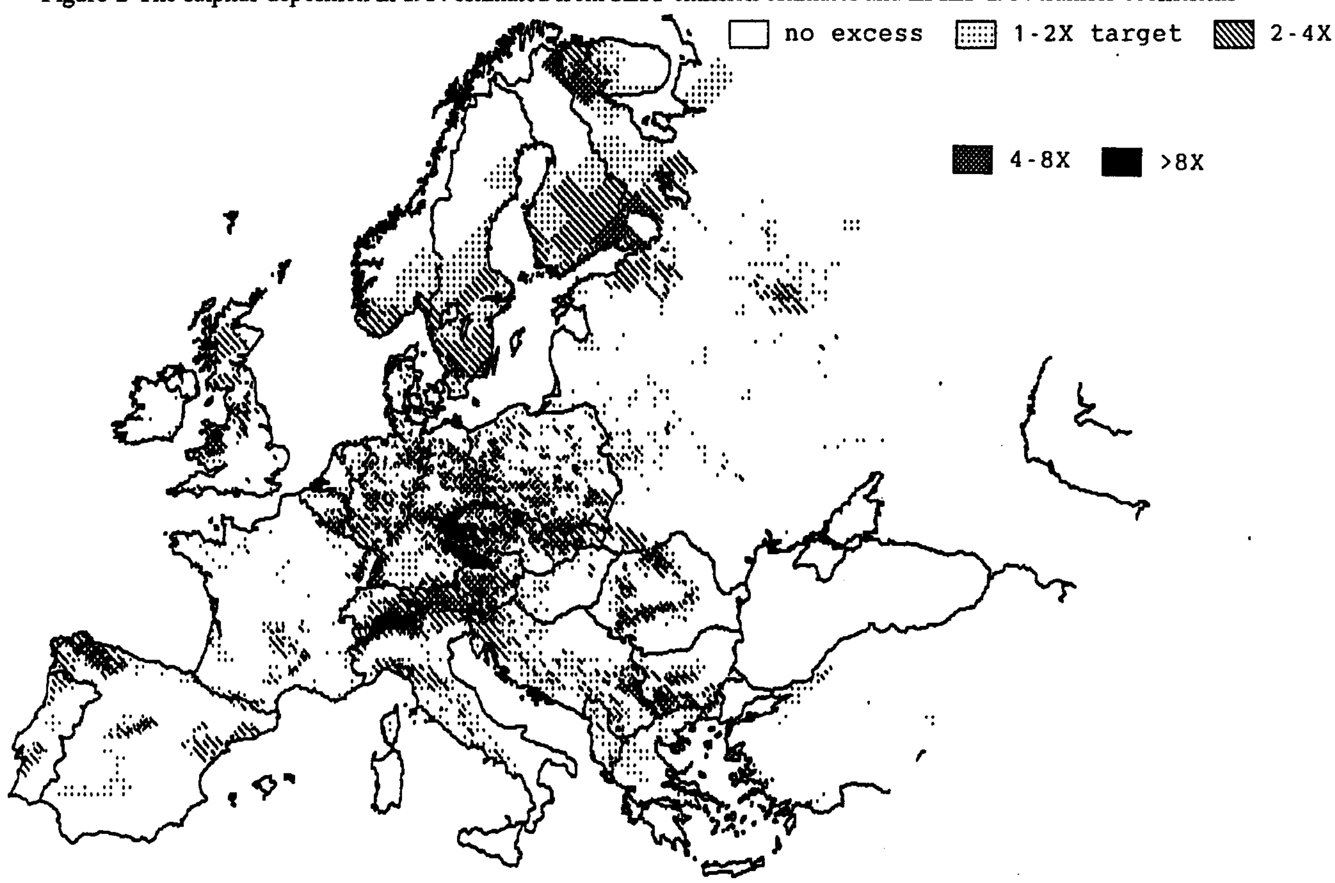

Figure 3 The exceedence of 1984 sulphur depositions to targets in relation to the targets

NITROGEN AS AN ACIDIFYING COMPONENT

Nitrogen depositions as nitrate or ammonium ions may acidify ecosystems only if the nitrate ions leach from the soil (Reuss and Johnsson, 1986). Nitrogen is an important plant nutrient and significant amounts may be taken up and removed when harvested. The uptake of nitrogen has been estimated by literature review and uptake rates applied to different types of land use, modified by climate. Nitrogen may also be immobilised in the soil organic matter and the regional immobilisation rates have been estimated by combining the main factors influencing the immobilisation: factors affecting mineralisation and nitrification rates (the C:N ratio); the drainage characteristics of soils; soil moisture and site attitude. Details of soil type C:N ratios and drainage characteristics have been estimated from information in the FAO Soil Map of the World (FAO-Unesco, 1981) and the Soil Map of the European Communities (EEC, 1985). The amount of acidity input to ecosystems from nitrogen depositions (N_{acid}) is calculated according to equation:

$$N_{acid} = (N_d - N_u) \times (1 - N_{i(acc)})$$

where: N_d = $NO_3^-{}_d + NH_4^+{}_d$ = annual nitrogen deposition;
N_u = annual nitrogen uptake by plants;
$N_{i(acc)}$ = proportion of the nitrogen immobilised.

The N_{acid} may then be summed to the sulphur deposition to give the total acidic input and the total exceedence calculated (base cation deposition may be taken into account).

THE SENSITIVITY OF VEGETATION TO SO_2

Acidification is not the only consequence of sulphur emissions since the concentrations of SO_2 may cause direct effects on vegetation. At the SEIY we have attempted to map the sensitivity of vegetation to SO_2 from factors such as the type of plant community, the soil moisture content, exposure to winter conditions, and the soil nutrient status. Target concentrations have been applied to the classes of sensitivity and these targets may be used in the optimisation procedures carried out in the CASM model.

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SECTION II: NATIONAL AND REGIONAL PRESENTATIONS

5 *Monitoring of Environmental Impacts on Soils in Austria*

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ABSTRACT

In this report the actual state of soil mapping is described together with methods and results of soil degradation monitoring and soil vulnerability assessment in the Federal Republic and in various states of Austria.

INTRODUCTION AND DEFINITION OF THE AIMS

In total, Austria covers 83,850 km² of which 32,000 km² are in forest (38%), 20,250 km² under grassland (24%), and 15,120 km² are cultivated (18%), including amongst others arable land and vine-yards. The remaining 16,480 km² (20%) includes mainly urban and socio-economic infrastructure such as traffic lines, settlements and industries (about 10,000 km² or 12%) and non-productive land (Blum and Wenzel, 1989). The total population of Austria amounts to 7.4 million.

In the following paragraphs the available information about soils in Austria (e.g. soil maps of different scales) is presented, the methods for the monitoring of environmental impacts at national and regional level are outlined, and the actual progress of monitoring soil degradation (mainly chemical impacts) in the different states of Austria is described.

SOIL MAPS OF AUSTRIA

Agricultural soil maps

Currently 93 per cent of the agricultural land (grassland and cultivated area) is mapped in the field at a scale of 1:10,000 and about 130 of 217 mapping areas are published at a scale of 1:25,000. The explanatory books for these maps include site and soil descriptions and laboratory data (Table 1). The mapping system is based on a genetic concept, similar to the German system, and considers ecological characteristics at lower taxonomic levels (Fink, 1969). The smallest mapping unit is the so-called soil form (Danneberg, 1986).

Table 1 Physical and chemical parameters on which the legends of the 1:25,000 agricultural soil maps are based

Soil parameters	Methods
Particle size distribution	Revut and Rode (1981)
pH	1:2.5 in 0.1 *M* $CaCl_2$
Humus content	Walkley-Black
Carbonate content	Scheibler

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Using this basic information, small scale regional maps on soil fertility, carbonate content and soil reaction, soil hydrology, risk of soil erosion and sensitivity to application of sewage sludge were compiled (Danneberg, 1986; Eisenhut, 1985; Jordan and Schwarzecker, 1983; Nelhiebel, 1985).

Forest soil and site classification maps

For the mapping of forest soils a combined site classification system is used, but only few maps are published (Kilian, 1986). In addition, soil degradation assessment is carried out within the framework of forest decline monitoring studies, but the results are not yet available to the public.

Soil taxation maps

A survey of the natural productivity of grassland and cropping areas exists for taxation purposes. Soil maps based on productivity indices, derived from field descriptions, are available at different scales, mainly 1:2880 and 1:2000 (Gessl, 1986; Krabichler, 1983).

THE ACTUAL STATE OF MONITORING OF CHEMICAL SOIL DEGRADATION IN AUSTRIA

Methods of soil pollution analysis, soil degradation assessment and vulnerability mapping

The first assessment of soil degradation was carried out in 1986/1987 in the state of Vorarlberg (Blum, 1988, 1990; Husz, 1987). Several methodological problems concerning soil sampling, sample preparation and laboratory procedures raised a discussion about the need for a generally accepted and unified methodology in Austria. Therefore, in 1988 the Ministry of Agriculture and Forestry supported the preparation of guidelines for soil inventories (concept, methods of soil sampling, sample preparation, laboratory analysis, evaluation of the results) by a working group of the Austrian Society of Soil Science. These guidelines were edited by Blum *et al.* (1989).

The working group proposed a grid of 4 x 4 km for basic investigations (standard programme) mainly to avoid a subjective selection of sampling sites. It was also proposed to increase sampling density according to the problems in each state, e.g. through the use of a closer grid and other methodological approaches.

Descriptions of soil and site characteristics are considered as essential for soil degradation assessment. Field descriptions are based on Arbeitsgruppe Bodenkunde (1982, partly modified), Blum *et al.* (1986) and Fink (1969).

Table 2 Soil sampling depths for different land use systems (in cm)

Number of samples	Forest soils Alpine pastures Extensive grassland	Intensive grassland	Arable land
0	O-horizons		
1	0 - 5	0 - 5	0 - 20
2	5 - 10	5 - 10	-
3	10 - 20	10 - 20	-
4	20 - 30	20 - 40	20 - 40
5	30 - 50	40 - 50	40 - 50
6	(50 - 70)	(50 - 70)	50 - 70

It is proposed to carry out soil sampling at predetermined depth intervals, dependent on land use, without regard to the genetic soil horizons (Table 2). This enables the horizontal and vertical comparison of soil characteristics, and element balances between different sites to be made. Moreover, it facilitates soil sampling by non-specifically trained personnel by eliminating influences of individual horizonation. From 16 to 20 subsamples are taken at the specified depths from an area with a diameter of 20 m. The subsamples for individual depth intervals are mixed before analyzing the fine earth fraction (< 2 mm). The results are expressed on an oven-dry matter basis (105 °C). Table 3 shows the parameters proposed for the analytical, standard programme.

Table 3 Physical and chemical parameters of the standard programme for soil inventories in Austria

Soil parameter	Methods
Bulk density	
Particle size distribution	Revut and Rode (1981)
pH	1:2.5 in $CaCl_2$
Total carbon	Dry combustion and IR-detection of CO_2
Carbonate content	Scheibler
Organic carbon	Total C - carbonate C
Total nitrogen	Kjeldahl
Exchangeable cations (Fe, Al, Mn, Ca, K, Mg, Na)	Modified Mehlich-method (batching with 0.1 *M* $BaCl_2$
CEC	1:20 for 2 hours)
Nutrients and pollutants (Ca, Mg, K, [Al], P, As, Cd, Co, Cr, Cu, Hg, Mn, Mo, Ni, Pb, V, Zn)	Aqua regia extraction
Mobile metals	0.1 *M* $BaCl_2$, 1:2.5
Base neutralization capacity	Meiwes *et al.* (1984)
Water extract (electrical conductivity, occasionally sulphate and other anions)	Batching with water 1:5 for 2 hours

The guidelines for soil degradation assessment also include methods for data interpretation, for example for the assessment of soil degradation caused by acid rain and heavy metal deposition. Moreover, guidelines for soil vulnerability mapping were established, mainly based on the work of Blume and Brümmer (1987), DVWK (1988), Herms and Brümmer (1980), Meiwes *et al.* (1984) and Ulrich (1981). In Table 4 an overview of the proposed interpretation schemes and necessary input parameters is given. Table 5 shows an example of the estimation of soil buffer potential for chemical impacts.

Table 4 Parameters for the assessment of soil vulnerability

Soil vulnerability	Parameter for assessment
general mechanical filter potential	particle size distribution, bulk density
general physico-chemical buffer potential	CEC
acidification and alkalinization resistance	pH, BNC, CEC
metal mobilization resistance	pH, CEC, clay content, humus content, colour (indicating sesquioxide content)
pesticide buffer potential	pH, CEC, clay content, humus content, colour (indicating sesquioxide content) soil hydrology (indicating redox conditions); pesticide characteristics

Table 5 Evaluation of the physico-chemical buffer potential of soils by CEC-measurement (Blum *et al.*, 1989)

CEC (meq kg^{-1})	Physico-chemical buffer potential
< 50	very low
50 - 100	low
100 - 200	medium
200 - 300	high
> 300	very high

Results

Vorarlberg was the first state of the Federal Republic of Austria which carried out a soil inventory for the monitoring of chemical impacts covering the whole country (Husz, 1987), but the methods of soil sampling (according to root density), of sample preparation (e.g. sieving to 1mm) and of laboratory analyses differ considerably from the guidelines of Blum *et al.* (1989). Styria (Amt der Steiermärkischen Landesregierung, 1988, 1989) started a programme for soil protection in 1986 which aims at the annual assessment of soil degradation in 12 agricultural main regions, subdivided into 134 sites. This concept also differs from the systematic approach of Blum *et al.* (1989), e.g. in the selection of sites, in soil sampling (in Styria according to genetic horizons) and in the standard analysis programme.

Tyrolia (Amt der Tiroler Landesregierung, 1989) was the first state which followed to a large extent the national guidelines. At the moment, Salzburg as well as Upper Austria and Lower Austria are preparing soil inventories according to the guidelines. Three other states, Carynthia, Burgenland and Vienna have not yet started.

From two regions of Lower Austria, the Marchfeld and the Vienna Woods, detailed data about soil degradation status are available (Köchl, 1987; Lindebner, 1990). Moreover, several other local inventories were carried out, for instance on soil degradation through fluorine deposition near an aluminium smelter in Upper Austria (Wenzel, 1990; Wenzel and Blum, 1991). At the moment, some regional inventories with high sampling density are in preparation, e.g. in Carynthia (Krappfeld, Karawanken) and in Styria (Basin of Köflach-Voithsberg).

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6 *Status of Research on Soil Vulnerability to Chemical Compounds and of Related Mapping Exercises in Belgium*

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ABSTRACT

An overview is given of past and continuing soil vulnerability research and related mapping exercises in Belgium. First, there is the whole range of research which focuses on the study and modelling of the behaviour of anthropogenic contaminants in the soil. Heavy metal pollution, radionuclide behaviour, acidification processes and movements of pesticides and fertilizers are investigated. These studies reveal the inherent vulnerability of the investigated soils for the different chemical compounds.
To enhance the use of the research results in decision making, a geographic interpretation has to be performed. Therefore pedo transfer functions have to be developed which estimate the inherent soil vulnerability parameters from soil properties which are easy to measure and available on a geographic basis. By integrating this inherent, static soil vulnerability in a land information system, together with other, dynamic, information layers, the actual soil vulnerability, under different development scenarios and abatement strategies, can be mapped. Moreover, this national, GIS based soil information system could form the framework within which research objectives are met, setting the right priorities for future soil vulnerability research, the integration of the results and ultimately, a better basis for decision making. This is elaborated upon by formulating some recommendations on the Belgian level.

INTRODUCTION

Research on soil vulnerability to chemical compounds in Belgium has evolved mainly from soil fertility studies. Over the last decade, research has been devoted to the study of undesirable side-effects of chemicals which otherwise were recognized as being beneficial for plant production, e.g. certain fertilizer and pesticide components. However, the study of the behaviour and effects of human-produced contaminants such as heavy metals and radionuclides on the capacity of soils to produce safe food crops, fodder, tissue and timber has gained in importance. This vulnerability research is mainly carried out by agricultural institutes for which the soil is a traditional research object and where expertise on soils is available. Understandingly, cultivated soils were included in the early research, but currently uncultivated forest and fallow soils are increasingly the subject of investigations.

In this paper, soil vulnerability is discussed for the following groups of human produced chemicals: (1) heavy metals, (2) radionuclides, (3) acidifying agents, originating from air pollution, (4) fertilizers, and (5) pesticides. This list is not exhaustive and as the groups cannot strictly be separated, much overlap exists. Some fertilizers may enhance soil acidification; pesticides may contribute to heavy metal pollution; etc.

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CONCEPTUAL FRAMEWORK

Soils are natural bodies which present both static and dynamic properties when they are considered on a short or medium time scale (a few years to a few decades). The occurrence of diagnostic horizons, the sequence of horizons and the horizon texture are more static soil features, the evolution of which is governed by modifications of climate and hydrology. The dynamic soil properties are mainly related to the use which is made of the soil and to other human activities having a remote impact on the soil (industry, traffic, urban infrastructure, etc.).

According to Arnold *et al.* (1990) within the latter group the content of water soluble substances, radionuclides and the biological soil activity can, among others, display changes on the short term (immediately or within a few years) as a result of fertilization practices, nuclear accidents and slurry application onto the soil. The litter composition, soil acidity status, heavy metal contents can change within a few decades as a result of industrial activities, waste disposal and fertilizer application. Changes in humus content, carbon-nitrogen ratio, clay, iron and chlorine distribution in the soil profile are expected to occur within hundreds of years. Thousands of years are necessary to modify pathways of soil development leading to a switch from one genetic group to another. All these changes will affect plant development to a greater or lesser extent. The dynamic properties can be regarded as a sample of where direct or indirect symptoms of soil pollution may be found.

Within each broad time-scale, the speed and intensity with which symptoms develop and effects on plant production emerge, i.e. the ability of the soil to cope with inputs of chemicals without compromising plant production, depends, for a given intensity and type of pollution, upon the static soil framework, the climatic and hydrologic environment as well as the management history of the soil, both in terms of use and accumulated pollution.

Because of the complexity of the system, the concept of "intrinsic soil vulnerability" is useful. This intrinsic vulnerability is mainly determined by the static soil attributes. In order to assess the "actual soil vulnerability", i.e. the time lag after which the quantity and/or quality of plant production will suffer considerably from the accumulated contaminants and induced changes, climate, hydrology, past, current and planned land use, and past, current and projected input of contaminants have to be taken into account.

The input of human-produced chemicals may however also have positive effects on plant production capacity and enhance the sustainability of the land use. This is illustrated by the well known example of better growth of tree species on sulphur deficient soils due to atmospheric input of sulphur containing substances through dry and wet deposition. The properties of Fimic Anthrosols which are generally recognized to have a high production capacity, result from the application, during centuries, of enormous amounts of diverse organic materials.

Mapping of spatial patterns of intrinsic soil vulnerability at medium and large scales is thought to be very well served by soil maps as the latter generally depict static soil attributes. As the legend of most soil maps is of a pedogenetic and thus abstract nature, upgrading of soil maps (Stiboka, 1988; Van Orshoven *et al.*, 1990) might be necessary. Through linkage of observed, measured or computed attributes of the more static kind to soil map units, soil maps can be converted to maps displaying the intrinsic vulnerability of soils to groups of chemical compounds. At larger scales interpolation techniques seem to be more promising for the prediction of soil vulnerability if georeferenced observations of a sufficient density are involved.

In order to construct actual vulnerability maps, the base polygon layer with static soil information, has to be further upgraded with extra soil attributes of the more dynamic type (e.g. hydraulic and thermal conductivity) and combined with climate and hydrology maps. Finally, point, line and polygon features related to pollution sources and land use are to be included. The new map units obtained present combinations of the base information layers to which land quality, and more specifically vulnerability ratings, can be assigned, based on expert knowledge or mathematical algorithms. GIS-technology has the capability to produce intrinsic vulnerability maps on the one hand and especially actual vulnerability maps on the other.

STATUS OF RESEARCH ON SOIL VULNERABILITY TO SPECIFIED GROUPS OF CHEMICAL COMPOUNDS

Fertilizers and soil vulnerability

Current research topics in Belgium on plant nutrition can be summarised under three major headings.

- First there is the group which describes empirically various aspects of soil contamination as a result of anthropogenic soil fertilization. A wide range of human produced substances are considered as soil pollutants such as fertilizers (Demyttenaere *et al.*, 1989; Destain *et al.*, 1989; Guiot *et al.*, 1989; Lambert *et al.*, 1990; Vlassak *et al.*, 1987;), harvest residues (Van Cleemput and Baert, 1980; Van Cleemput *et al.*, 1981); slurry (Van den Abbeel *et al.*, 1989), and composted municipal waste (De Coninck *et al.*, 1989).
- The second line of investigation analyses the various processes and underlying principles of soil pollution. Under this header mechanistic simulation models are being developed and validated using various sets of experimental data. The models describe N-mineralisation from crop residues (Dendooven, 1990), N-leaching on catchment scale (Vereecken *et al.*, 1989), impact of N-fertilisation on the chemical activity of major trace elements and heavy metals and on the biological activity in soils (Verloo *et al.*, 1987; Verloo and Willaert, 1989), the behaviour of zinc in mixed oxide Bh systems (Tits *et al.*, 1989), the capacity for complexation in natural organic matter (Maes and Cremers, 1989). The relationship between soil pH and adsorption of copper, zinc and cadmium in some soils and clay minerals was investigated by Halen and Van Bladel (1990).
- A third group of researchers investigated the adjustment of fertilizer recommendations so as to minimize environmental risks. Fertilizer recommendations are calculated on the basis of a routine pH, organic carbon content, and available cation analysis. Unfortunately, these large numbers of samples are of limited value for mapping exercises because they are poorly georeferenced. A breakthrough was made by the Belgian National Soil Service (Boon, 1981) by correlating the N-index, measured during early spring of the entire soil profile to the N requirement of the subsequent crop. Geographic adjustment of fertilizer recommendations within farmer's fields related to spatial soil variability are investigated by Deckers *et al.* (1990).

Heavy metals and soil vulnerability

The general approach is centred around the determination of the geochemical phase association of transition metal ions with Belgian soils and river sediments (Bosmans and Paenhuys, 1980; Tits *et al.*, 1989). The essential aim is to measure the distribution of transition metal ions between the solid and liquid phase and to interpret these data in terms of the separate contribution of different soil fractions.

From a fundamental point of view the calculation of the speciation under *in situ* conditions is based on the use of a thermodynamic data base. This approach assumes that the *in situ* behaviour can be described simply as a combination of independent processes occurring on different soil fractions. In this respect it is necessary to have a good knowledge of both the amount of each fraction (capacity factor) and the affinity of each fraction for the considered transition metal (affinity factor). In natural systems however interactions among the fractions occur and may result in changes of both factors. Research work at the Laboratory of Colloid Chemistry, Catholic University (K.U.) of Leuven, concentrates on methodologies for measuring the influence of the mutual interactions on the capacity- and affinity factors in both synthetic mixtures and natural systems.

Radioactive contamination and soil vulnerability

An additional aspect of environmental pollution is the radioactive contamination of soils resulting from fall-out after a nuclear accident such as the one in Chernobyl in April 1986. For several areas in Western Europe, fairly high depositions of radiocaesium (^{137}Cs; ^{134}Cs) have been recorded. It is known that radiocaesium is selectively adsorbed in micaceous clay minerals, such as illite, the dominant clay mineral in the soils of Western Europe (Cremers *et al.*, 1988).

Soil vulnerability with respect to radiocaesium contamination involves short-term and long-term effects. The short-term effect relates to the capacity of the soil to specifically retain radiocaesium, thus reducing the levels to which the plant roots are exposed, and therefore directly influence the soil-to-plant transfer. Such capacity is of course directly connected with illite clay content. Specific problem soils in this regard are therefore podzolic soils and peat soils which may in some cases show organic matter contents of up to 90 per cent.

The long-term effect relates to the rate of immobilisation of radiocaesium in the soils. It is known that, with time, radiocaesium diffuses into the crystal lattice, thus becoming irreversibly fixed and no longer available for plant uptake. However, current knowledge about the rate at which such a process occurs and whether such rate may be significantly different from one type of soil to another is limited. The reason for this is that no suitable methods are currently available to study such processes quantitatively. New methodologies are now being developed at the Laboratory of Colloid Chemistry, K.U. Leuven, which should enable a more quantitative assessment of such long term effects and to set up criteria with respect to soil vulnerability to radioactive contamination.

Components of wet and dry deposition and soil vulnerability

Research on the effects of acidifying and other components from dry and wet deposition is not further discussed for cultivated land although monitoring of the soil acidity status has developed gradually from the time of the second world war to support fertilizer recommendations. Interpretation of the available datasets is hampered by the difficulties in separating the influence of airborne agents from other human interference.

As a result of alarming observations on forest dieback in eastern and northern Europe in the early eighties, a number of research projects have been initiated for forest and fallow soils. For northern Belgium a sampling campaign took place in 1986 on more than one hundred forest and fallow sites by the National Institute of Chemical Research (ISO) revealing that compared to the period 1950-1960 a significant acidification of the soil solution (pH H_2O) had occurred in all soil types investigated whereas a significant total acidification, based on pH KCl measurements was found for the upper layers of Podzols and Regosols only (Ronse *et al.*, 1988). This acidification was found to be comparable to the pH decrease observed in the Netherlands by Van der Salm (1985) and in Nordrhein-Westfalen. Cation exchange capacities of the investigated soils did not show obvious trends while the organic matter content had increased for all soils examined.

In addition to the regional forest damage inventories in the pan-European 16 x 16 km grid, 10 forest plots were selected in the Flemish region on which not only tree health status is assessed, but on which also a number of soil and soil solution parameters are determined. These data, which were collected in 1990 by the Laboratory of Forestry, University of Gent, are still being processed. However, preliminary evaluation reveals that soil solution data are much more sensitive to environmental changes than traditional soil parameters as pH, CEC, exchangeable base cations, etc. and thus more likely to reveal possible air pollution effects. In the framework of the EC-programme "Network Integrated Monitoring of Forest Ecosystems" (NIMFE) this soil research will be extended to a more important number of plots and to a more numerous set of soil parameters (Ministerie van de Vlaamse Gemeenschap, 1990). This forest soil investigation programme is expected to provide static characterization data for the study plots as well as baseline measurements for future monitoring of the forest health-soil relationship. An important aspect of the programme is the use of common sampling, conservation, analysis and reporting techniques by the participating countries all over Europe (Ministerie van de Vlaamse

Gemeenschap, 1991). However, as insufficient knowledge is available on the optimum set of parameters to be measured in order to obtain a coherent dataset for cause-effect research, it can be expected that while the programme is progressing, new parameters might have to be included and others dropped from the measurement programme.

For the Wallonia region, research on the relationship between forest productivity and soil physical and chemical parameters is carried out by the universities of Gembloux (Unité de Pédologie Forestière) and Louvain-La-Neuve (Unité des Eaux et Forêts, Unité de la Science du Sol).

Pesticides and soil vulnerability

Research on soil contamination by pesticides is the subject of a few scattered efforts. Recently the policy makers have become aware of the possible harmful impact of large quantities of pesticides used in certain types of agricultural activity such as fruit growing. Pussemier (1990) suggests that the environmental threat of pesticides depends on their specific adsorption to soil colloids, chemical and/or microbial break down rate and rate of uptake by plants. Another important parameter is the mobility of these chemicals which depends on wether they are hydrophobic or hydrophillic. At present most research is conducted *in vitro*, but to translate these results to the complex environment of real soil profiles lies a long way ahead. The first attempt of this kind of work is done on 4 major Belgian soil units in a lysimeter study at the Department of Land and Forest Management of the Catholic University, Leuven.

THE LAND INFORMATION SYSTEM AS A TOOL FOR INTEGRATION AND MAPPING

To date, only a few attempts have been made in Belgium to present the investigation of soil vulnerability, as described earlier, on a geographic basis. Only in a few cases have maps been constructed indicating the severity and extent of the presence of a given contaminant. However, soil vulnerability maps are increasingly recognized to be major instruments in enhancing the political and social awareness of problems and dangers related to soil pollution, and as useful technical tools for supporting decisions on management problems. Major reasons for the absence of mapping efforts are thought to be: (1) the kind of research which currently is being conducted, i.e. research on the fundamental aspects of soil pollution and vulnerability at laboratory or very limited field scale, (2) the lack of background data and scientific procedures to extrapolate research results on a geographic basis, (3) the only recent awareness of the problems on government level, and (4) the imperfect spread of digital mapping and geographic analysis facilities in governmental and scientific institutions.

Points (3) and (4) have changed rapidly during the last few years but additional research efforts must be devoted to the development of procedures to extend research results geographically. Important benefits are expected from the national research project COBIS, conducted at the Department of Land and Forest Management, K.U. Leuven. This project aims at the multi-purpose interpretation of the Belgian Soil Map (scale 1:20,000). Within this framework a soil profile data base has been established (Van Orshoven *et al.*, 1988) and data have been processed statistically (Maes *et al.*, 1988) in order to extend the characterisation of the map units with basic properties. For the further interpretation of the soil map in terms of relevant land qualities Pedo Transfer Functions (PTFs) should be developed to relate the primary and available soil parameters to the input parameters of models which describe the processes of soil degradation, water movement in the soil etc. PTFs exist for the hydraulic conductivity-pressure head relationship and the moisture retention characteristic (Vereecken *et al.*, 1989, 1990). These functions are necessary input for models which describe the water movement in the soil profile. In the same way the input parameters for other models can be geographically extended and can be integrated with the soil data base. This is a first step in the construction of a national, geographical Land Information System.

The enormous advantage of organizing the information is, apart from the opportunity of a better integration of the different research activities, the possibility to construct maps in an automated way, over the whole or a part of the country, presenting the vulnerability of soils for different groups of chemical compounds and other soil related phenomena. Moreover, the integration of the national information into an international, for instance European, data base becomes easier. However, some practical problems might occur. The Belgian Soil Map (scale 1:20,000) is based upon the observation of soil profiles, one per hectare. As the level of detail is very high, a generalization procedure should be performed, before the information can be used at smaller scales. Fortunately, the structure of the Soil Information System enables an automatic, more justified and eventually repeated generalization. On the one hand geographical generalization can be performed on the basis of the existing soil unit boundaries. On the other hand, the existing profile descriptions and analyses (1 per 1-6 km^2), which are point observations, can be processed using geostatistical techniques. The technique used is determined by the scale of the problem.

Another advantage of the use of a geo-referenced Soil Information System is the possibility to combine soil based information with other, often dynamic, information layers including climate, land use and land elevation. In this way the actual status of the soil in relation to pollution by chemical compounds can be mapped.

SOME MAPPING EXAMPLES

Acidity status of the Zoniën forest

After a statistical upgrading of the soil map (Van Orshoven, 1990) of 5000 ha forest area with 301 historical (1954) pH-values related to 44 profile descriptions, maps of the acidity status at 5 and 50 cm depth were constructed. Using annual increments of H^+-concentration of KCl-extracts of the soil, derived from recent pH-measurements by Ronse *et al.* (1988), extrapolation was made to the year 1990. These extrapolations were validated for the dominant map unit on the basis of 27 new pH-measurements. In this exercise soil classification units and horizons were considered as basic spatial information carriers. Assuming that this trend remains in the future, one can estimate the future acidification. This has led to a prediction of pH-KCl values in the year 2000, being 3.0-3.5 at 5 cm depth in the profile and 3.5-4.0 at 50 cm depth. This information was introduced in an expansion table (Maes *et al.*, 1989), linked to the digital soil map of the forest area.

Exceedence of critical loads of sulphur and nitrogen on a European scale

This mapping exercise was based on the Critical Load concept (Task Force on Mapping, 1990). The critical load is defined as a quantitative estimate of an exposure to one or more pollutants below which significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge. A methodology was developed to map the critical load exceedance of wet deposited sulphur and nitrogen, on a European scale, in a qualitative, approximative way. For this purpose, a number of digital geographic information layers were combined using GIS techniques: the sulphur (SO_4^{2-}) and nitrogen (NO_3^-) concentration in the precipitation (Hanssen *et al.*, 1990), the sum of which was represented in SO_4^{2-} equivalents; the mean annual precipitation (CORINE, 1990); the Soil Map of Europe (CORINE, 1990). The overlay of the first two information layers resulted in a map of the wet deposition of sulphur and nitrogen on a yearly basis. This information was in his turn combined with the soil map, classified according to the buffering capacity. The critical load of wet deposited sulphur and nitrogen on a yearly basis, assumed to continue over a period of 50 years, was estimated for the Belgian loess soils, which have medium buffering capacity. The other classes were defined relatively, so that the map units where the critical load is exceeded could be defined. This qualitative mapping exercise shows a useful approach which however needs further research on the actual critical loads of soils with regard to different chemical compounds.

CONCLUSIONS AND RECOMMENDATIONS

The concept of soil vulnerability in this paper has been defined either as a static or as a dynamic vulnerability. The former comprises the land quality "inherent vulnerability", which can be assessed from static soil properties. The dynamic vulnerability is related to time and refers to the chemical time bombs concept. Most of the soil changes considered in this paper are classified as short to medium term changes. Research in this respect has been focusing on fertilizer use, heavy metal contamination, pollution with radionuclides, pesticides contamination and acidification through acid rain. A long way still lays ahead to properly understand the processes underlying soil pollution phenomena. To date, very little formal mapping of soil vulnerability has been done in Belgium, so the importance of a geographical approach in environmental research is emphasised. This leads us to some recommendations for future research:

- Research related to the speed of anthropogenic impact on pedogenetic processes should be boosted. In this context paleosols could teach us some lessons on the impact of previous environmental conditions on the pedogenetic pathways.
- The data base with fertility data of agricultural land could be upgraded significantly if all samples taken for routine analysis were geographically referenced.
- More research is needed on the development of pedo transfer functions which will allow a more elaborate use of existing data bases.
- Research on the behaviour of pesticides in real soil profiles should be expanded.
- Last but not least, research on the static and dynamic land qualities of our major soil units and soil associations will be necessary if mapping units are to be the key to extrapolate research results from point to catchment basis. Here adequate extrapolation techniques should be developed which take into account the inherent vertical and horizontal variability of soils within the mapping unit.

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7 Basic Procedures for Mapping the Chemical Contamination of Bulgarian Soils

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ABSTRACT

The basic procedures for assessing and mapping the chemical contamination of Bulgarian soils with specified chemical compounds are discussed in this paper.

INTRODUCTION

There are many hot spots of chemical contamination in Bulgaria. Of these, the chemical contamination of soils with toxic metals is considered to be the most dangerous for human beings, animals and plants, because these metals are strongly adsorbed by the soil clay-humus complex. The main sources of contamination with heavy metals are industry, transport and agriculture (irrigation and flooding with polluted water, and treatment of soils with pesticides and herbicides containing heavy metals).

The main tasks of the soil scientist, the chemist, the hydrologist and cartographer are to ascertain the regions where chemical contamination affects soils, sediments and groundwaters. This can be achieved by mapping and to that end some of the main methodological principles used in Bulgaria are stated.

SOURCES OF CHEMICAL CONTAMINATION

The contamination can be spot (e.g. factories, power stations), linear (e.g. highways) or global (e.g. acid rain). In addition, chemical contamination of soils, sediments and groundwaters may occur through flooding and irrigation with polluted water. The chemical contamination of cultivated soils, treated with pesticides and herbicides, has a heterogenous character. For instance, soils under vineyards may contain high concentrations of Cu, while soils used for vegetables may be contaminated by water enriched with arsenic.

MAPPING OF CHEMICALLY CONTAMINATED AREAS

Mapping procedure

Mapping must take into consideration the character of the contamination:

- When mapping soils and sediments in the proximity of a spot source, such as a factory, the following should be taken into consideration: the wind direction, the height to which gases are projected into the atmosphere, the area's relief, the nature of the soils and sediments, and land use (e.g. arable, pasture or woodland). We have established the following distances for taking samples, viz. 50, 100, 200, 500, 1000, 2000, 3000, 5000, 8000 and 10,000 m from the source of contamination.

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- Soils and sediments must be sampled at right angles from and on both sides of linear sources of contamination such as highways. The sampling distance is 10, 20, 50, 100, 200, 300 and 500 m. The actual degree of contamination will be determined mainly by the traffic intensity, the efficiency/quality of the combustion engines, the wind direction and the regional relief.

- Chemical contamination resulting from acid rain, radioactive fall-out, and gas clouds containing other toxic compounds may affect soil quality over large areas. The whole of Bulgaria was affected, for instance, by radioactive fall-out originating from the nuclear accident at Chernobyl. In case of global contamination, mapping must take place along transects which encompass the different relief forms, soils and sediments.

- When flooding and irrigation with polluted water has occurred on terraces, deltas, lagoons and plains, the soil and sediment samples should be taken from several transects positioned perpendicular to the source of flooding.

Mapping scale

The recommended scale for mapping the vulnerability of arable soils to chemical contamination varies with the aim of the study. The scale of 1:5 M is recommended for global studies, 1:1 M for studies at European level, 1:500,000 for individual countries (national maps), 1:200,000 for large areas within countries, 1:50,000 for particular regions, while the scale of 1:25,000 is recommended for mapping at the level of towns and villages. Hot spots of chemical pollution should be mapped at a scale of 1:1000 to 5000.

Sampling procedure

The recommended number of samples is basically determined by the scale of the map. The depth of sampling is determined by the composition and characteristics of the soils and sediments. Investigations in Bulgaria show that the depth to which contaminants, and especially heavy metals, penetrate into soils and sediments depends on the characteristics of these media.

For instance, with Planosols having a strongly acid reaction, the heavy metals Zn, Cu and Fe have accumulated in the upper humus-enriched horizons rather than the lower weathered horizons. The existence of a greater quantity of these heavy metals in the A-horizon than in the B-horizon is indicative for the fact that technogenic contamination has taken place. Where soils have an alkaline reaction, technogenic heavy metals are generally immobilized in the topsoil. Under these circumstances, the contamination of the subsoils can only be observed through prolonged monitoring. These peculiarities should be kept in mind when mapping chemically contaminated soils and sediments.

Soil and sediment samples must be taken to a depth of 50 cm, preferably using the standardized depth intervals of 0-10, 10-20, 20-30, and 30-50 cm. In order to reduce the influence from natural variability and heterogeneity of soils and sediments, as well as changes in the amount of chemical contamination in time, it is recommended to sample sites considered representative in terms of their relief and soils. These investigations can be repeated over a period of several years, thereby permitting the monitoring of the actual degree of environmental contamination with respect to specific contaminants.

The following key parameters should be measured: soil texture, water holding capacity, thickness of soil, salinity, filtration, sorption capacity, pH, organic mater content, and nature of the soil profile (genetic horizons and layers).

It is suggested that the degree of contamination is expressed in three categories: not, slightly, and strongly contaminated. The criteria for assessing the degree of contamination must still be worked out for Bulgaria.

CONCLUSIONS

For effective mapping of chemically contaminated soils and sediments it is necessary to specify the following criteria:

- The method of determination of heavy metal and other toxic compound concentrations in soils and sediments;
- Acceptable maximum tolerable concentrations for heavy metals and other toxic compounds in soils and sediments must be worked out for Europe as a whole;
- The parameters of chemical contamination which determine the vulnerability of soils and sediments, and the methods of their determination must be established;
- It is suggested that the maximum tolerable limits of heavy metals and other toxicants are defined as "plant available" fractions and not as total contents similar to the procedure used for determining N, P, and K in studies of plant nutrition;
- The method of estimation of pollution in soils and sediments contaminated with several, different chemical substances must be clarified;
- When the maximum tolerable concentrations of contaminants in soils and sediments are established, the upper limits can serve as a basis for formulating soil-cleaning, and will permit an economic assessment of reclamation costs. For example, the existence of lead, copper, cadmium and zinc in areas occurring near villages and towns must be determined so that the quality of farm products for consumption can be controlled.
- Mapping should provide an answer as to whether a particular crop may be cultivated safely in contaminated areas without causing harm to human beings and animals. Different criteria will be required for arable crops, forest and grassland. Food crops should not be grown within a radius of 5 to 8 km from known sources of contamination. Similarly, animal farms should not be built on polluted areas.

The described procedure for mapping and sampling contaminated soils permits the identification and characterization of the actual severity and occurrence of specific contaminants in a particular area. These concentrations can be compared with the critical loads for these compounds so as assess whether these critical values are exceeded or not. This knowledge forms the basis for formulating sound land use and emission abatement recommendations.

8 Soil Vulnerability to Acidification in Slovakia: Principles of Evaluation

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ABSTRACT

In this paper, the principles of evaluation of the vulnerability of soils to acidification in the territory of Slovakia are discussed, and the preliminary results are presented.

INTRODUCTION

The process of soil acidification, caused by different industrial, urban and agricultural activities is one of the environmental problems attracting attention in Czechoslovakia. In accordance with many authors (e.g. Várallyay *et al.*, 1989), we define soil acidification as a decrease of acid neutralizing capacity which may lead to the decreasing of soil pH.

Many types of soils occur in Slovakia. This diversity is reflected in the initial pH values. Of the agricultural soils, 20.3 per cent are acid, 29.4 per cent are slightly acid, 31.1 per cent have a neutral reaction, and 19.2 per cent are alkaline. Although these pH conditions are considered to be relatively favourable, heavy acid loads have made soil-acidification one of the most serious environmental problems in our country.

SOURCES OF ACIDIFICATION

Soil acidification depends on the concentration of different chemical substances entering soils from different sources. The main sources of acid deposition can be summarised as follows:
- SO_2: Power plants; refineries; other industry; traffic; house holds; fertilizers
- NO_x: Power plants; industry; traffic; fertilizers
- NH_x: Agriculture; industry.

Data on acid atmospheric deposition in Czechoslovakia are shown in Table 1 and graphically expressed in Figures 1 and 2 (except for NH_x data, which are not available).

Table 1 Dry, wet and total deposition of Sulphur and Nitrogen in Czechoslovakia in 1987 (expressed in 1000 tons of S or N)

	Dry	Wet	Total
S	603	296	899
N	109	60	169

The use of artificial fertilizers in Czechoslovakia increased until 1986 when it amounted to 260 kg NPK per hectare of agricultural land. Since that time, artificial fertilizer use has slightly decreased to the present level of about 200 kg ha^{-1}.

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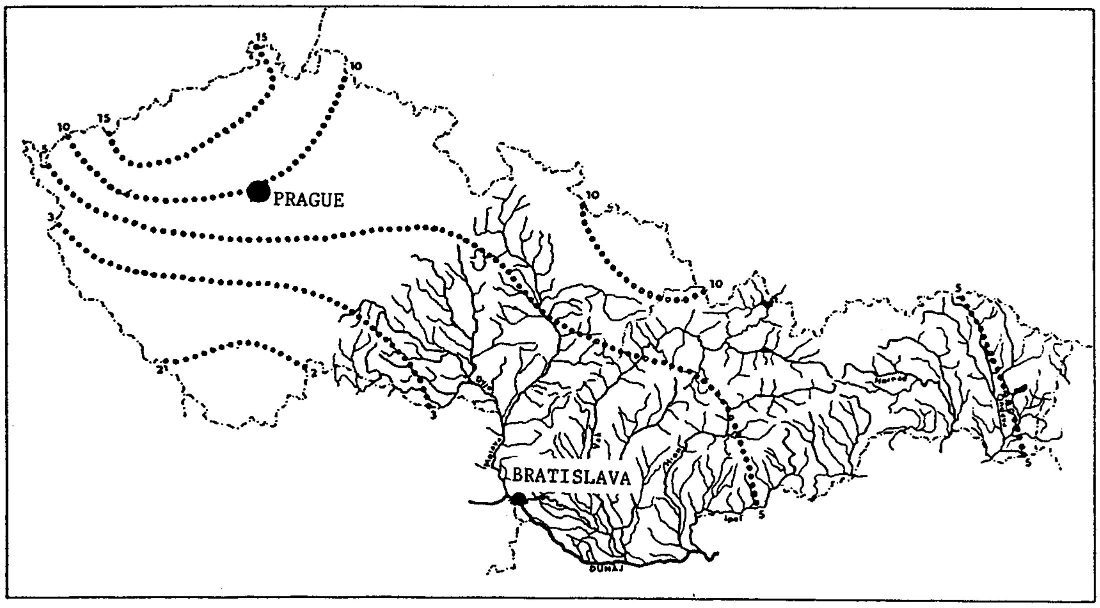

Figure 1 Total (dry and wet) sulphur deposition in 1987 in g of S m^{-2} (Modafter Zavodsky *et al.*, 1988)

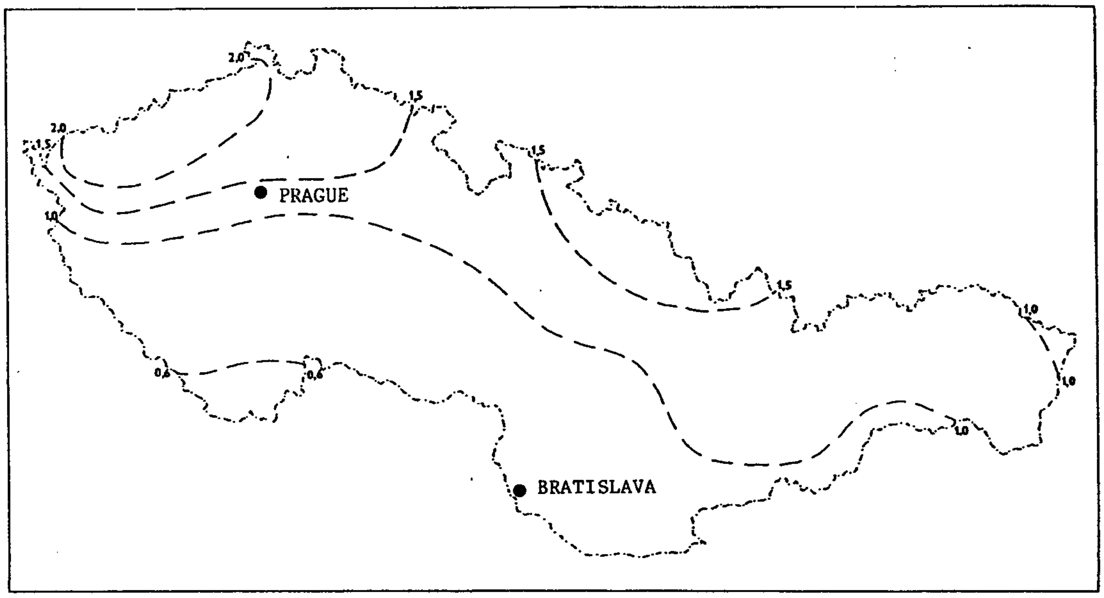

Figure 2 Total (dry and wet) NO_x deposition in 1987 in g of N m^{-2}

On agricultural land in Slovakia, the human-induced acidification is counteracted by intensive liming. The total amount of lime used, expressed as CaO, exceeds 400 thousand tons per annum.

SOIL VULNERABILITY TO ACIDIFICATION: AN HISTORICAL APPROACH TO CLASSIFICATION

Many authors have studied the effects of acid deposition on soil properties. The common feature of many of the published papers is the effort to categorize soils according to their vulnerability to acidification. Holobradý (1983) was one of the first to address this problem in Slovakia, distinguishing 6 classes of resistance to acidification and 5 classes of vulnerability of soils to acidification, using the following criteria in his classification scheme: humus quality and quantity, depth of humus horizon, clay content and type, parent material and base saturation.

Tomášek (1985) distinguished 5 classes of vulnerability, taking into account the fact whether data on the quantity and quality of the precipitation are available or not. As differentiating criteria, Tomásek used soil texture (light, medium, heavy), cation exchange capacity, base saturation and carbonate content.

Levine and Ciolkosz (1988) have constructed a soil association map, using a computer simulation model, on which 3 soil groups are depicted: "very sensitive", "slightly sensitive" and "not-sensitive" to acidification. The following soil parameters were used in the model: depth, bulk density, content of rock fragments, water capacity at 0.03 MPa tension, per cent of aluminium or iron oxides, per cent of base saturation, per cent of organic C, per cent of clay, exchangeable Ca, Mg, K and Na, CEC, soil pH and clay mineralogy.

Várallyay *et al.* (1989) distinguished 6 categories: "strongly acidic", "highly susceptible", "susceptible", "moderately susceptible", "slightly susceptible" and "not-susceptible" to acidification. These authors used the following criteria: chemical composition of the soil solution; content of carbonate minerals in the soil; quantity, quality and surface properties of the organic and inorganic fraction; and base saturation.

Lehotský (1990) only took into account the cation exchange capacity and base saturation to group the soils of Slovakia into 7 categories: soils with "smallest buffering capacity", "very small buffering capacity", "small buffering capacity", "medium to small buffering capacity", "medium buffering capacity", "high buffering capacity" and "very high buffering capacity".

Based on statistical analyses of experimental data, Glazovskaya (1990) found that the buffering capacity of soils is highly dependent on pH, $CaCO_3$ content, humus content, hydrolytic acidity, base saturation, cation exchange capacity, exchangeable Al content, soil texture, and the sand/clay ratio. This allowed the author to distinguish "prognostic soil groups", using two levels. At the first level the soils are grouped into 5 classes according to their reaction to acidification, while at the second level the buffering capacity is used to differentiate 23 subgroups. Glazovskaya (*op. cit.*) used the classification scheme to compile the "world map on soil resistance to acidification" at a scale of 1:80 M.

We are aware that this literature review is far from complete, but it clearly shows the diversity of approaches to different factors of importance in evaluation of soil vulnerability to acidification.

As a case study in the framework of the Chemical Time Bomb project, we would like to present the map of soil vulnerability to acidification in Slovakia. This map is being compiled based on Glazovskaya's (1990) scheme, with minor modifications, in that it we consider it the most comprehensive approach.

PRELIMINARY RESULTS

Extensive soil survey and soil research has been carried out in Slovakia during the past two decades. New analyses of humus and its quality, soil texture, CEC and base saturation, carbonate content and pH values are available.

The 1:50,000 map of soil vulnerability to acidification is not yet completed but, based on our preliminary findings, we are able to formulate some basic principles. The most important factors determining the resistance of soil to acidification are:

- carbonate content in the topsoil horizon (fine fraction)
- soil pH
- properties of the organic and mineral colloidal fraction.

Additional factors may also have to be taken into consideration, but they should play a less important role in determining the overall vulnerability to acidification.

General conclusions as to the vulnerability of Slovakian soils to acidification are drawn below:

- In the Danubian lowland area, the topsoils have a high carbonate content both in the alluvial and loess deposits; the corresponding soils are termed "not-susceptible to acidification".
- The carbonatic rendzinas (mostly shallow), which are also widely distributed, are not-susceptible or slightly susceptible to acidification.
- The soils which are developed on non-calcareous, loess-like and proluvial deposits situated in intermountain basins and peripheral parts of the lowlands are considered susceptible to acidification. They include fluvisols, pseudogley soils and some light to medium soils developed on deposits derived from non-calcareous flysch.
- The strongly acidic soils weathered from acid crystalline rocks, mostly occurring in high mountainous regions, show "restricted further acidification".
- The very coarse soils formed on eolian sands in the Záhorská Nížina lowland in western Slovakia are normally highly susceptible to acidification under natural conditions. Upon liming, however, these soils become slightly susceptible to acidification.

In order to compile the 1:50,000 map of soil vulnerability to acidification, we will need to identify the various determining factors and have to develop adequate methods. A coordinated, international cooperation will be beneficial in this respect.

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9 Danish Soil and Land Data Base System

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ABSTRACT

During the last 15 years a nation-wide soil data base system has been established in Denmark. It contains soil maps, analytical data, and classifications, and it has proved to be a useful tool for planning authorities. This paper describes the basic data comprising the soil data base system and how it has been, and will be, used in soil vulnerability mapping.

INTRODUCTION

Since the end of the second world war the expansion of urban settlements, road constructions and the demand for recreation areas made it necessary to protect the most valuable farmland from further degradation. For this purpose a soil survey was carried out by the Department of Land Data and Mapping (ADK) which initiated the establishment of a nation-wide soil data base system.

Today this system contains information from the Danish soil classification and from later soil investigations developing this classification. Furthermore, information from older maps, e.g. wetlands, has been computerized. All information has been digitized with reference to the UTM-coordinate system in order to provide facilities for production of computer-drawn soil maps at different scales and with different combinations of parameters.

THE DANISH SOIL CLASSIFICATION 1975-1980

In the period 1973 to 1975 local soil classifications were carried out on Bornholm and in north Jutland (Mathiesen, 1974 and 1975), mainly based on soil texture in the plough layer. In 1975, it was decided to make a nation-wide soil survey using a methodology much similar to that used by Mathiesen (1974, 1975). The soil survey was carried out by the Ministry of Agriculture over a 4-year period (Mathiesen and Nørr, 1976). By 1980 approximately 400 soil maps (scale 1:50,000) were available covering nearly the whole country. The soil maps are based on texture analyses of soil samples from approximately 35,000 sites, slope classes constructed from topographic maps, and the geological origin of the soil at 1 m depth, where these data are available. The geological information is available for 75 per cent of the country. Samples for texture analyses were taken at all sites from a depth of 0 to 20 cm and at selected sites from a depth of 35 to 55 cm. The samples were taken by local agronomists in cooperation with the staff of ADK. In the laboratory, texture, organic matter and calcium carbonate were determined in all samples, and the results stored in the computer system (Mathiesen, 1980).

The agricultural land was classified into 8 soil types according to the texture at 0 to 20 cm depth (Table 1). Each soil type was then given a map colour code ranging from 1 to 8. The remaining areas were divided into urban areas and forest areas. Table 1 shows that the soil types are further subdivided into 12 soil classes, coded JB1 to JB12. The 8 soil types were drawn on maps by local agronomists in cooperation with the staff at ADK. In this way the mapping benefitted from local experience.

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The agricultural land was also divided into three slope classes 0 to 6°, 6 to 12° and more than 12°. Experimental data show that in the first class mechanized tillage can be carried out without any problems, in class two minor difficulties may arise, while in class 3 mechanized tillage is nearly impossible.

Table 1 Definition of soil types for soil mapping in Denmark

Map colour code	Soil type	Soil class (JB)	Percentage by weight				
			Clay < 2 µm	Silt 2-20 µm	Fine Sand 20-200 µm	Total Sand 20-2000µm	Humus 58.7 % C
1	coarse sand	1	0-5	0-20	0-50	75-100	≤ 10
2	fine sand	2			50-100		
3	clayey sand	3	5-10	0-25	0-40	65-95	
		4			40-95		
4	sandy clay	5	10-15	0-30	0-40	55-90	
		6			40-90		
5	clay	7	15-25	0-35		40-85	
6	heavy clay or silt	8	25-45	0-45		10-75	
		9	45-100	0-50		0-55	
		10	0-50	20-100		0-80	
7	organic soils	11					> 10
8	atypic soils	12					

The maps have been published in colour with soil types shown in brown or yellow colours, the forests in green and the urban areas in white. The dominant geology is given for every 25 ha as a notation in the upper right corner in a grid. The slope classes are indicated by hatching. Figure 1 shows simplified nation-wide soil maps.

OTHER MAPS IMPROVING THE SOIL MAPS

A landscape map has been delineated on topographic maps at a scale of 1:100,000. The boundary lines between different landscapes were drawn on basis of the contour lines, former landscape maps, and geological surveys published at a scale of 1:100,000. The country has been divided into 9 different landforms: 1) Salt marsh; 2) Raised sea-floor, Littorina, and younger marine foreland; 3) Late glacial raised sea-floor; 4) Dune landscape; 5) Saale glaciation landscape; 6) Outwash plain; 7) Weichsel moraine landscape; 8) Reclaimed area; and 9) Rock.

Based on information from geological field surveys the texture of the soil at 1 m depth has been classified as sandy or clayey. It has not been possible to set up an exact limit for the clay content between the two types, but clayey subsoils contain normally more than 15 per cent clay, and sandy subsoils less than 10 per cent.

The wetlands were outlined from old topographic maps (1:20,000) showing the extent of wetlands 60 to 80 years ago. The old topographic maps were preferred to later ones because of the recent decrease in wetlands due to drainage. The wetlands include bogs, river valleys, salt marshes, littorina deposits and younger marine forelands. They cover roughly 20 per cent of the country.

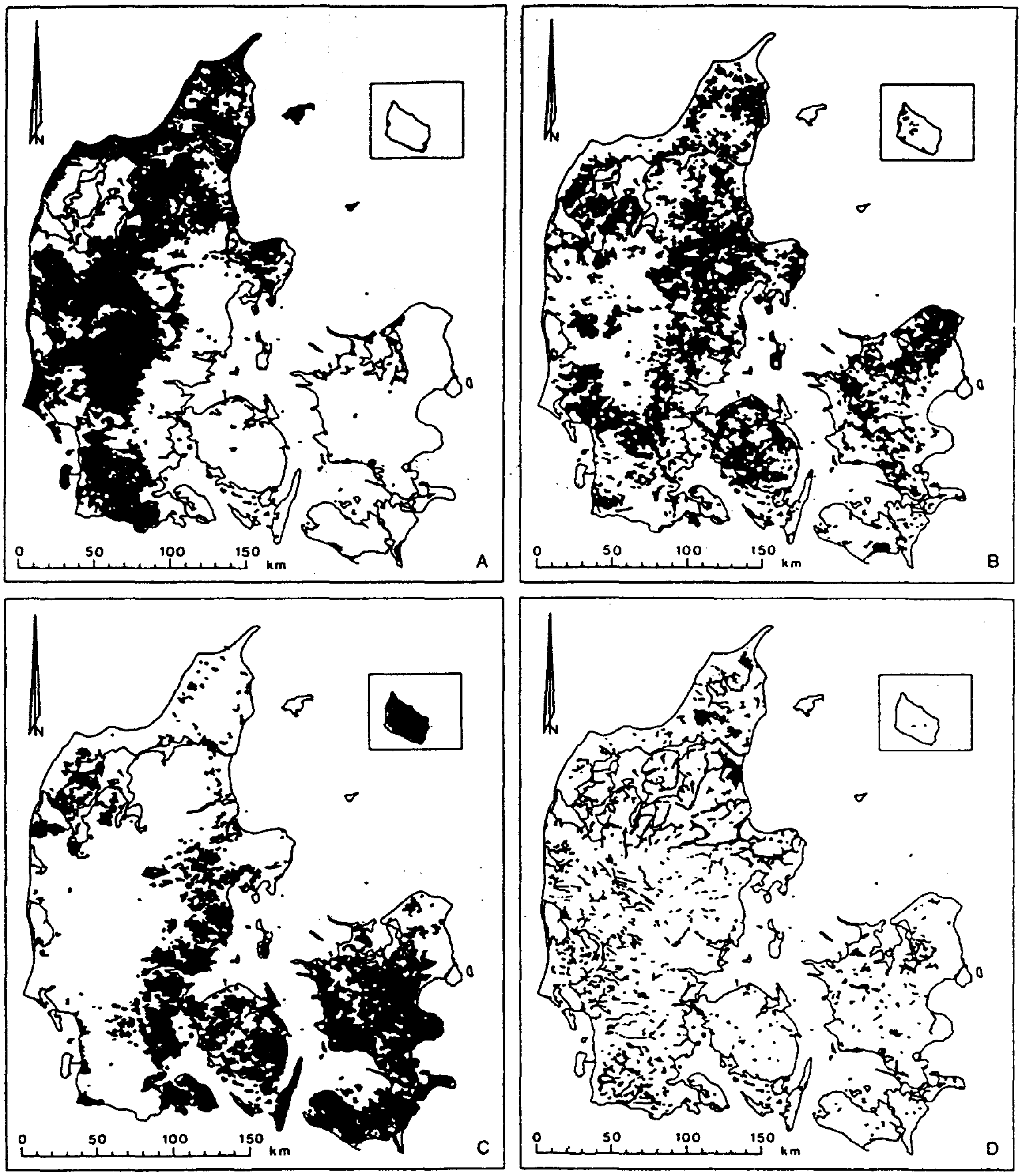

Figure 1 The location of different topsoils in Denmark
A = sandy topsoils (MCC 1,2)
B = loamy sandy topsoils (MCC 3)
C = loamy topsoils (MCC 4,5,6)
D = peaty topsoils (MCC 7)

In Jutland the water quality in some springs may be impaired by strong acidity and a high concentration of dissolved iron. This is due to the presence of iron sulphides in such amounts that acid sulphate soils develop when the land is drained. As iron sulphides are stable only under anaerobic conditions, acid sulphate soils will only be present in wetlands.

Mapping of potentially acid sulphate soils has been carried out in the years 1981-1984 (Madsen *et al.*, 1985a; Madsen and Jensen, 1988). Approximately 8000 soil profile descriptions have been made based on augering, and approximately 16,000 samples have been taken to be analyzed. In the laboratory the lime-free samples were freely exposed to the air and pH was measured after 2, 8 and 16 weeks. If pH dropped below 3.0 the samples were considered as acid sulphate samples. In the lime-containing samples the amount of pyrite and calcium carbonate was measured. Based on these results it was decided whether the samples were acid sulphate or not. Soil maps have then been elaborated dividing the wetlands into four classes based on the frequency of profiles containing acid sulphate samples.

PEDOLOGICAL INVESTIGATIONS

Several soil profile investigations have been carried out during the last decade. Among these, two large investigations will briefly be described. In relation to the establishment of the main gas pipeline system from the North Sea gasfield across Denmark in the years 1981-1984 (Fig. 2), pedological investigations along the lines were carried out (Madsen and Jensen, 1985). About 800 detailed profile descriptions and about 8000 soil profile classifications were made.

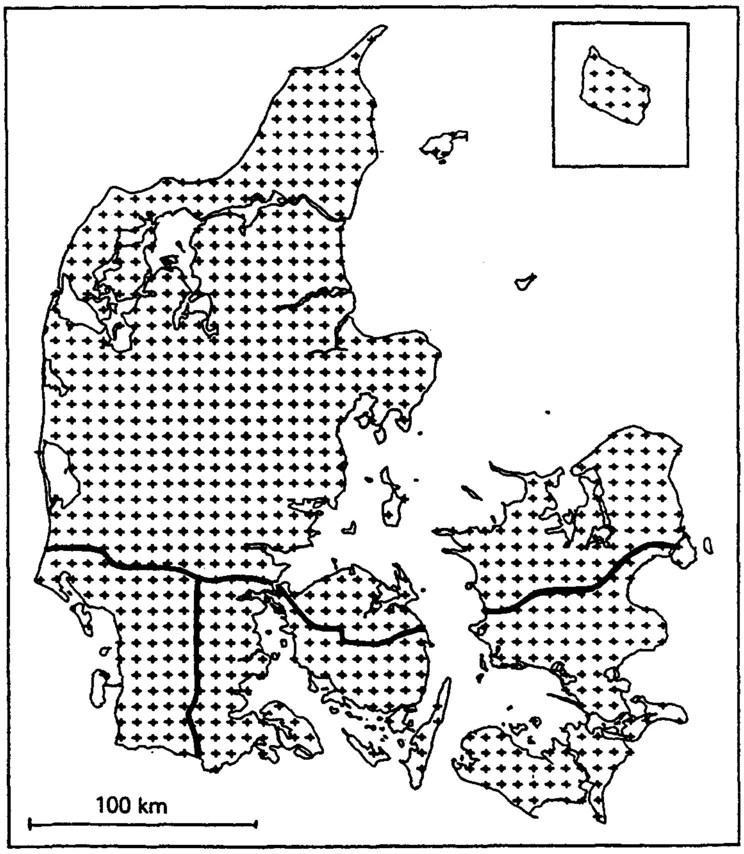

Figure 2 Locations for soil profile investigations (+ sampling sites in a 7-km grid; ▬▬ gas pipe line system)

In order to improve the use of nitrogen fertilizers in Danish farming, the Danish Agricultural Advisory Centre established a nation-wide 7-km grid, in which the inorganic nitrogen content would be determined periodically. The grid was established in 1986 and contains approximately 850 intersections (Fig. 2). In these, 50 x 50 m testplots were established in which the content of inorganic nitrogen was determined twice a year at four depths. Based on these data, the farmers are advised according to their use of N-fertilizer. In all the intersections pedological investigations have been carried out by ADK in cooperation with Geographical Institute University of Copenhagen during the years 1987-1989. Hereby a nationwide pedological data base has been established.

All the profiles were described in detail according to a system very similar to the FAO Guidelines for Soil Profile Description, and descriptions are stored in numerical form in the computer system at ADK. For each profile, samples were taken according to the horizon sequence, and texture, organic matter, pH and calcium carbonate were determined. From selected profiles, dithionite-citrate and pyrophosphate soluble iron and aluminium, CEC, exchangeable bases, total N and P, clay mineralogy, soil water retention and root densities were measured also. All analytical data and the location of the profiles are stored in the ADK-computer system, which makes it possible to combine the results from the profile investigations with the soil maps. Hereby, soil physical and chemical properties can be transferred to the mapping units on the map.

THE INTEGRATION AND USES OF THE DIFFERENT SOIL INFORMATION IN THE DATA BASE SYSTEM

The numerous investigations carried out during the last decade at ADK make it possible to construct new soil maps with far better information than is shown on the printed soil maps from the Danish soil classification. As all results are stored in the computer with reference to the UTM-coordinate system, the different investigations can be combined. Each of the eight mapping units on the soil maps can be subdivided into 9 types by combining the soil classes with the landscape map. These 72 units can be further subdivided according to slope classes, drainage classes, content of pyrite, and sandy or clayey subsoil. This gives, potentially, several hundred different mapping units.

From the approximately 2000 profiles studied in detail it will be possible to extrapolate analytical data to the mapping units. Thus, the soil maps can be transferred into other thematic maps such as irrigation maps, nitrate leaching maps, erosion risk maps or drainage class maps.

The soil data base system has been widely used for planning of rural land use at county and national level. First, the soil information was used for protection of valuable agricultural land around expanding urban settlements, but it was soon used in agricultural water planning (Madsen and Platou, 1983; Holst and Madsen, 1986 and 1988). Furthermore, it has been used for mapping wind- and water erosion (Madsen *et al.*, 1985b; Hasholt *et al.*, 1990), nitrate loss from farmland (Hansen *et al.*, 1984), areas giving rise to ochre pollution (Madsen *et al.*, 1985a; Madsen and Jensen, 1988), and marginal land (Madsen and Holst, 1987; Svendsen and Pedini, 1987).

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10 Estimation of Critical Phosphate Loads in Danish Sandy Soils

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ABSTRACT

Critical phosphate loads correspond to the amounts of phosphate which can be taken up (adsorbed) by soils at solution concentrations not harmful to the aquatic environment. Results obtained by investigating phosphate behaviour in Danish sandy soils (mainly Spodosols) suggest that critical phosphate loads can be considered to be proportional to the maximum phosphate adsorption capacities (Pmax) calculated from applying the Langmuir equation to measure(d) adsorption data or from contents of aluminium and iron oxides. The suggested proportions are 0.1 Pmax for Bh and Bhs horizons and 0.3 Pmax for Bs and C horizons above the ground water table.

INTRODUCTION

Leaching of dissolved phosphate from soils depends on the phosphate content and adsorption capacity of the soils. In Denmark, cultivated sandy soils, in particular, are susceptible to phosphate loss. Where leaching of phosphate results in concentrations of natural waters exceeding permissible (critical) levels, eutrophication may occur.

Considering these matters, the present paper attempts to provide guidelines for estimation of critical phosphate loads, i.e. the amounts of phosphate, which can be taken up (adsorbed) by soils at permissible (*in situ*) solution concentrations in the field.

PHOSPHATE CONTENTS/CONCENTRATIONS

Cultivated Danish sandy soils (mainly Spodosols or Spodosol-like soils) seem to contain 2 to 10 μM P g^{-1} as phosphate in the plough layer because of rather high indigenous phosphate contents in the parent materials (<1-4 μM P g^{-1}) and because of the application for many years of fertilizer phosphorous in amounts exceeding those removed by crops (Table 1). Consequently, the solution concentration of phosphate in the topsoils is high. In fact, high phosphate concentrations, in the range 2 to 24 μM (Olsen and Khasawneh, 1980) are needed, at least in the topsoils, to secure optimal plant growth. This is illustrated in Table 1 by calcium acetate-extractable phosphate (P_{CaAc_2}), which, although not equal to, is considered to reflect the solution concentration (phosphate mobility). It may be noticed that P_{CaAc_2} concentrations in the plough layers (Table 1) are within the range suggested by Olsen and Khasawneh (1980).

On the other hand, low phosphate concentrations, often in the range 0.2 to 2 μM, are normally found in unpolluted waters and natural subsoil drainage (Taylor and Kilmer 1980; Rebsdorf and Thyssen, 1986; Sharpley and Menzel, 1987). A critical limit for eutrophication of 1 μM has been suggested (Taylor and Kilmer, 1980), although the suitability of such limits has been questioned (Sharpley and Menzel, 1987), because the phosphate level leading to eutrophication can differ from one aquatic environment to another.

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Table 1 Phosphate characteristics of some cultivated Danish sandy soils

Soil, depth (cm)	[1]P_{CaAc_2} µM	[2]Pi µmol/g	[3]Pi/Pmax
SJ2, Orthic Haplohumod			
Ap (0-25)	21	8.71	
E (25-35)	13	1.29	
Bh (35-55)	<0.4	3.68	0.13
Bs (50-90)	<0.4	5.81	0.28
C2 (125-185)	0.8 (2.2)	3.87	0.52
SJ3(d), Typic Haplorthod			
Ap (0-28)	1.4	5.65	
Bh (28-35)	<0.4	2.23	0.11
Bhs (35-55)	<0.4	3.13	0.15
Bs1 (55-110)	<0.4	6.03	0.31
Bs2 (110-145)	<0.4	3.81	0.30
C (145-220)	<0.4(<0.4)	2.41	0.19
[4]SJ4(a), Typic Haplorthod			
Ap (0-30)	1.4	3.03	
Bh (30-40)	<0.4	2.23	0.09
Bhs (40-55)	<0.4	2.55	0.09
Bs1 (55-105)	<0.4	2.71	0.16
Bs2 (105-145)	<0.4	3.38	0.23
C (145-220)	<0.4(<0.4)	2.29	0.15
VJ4, Histic Humaquept			
Ap (0-25)	2.6	7.85	
Bw1 (25-32)	<0.4	2.90	0.09
Bw2 (32-50)	<0.4	0.87	0.05
C1 (50-100)	<0.4	0.68	0.14
C2 (100-150)	<0.4 (1.3)	1.32	0.16
VJ5, Humaqueptic Psammaquent			
Ap (0-20)	3.0	3.74	
C1 (20-36)	1.4	1.29	0.9
C2 (36-80)	<0.4	0.55	0.18
C3 (80-140)	<0.4(<0.4)	0.65	0.07

Soil, depth (cm)	[1]P_{CaAc_2} µM	[2]Pi µmol/g	[3]Pi/Pmax
MJ2, Fragihumod			
Ap (0-35)	13	4.26	
Bh (35-50)	0.8	2.58	0.20
Bs (50-90)	<0.4	1.39	0.14
C1 (90-105)	<0.4	3.39	0.21
C2 (105-120)	<0.4	5.0	0.41
C3 (120-)	<0.4 (0.7)	1.61	0.19
MJ3, Typic Haplumbrept			
Ap (0-28)	6.0	9.13	
Bhs (28-50)	<0.4	3.22	0.13
Bs (50-60)	<0.4	3.47	0.29
C1 (60-125)	0.6	3.90	0.35
C2 (125-225)	0.8 (1.3)	3.55	0.59
MJ4, Typic Haplohumod			
Ap (0-45)	18	6.81	
E (45-48)	<0.4	0.55	
Bh (48-53)	<0.4	2.00	0.04
Bs1 (53-85)	<0.4	1.42	0.05
Bs2 (85-115)	<0.4	2.13	0.09
C (115-170)	<0.4(<0.4)	0.29	0.08
MJ5, Typic Haplorthod			
Ap (0-25)	13	5.23	
E (25-27)	7.6	4.11	
Bh (27-28)	-	16.3	-
Bhs (28-40)	<0.4	2.45	0.06
Bsm (40-60)	-	2.16	-
C1 (60-100)	<0.4	0.48	0.03
C2 (100-)	<0.4 (0.8)	1.35	0.09
MJ10, Typic Haplorthod			
Ap (0-27)	7.6	10.1	
E (27-30)	0.6	1.32	
Bh (30-47)	2.6	21.5	1.0
Bhs (47-65)	1.8	8.71	0.58
Bs (65-90)	0.6	4.19	0.42
C (90-)	<0.4 (1.9)	1.48	0.24

[1] The phosphate concentrations in extracts obtained by shaking the soil for 7 days with 0.01M calcium acetate, pH 4.5, soil:solution 1:50. Values in brackets are phosphate concentrations in extracts obtained by shaking 10 g soil with 50 ml water for 1 day.

[2] Phosphate content determined by treating the soil with 6 *M* sulphuric acid for 10 min at 70° C followed by 1 hour at ambient temperature, soil:solution 1:10.

[3] The ratio between the phosphate content and the maximum phosphate adsorption capacity determined by applying the Langmuir adsorption equation to measured adsorption data as described by Borggaard *et al.* (1990).

[4] This soil has not received any phosphorus fertilizer since 1944.

Anyway, permissible phosphate concentrations are far below the present soil solution concentrations in plough layers. The concentration of phosphate leached from topsoils therefore must be reduced to permissible levels before entering the aquatic environment; otherwise eutrophication will occur. This reduction must take place in the subsoil. The capacity of subsoils to take up (adsorb) phosphate therefore must be measured. This adsorption capacity depends on the solution concentration with increased adsorption at increasing concentration. Since critical phosphate loads correspond to the amounts of phosphate adsorbed at permissible phosphate concentrations, such concentrations in subsoil solutions need to be known.

Ideally, the concentrations should not exceed those in unfertilized (natural) soils suggesting that concentrations $<\sim 2\ \mu M$ can be tolerated. This limit is well below the level of 3 to 6 μM found to promote algae growth in Danish streams (Iversen *et al.*, 1990). An upper limit of 2 μM should be considered a rough guideline value only, since different aquatic environments, as mentioned above, may respond differently to the same phosphate concentration.

MAXIMUM PHOSPHATE ADSORPTION CAPACITY

Apart from the solution concentration, the amount of phosphate to be adsorbed depends on phosphate loading (content) and the content and reactivity of phosphate adsorbents, *i.e.* aluminium and iron oxides in sandy soils (Parfitt, 1978; Borggaard, 1983a and 1983b; Van der Zee and Van Riemsdijk, 1986; Borggaard *et al.*, 1990). The maximum phosphate adsorption capacity (Pmax), corresponding to adsorption at high (infinite) phosphate concentrations, can be calculated by applying the Langmuir adsorption equation (Pads= Pmax - Pmax/(k·Peq)) to measured adsorption data (Borggaard, 1983a and b). Alternatively, it may be calculated from the content of poorly crystalline aluminium and iron oxides (Alo, Feo) and well crystallized iron oxides (Fed - Feo) according to the equation:

$$\text{Pcalc} = 0.221\ \text{Alo} + 0.115\ \text{Feo} + 0.05\ (\text{Fed} - \text{Feo}) + 0.3 \qquad \text{(Borggaard } et\ al.\text{, 1990).}$$

Measured and calculated maximum phosphate adsorption capacities are shown in Figure 1 for the B and C horizons in the soils investigated, except soil number MJ5 (insufficient data). The close relation between measured and calculated values emphasizes the suitability of the equation and the importance of the oxides as phosphate adsorbents. In fact, such a close relation seems surprising considering the strong variation of the Pi/Pmax ratio (Table 1), since a high ratio should indicate many of the adsorption sites on the adsorbents are occupied. This should decrease Pmax but not Pcalc, as previously anticipated (Borggaard, 1983b; Jørgensen and Borggaard, 1991). Rather, the results in Figure 1 suggest that adsorption is only limited affected by Pi. Possibly this phosphate occupies mainly interior adsorption sites, as shown by long-term adsorption studies (Willett *et al.*, 1988), which are unavailable from the short-term conditions used for Pmax determination. Another possibility could be the phosphate content of easily soluble phosphate minerals.

CRITICAL PHOSPHATE LOAD

Pmax (or Pcalc) can be considered a readily available and good measure of the capacity of individual soil layers to adsorb phosphate. Since the critical phosphate load should reflect the adsorption capacity, it is taken to be proportional to Pmax. However, Pmax corresponds to adsorption at phosphate concentrations much higher than what is considered the permissible upper limit in subsoils (2 μM). Therefore, as it stands, Pmax would overestimate the critical phosphate load, i.e. the critical phosphate load may be taken as a fraction (proportion) of Pmax.

Based on a comparative study of soils SJ3(d) and SJ4(a) (Table 1), proportions of 0.1 for Bh and Bhs horizons and 0.3 for Bs and C horizons have previously been suggested (Jørgensen and Borggaard, 1991). The only differences between these soils could be ascribed to a surplus application of ~1030 kg P ha^{-1} at SJ3(d). This has increased the phosphate content (Pi) to ~0.3

Pmax in the Bs horizons of that soil, whereas the Bh and Bhs horizons seem "saturated" under field conditions at ~0.1 Pmax. Very little increase has occurred in the C horizon. The difference between the capacities for Bh/Bhs (0.1 Pmax) and Bs/C horizons (0.3 Pmax) has been attributed to competition between phosphate and soil organic matter for adsorption sites (Jørgensen and Borggaard 1991). Although the in-field adsorption capacities of all horizons down to Bs2 in SJ3(d) seem exhausted, the solution concentrations are very low (<0.4 μM), i.e. much lower than the permissible upper limit. This indicates that the suggested proportions are conservative estimates from a pollution point of view.

The results from the other soils in Table 1 support these estimates. Thus, similar proportions for Bh and Bs horizons are seen for SJ2 and MJ3. In B and C horizons, where the phosphate contents exceeded these values, increased solution concentrations were found (SJ2(C), MJ2(Bh), MJ3(C), and MJ10(Bh, Bhs, Bs)). One the other hand, at lower phosphate loadings the solution concentrations were below the detection limit of 0.4 μM, e.g. in VJ4(B,C), VJ5(C), MJ2(C), MJ4(B, C), and MJ5(B, C). From these in-field capacities of individual subsoil horizons together with their bulk densities and thicknesses, critical phosphate loads per area unit, for instance hectare, can be calculated by summation. Only data for the subsoil horizons above the water table should be included in the summation, since phosphate adsorption capacities, for instance as a result of iron reduction, in water-saturated soil layers are considered to differ from those estimated above for well-aerated horizons.

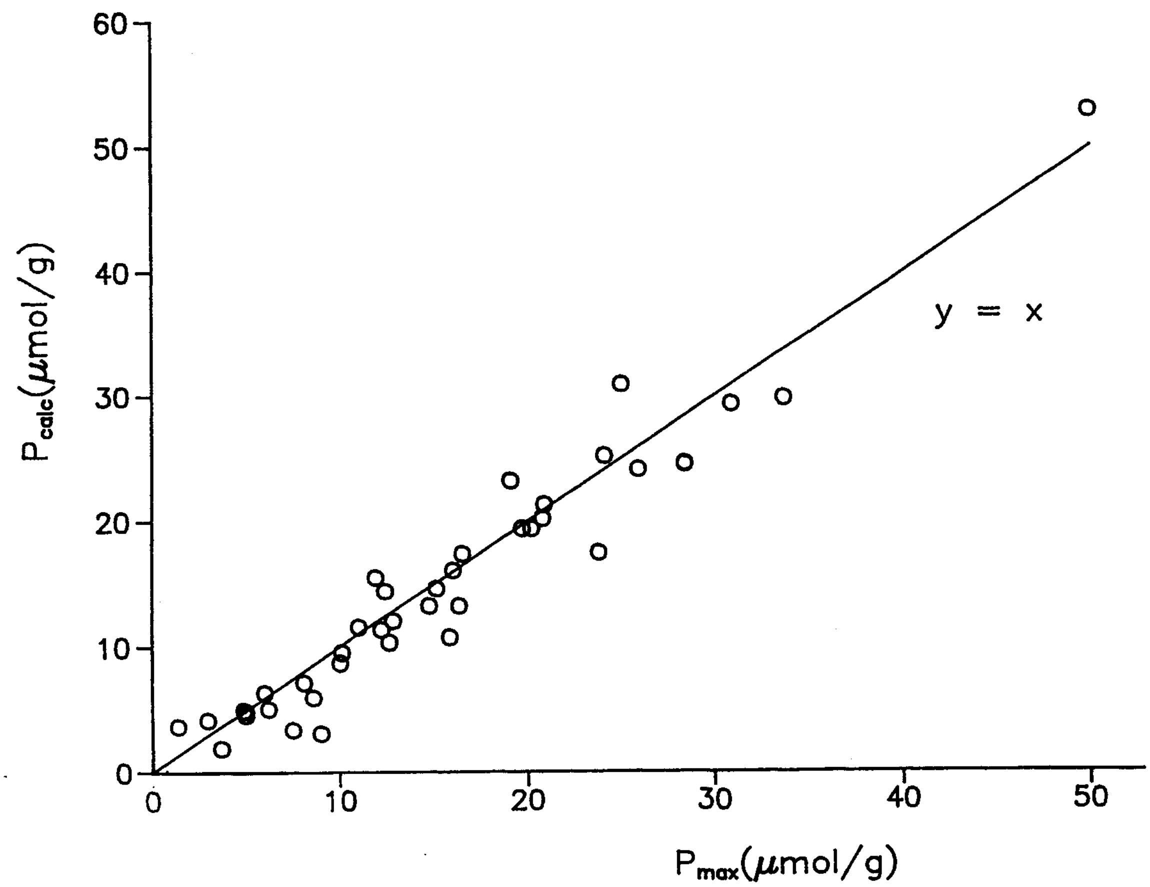

Figure 1 Calculated (Pcalc) and measured (Pmax) maximum phosphate adsorption capacities in B and C horizons in nine Danish sandy soils. Pmax was obtained by applying the Langmuir equation to measured adsorption data and Pcalc by the equation:Pcalc = 0.221Alo + 0.115Feo + 0.05(Fed - Feo) + 0.3 (Borggaard *et al.*, 1990)

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11 Soil Vulnerability Assessment and Chemical Soil Degradation in Eastern Germany

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ABSTRACT

Soil and terrain vulnerability are dependent on the following parameters: a) adsorption capacity of the A-horizon, b) water capacity and permeability, and c) dislocation of substances by surface run-off. Concerning the pollution of soils two types of contamination can be identified: a) direct substance input by deposition of industrial and communal wastes, and b) diffuse emissions of dust and/or specified groups of chemical compounds. For mapping it is necessary to define levels of soil and terrain vulnerability using the soil properties and the types of pollution.

INTRODUCTION

In the industrial countries of Europe soil contamination has increased considerably during the last two or three decades. When chemicals get into the soil, soil organisms and plants can be injured and the groundwater can be contaminated. As such, emissions of chemicals can cause changes in the quality and functions of soils. Therefore it is necessary to assess the vulnerability of soils to specified groups of chemical compounds and to control the level of pollution in order to limit the risks for human beings and the environment.

In assessing soil and terrain vulnerability two factors should be taken into consideration:
- The most important soil properties influencing the reaction of chemical substances (sorption, transformation, decomposition) and the translocation of these substances within and between the soils;
- The degree of substance input (loading) in that it will influence and change the characteristics of the soils.

This paper attempts to assess soil and terrain vulnerability using examples from Eastern Germany. Proposals for mapping the vulnerability of soils in Europe based on this experience will be presented.

VULNERABILITY ASSESSMENT USING SOIL PARAMETERS AND SOILS

Choice of parameters

Important soil properties influencing the sorption and decomposition of chemical contaminants are proposed by Blume and Brümmer (1987) and Litz and Blume (1989):
- clay content
- humus content
- pH-value
- content of soluble iron and total iron.

These are the "classic" parameters regulating chemical processes in soils. The cation exchange capacity can be used as a parameter to characterize the adsorptive capacity of soils. These

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parameters are used also to characterize the buffering and transformation properties, especially of A-horizons. The result is a subdivision of A-horizons according to those having a low and high adsorption capacity respectively.

The reaction and removal of chemical substances, however, depend on the filtering and transporting properties of the soil as an integrated whole. The above are determined by the water retention capacity (field capacity), the permeability (Kf-rate) and the groundwater level (Warstat, 1985). The result is a subdivision according to the water retention capacity of the soils. On this basis it is possible to assess the risk of groundwater deterioration.

Finally, in sloping areas the removal processes of substances by surface run-off are determined by the soil properties of infiltration/permeability, slope gradient and length. Hence the need for subdividing soils or mapping units according to the intensity of surface run-off.

Vulnerability assessment of soils and mapping units

In order to assess the vulnerability to chemical substances (Table 1), the soils and soil associations should be assessed and arranged by the following parameters (Table 2):
- Adsorption capacity of the A-horizon, for mapping units expressed by clay and humus content;
- Water capacity and leaching potential expressed by available water holding capacity and the depth of the groundwater table;
- Intensity of removal of chemical substances by surface run-off, as estimated from the slope gradient.

Table 1 Reaction and concentration of nutrient substances and contaminants in soils

Processes	Nutrient substances			Contaminants			
	N	P	K	heavy metals	pesti- cides	dioxins ...	soluble organic cont.
Immobilization in A-horizon	×	⊗	⊗	⊗	⊗	⊗	×
Leaching	⊗	.	×	.	×	.	⊗
Surface-translocation	.	×	.	×	.	(×)	.

⊗ dominant process
× subdominant process
. subordinate process

It is essential that simple yet reliable allocation to the parameters can be carried out. Blume *et al.* (1988) developed an algorithm to assess the adsorptive capacity of soils with regard to heavy metals and the migration to the groundwater. This procedure can be used to carry out assessments in 3 to 5 steps using actual or inferred data and to make a final (total) assessment. Eckelmann and Müller (1989) showed that this procedure can be computerized, permitting automated production of thematic maps showing the potential risk of soil pollution caused by heavy metals. The method can be used for large and medium scale soil maps but not for small scale maps because of the limited availability of data and general character of the map units at the latter scales. Instead a simplified method has to be found for the small scale mapping of soil and terrain vulnerability to specified chemical compounds in Europe.

Table 2 Assessment of soil and terrain vulnerability

Parameters		Grades of vulnerability		
		1 high	2 moderate	3 slight
Adsorptive capacity A-horizon	clay content (%)	< 8	8 - 18	> 18
	soil texture	sand	loamy sand/ sandy loam	loam, clay
	humus content (%)	< 1.5 (2.0)	1.5-3.0 (2.0-4.0)	> 3.0 (4.0)
water regime	moisture capacity (mm)	< 100	100 - 200	> 200
	groundwater level (m)	< 0.4	0.4 - 1.2	>1.2
surface run-off	slope angle (grade)	> 7	3 - 7	< 3

Proposal for soil vulnerability mapping in Europe

The adsorptive capacity, water capacity and intensity of surface run-off are each rated in 3 grades: (1) high/severe, (2) medium/moderate, and (3) low/slight. A proposal for this is shown in Table 2. The above parameters and grades can be used to determine the "overall" vulnerability class of mapping units. This approach has been applied to the Medium Scale Map of Agricultural Soils (Schmidt, 1975), the Soil Map of the German Democratic Republic (Haase and Schmidt, 1985), the Soil Map of the Federal German Republic (Roeschmann, 1986). In Table 3 it is shown how the procedure was applied to a section of the Soil Map of the World (FAO/Unesco, 1974-1981). Accordingly, it is possible to make the following statements:

1. The sandy soils of the German northern Lowlands can be divided into:
   - Typical Sandy Soils (Cambic Arenosols) with low adsorptive capacity and high permeability;
   - Loamy Sandy Soils and Sandy Soils with a loamy texture in the lower subsoil (Dystric Cambisols, Orthic Luvisols and Luvic Arenosols; unit= Bd67-2a,b) with low adsorptive capacity in the topsoil but moderate permeability. Additional subdivisions can be based on slope and surface run-off;
   - Gley Soils (Eutric and Dystric Gleysols; unit= Ge70-2a) with a shallow groundwater table and medium or high adsorptive capacity and low water retention capacity.

2. The soils of the loess regions can be differentiated into:
   - Chernozems (Haplic Chernozems and Luvic Phaeozems; unit= Ch23-2a) in flat positions with high adsorptive capacity and high water retention capacity;
   - Chernozems and eroded Chernozems (Calcic Chernozems and Calcaric Regosol) in hilly areas with high adsorptive capacity in the topsoil, medium water retention capacity and high surface run-off;
   - Para-Brown Earths (Orthic Luvisols; unit= Lo73-2ab) in hilly areas with high adsorptive capacity, high water retention capacity and high surface run-off;
   - Pseudogleys (Gleyic Luvisols; unit= Lg49-2ab) with medium adsorptive capacity in the topsoil, high water capacity and moderate surface run-off.

Table 3 Assessment of soil and terrain vulnerability for typical soil associations

FAO/Unesco-soil association	Soil map symbol	Steps of vulnerability					Evaluation of soil and terrain vulnerability (Sum)
		clay content	humus content	water capacity	groundwater level	slope inclination	
Eutric Fluvisols and Gleysols (Auen-Boden-gesellschaften)	Je87-2/3a	2	2	3	2	3	12
Eutric Gleysols and Dystric Gleysols (Sand-Gley-Bg)	Ge70-2/3a	1	2	1	2	3	9
Rendzinas and Eutric Cambisols (Berglehm/Ton-Rendzina-Braunerde-Bg.)	E22-2/3b	3	3	2	3	2	13
Haplic Chernozems and Luvic Chernozems. (Löß-Schwarzerde-Bg.)	Ch23-2a	3	3	3	3	3	15
Dystric Cambisols, partly Orthic Podzols. (Bergsand-lehm-Braunpodsol-Bg.)	Bd66-1/2bc	2	3	2	3	2	11
Dystric Cambisols, partly Gleyic Camb., Luvisols. (Tieflehm-Braunerde/-Fahlerde-Bg.)	Bd67-2b	1	2	2	3	3	11
Orthic Luvisols and Gleyic Luvisols (Löß-/Lehm-Parabraunerde/Pseudogley-Bg.)	Lo73-2ab	3	2	3	3	2	13
Gleyic Luvisols and Gleysols (Tieflehm-/Lehm-Pseudogley-Bg.)	Lg49-1/2ab	2	2	3	2	3	12
Eutric Histosols and Dystric Histosols (Moor-Bg.)	Oe13-a	(1)	3	3	1	3	11
Classes of evaluation 1 = high ≤ 9 = highly vulnerable 2 = moderate 10 - 12 = moderately vulnerable 3 = slight ≥ 13 = slightly vulnerable							

SOIL DETERIORATION CAUSED BY CHEMICAL CONTAMINANTS

The assessment of the potential soil and terrain vulnerability in relation to soil properties should be complemented with information about the soil deterioration by contaminating substances. Only by overlaying the above, the endangering sources and regional centres of chemical degradation can be determined.

With regard to the contamination of soils, two types of substance input can be differentiated:
- Direct or "localized" inputs of chemical substances into soils by deposition of industrial and communal wastes, waste-water, sewage sludge and mine-dumps;
- Diffuse emissions of dust and/or specified groups of chemical compounds such as emissions of SO_2 and NO_x, and pollution by heavy metals.

The "localized" inputs result in an actual contamination of the soils in limited areas, while the diffuse emissions influence soil quality over larger areas. By analyzing the map of forest damage in Eastern Germany it was possible to determine the following 4 types of emission-deposition (Hofmann and Heinsdorf, 1990):

- Sulphur-calcium fly ash is characteristic for the lignite-mining areas. The alkaline component of this fly ash buffers the acidifying effect of the SO_2-emissions. In the humus layers and topsoils increased Ca- and Fe-contents are commonly observed.
- Sulphur emissions/depositions are important in the mountainous regions, especially in the Erzgebirge, resulting in severe acidification of forest soils. On arable land, however, the acidifying effects of the SO_2 are counteracted by liming.
- In the lowlands, inputs of nitrogen have been augmented as a result of "over-intensification" of agriculture as well as by industrial pollution. Eutrophication of forest habitats has occurred, including modifications to the composition of the humus.
- Loading with heavy metals is characteristic for metallurgic centres, large industrial centres, and areas where waste-water is disposed.

The loading with chemical substances should be considered in the mapping exercise. This will permit an assessment of the liability that the soils will be degraded by a particular group of chemical compounds in a particular region. This aspect can also be shown on small-scale maps.

CONCLUSIONS

The planned mapping of soil and terrain vulnerability in Europe is considered essential in that it will emphasize the urgent need for soil protection to the public and policy makers. In its aims, the "vulnerability mapping exercise" complements very effectively the "World map of the status of human-induced soil degradation" (GLASOD, 1990). In spite of the fact that the vulnerability map will be compiled at a scale of 1:5 M, showing only general trends, the map can have a great significance both in the present and in the future. Often soil protection is mainly regarded as the reclamation of contaminated areas. The vulnerability map can show clearly that soil protection is a regional, cross-border task and that it has to be addressed particularly in and around large urban and industrial centres.

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12 *Soil Vulnerability Mapping in Hungary*

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ABSTRACT

In Hungary, large amounts of data have been accumulated during long-term observations of the environmental factors (meteorological, hydrological and geological conditions, and vegetation). Thematic soil maps were prepared for applications at the international (1:1 M - 1:5 M), national (1:500,000), regional (1:100,000), farm (1:25,000) and field (1:10,000) level. All available materials were stored into the computerized Hungarian Soil Information System (HunSIS = TIR).

"Soil vulnerability maps" were prepared for four purposes:

1. Erosion risk assessment.
2. Characterization of soils according to their susceptibility to physical degradation, such as structure breakdown and compaction.
3. Prediction of secondary salinization/alkalization processes from the groundwater.
4. Characterization of soils according to their susceptibility to acidification.

The status of soil pollution, the vulnerability of soils to various chemical compounds, and critical loads for soils, waters and other ecosystems are being studied in recently initiated projects.

DATA ON THE ENVIRONMENTAL FACTORS

Traditionally, large amounts of environmental data have been collected in Hungary. In part, these have been used to compile thematic maps at various scales and summary maps for different national atlases. A brief review follows:

1. Meteorological data have been collected since 1850 with respect to temperature, precipitation, wind direction and velocity, solar radiation, air humidity, and evapo(transpi)ration. Also the chemical composition of the wet and dry deposition is being monitored.
2. The hydrological data mainly pertain to:
   a) surface waters, with special reference to the quantity and quality of rivers, canals, lakes, reservoirs, etc.;
   b) subsurface waters or groundwaters: This monitoring programme was started in 1935 and now encompasses 600 to 1500 groundwater testing wells and about 50 piezometer installations. The following maps were compiled on the basis of these measurements:
   - A map of the average depth of the water table at a scale of 1:200,000;
   - A map of the groundwater quality (ionic composition) at a scale of 1:100,000;
   - A 1:1 M map of the actual depth of the water table. This map is updated monthly by the Water Resource Research Centre (VITUKI).
3. Geological surveys were carried out during the last 150 years resulting in publication of a series of geological maps at a scale of 1:200,000, as well as a number of thematic maps on smaller scales.
4. Geomorphological data for Hungary were used to compile a 1:200,000 geomorphological map, and to map relief characteristics such as gradient, length, complexity and exposure of slopes (contour maps, and digital relief models).
5. Maps of the actual and potential vegetation are being prepared and should be published in the near future.

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SOIL MAPS

Soil science, and soil survey/soil analysis practices, have contributed considerably to the development, planning and organization of agricultural production and environmental protection in Hungary. This is mainly a result of the fact that:

- the country is relatively small (93,000 km^2);
- the physical environment (meteorology, geology, hydrology, relief, etc.) is varied, resulting in a wide range of soils with high spatial and temporal variability;
- there is a wide range of land use related problems in Hungary (e.g. highly mechanized, large-scale farming which includes use of agro-chemicals; intensive animal husbandry; occurrence of diverse cropping patterns in the respective ecological zones; amelioration of various soils with limited fertility; prevention of various soil degradation processes; agricultural water management; rural and urban development);
- agriculture is a mainstay of the national economy;
- numerous natural resources surveys (e.g. meteorology, hydrology, geology and soils) have been prepared for the country.

The main stages of soil mapping in Hungary were summarized and evaluated by Várallyay (1989c). The following four levels of "decision-making" and, consequently soil mapping, can be distinguished:

- national level (1:500,000 scale)
- regional or watershed level (1:100,000 scale)
- farm level (1:10,000 to 1:25,000 scale)
- field or plot level (1:5000 to 1:10,000 scale)

The thematic soil maps available for Hungary are summarized in Table 1. Additional details are given in a paper on the "state-of-art" of soil mapping in Hungary (Várallyay, 1989c). In addition to various scientific and practical soil publications, some maps were published in the National Atlas of Hungary (1989).

Additionally, a number of small-scale maps have been prepared in Hungary within the framework of several international programmes:

- The 1:5 M scale soil map of Hungary for the FAO/Unesco World Soil Map Programme;
- The 1:1 M scale soil map of Hungary for the FAO European Soil Map Programme (National Atlas of Hungary, 1989);
- The 1:5 M and 1:500,000 scale maps of salt-affected soils in Hungary for the International Society of Soil Science's "World Map of Salt Affected Soils" Programme (Szabolcs, 1974);
- The 1:5 M scale map of Hungary for the "Global Assessment of Soil Degradation" Programme (GLASOD);
- The 1:5 M scale map on the "critical loads" for soils, waters and other ecosystems.

All the above-listed soil information was summarized, or at least taken into consideration, in the computerized geographical Soil Information System of Hungary (HunSIS = TIR) (Kummert *et al.*, 1989). The system contains:

- point information, including measured and derived characteristics of soil profiles specified per horizon;
- territorial information based on 1:25,000 scale digitized thematic soil maps;
- equations, relationships and models to describe relationships between the environmental factors, soil conditions and plant growth.

Possible outputs of HunSIS include:

- Data in digital or tabular form which can be obtained through simple queries addressed to the data base;
- Interpretative analyses in which the data are arranged into specific groups according to the questions being asked;
- Compilation of thematic soil maps at various scales.

Table 1 Thematic soil maps in Hungary

No	Map	Scale	Date of preparation	Prepared for	Content	Author(s)	References
1	Practical soil maps	1:25,000	1960-1975	whole country per topographical map sheets	m, tm, fd, ld, e	Kreybig and coll.	Kreybig, 1937
2	Large-scale genetic soil maps	1:10,000	1960-1975	60% of the agricultural land of Hungary, per farming units	m, tm, fd, ld, e	Coll.	Szabolcs, 1966
3	Soil conditions and the possibilities of irrigation	1:25,000	1960-1970	present and potential irrigated regions	6 thematic maps fd, ld	Coll.	Szabolcs, Darab, Várallyay, 1969
4	Large-scale maps for amelioration projects	1:5,000-1:10,000	1960-	amelioration projects (occasionally)	m, e	Coll.	
5	Soil factors determining the agro-ecological potential	1:100,000	1978-1980	whole country per topographical sheets	m (with a 8-digit code), c	Várallyay, G Szücs, L. Murányi, A. Rajkai, I. Zilahy, P.	Várallyay *et al.*, 1979, 1980a, 1985
6	Agro-topographical map	1:100,000	1987-1988	whole country per topographical sheets	m (with a 10-digit code), c	Várallyay, G Molnár, S. Szücs, L.	Várallyay and Molnár, 1989
7	Hydrophysical properties of soils	1:100,000	1978-1980	whole country per topographical sheets	m, c	Várallyay, G Szücs, L. Rajkai, I. Zilahy, P.	Várallyay *et al.*, 1980b
8	Limiting factors of soil fertility	1:500,000	1976	whole country	m	Szabolcs, I. Várallyay, Gy.	Szabolcs and Várallyay, 1978
9	Main types of moisture regimes	1:500,000	1983	whole country	m, c	Várallyay, Gy. Zilahy, P. Murányi, A.	Várallyay, 1989a
10	Main types of substance regime	1:500,000	1983	whole country	m, c	Várallyay, Gy. Szücs, L. Molnár, E.	Várallyay, 1989b
11	Soil erosion	1:500,000	1960-1964	whole country	m, tm, e	Stefanovits, P. Duck, T.	Stefanovits, 1964
12	Salt affected soils	1:500,000	1970-1974	whole country	m, e	Szabolcs, I. Várallyay, Gy. Mélyvölgyi, J.	Szabolcs, 1974
13	Susceptibility of soils to acidification	1:100,000 1:500,000	1985-1988	whole country	m, c	Várallyay, Gy. Rédly, M. Murányi, A.	Várallyay *et al.*, 1989
14	Susceptibility of soils to physical degradation	1:500,000	1985-1988	whole country	m, c	Várallyay, Gy. Leszták, M	Várallyay, Leszták, 1989

Key: m: soil map; tm: thematic map; fd: field description; ld: laboratory data; e: explanatory booklet; c: computer storage

MAPS OF SOIL VULNERABILITY

In Hungary, four types of vulnerability maps have been elaborated.

1) On the basis of 1:75,000 scale soil erosion maps, prepared between 1945 and 1955 for the hilly regions of Hungary, Stefanovits (1964) compiled the integrated 1:500,000 scale map of soil erosion in Hungary. The map shows non-, slightly, moderately and strongly eroded lands, as well as the location of sedimentation, wind erosion and forest areas. As the territorial conclusion of a comprehensive analysis of erosion processes, which takes into consideration the present status of soil erosion and the determining and influencing factors, such as climate, relief, soils, land use, cropping pattern, and agrotechnics, Stefanovits (1964) prepared a map on the "soil erosion trends" in Hungary. In 1974, Maté initiated a programme for erosion risk assessment. Later, this was extended by Dezsény and Marosi for large-scale (1:10,000-1:25,000) mapping of erosion hazard in the catchment area of Lake Balaton.

2) Várallyay and Leszták (1989) elaborated a classification to assess the susceptibility of Hungarian soils to physical degradation, such as structure breakdown and compaction. The main soil characteristics which are considered in this scheme are: type, subtype and local variant of the soil, parent material, texture, hydrophysical properties, carbonate content, salinity/alkalinity status, organic matter content, and depth of the soil. Based on detailed territorial information on the above-mentioned soil characteristics, Hungarian soils were classified into eight physical degradation (susceptibility) classes.

   For medium (1:100,000) and large-scale (1:25,000 to 1:10,000) mapping a more elaborate system, including more categories and subcategories with precise numerical limit values, will be developed.

3) In addition to the extensive salt affected territories on the Hungarian Plain, covering more than 20 per cent of the region which is the lowest part of the hydro-geologically closed Carpathian Basin, there are large potential salt affected areas. In these areas, soils are prone to secondary salinization/alkalization. Water from the deeper saline soil horizons and/or the shallow saline groundwater can be drawn upwards by "evaporation". The reclamation of saline/alkali soils is expensive as it requires complex amelioration techniques; prevention of salinization/alkalization on the Hungarian Plain therefore has special significance. Szabolcs *et al.* (1969) elaborated a comprehensive system permitting the prediction and prevention of secondary salinization/alkalization processes. Várallyay (1974), and latter Várallyay and Rajkai (1989), developed a model to describe the movement of water and solutes from the groundwater to the overlying soil horizons in case of stratified soil profiles with a fluctuating ground water table. On the basis of detailed soil surveys and laboratory analyses, a series of 1:25,000 scale thematic maps were prepared indicating the most important soil and groundwater characteristics. The above model was used to calculate and map the "critical depth" of the groundwater table below which salt accumulation from the groundwater should not occur. Subsequently, guidelines were elaborated to prevent secondary salinization/alkalization of the irrigated fields of the Hungarian Plain. The guidelines were used in the planning, implementation and exploitation of the Tisza-II (Kisköre) Irrigation Scheme.

4) Soil acidification, resulting from natural factors and anthropogenic effects such as acid deposition and incorrect fertilization, is a significant soil degradation process in Hungary. Soil acidification was defined by Várallyay *et al.* (1989) as a decrease in the acid neutralizing (buffering) capacity and resulting pH decrease.

   Soil acidity and soil acidification depend on the quantity, concentration and chemical composition of substances getting into the soil from various sources, as well as on the buffering capacity of soils which is determined especially by the original pH, texture, content and type of the clay minerals, content and quality of organic matter and humus compounds, and cation exchange capacity of the soil. The relationships between buffering capacity and various soil properties have been studied in detail and analyzed by stepwise-regression.

On the basis of "titration curves" determined for a representative set of soil samples, Hungarian soils were classified into six groups according to their susceptibility to acidification (Table 2):

1. Strongly acidic soils; their further acidification is restricted (13 % of the total area of Hungary).
2. Highly susceptible soils with low buffering capacity; non-calcareous, slightly acidic soils with light texture, low clay and organic matter contents (14 %).
3. Susceptible soils with medium buffering capacity, non-calcareous, slightly acidic soils with medium texture and organic matter content (5 %).
4. Moderately susceptible soils with high buffering capacity, non-calcareous, slightly acidic soils with heavy texture, high clay and/or organic matter contents (23 %).
5. Slightly susceptible, salt-affected soils non-calcareous from the surface (4 %).
6. Non-susceptible soils which are calcareous from the surface (41 %). There is no obvious change in their reaction (pH) until the complete neutralization (dissolution, mobilization) of their carbonate content.

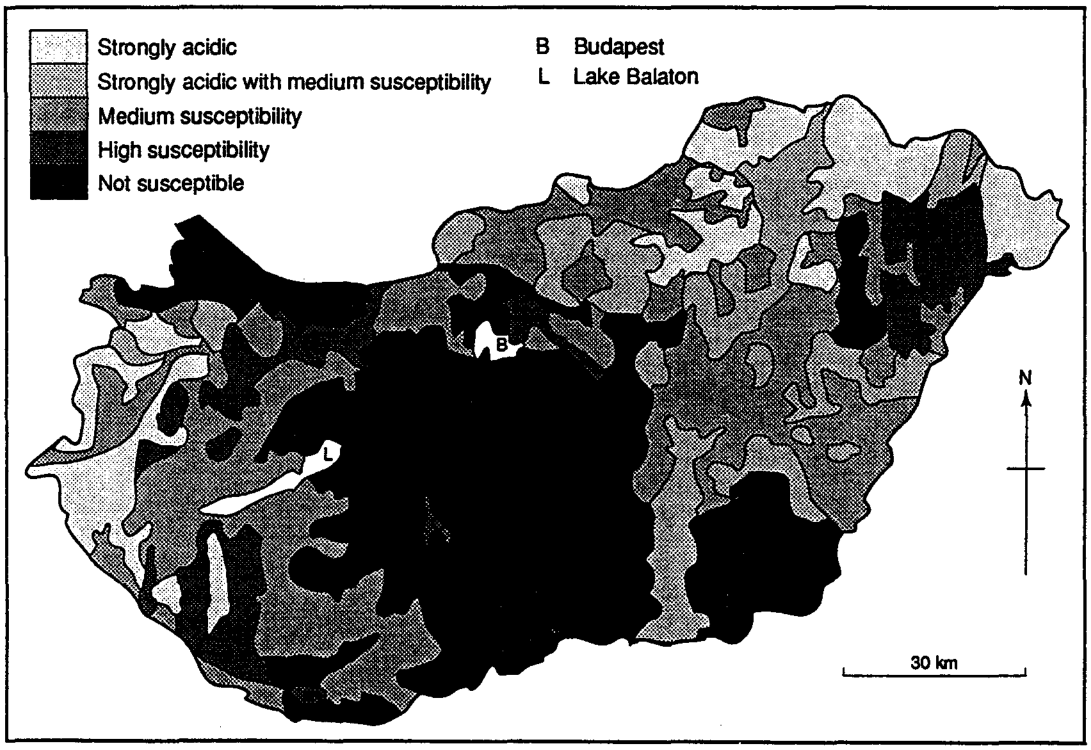

Figure 1 Map of the susceptibility of Hungarian soils to acidification (simplified after original supplied by the author)

The criteria for defining these classes are summarized in Table 2. The classes of "susceptibility to acidification" were mapped at a scale of 1:500,000 (Fig. 1) as well as 1:100,000, these maps in turn were digitized and stored in the computer.

The maps and accompanying attribute data can be used for the national and regional-level planning for the amelioration of acid soils, as well as for the prevention of soil acidification.

MAPS OF POLLUTION SOURCES

The new National Atlas of Hungary contains maps on the type of air-, water- and soil pollution sources; the distribution and nature of various chemical loads in the country and within the most polluted areas (cities, industrial centres and other "hot spots"). Several mapping activities are going on within the framework of two international projects:

- "Mapping of critical loads for soils, waters and various ecosystems and areas where they are exceeded" (RIVM, Bilthoven, the Netherlands); and
- "Long-term environmental risks for soils, sediments and groundwaters in the Danube Catchment Area" (RISSAC, Budapest, Hungary).

Table 2 Classification of Hungarian soils according to their susceptibility to acidification

Categories	Soil characteristics					Acreage in % of the total area of Hungary
	parent material	pH and carbonate status	texture	organic matter (t ha^{-1})	depth of solum (cm)	
1. Strongly acidic soils	-	strongly acidic	-	-	-	13
2. Highly susceptible soils due to their low buffering-capacity	-	slightly acidic	sand	-	-	14
			coarse fragments			
	anything except loess	slightly acidic	sandy loam	< 200	< 70	
3. Susceptible soils due to their high buffering-capacity	loess	slightly acidic	sandy loam	< 200	< 70	5
			sandy loam	> 200	> 70	
			loam	< 200	< 70	
4. Moderately susceptible soils due to their high buffering-capacity	-	slightly acidic	loam	> 200	> 70	23
			clay loam			
			clay			
			organic			
5. Slightly susceptible soils	-	salt affected soils non calcareous from the surface	-	-	-	4
6. Non susceptible soils	-	calcareous from the surface	-	-	-	41

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13 An Italian Approach to the Determination of Areas Vulnerable to Pollution

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ABSTRACT

A first approach to the determination of areas of varying degrees of vulnerability with respect to the kinds and amounts of herbicides, pesticides and fertilizers employed in agriculture is described. In Mediterranean countries, including Italy, the soil water balance is characterized by a long dry period during the hot season and water only leaches through soils sometimes in late winter and more often in early spring, so that the environmental pollution is partially independent of the physico-chemical characteristics of the pollutants. A study directed towards the delineation of areas of different vulnerability to pollution is described.

INTRODUCTION

The determination of areas of varying degrees of vulnerability with respect to the kinds and amounts of herbicides, pesticides and fertilizers employed in agriculture requires the evaluation of a complex series of environmental and anthropic characteristics that can favour or inhibit the mobilization of different organic and inorganic substances from the surface of the soil (i) towards the atmosphere by evaporation, or more frequently (ii) deeper into the soil by infiltration.

It follows that a study directed towards the delineation of areas of different risk must take into account essential territorial and environmental aspects. First of all, it must be recognized that models used and widely tested in other countries may well be unsuitable for use in Mediterranean environments and especially in Italy, where the distribution of population and human activities as well as the lack of pedological homogeneity and the varied climatic conditions such as temperature and precipitation, render the application of such models difficult or useless. On the other hand, for some data essential for determining the vulnerable areas, it is preferable to avoid complex models, such as Penman or Tombesi-Lauciani, as these require more complex operations than those proposed here.

This study represents a working tool for both the initial elaboration of our present knowledge and a preliminary classification of the vulnerability of soils to pollution. The ability to refine the procedures described, and the fact that the techniques reported here serve only in part to obtain an in-depth understanding of the mechanisms involved as well as to put into practice the initial measures required, should constitute a stimulus for action and emphasize the urgency of determining the environmentally vulnerable areas on a national scale.

OVERALL MODEL

Figure 1 shows the simplified overall model for the subdivision of the land into areas with different degrees of environmental vulnerability. The parts of the procedure which can be computerized are described in the following sections.

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Evapotranspiration and water balance

Part of the precipitation that reaches the soil evaporates from the soil surface and part is used by growing plants. The sum of these two quantities constitutes the effective evapotranspiration (EET) of the crop. A knowledge of EET for each crop during its growth cycle in a particular environment for a number of years allows the use of irrigation water to be programmed, while programming of the specific times of irrigation requires a knowledge of the data for the year in progress. Since direct measurement of EET is particularly laborious and costly (use of lysimeters), recourse is made to estimating a unit of measure that can be correlated with EET but which is easier to determine: the potential evapotranspiration (ETP). An internationally recognized method for calculating the evapotranspiration and water balance is the procedure of Thornthwaite and Mather (1957) and Blaney and Criddle (1962). They introduced the crop coefficient (Kc), determined experimentally for each plant species, which permits one to pass from potential evapotranspiration to the maximum evapotranspiration. A basic computer programme "BIL-IDR II" to manage the calculations has been developed for use on a personal computer (Ciavatta and Vianello, 1987).

Clearly, the use of such models makes it possible to determine the seasonal periods during which a surplus of water in the soil facilitates in-depth drainage, as well as those periods during which the soil suffers a lack of water, representing conditions when phenomena of evapotranspiration will be much more accentuated.

Soil use

The utilization of the earth's surface by man and its natural state (both in areas where a cover of vegetation exists and those constituted by outcrops of rock) represent basic cognitive data for evaluating the degree of protection required against toxic and nontoxic substances that can penetrate deeply into the soil. Indeed, it is evident that while a soil entirely covered with vegetation is partially protected from the processes of surface run-off and deep drainage of precipitation water, a soil without vegetation or still worse subjected to periodic deep ploughing is affected much more by the processes of leaching. The fertile horizons are depleted of essential plant nutrients and easily soluble chemicals are transported deeper into the soil. This means that an understanding of the way in which the soil is used constitutes a preliminary and essential information-base.

A separate discussion is necessary regarding the total destruction of the soil resources by the presence of the works of man (buildings, roads, infrastructure, etc.). The practical result is a profound alteration of the equilibria between atmosphere, soil and subsoil because the precipitation that falls on impermeable surfaces is directly collected in the secondary receivers and then in the primary receivers (large rivers, canals, ponds, lakes, ocean) without first passing through the soil.

The land use classification suggested here refers to a general model that can be extended to a national scale and which does not further complicate the already complex process of monitoring and elaboration of the data discussed here. In Italy, using the most recent aerial photographs of the Istituto Geografico Militare of Florence (IGM) and those which provide images with a scale of 1:33,000, or the images obtained by remote sensing available from the Società Telespazio S.p.A., or the European Space Agency (ESA), it is possible via photo-interpretation and photogrammetry to map the actual use of the soil. In addition, Cartographic Services have been operating for some time in many regions of Italy and have already produced land-use maps on different scales, some of which are already being up-dated. On the basis of these maps and information-bases it is possible to display both limited and extensive areas at the desired scale (preferably from 1:200,000 to 1:50,000).

Physico-chemical characteristics of soils

It is known that the capacity of the soil to adsorb organic and inorganic chemicals and to hold them or release them into the soil solution is a function of the soil composition and the physical and chemical characteristics that determine the soil structure, the soil particle size distribution, pH, organic matter content, and mineralogical composition of the clay fraction. The physico-chemical properties of the soil can be determined directly or inferred from soil maps. If such information is not available, it will be necessary to carry out soil tests, either according to a pre-established network or following the limits dictated by the particular physical characteristics of the area in question. Unlike most of the other European and non-European countries, Italy does not yet have a national soil organization (a proposal for a National Pedological Observatory is presently being studied by the Ministry of Agriculture and Forestry), nor does Italy have available homogeneous pedological cartographic documentation drawn on a useful scale for the entire country. An initial systematic collection of the pedological maps and derived products is presently available thanks to an initiative begun in 1986 by the Italian Cartographic Association (A.I.C.) in collaboration with the Centre for Experimental Studies and Analysis of Soil and the Department of Geography of the University of Bologna. This has the purpose of providing an as complete and up-to-date as possible collection of environmental maps (Vianello and Zecchi, 1988). The information collected provides a thorough picture of our present knowledge of Italian soils, a picture with a definite lack of homogeneity in the choice of scale and the classification systems adopted.

In order to use the model of environmental monitoring to classify the country into areas of different degrees of vulnerability to pollution, it is essential to "weigh" these parameters to attribute a degree of vulnerability to the soil for the purpose of interacting with other environmental or anthropic characteristics.

Hydrological situation

The areas that are at risk to water loss, including seasonal losses, and which are also only potentially susceptible to agricultural pollution must be evaluated from the hydrogeological point of view. The study and knowledge of the geological situation of the territory is important to determine all the zones at risk, especially those that place the soil in direct contact with the subsoil. Since the natural recharging of the groundwater occurs through infiltration of precipitation water, dispersion from waterways, and infiltration of irrigation water (if not appropriately used), it is essential that conditions that favour contact between these polluted waters and the groundwater are avoided. Areas that have water tables close to the surface during the entire year or in some periods of the year, and where this water can reach the deep aquifers, must be considered at risk.

The models used in the following sections take into account the various experiments that have been carried out, but the procedures have been simplified to provide essential information rather than introduce complex formulas or equations which require the use of data which is either unavailable or not very reliable. Taking into consideration the long time such studies would require in new survey areas, it is proposed to overcome these deficiencies, in the initial phase of the study on the vulnerability of the aquifers, by compiling isophreatic and piezometric maps. These will (i) indicate the levels of the water tables and the annual fluctuations, (ii) show the distribution of the wells in the monitoring network, and (iii) indicate possible limits in the water supply.

DETERMINATION OF VULNERABLE AREAS

Superimposition of the various parameters analyzed in the preceding sections leads to a final document that can be defined as a "monthly map of the vulnerable areas due to infiltration" (Fig. 2). Areas of different degrees of vulnerability may be assessed in one of five classes (excessive, considerable, medium, low, and very low vulnerability), each of which will be determined by summing, for each site involved, the weighted values determined from the thematic maps used as overlays in the construction of the final document. For instance, the matrix showing the relationship between some important soil parameters, and the matrix for the definition of the degree of infiltration are shown in Tables 1 and 2, respectively.

Table 1 Matrix showing the relationships between different soil parameters: texture, pH, organic matter content and clay mineralogy (relative values, "weights" on a scale from 1 to 5)

Particle size distribution	Clay minerals	Organic matter											
		< 0.8%			0.8%-1.8%			1.8%-2.6%			> 2.6%		
	pH	< 5	5-8	> 8	< 5	5-8	> 8	< 5	5-8	>8	< 5	5-8	> 8
Sa L Sa	kaolinite	5	5	5	5	5	5	5	4	5	4	3	4
	others	5	5	5	5	4	5	4	3	4	3	2	3
	smectite	5	4	5	4	3	4	3	2	3	2	1	2
Sa L C	kaolinite	5	5	5	5	4	5	4	3	4	3	2	3
	others	5	4	5	4	3	4	3	2	3	2	1	2
	smectite	4	3	4	3	2	3	2	1	2	1	1	1
Si C C L Sa C C Sa L	kaolinite	5	4	5	4	3	4	3	2	3	2	1	2
	others	4	3	4	3	2	3	2	1	2	1	1	1
	smectite	3	2	3	2	1	2	1	1	1	1	1	1
C Si L Si Sa L	kaolinite	4	3	4	3	2	3	2	1	2	1	1	1
	others	3	2	3	2	1	2	1	1	1	1	1	1
	smectite	2	1	2	1	1	1	1	1	1	1	1	1
Si L	kaolinite	3	2	3	2	1	2	1	1	1	1	1	1
	others	2	1	2	1	1	1	1	1	1	1	1	1
	smectite	1	1	1	1	1	1	1	1	1	1	1	1

Sa = Sand; L = Loam; C = Clay; Si = Silt

All the operations described so far can be computerized, utilising the chosen relationships and coefficients. Software is also available for the determination of vulnerable areas on the basis of a series of climatic, pedological, and hydrogeological data.

The determination of the substances commonly employed in agriculture that require monitoring cannot be obtained by a simple measurement of the consumption or by an inventory of agricultural practices. This information can be obtained by budgeting all the possible sources of these substances in the groundwater. Correct monitoring is the basis for both the determination of anomalous situations and the verification of the success of the measures taken.

In addition, it must be stressed that the vulnerable areas must be defined not only from a territorial point of view (extra-agricultural impact of the areas in the zone of the recipient aquifers) but also with respect to the impact exerted by the surrounding point sources and the overlying non-point sources.

The importance of a correct analysis of the landscape has already been mentioned in the introduction. Unlike for agricultural or forested land, precipitation on an impermeable surface moves materials to the surrounding areas. Alternatively, a quarry forms a preferential path for contaminants towards the water table. A highway must be seen as an impermeable surface, whereas a rail road bed, constructed after first having removed the soil, can be considered a preferential path.

Table 2 Matrix for the definition of the degree of infiltration

Parameters	Description of parameters and relative values				
Intensity of rainfall	100-70 mm h^{-1} (5)	70-50 mm h^{-1} (4)	50-25 mm h^{-1} (3)	25-10 mm h^{-1} (2)	< 10 mm h^{-1} (1)
Slope of terrain and watershed	Flat and depressed (sometimes below sea level) av. slope < 1% (5)	Relatively flat av. slope 5%-1% (4)	Rolling hills av. slope 10%-5% (3)	Hilly av. slope 20%-10% (2)	Steep hills and embankments av. slope > 20% (1)
Surface retention	Excessive. Soil surface considerably depressed, poorly defined courses of water, stagnant water over more than 90% of the soil (5)	High. Soil surface with many depressions meandering streams and rivers (4)	Normal. Soil surface with some depressions, lakes and swampland cover less than 2% of the watershed (3)	Low. Network of small well defined waterways; absence of swamps or wetland (2)	Negligible. Soil surface with few depressions, rapid waterways (1)
Soil characteristics	Texture: sandy or with detrital material, fluvial-glacial deposited or massive strongly fractured rock (5)	Texture: medium sandy and sandy silty (4)	Texture: medium silty an silty clayey (3)	Texture: clayey (2)	Texture: soil cover very thin or outcrops of massive, compact rock (1)
Vegetative cover	Lack of vegetation, broken or fractured lithic outcrops, areas of quarrying activity (5)	Cultivated areas with periodic working of the upper layers of the soil (4)	Wooded areas or permanent herbaceous cover (pasture) (3)	Wooded and forested areas (2)	Areas without vegetation and soil due to impermeabiliza-tion or compact massive rock outcrops (1)

The Degree of Infiltration is calculated as the sum of the relative values of the parameters (indicated between brackets):

very high	25-21
high	20-16
normal	15-11
low	10- 6
negligible	5

Ascertaining of these two fundamental types of areas constitutes the basic screening of the landscape and the first preliminary monitoring operation. Secondly, all the point sources must be mapped, and in particular:

- urban waste water treatment systems;
- industrial waste water treatment systems;
- inhabited centres (use of agrochemicals, such as pesticides, herbicides and fertilizers);
- roads and highways (use of herbicides and fertilizers);
- rail roads (use of herbicides).

The precipitation (snow and rain) and aquifers must be monitored simultaneously. It is sufficient to remember that part of the precipitation today already consists of water that is unfit for drinking. Monitoring operations will reveal the concentration and nature of the contaminates, which vary in space depending on the regional land use and the agricultural practices.

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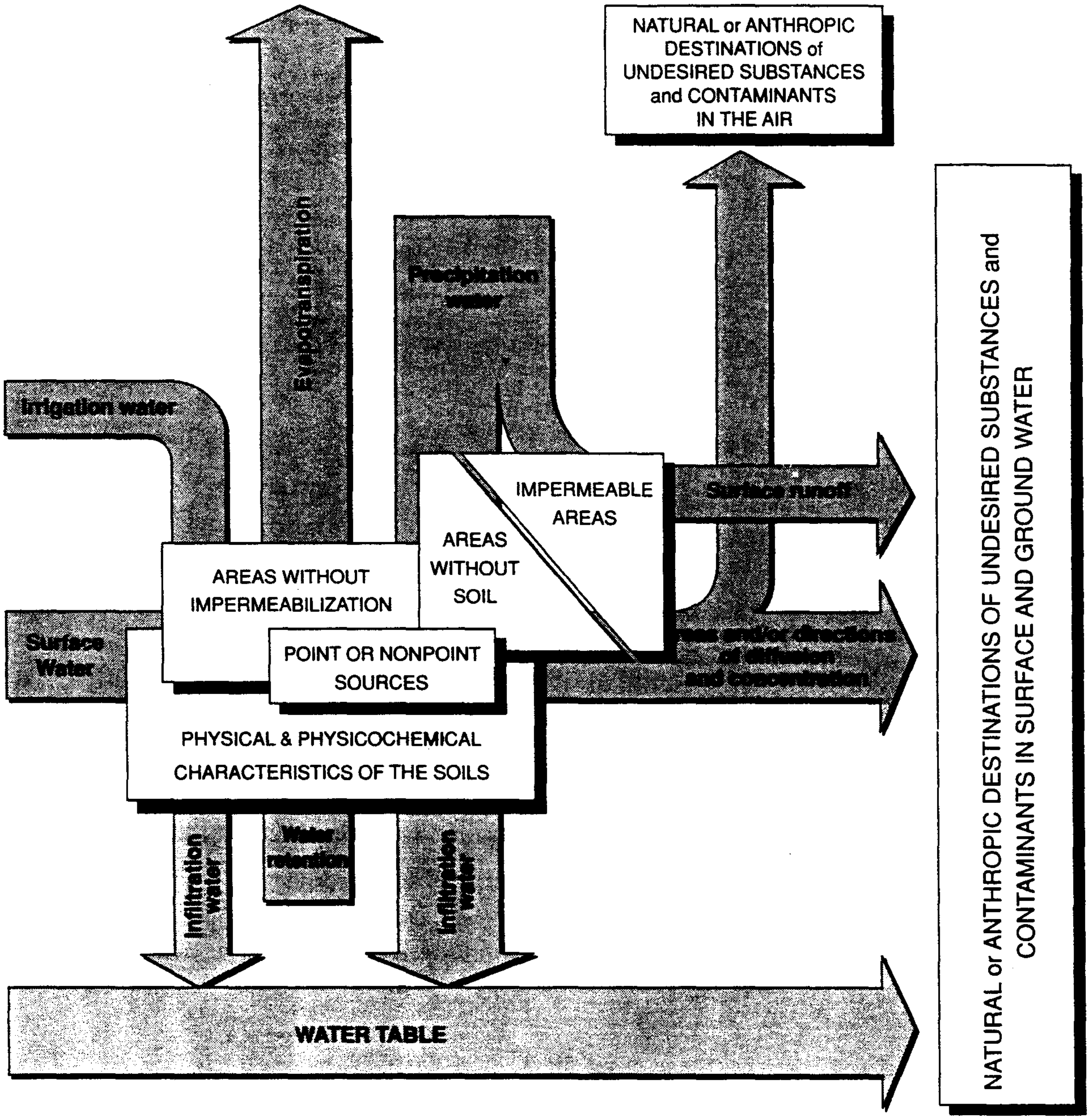

Figure 1 A comprehensive model for the subdivision of land into areas with different vulnerability (reference scheme and basic data to be monitored)

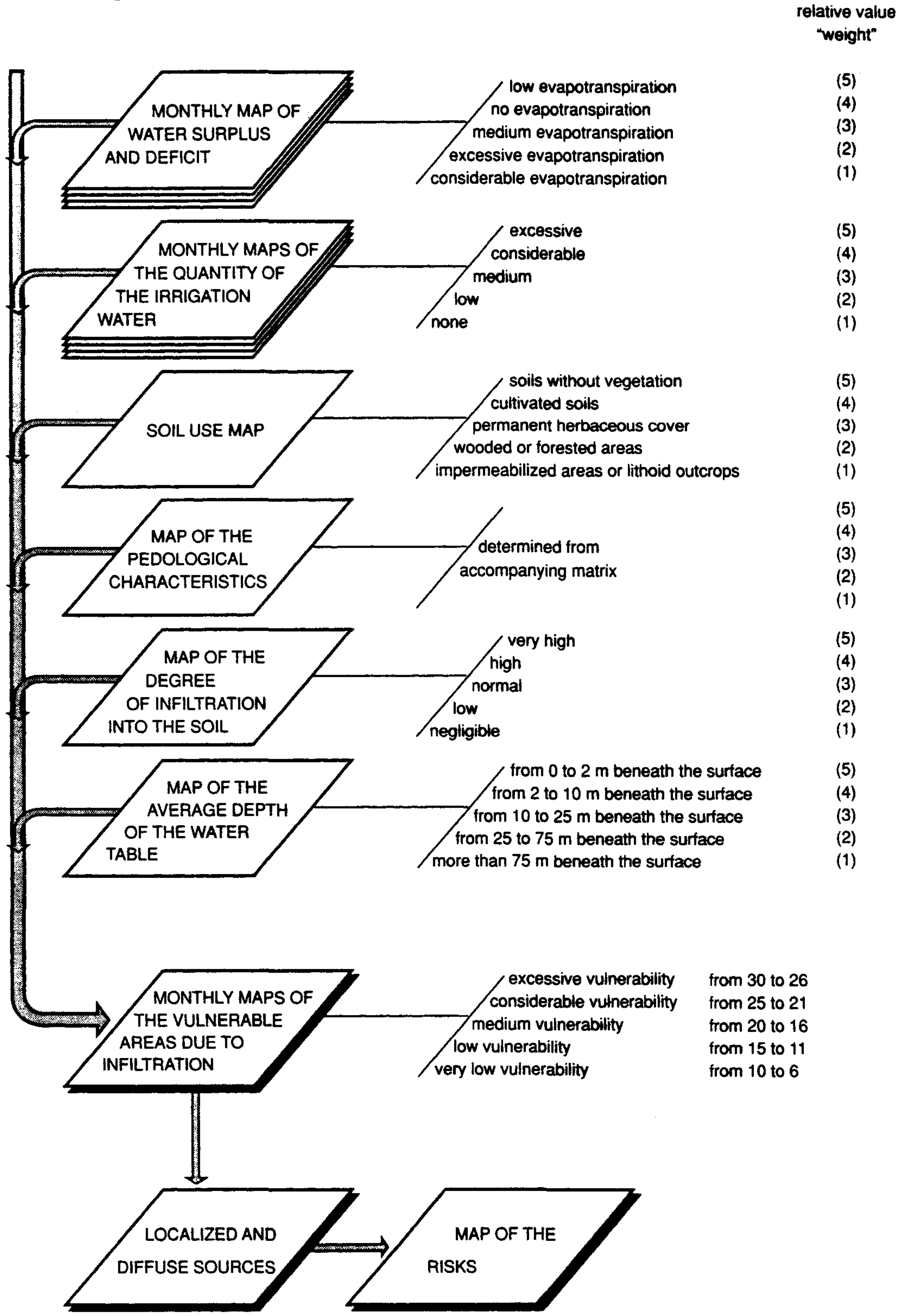

Figure 2 Simplified model of an environmental monitoring programme for the classification of land into areas with different degrees of environmental vulnerability

14 Chemical Pollution of Polish Soils

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ABSTRACT

Soil pollution and protection problems in Poland including chemical soil degradation, are solved on the basis of existing soil maps, a soil information system (BIGLEB), a method of evaluation and forecasting of soil degradation, principles of environmental monitoring, modelling and prediction of soil processes. All these aspects are discussed briefly in this paper.

INTRODUCTION

Poland is a lowland country with mainly mineral soils of light texture (about 50 per cent). It has a total surface of 312,683 km^2. Sixty per cent of the land is used for agriculture (46 per cent of arable land and 14 per cent of grassland) and 28 per cent under forest. Both marine and continental climates are observed in the country. The mean annual precipitation is about 600 mm, while mean air temperature ranges between 6 and 9° C.

SOURCES OF CONTAMINANTS AND CAUSES OF CHEMICAL SOIL DEGRADATION

Chemical soil degradation of Polish soils results from soil pollution and depletion of soil nutrients. The main sources of this degradation are (Kabata-Pendias and Pondel, 1985; Kabata-Pendias and Piotrowska, 1986):

- Emissions caused by coal burning, metal processing, manufacturing of fertilizers, and liquid fuel combustion.
- Disposal of municipal sludge, coal ashes, enrichment slurries, and wastes of metal smelters, the fertilizer industry and various other anthropogenic sources.
- Agricultural chemicals including fertilizers and pesticides.
- Radionuclides emitted during the Chernobyl accident.

The following chemical contaminants are considered the most dangerous in Poland: sulphur, trace metals (nickel, mercury, copper, lead, cobalt, cadmium, silver, beryllium, zinc, arsenic), fluorine and radioisotopes of caesium. The contents of some of the trace metals and fluorine in arable layers of Polish soils ares shown in Table 1.

The main soil degradation factor in Poland is acidification (Glinski, 1987; Dechnik *et al.*, 1990). Fifty eight per cent of Polish soils are very acid or acid (pH below 5.5), 25 per cent slightly acid (pH of 5.6-6.5) and only 17 per cent have neutral reaction (pH higher than 6.6). Soil acidification is influenced by the character of parent rocks (which are poor in bases), by the climatic conditions causing systematical leaching of basic cations from the arable layers, and by human activity. The latter results in atmospheric pollution by sulphur, nitrates and chlorine, and in consequence acid deposition.

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Table 1 Mean and maximum content of some trace metals and fluorine in arable layers of Polish soils (after Kabata-Pendias and Piotrowska, 1986)

Element	Content in mg kg^{-1}	
	Mean*	Maximum
Cd	0.5	290
Be	1.5	50
Cu	20	1600
Pb	30	4650
Zn	60	10000
F	300	13200

* The geochemical background

Poland twice received radioactive fall-out from Chernobyl on April 26 and 27, and again on May 5, 1986. After short-lasting but intensive contamination with iodine 131, stable isotopes of caesium 134 and 137 are now the main contaminants of soils in the regions affected. Although their levels are not very high, they may affect plant growth and the quality of plant products for many years to come. The relative degree of soil contamination by radionuclides in Poland after the accident at Chernobyl in 1986 is shown in Figure 1.

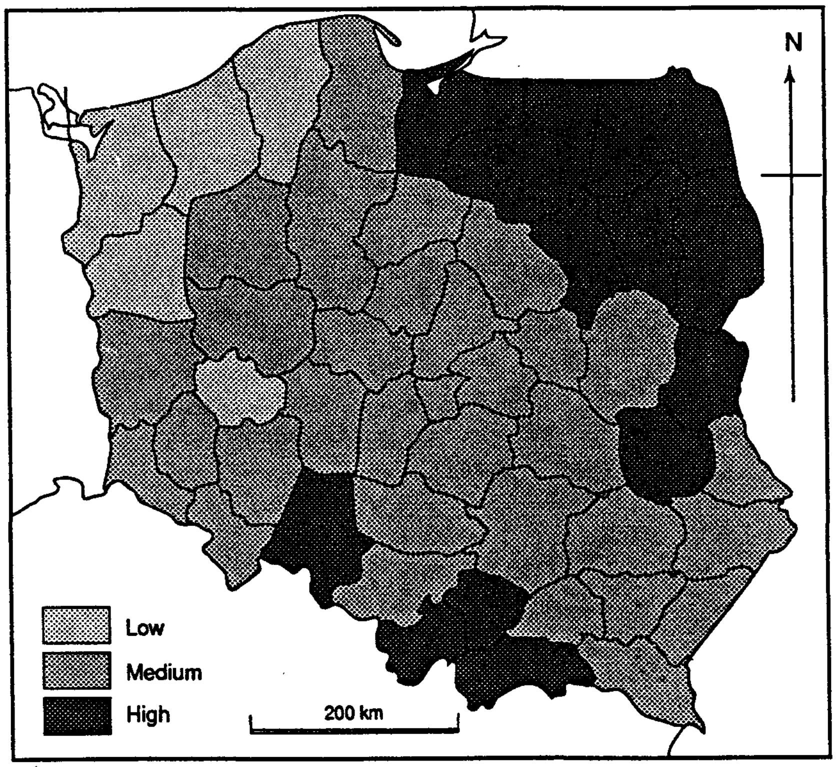

Figure 1 Map of the relative degree of land contamination in Poland after Chernobyl in 1986 (Raport o stanie, zagrozeniu i ochronie srodowiska, 1990). [1 - low, 2 - medium, 3 - high]

SOLUTION OF SOIL DEGRADATION PROBLEMS

Environmental pollution and protection problems are solved in Poland on the basis of the existing soil maps, a soil information system (BIGLEB), and a method to evaluate and forecast soil degradation, using principles of environmental monitoring, modelling and the prediction of soil processes.

Soil maps

Polish soils are very well mapped at various scales, including 1:300,000, 1:500,000, 1:1 M and 1:2 M. Soil-agricultural maps, which show the classification of soils and their suitability for plant production, have been compiled at the scale of 1:1 M, 1:100,000, 1:25,000 and 1:5000. So far, only 50 per cent of the 1:25,000 maps have been printed.

The susceptibility of soils to chemical degradation is closely connected with the geochemical resistance of the land to degradation, the latter depending mainly on the clay and humus content in the soil. Siuta (1990) compiled a map showing 5 classes of soils grouped according to their geochemical resistance to degradation. Dobrzanski *et al.* (1977) mapped the soils of Poland into 4 categories based on their specific surface area. Kern (1987) prepared thematic maps showing 5 classes of soil pH, as measured in a KCl solution, for the 0 to 50, 50 to 100, and 100 to 150 cm depth zone respectively.

The Soil information system BIGLEB

BIGLEB, a soil information system, was elaborated by the Polish Society of Soil Science (Kowalinski, 1977) on the basis of several million soil profile descriptions, about 10 million results of laboratory tests on soil samples, and millions of results of soil resource tests. It also includes maps at 1:5000 scale showing the spatial distribution of the soils and their classification for agricultural purposes.

BIGLEB is composed of complementary subsystems on the cartography of arable, grassland and forest soils, physical, chemical and biological properties and processes of soils, soil regionalization, amelioration and productivity evaluation, data files collecting information from existing documentation of soils and other natural environment research.

Evaluation, forecasting, monitoring and mapping of soil degradation

The spatial distribution of selected contaminants (S, Cu, Zn, Cd, Pb, Ni, Cr and Hg) up to the year 2000, and the economic consequences thereof, have been forecasted using the data bases of BIGLEB and SOWEP (Rejman-Czajkowska *et al.*, 1984; Truszkowska, 1986a; Truszkowska *et al.*, 1986).

One of components of BIGLEB is the computerized data base with acronym BIGLEB BKA-95 (Truszkowska, 1986b; Truszkowska and Rejman-Czajkowska, 1991). It contains information about the natural resources, and procedures to evaluate the environmental degradation/pollution caused by industrial development (mainly for sulphur and heavy metals). Special attention is paid to emissions of power-stations which produce over 80 per cent of the total amount of polluting agents in Poland. Maps (1:500,000) showing the areas which are likely to be contaminated by specific pollutants can be plotted automatically with the system. The attribute data are georeferenced using a standardized grid system. The following grid sizes are considered: 0.25, 1.0, 2.5 and 10 km^2.

Taking into consideration the sources of emission of contaminants, generalized maps of soil pollution with toxic elements (Fig. 2), and maps showing the amount of amount of CaO needed to neutralize the H_2SO_4 introduced into soils by emissions it was possible to compile a map. Maps showing soil zones with similar concentrations of SO_2 (< 10, < 20, 21-50, 51-100 and > 100 $\mu g\ m^{-3}$) and other toxic elements such as As, Cd, Cr, Cu, Hg, Pb and Zn (< 0.026, 0.027-0.066, 0.067-0.133 and > 0.133 $\mu g\ m^{-3}$) have been compiled also.

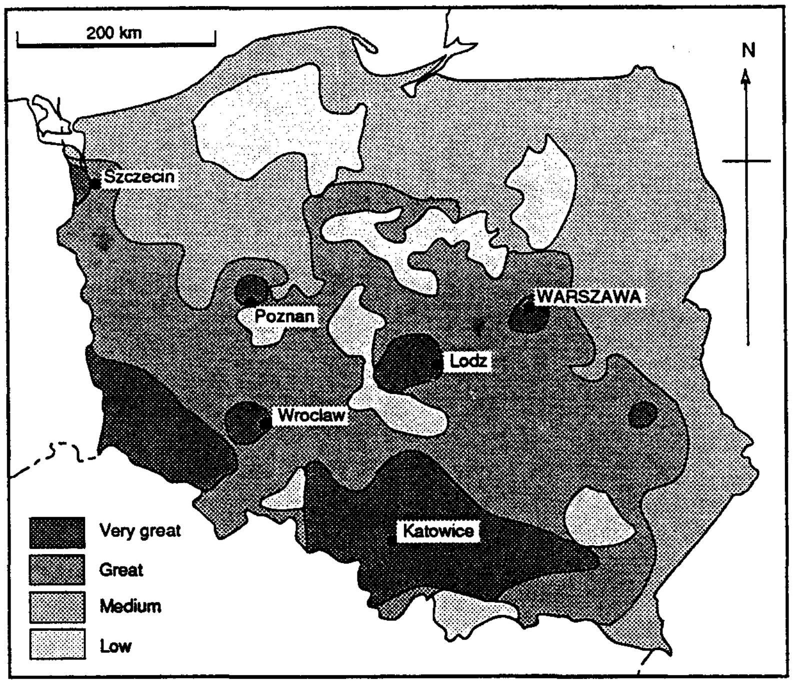

Figure 2 Map of soil contamination with toxic elements (Truszkowska *et al.*, 1986).
[1 - very great, 2 - great, 3 - medium, 4 - low].

Soil degradation maps have been produced at 1:500,000 scale showing protection zones for ecological engineering (Siuta, 1983). Also, so-called "sozological" maps have been prepared at a scale of 1:50,000 on the protection of nature and its resources (Mapa sozologiczna, 1989). They will contain, among others, maps of toxic contaminations of soils. The main types of human-induced soil degradation, including chemicals, in Poland are shown on the World Map of Soil Degradation (Oldeman *et al.*, 1990).

Concentrated areas of degradation occur in the neighbourhood of the main industrial works and urban areas, for instance near the copper smelting-works "Legnica" (Roszyk and Szerszen, 1985) or in soils of small gardens within Lublin town (Kukier, 1985). Analyses of soils of small urban gardens carried out in 110 locations in Poland, revealed an excess above the concentration considered safe for Cd (< 0.1 mg kg^{-1}) and Pb (< 20 mg kg^{-1}) in 30 per cent and 84 per cent of the locations respectively (Uminska, 1985).

In order to check the prognoses and preliminary maps it is necessary to store a lot of analytical data, to establish an extensive monitoring system in the field, and to model the processes transforming toxic chemicals in soils so as to propose abatement methods.

To evaluate the present status of chemical degradation of agricultural land, a special programme was initiated in 1988 by the Institute of Soil Science and Plant Cultivation (IUNG) under the co-ordination of Prof. R. Czuba. This programme consisted in taking 6546 individual samples from 3 soil horizons (0-20, 20-40 and 40-60 cm) and composite samples from the plough layers from 1091 places (from fields of surface area between 0.5-2 ha). The samples sites are located in the vicinity of industry, towns, big farms, dumping grounds, highways, as well as in un-contaminated areas. Their locations have been marked on soil maps at scales of 1:5000, 1:25,000, 1:300,000 and 1:500,000.

For future reference, the Institute of Agrophysics in Lublin has stored 3000 samples originating from 1000 profiles taken from the main mineral soils of Poland in 1989. These samples are analyzed, among others, for the total content of Pb, Ni, Cd, As, Cr, S and Se, and soluble forms of Cu, Mn, Fe, Zn, B and Mo. All the above mentioned locations are earmarked to be used for monitoring of soil pollution in the future.

The principles of environmental monitoring in Poland, including chemical pollution of soils, have been elaborated by the Institute of Environmental Protection in Warsaw. Monitoring of chemical pollution is done locally and still poorly coordinated in Poland. Two monitoring stations are not well equipped.

CONCLUSION

Numerous data are available in Poland to evaluate the vulnerability of soil and terrain units to specified groups of chemical compounds. However, this information is not yet stored in one central system and the various investigations are poorly coordinated. Financial constraints and the lack of modern instrumentation are limiting factors in the analyses of stored soil samples and the organization of a monitoring system to validate prognostic maps and processes.

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15 Some Aspects Concerning the Approach for Mapping of Soil and Terrain Vulnerability to Specified Groups of Chemical Compounds in Romania

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ABSTRACT

Based on the updated FAO-Unesco Soil Map of the World at 1:5 M scale, soil units in Romania were characterized according to the following parameters: texture class, slope class, soil depth, organic matter content, pH (H_2O), $CaCO_3$ content, CEC, dominant clay minerals, salinity and alkalinity, soil moisture regimes, and depth of groundwater level. Most of these parameters are presented by three classes of intensity. The values of each parameter corresponds to classes given in the tables. The following thematic maps were prepared at the same scale: climate, geology, hydrology, geomorphology, land use, and vegetation.
Taking into account the preceding data, soil vulnerability maps are compiled for acid rain, salinity and some heavy metals (Cd, Pb, Zn, Cu). For this purpose the criteria used for assessment of the soil vulnerability classes for different pollutants were established by an interpretive methodology.

INTRODUCTION

Past and present influxes of pollutants produced by different social and economic activities are damaging the soil's function as a chemical, physical, physico-chemical and biological substratum for biomass production. The natural functions of the soil for sanitation, filtering and buffering are changing, and the genetic diversity of plants and animals is being altered. The necessity to protect the atmosphere and hydrosphere from pollution has been understood for well over a century, but it is only in the last decade that public opinion and policy-makers agreed on the need to safeguard soils (Bridges, 1989; Răuţă and Cârstea, 1983). Other authors (Arnold *et al.*, 1990; Barth et L'Hermite, 1987; Kovda, 1990; Răuţă *et al.*, 1990) outlined the danger of increasing anthropogenic pollution upon the "natural functions of the soil environment".

Glazovskaya (1991) prepared global maps on soil vulnerability to "technogenic acidification" and "technogenic pollution by heavy metals". Siuta (1976) compiled a map on "soil vulnerability to technogenic acidification" for Poland. Similarly, Várallyay *et al.* (1989) compiled a map of the susceptibility of soil to acidification in Hungary.

SOIL DATA BASE

In Romania, much information on soil resources has been accumulated. Besides generalized soil maps at scales of 1:200,000, 1:500,000 and 1:1 M, soil maps have been compiled at a scale of 1:50,000 for all the agricultural areas. A soil map at 1:10,000 scale was also prepared for the arable areas of the country. All the soil data are computerized. Soil testing is provided for more than 25 per cent of the cultivated area, every year.

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Other data bases developed for Romania are:

- A land evaluation data base which contains data for homogeneous ecological areas (based on 24 soil, relief and climate parameters) on a scale of 1:50,000 for agricultural areas of Romania.
- A soil pollution monitoring data base in which data concerning the concentration of major pollutants in the impact areas are stored.

On the basis of these soil data bases, mathematical simulation models were developed to:

- Describe soil water dynamics and crop yield formation (SIBIL). This model was validated for a number of crops (wheat, maize, spring barley, soybean and sunflower) under various soil and climate conditions in Romania.
- Assess the risk of soil erosion (CREAMS). This model is in the validation stage.
- Describe the dynamics of heavy metals in the soil. This model was validated using laboratory columns.

THE MAIN PHYSICO-GEOGRAPHICAL CHARACTERISTICS OF THE ROMANIAN TERRITORY

The southern and extreme western parts of Romania are represented by a plain with a maximum altitude of 200 m. The region is characterized by a warm, dry to semi-humid climate. The native vegetation consists of steppe-forest and steppes, with deciduous forests in some areas. The dominant soils are Chernozems in association with Vertisols and Luvisols. Crops are grown in more than 90 per cent of the area, of which 60 per cent is irrigated.

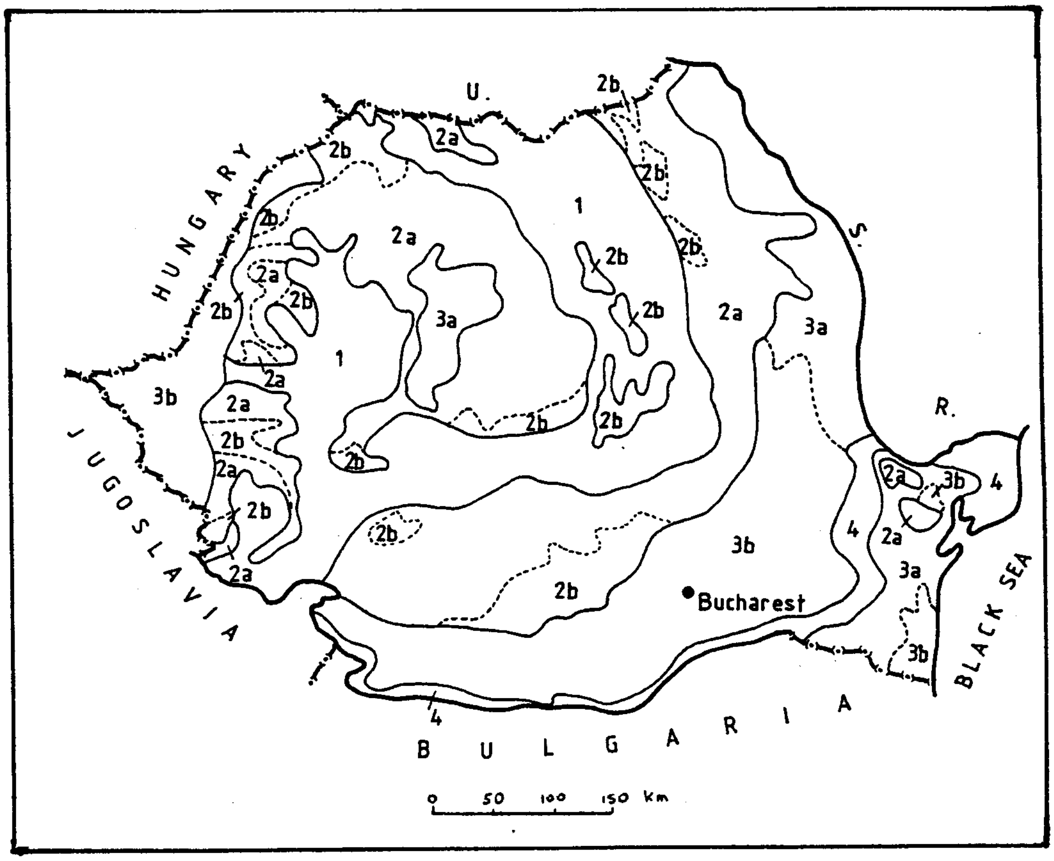
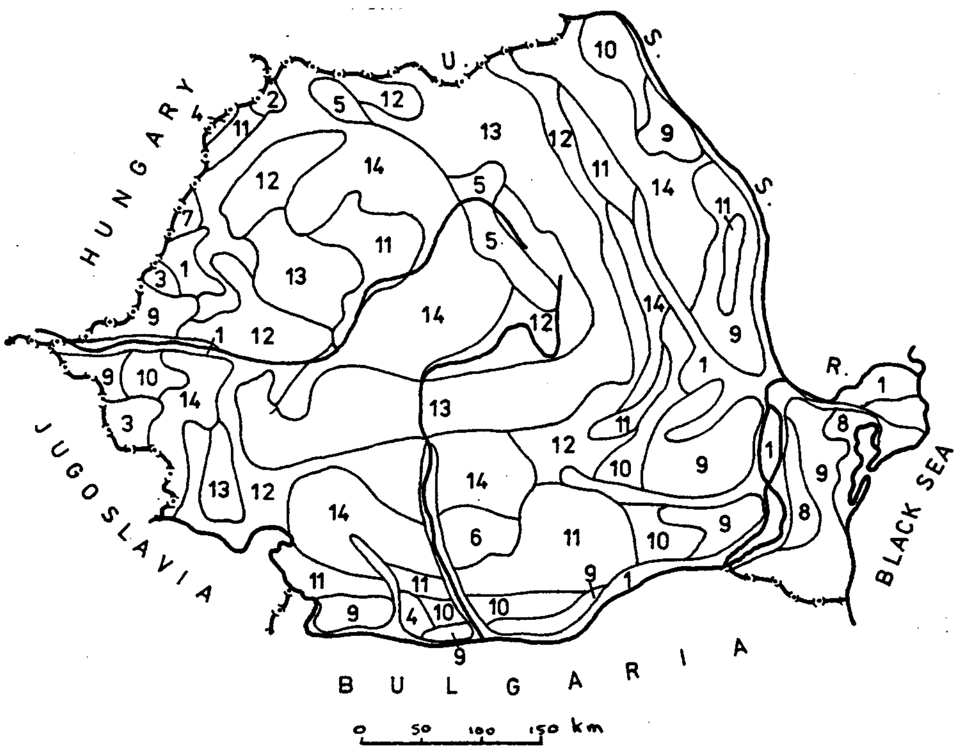


Figure 1 Ecological map of Romania (Legend: 1 - Mountainous domain of the coniferous and deciduous forest, predominantly with Cambisols and Podzols, steeply dissected; 2 - Deciduous forest domain, partially cleared, predominantly with Luvisols; 2a - with hilly-rolling relief, 2b - with flat-undulating relief; 3 - Steppe and sylvo-steppe domain, predominantly with Mollisols, 3a - with rolling- undulating relief, 3b - with flat relief; 4 - Flood plain and delta domain with mainly Fluvisols)



LEGEND

		Level of vulnerability to:		
		Acid rains	Salinity	Heavy metals
1	Calcareous alluvial soils	L	M - L	L - M
2	Smectitic- clayey soils, with high, organic matter content and shallow ground-water	H	L - M	M
3	Smectitic- clayey, mostly calcareous soils, with shallow ground-water	L	H	M
4	Sandy soils mostly calcareous and with low organic matter content	M	L	H
5	Acid, allophane-rich soils with very high organic matter content	H	L	M
6	Smectitic - clayey and neutral - alcaline soils	L	L	M
7	Alcaline soils, fine textured and with shallow ground-water	L	L - H	L - M
8	Calcareous soils, medium textured and with low organic matter content	L	L - H	L - M
9	Calcareous soils, medium textured and with medium organic matter content	L	L - H	L - M
10	Slightly acid to neutral soils, medium textured and with medium organic matter content	M	L - M	M
11	Slightly acid to neutral soils, with coarse to fine texture and low to high organic matter content	M	L	M
12	Acid to neutral soils, medium textured with medium to deep profile, and medium organic matter content	M	L	M - H
13	Acid soils with very high organic matter content, coarse textured and with shallow to medium profile	H	L	M - H
14	Acid to neutral soils, medium textured and with low organic matter content (mostly with low permeability).	M - H	L	M - H

Figure 2 Map of Romania showing categories of soils grouped according to relevant characteristics determining their vulnerability to chemical pollution. (Explanation of symbols: L = low or absent; M = medium; H = high)

The eastern and central part of the country is represented by hills and table lands, occurring at an altitude of 200 to 500 m, and has a warm-dry to cold-humid climate. The native vegetation, which consists of deciduous forests, now is partly replaced by agricultural crops (30-70 %). The main soils are Luvisols and Cambisols which are extensively affected by water erosion.

The mountainous area (1000-2500 m altitude) is characterized by a cold and humid climate. The native vegetation comprises deciduous and coniferous forests, while there are alpine grasslands above 2000 m of elevation. Cambisols and Podzols are the main soils in this region of Poland (Fig. 1).

FACTORS AND PARAMETERS DETERMINING THE VULNERABILITY OF SOILS TO PARTICULAR CATEGORIES OF CHEMICAL COMPOUNDS

In order to determine the vulnerability of soils with respect to specified group of chemical compounds, two groups of factors and parameters have to be taken into account:

- Environmental factors, not all quantifiable, which influence both the response to the impact of different pollutants and the behaviour of these pollutants in soils, ecosystems and landscapes. The relevant factors are: relief, lithology, hydrology, climate, native vegetation and land use. These factors are demarcated on thematic maps at 1:5 M scale, and present the global background to which the pollution hazard and risk is referred.
- Soil and environmental factors and parameters, mostly quantifiable, which directly determine soil buffering capacity to chemical pollution. These factors include slope of the land, texture, depth to hard rock, pH (H_2O), organic matter content, type of clay minerals, $CaCO_3$ content, CEC, soil salinity and alkalinity, groundwater table, and natural soil drainage. In Table 1 these factors are ranked into 2 to 5 classes, based on the updated FAO/Unesco map at 1:5 M scale for Romania.

Table 1 Soil and environmental factors and parameters

Factors and parameters	Intensity classes				
	Code and description (value)				
Textural classes	1/coarse		2/medium	3/fine	
Slope classes	a/flat-undulating		b/rolling-hilly	c/dissected-mountainous	
Soil depth on compact rocks (cm)	≤ 50 (shallow)		51-100 (medium)	> 100 (deep)	
Organic matter content (%)	≤ 2 (very low)	2-3 (low)	3-5 (medium)	5-8 (high)	8-25 (very high)
Soil reaction (pH)	≤ 5 (strongly acid)	5-7 (moderately acid-neutral)	7-8.5 (neutral moderately basic)	> 8.5 (strongly basic)	
Depth of occurrence of $CaCO_3$ (cm)	≤ 50		50-150	without	
CEC (meq/100g soil)	≤ 10 (low)		10-35 (medium)	> 35 (high)	
EC (salinity; dS/m)	≤ 2.7 (low)		2.8-32 (medium)	≥ 32 (high)	
Alkalinity (ESP; %)	< 5 (low)		6-15 (medium)	≥ 16 (high)	
Natural drainage	good		moderate	poor	
Groundwater table (m)	< 5m (shallow)		≥ 5m (deep)	without	

Table 2 Relevant characteristics with respect to the vulnerability of soils to pollution

No. of soil category	Symbol of soil units after FAO/Unesco Map 1:5 M	Characteristics (parameters)										
		Slope class	Textural class	Soil depth	Org. mat. content	Clay mineral	Soil reaction	Occurrence of $CaCO_3$	CEC	EC	ESP	Depth of groundwater
1	Ia49-1/3a, 61-a, 57-1/2a, 48-1/3a	level	coarse/ medium-fine	deep	low	smectitic-illitic	neutral-alkaline	shallow	medium	low	low	shallow
2	Gh23-3a	level	fine	deep	high	smectitic	neutral-alkaline	shallow	high	low	low	shallow
3	Gm14-2/3a Vp69-3a	level	medium-fine / fine	deep	medium	smectitic	neutral-alkaline	shallow between 50-100cm	high	low	low-medium	shallow
4	Rc48-lab	undulating	coarse	deep	low	illitic	neutral-alkaline	shallow	low	low	low	partially shallow
5	Th20-2bc	hilly-mountainous	medium	medium	very high	smectitic-illitic with allophanes	acid	without	high	low	low	without
6	Vp68-3a	level-undulating	fine	deep	medium	smectitic	neutral-alkaline	between 50-150cm	high	low	low	deep
7	Sm15-3a	level	fine	deep	low	smectitic	alkaline	shallow	medium	medium	high	shallow
8	Kk17-2a	level-undulating	medium	deep	low	smectitic-illitic	neutral-alkaline	shallow	medium	low	low	deep-shallow
9	Ck10-2ab Hc15-3a	level-rolling	medium	deep	medium	smectitic-illitic	neutral-alkaline	shallow	medium	low	low	deep-shallow
10	Hh25-1/3ab	level-rolling	medium	deep	medium	smectitic-illitic	acid-neutral	between 50-150cm	medium	low	low	deep
11	Hl45-1/3ab Hl46-2a Lc111-2ab	level-rolling	coarse/ fine, medium	deep	low-high	smectitic-illitic	acid-neutral	between 50-150cm	medium	low	low	deep
12	Be123-2b, 122,-2bc	rolling mountainous	medium	medium-deep	medium	smectitic-illitic	acid-neutral	between 50-150cm	medium	low	low	without
13	Bd66-1/2bc Pl7-1bc	hilly mountainous	coarse	medium-shallow	very high	illitic cloritic	acid	without	high	low	low	without
14	Lo20-2b Lg41-2/3ab We21-2ab	level-rolling	medium	deep	low	smectitic-illitic with intergrade minerals	acid-neutral	without	medium	low	low	deep

Clay mineral classes were established taking into account the dominant clay mineral, with reference to specific components (allophane and integrades). The dominant clay component was considered to be the one for which, on the average, the content is at least 10 to 15 per cent higher than that of the other components considered separately.

ROMANIAN SOIL VULNERABILITY MAPPING EXERCISE

Using the Romanian soil data bases, correlated with the information contained in the 1:5 M FAO/Unesco Soil Map of the World, the soils were grouped by taking into account the relevant characteristics concerning the vulnerability of soils to chemical pollution (Table 2).

The main soil characteristics considered within this exercise are: soil texture, $CaCO_3$ content, organic matter content, pH and in some cases the type of clay minerals, nature, and groundwater depth. As a result, 14 soil categories were demarcated on the soil map (Fig. 2). For each soil category, the degree of vulnerability was assessed for acid rain, salinity, and heavy metals, using three grades of vulnerability. As can be seen in Figure 2, four "soil categories" are vulnerable to salinity, 3 categories to heavy metals, and 3 categories to acid rain.

In Romania, soil vulnerability to pollution by heavy metals is considered the most dangerous, both in terms of severity and area that may be affected. Vulnerability of soils to salinity occurs on the Romanian plain where irrigation is applied extensively.

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16 Mediterranean Soils Degradation and Environment Contamination (Special reference to Andalusian soil mapping and evaluating activities)

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ABSTRACT

Many environmental problems are produced because crops are being cultivated without respect for physical soil properties. Land/soil mapping and evaluation make it possible to utilise the land according to its potentialities. This contribution points out the scarce Andalusian/Spanish information with which to develop a reconnaissance mapping exercise, along with an expert model for predicting the vulnerability of soils to two categories of chemical compounds, fertilizers and pesticides.

INTRODUCTION

To change the present unsustainable patterns of development which are causing environmental problems, it is necessary to get information and knowledge so that the right decisions may be made. Problems are being produced because plant species are cultivated without respect for physical soil properties. Land/soil mapping and evaluation make it possible to make use of the land according to its potentialities.

Natural and agricultural processes are the major causes of chemical degradation of soil quality causing, for instance, salinization/alkalinization and contamination with fertilizers, pesticides and heavy metals. Additional problems are created by urbanization and industrialization as they result in emissions of contaminants and dumping of all kinds of products, residues and wastes.

There is increasing concern not only for the deterioration of soil quality, but also about the accumulation of pollutants in soils ("critical load") and their transfer to surface/ground waters and the food chain. Loss of soil volume by water erosion, which is the dominant process of deterioration in Mediterranean regions, produces significant pollution of surface water. In the irrigation areas, past and present influxes of chemical compounds are modifying/reducing the initial buffering, filtering and transformation functions of soils, and thereby often result in contamination of the groundwater.

The major objectives of this contribution are: a) to identify the scarce Andalusian/Spanish land information (data and maps) available to carry out a reconnaissance "soil vulnerability mapping" exercise, and b) to explain a computer-based expert knowledge model as a methodological approach for the prediction of "soil vulnerability" to fertilizers and pesticides.

LAND CHARACTERIZATION

The Andalusian region of Spain is characterized by a low, variable rainfall and high temperatures during much of the growing season, and the dominance of highly fragile soils. In this semiarid

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Mediterranean climate there is little precipitation from May to October but the remaining months are generally rainy. The historical average rainfall for the latter period is 630 mm.

Table 1 shows several features concerning land characterization: dominant soils, present land uses, land capability classes and soil erosion risks. This information is derived from the 1:400,000 scale Ecological Land Resources Evaluation Maps of Andalusia (AMA, 1987). These small-scale maps seem the most appropriate for the investigation of soil vulnerability to chemical compounds in the whole region. Additional information to that end can be derived from other documents such as produced by AMA (1984 and 1986-87) and JA/CSIC (1989).

Table 1 Land characterization of the Andalusian region

Variable	Estimated extent (1000 ha)	Percentage
	Dominant Soils	
Entisols	2,636	30
Vertisols	983	11
Inceptisols	2,222	26
Aridisols	187	2
Mollisols	158	2
Alfisols	1,152	13
Others	1,362	16
	Present Land Use	
Irrigation crops	592	7
Rainfed crops	3,165	36
Forestry and grazing	4,007	46
Others	936	11
	Land Capability	
Class S1: Excellent	535	6
Class S2: Good	1,735	20
Class S3: Moderate	2,311	27
Class N: Marginal	4,073	47
	Soil Erosion Risk	
Class S1: Low	1,398	16
Class S2r: Moderate	3,379	39
Class S3r: High	3,136	36
Class Nr: Very High	785	9

Source: AMA (1987)

With reference to Spain, any soil mapping exercise will be limited by the lack of basic information already available; scale 1:1 M (ITGE, 1989) or smaller (IGN, in prep.). The Soil Map of the European Communities, at a scale of 1:1 M (CEC, 1986), seems the best reference basis for developing a qualitative land evaluation procedure to predict the vulnerability of soils to chemical compounds.

After many years of intensive cultivation, the best agricultural soils of Andalusia are becoming degraded, and the water resources increasingly polluted. In many sandy areas under irrigation, fertilizers (mainly nitrates) are polluting the soil, groundwater, surface water and air through leaching, run-off and volatilization of NH_3-N. The average consumption of fertilizer in Andalusia, which is similar to the mean for all the Spanish regions (Table 2), is almost four times less than that for the other European countries (Table 3). Similar comments can be made for pesticides of which the average consumption in Andalusia reached 9 kg ha^{-1} in 1988 (MOPU, 1990). Therefore, it is easy to imagine that environmental contamination problems will increase rapidly in the near future. Along with the traditional crops (wheat, sunflower, alfalfa, cotton and potato), other vegetable crops planted in winter and spring (celery, broccoli, Brussels sprouts, cauliflower, lettuce, spinach and strawberry) and permanent fruit crops (citrus, olives, grapes, peaches, nectarines and plums) are presently increasing in the irrigation zones.

Table 2 Fertiliser consumption in Spain for 1989

Region	Extent of arable lands (1000 ha)	Fertiliser used (kg ha^{-1})
Andalusia	4,167	98.05
Aragon	1,898	94.96
Asturias	31	228.64
Baleares	257	30.12
Canarias	142	193.60
Cantabria	19	500.86
Castilla-Mancha	4,252	49.81
Castilla-Leon	4,097	112.69
Cataluña	1,044	153.18
Valencia	933	192.23
Extremadura	1,484	89.94
Galicia	558	95.89
Madrid	276	82.78
Murcia	596	69.00
Navarra	373	136.86
Pais Vasco	104	158.57
Rioja	179	303.38
TOTAL	20,415	99.29

Source: MOPU (1989)

Table 3 Fertiliser consumption in the EEC in 1986

Country	Extent of arable land (1000 ha)	Fertiliser use (kg ha^{-1})
Germany	7,453	427.3
Belgium-Luxembourg	806	522.3
Denmark	2,620	242.0
Spain	20,415	81.9
France	18,928	300.9
Greece	3,940	173.9
Ireland	800	787.5
Italy	12,200	172.2
Netherlands	892	783.6
Portugal	2,760	87.3
UK	7,077	355.5
EEC-12	79,891	357.7

Source: MOPU (1989)

EVALUATION PROCESS

In the framework of MicroLEIS, the Microcomputer-based Mediterranean Land Evaluation Information System (De la Rosa *et al.*, 1991), several biophysical land evaluation methods are combined using appropriately scaled models. These include purely qualitative (reconnaissance), semi-quantitative (semi-detailed) and quantitative (detailed) empirical models. The broad aim of MicroLEIS is to establish an interactive and user-friendly procedure permitting optimal allocation of land use systems, and to define biophysically possible production levels for agroforestry under Mediterranean conditions. Also, two appendices of the land evaluation computing system are now being developed. The first, MicroLEIS/Eng., permits an assessment of the suitability of soils for engineering based on geotechnical terrain characteristics such as plasticity, shrink and swell properties, compressibility and shear strength. The second, MicroLEIS/Env., can be used for the estimation of the vulnerability of soils to chemical compounds, such as salts, fertilizers, pesticides and heavy metals.

Qualitative model

According to the scarce data and knowledge presently available, a first approximation of a qualitative physical land evaluation procedure has been developed for assessing the general vulnerability of the soils of Andalusia to chemical compounds. Expert knowledge was captured into the Automated Land Evaluation System (ALES), as developed by Rossiter (1990), through computer-based decision trees. The ALES system is a framework for evaluators to build their own expert model in accordance with FAO's Framework for Land Evaluation (FAO, 1976). The general criteria developed by Yassouglou (1987) for assessing of soil sensitivity in southern Europe were used to design the expert model. Only one land utilization type (LUT) was considered, namely an intensively managed Mediterranean farm type which generally includes irrigation practices.

The mobilization of agricultural pollutants (fertilizers and pesticides) through seepage into the groundwater are considered, but not the aspect of soil erosion/run-off/surface water. The land qualities (LQs) used are landform type, physical quality of the profile, and management system. They are rated into 3 grades of severity (3sl). The rating of these LQs was derived from selected land characteristics (LCs) such as geological period (4sl), depth of water-table (3sl), textural class (3sl), carbonate content (3sl), irrigation system (4sl), drainage system (2sl) and water extraction (2sl), according to the constructed decision trees. Finally, four vulnerability classes (S1-None, S2-Slight, S3-Moderate and S4-Severe) were determined from the set of severity levels of the LQs using decision trees. The first approximation of the decision trees of the land evaluation expert model is shown in the Appendix.

As pointed out by Van Lanen and Wopereis (1990), the application of this expert model for computer-captured expert knowledge in qualitative land evaluation appears to be useful to explore land use options. General results can be obtained quickly, thereby reducing the number of land uses which should be considered in follow-up studies. Within a relatively short time-period, policy-makers and researchers can now focus on the more promising options.

Quantitative approach

In order to establish a quantitative evaluation model so as to obtain more detailed results, a research project is being developed to determine the relationships between external influxes, mainly the application of fertilizers and pesticides, and the performance of selected benchmark soils. The processes determining the environmental fate of organic chemicals can be broadly grouped into five categories (Weber and Miller, 1989): a) sorption to organic matter, clays and other mineral surfaces; b) leaching through unsaturated and saturated zones and run-off; c) volatilization from the uppermost soil layer; d) degradation through chemical or biological processes; and e) plant uptake. The relative importance of each transportation and transformation process depends on the physical and chemical properties of the compound, the properties of the soil and water, and the prevailing climatic conditions.

Modelling is increasingly being used as a tool for evaluation of the environmental fate of pesticides or other organic pollutants (Wagenet and Rao, 1985). Data about processes can be calculated experimentally, obtained from the literature, or calculated from the soil properties using appropriate equations (Hermosin and Cornejo, 1989a and b). A useful model, introduced by Kunht (1990), for sorption processes could be enlarged by taking into account leaching, volatilization, and degradation processes in the soil-water-atmosphere ecosystem. From this conceptual model, a quantitative technique could be developed to predict the vulnerability of soils to chemical compounds.

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Appendix **Decision trees constructed for the qualitative land evaluation method, according to the ALES expert system**

1. Severity level of the LQ "landform type"

- > gp (geological period)
  - h (alluvial plains) > wd (water-table depth)
    - s (shallow .... : 3 (very sensitive)
    - m (moderate) .... : 2 (sensitive)
    - d (deep) .... : 1 (not sensitive)
    - ? .... : ?
  - p (terraces) .... : 2 (sensitive)
  - s (pliocene surfaces) ..... : 2 (sensitive)
  - t (rolling tertiary hill) .... : 1 (not sensitive)
  - ? .... : ?

2. Severity level of the LQ "soil profile quality"

- > tc (textural class)
  - c (coarse) > wd (water-table depth)
    - s (shallow) .... : 4 (very suscept.)
    - m (moderate) .... : 4 (very suscept.)
    - d (deep) .... : 3 (moder. suscept.)
    - ? .... : ?
  - m (medium) > wd (water-table depth)
    - s (shallow) > cc (carbonate content)
      - n (nul) .... : 4 (very suscept.)
      - m (moderate) .... : 3 (moder. suscept.)
      - h (high) .... : 3 (moder. suscept.)
      - ? .... : ?
    - m (moderate) > cc (carbonate content)
      - n (nul) .... : 2 (slightly suscept.)
      - m (moderate) .... : 2 (slightly suscept.)
      - h (high) .... : 1 (not suscept.)
      - ? .... : ?
    - d (deep) > cc (carbonate content)
      - n (nul) .... : 2 (slightly suscept.)
      - m (moderate) .... : 1 (not suscept.)
      - h (high) .... : 1 (not suscept.)
      - ? .... : ?
  - f (fine) > wd (water-table depth)
    - s (shallow) .... : 4 (very suscept.)
    - m (moderate) > cc (carbonate content)
      - n (nul) .... : 2 (slightly suscept.)
      - m (moderate) .... : 1 (not suscept.)
      - h (high) .... : 1 (not suscept.)
      - ? .... : ?
    - d (deep) .... : 1 (not suscept.)
    - ? .... :

3. Severity level of the LQ "management system"

- > is (irrigation system)
  - n (none) .... : 1 (very appropriate)
  - f (furrow) > ds (drainage system)
    - n (no) > we (water extraction)
      - n (no) .... : 3 (moder. appropr.)
      - p (yes) .... : 4 (non appropr.)
      - ? .... : ?
    - p (yes) .... : 2 (appropriate)
    - ? .... : ?
  - s (sprinkler) .... : 2
  - d (drip) > we (water extraction)
    - n (no) .... : 2 (appropriate)
    - p (yes) .... : 3 (moder. appropr.)
    - ? .... : ?

4. Physical subclass

- > lfm (landforms)
  - 1 (not sensitive) .... : 1
  - 2 (sensitive) > pps (profile physical quality)
    - 1 (not susceptible) > mnp (management practices)
      - 1 (very appropriate) ..... : 1
      - 2 (appropriate) .... : 2
      - 3 (moder. appropriate) ... : 2
      - 4 (non appropriate) ..... : 3
      - ? .... : ?
    - 2 (slightly susceptible) > mnp (management pract.)
      - 1 (very appropriate) ..... : 2
      - 2 (appropriate) .... : 2
      - 3 (moder. appropriate) ... : 3
      - 4 (non appropriate) ..... : 3
      - ? .... : ?
    - 3 (moder. susceptible) > mnp (management pract.)
      - 1 (very appropriate) ..... : 2
      - 2 (appropriate) .... : 3
      - 3 (moder. appropriate) ... : 3
      - 4 (non appropriate) ..... : 4
      - ? .... : ?
    - 4 (very susceptible) ..... : 4
    - ? .... : ?
  - 3 (very sensitive) .... : 4
  - ? .... : 4

17 *Soil Vulnerability Mapping in Sweden*

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ABSTRACT

The soil has often been regarded as an unlimited sink for chemical compounds. During the last 10 to 20 years many cases have occurred where the pedosphere has become a supplier rather than a sink of potentially harmful substances. Soil properties in Sweden and their changes are briefly described, including examples of mapping soil vulnerability to: soil acidification, nitrogen saturation, heavy metals, fluxes of greenhouse gases, and landfills as chemical time bombs.

INTRODUCTION

The soil has often been regarded as an unlimited sink for most chemical compounds. In the 1970s soil scientists were convinced that the buffering capacity against acid deposition was very high. Any substantial soil acidification was not expected. Now, 10 years later we know that "the impossibility was possible". A large scale soil acidification (10-100 times) over large areas in Europe has been documented. In the mid 1970s the mercury problem was thought to be solved in Sweden. The use of mercury compounds as fungicides was stopped and the emissions from chlor-alkali plants were decreased. Now, 15 years later, the mercury content in pike is exceeding the critical level of 1 mg kg^{-1} in fish in at least 10,000 lakes in Sweden. Accumulated mercury is mobilized through chemical and biological processes, and leached to the surface waters. Acidification is one process contributing to this mobilization.

These are just two examples where the pedosphere has become a supplier rather than a sink of potentially harmful substances. Additional examples could be given and we may expect several fresh chains of events to be discovered in the near future.

SOIL ACIDIFICATION

Soil acidification is now a well-documented process. Models have been developed to understand the processes and to predict the changes at various deposition scenarios. The results of Swedish studies show, among other things:

- Decrease in the pH of forest soils in southwest Sweden usually amount to 0.3 to 1.0 pH units (in some cases 1.5 to 2.0 pH units) in the last 40 to 50 years.
- Soil acidification has penetrated to a depth where it affects the shallow groundwater.
- The easily-available stores of base cations (calcium, magnesium) have been depleted by as much as 30 to 70 per cent in southernmost Sweden in the last 40 years.
- Concentrations of aluminium and some heavy metals (cobalt, cadmium, zinc) have increased as has the leaching into groundwater and surface water. The high leaching of cobalt may contribute to the appearance of some "problem algae" in the sea.
- pH in the mineral soils of a total forested area of about 650,000 hectares is below pH 4.4.
- The liming of Swedish agricultural soils is insufficient to maintain a pH of 6 to 7, which is considered the optimal pH for arable soils. As much as 45 per cent of arable land has a pH lower than 6.0. Crops may absorb more cadmium at lower pH.

The main causal factors are deposition of acid compounds, mainly sulphuric acid. However, biological processes contribute significantly to the acidification of the upper horizons of the soil.

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The use of nitrogen fertilizers enhances the process. Afforestation of arable land, using coniferous trees, will cause acidification of such areas. Thus accumulated heavy metals, such as cadmium, will be mobilized from the soil complex.

With respect to acidification, soil vulnerability mapping in Sweden includes:

- Forest Soil Surveys, covering the whole country every 10th-year. Land use, tree composition, tree growth, ground vegetation, soil type, soil texture and other variables are studied on 20,000 permanent plots. Soil samples are taken from different soil horizons and analyzed for pH, carbon and nitrogen. A much wider analytical programme (including calcium, magnesium, aluminium, heavy metals, etc.) has been applied on a smaller number of the samples.
- Surveys of the arable land, but in a less systematic way than for forest surveys, in order to optimize the use of lime and fertilizers.
- Compilation of critical load maps for Sweden based on the data base of the forest soil survey.
- More than 5000 wells have been surveyed for their chemical quality (pH, alkalinity, sulphate and heavy metals).

NITROGEN SATURATION / EUTROPHICATION

There are signs that forested areas are approaching a situation of nitrogen saturation in southernmost Sweden:

- In many cases, the trees do not respond by increased growth after an application of nitrogen fertilizers.
- The leaching of nitrate from forested land has increased markedly (in some cases sharply) in recent years.
- Plants favoured by nitrogen have increased in forest and rural areas.
- Coniferous trees in southernmost Sweden have a higher nitrogen content (and especially some amino acids) than those further north.

Nitrates are being leached from arable soils, especially in the southern part of the country. In areas of sandy soils, the nitrate concentrations exceed the critical levels of the drinking water quality guidelines.

The main causal factors are deposition of nitrogen compounds in forest lands and the application of manure and inorganic fertilizers on agricultural soils.

Soil vulnerability mapping in Sweden includes:

- Forest Soil Surveys in which the uptake of nitrogen by trees is calculated. Thus the critical load for nitrogen has been estimated. Changes in the vegetation are monitored in 20,000 plots.
- Site specific studies in research-oriented plots, including throughfall studies, chemical composition of needles, leaching of nitrate (watersheds, lysimeters, etc.).
- Arable soil survey which aims to determine an "adjusted fertilization", by taking into account the climatic conditions, the content of inorganic nitrogen in the soil and other factors.

HEAVY METALS

The environmental history of mercury in Sweden vividly illustrates the theme of this workshop and the concept of chemical time bomb. In the 1960s, the toxic effects on birds and other animals from the use of fungicides were obvious. In the 1970s emissions from industrial sources (e.g. chlor-alkali plants) were decreased to almost zero, thus it was thought that the mercury problem was solved. In the 1980s the problem has re-emerged as a delayed response. Now mercury is leaching from forest soils to surface waters, partly due to the acidification. The mercury content exceeds the critical level of 1 mg kg^{-1} fish in at least 10,000 lakes in Sweden. Recent results indicate that a substantial amount of the mercury flux is methyl-mercury, a species which is transformed from inorganic mercury originally deposited to the soil. Unless driving forces for the methylation and leaching processes are stopped, the soil will be a Hg-supplier for a long time.

Acidification causes mobilization of some other heavy metals as well (e.g. cadmium, zinc, cobalt). These elements are leached to ground and surface waters. Heavy metals accumulate in arable soils, as a result of input from deposition, fertilizers and the application of manure. The mean concentrations are rather low but taking a long-term perspective the critical concentrations (ecologically or health-related) may be exceeded. The mobilization of heavy metals is one argument against the shift from agricultural use to timber production with coniferous trees. The present concentrations of most heavy metals reflects the original content of the minerals in the soil to which some anthropogenic sources have been added.

With respect to heavy metals, soil vulnerability mapping in Sweden includes:
- Measurement of deposition of heavy metals using the moss technique every 5th-year.
- Mapping of heavy metals in the humus layer.
- Mapping of the content of cadmium in moose livers and kidneys (which shows a steep gradient from south to north).

FLUXES OF GREENHOUSE GASES

The terrestrial ecosystems are both major sinks and sources of carbon dioxide, methane and dinitrogen oxide. The flux from natural origins often dominates compared with any anthropogenic sources. Land use, chemical and biological changes may have a significant effect on the fluxes of these greenhouse gases. It is a challenge for SOVEUR to include these processes, which may be exemplified by the following questions:
- Can the national budgets of these gases be quantified?
- How much carbon is accumulated/released from forest and arable soils under various land uses?
- What impact does nitrate concentration, acidification and liming have on the fluxes?
- How does drainage of wetlands affect the flux of methane to the atmosphere?

These and other questions should be addressed by the SOVEUR programme. Currently, various approaches to these aspects of a mapping/monitoring programme are being discussed in Sweden.

LANDFILLS AS CHEMICAL TIME BOMBS

Strongly contaminated soils are rather localized in Sweden. Some major types are:
- Wastes at old or new mine sites from which heavy metals are leached. If oxygen and water are allowed to percolate, very high concentrations of heavy metals may continue to occur for a long time.
- Municipal wastes from which leaching is strongly dependent on the type of waste, the site hydrology, the method of tipping and cover system used.
- Industrial spills, e.g. arsenic and creosote as a consequence of impregnation of wood.

These types of point sources of pollution are fairly well mapped in Sweden. Programmes are in force to mitigate the environmental effects caused by old sites. It is not obvious how to include these point sources in the mapping of soil vulnerability.

18 Soil Vulnerability and Chemical Pollution: the Nitrogen Cycle in UK Agriculture as an Example

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ABSTRACT

This paper reports on the objectives and activities of the European Environmental Research Organization (EERO) and discusses aspects of soil vulnerability and chemical pollution in the United Kingdom using the nitrogen cycle as an example.

OBJECTIVES AND ACTIVITIES OF THE EERO

The EERO aims to promote the most effective use of available intellectual and technological resources for environmental research in Europe and the neighbouring countries. Initially, the following mechanisms are being used to achieve this objective:

- international long term fellowship awards for outstanding young postdoctoral scientists,
- international short term fellowship awards to enable talented scientists to visit foreign laboratories to learn newly developed techniques or initiate collaboration,
- advanced laboratory courses and workshops, and
- an annual symposium.

Although the potential scope of environmental research is broad, the initial efforts will be focused on the various aspects of chemical pollution:

- processes,
- impacts,
- remedial measures.

Clearly the properties of the soil are often of major importance in all these connections and so the participants in this meeting are warmly invited to consider whether scientists in their own laboratories might wish to apply for funding of EERO fellowships or workshops, or to receive holders of EERO fellowships from other European institutions.

SOIL VULNERABILITY AND CHEMICAL POLLUTION: THE NITROGEN CYCLE IN UK AGRICULTURE AS AN EXAMPLE

Information gathered about ten years ago in the UK (Table 1, references 1 and 2) can be used to illustrate some of the problems involved in tracing the fate of a particular chemical pollutant. UK agriculture could be proud of the five-fold increase between 1940 and 1980 in its contribution to the nitrogen content of the national diet, although some of this was in the form of free nitrate in leafy vegetables rather than in more desirable forms such as proteins. But the gain was obtained at the cost of a more than twenty-fold increase in the amount of nitrogen added to farmland in the form of fertilizers and imported animal feeds. Furthermore, the quantity added by nitrogen fixation was less than 25 per cent of that added as fertilizer, so that for the foreseeable future increases in the area of legumes grown or improvements in the efficiency of the fixation process could cause only a marginal decrease in the total national use of nitrogen fertilizer.

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Table 1 Nitrogen in UK agriculture (all values in Kt N)

Year	Added in agriculture	Ingested in home produced food	Added by fixation	Stored in soil
1940	60	40		
1980	1,450*	200	300	2.10^5

* includes 180 Kt N in imported animal feed

The 10^6 tons of added nitrogen that fails to find its way into the human diet becomes added to the soil reservoir, to surface waters and aquifers where it may affect the quality of drinking water supplies, and to the atmosphere where it may contribute to climate change. But the scale of these additions should be kept in perspective and for example the amount added annually to the soil is only 0.5 per cent of the total quantity of 2.10^8 tons already present.

SOIL PROPERTIES AND CHEMICAL POLLUTION PROCESSES

The process of nitrogen fixation clearly depends on soil physical, chemical and microbial properties as well as on temperature, soil water and the presence of legumes. Transformations by nitrification or denitrification depend on a similar range of properties and also on the state of aeration and redox potential.

The capacity of soil to store nitrogen varies greatly depending on organic matter content and the microbial biomass. Thus for some soils the amount added as fertilizer may equal or exceed the quantity stored, while for others it is an insignificant fraction. For chemical pollutants that are more persistent than nitrogen, the clay mineral content may be a much more significant factor in determining soil storage capacity.

SOIL PROPERTIES AND CHEMICAL POLLUTION IMPACTS

Differences in terrain can greatly affect surface run-off and its consequences for the nitrogen content of surface waters that may enter the human food chain through domestic supplies. Eutrophication and the whole ecology of freshwater depends critically on the nitrogen content of surface run-off. Apart from phosphorus, few other chemical pollutants have such a major role.

The impact on the nitrate content of water in aquifers that may eventually be used for domestic supplies depends on the micro and macro structure of both the soil and the underlying rock. Channels left by plant roots, earthworms or natural cracking may allow movement through media that would otherwise be only slowly permeable. Also, the nitrate content of the percolating water changes both as a result of interaction with soil microorganisms and through hydrodynamic dispersion by absorption into soil aggregates.

Additions from the soil to the atmosphere include oxides of nitrogen, ammonia, and free nitrogen gas. Only the last of these is neutral from a pollution point of view and the rates of release vary greatly with soil properties and environment.

The effects of nitrogen in changing soil microbial biomass and organic matter content again vary greatly with soil properties and since these are the main processes determining the amount of added nitrogen that remains stored in the soil for future exploitation they merit particular attention.

Nitrogen and many other chemicals from agriculture and other industries enter the natural and managed flora and fauna and ultimately enter the human food chain. Plants and animals may adapt or be selected to tolerate new levels of particular chemicals, but man can adapt only slowly if at all and the ultimate purpose of environmental protection and conservation must be to protect human health. Thus soil properties and vulnerability to pollutants have more far-reaching consequences than might at first be supposed.

The time course of these impacts is often crucial in terms of their detection and the remedial measures that might be taken. For example, the nitrogen released through a change from grassland to arable agriculture may take 20 years to reach aquifers under some soil profiles, while in others the transport may be almost immediate.

SOIL PROPERTIES AND REMEDIAL MEASURES

The fate of nitrogen fertilizer can be altered either by a change of land use or a change of soil management (Table 2 and reference 3).

Table 2 Leaching of fertilizer N (%)

Grassland	20
Arable	30
Direct drilling	20
Ploughing	30

A change from arable agriculture to grassland can typically cause a large decrease in the leaching of fertilizer nitrogen, but both the scale of the decrease and the practicability of making the change depend strongly on the soil type. Alternatively, changing within arable agriculture from conventional ploughing to direct drilling (zero tillage) also typically causes a large decrease in fertilizer leaching, but again such a management change is made much more easily on some soil types than on others.

CONCLUSION

The framework of processes, impacts and remedial measures may help to provide a basis for defining soil vulnerability to chemical pollutants and for assessing the usefulness of mapping terrain and soil properties.

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19 The Soils of Wales and their Vulnerability to Chemical Pollution

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ABSTRACT

Basic data are available about the soils of Wales from surveys at scales of 1:25,000, 1:63,360 and 1:250,000. Surveys have also taken place of potential sites of contamination and of the associated problems of dereliction. Soil contamination occurs in two forms: dispersed and concentrated. Dispersed forms of soil pollution result mainly from contaminants reaching the soil via the atmosphere, but may also occur through the use of sewage sludge and fertilizers spread on the land. Concentrated forms are usually the result of industrial activity on a particular site, where through spillage or leakage, noxious materials have infiltrated into the soil or where toxic waste products are dumped. The characteristics of potential significance to an assessment of the vulnerability of soils will be examined, and examples of problems encountered in Wales will be presented.

INTRODUCTION

Expressed in the simplest of terms, soils are composed of mineral and organic constituents with voids which contain either air or water. However, soils also have a definite structure and morphology which is recognised in their horizons, profiles and pedons, the latter giving the soil a three-dimensional quality. The possibility of contamination exists in all four components of the soil; solids with the mineral and organic constituents, liquids may contaminate the soil solution and migrating gases may displace the soil atmosphere. The distribution of contaminants may be influenced by the nature of the soil and the structure of its profile.

Many substances are present in small amounts or low concentrations in soils, these may not necessarily be harmful, but may be regarded as contaminants. Polluted soils are those which contain alien substances that are likely to cause harm, directly or indirectly to man, the environment, and occasionally to other targets. Thus a distinction may be drawn between contaminated and polluted soils, but conventional usage of the term *contaminated soils* ignores this distinction. Therefore it is necessary to make the position clear, the definition of contaminated soil has to be qualified by the statement that to be hazardous, pollutant substances must be present in sufficient quantity and concentrations above the background levels normally experienced (Bridges, 1990).

Experience in Wales has demonstrated that there are two broad groups of soil pollutants, those which arrive in the soil from the atmosphere and result in widely dispersed pollution and secondly, those which are restricted to relatively confined areas, but which may be more damaging as their concentrations are greater. Examples of the former are the effects of acid deposition and radioactive fall-out, and of the latter sites formerly occupied by a town gasworks or a metal smelter.

THE SOILS

The soils of Wales have been mapped by the Soil Survey of England and Wales at a scale of 1:250,000 (Rudeforth *et al.*, 1984) and more detailed maps are available of smaller areas at scales

Soil Vulnerability to Pollution in Europe
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of 1:63,360 and 1:25,000, scattered throughout the Principality. The parameters of soil formation in Wales are set by the cool wet climate, the strong relief and extensive outcrops of hard palaeozoic rocks, in part covered by glacial drifts, in which the processes of leaching, podzolization, gleying and peat accumulation have been dominant. Evidence of a former periglacial environment may be seen in the lower horizons of many soils, in which fragipans offer restriction to rooting depth and water penetration.

The most extensive soil mapped in Wales is the Manod association, 3744 km^2 or 18 per cent of the surface area. This mapping unit is dominated by brown podzolic soils with inclusions of brown earths and rankers and occurs on more elevated, steeply sloping valley sides under woodland or poor grazings with bracken. The soils are loamy and shallow with solid or shattered rock occurring at < 80 cm depth. At lower elevations the Denbigh association is widespread, 2019 km^2 or 10 per cent of the surface area. This association is dominated by permeable clay loams with a brown earth profile, having solid rock or shattered rock at < 80 cm depth. These soils are normally permanent grazings but some arable farming may take place in drier districts. In South Wales the Milford association, covers 1064 km^2 or 5 per cent of the surface area. The soils of this association are dominated by fine loamy brown earths developed from mudstones and siltstones on low coastal plateaux where they are extensively used for early potatoes, vegetables and improved pastures. Smaller areas of sandy brown earth soils occur on escarpments in South Wales but at higher elevations brown podzolic soils of the Withnell association occur. Argillic brown earths have a limited area in Wales; these fertile soils occur only on lowland in the Vale of Glamorgan where they are highly prized for arable and grazing land.

Seasonally waterlogged cambic stagnogley soils of the Cegin association, developed over lower palaeozoic rocks and derived glacial drifts, cover 1494 km^2 or 7 per cent of Wales. These soils occupy lower plateau surfaces and wet footslopes where loamy or clayey textures and slowly permeable subsoils confine their use to permanent grassland. On upland plateaux wet loamy stagnohumic gley soils of the Wilcocks association are extensive, covering 1232 km^2 or 5 per cent of Wales. A combination of the cool wet climate, low summer temperatures and a slowly permeable subsoil has resulted in strongly acid, gley soils with 10 to 30 cm thick peaty surface horizons. These soils are associated with amorphous peats of the Crowdy association which cover 682 km^2 on the higher hills of the country, particularly in North Wales. Alluvial soils are not extensive in Wales but are significant in the present context as they offer scarce areas of flat land for industrial development and are, therefore, highly likely to suffer from pollution.

DISPERSED POLLUTION

Soil contaminants may be considered in two broad groups, those which are being widely dispersed and those which are concentrated in relatively restricted areas. The title of this workshop suggests a concentration on the latter rather than the former but both give cause for alarm. Two examples of dispersed contamination which have seriously affected upland districts of Wales in recent years are the impact of acidification and radioactive fall-out. In both cases considerable research has been carried out which it is only possible to review briefly in this paper.

Acidification

Approximately 4000 km^2 of Wales is underlain by Lower Palaeozoic shales, grits and mudstones upon which brown podzolic soils, ferric stagnopodzols and oligomorphic peats have developed. These are soils with organic surface horizons, shallow profiles and a low buffering capacity and so have little resistance to the process of acidification. Precipitation in these mountainous areas of North Wales is in excess of 1500 mm rainfall and in places is over 2000 mm per annum. The average pH of rainwater over Wales is pH 4.7, but over the mountains of North Wales it is between pH 4.4 and 4.5 resulting in the deposition of 0.4-0.8 kg H^+ ha^{-1} yr^{-1} and around 10 kg ha^{-1} yr^{-1} excess sulphur (Cresser *et al.*, 1989; Edwards *et al.*, 1990; Omerod, 1990) (Fig.1).

Soil acidification is not a visually obvious feature, but where it occurs plant growth is affected and waters draining from the affected soils possess higher concentrations of exchangeable aluminium with serious impact on river life and possibly effects on human life if the link with Alzheimer's disease is correct. Experimental work in the mountains of Central Wales has shown the greater release of exchangeable aluminium from the gleyed eluvial horizons of stagnohumic gley soils. Severe acidity in soils interferes with microbial life, inhibits nitrification and leads to other environmental damage to the vegetation and to aquatic life. At low pH, the solubility and availability of other metallic elements becomes greater, and this too, may affect plant growth in certain locations.

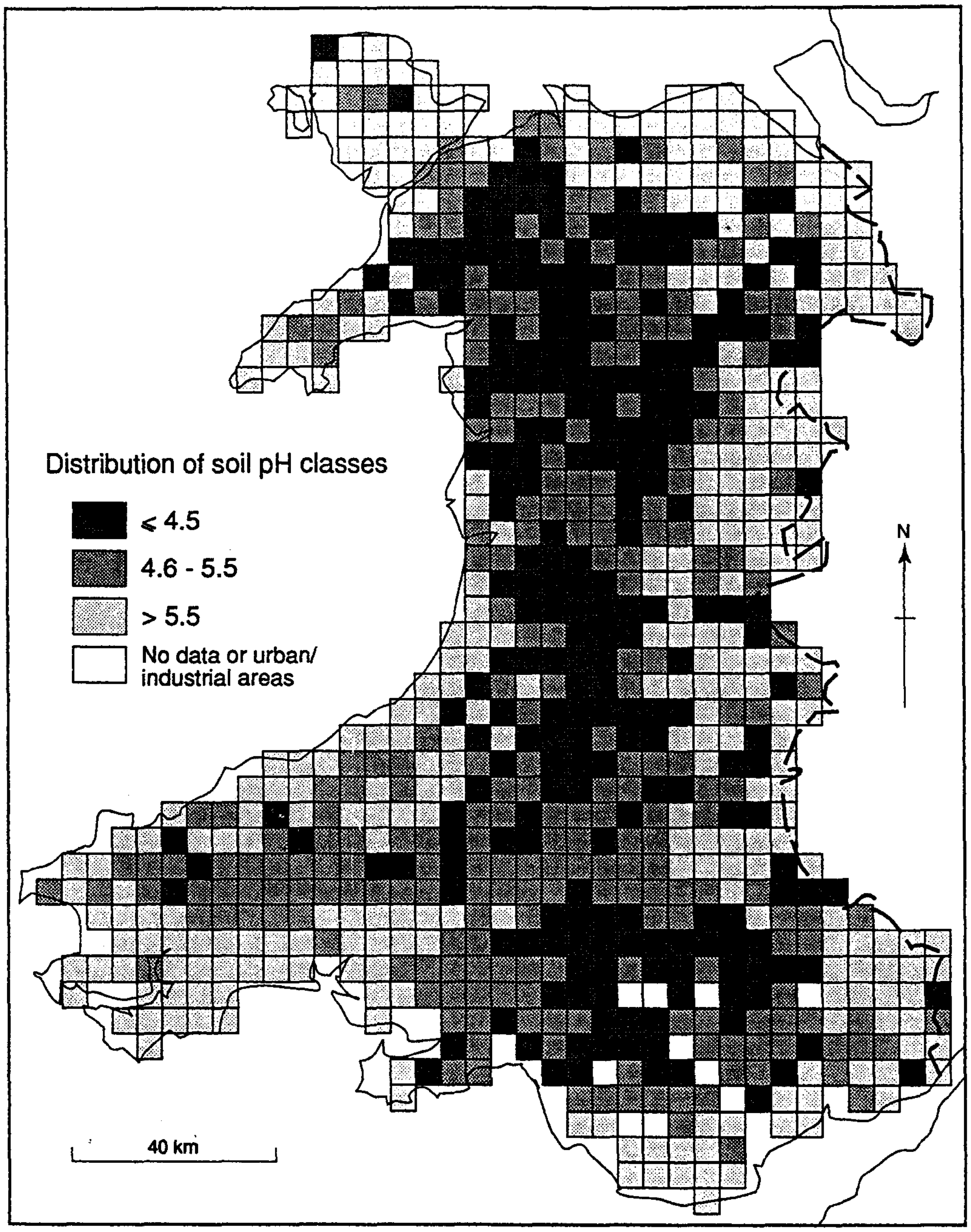

Figure 1 Distribution of soil pH classes in Wales (after Thompson and Loveland, 1985)

Radioactivity

Background levels of radioactivity have been the subject of investigations by AERE Harwell for the Welsh Office in the period 1984-1986. Measurements have been made of the accumulation of ^{134}Cs, ^{137}Cs and plutonium to the depth of 30 cm in permanent grassland soils in Wales. Twenty-seven sites throughout the country within a 30 km grid provided samples for the survey, the aim of which was to "establish the concentrations of radionuclides that have accumulated in the environment of Wales and to investigate the extent of sea-to-land transfer of radioactive elements". Additionally, the survey looked at the transfer of ^{90}Sr and ^{137}Cs from soil to crops and to man. The findings of this survey were typical of the amounts anticipated from weapons testing fall-out and were insignificant in terms of radiological hazard. However, a close relationship between high rainfall areas where the amounts could be up to three times greater than those in low rainfall, low relief areas. Small quantities of plutonium were involved in a sea-to-land movement on the north coast of Wales where concern had been expressed about discharges into the Irish Sea from Sellafield (Cawse *et al.*, 1988).

In the last year of this survey, the accident occurred at Chernobyl releasing a cloud of radioactivity which drifted across northern Europe and the British Isles. Substantial increases in ^{134}Cs and ^{137}Cs occurred in north and central Wales compared with the baseline established in earlier years of the survey through the scavenging effect of rainfall through the Chernobyl radioactive cloud (Fig.2). Theoretical predictions anticipated that the longer lived ^{137}Cs would quickly become adsorbed onto the clay lattice of the mineral soils, but the highly organic nature of soils in the mountainous regions of Wales enabled the ^{137}Cs to remain available for uptake by plants. Research in Scotland (Mayes *et al.*, 1987) has led to the statement that the ^{137}Cs concentration of certain sheep will continue to exceed the 1000 Bq kg^{-1} limit for some years to come (sheep movements from some farms are still restricted). The highest rate of failures occurs in farms where flushes and groundwater enrichment take place (Hartnup, pers. comm.), an observation which has been noted in a more general way by Bennett *et al.* (1988) with sediments of the river Wye. Observations by the Welsh Office Agriculture Department and details of the area currently affected have been refused on the grounds of confidentiality.

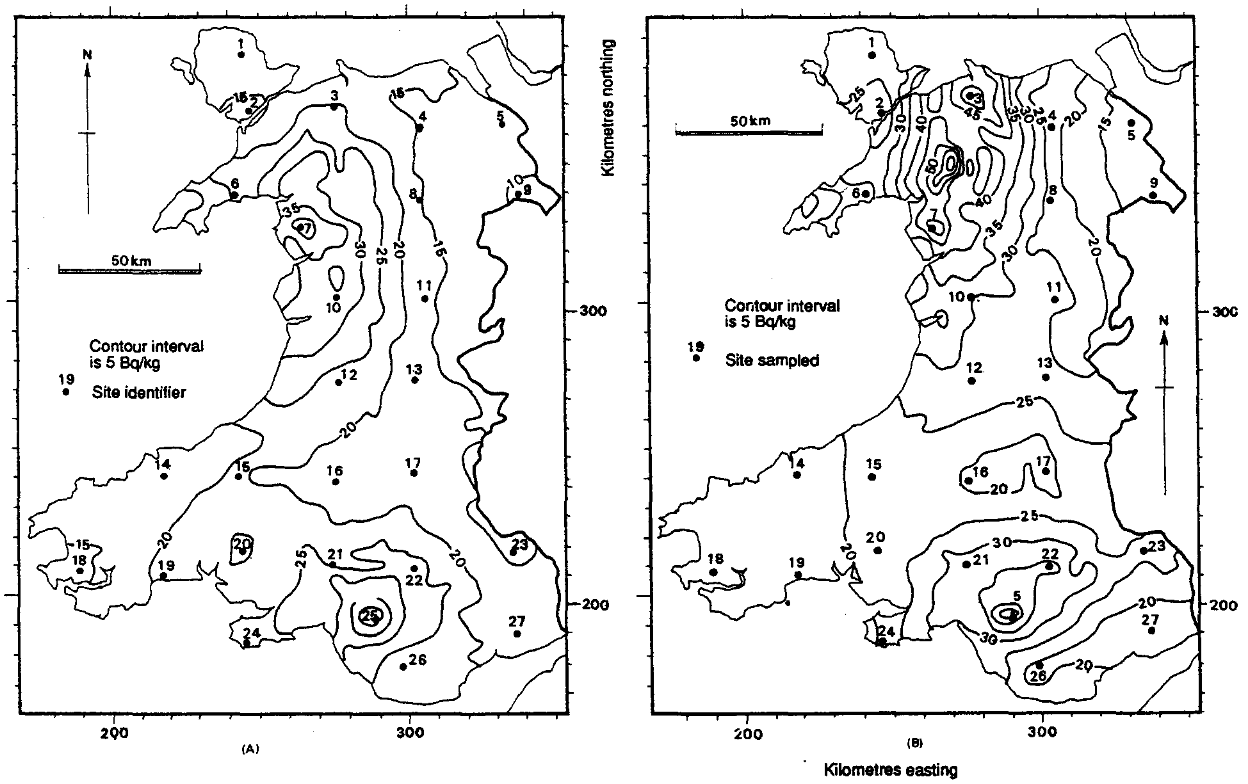

Figure 2 Concentration of ^{137}Cs in the topsoil (0-30 cm) of Welsh grasslands (Bq kg^{-1}; (A) in 1984 and (B) in 1986; after Cawse et al., 1988)

CONCENTRATED POLLUTION

Many human activities are likely to contaminate the soil to some degree, but some industrial processes are certain to result in pollution. These include mining, smelting and working of metals, gasworks, chemical and pharmaceutical works, pesticide manufacture, paint and colouring manufacture, explosives and munitions works, oil and petroleum production and storage, tanneries, wood preserving factories, asbestos factories, integrated circuits and semi-conductor manufacture, docks and railway land, scrapyards, sewage works and farms, landfills and waste disposal sites. The most common toxic substances observed to pollute soils include metallic elements and their compounds, organic chemicals, oils and tars, pesticides, radioactive materials, biologically active materials, combustible materials, explosive and asphyxiant gases and other hazardous minerals, such as asbestos (Bridges, 1988).

Surveys of contaminated land

In Wales, we are fortunate to have already in existence a survey of potentially polluted sites of more than 0.5 hectare. At the request of the Welsh Office, the Environmental Advisory Unit of the University of Liverpool compiled lists and maps of all suspect sites. The survey was achieved by studying all published maps and aerial photographs, as well as reference directories and guidebooks for specific industries. Information was obtained from the Welsh Water Authority and the Health and Safety Executive who maintain records of sites which are polluting the environment. There have also been surveys of derelict land which list many former industrial sites and local authorities hold valuable information about waste disposal sites. The original survey, carried out in 1982/83 revealed 712 sites, it has been revised in 1987/88 and the total now stands at 749. Although ground surveys of each site have not taken place, these surveys represent an invaluable register of potentially contaminated land which is unique in the British Isles. Data are held on computer and coded so that retrieval can be by a number of criteria, by county code, or by grid reference. Therefore unlike many other countries or provinces, in Wales we can at least claim to know the nature of contamination and its geographical position (Welsh Office, 1983 and 1988).

A key component of a desk-top survey, such as has been described is the development of an industry/contaminant matrix. This depends upon the assumption that particular industries have recognisable waste products and that these have characteristic effects on the site and its surroundings. The matrix has been compiled from case studies of former known industrial sites where the operational processes are well known. When processes have become obsolete and not been used for many years, deductions can be made using information from industrial archaeology. Such a matrix cannot be used to determine the concentration of waste materials, but it is useful in providing a general guide to the likely range of contaminants.

Surveys of heavy metals

Wales has a long industrial history of mining and refining metals which have left a legacy of toxicity in the soils of many parts of the country. Unproductive pastures along the Ystwyth and other rivers were explained by toxic levels of lead and zinc in the alluvial soils polluted by debris from mines, the distribution of which is shown by Davies and Alloway (1974). The Wolfson Geochemical Atlas (Webb, 1978) based on stream sediment analysis gives the broad picture of heavy metal anomalies throughout the United Kingdom. Davies and Roberts (1978) have studied the concentration of heavy metals in the soils of northeast Wales where galena (PbS) and sphalerite (ZnS) were mined and smelted. Distribution of the contamination and its impact on the population is discussed in the Halkyn Mountain Project Report (Davies, 1983).

As a result of the findings of these surveys, it was appreciated that a national survey of concentrations of heavy metals in soils would be helpful in identifying background values and distinguishing those areas where enhanced levels occurred. As a result, Davies and Paveley (1985 and 1987) undertook the analysis of 824 samples of A horizons and 646 samples of B horizons of

Welsh soils collected on a regular grid of 5 km interval. The data bank provides the opportunity to give realistic values for mean concentrations as well as the probability range encountered throughout Wales. The National Soil Inventory of the Soil Survey has concentrations of 19 elements including Cu, Pb, Zn, Cd, Cr, Mn, and Ba from a 5 km grid over Wales and England.

A heavy concentration of metal smelting occurred at Swansea in South Wales during the eighteenth and nineteenth centuries (Bridges, 1984, 1988 and 1990). This activity resulted in devastation of the vegetation, causing soil erosion and soil contamination with copper, lead, zinc and cadmium in the area known as the Lower Swansea Valley. A survey of heavy metals on the soils of the City of Swansea reveals enhanced concentrations are widespread, although the only one to give cause for alarm is the generally high concentrations of cadmium remaining in the soils in the vicinity of the former zinc smelters. Davies (1990) examined the contamination of soils around the nickel refinery immediately to the north of the city of Swansea, and Culbard *et al.* (1988) studied links between metal-contaminated soils and public health.

Movement of metallic pollutants into the soils has been mainly through the spread of particulate matter as dust. Measurement of this fine air-home dust has been attempted by the moss-bag technique. In the early 1960s it was observed that there was a moss-lichen desert in the Lower Swansea Valley, but any moss brought into the area rapidly picked up metal contamination. So, moss was collected from an uncontaminated district and placed in bags and suspended in the atmosphere. After an appropriate time had elapsed, the moss was analyzed and the extent of air-home contamination assessed. Surveys of this nature took place for the Welsh Office in Swansea and throughout South Wales where two large steel works, two large tinplate works, several oil refineries and many other smaller potential polluting industries were situated. Although not a measure of soil contamination as such, this technique does indicate the general movement of dust from works and from tip heaps of waste materials from the metallurgical industry (Goodman and Roberts, 1971; Welsh Office, 1975).

The residence time of metals in the soil is of critical concern if additions continue to be made through fall-out and sewage sludge. Bowen (1979) estimated the residence time of Cd in soils to be between 75 to 380 years, Hg persists for 500 to 1000 years, and more strongly adsorbed elements such as As, Cu, Pb, Se and Zn have residence times of 1000 to 3000 years, but Japanese authors give "half-lives" of these metals of approximately twice these figures. McGrath (1987) indicates that heavy metals derived from sludge deposited on fields has a residence time of 1000 to 10,000 years; this amounts to permanent contamination.

SOIL CHARACTERISTICS AND VULNERABILITY

The vulnerability of soils to certain contaminants rests upon those characteristics which enable soils to resist alteration and degradation, and which maintain the biological functions expected of a soil. As little study of this aspect of soil science has taken place, this section is a mixture of gleanings from the literature and the operation of basic principles to make some suggestions. It would appear that the basic mineralogy, pH values, organic matter content, texture and structure are worthy of consideration in this respect.

The basic mineral composition of soils will influence the texture and structure of the soil profile. In a simple example a coarse sand will allow rapid infiltration and permeability permitting the deep penetration of liquid contaminants such as spillage of petroleum. Soils with loamy textures and greater development of structure will respond differently with slower penetration and greater areal contamination. Infiltrating rainwater may be responsible for leaching contaminants out of chemical time bombs to the water table to pollute water courses or drinking water supplies. Deep penetration of immiscible liquids is stopped by the presence of a water table in ground-water gley soils. Much of a spillage can be removed from a permeable soil if a well is drilled and the spillage drawn into the cone of abstraction and pumped out.

Some soils, subsoils or parent materials have calcium carbonate present; these soils are well buffered and capable of withstanding the excessive leaching caused by acid deposition. Soils lacking carbonates or with low base saturation, especially acid, shallow skeletal soils, organic-rich mineral soils and peats, have little resistance to this process and rapidly develop symptoms of the "acid rain" syndrome. In north and west Wales, the soils of the higher mountain ranges have these characteristics and have been shown to be vulnerable to the process of acidification. Although few of the soils in the rest of Wales are calcareous, they possess sufficient exchangeable bases to buffer them against excessive leaching. When toxic metal ions are present in soils, the presence of carbonates reduces their mobility and the impact of their toxicity.

The role of soil colloids, mineral and organic, as the seat of exchange properties of the soil, is a significant characteristic which must be involved in the vulnerability of soils to chemical contamination. Most metallic contaminants of soils are in an ionic form in the soil and so are able to participate in exchange reactions. At the same time the process of adsorption controls the behaviour and availability of metals. In addition to the normal cation exchange, metals may be held by specific adsorption, involving the exchange of heavy metal cations and most anions with surface ligands to form partly covalent bonds with lattice ions. This enables the sorptive capacities of amorphous Fe and Al oxides to be between 7 and 26 times greater (for Zn) than the measured cation exchange capacity would indicate. Specific adsorption is strongly pH dependent and is related to the state of hydrolysis of the heavy metal ions. Ionic diffusion into minerals such as goethite, manganese oxides, mites, smectites also occurs. Metals also form chelation complexes with organic substances involving hydroxyl, phenoxyl and carboxyl groups, the latter play a predominant role in metal binding in both humic and fulvic acids (Alloway, 1990).

CONCLUSION

In addition to the basic role of production of biomass, Schroeder (1984) has described soils as having filtering, buffering and transformation functions which help protect the environment and mankind from the effects of pollution. Impairment of any function of soils diminishes their quality, value and capacity to provide the basic necessities to support ecosystems. It has been accepted that providing the soils capacity is not overloaded by a contaminant, it will retain its biological activity, but in some cases, as with some toxic metals, only small concentrations may reduce microbial activity drastically, and the soil is described as vulnerable, especially if environmental conditions change. In some cases the safety threshold effectively may be nil. At present, only a start has been made on soil vulnerability mapping exercises in Wales, but much of the basic information required for such studies is already in existence and usually can be accessed with the permission of the organisations holding it.

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ADDENDUM

As there was no participant specifically to speak for England at the workshop, the verbal contribution which accompanied this paper was extended to report upon work of the Soil Survey and Land Research Centre at Silsoe. Delegates were shown maps of England and Wales indicating those soils most vulnerable to acidification, and of weathering rates depicted in a modification of the Skokloster classification, the latter being a manuscript version of a map for a critical loads approach to soil contamination. Maps were shown of the distribution of radioactive fall-out on the soils of England and Wales, and attention was drawn to the scale of immobilisation capacity classes proposed by Loveland and Livens (1988)* for identification of those soils most affected by the Chernobyl episode in northwest England. This scale has been applied informally to Welsh soils as well.

The leaching of fertilisers and pesticides has been the focus of considerable research in England. The appearance of nitrates and pesticides in the waters of aquifers in eastern England has stimulated interest in the movement of these substances through soils and the geological materials overlying the aquifers from which drinking water is obtained. Using the hydrology of soil types and organic matter content, vulnerability classes for surface and ground waters have been produced. When the nature of the pesticide is taken into consideration, its mobility, persistence and toxicity, the crop to which it is applied, and the dominant soil of each 5 km grid square, maps can be produced for particular soil/pesticide relationships.

The Soil Survey's "LANDIS" data base has proved an invaluable tool for the study of a wide range of soil-related problems in England and Wales. Colleagues of the Soil Survey Land Research Centre and the Institute of Terrestrial Ecology have produced a study of The Principles of Soil Protection in the United Kingdom in which examples of mapping the risk and sensitivity of soils to currently perceived threats. Maps can be quickly produced from the Geographical Information

System to indicate the distribution of soil vulnerability problems, such as nitrate leaching and heavy metal accumulation.

The approach using critical loads of contaminants for soils is the subject of research in England. The Government commissioned a White Paper on the subject last year, entitled This Common Inheritance which has stimulated further interest in the acceptable concentrations of contaminants permissable in soils, particularly when used to produce foodstuffs and immediate introduction into the human food chain. The Institute of Biology has suggested that Environmental Quality Objectives be set up, similar to those applied to water pollution control. However, this approach accepts that threshold levels of contaminants are an acceptable method of approaching the problem whereas soil research has suggested there are problems with the presence of even minimal concentrations of some contaminants in soils. It does not take into account either any delayed reaction (of a chemical time bomb nature) related to environmental change.

*Livens, F.R. and P.J. Loveland, 1988. The influence of soil properties on the environmental mobility of caesium in Cumbria. Soil Use and Management 4:69-75.

20 Mapping Critical Loads of Acid Deposition on Scottish Soils and Predicting the Susceptibility of Surface Water Acidification in Scotland

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ABSTRACT

This paper describes the general principles and methodology used for the compilation of maps showing the distribution of critical loads to soils and the likely occurrence of surface water acidification in Scotland. The approach adopted makes use of the 580 soil units identified in the mapping of the soils of Scotland at a scale of 1:250,000, and ranks these units in terms of their critical load class and their susceptibility to yielding acidified surface waters under various conditions of flow. The maps produced indicate that large areas of Scotland are potentially or actually at risk from soil and surface water acidification.

INTRODUCTION

As part of the Commission of European Communities (CEC) programme on acid deposition, a task force has been established for the mapping of critical levels and loads of transboundary air pollutants. Member states have been requested to produce maps showing the geographical extent of different sensitivities of vegetation, waters and soils to acidifying pollutants, with the intention of using such national maps as the basis for the compilation of European critical load maps. "The mapping resolution and map unit is flexible to allow each country to work at the scale appropriate for their data, but must use primary grids of a resolution not larger than 1° longitude by 0.5° latitude ($\approx$ 50 x 60 km in central Europe) or uniform subdivisions of this grid. Within a nation, variable grid sizes may be used as long as they conform to these guidelines and critical loads can be set for both high or low resolution grids" (Draft Manual for Mapping Critical Levels/Loads, 1990).

The work described here deals with the critical loads of acid deposition for soils in Scotland and was sponsored by the Scottish Development Department. The principles for establishing critical loads followed those proposed by the Workshop held at Skokloster in Sweden (Nilsson and Grennfelt, 1988) and the approach used was agreed following discussions with the UK Critical Load Advisory Group for Soils, thus ensuring that comparable methods were used over the country as a whole. Following this work, a further mapping exercise was embarked upon aimed at predicting the likely occurrence of stream water acidification in Scotland under various conditions of hydrological flow. This work was also sponsored by the SDD, but is again part of a UK exercise, and was based upon the combined influence of geology, soils and land use as described by Hornung *et al.* (1990). The objective of the present paper is to describe for both of the above exercises the general principles underlying the approach adopted, the methodology used and its application to Scottish soils and, briefly, the results obtained.

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GENERAL PRINCIPLES

Critical loads

For forest soils critical load has been defined as "the highest deposition of acidifying compounds that will not cause chemical changes in soil leading to long term harmful effects on ecosystem structure and function" (Nilsson and Grennfelt, 1988). It is implied in this definition that in areas where critical load is exceeded then there should be discernible soil and ecological effects. The fundamental process that determines the susceptibility of a soil to acidification is the rate of chemical weathering of the soil minerals, and in general terms if the basic cations being released by this process do not keep pace with the depletion of such cations by uptake into the biomass or by leaching to ground or surface waters, then soil acidification will inevitably occur. Soil acidification is, of course, a completely natural process but it is now becoming apparent that acid inputs from the atmosphere as a result of emissions of pollutant gases may exacerbate natural acidification over a relatively short period of time (Berden *et al.*, 1987).

Five classes for critical loads of acidity to forest soils to a depth of 50 cm are shown in Table 1 along with matching information on soil mineralogy and the parent rock with which this mineralogy is associated. This table indicates, for example, that in general a soil consisting of up to 5 per cent of pyroxene, epidote or olivine minerals will be able to neutralize acid inputs up to the equivalent of 32 kg S ha^{-1} yr^{-1} by virtue of the basic cations released by the weathering of these minerals. In contrast, in soils derived from granite or quartzite and containing few weatherable minerals, then even acid inputs equivalent to 3 kg S ha^{-1} yr^{-1} are sufficient to overstep the critical load. There are, however, secondary factors which may modify the critical load determined by mineralogical criteria, either in a positive or a negative sense, and these are indicated in Table 2.

Both Tables 1 and 2 derive from the report of the Skokloster Workshop referred to previously (Nilsson and Grennfelt, 1988).

Table 1 Mineralogical and petrological classification of soil material for soil sensitivity to acid deposition in relation to critical loads

Class	Minerals controlling Weathering	Usual Parent Rock	Total Acidity (kmol(H^+) km^{-1} yr^{-1})	Equivalent sulphur (kg ha^{-1} yr^{-1})
5	Quartz Potassium Feldspar	Granite Quartzite	< 20	3
4	Muscovite Plagioclase Biotite (<5%)	Granite Gneiss	20 - 50	8
3	Biotite Amphibole (<5%) Schist	Granodiorite Greywacke Gabbro	50 - 100	16
2	Pyroxene Epidote Olivine (<5%)	Gabbro Basalt	100 - 200	32
1	Carbonates	Limestone Marl	> 200	64

Table 2 Conditions influencing critical loads to forest soils

	Decreasing Critical Load	Increasing Critical Load
Precipitation	high	low
Vegetation	Coniferous	Deciduous
Elevation/Slope	high	low
Soil Texture	coarse-sandy	fine
Soil Drainage	free	confined
Soil/Till Depth	shallow	tick
Soil Sulphate Adsorption	low	high
Base Cation Deposition	low	high

Predicting stream water acidification under various conditions of flow

Stream waters generally originate following percolation of precipitation waters through soils and/or underlying bedrock. The chemistry of the percolating water will be strongly influenced by the minerals with which it comes into contact and, for example, a high content of carbonate and/or weatherable silicate minerals in soils or rocks will greatly reduce the sensitivity of waters to acidification. However, residence time and conditions of hydrological flow are also important. Thus, during periods of low flow, stream waters will be largely derived from groundwater and its chemistry will reflect the nature of the geological materials with which it has been in contact for a relatively long period of time. During periods of high flow on the other hand, stream waters will increasingly be supplied by transmission through the soil column and the hydrochemistry will to a large extent reflect the ability of the soils to buffer incoming acidity principally through the mechanism of cation exchange from organic matter or fine-grained minerals.

These generalizations indicate that information on geology and soils can be used to assess the likelihood of surface water acidification under a variety of flow conditions. For geology, a classification showing the susceptibility to acidification of various rock types was adopted from the work of Kinniburgh and Edmunds (1986) (Table 3).

Table 3 Acidification susceptibility classification of solid geology

Category	Rock type
High Susc.	Granite, acid igneous, metasediments, grits, quartz sandstones, some quaternary sands
Medium Susc.	Intermediate igneous, metasediments, impure sandstones and shales, coal measure sediments.
Low Susc.	Basic and ultrabasic igneous, calcareous sandstones, mudstones, marls, drift alluvial deposits.
Not Susc.	Limestones, chalk, dolomites and related sediments.

For soils, three categories were erected according to the percentage base saturation found in the B/C horizon to a depth of up to 60 cm (Table 4).

Table 4 Acidification sensitivity classification of soils (B and C Horizons)

Category	Soil characteristics
High Susc.	pH < 4.5 or base saturation $< 20\%$
Medium Susc.	pH > 4.5 and < 5.5 or base saturation $> 20\%$ and $< 60\%$
Low Susc.	pH > 5.5 or base saturation $> 60\%$

These three categories corresponded to three distinct groupings observed when mean base saturation data were collated for the major soil series of Scotland. Combining geological and soil sensitivities and assuming the conditions of flow outlined above enables a set of five categories showing the probability of stream water acidification to be generated (Table 5).

Table 5 Geology and soil sensitivity and predicted likelihood of surface water acidification.

		Geological Sensitivity			
		High	Medium	Low	None
	High	5	4	3	2
Soil	Medium	4	4	3	2
sensitivity	Low	1	1	1	1

1. Acidification of surface waters will not occur.
2. Acidification may occur at very high flows.
3. Acidification likely at moderate to high flows.
4. Acidification may occur at all levels of flow.
5. Acidification widespread at all levels of flow.

METHODOLOGY

Scottish soil maps group soils according to their parent material (the Soil Association). This grouping was considered to be particularly appropriate for assessment of the critical load of the soil according to the classes proposed at the Skokloster conference (Nilsson and Grennfelt, 1988). The first step was, therefore, to assign each of the 118 Soil Associations in Scotland to a critical load class, based as far as possible on the mineralogy of the parent material. This initial assignment was then refined by taking into account some of the modifying secondary factors listed in Table 2, as applied to all of the 580 individual soil map units identified during the compilation of the 1:250,000 Soils Maps for Scotland (Soil Survey of Scotland, 1982). Each of these units was considered for soil type, topography, drainage and texture and these attributes employed as modifiers. In the final phase of application land use was also taken into account and where the land was under agriculture its critical load was reduced by one class, that is made less sensitive. The procedure is summarized in Figure 1. Ultimately, maps were produced by assigning each 1 km square to a critical load class based on the dominant soil unit of that square.

118 Soil Associations Mineralogy and Petrology	Phase I
580 Soil Units differentiated by dominant soil characteristics, Drainage texture, depth	Phase II (map 1)
dominant land use	Phase III (map 2)

Figure 1 Application and mapping of critical loads to Scottish soils

A map showing the susceptibility of surface waters to acidification was compiled in the following way. Firstly, the geological parent material on which the Soil Associations are based was classified for acidification susceptibility along the lines suggested by Kinniburgh and Edmunds (1986). This parent material largely consists of glacial tills but experience has shown that its mineralogy will to a large extent be similar to that of the parent rock. The use of soil parent material as a surrogate for solid geology actually enhances the resolution of the susceptibility classes adopted. The next step was to classify the acid sensitivity of the Scottish Soil Series (in the Scottish Soil Survey an Association is divided into a number of Series according to drainage status and soil type) on the basis of their mean percentage base saturation calculated from the results in the Soil Data Base. Each of the 580 soil map units used in 1:250,000 soil maps were then assigned an acidification sensitivity category. It was considered unlikely that waters draining soils under agricultural management would be acidic or susceptible to acidification and soil units being managed in this way were assigned a reduced sensitivity. The final map showing the probability of streamwater acidification under various conditions of flow was then constructed by overlaying the modified soil sensitivity map on to the map of geological sensitivity.

It should perhaps be stressed that the map units, on which both sets of maps are based, comprise *groups* of soils from a given Soil Association occurring within a distinct landscape/geomorphological unit. The units can therefore encompass considerable variation in soil type, a variation that is lost in the final maps which are based on the most widespread soil within the unit.

APPLICATION AND RESULTS

The application of the above approach and methodology is illustrated by the critical load and surface water sensitivity maps that will be available for inspection by Workshop participants. The areas of Scotland covered by the different critical load classes are shown in Table 6.

Table 6 Areas (km^2) covered by critical load classes for soil associations and units

Class	Association	Unit	Unit with Land Use
1	670	2,624	4,526
2	6,621	8,549	14,795
3	15,912	13,994	14,168
3-4	7,584		
4	35,952	40,692	32,379
5	1,255	2,501	2,501
Organic	7,660	7,660	7,660

The most extensive class is Class 4, whose critical load is 50 Kmol(H^+) km^{-2} yr^{-1} (equivalent to 8 kg S ha^{-1} yr^{-1}) which occurs on either side of the Midland Valley. These areas are dominated by acid soils of low base saturation derived from acidic slow weathering rocks such as lightly metamorphosed shales, grits and greywackes to the south and schists, gneisses and granulites to the north. In general, the distribution of critical load classes reflects a combination of underlying geology and topographic relief. The most sensitive soils are thin and occur on steep slopes in upland areas on parent materials with few weatherable minerals. The least sensitive soils are typically found in low lying areas on gentle slopes over relatively easily weathered parent materials.

When maps of current levels of deposition of non-marine sulphur are overlain on the critical load map, a map can be produced showing where the areas of exceedance occur. Two approaches were adopted. In the first, the current levels of acid deposition were compared with the critical load for the most sensitive soils within each 20 x 20 km grid square. The resultant map shows that soils whose critical loads are exceeded are widespread across most of Scotland, although the map is, of course, strongly influenced by the occurrence of small areas of the most sensitive soils. In the second (possibly more realistic) approach, the critical load of the 20 x 20 km grid square is considered to be wholly exceeded only if the critical load of 75 per cent or more of the soils making up that square are exceeded. Using this approach well-defined areas of exceedance become delineated, principally over large areas of the southern Uplands and Galloway in southern Scotland and to the north and west of the Midland Valley running up the west coast and extending eastward as far as the Cairngorms. On this basis the total area of critical load exceedance for acid deposition is 28,400 km^2, approximately 37 per cent of the total area of Scotland.

With regard to the distribution of acid-sensitive waters, the geological maps show that there are extensive areas in Scotland which in principle would be regarded as likely to yield acidified groundwaters. These areas are associated with highly siliceous rocks of igneous and metamorphic origin with little capacity for neutralizing acidity. More than half the country is occupied by such material, mainly to the north of the Highland Boundary Fault (Table 7).

Table 7 Percentage cover of geological sensitivity classes in Scotland

Geological sensitivity	km^2	%
Not sensitive	670	0.0
Low	13 558	17.9
Medium	19 865	26.3
High	41 561	54.9

Similarly, most of the country is occupied by highly sensitive soils with base saturation in the B and C horizons of less than 20 per cent (Table 8).

Table 8 Percentage cover of soil sensitivity classes in Scotland with and without land use

Soil sensitivity	Without land use	With land use
Low	15.3	5.4
Medium	18.9	7.3
High	65.8	57.3

These soils generally coincide with highly sensitive geology which leads to the prediction that surface water acidification under all conditions of flow is probable over much of the Highlands, Southern Uplands, including Galloway, and the Outer Hebrides and Shetland Isles.

CONCLUSIONS

The maps described above and illustrated in this Workshop suggest that large areas of Scotland are potentially or actually at risk from soil and surface water acidification. However, the methods used involve a large number of generalizations that may or may not be completely warranted. Such an approach must lead to a loss of resolution, so that even though the overall picture may be generally valid, there will inevitably be inaccuracies at a detailed level. Further work is therefore required in order to refine and validate the maps.

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21 *Mapping of Soil Vulnerability to Acidification and Fluorine Accumulation*

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ABSTRACT

This papers reports on soil vulnerability mapping exercises carried out in the European USSR. The general approach, principles of grouping soils according to their vulnerability to acidification and fluorine, and the vulnerability mapping procedure are discussed. Data on loads of selected contaminants in the European USSR are presented.

GENERAL APPROACHES

Two groups of chemicals have been chosen to demonstrate the principles of chemical time bombs, and guidelines for their mapping are discussed in this presentation.

Soil acidification is considered to originate from industrial point sources and agricultural diffuse sources (acid fertilizers). The sources of fluorine input into soils are similar. The harmful effects of acidification caused by N and S compounds on soils, biota and bio-production is well known, and methods of its assessment, quantification and mapping have been developed (Glazovskaya, 1990; Bogdanova, 1991). Much less is known about the impact of fluorine on soils.

The soil degradation rate, or in chemical time bomb (CTB) terms the capacity of soils to buffer the system against adverse effects, is determined by two main factors: a) the loading, its type, duration and intensity; b) the properties and regimes of the initial soils. If data on loading are relatively easy to obtain (e.g. from statistical yearbooks, economical reviews and hydro-meteorological information), the pathways of contaminants and their storage in landscapes may be evaluated only by deciphering information associated with the soil genetic groups. In other words, the soil map, as a data base, may serve to construct a series of specific maps on the susceptibility of soils to different pollutants and to reveal sites of future CTB manifestations. The latter function of the soil map is substantiated by "concealed" information in each mapping unit, such as the pH - redox situation, heat - moisture regime, catenary position of the soil and type of parent rock, and consequently the capability for geochemical migrations and general behaviour of the elements in the landscape.

Combined with other special maps (e.g. geomorphology, Quaternary deposits and land use), the soil map may be very helpful in determining probable locations of CTBs, for example, those "hidden" in soils and water bodies.

PRINCIPLES OF SOIL GROUPING

Vulnerability of soils to technogenic acidification

It is well known that the rate of soil degradation depends on the initial pH values in the solum. Therefore, all the soils, occurring in the European USSR, have been grouped into 4 categories according to their acidity and their profile characteristics (Table 1). This information is derived

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from basic knowledge about soil genesis which is applied to soils at the taxonomic level used on the soil map.

The reaction to acidification of soils, or their capacity to resist change, is determined by a complex of interrelated soil properties. During the last 10 to 15 years numerous data on changes in the soil physico-chemical and chemical parameters caused by prolonged anthropogenic acidification, as well as data obtained in laboratory experiments and by field observations have been accumulated. A review of this information was made by Glazovskaya (1990) and Bogdanova (1991). All these data permitted correlations to be made between the soil buffering capacity and soil properties, such as organic matter content, CEC, non-silicate Fe and Al, clay (amount and composition), carbonates and other properties. The buffering capacity is determined by different reactions operative in soils, for example, exchange reactions on the adsorption complex, weathering, dissolution and non-exchangeable sorption.

The quantitative characteristics of soil properties and their combinations may be used to evaluate the resistance of soils to acidification. A rather generalized description of these criteria is considered to be adequate for small scale mapping exercises. At the same time, the capacity to resist degradation appears to be a more complex characteristic than the soil buffering capacity alone.

By combining the two attributes on the legend (i.e. the initial pH and acidification resistance capacity) 15 groups of soils (mapping units) may be distinguished which differ in their response to acidification (Table 1). The least resistant, or most vulnerable, are soils having the following set of features: sandy texture, low humus content, low CEC and an albic horizon. The presence of peat or forest litter contribute to a higher level of stability. A medium vulnerability is associated with soils on basic parent rocks or with soils having a carbonate horizon. Soils with a calcic or salic horizon at a shallow depth as well as peaty soils display a low vulnerability.

Table 1 Vulnerability of soils to technogenic acidification

acidification resistance capacity		Initial soil properties (pH range)			
		acid non calcareous		neutral and alkaline with a calcic horizon	
		very acid (pH<4.7) and acid throughout the profile	weakly acid to neutral pH: 5.5-6.5 in the A horizon, and pH: 6.5-7.0 in the B hor.	neutral to alkaline pH: 6.5-7.5 in the A horizon, and pH: 7.5-8.5 in the B hor.	weakly alkaline to alkaline pH: 7.5-8.0 in the A horizon, and pH: 8.5-9.0 in the B hor.
class	weighting	1	2	3	4
low	2	2	4	6	
medium	4	4	8	12	16
above medium	6	6	12	18	24
high	8	8	16	24	32

Vulnerability of soils to fluorine

The vulnerability of soils to fluorine may be assessed as the potential danger caused by its accumulation. Field observations and laboratory experiments reveal a relationship between fluorine accumulation in soils and the amount of clay and physical clay fractions (fractions below 1 μm and 10 μm, respectively), amorphous Fe and Al hydroxides and the contents of water soluble and exchangeable Ca.

The fluorine fixation capacity of Fe and Al hydroxides is regulated by redox conditions. It is increased in oxidative media especially in acid soils, and decreases under acid reducing conditions through mobilization of fluorine fixed in Fe- and Al-organic complexes. Fluorine is more mobile in alkaline media created where sodium carbonate occurs than in acid soils, but it becomes immobilized if $CaCO_3$ or $MgCO_3$ are present.

The accumulation of mobile fluorine compounds is affected also by the soil water regime. Under a stagnant water regime these contents increase considerably, becoming much more dangerous in hydromorphic soils with an evaporative water regime. In freely drained soils with a normal percolative regime, the risk of mobile fluorine concentrating diminishes.

Investigations upon the occurrence of fluorine in technogenically polluted landscapes showed its behaviour (i.e. migration and accumulation rates) depended on the soil-geochemical situation (see Kremlenkova, 1988). In chernozems and kastanozems fluorine is least mobile in calcic horizons. In gley horizons of excessively moistened sod-podzolic soils, alluvial, meadow-boggy, meadow-chernozemic, and peaty soils, fluorine is rather mobile. Within this series of soils higher fluorine mobility was observed in natric horizons of meadow-chernozemic solonetzic soils and in heavy-textured sod-podzolic soils. High concentrations of fluorine coupled with low mobility are characteristic of ferruginous and peaty soils.

Table 2 Rating of the soil-geochemical conditions controlling the fixation and mobilization of fluorine in soils

a) Fluorine fixation in the upper soil horizon		weighting
Water regime type	percolative	1
	percolative with periodical extra-moistening	3
	stagnant	7
	periodically non-percolative	2
	non-percolative	4
	pulsating	5
	strongly non-percolative	7
	periodical flooding	6
Texture	clay and loam	4
	sand and loamy sand	2
	presence of weakly crystallised Fe and Al hydroxides	2
	high content of exchangeable Ca	2
b) Fluorine immobilization		
Redox conditions	reductive	6
	periodically reductive	4
	oxidative	2
pH conditions	acid and very acid	2
	weakly acid and neutral	4
	alkaline and strongly alkaline	6

The first step when applying this information to evaluate the capacity of soils to store fluorine consisted of grouping the basic soil parameters accounting for fluorine behaviour (fixation - mobilization) and to assigning them "weights" (Table 2). When soils have been assessed in terms of fluorine pollution risk by combining the "weights" given to four parameters ("weight total" in Table 3), the numbers obtained have been placed into vulnerability classes. Thus, the category with high capacity comprises diverse soils with advanced humus accumulation, gley or calcic horizons as well as soils with impeded drainage and/or medium and heavy texture. Soils with a low capacity are less numerous, and include various podzols, non-calcic gley soils, arenosols.

Table 3 Grouping of soils according to their potential danger of pollution by fluorine

Danger	Weight total	Soils
very high	25	solonchaks
	24	alluvial meadow and soddy calcareous, saturated, solonchakous and solonetzic
	22	peaty and peaty-gley boggy soils
	21	tundra gley soils, tundra boggy soils, tundra eluvial-gley soils, meadow-boggy, alluvial boggy soils
high	20	meadow, meadow-chernozemic
	19	meadow-chestnut, solonetzic chernozems, solonetzes
		chestnut, chestnut solonetzic, meadow-chestnut solonetzic,
	18	brown semidesertic solonetzic
	17	chernozems: typical, ordinary, southern, mycelium-carbonate, calcaric
medium	15	gley-podzolic, boggy-podzolic, podzolic
	14	grey forest, dark grey forest, leached chernozems
	13	sod-podzolic with gley, humus-gley, rendzinas, podzolic, residually-calcareous
	11	sod-podzolic, sod-pale-podzolic
low	10	arenosols
	7	iron podzols, iron-humus podzols, gley podzols, contact-eluvial podzolic, sod podzols

VULNERABILITY MAPPING PROCEDURE

The 1:4 M soil map, recently compiled at Moscow State University, served as the cartographic basis for the vulnerability mapping exercise. The map is rather detailed, comprising new pedological ideas, and its scale is close to the one proposed for the "European soil vulnerability mapping" programme. The soils are correlated with their equivalents in the FAO legend. The information on loads has been obtained from special yearbooks and reference books (VINITI, 1990; Goskomhydromet, 1990).

The legends for soil vulnerability maps are presented in tabular form with two entries based on the assessment of soil properties and loadings. Each entry received its expert rating numbers (weighting). The superposition of loadings upon the mapping units with different vulnerability permits the delineation of areas of particular accumulation under the present environmental conditions. Examples of such legends are given in Tables 4 and 5.

Changes in the environment affect soil properties and may bring them to a critical level at which contaminants may be released from soils. Some possible scenarios for fluorine are discussed below.

If pH values are raised (e.g. due to liming of acid soils or the effect of alkaline pollutants) the mobility of fluorine increases. Similarly, changes in the soil redox conditions are caused by flooding or raising the ground water table, both naturally or artificially, also increase its mobility. Fluorine concentrations may thus reach a critical level under these conditions. Soil acidification, promotes fluorine fixation capacity, but restricts fluorine mobility. Thus if an acidified soil (e.g.

a field on a floodplain) receives extra fluorine in solution (e.g. from a limed field on the interfluve), its concentration of fluorine will raise and it may quickly approach the "chemical time bomb" phase.

LOADING WITH CONTAMINATES

Data on soil loading for the European USSR have been acquired from recent economic publications available in Moscow. They are of two kinds:

- amounts of N and P fertilizers applied to arable areas per administrative district or republic. They were presented as modules per area unit (kg ha^{-1} y^{-1});
- amounts of atmospheric pollutants (NO_x, SO_x and F) produced by industry and measured by meteorological stations in towns.

All these loads have been categorized (5 to 6 categories for each) and each received its weighting number. Further superposition of weighed vulnerability mapping units and ranked loadings contributes to the search for chemical time bombs.

Table 4 Legend to the map of vulnerable areas (anthropogenic acidification)

Changes in:	soils	degradation	weak degradation	no changes	no changes or weak progradation
	waters	strong pollution		weak pollution	no pollution
total loading (kg ha^{-1} arable land)	weighting	1-7	8-15	16-24	25-32
40-80					
80-120					
120-160					
160-200					
200-250					

Table 5 Legend to the map of vulnerable areas (fluorine applied to soils with fertilizers)

Total agricultural load of NO_x, SO_x (kg F ha^{-1} yr^{-1} arable land)		Groups of soils with different vulnerability to fluorine			
		very high	high	medium	low
	weighting	21 - 25	16 - 20	11 - 15	6 - 10
6 - 8	15	40	35	30	25
4 - 6	10	35	30	25	20
2 - 4	5	30	25	20	15

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22 *Data Base for the Regionalisation of Soil and Terrain Vulnerability to Specific Groups of Chemical Compounds in 1:5 M Scale*

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ABSTRACT

A data base for compiling a 1:5 M map of soil and terrain vulnerability to specified groups of chemical compounds should include both data on soil properties (pH, humus content, CEC and texture) and soil forming factors (moisture regime, relief, permafrost). The proposed numerical approach gives about 1000 possible mapping units without taking into account different types of land use.

INTRODUCTION

The most essential part of any map is its data base because it determines both the scientific and practical applications of the map. It is well known that the difficulty in compiling soil data for cartography is related to the scale of mapping. The need to take into account the scale of mapping, and the degree of cartographic generalization of the data shown on the map, is a specific feature of cartographic work.

A soil map at 1:5 M scale reflects a conceptual view of the soil cover, and shows the highest categories of structural organization of the soil mantle: regions, districts, provinces and zones. It is compiled by generalization, and usually the mapping units are distinguished on the basis of an analysis of the factors of soil formation. First of all, lithological and geomorphological factors are used for this purpose. The resulting maps reflect the general regularities of the spatial patterns of soils within the "factor-soil" scheme. This means that it does not make any sense to try drawing too detailed conclusions based on such small scale maps. The latter will require more detailed soil maps.

One square cm on a 1:5 M map corresponds with 2500 km^2 on the ground. Morphometric analyses of detailed soil maps of the central part of the European USSR revealed that the average size of the areas occupied by individual soils vary from 100 to 300 square metres. This means that a mapping unit on a 1:5 M map may contain from 2500 to 800 areas with sharply contrasting soil properties, such as podzols, rendzinas and bog soils. Therefore, it is rather difficult to choose one representative soil for each mapping unit (association) to estimate the vulnerability or "capability to be harmed by pollutants".

One problem in preparation of the map is that the land use structure of the USSR has not been completely elaborated as compared with that of the West European countries. Varieties of the land use patterns and trends have not been investigated or mapped. Finally, the quality and quantity of contamination also may vary greatly and this will result also influence choice of the map units.

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DISCUSSION

Based on the preceding remarks it is possible to conclude that the data base for a 1:5 M map on the vulnerability of soils in Europe to different groups of pollutants should be compiled using a few general parameters. A limited number of soil forming factors and soil characteristics should be placed in approximate grades according to their impact upon soil and pollutants.

Currently, rather detailed studies are carried out in the USSR to determine how the soil-geographical features influence the accumulation and migration of different pollutants. In spite of the widely differing responses of the various groups of pollutants to similar soil and environmental factors, a number of general conclusions can be drawn with respect to their interactions. Suitable data illustrating these interactions are given for the 1:5 M scale map in the following paragraphs and tables.

Table 1 shows the standards used in the Soviet Union for assessing the chemical hazard caused by chemical substances. It can be seen that only two out of the six criteria depend directly upon the soil conditions, namely the persistence and mobility of chemical compounds. The other properties, such as toxicity, are related to biological features. It is necessary to attempt an analysis of the common factors determining the persistence and migration of pollutants in soils.

Table 1 Hazard criteria of chemical substances (after State Standards, 1983)

Criteria	Hazard level		
	High	Medium	Low
1. Toxicity (LD-50 ppm)	< 200	200-1000	> 1000
2. Persistence in soils (month)	> 12	6-12	< 6
3. Critical load in soils (mg kg^{-1})	< 0.2	0.2 - 0.5	> 0.5
4. Mobility	highly mobile	mobile	immobile
5. Persistence in plants (month)	≥ 3	1 - 3	< 1
6. Influence on food quality	high	medium	no

Table 2 shows criteria for assessing the relative hazard of pollutants to soils, indicating that it depends on the moisture coefficient and the prevailing soil water regime. Additionally, it is influenced by soil texture and permafrost.

Table 2 The relative hazard of soil pollution (after Glazovskaya, 1978)

Moisture coefficient and prevailing water regime	Texture and permafrost			
	Sand	Loam	Clay	Different texture with permafrost
> 2, strongly leaching	+	+ +	+ + +	+ + +
2 - 1, mainly leaching	+ +	+ + +	+ + + +	+ + + +
1 - 0.5, dry	+ + +	+ + + +	+ + + + +	+ + + + +
< 0.5, extremely dry	+ + + +	+ + + + +	+ + + + +	

Degree of hazard: ext. low (+); low (+ +); medium (+ + +); high (+ + + +); ext. high (+ + + + +)

Table 3 presents a classification of the degree of pesticide sorption in soils. This sorption depends on humus content, pH, CEC and the clay content (less than 0.01 mm).

Table 3 Classification of the degree of pesticide sorption (after Molozhanova, 1985)

Degree	Soil properties			
	Humus (%)	pH	CEC	Clay (%)
Extremely high	> 8	5.0 - 6.0	> 60	45 - 40
High	6 - 8	6.0 - 6.7	40 - 60	40 - 30
Medium	4 - 6	6.5 - 7.0	20 - 40	30 - 20
Low	2 - 4	7.0 - 7.5	10 - 20	20 - 15
Extremely low	1 - 2	> 7.5	< 10	15 - 10

Table 4 shows the mobility of biochemically active trace elements arranged according to geochemical associations of soils. It depends mostly on pH.

Table 4 Mobility of biochemically active trace elements (after Glazovskaya, 1978)

Geochemical associations of soils	Mobility of elements		
	Practically immobile	Moderately mobile	Easily mobile
Acid (pH < 5.5)	Mo^4	Pb^{2-4}, Cr^{3-6}, Ni^{2-3}, V^{4-5}, As^3, Se^3, Co^{2-3}	Sr, Ba, Cu, Zn, Cd, Hg, S^6
Neutral and weakly acid (pH: 5.5 - 7.5)	Pb	Sr, Ba, Cu, Cd, Cr^{3-6}, Ni^{2-3}, Co^{2-3}, Mo^4	Zn, V^5, As^5, S^6
Alkaline, strongly alkaline (pH: 7.5 - 9.5)	Pb, Ba, Co	Zn, Ag, Sr, Cu, Cd	Mo^6, V^5, As^5, S^6

Summarizing the data shown in the tables, it is possible to compile a data base for the regional map of soil vulnerability at a scale of 1:5 M (Table 5). This may seem too generalized an approach, but if a numerical approach is used the total amount of possible combinations (mapping units) may be calculated using the formula:

$$N = \prod_{j}^{m} G_j$$

where N is the number of possibilities, m the number of properties, G_j the number of grades for property j. A combination of three grades of pH (acid, neutral and alkaline) and three textural classes (fine, medium, coarse) gives nine possibilities. Some of these combinations do not occur physically, and as such may be excluded. For example, a strongly leaching soil water regime and alkaline geochemical associations. This is why the total number of possibilities will be about 1000. On the other hand, if the different types of land use are taken into account the total number of combinations (units) will increase. This should be satisfactory for the proposed 1:5 M European soil vulnerability map.

Table 5 Criteria to produce a data base for the regionalization map at scale 1:5 M

Factors	Number of grades	Source
Moisture coefficient	3	Climate inf.
Relief	3	FAO
Permafrost	2	FAO
Soils		
pH	3	FAO
Humus content	3	FAO
CEC	3	FAO
Texture	3	FAO

Total number of realistic possibilities about 1000

CONCLUSION

The main points of this contribution, which may be seen as recommendations on how to proceed in compiling the 1:5 M "soil vulnerability" map, are summarized below:

- The criteria used to distinguish the different regions (Table 5) can be used as a basis to indicate soil vulnerability;
- According to our point of view, the interpretation with regard to soil vulnerability has to reflect two aspects:
  - the capability of the soil to store different kinds of pollutants, and
  - the qualities of the soil as a medium for the mobility of the pollutants;
- The relevant criteria can be derived from the 1:5 M FAO/Unesco Soil Map of the World and accompanying documentation since the level of generalisation used is comparable to the scale of the SOVEUR Soil Vulnerability Map.

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23 *Available Data and Possibilities of Preparing of Soil Vulnerability Maps in Yugoslavia*

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ABSTRACT

In connection with the European project SOVEUR, this paper gives a short review of existing pedological research in Yugoslavia, the available data and other information from other branches of soil science, as well as from the related fields. Next, it contains reflections on potential and actual pollutants, critical soil properties and risk criteria, according to recent knowledge and the authors' experience. Certain suggestions are made for preparing a general or global Soil Vulnerability Map at the scale of 1:5 M, mainly for illustrative and educational purposes. There is, however, an expressed regional and national interest for more precise thematic, or so-called vulnerability management maps at larger scales (1:200,000 and 1:500,000). This may serve as an indication for directing future international cooperation and financial assistance of EC and other developed countries.

INTRODUCTION

Environmental protection, and soil protection in particular, is one of the key problems of the present time, as a result of a large expansion of industry, residential areas and traffic facilities, strip mining, power plants, unsolved problems of soil and liquid waste disposal, releasing of harmful gases and dust into the air, and the increasing use of various chemicals in households, agriculture and forestry (UNEP, 1987; Unesco, 1989; Arnold *et al.*, 1990; Racz, 1990).

According to recent research investigations, chemical pollutants threaten the "natural" functions of the soil, not only by reducing its productive capacity, which has been the most frequent topic of interest, but also by affecting numerous other properties and processes taking place in soil. For example, application of certain chemicals results in a gradual saturation and reduction of sorption and buffering capacity of the soil, changes in transformation and displacement of mineral and organic matter in soil, with further unfavourable effects on other physical and biological properties of soils (Ulrich, 1986; TNO, 1987; Stigliani, 1988; Szabolcs, 1989; Glazovskaya, 1990; Várallyay, 1990).

In accordance with instructions accompanying the invitation to the workshop, an inventory was drawn up of the available pedological and other relevant data required to prepare a 1:5 M educational wall chart on soil and terrain (landform) vulnerability to specific groups of chemicals. In the authors' opinion, the preliminary stage of mapping will be possible with a comparatively small investment from funding organizations. However, the second stage of compiling more detailed maps will require considerably more extensive work and funds to support it. At present there are neither government agencies nor authorized scientific institutions, either at the Federal or Republic level in Yugoslavia, professionally involved in activities such as proposed by the "European Soil Vulnerability" project (SOVEUR).

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AVAILABLE DATA

Review of earlier soil mapping research

As a result of several years cooperation with FAO, Yugoslavia is included in the Soil Map of Europe, published jointly by FAO-Unesco (1981). The Yugoslav authors quoted are Skoric and Ciric, and collectively the Yugoslav Soil Science Society.

Other data include:
- pedological map of Yugoslavia, scale 1:2 M (Skoric and Bogunovic (1988), printed in pedological textbooks for educational purposes (Skoric, 1977a)),
- pedological map of the Republic of Croatia at 1:3 M scale, printed in the Yugoslav Encyclopedia (Skoric and Bogunovic, 1988), and
- several regional soil maps, scale 1:200,000 to 1:500,000, printed in various Republics (e.g. Zivkovic *et al.*, 1972; Skoric, 1977b and 1987).

Basic pedological maps have been completed in Yugoslavia at the scale of 1:50,000, and in Croatia over 90 per cent of these have been printed. Finally, for most of the flatland parts of the first and second agricultural regions in Yugoslavia there are large scale pedological maps, 1:2000 to 1:5000, prepared mainly to serve the hydro-amelioration and agricultural amelioration purposes, such as laying out orchard and vineyard plantations, liming and fertilizing.

Other data and sources of information

Other available data include:
- hypsometric, geomorphological, geological-lithological, climate and vegetation maps of Yugoslavia, scale 1:3.5 M (SNL, 1988),
- synthetic maps of relief, climate, and zonal and interzonal forest communities in Yugoslavia, scale 1:2.5 M, and Croatia, scale 1:2 M (Bertovic and Lovric, 1988 and 1990),
- petrographic maps of Yugoslavia, scale 1:4 M and 1:2.5 M (Velic and Velic, 1983 and 1987), and
- distribution, properties and types of loess and loess-like sediments in Croatia (Bognar, 1979).

On the basis of the preceding data it is possible to prepare the pedological map of Yugoslavia at a scale of 1:1 M or 1:2 M amended by the new FAO-Unesco revised legend for the soil map of the world.

In our opinion, preparations for a small-scale European soil vulnerability map, would be facilitated by the attached map of pedogeographic districts of Yugoslavia, at the scale of 1:5 M (Fig. 1), and the Soil Degradation Map of Yugoslavia with accompanying English text (Resulovic *et al.*, 1988).

The Soil Degradation Map was prepared according to the methods of the International Soil Reference and Information Centre, Wageningen, the Netherlands. As this map is also based on the pedogeographic districts of Yugoslavia it may be used also in the compilation of a European Soil Vulnerability map.

The following text contains a short description of the separate districts, which may be amended by qualitative assessment of soil vulnerability according to major soil forming processes in predominant soils, here described in their local names (similar to former IRB proposals for soil classification; Dudal, 1990).

The first pedogeographic district comprises the former steppe and steppe-forest areas of the Pannonian Plain in north-eastern Yugoslavia. This is the cereal-growing region of Yugoslavia which lies between the Danube and the Tisa rivers. Chernozem soils predominate, developed on loess plateaux and terraces. Lower parts are occupied by humogley soils and halomorphic soils, with fluvisols along the rivers on recent alluvium.

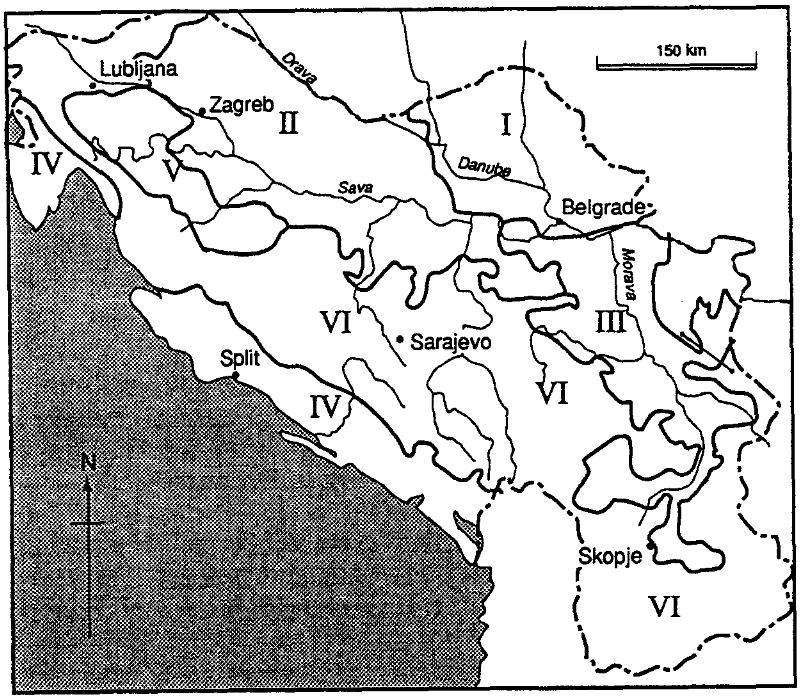

Figure 1 Pedogeographic districts of Yugoslavia (after Ciric and Filipovski (1972) and Skoric (1986); see the text for a description of districts I to VI)

The second district comprises the western peripheral parts of the Pannonian plain the river valleys of the Sava and the Drava and tributaries of the Danube. There is a gradual transition towards the hilly land in the northern and north-western parts of Bosnia, Croatia and Slovenia. The climate is mainly humid, moderately continental, with natural forest vegetation. Here chernozems are less common, and the zone of eutric cambisol westwards to extensive areas of typical and pseudogley (Albi-gleyic) luvisols. Along the rivers, fluvisols and humofluvisols are found, and in the central zones of the river valleys, the eugleys. On the loess plains, secondary and primary pseudogley soils are dominant.

The third district comprises the lowland, undulating, hilly and low mountain areas of central Serbia and a small section of northern Macedonia. Unlike the second district, the climate is semi-humid with xerothermic forests. On texturally lighter and carbonate, or lacustrine sediments rich in bases, eutric and luvic brown soils prevail, while on heavier substrata smonitzas (vertisols) occur.

The fourth district comprises the wider Adriatic Coast zone, including the islands. The climate is Mediterranean to sub-Mediterranean, with evergreen oak forests and maquis, and xerothermic deciduous oak and hornbeam forests. Calcareous and dolomitic rocks are dominant, with karst phenomena and the corresponding soils (calco-cambisol or terra rossa - calco-melanosol). In synclines on clastic flysch sediments, regosols, rendzinas (vertisols) and eutric cambisols are found. On footslope positions colluvial soils occur.

The fifth district comprises the northern part of the calcareous - dolomitic Dinarides and an area of so-called covered or shallow karst, with prevailing rather acid acrisols. The climate is humid to perhumid, and the vegetation consists of mixed oak and hornbeam forests, and beech and fir in the mountain zone. Podzolic and brown-podzolic soils occur sporadically on acid silicate substrata.

The sixth district comprises the central mountain massifs, extending from the Alps in Slovenia to the Carpathian-Balkans system in eastern Serbia, and the Rodopian massif and the Sara system in Macedonia. However, in the western and the central parts calcareous-dolomitic rocks and karst relief prevail, in the eastern and south-eastern parts the predominant formations are of volcanic and metamorphic rocks, with corresponding soil series. The climate is humid, becoming more severe in the mountains where long snow covers occur in winter; the forests are replaced gradually by mountain meadows with predominantly more shallow and more humic soils (calcomelanosols, rankers and rendzinas)

CONTRIBUTION TO OTHER DISCUSSIONS ON RISK ASSESSMENT AND POTENTIAL POLLUTANTS IN YUGOSLAVIA

It is hoped that the first stage of working out of the European soil vulnerability map will be completed successfully according to schedule. However, in view of the present and future requirements of environmental protection it is strongly recommended that the research be continued, either through the World Soils and Terrain Digital Data Base (SOTER) project, regional projects (Mondiaal Alternatief, 1990), or other means of international cooperation. In this context, the approach and possibility of preparing so-called "management maps" requiring more complete information on pollution sources (or emissions), environmental properties which may be affected, and the actual vulnerability assessment are of great interest (Cramer and Vrba, 1987).

Thus, the subject is quantitative risk assessment and management, which is very complex, requiring comprehensive (holistic) and cross-disciplinary approach (Haines, 1989). With respect to soils it is necessary to assess, in a complex manner, all its three functions: the function of soil as a filter in a general sense, including its buffering capacity; then, soil as the source and transfer of nutrients and other components of fertility, essential to normal growth and development of crops; and finally, the possible role of soil as mediator in food and water pollution, with potentially adverse effects on the biosphere and human health. This, of course, will not be easy, but it is worth trying and directing future research to this objective.

As in other European countries, the phenomena of soil acidification and forest degradation, resulting from acid rain, are seen in Yugoslavia, particularly in fir and spruce forests in the mountain areas. According to the available data, the lowest pH of rain registered during recent years in Zagreb was 3.7, while the total dry and wet sulphur depositions in Yugoslavia were 1.87 to 4.91 ton S km^{-2} which is well over the permissible threshold values (Petkovsek, 1987; Milutinovic, 1989).

For most industrial and urban areas there are data on pollution by heavy metals, in particular lead. However, pedological and geochemical maps have been published only for the areas surrounding Celje, in Slovenia, and for Istria (Hrustel-Majcen and Lobnik, 1989; Prohic *et al.*, 1990).

In lowland areas and soils with a descending soil water regime, ground-water pollution by nitrates is possible, although there are no systematic data on the subject at present. Livestock production in Yugoslavia is mostly extensive and run by private farmers; this is probably one of the reasons why there are no major nitrate and phosphorus pollution problems at present.

Finally, it is noted that several national and international projects have been proposed recently for the purpose of soil and water protection in agroecosystems, for the production of healthy food, and to aid the development of information and communication systems for environmental research.

CONCLUSIONS

On the basis of previous pedological research and other available data and documents, the authors propose the following:

- Updating and publishing pedological maps of Yugoslavia, at the scales of 1:1 M and 1:2 M, within the framework of the corresponding new pedological map of Europe,
- Preparing the corresponding part of the European soil vulnerability map, at the scale of 1:5 M, by application of the existing pedogeographic map of Yugoslavia and the evaluation of susceptibility according to process dynamics and properties of main soil types,
- Continuation of research within the World Soil and Terrain Digital Data Base (SOTER), in order to obtain, as soon as possible, the necessary quantitative indices for better environmental risk evaluation.

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24 Computer Graphics used in Slovakia for Land Use Presentation and Mapping

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ABSTRACT

This contribution gives a brief description of work at the Water Research Institute and cooperating organisations in the field of computer - based land cover data presentation for Slovakia. The morphometric terrain analysis theory was used for the grid-based digital model of geo-relief by J. Krcho (Faculty of Natural Sciences, Comenius University, Bratislava) and E. Micietová (Institute of Geography, Slovak Academy of Sciences) and for modelling applications in hydrology and water management. An example of its use for the upper Váh river area is presented. At the Institute of Geography of SAS, J. Feranec evaluated land use and land surface type data obtained by remote sensing. The methodology of its application in mapping is briefly discussed. The Institute of Geography of the Czechoslovak Academy of Sciences in Brno applied a computer based graphical presentation on environmental characteristics of the Czech Republic, a part of which, the Morava tributary of the Danube, is shown. A methodological approach to software use and needs for the mapping of soil vulnerability in the Danube Catchment Area is discussed.

INTRODUCTION

The Water Research Institute Bratislava, founded in 1951, is responsible for research and scientific support in the field of water quantity and quality and related disciplines for the whole of Slovakia. Although the institute has a relatively short history, it has been involved in solving various local and international problems generally related to the Danube river catchment area (Stancik *et al.*, 1988). This experience, and the latest activity of the Netherlands Ministry of Physical Planning, Environment and Housing (VROM) in support of the project entitled "Chemical Time Bombs - Long Term Environmental Risks for Soils, Sediments and Groundwater in the Danube Catchment Area", led to our cooperation in this field.

The aim of this contribution is to present results obtained by the introduction of computer graphics to applied studies, not only in our institute but in other institutions which will cooperate in this international project. We would like also to outline our methodological ideas on soil vulnerability mapping for the Danube catchment area.

TERRAIN, GEOMORPHOLOGICAL CHARACTERISTICS AND MAPPING

The theoretical approach to terrain configuration and morphology specification was worked out by Krcho (1990). His methodology was used by a group of co-workers in various organisations for digitising the Slovakian territory and, among others, for creating METEOSYS, a hydro-meteorological information system and data bank. Two "densities" of data base were used: a 1 x 1 km grid and a 100 x 100 m grid.

For data presentation and practical use the Complex Digital Model of Spatial Structure (CDMSS) was assembled. It permits land surface modelling and presentation, and is based on a theory of morphometric analysis of a topographic surface in which geometric and physical properties are presented in a two-dimensional field (matrix). A specific spatial structure-georelief, according to this theory, is considered as a continuous field of elevations (a.s.l.). Its properties from the point

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of view of geometry are expressed by quantitative variables. In addition to this, the physical interpretation of surface properties is studied. In the case of georelief, the characteristics form the basis for the analysis of surface formation, which is influenced by phenomena of interaction between the atmosphere, hydrosphere and lithosphere. An example of such a study was presented at the Vienna's World-Tech exhibition (Krcho and Micietova, 1990). From the point of view of the Chemical Time Bombs (CTB) project, this approach would be usable, for instance, to determine the spatial occurrence of erosion.

Properties of continuous topographic surface, as an interpolated scalar field of elevations (z=f(x,y)), can be expressed, from the geometric point of view, by the following morphometric parameters:

- the gradient of scalar z which determines the declivity of a topographic surface,
- tg(gamma(N)), where gamma(N) is the relief slope angle in the direction of the "drop line", which is between the normal vector to the topographic surface and the vector oriented to the zenith,
- the direction of gradient z, expressed by the direction angle AN, which describes relief orientation with respect to the cardinal points, assuming that x is oriented to the south and y to the east,
- Kr, the horizontal curvature of georelief, expressing the curvature of contour lines and allowing for separate convex and concave formation of terrain,
- the normal curvature of georelief (omega) determining the curvature of "drop lines" at the topographic surface,
- the geometrical formation of georelief expressing the degree of convexity or concavity both in horizontal and normal directions and with the capability of qualitative description or quantitative characterization.

Particular morphometric parameters can be considered individually or used as input parameters for other characteristic phenomena describing field evaluation. In this way it is possible, for example, to use the relief slope angle gamma(N) and orientations AN for computing the dynamics of terrain insolation. This is generally expressed by:

- delta(exp), the incidence angle of the sun's rays at any point of the topographic surface (georelief),
- delta(exp_{extr}), the extreme value of delta(exp) for any day,
- SUMT, the so-called astronomically possible sunshine duration for any point of georelief and for any day,
- Ic, the intensity of direct sun radiation expressed in energy units (Joule) per given period.

The theoretical conception of complex morphometric analysis of topographic surfaces represents the starting point for each study based on spatial distribution depending, among other factors, on terrain characteristics and/or configuration, which can influence the risk evaluation. This is the case for CTBs too.

LAND USE DATA

Land use data represent information about various aspects of environmental studies (e.g. hydrological and pedological). Their application simplifies the expression and use of parameters in environmental models, based on spatial distribution. An example from the upper Váh river sub-basin was presented by Petrovic (1990). The distribution of elevation and land use in the highest part of the Váh river sub-basins was processed point by point in the programming language BASIC.

New methods of mapping land cover and/or land use characteristics have been considered and, as a first basic step to automated processing, the colour infrared space photographs (obtained by a KFA 1000 camera) were analysed for the whole of Slovakia by Otahel and Feranec (1991) at the Institute of Geography of SAS, Bratislava. The concept of land cover (landscape physiognomy) is oriented to the characteristic appearance of significant landscape objects, manifesting themselves in space photographs (e.g. spectrozonal) by the shape, size, colour and texture of images, forming a characteristic pattern. The aim of their work was the identification of the spatial structure of landscape elements (objects), both from the viewpoint of their vertical (synergic) relations and their location on the earth's surface with respect to possible horizontal interactions with the surrounding area. In this way, it is possible also to obtain the spatial organisation and structure of the surface from the ecological point of view. With respect to the scale of primary information, the geomorphic forms of the landscape or the land cover will be mapped on a scale of 1:500,000. In total, more than 16 land use/cover categories are recognised.

ENVIRONMENTAL CHARACTERISTICS OF THE MORAVA SUB-BASIN

The Geographical Institute of the Czechoslovak Academy of Sciences in Brno produced a study on the state of the environment in the Czech Republic, which covers the Morava river catchment area, a part of the Danube Basin (CSAS, 1990).

The study produced an explanatory booklet with 50 maps, showing, for example, the occurrence of arable land and soil vulnerability to acidification. Processing was done for 298 regions according to urban-rural counties and for 261 areas according to the distribution of physical-geographical regions in the Czech Republic (this data will be used in the Labex project also). The software is written in the PASCAL language, again processing information/data point by point. It is anticipated, that IG-CSAS at Brno will be a cooperating organisation for processing the Morava sub-basin area in the Chemical Time Bombs (CTB) Project.

METHODOLOGY OF VULNERABILITY MAPPING

The Water Research Institute at Bratislava would like to develop the methodology for presenting and mapping the CTB results. Our basic ideas can be expressed by the following points:

- a review of existing geographical information systems in riparian countries of Danube river, based on a questionnaire,
- a comparison of the advantages and disadvantages of these systems with respect to the expected format needed for presenting results presentation (vector and grid approach), based on a practical application using the most commonly used systems (participation of a "western" expert for some time would be welcomed),
- organisation of a small expert workshop, where common guidelines for data transfer will be drafted,
- processing of all the point and phenomena required (in so far this is possible) using computer supported graphics on the base of a digitised geographical map of the Danube catchment area, prepared by the Austrian Institute for East European Studies. This same map was used also in the monograph on the Hydrology of the river Danube (Stancik *et al.*, 1988).

The cooperation of all the Czechoslovakian Institutes mentioned in this paper is assumed for future joint work on the CTB Project. All pedological information and soil science expertise should be taken into consideration to create a usable map of any environmental risks to soils, sediments and groundwaters in the Danube catchment area.

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25 Mapping of Geochemical Composition and Weathering Rates of Forest Land in Sweden

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EXTENDED ABSTRACT

The geochemical composition and weathering rates of soil mineral material are essential soil properties with respect to biomass growth and soil acidification. Weathering provides the biomass with nutrients and counteracts pH decrease caused by natural and anthropogenic acid deposition. Good estimates of weathering rates therefore are important when assessing long-term forest production and prescribing silvicultural practises and soil conservation measures. The geochemical composition of Swedish soils is monitored in various projects by the Department of Forest Soils at the Swedish University of Agricultural Sciences, the Geological Survey of Sweden and the National Swedish Environment Protection Board. The aim of this report is to present the findings of a national survey of geochemical properties and weathering rates of till under forest in Sweden, based on investigations carried out at the Department of Forest Soils at the Swedish University of Agricultural Sciences.

The research was performed in three steps. First, weathering rates were determined as a function of the geochemical properties of the till matrix and the temperature sum during the growing season (cumulative daily mean air temperatures above +5 °C). The temperature sums were calculated from the latitudinal and altitudinal position of the site. Cumulative loss of soil material and of major elements were calculated from the present geochemical composition of till matrix at 11 sites, representing mineralogical and climatical properties typical for Sweden. Zr was used as an internal standard. Weathering rates were defined as the annual average loss of elements since deglaciation. Linear regressions with correlation coefficients around 0.8 were achieved for Ca, Mg, K, Na, Fe, Si and Al.

The second step was to map the geochemical composition of forest land on till in Sweden. This was carried out as a part of the Forest Survey programme at the Swedish University of Agricultural Sciences. Samples were taken from 1500 randomly chosen plots during the period 1983-1987, at a depth of 50 cm. In Sweden, this depth corresponds frequently to BC horizons. Total contents of major and trace elements in till matrix (particle sizes < 2 mm) were determined by multi-element ICP analysis. The samples were ignited before analysis and ground after cooling. The mineralogical composition was calculated on the basis of the elemental composition of the till matrix, assuming a specific geochemical composition of the major minerals. For 100 samples the calculated mineralogical composition was controlled with results from XRD analyses. The third step was to apply the weathering function to the geochemical map.

The results of the geochemical monitoring, the mineralogy and the weathering rate calculations were expressed as rolling arithmetical means for topographical sheets 25 x 25 km, displayed as squares on the national map. Each sheet or square consisted of 1 to 3 observations. Distribution of 26 different elements, quartz, K-feldspar, oligoclase, amphibole, chlorite, apatite, calcite and weathering rates for Ca, Mg, K and Na were presented on maps. The maps display a wide range of properties, but in general, the western part of central Sweden shows the poorest conditions. The northern part of Sweden and several regions in central and southern Sweden are characterized by moderately base-rich conditions. The results are consistent with bedrock maps, indicating a close relation on a broad scale between bedrock composition and till properties.

Soil Vulnerability to Pollution in Europe
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SECTION III: EXECUTIVE SUMMARY

26 Proposal of an All-European Workshop organised to Evaluate the Possibility of Mapping Soil and Terrain Vulnerability to Specified Groups of Chemical Compounds

INTRODUCTION

Soil is necessary for the growth of commercial crops of food and fibre and it is an essential component of all terrestrial ecosystems. Consequently, the role of the soil is of vital importance to mankind and the maintenance of a healthy natural environment.

Realizing on the one hand the rapidly increasing world population and the increasing expectations of part of that population for higher living standards, and on the other the limits imposed on the land area of the world that can be used for agriculture, soils must be seen as an essential, valuable natural resource which must be carefully managed and conserved. The area of productive fertile soils, capable of sustained agricultural and horticultural use, is finite and further losses or damage to the world's soil resources must be avoided.

The close environmental links between soils, food crops and water supplies mean that if soils are polluted, there is every likelihood that food and drinking waters will also be contaminated. Any pollutant which detracts from the productivity of soils, or reduces their capacity to filter, buffer and transfer metallic and organic substances, diminishes their quality, value and capacity to support ecosystems. Therefore, any pollutant which detracts from the biological activity of soils must be of immediate concern to all who are responsible for the environment and quality of human life.

During the past 5 to 10 years it has become evident that, as a result of man's industrial and social activities, certain chemical substances have accumulated in European soils to the extent that in some cases concentrations have reached thresholds above which they become an environmental liability. In other cases there is evidence that even small quantities or concentrations of contaminants, well below the threshold of obvious damage, have harmful effects.

The need to protect the atmosphere and hydrosphere has been understood for well over a century. The unique capability of the soil for re-cycling metallic and organic wastes from agriculture, as well as society generally, has led to complacency, and concern for the well-being of soils has been slight. It is vitally important that this attitude should change rapidly and measures to protect soils from chemical contamination be implemented immediately.

EVIDENCE OF SOIL AND GROUNDWATER POLLUTION

Some damaging effects have already been documented. For example, there is an extensive literature on the problem of soil acidification in many European countries. Several other problems have emerged with nitrates, phosphates and pesticides in countries such as UK, the Netherlands, France and Germany where these are being leached from soils to aquifers which supply drinking water. Difficulty in the disposal of sewage sludge and other organic animal wastes has become a soil-related problem, particularly in the Netherlands. The toxic metals (Cu, Pb, Zn, Ni, Hg and Cd) also are a well-documented problem with an extensive literature.

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Some of these cases represent the gradual accumulation of a pollutant which may be completely retained in the soil or may "leak" slowly from the soil into the underlying rocks and aquifers. Such occurrences may be troublesome, but cannot be described as catastrophic episodes of pollution.

In certain circumstances the possibility of catastrophic releases of accumulated pollutant substances may take place. Such occurrences have been referred to as "chemical time bombs" in that they may remain inactive until some trigger mechanism causes them to "explode". The trigger for release of substances could be changes in acidity, aeration, organic matter content, hydrological regime or temperature. An example is mercury (Hg) which in Sweden had been brought under strict industrial control, and it was thought no longer to be a problem. However, acidification has been the trigger which caused the release of mercury previously held securely within the soil.

Certain soils are capable of absorbing, retaining and re-cycling contaminating substances better than others. Identification of those soils most at risk from contamination and their geographical distribution would be most valuable information to have available. Therefore it has been proposed to map the vulnerability of soils to certain chemical contaminants in Europe.

THE WORKSHOP ON SOIL VULNERABILITY MAPPING FOR EUROPE (SOVEUR)

Since January 1990, the Netherlands Ministry of Housing, Physical Planning and the Environment (VROM) together with the International Institute of Applied Systems Analysis (IIASA) have sponsored a series of meetings on chemicals in the European environment. Within this framework, the International Soil Reference and Information Centre (ISRIC) convened an international workshop on the feasibility and desirability of a project upon Soil Vulnerability Mapping for Europe (SOVEUR). This workshop took place between 20-23 March 1991 with delegates from 17 European countries participating, including representatives from Bulgaria, Czechoslovakia, Hungary, Poland, Romania, USSR and Yugoslavia.

The aims of the SOVEUR workshop may be summarized as follows:

- To create and strengthen awareness of the need to protect soils (and by implication human beings and the environment generally) from soil pollution.
- To make preparation for the production of a map of soil vulnerability in Europe, at 1:5 M scale, identifying the areas of soil at risk from pollution.
- To develop methodological guidelines to be used by participants from all European countries, and to identify the basic data and cartographic information required.
- To discuss the feasibility of a time-scale for production of the 1:5 M Soil Vulnerability Map of Europe and other associated activities, including work of a more detailed nature.

The workshop defined vulnerability as the "capability for the soil system to be harmed in one or more of its ecological functions". The ecological functions of a soil were agreed to be production of biomass, filtering, storage, buffering and transformations (of heavy metals and organic materials). Additionally, the protective role of soil and the genetic reserve of its soil-living flora and fauna were regarded as significant issues. The factors and/or processes influencing soil vulnerability to various contaminants and pollutants are: acidification, eutrophication, salinization, erosion, climate change, hydrological changes and land use changes. Soils may react in different ways to pollutants. A "strong delayed response" may be observed in soil systems which can store high amounts of potentially mobilisable chemical compounds. These have been referred to as "chemical time bombs". In other soils a "weak rapid response" may be observed where chemical compounds are easily lost in continual small amounts. These may be referred to as "trickles" or "whimpers".

The workshop identified several significant soil-environmental parameters which would be critical for the identification of soils at risk from chemical contaminants. In the context of a 1:5 M map, it was concluded that pH, clay content, clay mineral type, texture and organic matter content were criteria which are readily available and should be used in the compilation of the map. In addition, the site relief, total depth of soil, water regime and length of growing season were other features, closely related to soils and their capability to resist deleterious changes, which should be used also. In order to maintain uniformity of procedures throughout Europe, workshop participants agreed to use the internationally endorsed SOTER[1] data base, with elements of the EEC-CORINE[2] programme where appropriate.

Proposals for identifying mapping units on a 1:5 M map and their classification into susceptibility classes were agreed in principle.

It was accepted that within the constraints of time, finance and publication scale, it would be desirable initially to focus upon the impact on European soils of three significant groups of soil pollutants: toxic metals, pesticides and a restricted number of other xenobiotic substances such as fluorine.

PROPOSALS

The SOVEUR workshop recognised the need for action on the subject of soil vulnerability mapping and proposed that three projects be implemented which could run in succession or in parallel, depending upon the availability and amount of funding realised. The three European projects may be outlined as follows:

Project 1: In this programme the capacity of soil systems to absorb, hold and release specified chemical compounds will be considered together with the relevant dynamics to show where the most vulnerable soils occur. This will encompass the assessment of the capability of soils to release accumulated pollutants where "triggered" by changes in land use, global acidification or climate change. The relevant dynamics will be described using qualitative assumptions and threshold models compatible with the resolution of the mapping exercise. This map and explanatory booklet would be completed as a contribution to the Chemical Time Bombs project, and can be carried out within one year.

Project 2: As for project 1, plus identification of major sources of soil pollution and mapping of the accumulated load and rate of loading of the soil system so as to assess the risk of occurrence of CTBs. This approach can only be successful at European level if standardized sampling, analysis and methodological procedures are introduced. The relevant principles and procedures will be documented in a manual. This approach will be developed and refined in sample areas at scales larger than 1:1 M (e.g. Danube project, Finno-Scandian area, Central Europe). Maps of actual loading and quantified assessments of capacities should also be prepared for these sample areas. Completion of this project will require at least two years.

Project 3: Study of delayed dose-response relationships using dynamic simulation models developed for specific chemicals so as to predict the risk, severity and time of occurrence of chemical time bombs in a given location. Additionally, there is a need for mapping and studying "hot spots" which are geographically defined, highly polluted areas corresponding with already "exploded" chemical time bombs (e.g. Danube Catchment Area project). The duration of this project is at least three years.

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[1]World Soils and Terrain Digital Database

[2]Co-ordinated Information on the European Environment

IMPLEMENTATION

The first priority is to secure appropriate funding in the order of 225,000 ECUs for work on the initial project to begin. As additional funds become available a start may be made on the second and third projects, but their closely interwoven nature means that a clear indication for funding would facilitate an efficient use of time and resources. When funds are committed for the first project, then the following actions are foreseen:

1. The compilation at ISRIC of a draft physiographic map of Europe, with FAO/Unesco soil map infilling, which will be circulated for regional feedback/updating amongst the participants from the respective countries of Europe. This will include such revisions necessary to incorporate the information held in national soil survey data banks.
   Proposals for identifying mapping units on a 1:5 M soil vulnerability map of Europe and their classification into susceptibility classes were agreed in principle during the SOVEUR workshop. These methodological guidelines will be refined by expert-teams, with reference to selected categories of organic and inorganic (heavy metals) chemical compounds, during international workshops which are to be hosted at the central coordinating centre or elsewhere.

2. Collection and compilation of the necessary materials/maps (e.g. climate, lithology, hydrology, soils and land use) by the various national organisations.

3. Preparation of sets of key parameters (e.g. pH, carbonate content, texture, type of clay minerals, organic matter content/type, cation exchange capacity) and information on site relief, depth of soil, depth of ground-water table, and length of growing season required to assess soil vulnerability. In order to maintain uniformity of procedures at the European level it was agreed, in principle, that the procedures and terminology of SOTER, the internationally endorsed World Soils and Terrain Digital Data Base programme of ISSS/ISRIC, using criteria of the EEC-CORINE where appropriate, should be used to "harness" both the spatial and key attributes.

4. Following circulation for comments, the national participants will apply the methodological guidelines to their country data. These national maps subsequently will be compiled into the final 1:5 M "soil vulnerability" map with accompanying tabular output and digitized at the central office.

5. Individual countries have agreed to begin work on a "window" as soon as possible to demonstrate soil-pollution relationships. Cartographic work on this larger-scale excerpt should be based on a Geographical Information System so that a series of colour maps can be generated of soil and pollutant characteristics to illustrate the possibilities of the approach.

CONCLUSIONS

Research into the impact and speed of anthropogenic changes in soils has been overlooked and is now in urgent need of support from funding bodies. The present project forms a European-wide approach to this vitally important area of soil and mankind relationships.

The production of soil vulnerability maps has been requested at the 6th Ministerial Conference of the Council of Europe, and already many soil research institutes have begun programmes of investigation into soil vulnerability. There is a demonstrated need for initiative at a European level to co-ordinate this work for the benefit of all. Moreover, it provides an excellent opportunity for co-operation between the formerly divided countries of Eastern and Western Europe.

The SOVEUR workshop revealed a large amount of scientific interest and enthusiasm from all delegates, with scientists from many national research institutes and universities willing to cooperate in the production of soil vulnerability maps at continental and national levels. This interest and enthusiasm should be capitalised upon immediately while it is freely available as it will greatly reduce the overall costs of any Europe-wide project.

Initial funding for this workshop was made available by VROM and IIASA through the Foundation for Ecological Development Alternatives (Mondiaal Alternatief). The proposed project has already the scientific support of the International Society of Soil Science (ISSS), the European Environmental Research Organisation (EERO), the Food and Agricultural Organisation of the United Nations (FAO) and the International Soil Reference and Information Centre (ISRIC), through its programme of a world soils digital soil and terrain data base development. Funding is now sought for continuation of this work as outlined in the proposals.

APPENDIX

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